HQ Air Force Center for
Environmental Excellence

Monitoring and Remediation Optimization System (MAROS)

SOFTWARE Version 2.2

User's Guide

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AFCEE
Monitoring and Remediation Optimization System (MAROS) Software

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List of Acronyms

ACRONYM	DEFINITION
AFCEE	Air Force Center for Environmental Excellence
AR	Area Ratio
ASTM	American Society for Testing and Materials
CERCLA	Comprehensive Environmental Response, Comprehensive and Liability Act
CES	Cost Effective Sampling
COC	Constituent of Concern
CR	Concentration Ratio
CT	Concentration Trend
DL	Detection Limit
ERPIMS	Environmental Resources Program Information Management System
LLNL	Lawrence Livermore National Laboratory
LOE	Lines of Evidence
LTM	Long-Term Monitoring
LTMO	Long-Term Monitoring Optimization
LR	Likelihood Ratio
MAROS	Monitoring and Remediation Optimization System
MCL	Maximum Concentration Level
NAPL	Non-Aqueous Phase Liquids
N/A	Not Applicable (insufficient data)
ND	Non-Detect
NT	No Trend
PRG	Preliminary Remediation Goal

RCRA	Risk-based Corrective Action
ROC	Rate of Change
SF	Slope Factor
UST	Underground Storage Tank

INTRODUCTION

The AFCEE Monitoring and Remediation Optimization System (MAROS) Software is a Microsoft Access® database application developed to assist users with groundwater data trend analysis and long term monitoring optimization at contaminated groundwater sites. This program was developed in accordance with the Long-Term Monitoring Optimization Guide Version 1.1 developed by AFCEE. The Monitoring and Remediation Optimization System (MAROS) methodology provides an optimal monitoring network solution, given the parameters within a complicated groundwater system which will increase its effectiveness. By applying statistical techniques to existing historical and current site analytical data, as well as considering hydrogeologic factors and the location of potential receptors, the software suggests an optimal plan along with an analysis of individual monitoring wells for the current monitoring system. The software uses both statistical plume analyses (parametric and nonparametric trend analysis) developed by Groundwater Services, Inc., as well as allowing users to enter External Plume Information (empirical or modeling results) for the site. These analyses allow recommendations as to future sampling frequency, location and density in order to optimize the current site monitoring network while maintaining while maintaining adequate delineation of the plume as well as knowledge of the plume state over time in order to meet future compliance monitoring goals for their specific site. This User's Guide will walk the user through several typical uses of the software as well as provide screen-by-screen detailed instructions.

INTENDED USES FOR THE MAROS SOFTWARE

The MAROS software tool is designed to analyze data from a mature site investigation, specifically a groundwater plume that has been delineated and monitored for more than four sample events. Along with the guidance found in the Long-Term Monitoring Optimization Guide (AFCEE, 1997) you can use the software to answer important compliance monitoring data questions:

- What COCs are identified at the site?
- Is the temporal trend in the groundwater site analytical data significant?
- What is the spatial distribution of the temporal trends for each COC?
- Where is the approximate center of mass and is it moving over time?
- Are there redundant wells in the current monitoring network?
- What is the suggested future sampling frequency?
- Do new wells need to be added to the monitoring network to adequately characterize the plume?

The MAROS software can be utilized in a step-by-step fashion, with each progressive step along the way yielding information that can be applied to answering site-specific compliance monitoring questions. At each phase in the software, results that are presented are based on increasingly more consolidated data. These data consolidation steps will lead to more stringent assumptions being used in order to reach a result or site specific results (Figure 1). The assumptions you make along the way, will affect the outcome of the software tool results. However, because the assumptions are arranged in a logical, explicit fashion, they can be reviewed and altered should more site data become available. Also, the validity of the results or recommendation will rely on the extent and quality of input data. The data imported into the software must meet minimum data requirements as to the frequency of sampling, duration of the sampling intervals for trend analysis and sampling density for the site as well as the quality of the measurements (decreased amount of false positives/negatives).

- Basic output: 1 page Sampling Plan that is intended to be used as a "strawman" or basis for discussion (not as an authoritative, detailed statistically based product). The user can apply additional tools in MAROS to refine this basic plan. An important premise for the report is knowledge of historical trends for each COC and each well. However, the software is **not** a kriging tool at this time. Sample data reduction and data analysis tools result in summary reports.

Note: For kriging, available software products include: GEOEAS or GEOPack from the U.S. EPA. Also, some commercial software for kriging include "GS+ Geostatistics for the Environmental Sciences", GMS (Groundwater Modeling System), ArcGIS products, Terraseer STIS and EarthVision. These software products include variograms and kriging for the purpose of interpolation, but are not specifically geared toward groundwater well network optimization. A higher level of statistical knowledge and background would be required to implement these geostatistical tools.

The AFCEE MAROS Software should be used in Access 2003® (or later version) along with Excel in order to analyze the trends in groundwater data as well as perform statistical optimization of well location, sampling frequency and duration. The software can be used to export data to an Access archive file for future software use. Groundwater data can be imported from Excel or ERPIMS files as well as entered manually.

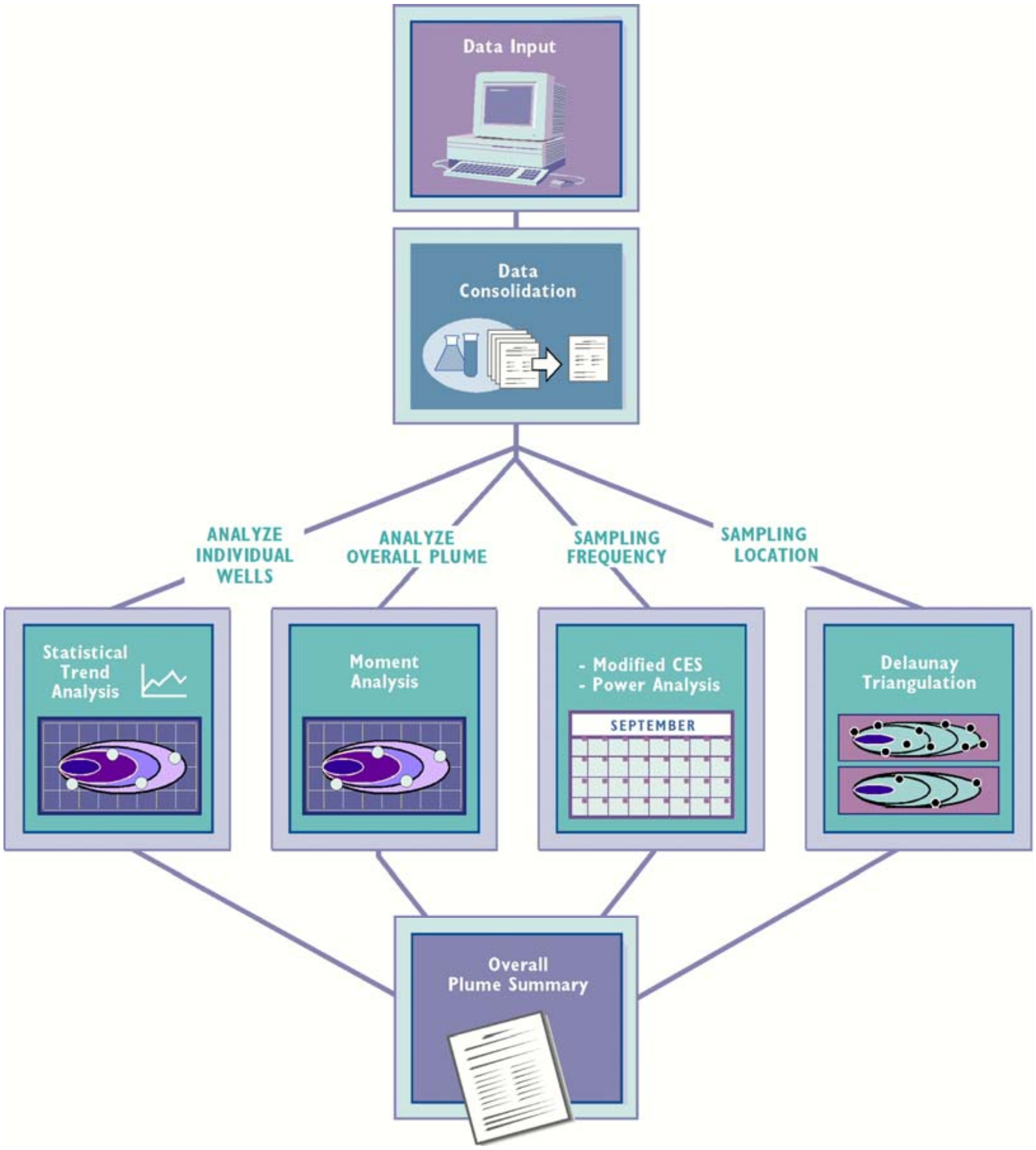


FIGURE 1 MONITORING AND REMEDIATION OPTIMIZATION SYSTEM (MAROS) PROGRAM FLOW

FUNDAMENTALS OF COMPLIANCE MONITORING

Remediation monitoring of affected groundwater is a significant cost driver for future environmental restoration activities. These monitoring systems whether applied for process control, performance measurement or compliance purposes, referred to as long-term monitoring, are dictated by RCRA, CERCLA and UST programs. Although an individual long-term monitoring data point is relatively small, the scale of the required data collection effort and the time commitment makes the cumulative costs very high. Consequently, improving the efficiency of these systems through improved methodology for developing future long-term monitoring plans has the potential for substantial cost savings.

The features available in the MAROS software are designed to optimize a site-specific monitoring program that is currently tracking the occurrence of contaminant migration in groundwater. MAROS is a decision support tool based on statistical methods applied to site-specific data that account for hydrogeologic conditions, groundwater plume stability, and available monitoring data. This process focuses on analyzing relevant current and historical site data and optimizing the current monitoring system in order to efficiently achieve the termination of the monitoring program. For example plumes that appear to be decreasing in extent, based on adequate monitoring data over a several year period, can be analyzed statistically to determine the strength and reliability of the trend. If it can be demonstrated statistically through statistical plume analyses (i.e. Mann-Kendall Trend Analysis and/or Linear Regression Trend Analysis or Moment Analysis) and/or External Plume Information (modeling or empirical) that the plume is shrinking with a high degree of confidence, then future monitoring can either be suspended or reduced in scope (i.e. from annual monitoring to biennial monitoring).

MAROS has the option to either use simple rules based on trend analysis results and site information or more rigorous statistical methods to determine the minimum number of wells and the minimum sampling frequency and well density required for future compliance monitoring at the site. These preliminary monitoring optimization recommendations will give the user a basis for which to make more cost effective, scientifically based future long-term monitoring decisions. As the monitoring program proceeds, more recent sampling results can be added to historical data to assess the progress of the current monitoring strategy. Then the optimization process can be reviewed and updated periodically using the MAROS guidance recommendations.

QUICK START

Minimum System Requirements

The AFCEE Monitoring and Remediation Optimization System Software runs with Microsoft® Access 2000 database software and Microsoft® Excel 2000. Operation requires an IBM®-compatible PC with Pentium or later processor. To operate efficiently we recommend that the PC have a minimum of 64 MB RAM (optimal 128 MB RAM), Pentium III, and EGA or VGA graphics display. Microsoft Access 2000®, Microsoft Excel 2000®, plus Windows 98® or later or Windows NT® are required software.

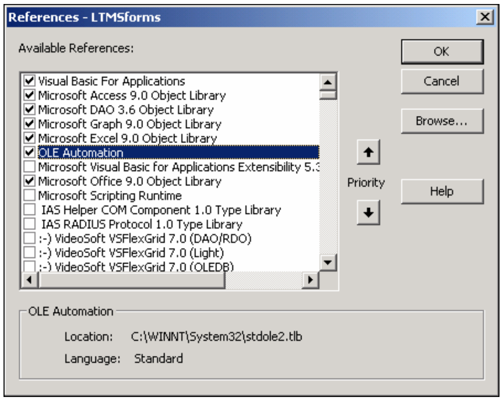
Installation and Start Up

Copy MAROS_SETUP.EXE to your hard drive, then run MAROS_SETUP.EXE either by selecting Run from the File menu in Program Manager or by double-clicking on the file MAROS_SETUP.EXE in File Manager (or Windows 98/NT/2000/XP Explorer). The installation process creates the C:\AFCEE_MAROS subdirectory on your hard drive, unless you install it elsewhere, and copies the MAROS files into the new directory. This folder contains five files needed to use the software and six instruction and user support files.

1) AFCEE Monitoring and Remediation Optimization System Software: “afcee_MAROS_v2.mdb”
2) Help file: “afcee_MAROS.hlp”
3) Optimization Excel File: “xlsDelaunay2k.xls”
4) Trend Visualization Excel File: “xlsLOEresults.xls”
5) Location Addition Excel File: “xlsLocation.xls”
6) MAROS Manual: “afcee_MAROS_Manual.pdf”
7) MAROS Tutorial File: “TutorialExampleData.xls”

8) Data input templates: "MAROS_AccessImportTemplate.mdb;
 MAROS_ExcelImportTemplate.xls; "MAROS_ERPIMS_Import_Template2000.mdb"
9) Constituent name list: "MAROS_ConstituentList.xls"
10)

To start the software after installation, double click on the "afcee_MAROS.mdb" file or open the file from within Access 2000®.



☑ Visual Basic For Applications
☑ Microsoft Access 9.0 Object Library
☑ Microsoft DAO 3.6 Object Library
☑ Microsoft Graph 9.0 Object Library
☑ Microsoft Excel 9.0 Object Library
☑ OLE Automation
☐ Microsoft Visual Basic for Applications Extensibility 5.3
☑ Microsoft Office 9.0 Object Library
☐ Microsoft Scripting Runtime
☐ IAS Helper COM Component 1.0 Type Library
☐ IAS RADIUS Protocol 1.0 Type Library
☐ :-) VideoSoft VSFlexGrid 7.0 (DAO/RDO)
☐ :-) VideoSoft VSFlexGrid 7.0 (Light)
☐ :-) VideoSoft VSFlexGrid 7.0 (OLEDB)

Location: C:\WINNT\System32\stdole2.tlb
Language: Standard

Note: *Although some users are likely to have the complete set of libraries "turned on" to run the program, the following procedure should be applied the* ***first*** *time the software is used.*

1) Start up main software "afcee_MAROS.mdb". The Start up screen will appear. Press "F11" on the keyboard.

2) The Main Access Program will appear. Click on the tab "Modules". Open the Module "A MAROS Initial Start Up References".

3) Go to the Menu Item "Tools…. References…." A pop-up list of items will appear. Choose the following libraries to utilize. Click on the following libraries IF they are not already chosen

Visual Basic for Application; Microsoft Access 9.0 Object Library; Microsoft DAO 3.6 Object Library; Microsoft Graph 8.0 Object Library; Microsoft Excel 9.0 Object Library, Microsoft Office 9.0 Object Library.

Click on "OK" when finished.

4) Exit Access from the Menu Item "File…. Exit"

MAROS SOFTWARE STEP-BY-STEP

MAROS Step-by-step instructions will guide the user through the most commonly used features of the software. Figure 1 directs the user through the complete MAROS program flow which will assist the user in becoming familiar with the use of the software.

What do I need before I start?

The MAROS Software requires a small but specific set of data in order to produce a result. The data must be carefully formatted to fit the entry requirements in MAROS. Data preparation is often the most difficult and time consuming part of the analysis. Detailed descriptions of import file formats are presented in Appendix A.1.

1) Well sampling data including the well name, constituents sampled, sample dates, results and well locations should be entered into either Excel or Access as described in Appendix A1 of this manual. Sample detection limits are required, but can be estimated if the information is not available. Laboratory Quality Assurance/Quality Control data, matrix spikes and field blanks are not required. Water quality parameters such as pH and conductivity are not required.

2) Aquifer and general plume characteristics should be identified before plume analysis begins. The MAROS tool requires a general value for aquifer seepage velocity, porosity, saturated thickness and flow direction. A MAROS file can be run multiple times using different aquifer parameters, to examine sensitivity to varying hydraulic characteristics within an aquifer. The plume length and width as well as an approximate source location and estimate of distance to potential receptors are also required. Groundwater sample locations should be identified as being in the source or tail region of the plume.

3) If you are running MAROS for the first time, it is advisable to start with a limited data input set until you become familiar with the software. MAROS can examine data for up to 5 constituents at once, but a simple file with one to three constituents is easier to handle for a preliminary run.

How can I import/enter groundwater data into MAROS?

The MAROS Software allows manual data entry or importation of data into the software.

To import data within the software:

1) ***Main Menu:*** From the *Main Menu*, select “Data Management” by clicking on the button next to the label. This will take you to the *Data Management Menu* Screen.

2) ***Data Management Menu:*** From the *Data Management Menu*, select “Import New Data” by clicking on the button next to the label. This will take you to the *Import New Data* Screen.

3) ***Import New Data:*** Choose the type of data import to be performed by clicking on the appropriate button (Excel or ERPIMS). Enter the full file path and filename of the file to import (or click the browse button to find the import file). The Folder and File name you choose will appear in the top two boxes. (See Notes below for ERPIMS and Excel file format/names.) Choose the import option that corresponds to the import data format. (Note that the “Import New Data” option will *replace* the existing data in the database.) Click

"Import" to proceed with importing the file to the existing database. (See Appendix A.1 for more information).

To enter individual data records manually within the software:

1) *Main Menu:* From the *Main Menu*, select "Data Management" by clicking on the button next to the label. This will take you to the *Data Management Menu* Screen.

2) ***Data Management Menu:*** From the *Data Management Menu*, select "Manual Data Addition" by clicking on the button next to the label. This will take you to the *Manual Data Addition* Screen.

3) ***Manual Data Addition:*** Fill in the appropriate information within each field. Fields such as "Constituent Type" and Constituent have dropdown boxes to assist in data entry. Choose Constituent Type before choosing the Constituent. Review information before adding the record. When all the data is entered, click on the "Add Record" button.

Note: If the result is "ND" (non-detect) then fill in the Detection Limit in the Result cell.

How will MAROS help perform a trend analysis and give a Site-Specific Recommendation based on groundwater data and site conditions?

The MAROS Tool can generate a summary report for a selected set of data imported by the user. To generate the summary report for the Mann Kendall or Linear Regression Trend Analysis:

1) ***Follow directions for Importing/Entering Data above.***

2) ***Main Menu:*** From the *Main Menu*, select "Site Details" by clicking the button next to the label. This action will take the user to the *Site Information* screen.

3) ***Site Details:*** In each screen select the information that describes the site, click on "Next" to continue to the next screen. First, enter the site details on the *Site Information* screen. Next, define sample events on the *Sample Events* screen. Then select the representative wells in the Source and Tail zones on the *Source/Tail Zone Selection* screen. Continue to the *Constituents of Concern Decision* screen to choose the representative COCs for the site. The next screen, *Initial Data Table* , will show the data to be evaluated. To proceed click "Next". The site details portion of the software is complete.

4) ***Main Menu:*** From the *Main Menu*, select "Trend Analysis" by clicking the button next to the label. This action will take the user to the *Plume Analysis Menu* screen.

5) ***Plume Analysis Menu:*** From the *Plume Analysis Menu*, select "Data Reduction" by clicking the button next to the label. This action will take the user to the *Data Reduction Part 1 of 2* screen.

6) ***Data Reduction:*** In each screen select the information that will define the data you would like to analyze, click "Next" to continue to the next screen. First, enter the period of interest as well as data consolidation options on the *Data Reduction Part 1 of 2* screen. Next, define delimit the data on the *Data Reduction Part 2 of 2* screen. Continue to the *Reduced Data Table* screen to view the results of data consolidation. To proceed click "Next". The data reduction portion of the software is complete.

7) ***Plume Analysis Menu:*** From the *Plume Analysis Menu*, select "Statistical Plume Analysis" by clicking the button next to the label. This action will take the user to the *Mann Kendall Statistics* screen.

8) ***Statistical Plume Analysis:*** In each screen view the information from both the Mann Kendall and Linear Regression Statistical Analyses, click "Next" to continue to the next screen. Results of the Mann Kendall Trend Analysis are shown on the *Mann Kendall Statistics* screen. Next, results of the Linear Regression Trend Analysis are shown on the *Linear Regression Statistics* screen. Continue to the *Linear Regression* screen to view the results in graphical form. Finally a summary of both the Mann Kendall and Linear Regression results are shown on the *Trend Analysis Summary by Well* screen. To proceed click "Next". The Statistical Plume Analysis portion of the software is complete.

9) ***Plume Analysis Menu:*** From the *Plume Analysis Menu*, select "Spatial Moment Analysis" by clicking the button next to the label. This action will take the user to the *Moment Site Details* screen.

10) ***Spatial Moment Analysis:*** First, enter the site details on the *Moment Analysis Site Details* screen. Then in each screen view the information from the 0th, 1st, and 2nd Moment Analysis Results, click "Next" to continue to the next screen. Finally a summary of both the Moment Analysis results are shown on the *Spatial Moment Analysis Summary* screen. To proceed click "Next". The Spatial Moment Analysis portion of the software is complete.

11) ***Plume Analysis Menu:*** From the *Plume Analysis Menu*, select "External Plume Information" by clicking the button next to the label. This action will take the user to the *External Plume Information: Modeling Results* screen.

12) ***External Plume Information:*** In each screen select the information that pertains to the site for both Modeling and Empirical results, click "Next" to continue to the next screen. Results for modeling studies are entered on the *External Plume Information: Modeling Results* screen. Next, results of any empirical evidence are entered on the *External Plume Information: Empirical Results* screen. To proceed click "Next". The External Plume Information portion of the software is complete.

13) ***Plume Analysis Menu:*** From the *Plume Analysis Menu*, select "MAROS Analysis" by clicking the button next to the label. This action will take the user to the *Lines of Evidence Summary by Well* screen.

14) ***MAROS Analysis:*** In each screen select to weight the Lines of Evidence or individual wells as pertains to your site, click "Next" to continue to the next screen. Results for all lines of evidence are summarized on the *Lines of Evidence Summary by Well* screen. Next, the choice to weight the Lines of Evidence by "All Chemicals" or "Individual Chemicals" is made on the *Trend Summary Weighting* screen. Continue to the *Results of Trend Weighting* screen to view the results in table form. Finally the option to weight individual wells is available on the *Lines of Evidence by Well Weighting* screen. The *Monitoring System Category* screen shows a summary of the source and tail well results for the COCs chosen, the Monitoring System Category is displayed for these results. To proceed click "Next". The Trend Analysis portion of the software is complete.

15) Main Menu: From the *Main Menu*, select "MAROS Output" by clicking the button next to the label. This action will take the user to the *MAROS Reports/Graphs* screen.

16) MAROS Reports/Graphs: Select the report or graph you would like to view, then click on the button next to the list. This action will take the user to the report or graph chosen. To print, select the print icon on the tool bar or select "Print" from the file menu. Click "Close" to exit the Report.

What COCs should I choose for my site?

The MAROS Tool can help the use to choose the Constituents of Concern for your site. Up to five COCs can be analyzed at one time by the MAROS software. However, the tool works best when one to three representative COCs are chosen. To receive input from the software on how to rank or choose COCs:

1) ***Follow directions for Importing/Entering Data above.***

2) Main Menu: From the *Main Menu*, select "Site Details" by clicking the button next to the label. This action will take the user to the *Site Information* screen.

3) Site Details: In each screen select the information that describes the site, click on "Next" to continue to the next screen. First, enter the site details on the *Site Information* screen. Next, define sample events on the *Sample Events* screen. Then select the representative wells in the Source and Tail zones on the *Source/Tail Zone Selection* screen. Continue to the *Constituents of Concern Decision* screen to choose the representative COCs for the site.

4) ***Constituents of Concern:*** From the *Constituents of Concern* screen, click on "Recommended COCs". The next screen, *Risk Level Assessment*, will show the data for COCs that are currently in the database to be evaluated. Choose from the list of generic Preliminary Remediation Goal (PRG) recommendations. Choose from the list of generic Preliminary Remediation Goal (PRG) recommendations. Click on the appropriate standard to be used in database comparisons for COC recommendations. Enter your own modifications to cleanup goals under "custom goals" in mg/L. The next screen, COC Decision screen shows up to 10 of the recommended COCs based on Toxicity, Prevalence, and Mobility. Enter up to 5 COCs for the site in the boxes to the left. If you would like a detailed view of the process used to make the COC recommendation, click on "Toxicity", "Prevalence" or "Mobility" at the left side of the screen. The information displayed in this screen can also be viewed in report form, "COC Assessment Report" from the *MAROS Output* Screen. To proceed with the next step in the software click "Back".

How can I access the Sampling Optimization module?

The Sampling Optimization module is an optional extension of the MAROS software. It may optimize the sampling plan by eliminating redundant sampling locations and determining the lowest sampling frequencies for these sampling locations. It also provides data sufficiency analyses for the current monitoring program. To access the Sampling Optimization module, complete the following steps:

1) Start Screen: After starting the MAROS software, the *Start Screen* is shown, input user name and project name and click button *Start*. You will enter the *Main Menu*.

2) ***Main Menu:*** In the *Main Menu*, the *Sampling Optimization* module is the fourth option. The *Sampling Optimization* label is red and the button next to it is deactivated. Follow instructions and complete the three modules above the *Sampling Optimization* module in that order. They are *Data Management*, *Site Details* and *Plume Analysis*. After running through the three modules, go back to Main Menu, the button next to label *Sampling Optimization* will be activated, click this button, the *Sampling Optimization* screen will appear.

3) ***Sampling Optimization:*** The sampling optimization screen is a main menu for three sub-modules: *Sampling Location Analysis*, *Sampling Frequency Analysis*, and *Data Sufficiency Analysis*. Now you can follow the instructions and perform the three analyses.

To View/Print Report:

1) ***Module-end Results Reports:*** At the *Results* screen(s) of each sub-module (e.g., screen *Risk-Based Power Analysis Results*), there is a button named *View Report*. Click this button and follow instructions to view or print the results report.

2) ***MAROS Output Reports:*** After running through the Sampling Optimization module, the *MAROS Output Reports* screen can be accessed from screen *Main Menu*. From the *Report* listbox, select the report you want to view (e.g., *Sampling Location Optimization Report*) by clicking on that item (available only after that sub-module has been successfully performed). Then click button *View/Print Report* and follow instructions to view or print the report.

How will the Sampling Optimization module help me optimize a sampling plan?

The Sampling Optimization module is used to determine the minimal number of sampling locations and the lowest sampling frequencies that can still meet the requirements of spatial sampling and temporal sampling for the monitoring program. A data sufficiency analysis is also provided in this module to examine the cleanup status and the significance of concentration trend at individual wells and the risk-based site cleanup status. These analyses are based on each Constituent of Concern (COC) and the results are given on a COC-by-COC basis.

1) ***Sampling Location Analysis:*** This sub-module uses the Delaunay method to eliminate "redundant" wells from the monitoring network based on spatial data analyses. Monitoring data from multiple sampling events can be used in this analysis. Major steps to be followed are:

   a) ***Sampling Location: Delaunay Method****:* In this screen, select the series of sample events intended for analysis by defining the *From* and *To* sampling events and click *Confirm*. Then choose between *Access Module* and *Excel Module* (the latter one is available only when a single sampling event is chosen for analysis).

   b) ***Sampling Location Analysis - Access Module***: In this screen, set up the *Selected?* and *Removable?* properties of potential sampling locations and if needed change the optimization parameters by clicking button *Options*. Then click button *Preliminary Analysis* to proceed. All COCs will be analyzed and several steps are to be followed to complete this analysis.

   Or

c) ***Sampling Location Analysis - Excel Module****:* In this screen, set up the *Selected?* and *Removable?* properties of potential sampling locations for a COC and then click *Analysis*. The *xlsDelaunay2K* worksheet will pop up and the user is required to finish optimization there. After sending back the results for that COC from *xlsDelaunay2K* (by clicking *Back To Access* in *xlsDelaunay2K*), this screen will re-appear. Run through all COCs in the same way and click *Next* to proceed.

2) Sampling Frequency Analysis: This sub-module uses the Modified CES method to determine the lowest sampling frequency for each sampling location. The method is based on the analysis of time-series data by assessing the Rate of Change (ROC) and Concentration Trend (CT) of each Constituent of Concern (COC) and considering both recent trends and overall (long-term) trends of the data. The analysis is performed according to each COC. Major steps to be followed are:

   a) Sampling Frequency Analysis*:* In this screen, define the "recent period" by selecting the *From* and *To* sampling events and then click button *Confirm*. Click button *Option* and change the *Rate of Change* parameters if necessary. Click *Analysis* to proceed.

   b) Sampling Frequency Recommendation: View results for all COCs and click button *Next* to complete.

3) Data Sufficiency Analysis: This sub-module uses statistical power analysis to determine the cleanup status and the significance of concentration trends at individual wells and the risk-based site cleanup status. Statistical power and the expected sample size associated with each evaluation are provided. Results from this module can be used to assess the sufficiency of monitoring plans, providing auxiliary information for optimizing sampling locations and sampling frequency. Major steps to be followed are:

   a) Data Sufficiency Analysis Menu*:* There are two types of analyses to choose at this screen: *Power Analysis at Individual Wells* and *Risk-Based Power Analysis*. Before proceeding to either of the analyses, click button *Options* to enter screen *Data Sufficiency Analysis - Options* where the user should to check or specify the parameters used in the statistical power analysis. Then click the corresponding button to perform any of the two analyses.

   b) Power Analysis at Individual Wells: Clicking this button will take the user to the individual well cleanup status evaluation. The user needs to select the series of sample events intended for analysis and define some other parameters. There are several steps to follow to finish this analysis and results reports can be viewed immediately after the evaluations are finished.

   c) Risk-Based Power Analysis: Clicking this button will take the user to the risk-based site cleanup evaluation. The user needs to specify four sets of parameters in screen *Parameters for Risk-Based Power Analysis* before continuing the analysis. Regression of plume centerline concentrations, projection of concentrations, and the risk-based site cleanup evaluation are determined sequentially. Results reports become available immediately after each step is finished.

The user can choose to run either *Sampling Location Analysis* or *Sampling Frequency Analysis* first. Because *Data Sufficiency Analysis* uses qualitative concentration trend results from *Sampling Frequency Analysis*, it cannot be selected before *Sampling Frequency Analysis* is successfully performed. For detailed instructions on how to run these modules, refer to the next chapter MAROS DETAILED SCREEN DESCRIPTIONS.

MAROS DETAILED SCREEN DESCRIPTIONS

Start Screen

The Start Screen gives the user access to the software system. Enter the User Name and Project Name in the boxes to the left of the Start Button. The User Name and Project Name will appear in the headings of MAROS output reports. Click “Start” to proceed to use the database software.

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University of Houston

Jim Gonzales
Javier Santillan
AFCEE

Data management tool for analyzing and optimizing groundwater monitoring programs.

User Name:

Project Name:

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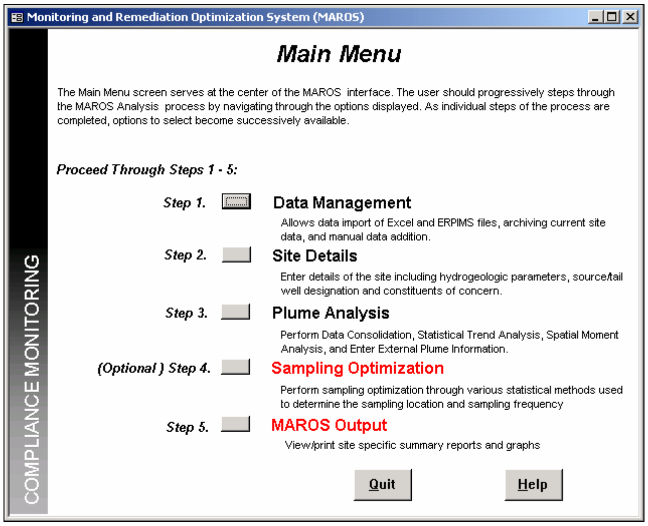
Utilizing the MAROS software is analogous to a train trip. You begin the expedition by importing your raw groundwater data that has been collected over several sampling periods from the field site of interest. As you journey through the software, you can get off at any station along the way. The results that you are presented with at each stop whether graphical or in a report will be based on increasingly more consolidated data. These data consolidation steps will lead to a higher degree of assumptions being used in order to reach a result or site specific recommendation. The assumptions you make along the way, will affect the outcome of the software tool results. Also, the validity of the results or recommendation will rely on the extent and quality of your data. For instance, more data doesn’t necessarily mean better results. The data must meet minimum data requirements as to the frequency of sampling, duration of the sampling intervals for trend analysis and sampling density for the site as well as the quality of the measurements (decreased amount of false positives/negatives).

Main Menu

The Main screen serves at the center of the user interface. The user progressively steps through the Compliance Monitoring Trend Analysis and Optimization Evaluation process by navigating through the options displayed. As individual steps of the process are completed, options to select become successively available.



Main Menu

The Main Menu screen serves at the center of the MAROS interface. The user should progressively steps through the MAROS Analysis process by navigating through the options displayed. As individual steps of the process are completed, options to select become successively available.

Proceed Through Steps 1 - 5:

Step 1. Data Management
Allows data import of Excel and ERPIMS files, archiving current site data, and manual data addition.

Step 2. Site Details
Enter details of the site including hydrogeologic parameters, source/tail well designation and constituents of concern.

Step 3. Plume Analysis
Perform Data Consolidation, Statistical Trend Analysis, Spatial Moment Analysis, and Enter External Plume Information.

(Optional) Step 4. Sampling Optimization
Perform sampling optimization through various statistical methods used to determine the sampling location and sampling frequency

Step 5. MAROS Output
View/print site specific summary reports and graphs

The *Main Menu* screen allows the user to choose between performing:

- Step 1: Data Management
- Step 2: Site Details
- Step 3: Plume Analysis
- Step 4: Sampling Optimization
- Step 5: MAROS Output

Select the desired option by clicking the applicable button. Proceed through Steps 1 – 5.

Data Management: Allows data import of Excel and ERPIMS files, archiving current site data, and manual data addition.

Site Details: Initial definition of site specific data including choosing the “Source” and “Tail” wells, sample events and providing site-specific Constituents of Concern (COC’s).

Plume Analysis: Allows the user to perform data reduction as well as trend analysis through both Statistical Plume Analysis, Spatial Moment Analysis, and External Plume Information. Also allows the user to apply final Analysis Consolidation to the trend results.

Sampling Optimization: Allows the user to perform sampling optimization through various statistical methods used to determine the sampling location and sampling frequency.

MAROS Output: Allows the user to view/print site-specific summary reports and graphs.

Quit: Closes the database program and Access. When the database is closed any data that you are currently working on will be erased. It is suggested that you Archive the current database if necessary before exiting.

Help: Provides additional information on software operation and screen-specific input requirements.

Data Management

The *Data Management* Menu (accessed from the *Main Menu*) is used to perform database operations such as importing, manual data addition and archiving. These operations are used to import initial site data as well as additional data into the software. Import file formats are discussed in detail in Appendix A.1

The Database Management menu allows you to perform database operations such as importing, manual data addition and archiving. These operations are used initially to import site data into the software in order to perform analysis. After you have performed the data analysis, you can archive your data file for future use.

Import New Data: Choose between importing ERPIMS files or and Excel file in the standard MAROS format. import previously archived data files

Manual Data Addition: To add individual Records to the MAROS underlying database for analysis.

Import MAROS Archive File: Import previously archived MAROS files.

Export MAROS Archive File: Export a MAROS data to an archive database file to be used in future MAROS analyses.

Choose the option of interest by clicking the applicable button.

Import New Data: New data can be imported from Excel, Access or ERPIMS data files.

Manual Data Addition: This option allows the user to input data manually. Manual addition is generally useful for a very small amount of supplemental data.

Import MAROS Archive File: MAROS archive files can be created in the software in two locations after the initial data have been imported. Archive files are in Access and contain the site data as well as site details.

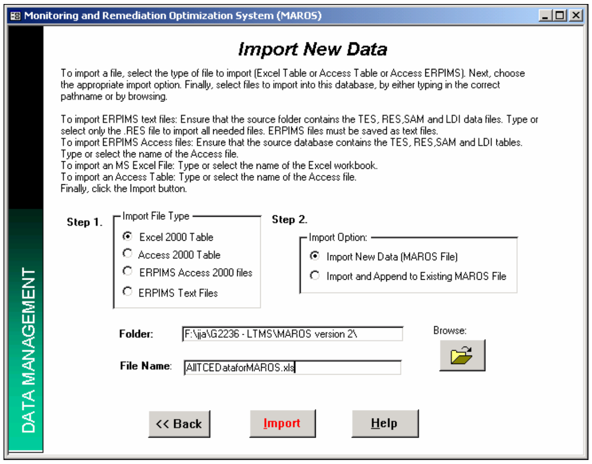
Export MAROS Archive File: MAROS creates an archive database file containing the sample data in a format that can be imported under the previous protocol.

Main Menu: Returns the user to the *Main Menu*.

Help: Provides information on the screen-specific input requirements.

Import New Data

Import New Data (accessed from the *Data Management* screen) is used to choose between importing ERPIMS files or an Excel or Access file in the standard MAROS format (see Appendix A.1) to the database as follows:



Import New Data

To import a file, select the type of file to import (Excel Table or Access Table or Access ERPIMS). Next, choose the appropriate import option. Finally, select files to import into this database, by either typing in the correct pathname or by browsing.

To import ERPIMS text files: Ensure that the source folder contains the TES, RES,SAM and LDI data files. Type or select only the .RES file to import all needed files. ERPIMS files must be saved as text files.
To import ERPIMS Access files: Ensure that the source database contains the TES, RES,SAM and LDI tables. Type or select the name of the Access file.
To import an MS Excel File: Type or select the name of the Excel workbook.
To import an Access Table: Type or select the name of the Access file.
Finally, click the Import button.

Step 1. Import File Type
● Excel 2000 Table
○ Access 2000 Table
○ ERPIMS Access 2000 files
○ ERPIMS Text Files

Step 2. Import Option:
● Import New Data (MAROS File)
○ Import and Append to Existing MAROS File

Folder: F:\jja\G2236 - LTMS\MAROS version 2\
File Name: AllTCEDataforMAROS.xls

Choose the type of data import to be performed by clicking on the appropriate button.

To import data into the software:

1) In the Step 1 dialog box enter the file type for the new data. Next, enter the full file path and filename of the file to import (or click the browse button to find the import file). The Folder and File name you choose will appear in the top two boxes. (See Notes below for ERPIMS, Access, and Excel file format/names.)

2) In the Step 2 dialog box, choose if the data file will replace all data currently in the MAROS toolbox (or replace the empty MAROS files) or if the data should be appended to the current file.

3) Click "Import" to proceed with importing the file to the existing database. A dialog box will appear with the number of wells and the date range of the data—*check these data to make sure they are consistent with your import file. Too few wells or too few dates means that some of your data is not importing properly and you may need to repair your input file.*

Back: Takes the user back to the *Data Management* screen.

Help: Provides information on the screen-specific input requirements.

NOTES:
To import an Excel 2000 spreadsheet:
1) Type or select the name of the Excel workbook.
2) The import option requires an Excel file format with fields *identical* in name and structure to those outlined in Appendix A.1. Each field must have the columns filled in. Do not import files with missing data, this will result in incorrect data evaluation within the software. The columns must include the field names in the first line. The template file "MAROS_ExcelImportTemplate.xls" is provided with the software with example data. Also, a list of permissible constituent names is found in the file, "MAROS_ConstituentList.xls".

To import an Access 2000 Table:
1) Type or select the name of the Access File.
2) The import option requires an Access Table format with fields identical to those outlined in Appendix A.1. Only one import table should be in the Access file. Each field must have the columns filled in. Do not import files with missing data, this will result in incorrect data evaluation within the software. The columns must include the field names as they are in the Access Template file and the table name should be "ImportData". The template file "MAROS_AccessImportTemplate.mdb" is provided with the software with example data.

Also, a list of permissible constituent names is found in the file, "MAROS_ConstituentList.xls".

To import ERPIMS files:

1) Ensure that the source folder contains the .SAM, .TES, .RES and .LDI data files.
2) Type or select only the .RES file to import all needed files**.

* * Before importing ERPIMS files they **must** be saved in text format in Microsoft Word 2000 with fields identical to those already in the database system (i.e. the format matching that used by ERPIMS system). To save the ERPIMS files as text files, open each file (.SAM, .TES, .RES and .LDI files) one at a time in Word. You will be prompted to "Choose the encoding used for loading this file", check "Plain Text". When the file is opened in Word, under the Menu option click "Save as". You will be prompted to "Save as type:", choose "Text only (*.txt)". Make sure you do not have the .txt extension on the end of the file name, only the original file name with the .RES, .SAM, .TES or .LDI file extension should appear. All files should have the same name (e.g. Hillgwdata.RES, Hillgwdata.LDI, Hillgwdata.TES and Hillgwdata.TES). No field names should appear in the files.

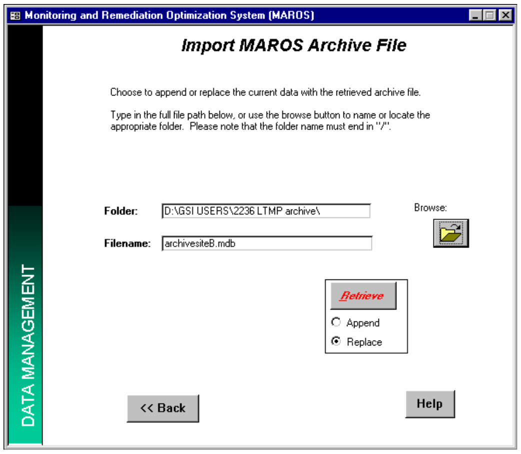
There is a limit on the amount of data that can be opened in Microsoft Word 2000, this will be controlled by the amount of RAM in your computer. The rule of thumb for large files is that your computer should have at least 3 times the amount of RAM as the size of the file. For instance if you have a 80 MB file you should have at least 256 MB of RAM to open this type of file in Word. If you do not know the amount of RAM on your computer, from the "Start" Button go to "Settings" and "Control Panel". In the control panel, open the "System" Icon and look at the "General" tab. This indicates the amount of RAM in your computer.

To import ERPIMS files from an Access 2000 database:

1) Type or select the name of the Access 2000 database.
2) Ensure that the tables included in the database file are named as follows SAM, .TES, .RES and .LDI data tables. The import option requires an Access file format with fields identical to those outlined in Appendix A.7**.** Each field must have the mandatory columns filled in. Do not import files with missing data, this will result in incorrect data evaluation within the software. The columns must include the field names as outlined in Appendix A.6. The template file "MAROS_ERPMSAccessTemplate.mdb" is provided with the software with example data.

Import MAROS Archive File

Import Archive File (accessed from the *Data Management Menu* screen) is used to import previously archived data files as follows:



Choose to append or replace the current data with the retrieved archive file.

Type in the full file path below, or use the browse button to name or locate the appropriate folder. Please note that the folder name must end in "/".

Folder: D:\GSI USERS\2236 LTMP archive\

Filename: archivesiteB.mdb

○ Append
● Replace

To import archived data into the full database:

1) Enter the full file path and filename of the archived file to import (or click the browse button to find the import file). The Folder and File name you choose will appear in the top two boxes.
2) Choose the import option that corresponds to the import data. Choose 'Replace' if all the data for the analysis are in the file to be imported. 'Replace' should be chosen for a new analysis (you are replacing an empty file). After you choose 'Replace', a dialog box will ask if you really want to replace the data—select 'Yes'. Choose 'Append' if the file represents additional data to those already present in the database. Appended data may be data for a new sample event or additional well data.
3) Click "Retrieve" to proceed with importing the archived file to the existing database. A dialog box will inform you if the data have been successfully imported.

Back: Takes the user back to the *Data Management* screen after the data have been imported.

Help: Provides information on the screen-specific input requirements.

Note: To import a MAROS 1.0 archive file, the file must first be converted to Access 2000. To convert a an archive file to Access 2000, open the file within Access 2000 and choose the option "Convert Database" and save the file under a new name. Once the archive file is converted to Access 2000, you will be able to import the file into the MAROS 2.0 software.

Export MAROS Archive File

Export Archive File (accessed from the *Data Management Menu* screen) is used to export a MAROS data file.

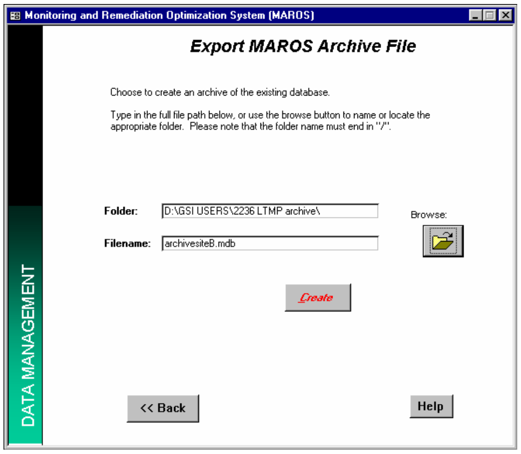
To export data into an archive database file:

1) Enter the full file path and filename of the archived file to export (or click the browse button to find the archive file to overwrite). The Folder and File name you choose will appear in the top two boxes.

2) Click "Create" to proceed with exporting the data to the archive file.

Back: Takes the user back to the *Data Management* screen.

Help: Provides information on the screen-specific input requirements.



Choose to create an archive of the existing database.

Type in the full file path below, or use the browse button to name or locate the appropriate folder. Please note that the folder name must end in "/".

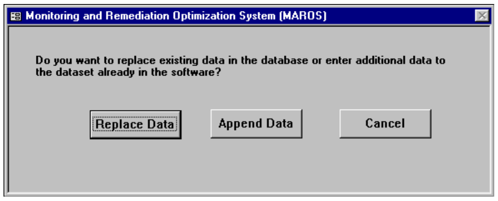
Folder: D:\GSI USERS\2236 LTMP archive\

Filename: archivesiteB.mdb

A MAROS archive file can also be created at the end of the "*Site Details*" section of the software. The archive file will contain the site details such as seepage velocity and source and tail well designations. Archive files are in Access format (*.mdb), and should be named to distinguish them from MAROS Output files.

Manual Data Addition

Manual Record Addition (accessed from the *Data Management Menu* Screen) can be used to add individual Records to the database.



Do you want to replace existing data in the database or enter additional data to the dataset already in the software?

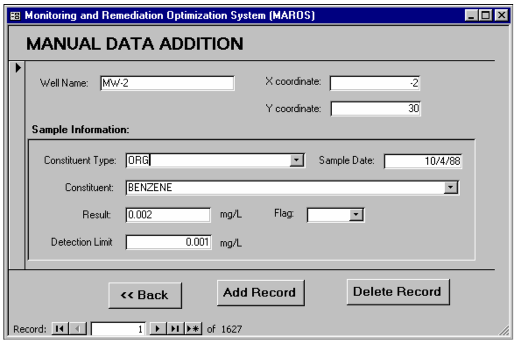
Steps for use:

1) Choose to "Replace Data" or "Append Data" to the groundwater data already in the software.

2) Fill in the appropriate information within each field. Fields such as "Constituent Type" and Constituent have dropdown boxes to assist in data entry. Choose Constituent Type before choosing the Constituent.

Note: If the result is "ND" then fill in the Detection Limit.

3) Review information before adding the record. When all the data is entered, click on the "Add Record" button.



Well Name: MW-2

X coordinate: -2

Y coordinate: 30

Constituent Type: ORG

Sample Date: 10/4/88

Constituent: BENZENE

Result: 0.002 mg/L

Flag:

Detection Limit: 0.001 mg/L

Record: 1 of 1627

Add Record: To add a new record, choose the entries from the selection boxes or type in the record information.

Delete Record: To delete the record currently shown on the screen. Deleting a record is a permanent operation.

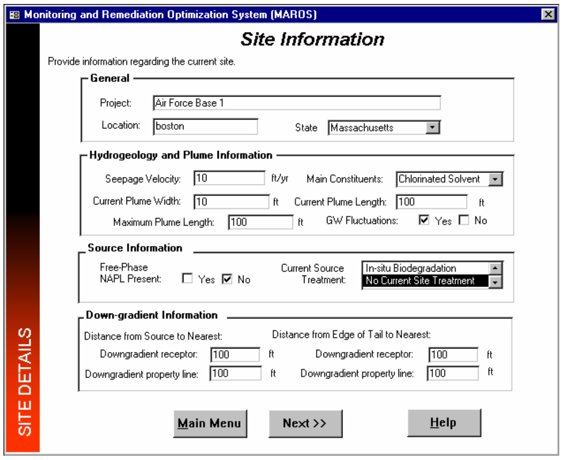
Alls fields should be filled in to ensure minimum information for added records. However, if X and Y coordinates are unknown these fields can be left blank.

Back: Takes the user back to the *Data Management* screen.

Help: Provides information on the screen-specific input requirements.

Site Details

Site Information (accessed from the *Main Menu* Screen) is the first step in defining the site type as well as parameters unique to the site.



Site Information

Provide information regarding the current site.

General

Project: Air Force Base 1
Location: boston
State: Massachusetts

Hydrogeology and Plume Information

Seepage Velocity: 10 ft/yr
Main Constituents: Chlorinated Solvent
Current Plume Width: 10 ft
Current Plume Length: 100 ft
Maximum Plume Length: 100 ft
GW Fluctuations: ☑ Yes ☐ No

Source Information

Free-Phase NAPL Present: ☐ Yes ☑ No
Current Source Treatment: In-situ Biodegradation / No Current Site Treatment

Down-gradient Information

Distance from Source to Nearest:
Downgradient receptor: 100 ft
Downgradient property line: 100 ft

Distance from Edge of Tail to Nearest:
Downgradient receptor: 100 ft
Downgradient property line: 100 ft

Fill in the appropriate information within each field. Fields such as "State" and "Current Source Treatment" have dropdown boxes to assist in data entry.

Note: All fields on this form are mandatory entry. The user will be prompted if the fields are not filled in. Under the 'Downgradient Information' section, a non-zero number is required in the 'distance to receptor' cells. The number can be small (1) or negative, in the event the plume has extended beyond the possible point of exposure.

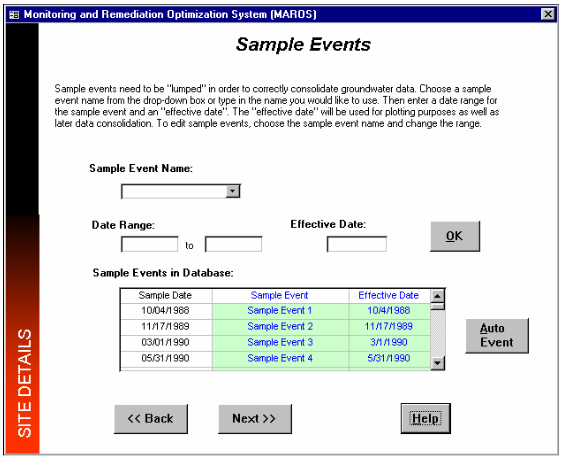
Next: Takes the user to the *Sample Events* screen.

Main Menu: Takes the user back to the *Main Menu* screen.

Help: Provides information on the screen-specific input requirements.

Site Details

Sample Events (accessed from the *Site Information* screen) allows the user to define sample events and dates to be used for graphing and data consolidation. For this section, a sample event is defined as the date range during which one episode in the monitoring program was carried out. For example, if all wells were sampled between 3/1/2002 and 3/5/2002, the sample event could be defined for all the wells as occurring on 3/3/2002.



Sample events need to be "lumped" in order to correctly consolidate groundwater data. Choose a sample event name from the drop-down box or type in the name you would like to use. Then enter a date range for the sample event and an "effective date". The "effective date" will be used for plotting purposes as well as later data consolidation. To edit sample events, choose the sample event name and change the range.

Sample Date	Sample Event	Effective Date
10/04/1988	Sample Event 1	10/4/1988
11/17/1989	Sample Event 2	11/17/1989
03/01/1990	Sample Event 3	3/1/1990
05/31/1990	Sample Event 4	5/31/1990

Steps for use:

1) Choose a sample event name from the drop-down box or type in the name you would like to use.
2) Enter a date range for the sample event (e.g. 10/04/1998 to 10/06/1998) and an "effective date" (e.g. 10/04/1998). The "effective date" will be used for plotting purposes and further data consolidation.
3) Select "OK" to update the sample event information.

Note: To edit sample events, choose the sample event name and change the range.

Auto Event: Allows the user to update sample events automatically. The software will assign the actual sample date as the effective date. Also, each sample event will be assigned to a unique original date. This option should only be used if the data only has one date per sampling event.

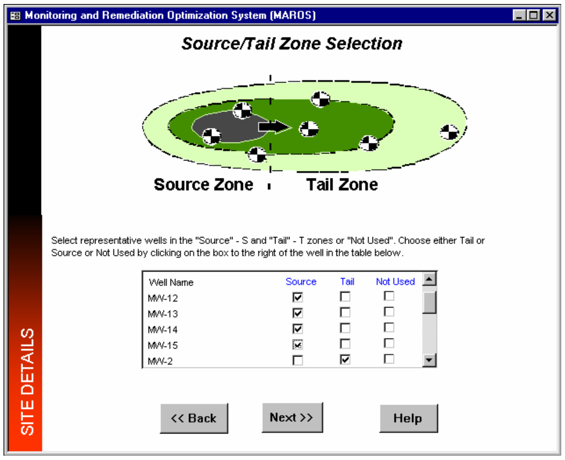
Next: Takes the user to the *Source/Tail Zone Selection* screen.

Back: Returns the user back to the *Site Information* screen.

Help: Provides information on the screen-specific input requirements.

Site Details

Source/Tail Zone Selection (accessed from the *Sample Events* Screen) allows the user to define the well type for the wells in the database. The MAROS software divides the wells for the site into two different zones (e.g. "Source" zone and "Tail" zone). The "Source" area include zones with NAPLs, contaminated vadose zone soils, and areas where aqueous-phase releases have been introduced into groundwater. The source area is generally the location with the highest groundwater concentrations of constituents of concern. The downgradient groundwater plume ("Tail") zone is the area downgradient of the contaminant source zone. The Tail only contains contaminants in the dissolved phase and the sorbed phase, but contains no sources of contamination.



Select representative wells in the "Source" - S and "Tail" - T zones or "Not Used". Choose either Tail or Source or Not Used by clicking on the box to the right of the well in the table below.

Well Name	Source	Tail	Not Used
MW-12	☑	☐	☐
MW-13	☑	☐	☐
MW-14	☑	☐	☐
MW-15	☑	☐	☐
MW-2	☐	☑	☐

Select representative wells in the "Source" - S and "Tail" - T zones or "Not Used". Choose either Tail or Source or Not Used by clicking on the box to the right of the well in the table. Select representative wells in the "Source" and "Tail" zones.

Next: Takes the user to the *Well Coordinates* screen.

Back: Returns the user back to the *Sample Events* screen.

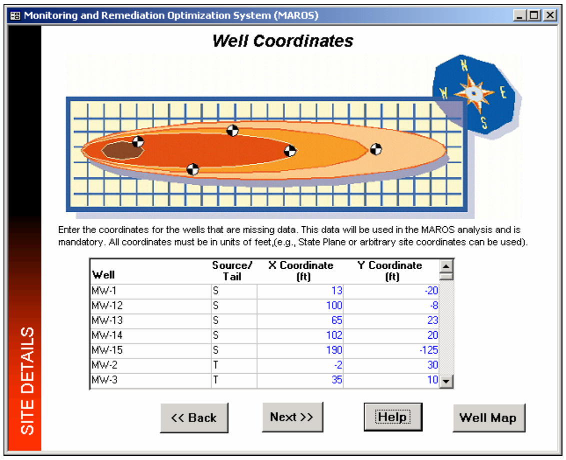
Help: Provides information on the screen specific input requirements.

Well Coordinates (accessed from the *Source/Tail Zone Selection* Screen) allows the user to define and/or revise the well coordinates if they were not defined in the import file. Well coordinates are mandatory and should be in feet (e.g. State Plane coordinates or arbitrary site coordinates).

Next: Takes the user to the *COC Decision* screen.

Back: Returns the user back to the *Source/Tail Zone Selection* screen.

Help: Provides information on the screen specific input requirements.



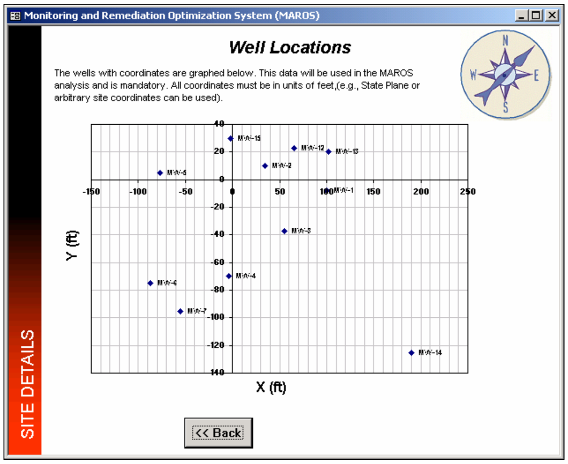
Enter the coordinates for the wells that are missing data. This data will be used in the MAROS analysis and is mandatory. All coordinates must be in units of feet,(e.g., State Plane or arbitrary site coordinates can be used).

Well	Source/ Tail	X Coordinate (ft)	Y Coordinate (ft)
MW-1	S	13	-20
MW-12	S	100	-8
MW-13	S	65	23
MW-14	S	102	20
MW-15	S	190	-125
MW-2	T	-2	30
MW-3	T	35	10

Site Details

Well Locations (accessed from the *Well Coordinates* Screen) allows the user to review the well coordinates in their relative locations. Well coordinates are mandatory and should be in feet (e.g. State Plane coordinates or arbitrary site coordinates).

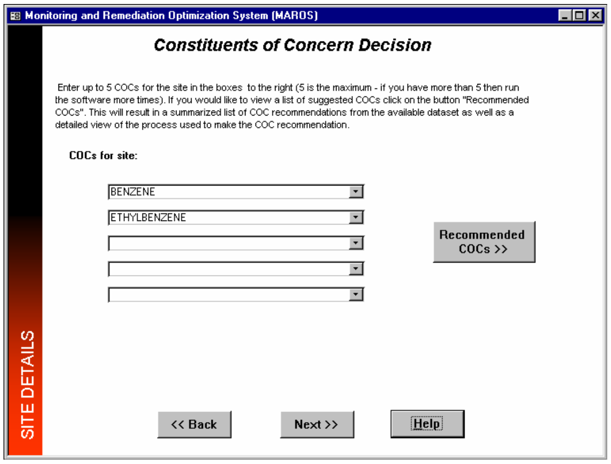
Back: Returns the user back to the *Well Coordinates* screen.


Monitoring and Remediation Optimization System (MAROS)

Well Locations

The wells with coordinates are graphed below. This data will be used in the MAROS analysis and is mandatory. All coordinates must be in units of feet,(e.g., State Plane or arbitrary site coordinates can be used).

Constituents of Concern Decision (accessed from the *Source/Tail Zone Selection* Screen) allows the user to define up to five constituents to be evaluated at the site.


Monitoring and Remediation Optimization System (MAROS)

Constituents of Concern Decision

Enter up to 5 COCs for the site in the boxes to the right (5 is the maximum - if you have more than 5 then run the software more times). If you would like to view a list of suggested COCs click on the button "Recommended COCs". This will result in a summarized list of COC recommendations from the available dataset as well as a detailed view of the process used to make the COC recommendation.

COCs for site:

BENZENE

ETHYLBENZENE

Enter up to 5 COCs for the site in the boxes to the right (5 is the maximum - if you have more than 5 then run the software more times). *In general, choosing 1 to 3 COCs with different chemical characteristics per analysis works best*. If you would like to view a list of suggested COCs click on the button "Recommended COCs". This will result in a summarized list of COC recommendations from the available dataset as well as a criteria ranking system—toxicity, prevalence or mobility-- used to make the COC recommendation (see below).

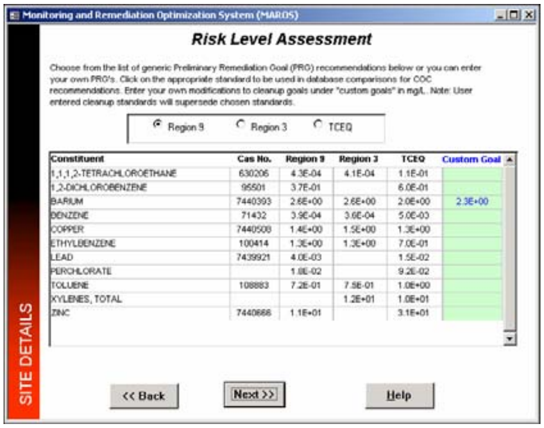
Next: Takes the user to the *Initial Data Table* screen.

Back: Returns the user back to the *Well Coordinates* screen.

Help: Provides information on the screen-specific input requirements.

Site Details

Risk Level Assessment (accessed from the *COC Decision* screen) allows the user to choose a preliminary remediation goal (PRG) used to screen representative concentrations from the dataset.



Risk Level Assessment

Choose from the list of generic Preliminary Remediation Goal (PRG) recommendations below or you can enter your own PRG's. Click on the appropriate standard to be used in database comparisons for COC recommendations. Enter your own modifications to cleanup goals under "custom goals" in mg/L. Note: User entered cleanup standards will supersede chosen standards.

● Region 9 ○ Region 3 ○ TCEQ

Constituent	Cas No.	Region 9	Region 3	TCEQ	Custom Goal
1,1,1,2-TETRACHLOROETHANE	630206	4.3E-04	4.1E-04	1.1E-01	
1,2-DICHLOROBENZENE	95501	3.7E-01		6.0E-01	
BARIUM	7440393	2.6E+00	2.6E+00	2.0E+00	2.3E+00
BENZENE	71432	3.9E-04	3.6E-04	5.0E-03	
COPPER	7440508	1.4E+00	1.5E+00	1.3E+00	
ETHYLBENZENE	100414	1.3E+00	1.3E+00	7.0E-01	
LEAD	7439921	4.0E-03		1.5E-02	
PERCHLORATE		1.8E-02		9.2E-02	
TOLUENE	108883	7.2E-01	7.5E-01	1.0E+00	
XYLENES, TOTAL			1.2E+01	1.0E+01	
ZINC	7440666	1.1E+01		3.1E+01	

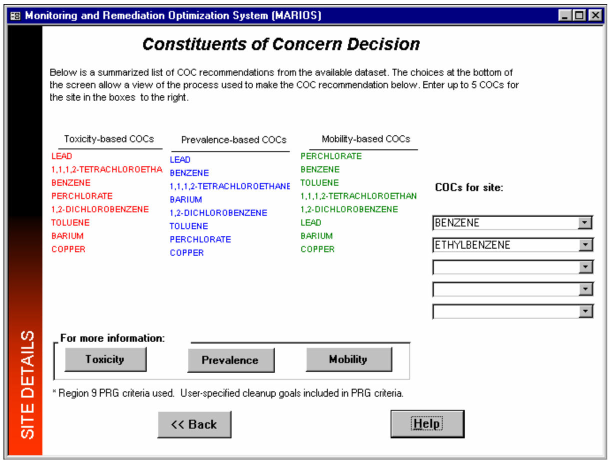
Choose from the list of generic Preliminary Remediation Goal (PRG) recommendations. Click on the appropriate standard to be used in database comparisons for COC recommendations. Enter your own modifications to cleanup goals under "custom goals" in mg/L. Note: User entered cleanup standards will supersede chosen standards.

Back: Returns the user to the *COC Decision* screen.

Next: Takes the user to the *COC Recommendation* Screen.

Help: Provides information on the screen-specific input requirements.

COC Recommendation (accessed from the *Risk Level Assessment* screen) allows the user to choose COCs based on Toxicity, Prevalence and Mobility of samples from the dataset.



Constituents of Concern Decision

Below is a summarized list of COC recommendations from the available dataset. The choices at the bottom of the screen allow a view of the process used to make the COC recommendation below. Enter up to 5 COCs for the site in the boxes to the right.

Toxicity-based COCs	Prevalence-based COCs	Mobility-based COCs
LEAD	LEAD	PERCHLORATE
1,1,1,2-TETRACHLOROETHA	BENZENE	BENZENE
BENZENE	1,1,1,2-TETRACHLOROETHANE	TOLUENE
PERCHLORATE	BARIUM	1,1,1,2-TETRACHLOROETHAN
1,2-DICHLOROBENZENE	1,2-DICHLOROBENZENE	1,2-DICHLOROBENZENE
TOLUENE	TOLUENE	LEAD
BARIUM	PERCHLORATE	BARIUM
COPPER	COPPER	COPPER

COCs for site:
BENZENE
ETHYLBENZENE

* Region 9 PRG criteria used. User-specified cleanup goals included in PRG criteria.

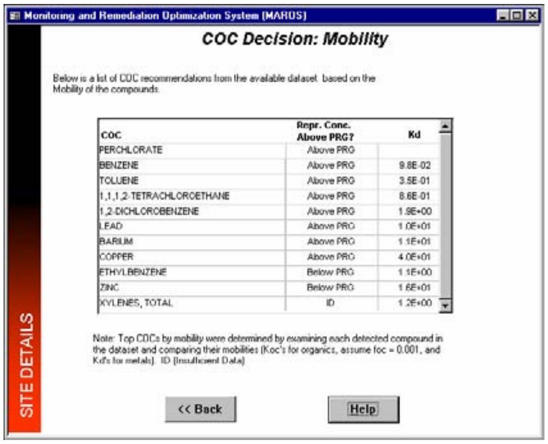
Enter up to 5 COCs for the site in the boxes to the left. If you would like a detailed view of the process used to make the COC recommendation, click on "Toxicity", "Prevalence" or "Mobility at the left side of the screen.

The information displayed in this screen can also be viewed in report form, "COC Assessment Report" from the *MAROS Output* Screen (see Appendix A.8 for an example report).

Back: Returns the user to the *Risk Level Assessment* screen.

Help: Provides information on the screen-specific input requirements.

Site Details



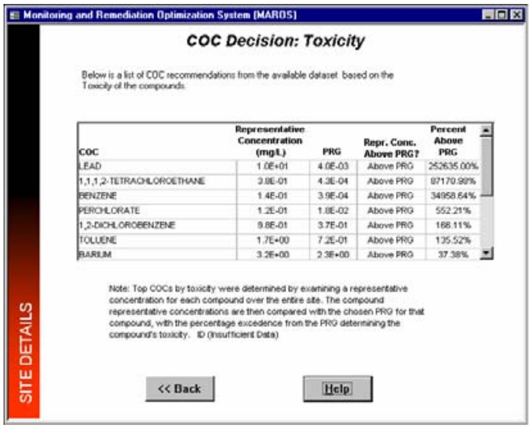
COC Decision: Mobility

Below is a list of COC recommendations from the available dataset based on the Mobility of the compounds.

COC	Repr. Conc. Above PRG?	Kd
PERCHLORATE	Above PRG	
BENZENE	Above PRG	9.8E-02
TOLUENE	Above PRG	3.5E-01
1,1,1,2-TETRACHLOROETHANE	Above PRG	8.6E-01
1,2-DICHLOROBENZENE	Above PRG	1.9E+00
LEAD	Above PRG	1.0E+01
BARIUM	Above PRG	1.1E+01
COPPER	Above PRG	4.0E+01
ETHYLBENZENE	Below PRG	1.1E+00
ZINC	Below PRG	1.6E+01
XYLENES, TOTAL	ID	1.2E+00

Note: Top COCs by mobility were determined by examining each detected compound in the dataset and comparing their mobilities (Koc's for organics, assume foc = 0.001, and Kd's for metals). ID (Insufficient Data)

COC Decision Mobility shows a list of COC recommendations from the available dataset based on the Mobility of the compounds. Top COCs by mobility were determined by examining each detected compound in the dataset and comparing their mobilities. (Koc's for organics, assume foc = 0.001, and Kd's for metals). Compounds listed first are those above the PRG and are shown on the *COC Decision* screen.



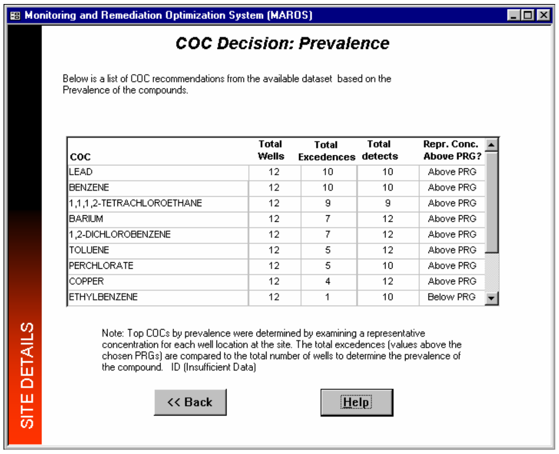
COC Decision: Toxicity

Below is a list of COC recommendations from the available dataset based on the Toxicity of the compounds.

COC	Representative Concentration (mg/L)	PRG	Repr. Conc. Above PRG?	Percent Above PRG
LEAD	1.0E+01	4.0E-03	Above PRG	252635.00%
1,1,1,2-TETRACHLOROETHANE	3.8E-01	4.3E-04	Above PRG	87170.98%
BENZENE	1.4E-01	3.9E-04	Above PRG	34958.64%
PERCHLORATE	1.2E-01	1.8E-02	Above PRG	552.21%
1,2-DICHLOROBENZENE	9.8E-01	3.7E-01	Above PRG	168.11%
TOLUENE	1.7E+00	7.2E-01	Above PRG	135.52%
BARIUM	3.2E+00	2.3E+00	Above PRG	37.38%

Note: Top COCs by toxicity were determined by examining a representative concentration for each compound over the entire site. The compound representative concentrations are then compared with the chosen PRG for that compound, with the percentage excedence from the PRG determining the compound's toxicity. ID (Insufficient Data)

COC Decision Toxicity shows a list of COC recommendations from the available dataset based on the Toxicity of the compounds. Top COCs by toxicity were determined by examining a representative concentration for each compound over the entire site. (Note: The representative concentration can be skewed by high variability in the detection limit for non-detects.) The compound representative concentrations are then compared with the chosen PRG for that compound, with the percentage excedence from the PRG determining the compound's toxicity. Compounds listed first are those above the PRG and are shown on the *COC Decision* screen.



COC Decision: Prevalence

Below is a list of COC recommendations from the available dataset based on the Prevalence of the compounds.

COC	Total Wells	Total Excedences	Total detects	Repr. Conc. Above PRG?
LEAD	12	10	10	Above PRG
BENZENE	12	10	10	Above PRG
1,1,1,2-TETRACHLOROETHANE	12	9	9	Above PRG
BARIUM	12	7	12	Above PRG
1,2-DICHLOROBENZENE	12	7	12	Above PRG
TOLUENE	12	5	12	Above PRG
PERCHLORATE	12	5	10	Above PRG
COPPER	12	4	12	Above PRG
ETHYLBENZENE	12	1	10	Below PRG

Note: Top COCs by prevalence were determined by examining a representative concentration for each well location at the site. The total excedences (values above the chosen PRGs) are compared to the total number of wells to determine the prevalence of the compound. ID (Insufficient Data)

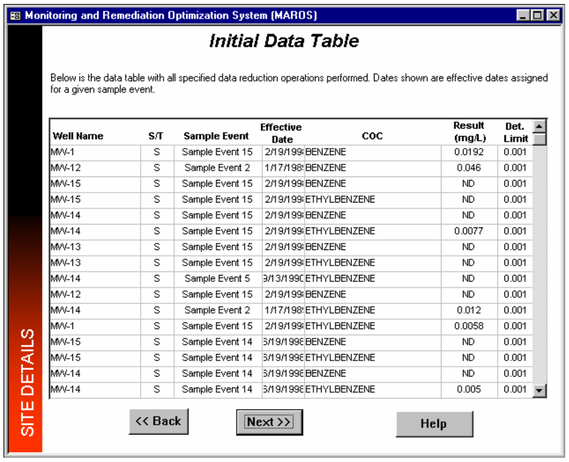
COC Decision Prevalence shows a list of COC recommendations from the available dataset based on the Prevalence of the compounds. Top COCs by prevalence were determined by examining a representative concentration for each well location at the site. The total excedences (values above the chosen PRGs) are compared to the total number of wells to determine the prevalence of the compound. Compounds listed first are those above the PRG and are shown on the *COC Decision* screen.

Back: Returns the user to the *COC Decision* screen.

Help: Provides information on the screen-specific input requirements.

Site Details

Initial Data Table (accessed from the *COC Decision* screen) allows the user to view the initial data table with the COCs chosen as well as the sample events defined and effective dates. This table is not available for editing, but should be used to check for proper importation and sorting of data for the rest of the analysis..



Initial Data Table

Below is the data table with all specified data reduction operations performed. Dates shown are effective dates assigned for a given sample event.

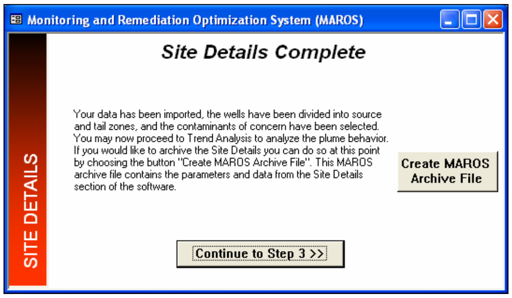
Well Name	S/T	Sample Event	Effective Date	COC	Result (mg/L)	Det. Limit
MW-1	S	Sample Event 15	2/19/199	BENZENE	0.0192	0.001
MW-12	S	Sample Event 2	1/17/198	BENZENE	0.046	0.001
MW-15	S	Sample Event 15	2/19/199	BENZENE	ND	0.001
MW-15	S	Sample Event 15	2/19/199	ETHYLBENZENE	ND	0.001
MW-14	S	Sample Event 15	2/19/199	BENZENE	ND	0.001
MW-14	S	Sample Event 15	2/19/199	ETHYLBENZENE	0.0077	0.001
MW-13	S	Sample Event 15	2/19/199	BENZENE	ND	0.001
MW-13	S	Sample Event 15	2/19/199	ETHYLBENZENE	ND	0.001
MW-14	S	Sample Event 5	3/13/1990	ETHYLBENZENE	ND	0.001
MW-12	S	Sample Event 15	2/19/199	BENZENE	ND	0.001
MW-14	S	Sample Event 2	1/17/198	ETHYLBENZENE	0.012	0.001
MW-1	S	Sample Event 15	2/19/199	ETHYLBENZENE	0.0058	0.001
MW-15	S	Sample Event 14	5/19/1998	BENZENE	ND	0.001
MW-15	S	Sample Event 14	5/19/1998	ETHYLBENZENE	ND	0.001
MW-14	S	Sample Event 14	5/19/1998	BENZENE	ND	0.001
MW-14	S	Sample Event 14	5/19/1998	ETHYLBENZENE	0.005	0.001

Back: Returns the user to the *COC Decision* screen.

Next: Takes the user to the *Main Menu* screen.

Help: Provides information on the screen-specific input requirements.

At this point your data has been imported, the wells have been divided into source and tail zones, and the constituents of concern have been selected. You may now proceed to Trend Analysis to analyze the plume behavior.



Site Details Complete

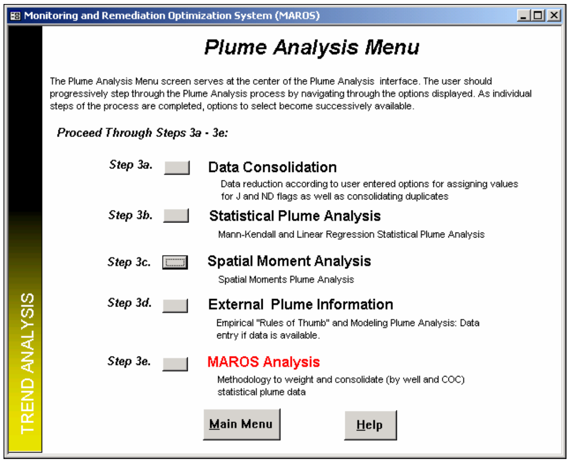
Your data has been imported, the wells have been divided into source and tail zones, and the contaminants of concern have been selected. You may now proceed to Trend Analysis to analyze the plume behavior. If you would like to archive the Site Details you can do so at this point by choosing the button "Create MAROS Archive File". This MAROS archive file contains the parameters and data from the Site Details section of the software.

Continue to Step 3: Returns the user to the *Main Menu* to proceed to Trend Analysis to analyze the plume behavior. The *Main Menu* screen will be displayed.

Create MAROS Archive File: There is also an option to create an archive file of the site details which have been entered, "Create MAROS Archive File" links to a dialog box where a 'mdb' file containing the imported data, site details and source and tail well designations can be stored for later importation ('Import MAROS Archive File' under 'Data Management').. The 'mdb' file created should be named to distinguish it from MAROS output files and other site related databases..

Plume Analysis

The *Plume Analysis Menu* screen serves at the center of the trend analysis user interface. The user progressively steps through the Long Term Monitoring Plume Analysis process by navigating through the options displayed. As individual steps of the process are completed, options to select become successively available.



Plume Analysis Menu

The Plume Analysis Menu screen serves at the center of the Plume Analysis interface. The user should progressively step through the Plume Analysis process by navigating through the options displayed. As individual steps of the process are completed, options to select become successively available.

Proceed Through Steps 3a - 3e:

Step 3a. Data Consolidation
Data reduction according to user entered options for assigning values for J and ND flags as well as consolidating duplicates

Step 3b. Statistical Plume Analysis
Mann-Kendall and Linear Regression Statistical Plume Analysis

Step 3c. Spatial Moment Analysis
Spatial Moments Plume Analysis

Step 3d. External Plume Information
Empirical "Rules of Thumb" and Modeling Plume Analysis: Data entry if data is available.

Step 3e. MAROS Analysis
Methodology to weight and consolidate (by well and COC) statistical plume data

The *Plume Analysis Menu* screen allows the user to choose between performing:

- Step 3a: Data Consolidation
- Step 3b: Statistical Plume Analysis
- Step 3c: Spatial Moment Analysis
- Step 3d: External Plume Information
- Step 3e: MAROS Analysis

Select the desired option by clicking the applicable button. Proceed through Steps 3a – 3e.

The functions accessed by each choice are as follows:

Data Consolidation: Allows reduction of data based on dates as well as consolidating duplicates based on statistical functions (i.e. average, median, etc.). This step also allows for assigning values to non-detects and J flag data.

Statistical Plume Analysis: Perform Mann-Kendall Analysis and Linear Regression Analysis.

Spatial Moment Analysis: Perform Moment Analysis (Zero, First, and Second Moments calculated).

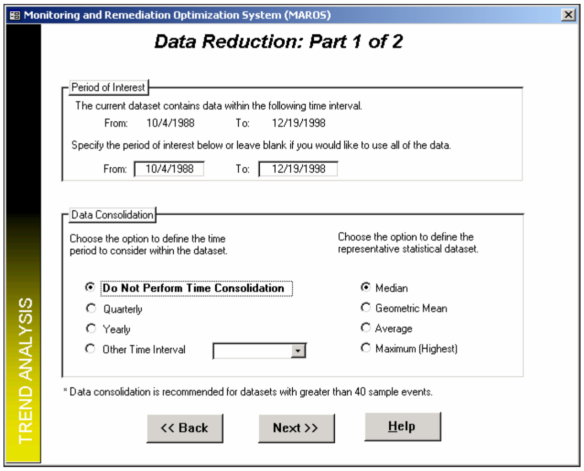
External Plume Information: Enter applicable modeling data and/or empirical data.

MAROS Analysis: Allows user to weight the trend analysis data and weight well data. Final suggested monitoring system categories for each COC are displayed.

Help: Provides additional information on software operation and screen-specific input requirements.

Data Reduction

Data Reduction: *Part 1 of 2* (accessed from the *Plume Analysis Menu* screen) allows the user to consolidate the data based on time intervals and parameters chosen.



Data Reduction: Part 1 of 2

Period of Interest

The current dataset contains data within the following time interval.

From: 10/4/1988 To: 12/19/1998

Specify the period of interest below or leave blank if you would like to use all of the data.

From: 10/4/1988 To: 12/19/1998

Data Consolidation

Choose the option to define the time period to consider within the dataset.

- ● Do Not Perform Time Consolidation
- ○ Quarterly
- ○ Yearly
- ○ Other Time Interval

Choose the option to define the representative statistical dataset.

- ● Median
- ○ Geometric Mean
- ○ Average
- ○ Maximum (Highest)

* Data consolidation is recommended for datasets with greater than 40 sample events.

Steps for use:

1) The box at the top of the screen indicates the current dataset time range. This is the location to specify the date range for the analysis. For example, if the import data ranges from 1979 to 2004, but the analyst is only interested in the time period from 1999 to 2003, the user can specify the date range at this location in the software. The user should specify the period of interest in the boxes or leave blank if all of the data is to be used.

2) Choose the option to consolidate the time period to consider within the dataset by clicking on the options on the bottom left of the screen. If you do not wish to perform any data consolidation, choose "Do Not Perform Time Consolidation".

3) Choose the option to define the representative statistical dataset within the consolidated time interval at the bottom right of the screen. Note: This option is not needed if you have chosen "Do Not Perform Time Consolidation".

Back: Returns the user to the *Plume Analysis Menu* screen.

Next: Takes the user to the *Data Reduction Part 2 of 2* Screen.

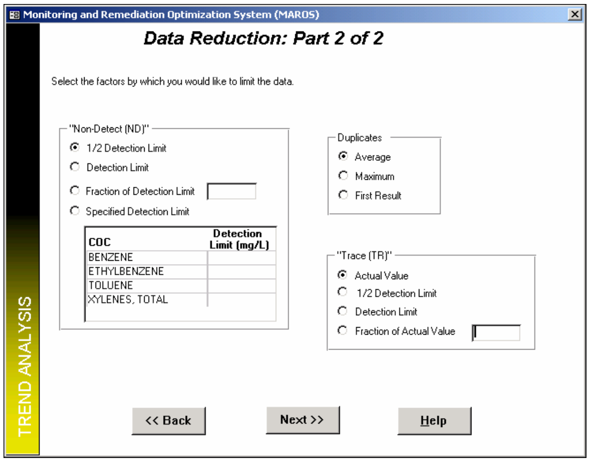
Help: Provides information on the screen-specific input requirements.

Note: Data consolidation is recommended for datasets with greater than 40 sample events.

Data Reduction

Data Reduction: *Part 2 of 2* (accessed from the *Data Reduction Part 1 of 2* screen) allows the user to consolidate the data based on concentration parameters chosen.

Select the factors by which you would like to limit the data.



Data Reduction: Part 2 of 2

Select the factors by which you would like to limit the data.

"Non-Detect (ND)"
● 1/2 Detection Limit
○ Detection Limit
○ Fraction of Detection Limit
○ Specified Detection Limit

COC	Detection Limit (mg/L)
BENZENE	
ETHYLBENZENE	
TOLUENE	
XYLENES, TOTAL	

Duplicates
● Average
○ Maximum
○ First Result

"Trace (TR)"
● Actual Value
○ 1/2 Detection Limit
○ Detection Limit
○ Fraction of Actual Value

"Duplicates": Choose the option to consolidate duplicates. Note: Duplicates are samples that have the same constituent, date, and well name. If you have given the same "effective date" to two samples they will be consolidated as duplicates.

"Non-Detect (ND)": Choose the number value you would like to represent a non-detect result in the data. If you would like to apply a specific detection limit for each chemical choose "Specified Detection Limit". The suggested detection limit is the minimum detection limit. Note: Changes in detection limit over time can create artifacts such as false trends in the analysis when there are several non-detect samples.

"Trace (TR)": Choose the number value you would like to represent a Trace result in the data. (The "TR" flag is equivalent to the "J" flag used by most labs, to indicate a result that is reported but is below the method detection limit)

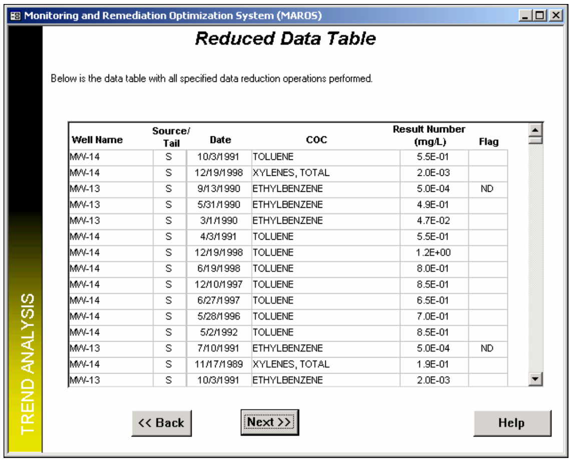
Back: Returns the user to the *Data Reduction Part 2 of 2* screen.

Next: Takes the user to the *Reduced Data Table* Screen.

Help: Provides information on the screen-specific input requirements.

Data Reduction

Reduced Data Table (accessed from the *Data Reduction Part 2 of 2* screen) allows the user to view the reduced data table with the COCs chosen as well as the data consolidation performed. This table is not available for editing.



Reduced Data Table

Below is the data table with all specified data reduction operations performed.

Well Name	Source/ Tail	Date	COC	Result Number (mg/L)	Flag
MW-14	S	10/3/1991	TOLUENE	5.5E-01	
MW-14	S	12/19/1998	XYLENES, TOTAL	2.0E-03	
MW-13	S	9/13/1990	ETHYLBENZENE	5.0E-04	ND
MW-13	S	5/31/1990	ETHYLBENZENE	4.9E-01	
MW-13	S	3/1/1990	ETHYLBENZENE	4.7E-02	
MW-14	S	4/3/1991	TOLUENE	5.5E-01	
MW-14	S	12/19/1998	TOLUENE	1.2E+00	
MW-14	S	6/19/1998	TOLUENE	8.0E-01	
MW-14	S	12/10/1997	TOLUENE	8.5E-01	
MW-14	S	6/27/1997	TOLUENE	6.5E-01	
MW-14	S	5/28/1996	TOLUENE	7.0E-01	
MW-14	S	5/2/1992	TOLUENE	8.5E-01	
MW-13	S	7/10/1991	ETHYLBENZENE	5.0E-04	ND
MW-14	S	11/17/1989	XYLENES, TOTAL	1.9E-01	
MW-13	S	10/3/1991	ETHYLBENZENE	2.0E-03	

Back: Returns the user to the *Data Reduction Part 2 of 2* screen.

Next: Takes the user to the *Reduced Data Plot* screen.

Help: Provides information on the screen-specific input requirements.

Reduced Data Plot (accessed from the *Reduced Data Table* screen) allows the user to view the reduced data in graphical form.

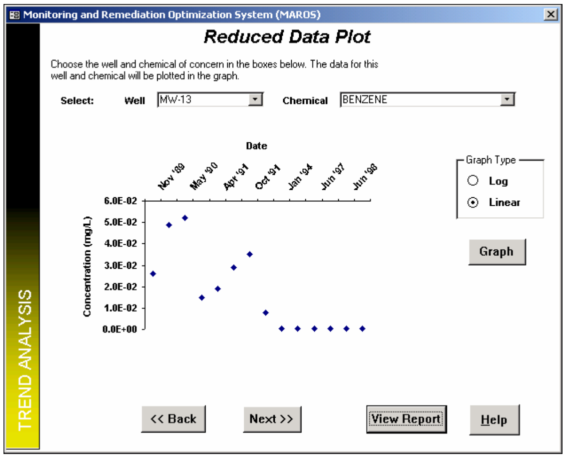
Choose the Well and Chemical of interest from the dropdown boxes at the top of the screen. Choose the graph type (i.e. Log or Linear). Click "Graph" on graph to proceed.

View Report: To print the current graph and data, click "View Report" to proceed.

Back: Returns the user to the *Reduced Data Table* screen.

Next: Takes the user to the *Main Menu* screen.

Help: Provides information on the screen-specific input requirements.

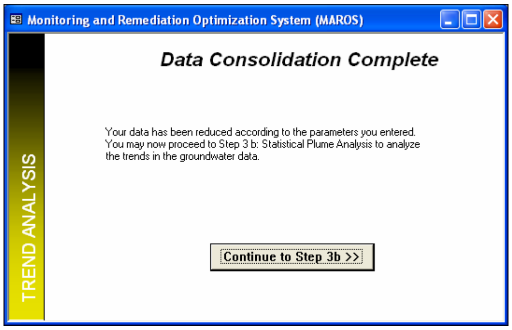


Reduced Data Plot

Choose the well and chemical of concern in the boxes below. The data for this well and chemical will be plotted in the graph.

Select: Well MW-13 Chemical BENZENE

Graph Type
○ Log
● Linear



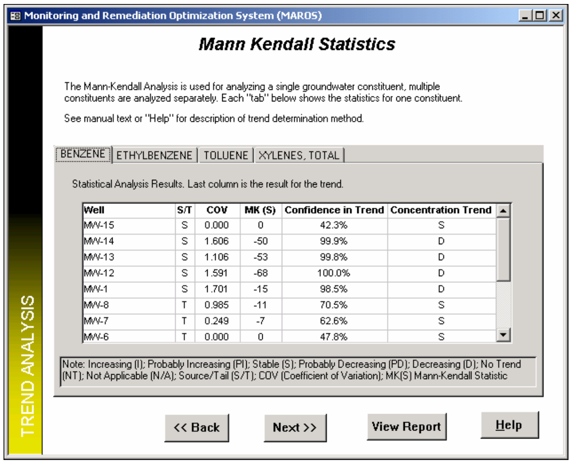
Data Consolidation Complete

Your data has been reduced according to the parameters you entered. You may now proceed to Step 3 b: Statistical Plume Analysis to analyze the trends in the groundwater data.

At this point your data has been reduced according to the parameters you entered. You may now proceed to Step 3b Statistical Plume Analysis and analyze the trends in the groundwater data.

Statistical Plume Analysis

Mann-Kendall Statistics (accessed from the *Plume Analysis Menu*) allows the user to view the Mann-Kendall Trend Analysis results by well and constituent. For further details on the Mann-Kendall Analysis Method see Appendix A.2.



Mann Kendall Statistics

The Mann-Kendall Analysis is used for analyzing a single groundwater constituent, multiple constituents are analyzed separately. Each "tab" below shows the statistics for one constituent.

See manual text or "Help" for description of trend determination method.

Statistical Analysis Results. Last column is the result for the trend.

Well	S/T	COV	MK (S)	Confidence in Trend	Concentration Trend
MW-15	S	0.000	0	42.3%	S
MW-14	S	1.606	-50	99.9%	D
MW-13	S	1.106	-53	99.8%	D
MW-12	S	1.591	-68	100.0%	D
MW-1	S	1.701	-15	98.5%	D
MW-8	T	0.985	-11	70.5%	S
MW-7	T	0.249	-7	62.6%	S
MW-6	T	0.000	0	47.8%	S

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T); COV (Coefficient of Variation); MK(S) Mann-Kendall Statistic

To navigate the results for individual constituents click on the tabs at the top of the screen.

COV: The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. The coefficient of variation, defined as the standard deviation divided by the average. Values near 1.00 indicate that the data form a relatively close group about the mean value. Values either larger or smaller than 1.00 indicate that the data show a greater degree of scatter about the mean.

MK (S): The Mann-Kendall Statistic (S) measures the trend in the data. Positive values indicate an increase in constituent concentrations over time, whereas negative values indicate a decrease in constituent concentrations over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend).

Confidence in Trend: The "Confidence in Trend" is the statistical confidence that the constituent concentration is increasing (S>0) or decreasing (S<0).

Concentration Trend: The "Concentration Trend" for each well is determined according to the rules outlined in Appendix A.2. Results for the trend include: Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

The information displayed in this screen can also be viewed in report form, "Mann-Kendall Statistics Report" from the *MAROS Output* Screen or by clicking on "View Report" (see Appendix A.10 for an example report)..

View Report: To print the "Mann-Kendall Statistics Report" (or save the report in pdf format) and consolidated data, click "View Report" to proceed.

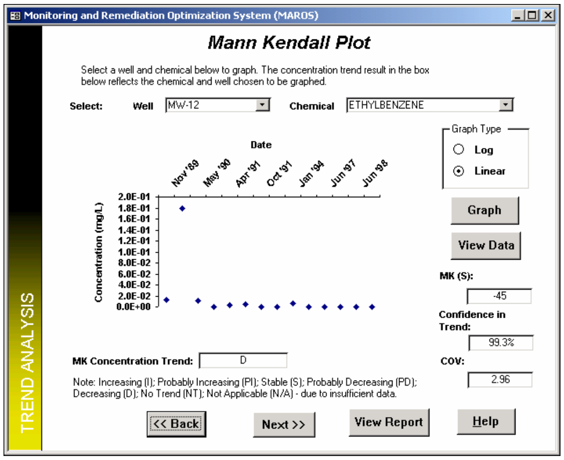
Back: Returns the user to the *Plume Analysis Menu*.

Next: Takes the user to the *Mann-Kendall Plot* Screen.

Help: Provides information on the screen-specific input requirements.

Statistical Plume Analysis

Mann-Kendall Plot (accessed from the *Mann-Kendall Statistics* screen) allows the user to view the Mann-Kendall Trend Analysis results by well and constituent.



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-12 Chemical ETHYLBENZENE

Graph Type: ○ Log ● Linear

MK (S): -45

Confidence in Trend: 99.3%

COV: 2.96

MK Concentration Trend: D

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - due to insufficient data.

Choose the Well and chemical of interest from the dropdown boxes at the top of the screen. Choose the graph type (i.e. Log or Linear). Click "Graph" on graph to proceed.

View Report: To print the current graph, click "View Report" to proceed.

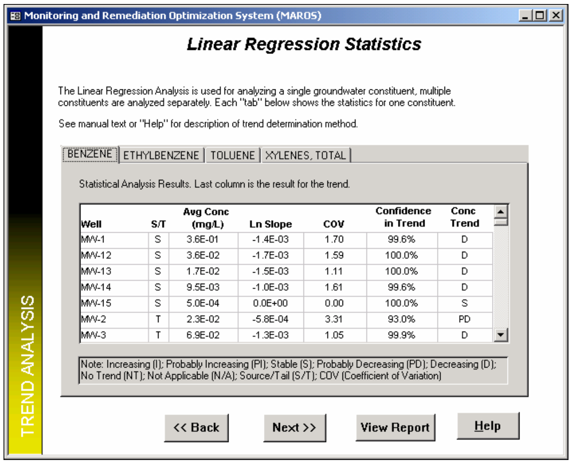
Back: Returns the user to the *Mann-Kendall Statistics* screen.

Next: Takes the user to the *Linear Regression Statistics* screen.

Help: Provides information on the screen-specific input requirements.

Statistical Plume Analysis

Linear Regression Statistics (accessed from the *Mann-Kendall Plot* screen) allows the user to view the Linear Regression Analysis results by well and constituent. For further details on the Linear Regression Analysis Method see Appendix A.2.



Linear Regression Statistics

The Linear Regression Analysis is used for analyzing a single groundwater constituent, multiple constituents are analyzed separately. Each "tab" below shows the statistics for one constituent.

See manual text or "Help" for description of trend determination method.

Statistical Analysis Results. Last column is the result for the trend.

Well	S/T	Avg Conc (mg/L)	Ln Slope	COV	Confidence in Trend	Conc Trend
MW-1	S	3.6E-01	-1.4E-03	1.70	99.6%	D
MW-12	S	3.6E-02	-1.7E-03	1.59	100.0%	D
MW-13	S	1.7E-02	-1.5E-03	1.11	100.0%	D
MW-14	S	9.5E-03	-1.0E-03	1.61	99.6%	D
MW-15	S	5.0E-04	0.0E+00	0.00	100.0%	S
MW-2	T	2.3E-02	-5.8E-04	3.31	93.0%	PD
MW-3	T	6.9E-02	-1.3E-03	1.05	99.9%	D

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T); COV (Coefficient of Variation)

To navigate the results for individual constituents click on the tabs at the top of the screen.

COV: The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. The coefficient of variation, defined as the standard deviation divided by the average. Values near 1.00 indicate that the data form a relatively close group about the mean value. Values either larger or smaller than 1.00 indicate that the data show a greater degree of scatter about the mean.

Residuals COV: The Coefficient of Variation (COV) of the residuals is a statistical measure of how the residuals (the difference between the predicted values and observed values) vary about the mean value. Values near 1.00 indicate that the data form a relatively close group about the mean value, and that the Linear Regression statistics can be relied upon more strongly. Values either larger or smaller than 1.00 indicate that the data show a greater degree of scatter about the mean, and therefore the Mann-Kendall analysis should be relied upon more strongly.

Slope: The slope of the least square fit through the given data indicates the trend in the data. Positive values indicate an increase in constituent concentrations over time, whereas negative values indicate a decrease in constituent concentrations over time.

Confidence in Trend: The "Confidence in Trend" is the statistical confidence that the constituent concentration is increasing (slope>0) or decreasing (slope<0).

Concentration Trend: The "Concentration Trend" for each well is determined according to the rules outlined in Appendix A.2. Results for the trend include: Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

The information displayed in this screen can also be viewed in report form, "Linear Regression Statistics Report" from the *MAROS Output* Screen (see Appendix A.10 for an example report).

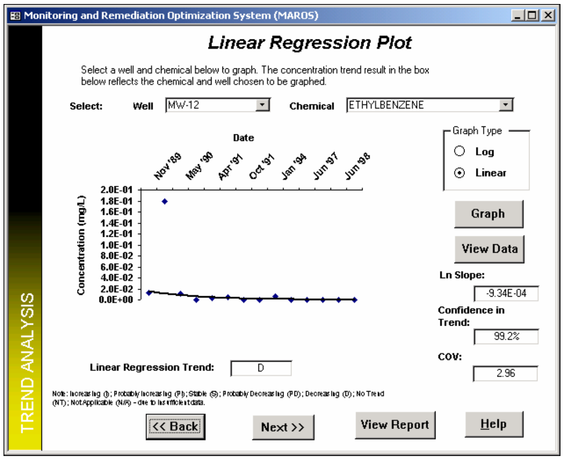
Back: Returns the user to the *Mann Kendall Plot* Screen.

Next: Takes the user to the *Linear Regression Plot* Screen.

Help: Provides information on the screen-specific input requirements.

Statistical Plume Analysis

Linear Regression Plot (accessed from the *Linear Regression Statistics* screen) allows the user to view the linear regression data in graphical form.



Linear Regression 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-12 Chemical ETHYLBENZENE

Graph Type: ○ Log ● Linear

Ln Slope: -9.34E-04

Confidence in Trend: 99.2%

COV: 2.96

Linear Regression Trend: D

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) – due to insufficient data.

Choose the Well and chemical of interest from the dropdown boxes at the top of the screen. Choose the graph type (i.e. Log or Linear). Click "Graph" on graph to proceed.

View Report: To print the current graph, click "View Report" to proceed.

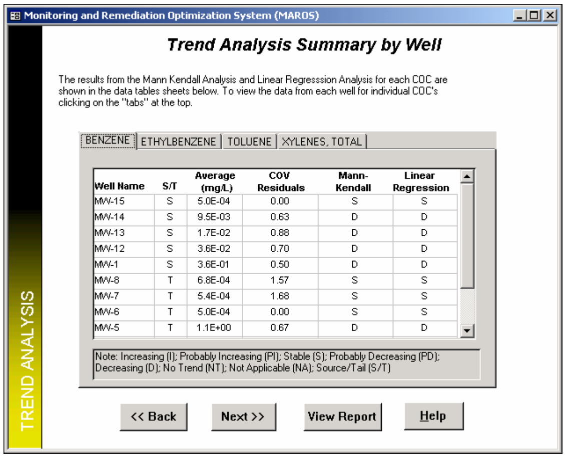
Back: Returns the user to the *Linear Regression Statistics* screen.

Next: Takes the user to the *Statistical Plume Analysis Summary* screen.

Help: Provides information on the screen-specific input requirements.

Summarizing Statistical Plume Analysis

Trend Analysis Statistics Summary by Well (accessed from the *Linear Regression Plot* screen) allows the user to view the Mann-Kendall Trend Analysis and Linear Regression Analysis results by well and constituent.



Trend Analysis Summary by Well

The results from the Mann Kendall Analysis and Linear Regresssion Analysis for each COC are shown in the data tables sheets below. To view the data from each well for individual COC's clicking on the "tabs" at the top.

Well Name	S/T	Average (mg/L)	COV Residuals	Mann-Kendall	Linear Regression
MW-15	S	5.0E-04	0.00	S	S
MW-14	S	9.5E-03	0.63	D	D
MW-13	S	1.7E-02	0.88	D	D
MW-12	S	3.6E-02	0.70	D	D
MW-1	S	3.6E-01	0.50	D	D
MW-8	T	6.8E-04	1.57	S	S
MW-7	T	5.4E-04	1.68	S	S
MW-6	T	5.0E-04	0.00	S	S
MW-5	T	1.1E+00	0.67	D	D

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (NA); Source/Tail (S/T)

To navigate the results for individual constituents click on the tabs at the top of the screen.

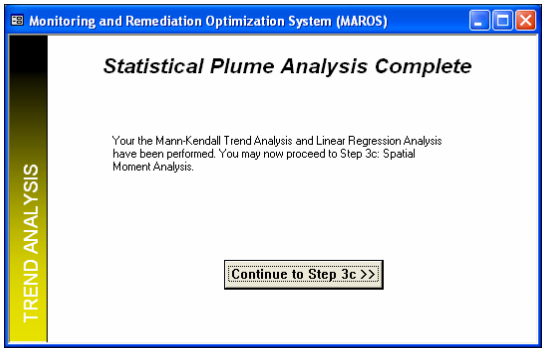
The information displayed in this screen can also be viewed in report form, "Statistical Plume Analysis Summary Report" from the *MAROS Output* Screen or by clicking on "View Report".

Back: Returns the user to the *Linear Regression Plot*.

Next: Takes the user to the *Main Menu* Screen.

Help: Provides information on the screen-specific input requirements.

At this point the Mann-Kendall Trend Analysis and Linear Regression Analysis have been performed. You may now proceed to the Step 3c: Spatial Moment Analysis.

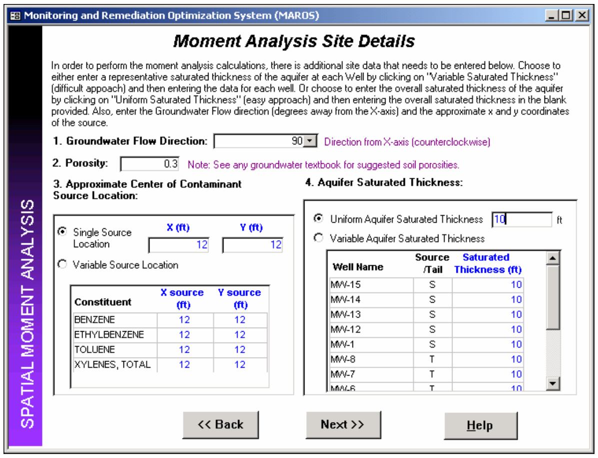


Statistical Plume Analysis Complete

Your the Mann-Kendall Trend Analysis and Linear Regression Analysis have been performed. You may now proceed to Step 3c: Spatial Moment Analysis.

Spatial Moment Analysis

Moment Analysis Site Details (accessed from the *Plume Analysis Menu* screen) allows the user to enter data by well and constituent to be used in the Moment Analysis.



Moment Analysis Site Details

In order to perform the moment analysis calculations, there is additional site data that needs to be entered below. Choose to either enter a representative saturated thickness of the aquifer at each Well by clicking on "Variable Saturated Thickness" (difficult appoach) and then entering the data for each well. Or choose to enter the overall saturated thickness of the aquifer by clicking on "Uniform Saturated Thickness" (easy approach) and then entering the overall saturated thickness in the blank provided. Also, enter the Groundwater Flow direction (degrees away from the X-axis) and the approximate x and y coordinates of the source.

1. Groundwater Flow Direction: 90 Direction from X-axis (counterclockwise)

2. Porosity: 0.3 Note: See any groundwater textbook for suggested soil porosities.

3. Approximate Center of Contaminant Source Location:

● Single Source Location X (ft) 12 Y (ft) 12

○ Variable Source Location

Constituent	X source (ft)	Y source (ft)
BENZENE	12	12
ETHYLBENZENE	12	12
TOLUENE	12	12
XYLENES, TOTAL	12	12

4. Aquifer Saturated Thickness:

● Uniform Aquifer Saturated Thickness 10 ft

○ Variable Aquifer Saturated Thickness

Well Name	Source /Tail	Saturated Thickness (ft)
MW-15	S	10
MW-14	S	10
MW-13	S	10
MW-12	S	10
MW-1	S	10
MW-8	T	10
MW-7	T	10
MW-6	T	10

Note: All Data entry items are mandatory. data required includes porosity, groundwater flow direction, approximate contaminant source location, and aquifer saturated thickness.

The current version of MAROS only allows for designation of one source location and one saturated thickness.

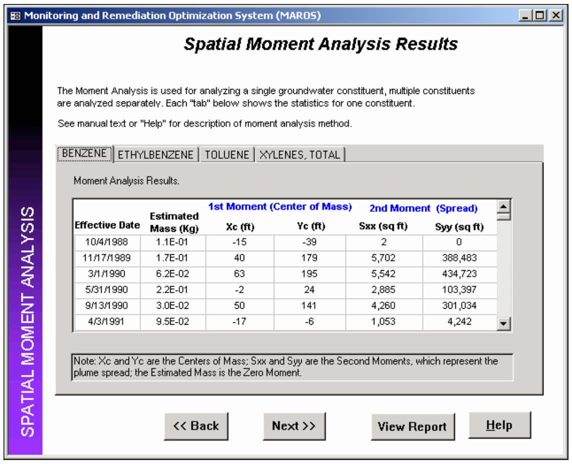
Back: Returns the user to the *Plume Analysis Menu*.

Next: Takes the user to the *Moment Analysis Statistics* Screen.

Help: Provides information on the screen-specific input requirements.

Spatial Moment Analysis

Moment Analysis Statistics (accessed from the *Moment Analysis Site Details* screen) allows the user to view the Spatial Moment Analysis results by well and constituent.



Spatial Moment Analysis Results

The Moment Analysis is used for analyzing a single groundwater constituent, multiple constituents are analyzed separately. Each "tab" below shows the statistics for one constituent.

See manual text or "Help" for description of moment analysis method.

Moment Analysis Results.

Effective Date	Estimated Mass (Kg)	1st Moment (Center of Mass) Xc (ft)	1st Moment (Center of Mass) Yc (ft)	2nd Moment (Spread) Sxx (sq ft)	2nd Moment (Spread) Syy (sq ft)
10/4/1988	1.1E-01	-15	-39	2	0
11/17/1989	1.7E-01	40	179	5,702	388,483
3/1/1990	6.2E-02	63	195	5,542	434,723
5/31/1990	2.2E-01	-2	24	2,885	103,397
9/13/1990	3.0E-02	50	141	4,260	301,034
4/3/1991	9.5E-02	-17	-6	1,053	4,242

Note: Xc and Yc are the Centers of Mass; Sxx and Syy are the Second Moments, which represent the plume spread; the Estimated Mass is the Zero Moment.

To navigate the results for individual constituents click on the tabs at the top of the screen.

Zeroth Moment (Estimated Mass): The zeroth moment is a mass estimate for each sample event and COC. The estimated mass is used to evaluate the change in total mass of the plume over time.

First Moment (Center of Mass): The first moment estimates the center of mass of the plume (as coordinates Xc and Yc) for each sample event and COC. The center of mass locations indicate the movement of the center of mass over time.

Second Moment (Spread of Plume): The second moment indicates the spread of the contaminant about the center of mass (Sxx and Syy), or the distance of contamination from the center of mass. The Second Moment represents the spread of the plume over time.

The information displayed in this screen can also be viewed in report form, “Spatial Moment Analysis Report” from the *MAROS Output* Screen or by clicking on “View Report” (see Appendix A.10 for an example report). The next screens will go through each moment analysis result in detail as well as looking at trends in the data over time. For further details on the Spatial Moment Analysis Method see Appendix A.5.

View Report: To print the “Spatial Moment Analysis Report” and analysis results, click “View Report” to proceed.

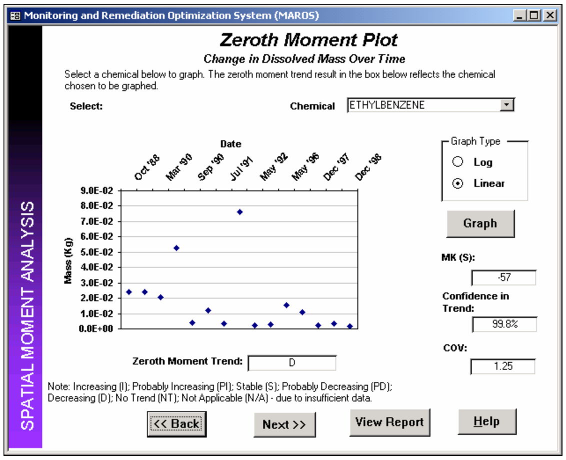
Back: Returns the user to the *Moment Analysis Site Details*.

Next: Takes the user to the *Zeroth Moment Plot* Screen.

Help: Provides information on the screen-specific input requirements.

Spatial Moment Analysis: Change in Dissolved Mass Over Time

Zeroth Moment Plot (accessed from the *Moment Analysis Statistics* screen) allows the user to view the Zeroth Moment Analysis results by constituent over time. The zero moment in MAROS calculates an estimate of the mass of a constituent in the plume for each sample event. The estimated mass over time is then evaluated using the Mann Kendall method to determine the trend in total mass of the plume over time.



Zeroth Moment Plot

Change in Dissolved Mass Over Time

Select a chemical below to graph. The zeroth moment trend result in the box below reflects the chemical chosen to be graphed.

Select: Chemical ETHYLBENZENE

MK (S): -57

Confidence in Trend: 99.8%

COV: 1.25

Zeroth Moment Trend: D

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - due to insufficient data.

Choose the chemical of interest from the dropdown boxes at the top of the screen. Choose the graph type (i.e. Log or Linear). Click "Graph" on graph to proceed.

Zeroth Moment Trend: The Zero Moment trend over time is determined by using the Mann-Kendall Trend Methodology. The "Zeroth Moment" Trend for each COC is determined according to the rules outlined in Appendix A.2. Results for the trend include: Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

MK (S): The Mann-Kendall Statistic (S) measures the trend in the data. Positive values indicate an increase in estimated mass over time, whereas negative values indicate a decrease in estimated mass over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend).

Confidence in Trend: The "Confidence in Trend" is the statistical confidence that the estimated mass is increasing (S>0) or decreasing (S<0).

COV: The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. The coefficient of variation, defined as the standard deviation divided by the average. Values near 1.00 indicate that the data form a relatively close group about the mean value. Values either larger or smaller than 1.00 indicate that the data show a greater degree of scatter about the mean.

View Report: To print the "Zeroth Moment Analysis Report" and analysis results, click "View Report" to proceed.

Back: Returns the user to the *Moment Analysis Site Details*.

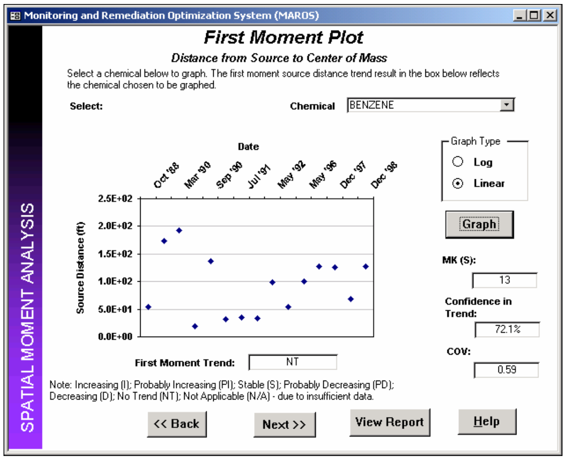
Next: Takes the user to the *First Moment Plot* Screen.

Help: Provides information on the screen-specific input requirements.

Note: The information displayed in this screen can also be viewed in report form, "Zeroth Moment Report" from the *MAROS Output* Screen or by clicking on "View Report" (see Appendix A.10 for an example report). For further details on the Mann-Kendall Analysis Method or Moment Analysis see Appendix A.2 and A.5 respectively.

Spatial Moment Analysis: Distance from Source to Center of Mass

First Moment Plot: Distance from Source to Center of Mass (accessed from the *Zero Moment Plot* screen) allows the user to view the First Moment Analysis results by constituent over time. The first moment estimates the center of mass, coordinates (Xc and Yc) for each sample event and COC. The distance from the original source location to the center of mass locations indicate the movement of the center of mass over time relative to the original source.



First Moment Plot

Distance from Source to Center of Mass

Select a chemical below to graph. The first moment source distance trend result in the box below reflects the chemical chosen to be graphed.

Select: Chemical BENZENE

○ Log
● Linear

MK (S): 13

Confidence in Trend: 72.1%

COV: 0.59

First Moment Trend: NT

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - due to insufficient data.

Choose the chemical of interest from the dropdown boxes at the top of the screen. Choose the graph type (i.e. Log or Linear). Click "Graph" on graph to proceed.

First Moment Trend: The First Moment trend of the distance to the center of mass over time is determined by using the Mann-Kendall Trend Methodology. The "First Moment" trend for each COC is determined according to the rules outlined in Appendix A.2. Results for the trend include: Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

MK (S): The Mann-Kendall Statistic (S) measures the trend in the data. Positive values indicate an increase in the distance from the source to the center of mass over time, whereas negative values indicate a decrease in the distance from the source to the center of mass over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend).

Confidence in Trend: The "Confidence in Trend" is the statistical confidence that the distance to the from the source to the center of mass is increasing (S>0) or decreasing (S<0).

COV: The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. The coefficient of variation, defined as the standard deviation divided by the average. Values near 1.00 indicate that the data form a relatively close group about the mean value. Values either larger or smaller than 1.00 indicate that the data show a greater degree of scatter about the mean.

View Report: To print the "First Moment: Distance from Source to Center of Mass Report" and analysis results, click "View Report" to proceed.

Back: Returns the user to the *Zeroth Moment Plot* screen.

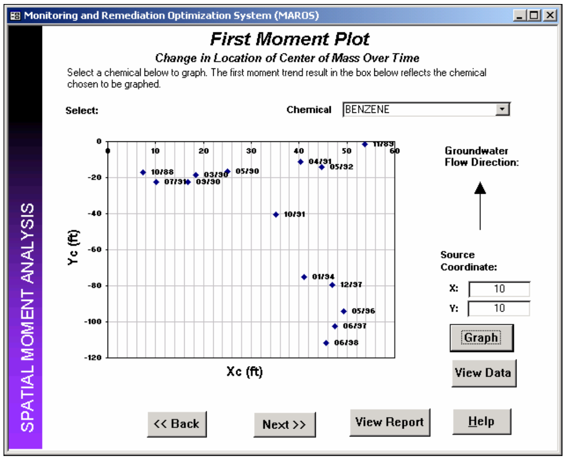
Next: Takes the user to the *First Moment Plot: Change in Location of Mass Over Time* screen.

Help: Provides information on the screen-specific input requirements.

Note: The information displayed in this screen can also be viewed in report form, "First Moment Report" from the *MAROS Output* Screen or by clicking on "View Report" (see Appendix A.10 for an example report). For further details on the Mann-Kendall Analysis Method or Moment Analysis see Appendix A.2 and A.5 respectively.

Spatial Moment Analysis: Change in Location of Mass Center Over Time

First Moment Plot: Change in Location of Mass Over Time (accessed from the *First Moment Plot: Distance from Source to Center of Mass* screen) allows the user to view the First Moment Analysis results by constituent over time. The first moment estimates the center of mass of the plume coordinates (Xc and Yc) for each sample event and COC. The center of mass locations indicate the movement of the center of mass over time.



Monitoring and Remediation Optimization System (MAROS)

First Moment Plot

Change in Location of Center of Mass Over Time

Select a chemical below to graph. The first moment trend result in the box below reflects the chemical chosen to be graphed.

Select: Chemical BENZENE

Source Coordinate:
X: 10
Y: 10

Choose the chemical of interest from the dropdown boxes at the top of the screen. Choose the graph type (i.e. Log or Linear). Click "Graph" on graph to proceed.

The source location coordinates are shown on the screen left. To view the data for the graph, choose "View Data", this shows a table with the Xc, Yc, and Source Distance for all sample events.

View Report: To print the "First Moment: Change in Location of Center of Mass Report" and analysis results, click "View Report" to proceed.

Back: Returns the user to the *First Moment Plot: Distance from Source to Center of Mass* screen.

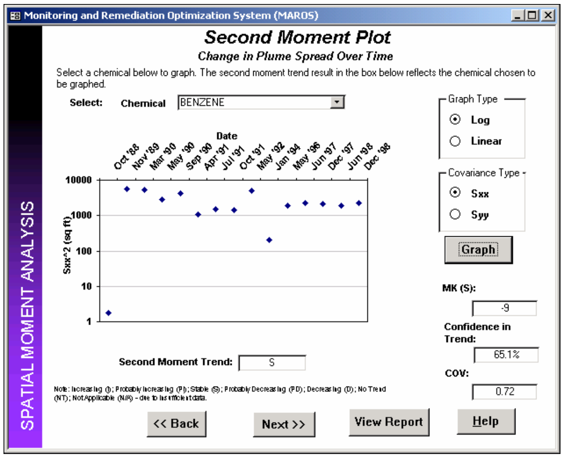
Next: Takes the user to the *Second Moment Plot* screen.

Help: Provides information on the screen-specific input requirements.

Note: The information displayed in this screen can also be viewed in report form, "First Moment: Change in Location of Mass Center Over Time Report" from the *MAROS Output* Screen or by clicking on "View Report" (see Appendix A.10 for an example report).

Spatial Moment Analysis: Change in Plume Spread Over Time

Second Moment Plot: Change in Plume Spread Over Time (accessed from the *First Moment Plot: Change in Location of Mass Over Time* screen) allows the user to view the Second Moment Analysis results by constituent over time. The second moment indicates the spread of the contaminant about the center of mass (Sxx and Syy), or the distance of contamination from the center of mass. The Second Moment represents the spread of the plume over time in both the x and y directions.



Select a chemical below to graph. The second moment trend result in the box below reflects the chemical chosen to be graphed.

Select: Chemical BENZENE

Graph Type: ● Log ○ Linear

Covariance Type: ● Sxx ○ Syy

MK (S): -9

Confidence in Trend: 65.1%

COV: 0.72

Second Moment Trend: S

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - due to Insufficient data.

Choose the chemical of interest from the dropdown boxes at the top of the screen. Choose the graph type (i.e. Log or Linear). Choose the Covariance Type (i.e. Sxx or Syy). Click "Graph" on graph to proceed.

Second Moment Trend: The Second Moment trend of the Spread of the Plume in the X or Y direction over time is determined by using the Mann-Kendall Trend Methodology. The "Second Moment" trend for each COC is determined according to the rules outlined in Appendix A.2. Results for the trend include: Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

MK (S): The Mann-Kendall Statistic (S) measures the trend in the data. Positive values indicate an increase in the spread of the plume over time (expanding plume), whereas negative values indicate a decrease in the spread of the plume over time (shrinking plume). The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend).

Confidence in Trend: The "Confidence in Trend" is the statistical confidence that the spread of the plume in the x or y direction is increasing (S>0) or decreasing (S<0).

COV: The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. The coefficient of variation, defined as the standard deviation divided by the average. Values near 1.00 indicate that the data form a relatively close group about the mean value. Values either larger or smaller than 1.00 indicate that the data show a greater degree of scatter about the mean.

View Report: To print the "Second Moment: Change Plume Spread Over Time Report" and analysis results, click "View Report" to proceed.

Back: Returns the user to the *First Moment Plot: Change in Location of Mass Over Time* screen.

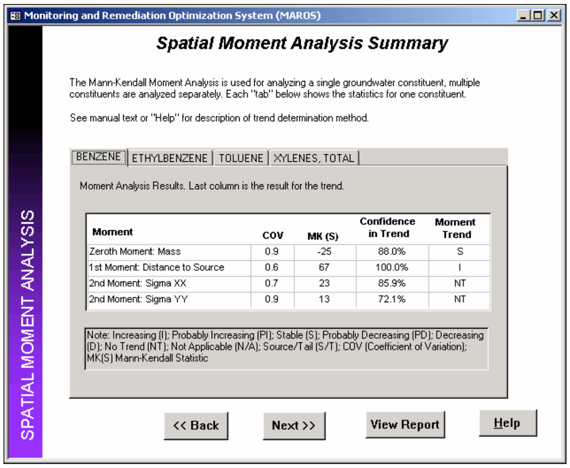
Next: Takes the user to the *Spatial Moment Analysis Summary* screen.

Help: Provides information on the screen-specific input requirements.

Note: The information displayed in this screen can also be viewed in report form, "Second Moment: Change Plume Spread Over Time Report" from the *MAROS Output* Screen or by clicking on "View Report" (see Appendix A.10 for an example report). For further details on the Mann-Kendall Analysis Method or Moment Analysis see Appendix A.2 and A.5 respectively.

Summarizing Spatial Moment Analysis

Spatial Moment Analysis Summary (accessed from the *Second Moment Plot: Change in Plume Spread Over Time* screen) allows the user to view the Moment Analysis Mann-Kendall results by constituent.



Spatial Moment Analysis Summary

The Mann-Kendall Moment Analysis is used for analyzing a single groundwater constituent, multiple constituents are analyzed separately. Each "tab" below shows the statistics for one constituent.

See manual text or "Help" for description of trend determination method.

Moment Analysis Results. Last column is the result for the trend.

Moment	COV	MK (S)	Confidence in Trend	Moment Trend
Zeroth Moment: Mass	0.9	-25	88.0%	S
1st Moment: Distance to Source	0.6	67	100.0%	I
2nd Moment: Sigma XX	0.7	23	85.9%	NT
2nd Moment: Sigma YY	0.9	13	72.1%	NT

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T); COV (Coefficient of Variation); MK(S) Mann-Kendall Statistic

To navigate the results for individual constituents click on the tabs at the top of the screen.

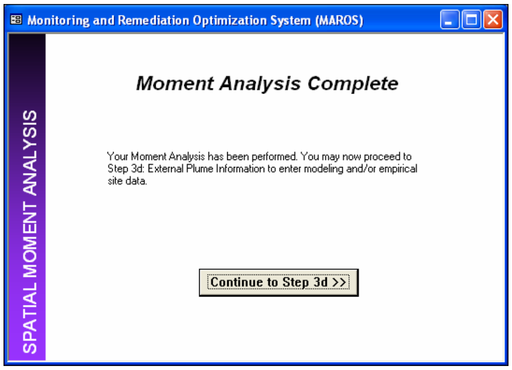
The information displayed in this screen can also be viewed in report form, "Spatial Moment Analysis Summary Report" from the *MAROS Output* Screen or by clicking on "View Report".

Back: Returns the user to the *Second Moment Plot*.

Next: Takes the user to the *Plume Analysis Menu* Screen.

Help: Provides information on the screen-specific input requirements.

At this point the Spatial Moment Analysis has been performed. You may now proceed to the Step 3d: External Plume Information.

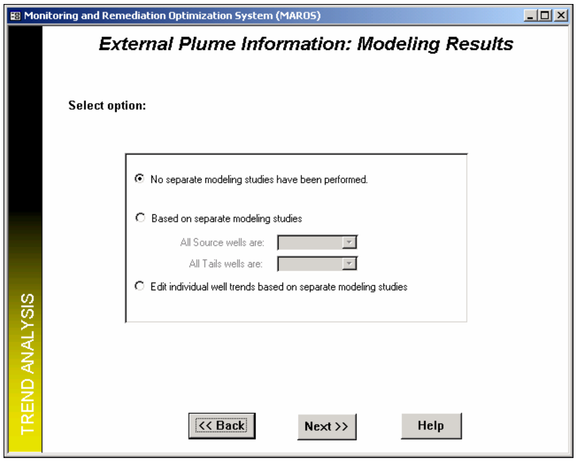


Moment Analysis Complete

Your Moment Analysis has been performed. You may now proceed to Step 3d: External Plume Information to enter modeling and/or empirical site data.

External Plume Information

External Plume Information: Modeling Results (accessed from the *Plume Analysis Menu* screen) allows the user to enter statistical modeling results by well and constituent or for all source or all tail wells.



External Plume Information: Modeling Results

Select option:

● No separate modeling studies have been performed.

○ Based on separate modeling studies

All Source wells are:

All Tails wells are:

○ Edit individual well trends based on separate modeling studies

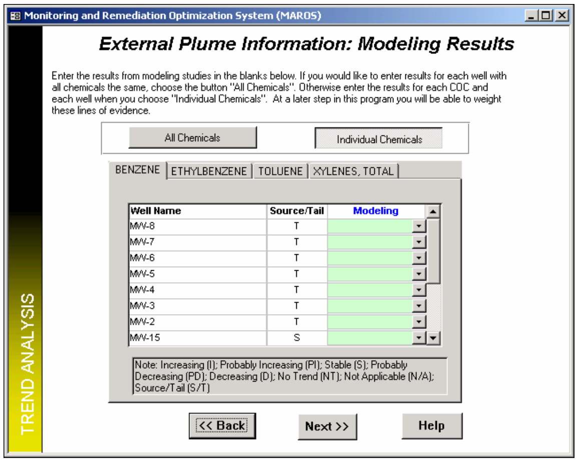
Options include entering modeling trend results i) based on separate modeling studies for both source and tail wells; ii) individual well trends based on separate modeling studies. If there are no modeling results choose the option "No separate modeling studies have been performed".

Back: Returns the user to the *Plume Analysis Menu*.

Next: Takes the user to the *External Plume Information* screen. Note: If "Edit individual well trends based on separate modeling studies" is chosen, the next screen will allow this data entry.

Help: Provides information on the screen-specific input requirements.

External Plume Information: Modeling Results allows the user to enter modeling results obtained by methods different from Mann-Kendall or Linear Regression. Results of alternative statistical analyses can be entered by well and constituent.



External Plume Information: Modeling Results

Enter the results from modeling studies in the blanks below. If you would like to enter results for each well with all chemicals the same, choose the button "All Chemicals". Otherwise enter the results for each COC and each well when you choose "Individual Chemicals". At a later step in this program you will be able to weight these lines of evidence.

Well Name	Source/Tail	Modeling
MW-8	T	
MW-7	T	
MW-6	T	
MW-5	T	
MW-4	T	
MW-3	T	
MW-2	T	
MW-15	S	

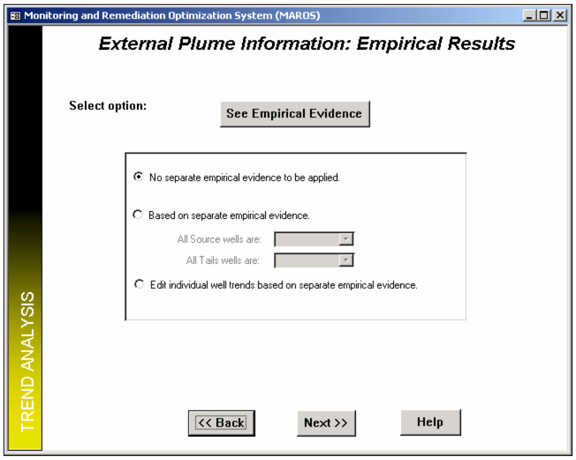
Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T)

Enter the results from modeling studies (e.g. Increasing (I), Stable (S), etc.) in the blanks provided next to the well name. To navigate the results for individual constituents click on the tabs at the top of the screen. If you would like to weight all chemicals the same choose the button "All Chemicals". Otherwise enter the results for each COC and each well when you choose "Individual Chemicals". At a later step in this program you will be able to weight these lines of evidence.

Modeling results should be taken from fate and transport models that take site specific data and predict the ultimate extent of constituent migration (either for natural attenuation process or site undergoing remediation). Results for the modeling trend that can be entered in the software include: Increasing (I), Probably Increasing (PI), No Trend (NT), Stable (S), Probably Decreasing (PD), Decreasing (D) or Not Applicable (NA- Insufficient Data).

External Plume Information

External Plume Information: Empirical Results (accessed from the *External Plume Information: Modeling Results* screen) allows the user to enter empirical trend information by well and constituent or for all source or all tail wells. The rationale and limitations to this approach is outlined in Appendix A.4.



External Plume Information: Empirical Results

Select option:

● No separate empirical evidence to be applied.

○ Based on separate empirical evidence.

All Source wells are:

All Tails wells are:

○ Edit individual well trends based on separate empirical evidence.

Options include entering empirical trend results i) based on separate empirical evidence for both source and tail wells; ii) individual well trends based on separate empirical rules. If there are no empirical results choose the option "No separate empirical evidence to be applied".

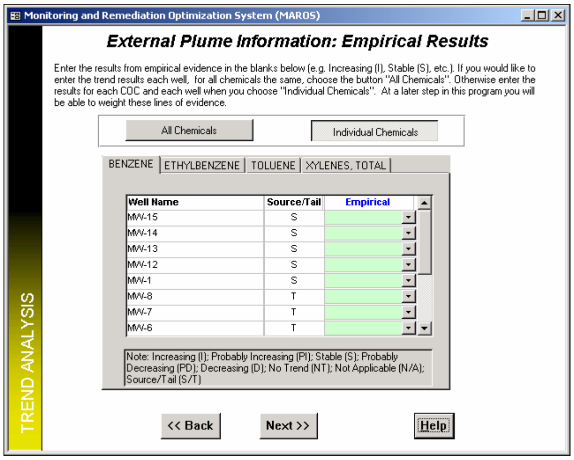
See Empirical Evidence: Takes the user to the *Empirical Evidence,* by State.

Back: Returns the user to the *Modeling Results*.

Next: Takes the user to the *External Plume Information Summary* Screen. Note: If "Edit individual well trends based on separate empirical studies" is chosen, the next screen will allow this data entry.

Help: Provides information on the screen-specific input requirements.

External Plume Information: Empirical Results allows the user to enter empirical results by well and constituent.



External Plume Information: Empirical Results

Enter the results from empirical evidence in the blanks below (e.g. Increasing (I), Stable (S), etc.). If you would like to enter the trend results each well, for all chemicals the same, choose the button "All Chemicals". Otherwise enter the results for each COC and each well when you choose "Individual Chemicals". At a later step in this program you will be able to weight these lines of evidence.

Well Name	Source/Tail	Empirical
MW-15	S	
MW-14	S	
MW-13	S	
MW-12	S	
MW-1	S	
MW-8	T	
MW-7	T	
MW-6	T	

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T)

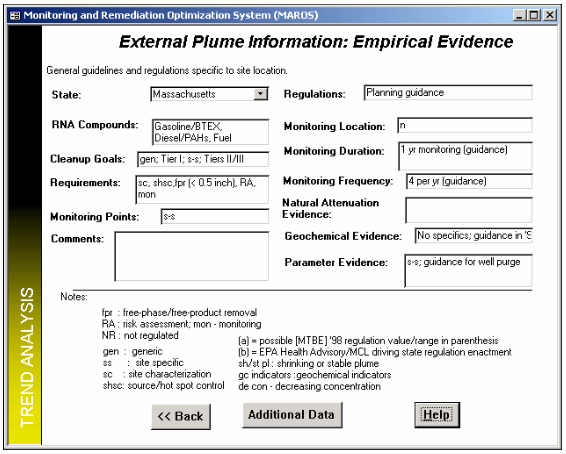
Enter the results from empirical evidence (e.g. Increasing (I), Stable (S), etc.) in the blanks provided next to the well name. To navigate the results for individual constituents click on the tabs at the top of the screen. If you would like to weight all chemicals the same choose the button "All Chemicals". Otherwise enter the results for each COC and each well when you choose "Individual Chemicals". At a later step in this program you will be able to weight these lines of evidence.

Empirical results should be developed on the basis of data from previous similar site studies (e.g. "plume-a-thon" studies such as the Lawrence Livermore study, the BEG studies and the AFCEE chlorinated database). For further Empirical result guidelines see Appendix A.4. Also, state rules are provided to guide the user to site-specific guidelines for natural attenuation. Results for the empirical trend that can be entered in the software include: Increasing (I), Probably Increasing (PI), No Trend (NT), Stable (S), Probably Decreasing (PD), Decreasing (D) or Not Applicable (NA- Insufficient Data).

External Plume Information: Empirical Evidence (accessed from the *External Plume Information: Empirical Results* screen) gives the user guidance for empirical evidence for trends by State.

External Plume Information

To view information pertaining to the state of interest, choose the state name from the drop down box at the top left. Information on general guidelines and regulations specific for Long Term Monitoring are shown.



External Plume Information: Empirical Evidence

General guidelines and regulations specific to site location.

State: Massachusetts
Regulations: Planning guidance
RNA Compounds: Gasoline/BTEX, Diesel/PAHs, Fuel
Monitoring Location: n
Monitoring Duration: 1 yr monitoring (guidance)
Cleanup Goals: gen; Tier I; s-s; Tiers II/III
Requirements: sc, shsc,fpr (< 0.5 inch), RA, mon
Monitoring Frequency: 4 per yr (guidance)
Natural Attenuation Evidence:
Monitoring Points: s-s
Geochemical Evidence: No specifics; guidance in 'S
Comments:
Parameter Evidence: s-s; guidance for well purge

Notes:

fpr : free-phase/free-product removal
RA : risk assessment; mon - monitoring
NR : not regulated
gen : generic
ss : site specific
sc : site characterization
shsc: source/hot spot control
(a) = possible [MTBE] '98 regulation value/range in parenthesis
(b) = EPA Health Advisory/MCL driving state regulation enactment
sh/st pl : shrinking or stable plume
gc indicators :geochemical indicators
de con - decreasing concentration

Additional Data: Takes the user to the *Screen Criteria*, by State.

Back: Returns the user to the *Empirical Results*.

Help: Provides information on the screen-specific input requirements.

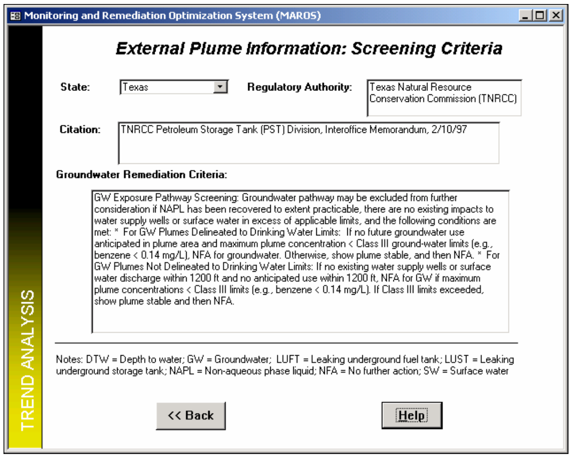
Sources for this information include:

Martinson, M., 1998 and Groundwater Services, Inc. (www.gsi-net.com/ rbcapol)

External Plume Information: Screening Criteria (accessed from the *External Plume Information: Empirical Evidence* screen) gives the user additional guidance for empirical evidence for trends by State.

To view information pertaining to the state of interest, choose the state name from the drop down box at the top left. Information on general guidelines and regulations specific for Long Term Monitoring are shown.

Back: Returns the user to the *Empirical Evidence*.



External Plume Information: Screening Criteria

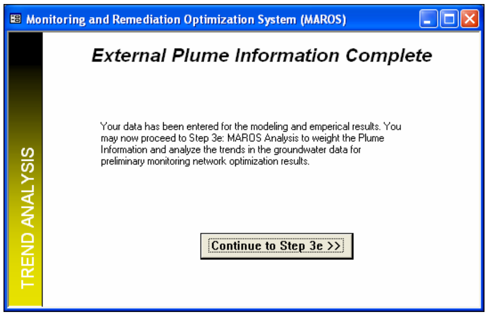
State: Texas
Regulatory Authority: Texas Natural Resource Conservation Commission (TNRCC)
Citation: TNRCC Petroleum Storage Tank (PST) Division, Interoffice Memorandum, 2/10/97

Groundwater Remediation Criteria:

GW Exposure Pathway Screening: Groundwater pathway may be excluded from further consideration if NAPL has been recovered to extent practicable, there are no existing impacts to water supply wells or surface water in excess of applicable limits, and the following conditions are met: * For GW Plumes Delineated to Drinking Water Limits: If no future groundwater use anticipated in plume area and maximum plume concentration < Class III ground-water limits (e.g., benzene < 0.14 mg/L), NFA for groundwater. Otherwise, show plume stable, and then NFA. * For GW Plumes Not Delineated to Drinking Water Limits: If no existing water supply wells or surface water discharge within 1200 ft and no anticipated use within 1200 ft, NFA for GW if maximum plume concentrations < Class III limits (e.g., benzene < 0.14 mg/L). If Class III limits exceeded, show plume stable and then NFA.

Notes: DTW = Depth to water; GW = Groundwater; LUFT = Leaking underground fuel tank; LUST = Leaking underground storage tank; NAPL = Non-aqueous phase liquid; NFA = No further action; SW = Surface water

Help: Provides information on the screen-specific input requirements.



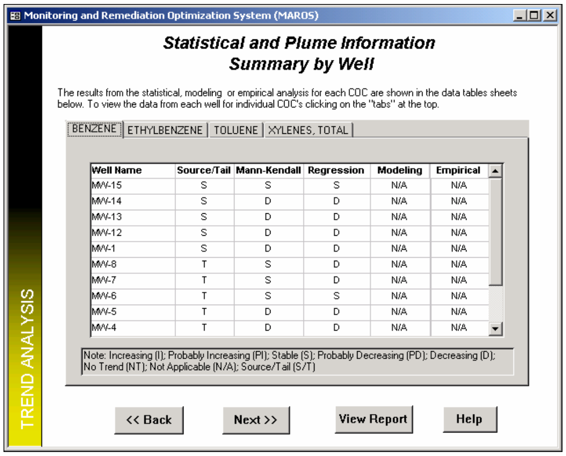
External Plume Information Complete

Your data has been entered for the modeling and emperical results. You may now proceed to Step 3e: MAROS Analysis to weight the Plume Information and analyze the trends in the groundwater data for preliminary monitoring network optimization results.

At this point the Modeling and Empirical Trend results have been entered. You may now proceed to the Step 3e: LTM (Long Term Monitoring) Analysis to weight the Plume Information and analyze the trends in the groundwater data.

MAROS Analysis

Statistical and Plume Information Summary by Well (accessed from the *Plume Analysis Menu* screen) allows the user to view the Mann-Kendall Trend Analysis, Linear Regression Analysis, Modeling and Empirical results by well and constituent.



Statistical and Plume Information Summary by Well

The results from the statistical, modeling or empirical analysis for each COC are shown in the data tables sheets below. To view the data from each well for individual COC's clicking on the "tabs" at the top.

Well Name	Source/Tail	Mann-Kendall	Regression	Modeling	Empirical
MW-15	S	S	S	N/A	N/A
MW-14	S	D	D	N/A	N/A
MW-13	S	D	D	N/A	N/A
MW-12	S	D	D	N/A	N/A
MW-1	S	D	D	N/A	N/A
MW-8	T	S	D	N/A	N/A
MW-7	T	S	D	N/A	N/A
MW-6	T	S	S	N/A	N/A
MW-5	T	D	D	N/A	N/A
MW-4	T	D	D	N/A	N/A

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T)

To navigate the individual constituent results, click on the tabs at the top of the screen.

The information displayed in this screen can also be viewed in report form, "Lines of Evidence Summary Report" from the *MAROS Output* Screen (see Appendix A.10 for an example report).

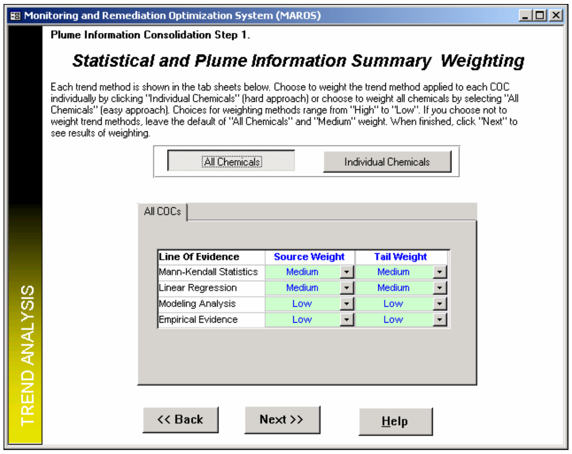
Back: Returns the user to the *Plume Analysis Menu*.

Next: Takes the user to the *Statistical and Plume Information Summary Weighting* Screen.

Help: Provides information on the screen-specific input requirements.

MAROS Analysis – Statistical and Plume Information Weighting

Statistical and Plume Information Summary Weighting (accessed from the *Statistical and Plume Information Summary by Well* screen) allows the user to weight the individual lines of evidence (i.e. Mann-Kendall Trend Analysis, Linear Regression Analysis, Modeling and Empirical results).



Plume Information Consolidation Step 1.

Statistical and Plume Information Summary Weighting

Each trend method is shown in the tab sheets below. Choose to weight the trend method applied to each COC individually by clicking "Individual Chemicals" (hard approach) or choose to weight all chemicals by selecting "All Chemicals" (easy approach). Choices for weighting methods range from "High" to "Low". If you choose not to weight trend methods, leave the default of "All Chemicals" and "Medium" weight. When finished, click "Next" to see results of weighting.

Line Of Evidence	Source Weight	Tail Weight
Mann-Kendall Statistics	Medium	Medium
Linear Regression	Medium	Medium
Modeling Analysis	Low	Low
Empirical Evidence	Low	Low

Each trend method is shown in the tab sheets. Choose to weight the trend methods applied to each COC individually by clicking "Individual Chemicals" (difficult approach) or choose to weight all chemicals by selecting "All Chemicals" (easy approach). Choices for weighting methods range from "High" to "Low". If you choose not to weight trend methods, leave the default of "All Chemicals" and "Medium" weight. If you choose to not include the "Empirical Evidence", choose "Not Used". When finished, click "Next" to see results of weighting.

Back: Returns the user to the *Statistical and Plume Information Summary by Well* screen.

Next: Takes the user to the *Results of Information Weighting* screen.

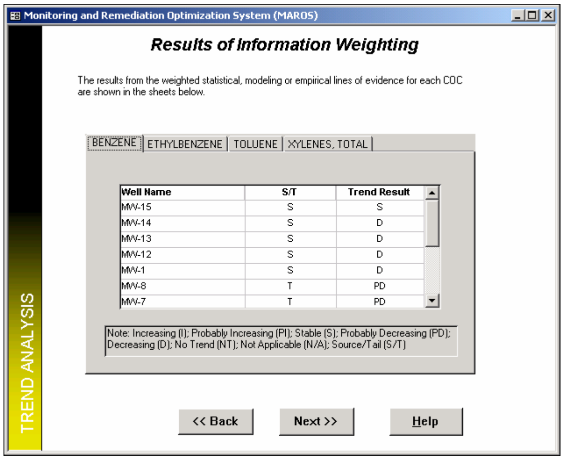
Help: Provides information on the screen-specific input requirements.

Results of Information Weighting (accessed from the *Statistical and Plume Information Summary by Well* screen) allows the user to view the weighted statistical, modeling and empirical lines of evidence for each COC.

To navigate the results for individual constituents, click on the tabs at the top of the screen.

Back: Returns the user to the *Statistical and Plume Information Summary Weighting* screen.

Next: Takes the user to the *Plume Information by Well Weighting* screen.



Results of Information Weighting

The results from the weighted statistical, modeling or empirical lines of evidence for each COC are shown in the sheets below.

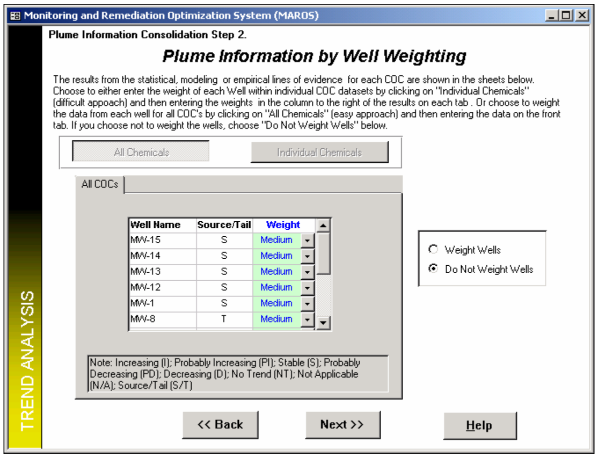
Well Name	S/T	Trend Result
MW-15	S	S
MW-14	S	D
MW-13	S	D
MW-12	S	D
MW-1	S	D
MW-8	T	PD
MW-7	T	PD

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T)

Help: Provides information on the screen-specific input requirements.

MAROS Analysis – Weighting Wells

Plume Information by Well Weighting (accessed from the *Results of Information Weighting* screen) allows the user to weight the individual wells by all chemicals or by constituent.



Plume Information Consolidation Step 2.

Plume Information by Well Weighting

The results from the statistical, modeling or empirical lines of evidence for each COC are shown in the sheets below. Choose to either enter the weight of each Well within individual COC datasets by clicking on "Individual Chemicals" (difficult appoach) and then entering the weights in the column to the right of the results on each tab . Or choose to weight the data from each well for all COC's by clicking on "All Chemicals" (easy approach) and then entering the data on the front tab. If you choose not to weight the wells, choose "Do Not Weight Wells" below.

Well Name	Source/Tail	Weight
MW-15	S	Medium
MW-14	S	Medium
MW-13	S	Medium
MW-12	S	Medium
MW-1	S	Medium
MW-8	T	Medium

○ Weight Wells
● Do Not Weight Wells

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T)

To weight wells, select “Weight Wells” on the right side of the screen. Then, choose to either enter the weight of each well within individual COC datasets by clicking on "Individual Chemicals" (difficult approach) and then entering the weights in the column to the right of the results on each tab. Or choose to weight the data from each well for all COC's by clicking on "All Chemicals" (easy approach) and then entering the data on the front tab.

Choices for weighting methods range from "High" to "Low". If you choose to weight trend methods, select “Do Not Weight Wells” on the right side of the screen. When finished, click "Next" to see results of weighting.

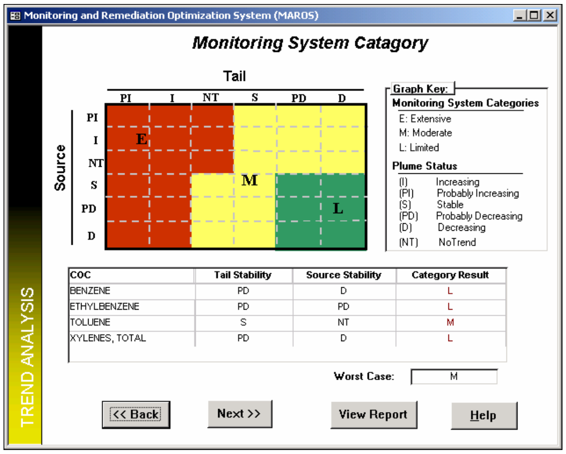
Back: Returns the user to the *Results of Information Weighting* screen.

Next: Takes the user to the *Monitoring System Category* screen.

Help: Provides information on the screen-specific input requirements.

MAROS Analysis- Overall Analysis

Monitoring System Category (accessed from the *Plume Information by Well Weighting* screen) allows the user to view the suggested design category for each COC.



COC	Tail Stability	Source Stability	Category Result
BENZENE	PD	D	L
ETHYLBENZENE	PD	PD	L
TOLUENE	S	NT	M
XYLENES, TOTAL	PD	D	L

Worst Case: M

Trend results for both tail and source wells are given. From these results a monitoring system category that characterizes the site for an individual constituent is shown. Categories include Extensive (E), Moderate (M), and Limited (L) long term monitoring required for the site.

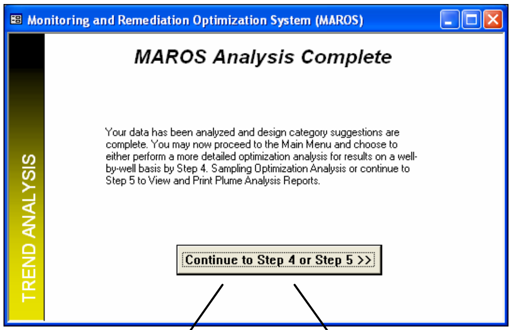
View Report: To Print a summary report click "View Report".

Back: Returns the user to the *Plume Information by Well Weighting* screen.

Next: Takes the user to the *Main Menu* screen.

Help: Provides information on the screen-specific input requirements.

At this point in the software, your data has been analyzed and design category suggestions are complete. You may now proceed to the Main Menu and choose to either perform Well-by-Well Sampling Optimization Analysis or choose MAROS Output (Print Standard Reports/Graphs).



Your data has been analyzed and design category suggestions are complete. You may now proceed to the Main Menu and choose to either perform a more detailed optimization analysis for results on a well-by-well basis by Step 4. Sampling Optimization Analysis or continue to Step 5 to View and Print Plume Analysis Reports.

Standard Approach

OVERALL PLUME RESULTS

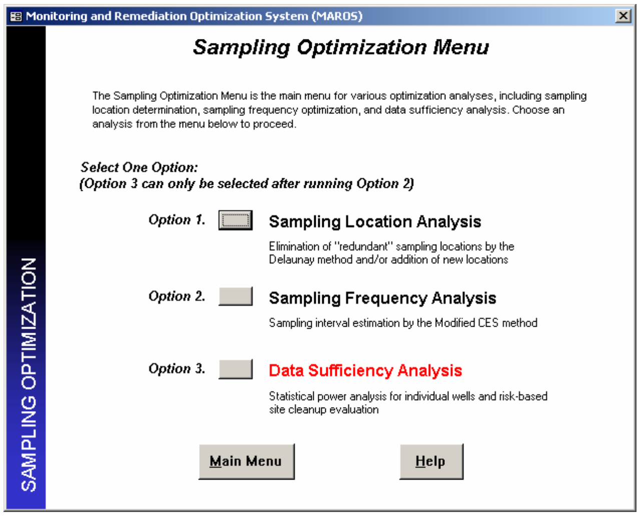
MAROS Output: (Choose to Print/View Reports). Standard Reports, including the one-page heuristic approach to sampling optimization based on plume stability and site parameters with results for sampling frequency, duration and density. **GOTO PAGE 82**

Detailed Approach

WELL SPECIFIC RESULTS

Sampling Optimization: Rigorous detailed statistical approach to sampling optimization with modules to optimize sampling location by Delaunay Triagulation and Sampling Frequency by the Modified CES method or Power Analysis. **GOTO PAGE 47**

Sampling Optimization: Detailed Approach



The Sampling Optimization Menu is the main menu for various optimization analyses, including sampling location determination, sampling frequency optimization, and data sufficiency analysis. Choose an analysis from the menu below to proceed.

Select One Option:
(Option 3 can only be selected after running Option 2)

Elimination of "redundant" sampling locations by the Delaunay method and/or addition of new locations

Sampling interval estimation by the Modified CES method

Statistical power analysis for individual wells and risk-based site cleanup evaluation

The *Sampling Optimization Menu* screen (accessed from the *Main Menu* screen by clicking *Sampling Optimization*) is the main menu for sampling optimization and data sufficiency analysis. It allows the user to choose between performing:

- Sampling Location Analysis
- Sampling Frequency Analysis
- Data Sufficiency Analysis

The functions accessed by each choice are as follows:

Sampling Location Analysis

Determines sampling locations by the Delaunay method, removing "redundant" sampling locations from the monitoring network, and/or add new sampling locations. The theoretical basis of the Delaunay method is given in Appendix A.3.

Sampling Frequency Analysis

Determines the sampling interval for each sampling location by the Modified CES method. The procedures used in the Modified CES method are given in Appendix A.9.

Data Sufficiency Analysis

Evaluates the cleanup status and concentration trend accuracy for individual wells and the risk-based site cleanup status using statistical power analysis. The theoretical basis of this analysis is given in Appendix A.6.

Main Menu: Returns the user to the *Main Menu* screen. Reports on sampling optimization results are available by choosing *MAROS Output* in the *Main Menu* screen.

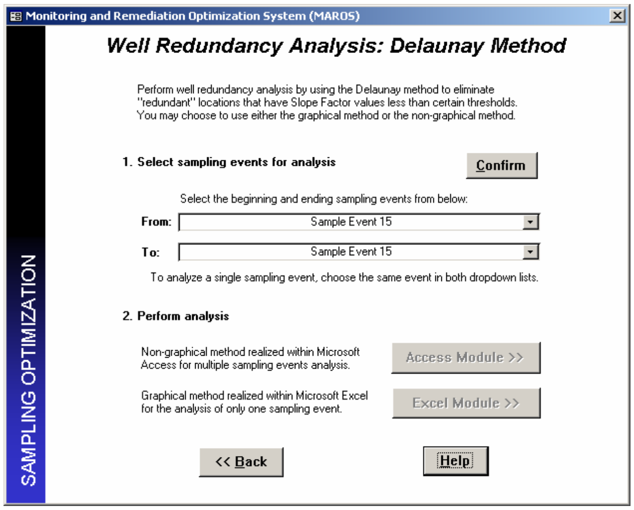
Help: Provides additional information on software operation and screen-specific input requirements.

Steps for use:

1) Either *Sampling Location Analysis* or *Sampling Frequency Analysis* can be performed first. *Data Sufficiency Analysis* (red label means it cannot be accessed) will become available only after *Sampling Frequency Analysis* has been successfully finished.
2) Result reports are available either during the analysis process or by choosing *MAROS Output* in the *Main Menu* screen.

Well Redundancy Analysis: Delaunay Method

Well Redundancy Analysis: Delaunay Method (accessed from the *Sampling Optimization* screen by clicking *Sampling Location Analysis*) is used to perform well redundancy analysis by the Delaunay method. This is designed to eliminate "redundant" locations from the monitoring network based on analysis of spatial sampling data. Details of the Delaunay method can be found in Appendix A.3.



Well Redundancy Analysis: Delaunay Method

Perform well redundancy analysis by using the Delaunay method to eliminate "redundant" locations that have Slope Factor values less than certain thresholds. You may choose to use either the graphical method or the non-graphical method.

1. Select sampling events for analysis

Select the beginning and ending sampling events from below:

From: Sample Event 15
To: Sample Event 15

To analyze a single sampling event, choose the same event in both dropdown lists.

2. Perform analysis

Non-graphical method realized within Microsoft Access for multiple sampling events analysis.

Graphical method realized within Microsoft Excel for the analysis of only one sampling event.

Confirm: Confirms the series of continuous sampling events selected by the user. The user can also choose to analyze one sampling event.

Access Module: Applies the Delaunay method built within Microsoft Access to optimize sampling locations (suitable for multiple events).

Excel Module: Applies the Delaunay method built within Microsoft Excel that includes a graphical interface and flexible operations. Data are sent to Excel Module and results will be transferred back. This is applicable to the analysis of only one sampling event.

Back: Returns the user to the *Sampling Optimization* screen.

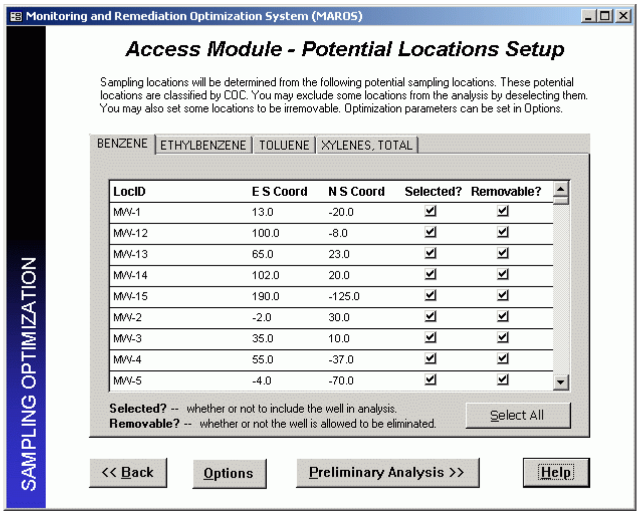
Help: Provides additional information on software operation and screen-specific input requirements.

Steps for use:

1) Select the sampling events for analysis by choosing from the *From* and *To* dropdown lists or typing in the names of the sampling events. The *From* sampling event should be no later than the *To* sampling event. If one sampling event is to be analyzed, simply select the same sampling event in both dropdown lists.
2) Click button *Confirm* to confirm the selection. After confirmation, the *Access Module* button will be activated. The *Excel Module* button will be activated only if the sampling events in both *From* and *To* dropdown lists are the same.
3) Click either *Access Module* or *Excel Module* (if activated) to proceed.

Access Module – Potential Locations Setup

This screen (accessed from the *Well Redundancy Analysis: Delaunay Method* screen by clicking *Access Module*) is used to set up the properties of potential locations and the options used in the Delaunay method.



Access Module - Potential Locations Setup

Sampling locations will be determined from the following potential sampling locations. These potential locations are classified by COC. You may exclude some locations from the analysis by deselecting them. You may also set some locations to be irremovable. Optimization parameters can be set in Options.

LocID	E S Coord	N S Coord	Selected?	Removable?
MW-1	13.0	-20.0	☑	☑
MW-12	100.0	-8.0	☑	☑
MW-13	65.0	23.0	☑	☑
MW-14	102.0	20.0	☑	☑
MW-15	190.0	-125.0	☑	☑
MW-2	-2.0	30.0	☑	☑
MW-3	35.0	10.0	☑	☑
MW-4	55.0	-37.0	☑	☑
MW-5	-4.0	-70.0	☑	☑

Selected? -- whether or not to include the well in analysis.
Removable? -- whether or not the well is allowed to be eliminated.

Selected?: Decides whether or not a location is included in the analysis. Check the button to include or uncheck the button to remove this location from the list of potential locations.

Removable?: Decides whether or not a location is allowed to be eliminated by the optimizing process if it is considered to be redundant. For example, a sentinel well might be unchecked since it cannot be eliminated.

Select All: Sets all the sampling locations as potential locations. The *Selected?* status will be set to True for all locations for the selected COC.

Back: Returns the user to the *Well Redundancy Analysis: Delaunay Method* screen.

Options: Shows screen *Well Redundancy Analysis – Options*, where the optimization parameters can be set. Otherwise, the default settings or the settings from the previous analysis will be used.

Preliminary Analysis: Calculates the sampling-events-averaged Slope Factor (SF) values for all locations for each COC and then proceeds to the *Access Module – Slope Factor Values* screen.

Help: Provides additional information on software operation and screen-specific input requirements.

Steps for use:

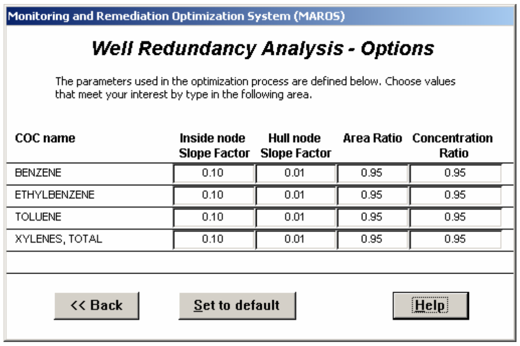
1) Browse sampling locations for each COC by clicking the tab on the page frame. For example, click "Benzene" to view sampling locations where Benzene concentrations were measured.
2) Remove a location from the potential locations by unselecting the *Selected?* check box. Select *Removable?* check box to decide if a location can be eliminated by the optimizing process.
3) Set up the properties of potential locations for all COCs and then proceed to *Preliminary Analysis*.

During the process, you can click button *Options* to change the optimization parameters that are used by the Delaunay method. Each COC has its own parameters.

Note: The Slope Factor in MAROS is a parameter indicating the relative importance of a location in the monitoring network, and is not related to toxicological values for a particular COC (i.e., carcinogenic risk).

Well Redundancy Analysis - Options

This screen (accessed from the *Access Module – Potential Locations Setup* screen by clicking *Options*) is used for setting the optimization parameters (thresholds) that are used by the Delaunay method. Each COC has its own set of parameters.


Monitoring and Remediation Optimization System (MAROS)

Well Redundancy Analysis - Options

The parameters used in the optimization process are defined below. Choose values that meet your interest by type in the following area.

COC name	Inside node Slope Factor	Hull node Slope Factor	Area Ratio	Concentration Ratio
BENZENE	0.10	0.01	0.95	0.95
ETHYLBENZENE	0.10	0.01	0.95	0.95
TOLUENE	0.10	0.01	0.95	0.95
XYLENES, TOTAL	0.10	0.01	0.95	0.95

These parameters include *Inside node Slope Factor* (SF), *Hull node Slope Factor*, *Area Ratio* (AR), and *Concentration Ratio* (CR). The default values for these parameters are 0.10, 0.01, 0.95 and 0.95, respectively, for all COCs. For detailed explanations of these parameters, refer to Appendix A.3. The user can change parameters by entering new values in the corresponding fields directly.

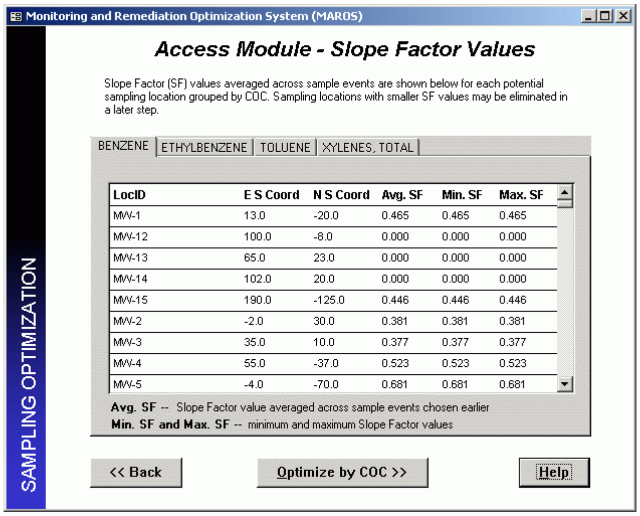
Back: Keeps the changes made by the user and returns the user to the *Access Module – Potential Locations Setup* screen.

Set to default: Sets all parameters for all COCs to the system default.

Help: Provides additional information on software operation and screen-specific input requirements.

Access Module - Slope Factor Values

This screen (accessed from the *Access Module – Potential Locations Setup* screen by clicking *Preliminary Analysis*) is used to display the sampling-events-averaged SF values of sampling locations for each COC. The lumped SF value of a location provides a measure of its overall importance to a monitoring network.



Access Module - Slope Factor Values

Slope Factor (SF) values averaged across sample events are shown below for each potential sampling location grouped by COC. Sampling locations with smaller SF values may be eliminated in a later step.

LocID	E S Coord	N S Coord	Avg. SF	Min. SF	Max. SF
MW-1	13.0	-20.0	0.465	0.465	0.465
MW-12	100.0	-8.0	0.000	0.000	0.000
MW-13	65.0	23.0	0.000	0.000	0.000
MW-14	102.0	20.0	0.000	0.000	0.000
MW-15	190.0	-125.0	0.446	0.446	0.446
MW-2	-2.0	30.0	0.381	0.381	0.381
MW-3	35.0	10.0	0.377	0.377	0.377
MW-4	55.0	-37.0	0.523	0.523	0.523
MW-5	-4.0	-70.0	0.681	0.681	0.681

Avg. SF -- Slope Factor value averaged across sample events chosen earlier
Min. SF and Max. SF -- minimum and maximum Slope Factor values

Avg. SF: Displays the lumped SF value of a location that is calculated by averaging the SF values obtained in each sampling event across all sampling events selected by the user.

Min. SF: Displays the minimum SF value of a location obtained from one of the sampling events.

Max. SF: Displays the maximum SF value of a location obtained from one of the sampling events.

Back: Returns the user to the *Access Module – Potential Locations Setup* screen.

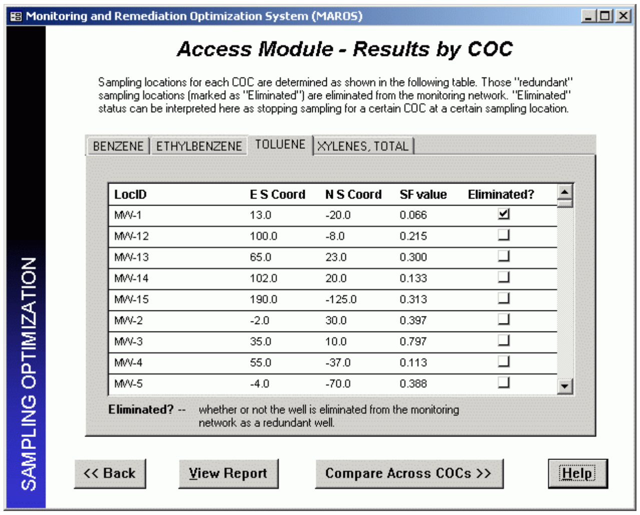
Optimize by COC: Performs optimization for each COC by eliminating redundant sampling locations in each COC and then proceeds to the *Access Module – Results by COC* screen.

Help: Provides additional information on software operation and screen-specific input requirements.

Note: the Slope Factor in MAROS is a parameter indicating the relative importance of a location in the monitoring network, and is not related to toxicological values for a particular COC (i.e., carcinogenic risk).

Access Module - Results by COC

This screen (accessed from the *Access Module – Slope Factor Values* screen by clicking *Optimize by COC*) is used to display the sampling location optimization results for each COC. Redundant locations that are eliminated are marked. The remaining locations are unmarked and are recommended for the next round of sampling. Elimination of a location from a COC only means to stop sampling for that COC at that location, since other COCs may still need to be sampled at this location.



Access Module - Results by COC

Sampling locations for each COC are determined as shown in the following table. Those "redundant" sampling locations (marked as "Eliminated") are eliminated from the monitoring network. "Eliminated" status can be interpreted here as stopping sampling for a certain COC at a certain sampling location.

LocID	E S Coord	N S Coord	SF value	Eliminated?
MW-1	13.0	-20.0	0.066	☑
MW-12	100.0	-8.0	0.215	☐
MW-13	65.0	23.0	0.300	☐
MW-14	102.0	20.0	0.133	☐
MW-15	190.0	-125.0	0.313	☐
MW-2	-2.0	30.0	0.397	☐
MW-3	35.0	10.0	0.797	☐
MW-4	55.0	-37.0	0.113	☐
MW-5	-4.0	-70.0	0.388	☐

Eliminated? -- whether or not the well is eliminated from the monitoring network as a redundant well.

SF value: Displays the lumped SF value of a location that is calculated by averaging the SF values obtained in each sampling event across all sampling events selected by the user.

Eliminated?: Displays whether or not a location is considered redundant and should be eliminated. A check mark in this field stands for the elimination of a location.

Back: Returns the user to the *Access Module – Slope Factor Values* screen.

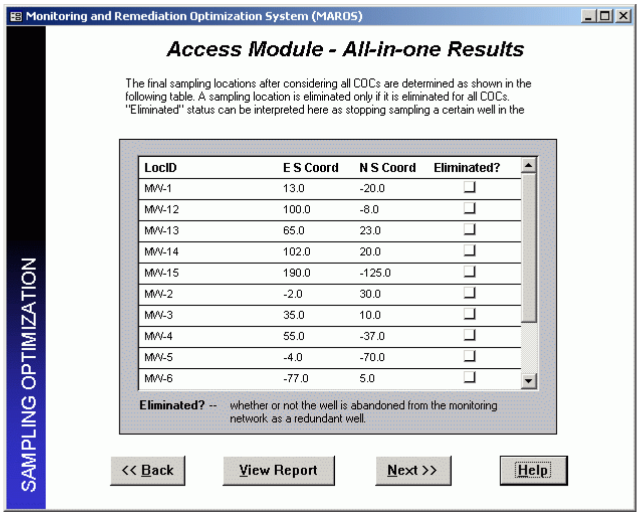
View Report: Generates a report with sampling location optimization results for each COC. This report can be viewed or printed. The user can go back to re-run the analysis by changing parameters or selecting a different series of sampling vents.

Compare Across COCs: Determines the conservative all-in-one results by considering all COCs and then proceeds to the *Access Module – All-in-one Results* screen.

Help: Provides additional information on software operation and screen-specific input requirements.

Access Module - All-in-one Results

This screen (accessed from the *Access Module – Results by COC* screen by clicking *Compare Across COCs*) is used to display the conservative all-in-one sampling location optimization results. A location is marked for elimination only if this location is eliminated from all COCs. Here elimination of a location is equivalent to stopping sampling at this location.



Access Module - All-in-one Results

The final sampling locations after considering all COCs are determined as shown in the following table. A sampling location is eliminated only if it is eliminated for all COCs. "Eliminated" status can be interpreted here as stopping sampling a certain well in the

LocID	E S Coord	N S Coord	Eliminated?
MW-1	13.0	-20.0	☐
MW-12	100.0	-8.0	☐
MW-13	65.0	23.0	☐
MW-14	102.0	20.0	☐
MW-15	190.0	-125.0	☐
MW-2	-2.0	30.0	☐
MW-3	35.0	10.0	☐
MW-4	55.0	-37.0	☐
MW-5	-4.0	-70.0	☐
MW-6	-77.0	5.0	☐

Eliminated? -- whether or not the well is abandoned from the monitoring network as a redundant well.

<u>Eliminated?:</u> Displays whether or not a location is considered redundant and should be eliminated. A check mark in this field stands for the elimination of a location.

Back: Returns the user to the *Access Module – Results by COC* screen.

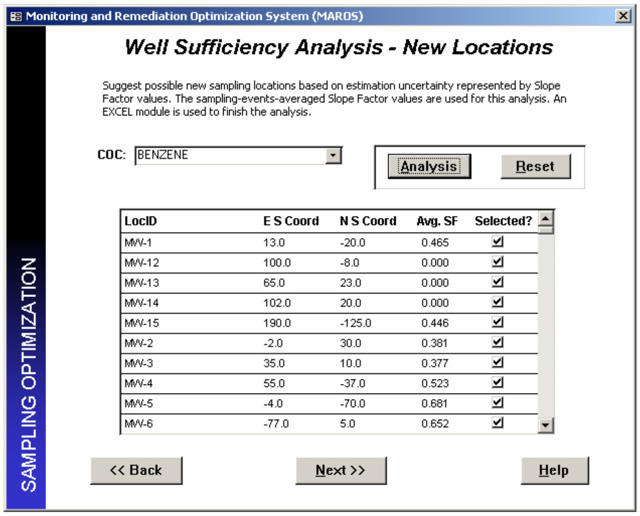
View Report: Generates a report with the all-in-one sampling location optimization results. This report can be viewed or printed. The user can go back to re-run the analysis by changing parameters or selecting a different series of sampling events.

Next: Proceeds to the *Well Sufficiency Analysis* screen.

Help: Provides additional information on software operation and screen-specific input requirements.

Well Sufficiency Analysis – New Locations

This screen (accessed from the *Access Module – All-in-one Results* screen by clicking *Next*) is a control screen for applying a Microsoft Excel module that is used to perform well redundancy analysis, that is, recommending potential areas for new sampling locations.



Suggest possible new sampling locations based on estimation uncertainty represented by Slope Factor values. The sampling-events-averaged Slope Factor values are used for this analysis. An EXCEL module is used to finish the analysis.

COC: BENZENE

LocID	E S Coord	N S Coord	Avg. SF	Selected?
MW-1	13.0	-20.0	0.465	☑
MW-12	100.0	-8.0	0.000	☑
MW-13	65.0	23.0	0.000	☑
MW-14	102.0	20.0	0.000	☑
MW-15	190.0	-125.0	0.446	☑
MW-2	-2.0	30.0	0.381	☑
MW-3	35.0	10.0	0.377	☑
MW-4	55.0	-37.0	0.523	☑
MW-5	-4.0	-70.0	0.681	☑
MW-6	-77.0	5.0	0.652	☑

COC: Selects the COC you want to analyze from the dropdown list.

Selected?: Decides whether or not a location is included in the analysis of new sampling locations. All wells are selected by default.

Analysis: Runs the Microsoft Excel module. The *xlsNewLocation* worksheet will pop up and becomes the current screen. The analysis is performed for the currently selected COC.

Reset: Selects all the sampling locations for the current COC. The *Selected?* status of each location will be set to True.

Back: Returns the user to the *Access Module – All-in-one Results* screen.

Next: Proceed to the *Sampling Location Analysis Complete – Access Module* screen.

Help: Provides additional information on software operation and screen-specific input requirements.

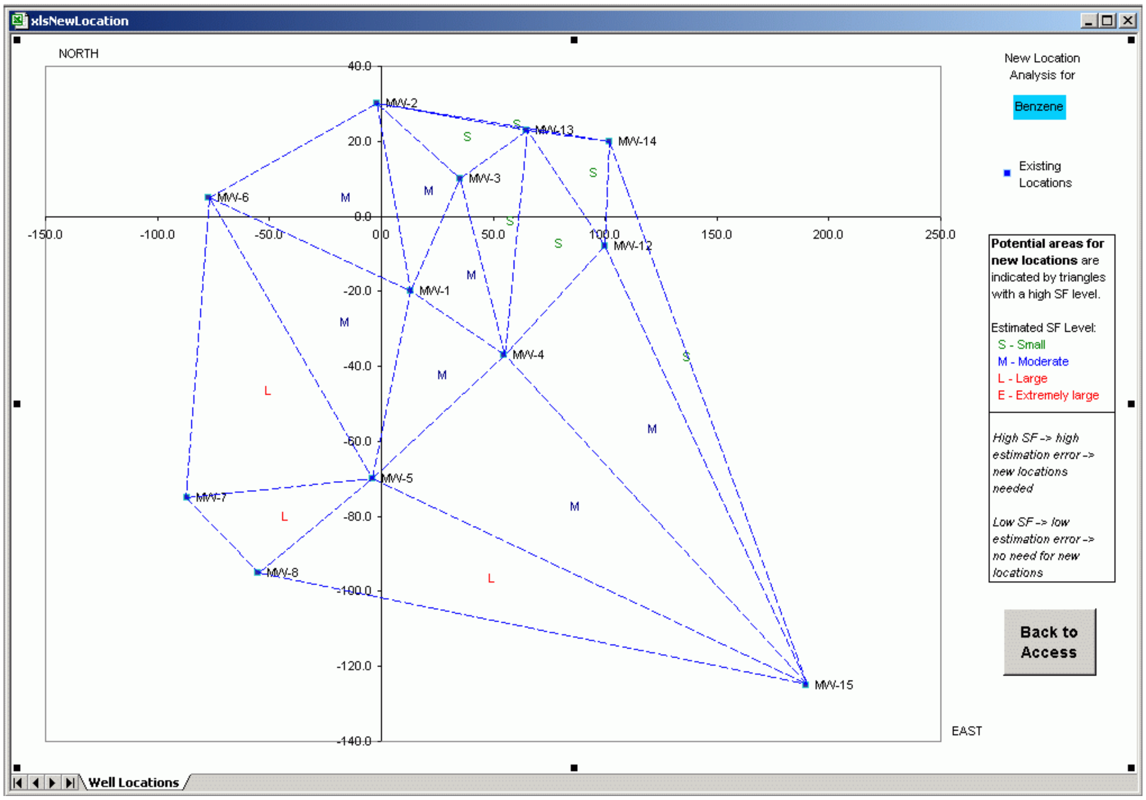
Steps for use:

1) Choose the COC for analysis by selecting from the COC dropdown list or typing in the name.
2) Set the *Selected?* check box of a location to decide whether this location is included in the analysis.
3) Click the *Analysis* button and the screen will switch to Excel worksheet *xlsNewLocation*. The data will be transferred to *xlsNewLocation*.
4) Run *xlsNewLocation* following instructions given in screen *xlsNewLocation* (introduced below).

xlsNewLocation

xlsNewLocation (accessed from the *Well Sufficiency Analysis – New Locations* screen by clicking *Analysis*) is a Microsoft Excel worksheet used to display the well sufficiency analysis results, i.e., recommending potential areas for new sampling locations. Method details can be found in the last section of Appendix A.3

The results are shown in the *Well Locations* chart-sheet, which is shown below. A plot area is located in the center where the sampling locations are plotted in the state coordinate system (or relative coordinate system). Graph legends and command buttons are on the right side of the chart.



New Location Analysis for Benzene

Potential areas for new locations are indicated by triangles with a high SF level.

Estimated SF Level:
- S - Small
- M - Moderate
- L - Large
- E - Extremely large

High SF -> high estimation error -> new locations needed

Low SF -> low estimation error -> no need for new locations

Estimated SF Level: The estimated Slope Factor (SF) value at a potential area (indicated by a triangle formed by blue lines) for new sampling locations. The SF value is used to quantify the concentration estimation error at a potential area. The larger the SF value, the greater the estimation error. Potential areas with high SF values could be regions in which new wells can be placed. SF values are classified into four levels: S–Small (<0.3), M–Moderate (0.3~0.6), L–Large (0.6~0.9), and E–Extremely large (0.9~1.0). A colored label around the center (centroid) of each triangle is used to indicate the SF level at a potential area.

Back to Access: Switches to the MAROS interface in Microsoft Access.

The user loads and enters this module from the *Well Sufficiency Analysis – New Locations* screen by clicking the *Analysis* button. The data will be transferred from Microsoft Access and the analysis is completed once the *xlsNewLocation* interface shows up. The user can proceed with the following steps:

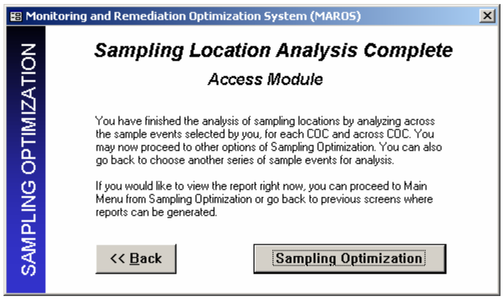
1) Search the potential areas for new sampling locations with *L* (large) or *E* (extremely large) labels. New wells could be placed inside these regions, e.g., at the centroid of a triangle.
2) Click *Back to Access* to return to Microsoft Access. The *xlsNewLocation* worksheet will remain open until the user closes it. The user can save the file with another name to prevent the current results from being overridden by a new analysis.
3) To perform another analysis, choose a COC from the *Well Sufficiency Analysis – New Locations* screen and then click the *Analysis* button to enter the *xlsNewLocation* module, then go to step 1.

WARNING: Do not change the name of worksheet *xlsNewLocation* or move it to other folders.

However, you can use the Excel menu option 'Save As', and save the file under a different name. It will open with the saved data in the future. The data display can also be saved as a pdf file using the Adobe Acrobat application.

Sampling Location Analysis Complete – Access Module

This screen (accessed from the *Well Sufficiency Analysis – New Locations* screen by clicking *Next*) is a message screen telling that sampling location determination by the *Access Module* has been completed and the user can go back to proceed to other analyses.



Sampling Location Analysis Complete

Access Module

You have finished the analysis of sampling locations by analyzing across the sample events selected by you, for each COC and across COC. You may now proceed to other options of Sampling Optimization. You can also go back to choose another series of sample events for analysis.

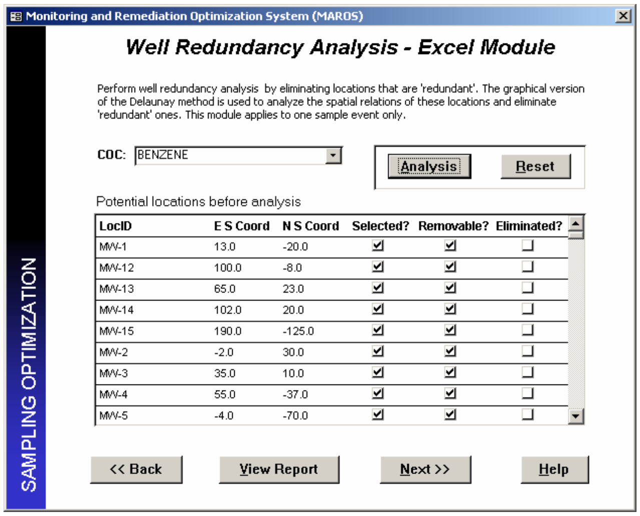
If you would like to view the report right now, you can proceed to Main Menu from Sampling Optimization or go back to previous screens where reports can be generated.

Back: Returns the user to the *Well Sufficiency Analysis – New Locations* screen. The user can go back to re-run the analysis by changing parameters or selecting a different series of sampling vents.

Sampling Optimization: Returns the user to the *Sampling Optimization* screen.

Well Redundancy Analysis – Excel Module

Well Redundancy Analysis – Excel Module (accessed from the *Well Redundancy Analysis: Delaunay Method* screen by clicking *Excel Module*) is a control screen for applying the Delaunay method in a stand-alone Microsoft Excel module. It is used for 1) setting up the properties of potential locations; 2) proceeding to the Excel module for optimization; and 3) displaying the results transferred back from the *Excel Module*. The stand-alone Excel module "*xlsDelaunay2K*" is explained below.



Perform well redundancy analysis by eliminating locations that are 'redundant'. The graphical version of the Delaunay method is used to analyze the spatial relations of these locations and eliminate 'redundant' ones. This module applies to one sample event only.

COC: BENZENE

Potential locations before analysis

LocID	E S Coord	N S Coord	Selected?	Removable?	Eliminated?
MW-1	13.0	-20.0	☑	☑	☐
MW-12	100.0	-8.0	☑	☑	☐
MW-13	65.0	23.0	☑	☑	☐
MW-14	102.0	20.0	☑	☑	☐
MW-15	190.0	-125.0	☑	☑	☐
MW-2	-2.0	30.0	☑	☑	☐
MW-3	35.0	10.0	☑	☑	☐
MW-4	55.0	-37.0	☑	☑	☐
MW-5	-4.0	-70.0	☑	☑	☐

The data table is similar to that in the screen *Access Module - Potential Locations Setup*.

COC: Selects the COC you want to analyze from the dropdown list.

Analysis: Runs the Excel module. The *xlsDelaunay2K* worksheet will be opened and becomes the current screen. The analysis is performed for the currently selected COC and for one sampling event only.

Reset: Sets all the sampling locations in a COC as potential locations. The *Selected?* status of each location will be set to True.

Back: Returns the user to the *Well Redundancy Analysis: Delaunay Method* screen.

View Report: Generates a report with sampling location optimization results for the one sampling event selected by the user. The user should analyze COCs before viewing the report. After getting feedback from the report, the user can go back to re-run the analysis by changing parameters or selecting a different series of sampling vents.

Next: Proceed to the *Excel Module – All-in-one Results* screen.

Help: Provides additional information on software operation and screen-specific input requirements.

Steps for use:

1) Choose the COC for analysis by selecting from the COC dropdown list or typing in the name.
2) Set the *Selected?* check box of a location to decide whether this location is included in the analysis. Set *Removable?* check box to decide whether a location can be eliminated by the optimizing process.

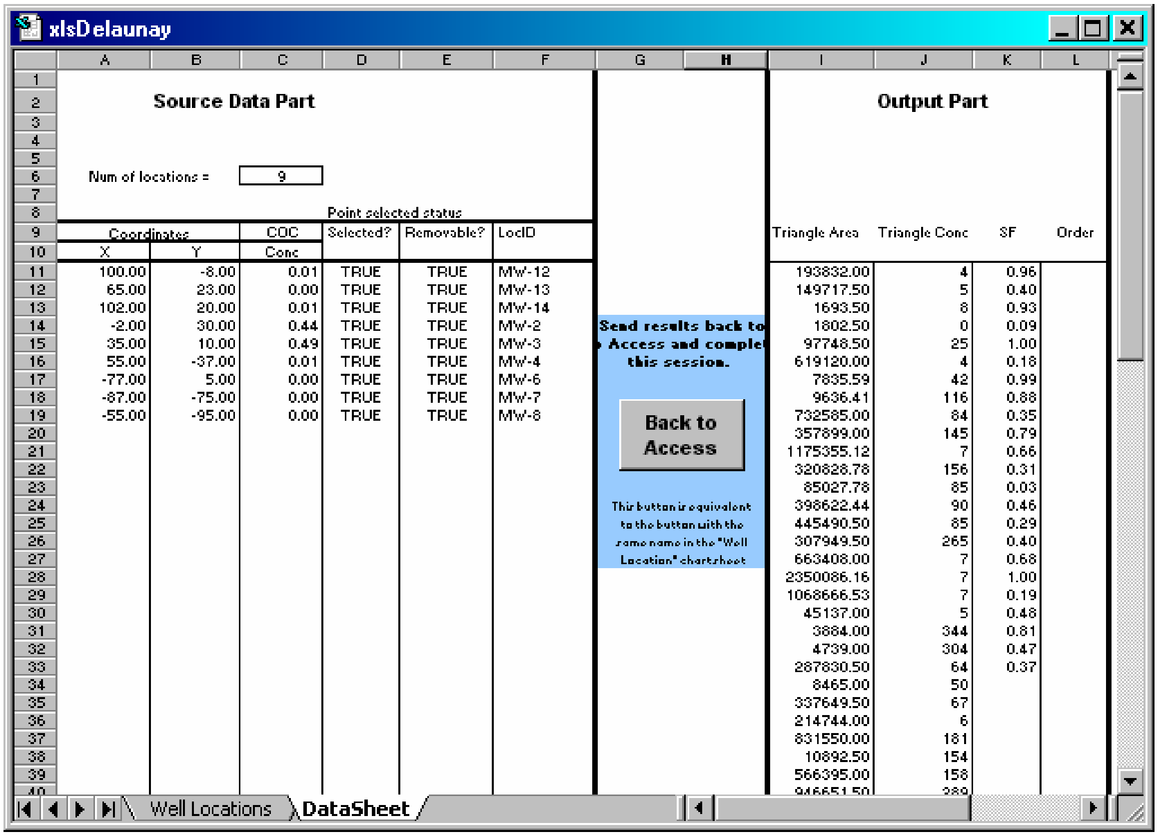
Or

2) Set the *Selected?* and *Removable?* status of a location by using the Shortcut Menu in worksheet *xlsDelaunay2K*. This can be performed only when the worksheet *xlsDelaunay2K* is running.
3) Press button *Analysis* and the screen will switch to worksheet *xlsDelaunay2K*. The data will be transferred to worksheet *xlsDelaunay2K*.

4) Run worksheet *xlsDelaunay2K* by following the instructions shown in screen *xlsDelaunay2K* (introduced shortly).
5) After finishing analysis in worksheet *xlsDelaunay2K*, send results back by pressing *Back to Access* button. The screen will switch back and locations that have been eliminated will be shown in field *Eliminated?*. *Selected?* and *Removable?* fields will also be updated if any change has been made in module *xlsDelaunay2K*.
6) Select other COCs and go back to step 1 until all the COCs have been analyzed.

xlsDelaunay2K

xlsDelaunay2K (accessed from the *Well Redundancy Analysis – Excel Module* screen by clicking *Analysis*) is a stand-alone Microsoft Excel worksheet used to perform well redundancy analysis by the Delaunay method. This worksheet contains two parts: a chart-sheet *Well Locations* and a datasheet *DataSheet*. The user can click the sheet tab on the lower left corner of the worksheet to switch between the two parts. The *Well Locations* chart-sheet is shown on the next page. The figure below shows the *DataSheet*.



Source Data Part

Num of locations = 9

Point selected status

Coordinates X	Coordinates Y	COC Conc	Selected?	Removable?	LocID
100.00	-8.00	0.01	TRUE	TRUE	MW-12
65.00	23.00	0.00	TRUE	TRUE	MW-13
102.00	20.00	0.01	TRUE	TRUE	MW-14
-2.00	30.00	0.44	TRUE	TRUE	MW-2
35.00	10.00	0.49	TRUE	TRUE	MW-3
55.00	-37.00	0.01	TRUE	TRUE	MW-4
-77.00	5.00	0.00	TRUE	TRUE	MW-6
-87.00	-75.00	0.00	TRUE	TRUE	MW-7
-55.00	-95.00	0.00	TRUE	TRUE	MW-8

Send results back to Access and complete this session.

This button is equivalent to the button with the same name in the "Well Location" chartsheet

Output Part

Triangle Area	Triangle Conc	SF	Order
193832.00	4	0.96	
149717.50	5	0.40	
1693.50	8	0.93	
1802.50	0	0.09	
97748.50	25	1.00	
619120.00	4	0.18	
7835.59	42	0.99	
9636.41	116	0.88	
732585.00	84	0.35	
357899.00	145	0.79	
1175355.12	7	0.66	
320828.78	156	0.31	
85027.78	85	0.03	
398622.44	90	0.46	
445490.50	85	0.29	
307949.50	265	0.40	
663408.00	7	0.68	
2350086.16	7	1.00	
1068666.53	7	0.19	
45137.00	5	0.48	
3884.00	344	0.81	
4739.00	304	0.47	
287830.50	64	0.37	
8465.00	50		
337649.50	67		
214744.00	6		
831550.00	181		
10892.50	154		
566395.00	158		

Back to Access: Sends results back to the Microsoft Access screen *Well Redundancy Analysis – Excel Module*. The user can also do this by clicking the button with the same name in the *Well Locations* chart-sheet.

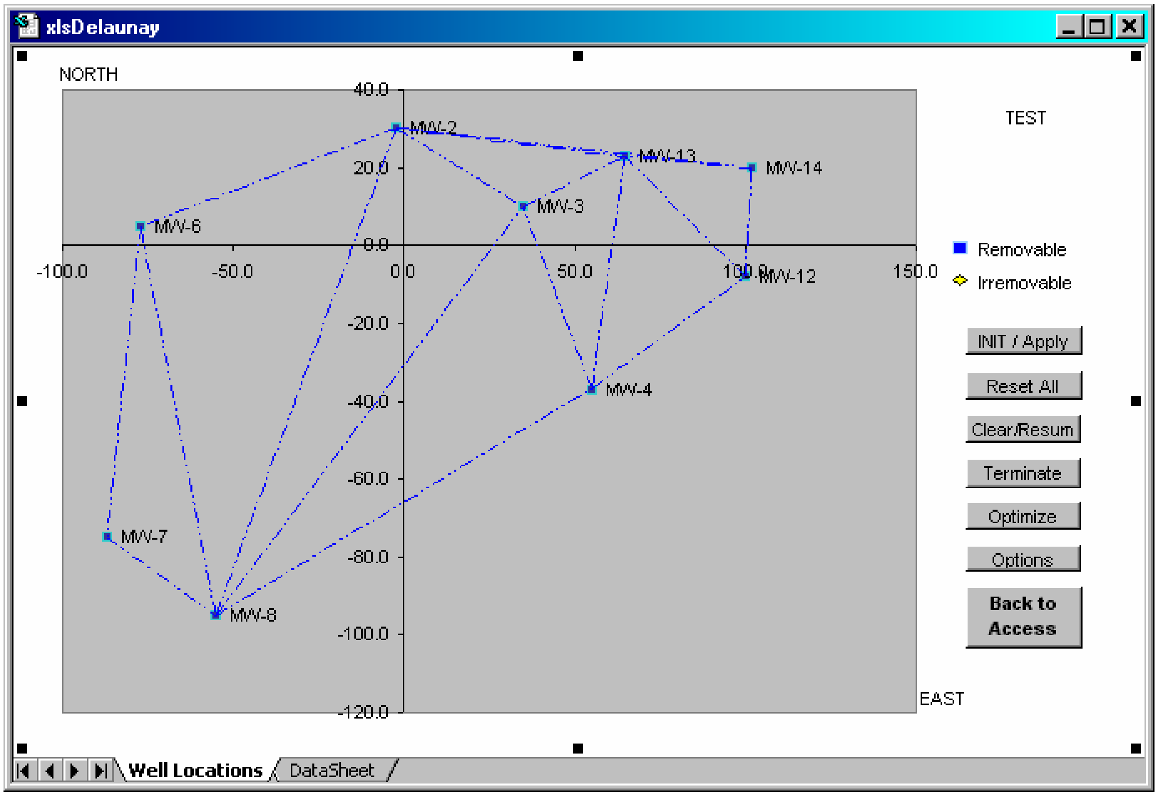
Source Data Part: Stores the data transferred from Microsoft Access.

Output Part: Outputs some of the intermediate results generated during the optimizing process, including the wells eliminated, area ratio and concentration ratio.

WARNING:

Before clicking the *Back to Access* button, the user should have performed the optimization by using the *Well Locations* chart-sheet (see instructions on the next page). If not, the original set of data will be returned. Do not make changes in this sheet. Furthermore, it is recommended that the user operate in the *Well Locations* chart-sheet.

The *Well Locations* chart-sheet is shown below. A plot area is located in the center where the sampling locations are plotted in the EAST-NORTH coordinate system (or relative coordinates system). The legend is in the upper right side. The middle right side contains the command buttons used to control the optimization process.



INIT/Apply: Initializes the program in order to begin an analysis. This is a starting point.

Reset All: Allows all potential locations to be selected. This is very helpful when you have eliminated some locations and then want to recover them.

Clear/Resume: To clear/resume all the lines drawn on the plot area. It is only a switch for graphic output. Data will not be altered.

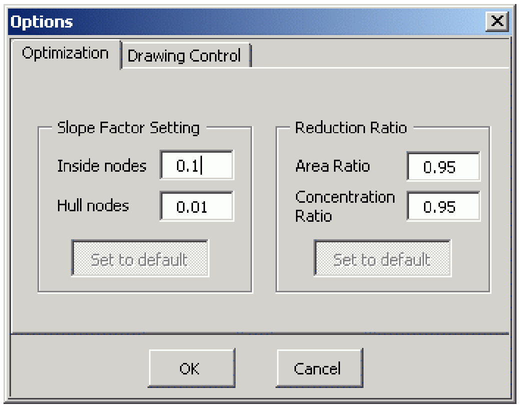
Terminate: Clears memory and stops the program while remaining in the worksheet. To restart an analysis after pressing this button, press *INIT/Apply* again.

Optimize: Performs optimization, i.e., eliminating "redundant" locations from the network.

Options: Shows the *Options Form* that includes optimization parameters used in the Delaunay method and the options for graphic output.

Back to Access: Sends results back to the Microsoft Access screen *Well Redundancy Analysis – Excel Module*.

The *Options Form* can only be used in the *Well Locations* chart-sheet.

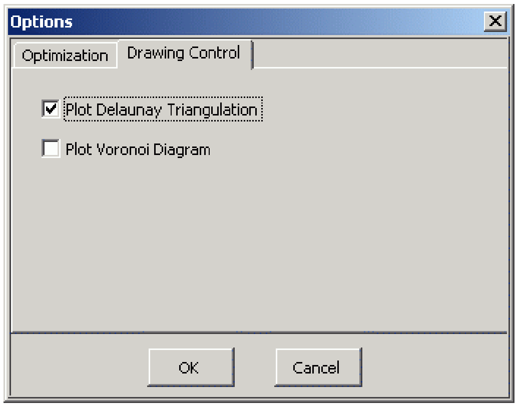


Inside nodes: 0.1
Hull nodes: 0.01
Area Ratio: 0.95
Concentration Ratio: 0.95

The *Option Form* is accessed by clicking the *Options* button. It has two pages.

Shown on the left is the *Optimization* page. Parameters include *Inside node Slope Factor* (SF), *Hull node Slope Factor*, *Area Ratio* (AR), and *Concentration Ratio* (CR). The default values are the same as those in the *Access Module*.

Set to default: Sets the parameters to system default. The button will be activated only if the parameter value is not equal to the default value.



☑ Plot Delaunay Triangulation
☐ Plot Voronoi Diagram

Shown on the left is the *Drawing Control* page.

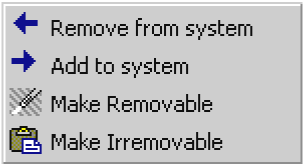
Plot Delaunay Triangulation: By checking this box, the blue triangulation lines will be plotted in the plot area of the chart-sheet.

Plot Voronoi Diagram: By checking this box, the Voronoi diagram (or Thiessen polygon) will be plotted in the plot area of the chart-sheet.

Ok: Saves user changes to the parameters and closes this form. The changes will be effective the next time the user performs an optimization. The drawing options will be effective immediately.

Cancel: Cancels user changes and quits the form.

The *Shortcut Menu* allows you to locate a node (location) on the graph and sets its *Selected?* status and *Removale?* status easily. The shortcut menu is available only in the *Well Locations* chart-sheet.



To access the *Shortcut Menu*, click left mouse button on a node or the name of the node beside it. Click again at the same place and the shortcut menu will pop up. The *first click* ensures the data-series has been selected. The *second click* returns the node information to the program.

Remove from system: Excludes a node from the network by setting *Selected?* status to False.

Add to system: Includes or inserts a node into the network by setting *Selected?* status to True.

Make Removable: Makes a node removable by setting *Removable?* status to True.

Make Irremovable: Makes a node irremovable by setting *Removable?* status to False.

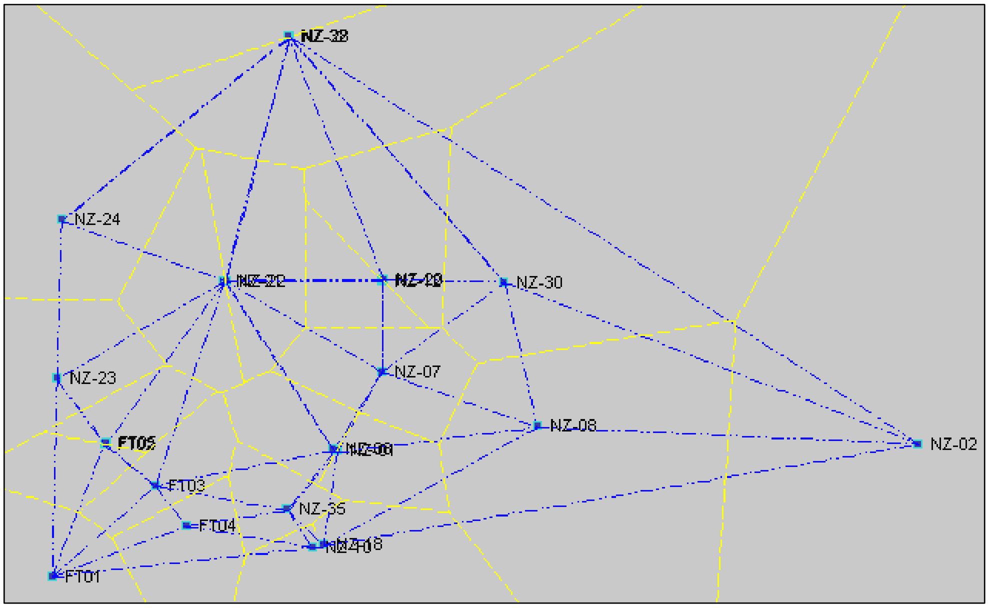
Steps for use:

1) Start the program (only if it is not automatically loaded) by clicking the *INIT/Apply* button in the *Well Locations* chart-sheet. The Delaunay triangles are plotted by default.
2) Set the optimization and drawing control parameters in the *Options Form*. Activate this form by clicking the *Options* button in the *Well Locations* chart-sheet. You can skip this step if you want to use the default parameters.
3) If you do not want to see graphs in the plot area, click the *Clear/Resume* button in the *Well Locations* chart-sheet. Clicking it again will turn on the graph output. You can also achieve this by deselecting the two drawing parameters in the *Options Form*.
4) If you want to use all locations as potential locations for analysis when some of them have previously been eliminated, click the *Reset All* button in the *Well Locations* chart-sheet. This action will reset the potential locations and redraw the graph.
5) Perform optimization by clicking the *Optimize* button in the chart-sheet *Well Locations*. If locations are eliminated from the network, you may notice the change in the graph, if the graph output is turned on.
6) Check the results in the plot area in the *Well Locations* chart-sheet or in the *Output Part* in the *DataSheet*. If you want to change parameters and run the analysis again, go back to step 2.
7) Send results back to Access (the *Well Redundancy Analysis – Excel Module* screen) by clicking the *Back to Access* button. This will work only when this worksheet is loaded through MAROS.

Or

7) Stop the program by clicking the *Terminate* button in the *Well Locations* chart-sheet. Go to Step 1 if you want to re-analyze.

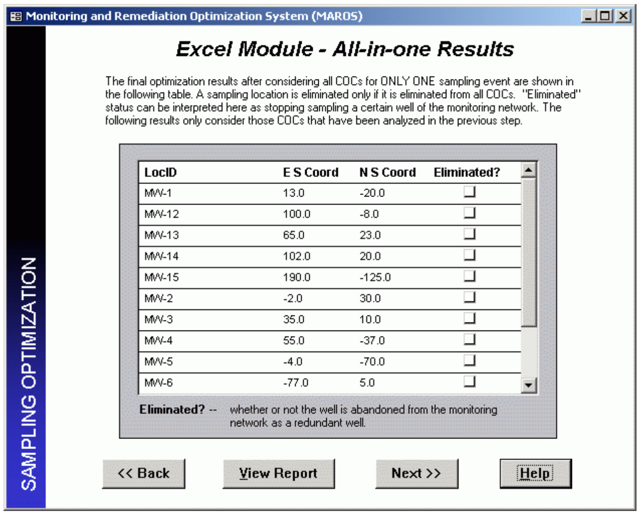
The *xlsDelaunay2K* worksheet will remain open until the user closes it. All the results and graph output are kept if the user chooses to save the file before closing it. The graph output in the plot area is similar to the screen shot shown below:



WARNING: Do not change the name of worksheet *xlsDelaunay2K* or move it to other folders.

Excel Module - All-in-one Results

This screen (accessed from the *Well Redundancy Analysis – Excel Module* screen by clicking *Next*) is used to display the all-in-one sampling location optimization results for the analysis of only one sampling event. A location is marked for elimination only if this location is eliminated for all COCs. Elimination of a location is interpreted as stopping sampling at this location. If in the previous step some COCs were not analyzed, the results given in this form may be incorrect due to incomplete analyses.



Excel Module - All-in-one Results

The final optimization results after considering all COCs for ONLY ONE sampling event are shown in the following table. A sampling location is eliminated only if it is eliminated from all COCs. "Eliminated" status can be interpreted here as stopping sampling a certain well of the monitoring network. The following results only consider those COCs that have been analyzed in the previous step.

LocID	E S Coord	N S Coord	Eliminated?
MW-1	13.0	-20.0	☐
MW-12	100.0	-8.0	☐
MW-13	65.0	23.0	☐
MW-14	102.0	20.0	☐
MW-15	190.0	-125.0	☐
MW-2	-2.0	30.0	☐
MW-3	35.0	10.0	☐
MW-4	55.0	-37.0	☐
MW-5	-4.0	-70.0	☐
MW-6	-77.0	5.0	☐

Eliminated? -- whether or not the well is abandoned from the monitoring network as a redundant well.

Eliminated?: Displays whether a location is considered redundant and should be eliminated. A check mark in this field stands for the elimination of a location.

Back: Returns the user to the *Well Redundancy Analysis – Excel Module* screen.

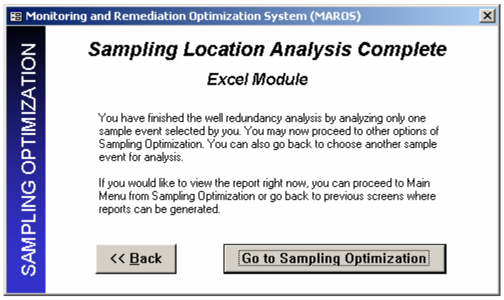
Next: Proceeds to the *Sampling Location Analysis Complete – Excel Module* screen.

View Report: Generates a report with the all-in-one sampling location optimization results. The user can then go back to re-run the analysis by changing parameters or by selecting a different series of sampling events. If not all COCs are analyzed in the previous step, results shown in the report may be incorrect due to incomplete analysis.

Help: Provides additional information on software operation and screen-specific input requirements.

Sampling Location Analysis Complete – Excel Module

This screen (accessed from the *Excel Module – All-in-one Results* screen by clicking *Next*) is a message screen indicating that the sampling location determination by the Excel module has been completed and the user can proceed to other analyses.



Sampling Location Analysis Complete

Excel Module

You have finished the well redundancy analysis by analyzing only one sample event selected by you. You may now proceed to other options of Sampling Optimization. You can also go back to choose another sample event for analysis.

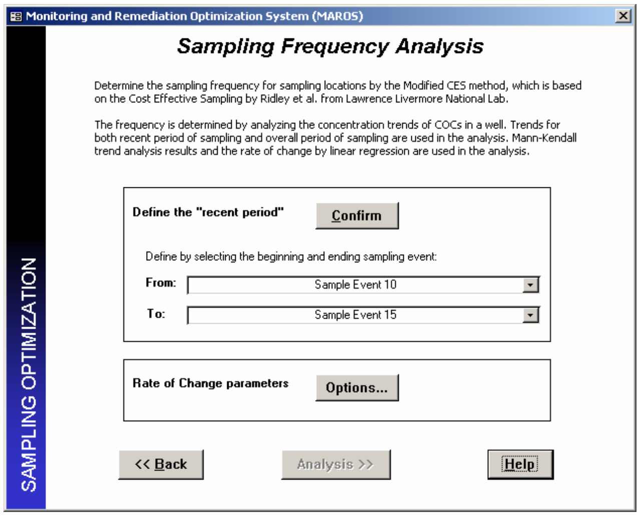
If you would like to view the report right now, you can proceed to Main Menu from Sampling Optimization or go back to previous screens where reports can be generated.

Back: Returns the user to the *Excel Module – All-in-one Results* screen. The user can go back to re-run the analysis by changing parameters or by selecting a different series of sampling vents.

Go to Sampling Optimization: Returns the user to the *Sampling Optimization* screen.

Sampling Frequency Analysis

Sampling Frequency Analysis (accessed from the *Sampling Optimization* screen by clicking *Sampling Frequency Analysis*) is the control screen to determine the frequency of sampling at each location. The Modified CES method (adopted from Cost Effective Sampling by Ridley et al. 1998) is applied. This method is based on the analysis of recent and overall trends of COC concentrations. Details of the method are available in Appendix A.9.



Sampling Frequency Analysis

Determine the sampling frequency for sampling locations by the Modified CES method, which is based on the Cost Effective Sampling by Ridley et al. from Lawrence Livermore National Lab.

The frequency is determined by analyzing the concentration trends of COCs in a well. Trends for both recent period of sampling and overall period of sampling are used in the analysis. Mann-Kendall trend analysis results and the rate of change by linear regression are used in the analysis.

Define the "recent period"

Define by selecting the beginning and ending sampling event:

From: Sample Event 10

To: Sample Event 15

Rate of Change parameters

The term "recent period" refers to the time period in which the latest series of sampling events occurred. It is used to differentiate for example, the latest two years of sampling, from the history of sampling (all sampling events). The "recent period" could contain any series of continuous sampling events ending with the latest sampling event.

From: Selects a sampling event from the dropdown list as the beginning of the "recent period".

To: Selects a sampling event as the end of the "recent period".

Confirm: Confirms the "recent period" defined by the user.

Options: Shows the *Sampling Frequency Analysis - Options* screen, where the *Rate of Change* parameters for analyzing the concentration trends can be set.

Back: Returns the user to the *Sampling Optimization* screen.

Analysis: Determines sampling frequencies at all sampling locations for each COC by using the Modified CES method. The *Sampling Frequency Recommendation* screen will pop up.

Help: Provides additional information on software operation and screen-specific input requirements.

Steps for use:

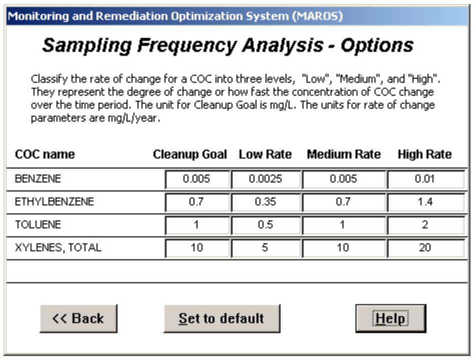
1) Define the "recent period" first. The ending sampling event should be later than the beginning sampling event. A minimum of six sampling events is recommended for the analysis. For analysis with less than six samples, the results could be inaccurate.

Or

1) Use previously selected sampling events shown on the *From* and *To* dropdown lists.
2) Click the *Confirm* button to confirm the selection.
3) Click the *Options* button and enter the *Sampling Frequency Analysis – Options* screen. Define field specific *Rate of Change* parameters for COCs there. Close that screen and return. Default values will be used if parameters are not defined.
4) Click the *Analysis* button to perform the analysis.

Sampling Frequency Analysis - Options

This screen (accessed from the *Sampling Frequency Analysis* screen by clicking *Options*) is used for setting the *Rate of Change* (ROC) parameters that are required by the Modified CES method.



Classify the rate of change for a COC into three levels, "Low", "Medium", and "High". They represent the degree of change or how fast the concentration of COC change over the time period. The unit for Cleanup Goal is mg/L. The units for rate of change parameters are mg/L/year.

COC name	Cleanup Goal	Low Rate	Medium Rate	High Rate
BENZENE	0.005	0.0025	0.005	0.01
ETHYLBENZENE	0.7	0.35	0.7	1.4
TOLUENE	1	0.5	1	2
XYLENES, TOTAL	10	5	10	20

These parameters include *Low Rate*, *Medium Rate* and *High Rate*. Here *Cleanup Goal* (*PRG*: Preliminary Remediation Goal, mg/L) is used as a reference for defining the rate of change parameters. By default, the low rate is defined as 0.5 PRG/year, medium rate is defined as 1.0 PRG/year and high rate is defined as 2.0 PRG/year, for a certain COC. When Cleanup Goal of a COC is not available in the database, the user is prompted to enter the value and the three rate parameters. Otherwise, this COC will not be analyzed. The user should provide specific *Rate of Change* values for a specific field of study, if available. Refer to Appendix A.9 for details.

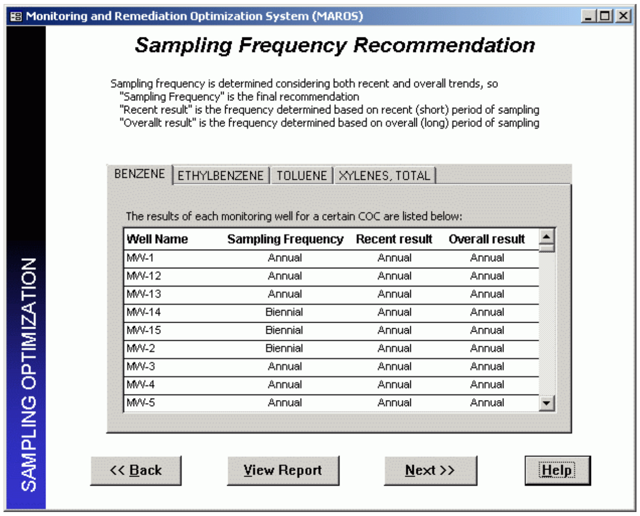
Back: Closes this screen and returns to the *Sampling Frequency Analysis* screen.

Set to default: Sets all these parameters to system default.

Help: Provides additional information on software operation and screen-specific input requirements.

Sampling Frequency Recommendation

Sampling Frequency Recommendation (accessed from the *Sampling Frequency Analysis* screen by clicking *Analysis*) is used to display the frequency of sampling for each sampling location and each COC.



Sampling Frequency Recommendation

Sampling frequency is determined considering both recent and overall trends, so
"Sampling Frequency" is the final recommendation
"Recent result" is the frequency determined based on recent (short) period of sampling
"Overallt result" is the frequency determined based on overall (long) period of sampling

The results of each monitoring well for a certain COC are listed below:

Well Name	Sampling Frequency	Recent result	Overall result
MW-1	Annual	Annual	Annual
MW-12	Annual	Annual	Annual
MW-13	Annual	Annual	Annual
MW-14	Biennial	Annual	Annual
MW-15	Biennial	Annual	Annual
MW-2	Biennial	Annual	Annual
MW-3	Annual	Annual	Annual
MW-4	Annual	Annual	Annual
MW-5	Annual	Annual	Annual

Select the page with a certain COC name to display the recommended results for that COC.

<u>Sampling Frequency:</u> The final frequency recommendation determined based on overall and recent trends and other factors.

<u>Recent Result:</u> The frequency determined based on the recent period of data.

<u>Overall Result:</u> The frequency determined based on the overall period of data.

Back: Returns the user to the *Sampling Frequency Analysis* screen, where the user can change *Rate of Change* parameters and perform a new analysis.

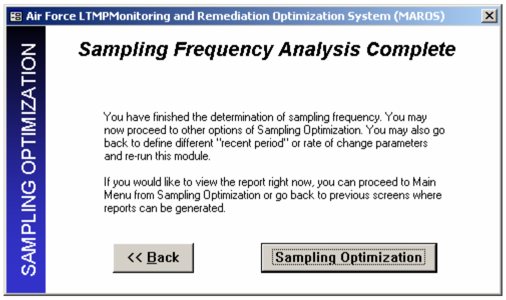
View Report: Generates a report with sampling frequency recommendations for the sampling events selected by the user. The user can go back to re-run the analysis by changing parameters or selecting a different series of sampling vents.

Next: Proceed to the *Sampling Frequency Analysis Complete* screen.

Help: Provides additional information on software operation and screen-specific input requirements.

Sampling Frequency Analysis Complete

This screen (accessed from the *Sampling Frequency Recommendation* screen by clicking *Next*) is a message screen indicating that sampling frequency determination has been completed and the user can proceed to other analyses.



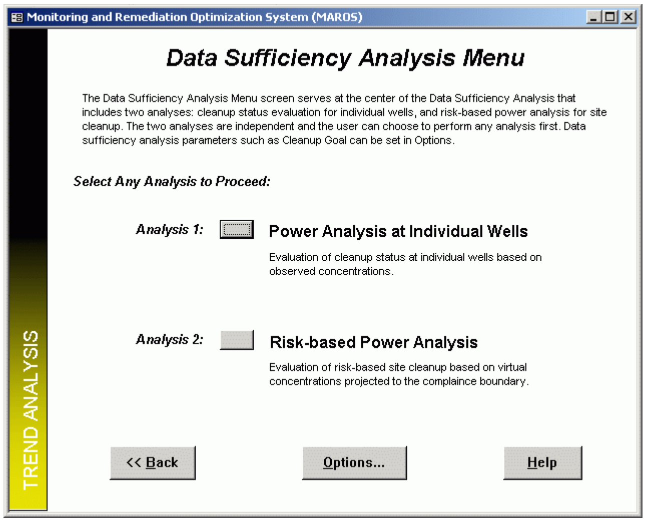
You have finished the determination of sampling frequency. You may now proceed to other options of Sampling Optimization. You may also go back to define different "recent period" or rate of change parameters and re-run this module.

If you would like to view the report right now, you can proceed to Main Menu from Sampling Optimization or go back to previous screens where reports can be generated.

Back: Returns to the *Sampling Frequency Recommendation* screen. The user can go back to re-run the analysis by changing parameters or selecting a different series of sampling vents.

Sampling Optimization: Returns the user to the *Sampling Optimization* screen.

Data Sufficiency Analysis Menu



The Data Sufficiency Analysis Menu screen serves at the center of the Data Sufficiency Analysis that includes two analyses: cleanup status evaluation for individual wells, and risk-based power analysis for site cleanup. The two analyses are independent and the user can choose to perform any analysis first. Data sufficiency analysis parameters such as Cleanup Goal can be set in Options.

Evaluation of cleanup status at individual wells based on observed concentrations.

Evaluation of risk-based site cleanup based on virtual concentrations projected to the complaince boundary.

Data Sufficiency Analysis Menu (accessed from the *Sampling Optimization* screen by clicking *Data Sufficiency Analysis*) is the main menu for data sufficiency analysis that includes two types of statistical power analyses.

It allows the user to choose between performing:

- Power Analysis at Individual Wells
- Risk-Based Power Analysis for the site

The analyses accessed by each choice are as follows:

Statistical and Power Analyses at Individual Wells

Determines the cleanup status of individual wells using a sequential t-test from EPA (1992). An optional power analysis based on the Student's t-test on mean difference is also provided. Refer to Appendix A.6 for details.

Risk-based Power Analysis

Determines the risk-based site cleanup status using estimated concentrations projected to the compliance boundary (delineated based on the nearest downgradient receptor). Concentrations from wells in a sampling event are used as a group in this analysis. Refer to Appendix A.6 for details.

Back: Returns the user to the *Sampling Optimization* screen.

Options: Shows the *Data Sufficiency Analysis – Options* screen where the parameters for the two types of analyses are defined.

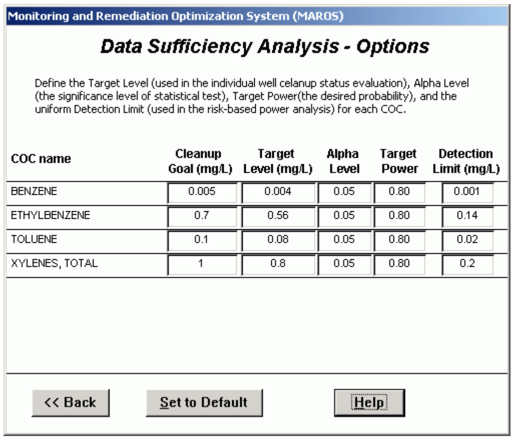
Help: Provides information on the screen-specific input requirements.

Steps for use:

1) Check data sufficiency analysis parameters by clicking the *Options* button. The user can choose to use the default values or specify new values for the parameters. Missing or invalidated values of certain parameters may prevent the analysis from proceeding.
2) Since the two analyses are independent from each other, the user can choose to perform any analysis first.

Data Sufficiency Analysis – Options

This screen (accessed from the *Data Sufficiency Analysis Menu* screen by clicking *Options*) is used for setting the parameters required in the statistical power analysis.



Data Sufficiency Analysis - Options

Define the Target Level (used in the individual well celanup status evaluation), Alpha Level (the significance level of statistical test), Target Power(the desired probability), and the uniform Detection Limit (used in the risk-based power analysis) for each COC.

COC name	Cleanup Goal (mg/L)	Target Level (mg/L)	Alpha Level	Target Power	Detection Limit (mg/L)
BENZENE	0.005	0.004	0.05	0.80	0.001
ETHYLBENZENE	0.7	0.56	0.05	0.80	0.14
TOLUENE	0.1	0.08	0.05	0.80	0.02
XYLENES, TOTAL	1	0.8	0.05	0.80	0.2

These parameters include *Cleanup Goal* (the *PRG,* mg/L), *Target Level* (mg/L), *Alpha Level* (the *significance level*), *Target Power, and Detection Limit (mg/L)*. The *Cleanup Goal* is by default set to the Maximum Contaminant Level (MCL) of a COC. If there is no available *Cleanup Goal* for a COC in the database, the user is asked to define it and the *Target Level*. Otherwise, the analysis for that COC will be canceled. By default, the *Target Level* is set to 0.8*PRG*), the *Alpha Level* (the significance level of a statistical test) is set to 0.05 and the *Target Power* (false negative rate) is set to 0.80. In the risk-based power analysis, the *Detection Limit* specified here is used to indicate whether the projected concentration is less than it. If the user has already specified uniform *Detection Limits* in the *Data Reduction: Part 2 of* 2 screen, they will show up in this screen as default values. Refer to Appendix A.6 for details.

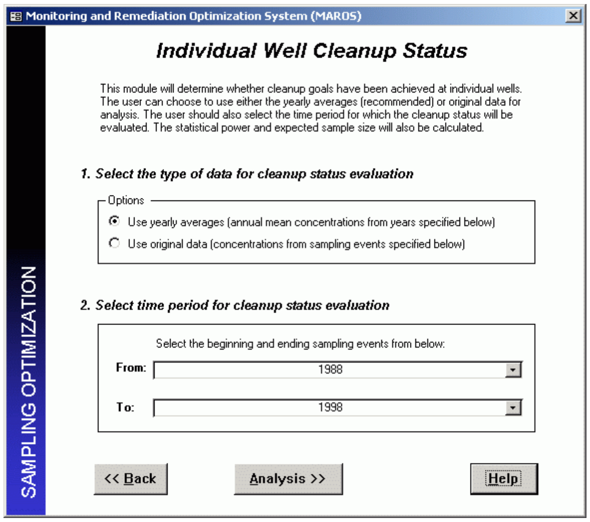
Back: Returns to the *Data Sufficiency Analysis Menu* screen.

Set to default: Sets all parameters to the system default.

Help: Provides information on the screen-specific input requirements.

Individual Well Cleanup Status

This screen (accessed from the *Data Sufficiency Analysis Menu* screen by clicking *Analysis 1*) is used for selecting the type of data (yearly averages or original data) and time period (defined by a series of sampling events) used in the cleanup status evaluation for individual wells.



Individual Well Cleanup Status

This module will determine whether cleanup goals have been achieved at individual wells. The user can choose to use either the yearly averages (recommended) or original data for analysis. The user should also select the time period for which the cleanup status will be evaluated. The statistical power and expected sample size will also be calculated.

1. Select the type of data for cleanup status evaluation

Options

● Use yearly averages (annual mean concentrations from years specified below)

○ Use original data (concentrations from sampling events specified below)

2. Select time period for cleanup status evaluation

Select the beginning and ending sampling events from below:

From: 1988

To: 1998

1. Select the type of data:

Two types of data can be used: yearly averages or original data from each sampling event. A yearly average is obtained by averaging data for that year and is treated as one sample. The original data from each sampling event can be reduced in *Data Reduction*. Yearly averages are recommended if there are more than 4 years of data. At least 4 data (yearly averages or original data) are required for the analysis. Click on the option box to select the type of data you want to use.

2. Select the time period for evaluation:

Concentration data from an individual well over the time period specified will be used in the analysis. Selecting a different time period may lead to different results.

<u>From:</u> Selects the starting year from the dropdown list.

<u>To:</u> Selects the ending year from the dropdown list.

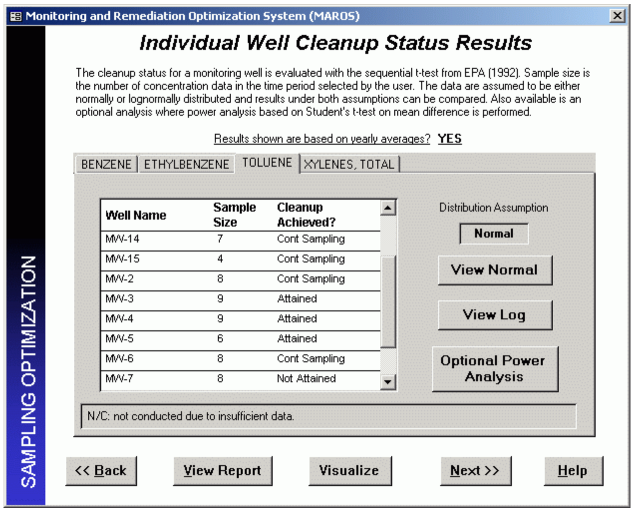
Back: Returns the user to the *Data Sufficiency Analysis Menu* screen.

Analysis: Calculates the cleanup status, power, and expected sample size for each individual well for each COC for the time period selected by the user. The *Individual Well Cleanup Status Results* screen will pop up.

Help: Provides additional information on software operation and screen-specific input requirements.

Individual Well Cleanup Status Results

This screen (accessed from the *Individual Well Cleanup Status* screen by clicking *Analysis*) is used to display the results for individual well cleanup status evaluations, grouped by COC.



Individual Well Cleanup Status Results

The cleanup status for a monitoring well is evaluated with the sequential t-test from EPA (1992). Sample size is the number of concentration data in the time period selected by the user. The data are assumed to be either normally or lognormally distributed and results under both assumptions can be compared. Also available is an optional analysis where power analysis based on Student's t-test on mean difference is performed.

Results shown are based on yearly averages? YES

Well Name	Sample Size	Cleanup Achieved?
MW-14	7	Cont Sampling
MW-15	4	Cont Sampling
MW-2	8	Cont Sampling
MW-3	9	Attained
MW-4	9	Attained
MW-5	6	Attained
MW-6	8	Cont Sampling
MW-7	8	Not Attained

N/C: not conducted due to insufficient data.

Sample Size: The number of data records (yearly averages or original data) that is used in the evaluation.

Cleanup Achieved?: Indicates whether the cleanup goal is achieved in the well. Results could be *Attained*, *Cont. Sampling* (continue sampling), *Not Attained*, or *N/C* (not conducted due to insufficient data).

To facilitate the power analysis, concentration data are assumed to be either normally or lognormally distributed. Results for both assumptions are calculated and provided for comparison. See Appendix A.6 for detailed explanations.

View Normal: Views results calculated under the assumption that data are normally distributed.

View Log: Views results calculated under the assumption that data are lognormally distributed.

Optional Power Analysis: Shows the *Individual Well Cleanup Status – Optional Power Analysis* screen where power analyses results based on the Student's t-test on mean difference are given.

Back: Returns the user to the *Individual Well Cleanup Status* screen.

View Report: Generates a report with individual well cleanup status results for the type of data and time period selected by the user. The user can go back to re-run the analysis by selecting a different type of data or by selecting a different time period.

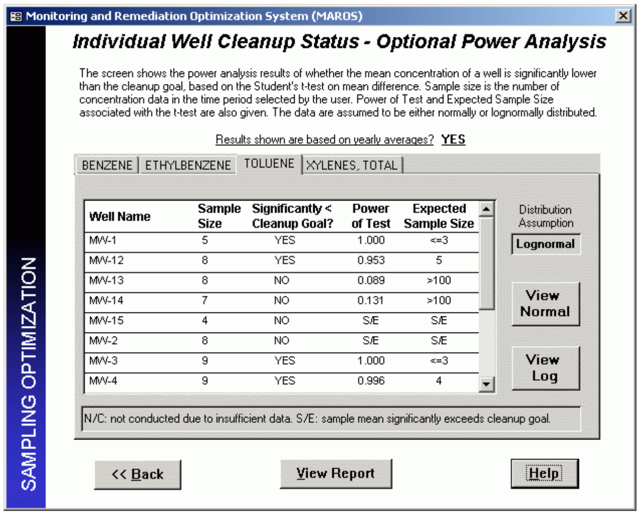
Visualize: Views the results in a map in which wells are shown spatially with different colors indicating their cleanup status. This provides a way to visualize the individual well cleanup status spatially on the site scale.

Next: Proceeds to the *Individual Well Power Analysis Complete* screen.

Help: Provides information on the screen-specific input requirements.

Individual Well Cleanup Status – Optional Power Analysis

This screen (accessed from the *Individual Well Cleanup Status Results* screen by clicking *Optional Power Analysis*) is used to show power analysis results of whether the mean concentration of a well is significantly lower than the cleanup goal, based on the Student's t-test on mean difference.



Individual Well Cleanup Status - Optional Power Analysis

The screen shows the power analysis results of whether the mean concentration of a well is significantly lower than the cleanup goal, based on the Student's t-test on mean difference. Sample size is the number of concentration data in the time period selected by the user. Power of Test and Expected Sample Size associated with the t-test are also given. The data are assumed to be either normally or lognormally distributed.

Results shown are based on yearly averages? YES

Well Name	Sample Size	Significantly < Cleanup Goal?	Power of Test	Expected Sample Size
MW-1	5	YES	1.000	<=3
MW-12	8	YES	0.953	5
MW-13	8	NO	0.089	>100
MW-14	7	NO	0.131	>100
MW-15	4	NO	S/E	S/E
MW-2	8	NO	S/E	S/E
MW-3	9	YES	1.000	<=3
MW-4	9	YES	0.996	4

N/C: not conducted due to insufficient data. S/E: sample mean significantly exceeds cleanup goal.

Sample Size: The number of data (yearly averages or original data) that is used in the evaluation.

Significantly < Cleanup Goal?: Indicates whether the mean concentration of a well is significantly lower than the cleanup goal. Results could be *YES* (significantly lower than the cleanup goal), *NO* (not significantly lower or higher than the cleanup goal), or *N/C* (not conducted due to insufficient data).

Power of Test: The probability that the correct conclusion can be made when the average concentration from a well is truly lower than the cleanup goal. The power values range from 0 to 1.0. *N/C* indicates the analysis is not conducted because of insufficient data (sample size < 4). *S/E* indicates the analysis is not conducted because the mean concentration significantly exceeds the cleanup goal.

Expected Sample Size: The amount of data required to achieve the expected power with the variability shown in the data. <=*3* indicates that the data have a very small variability, resulting in a high power. >*100* indicates the opposite. *N/C* indicates the analysis is not conducted because of insufficient data (sample size < 4). *S/E* indicates the analysis is not conducted because the mean concentration significantly exceeds the cleanup goal.

To facilitate the power analysis, concentration data are assumed to be either normally or lognormally distributed. Results for both assumptions are calculated and provided for comparison. In most cases, they agree with each other. See Appendix A.6 for detailed explanations.

View Normal: Views results calculated under the assumption that data are normally distributed.

View Log: Views results calculated under the assumption that data are lognormally distributed.

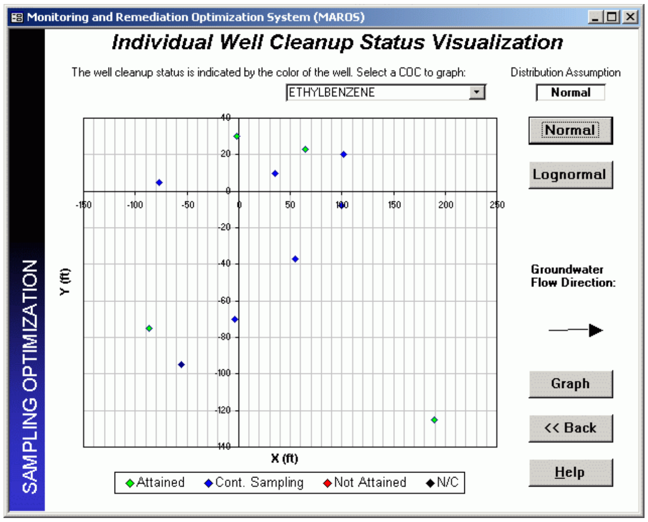
Back: Closes this screen and returns to the *Individual Well Cleanup Status Results* screen.

View Report: Generates a report with optional power analysis results for the type of data and time period selected by the user. The user can go back to re-run the analysis by selecting a different type of data or by selecting a different time period.

Help: Provides information on the screen-specific input requirements.

Individual Well Cleanup Status Visualization

This screen (accessed from the *Individual Well Cleanup Status Results* screen by clicking *Visualize*) allows the user to view the individual well cleanup status spatially on the site scale. Results based on the period specified by the user are shown graphically for each COC. A diamond indicates a well location. The well's cleanup status is indicated by its color. Well names are not shown for readability.



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: ETHYLBENZENE

Distribution Assumption: Normal

Choose the COC of interest from the dropdown list at the top of the screen. Then choose button *Normal* or *Lognormal* (see explanations below) or click button *Graph* to view. The default graph type is *Normal*.

To facilitate the statistical power analysis, concentration data are assumed to be either normally or lognormally distributed. Results for both assumptions are calculated and provided for comparison. See Appendix A.6 for detailed explanations.

<u>Groundwater Flow Direction:</u> Indicates the general groundwater flow direction specified by the user in the *Spatial Moment Analysis* module. If the flow direction is not previously specified, a default direction is shown.

Normal: Views results calculated under the assumption that data are normally distributed.

Lognormal: Views results calculated under the assumption that data are lognormally distributed.

Graph: Plots or refreshes the graph.

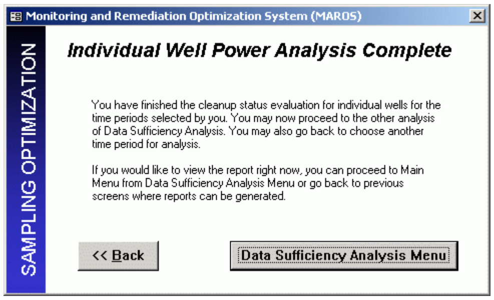
Back: Closes this screen and returns to the *Individual Well Cleanup Status Results* screen.

Help: Provides information on the screen-specific input requirements.

Note: This graph can also be viewed and printed from the *MAROS Output* screen. See Appendix A.10 for an example graph.

Individual Well Power Analysis Complete

This screen (accessed from the *Individual Well Cleanup Status Results* screen by clicking *Next*) is a message screen indicating that individual well power analysis has been completed and the user can proceed to other analyses.



You have finished the cleanup status evaluation for individual wells for the time periods selected by you. You may now proceed to the other analysis of Data Sufficiency Analysis. You may also go back to choose another time period for analysis.

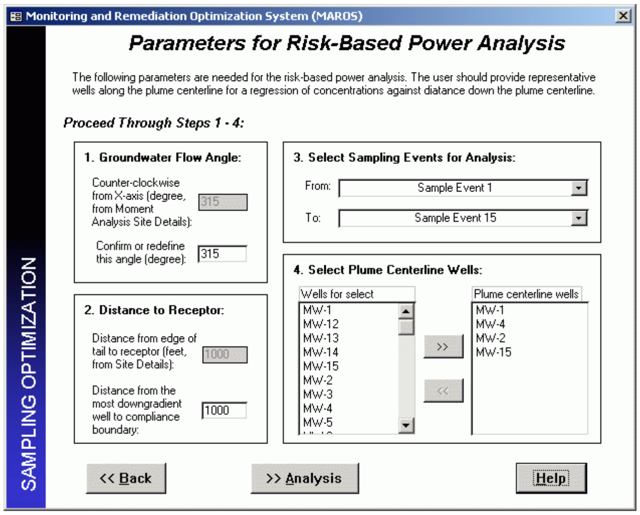
If you would like to view the report right now, you can proceed to Main Menu from Data Sufficiency Analysis Menu or go back to previous screens where reports can be generated.

Back: Returns to the *Individual Well Cleanup Status Results* screen. The user can go back to re-run the previous analyses by changing parameters or selecting a different time period.

Data Sufficiency Analysis Menu: Returns the user to the *Data Sufficiency Analysis Menu* screen.

Parameters for Risk-Based Power Analysis

This screen (accessed from the *Data Sufficiency Analysis Menu* screen by clicking *Analysis* 2) is used for specifying the parameters used in the risk-based power analysis. The user should ensure the correctness of the selected parameters before proceeding to further analysis.



Monitoring and Remediation Optimization System (MAROS)

Parameters for Risk-Based Power Analysis

The following parameters are needed for the risk-based power analysis. The user should provide representative wells along the plume centerline for a regression of concentrations against diatance down the plume centerline.

Proceed Through Steps 1 - 4:

1. Groundwater Flow Angle:

Counter-clockwise from X-axis (degree, from Moment Analysis Site Details): 315

Confirm or redefine this angle (degree): 315

2. Distance to Receptor:

Distance from edge of tail to receptor (feet, from Site Details): 1000

Distance from the most downgradient well to compliance boundary: 1000

3. Select Sampling Events for Analysis:

From: Sample Event 1

To: Sample Event 15

4. Select Plume Centerline Wells:

Wells for select	Plume centerline wells
MW-1	MW-1
MW-12	MW-4
MW-13	MW-2
MW-14	MW-15
MW-15	
MW-2	
MW-3	
MW-4	
MW-5	

1. *Groundwater Flow Angle:* The preferential groundwater flow direction measured in degrees counter-clockwise from the X-axis or the Easting in State coordinate systems. If the angle is provided earlier in the *Plume Moment Analysis*, it will be shown in the gray textbox as a default value. This angle is very important for the risk-based analysis and errors in this value may cause erroneous results.

2. *Distance to Receptor:* The distance in feet from the most downgradient well to the compliance boundary, delineated according to the nearest downgradient receptor. The value shown in the gray textbox is the distance from plume tail to receptors provided in Site Details and is used as a reference only. The compliance boundary can be at or upgradient of the nearest downgradient receptor. See Appendix A.6 and Figure A.6.4 for details about this parameter.

3. *Select Sampling Events for Analysis:* Selects the starting and ending sampling events from the *From* and *To* dropdown lists, respectively. The user can choose to analyze one or more sampling events.

4. *Select Plume Centerline Wells:* Selects the representative wells along the plume centerline from source to tail. Data from these wells will be used in the regression of plume centerline concentrations against the distance down the plume centerline. The plume centerline wells should be selected in the same way as in the BIOSCREEN and BIOCHLOR applications. To select, click on the well in the *Wells for select* listbox and then click the >> button. To deselect, click on the well in the *Plume centerline wells* listbox and then click the << button. At least three wells are needed for the regression analysis. The selected wells do not have to be ordered. Refer to Appendix A.6 for details.

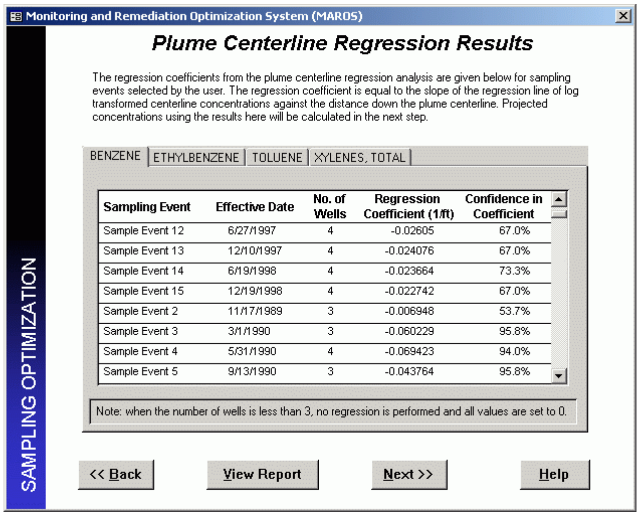
Back: Returns the user to the *Data Sufficiency Analysis Menu* screen.

Analysis: Determines the plume centerline concentration regression coefficients based on the selected plume centerline wells for the sampling events selected by the user. The screen *Plume Centerline Regression Results* will pop up.

Help: Provides additional information on software operation and screen-specific input requirements.

Plume Centerline Regression Results

This screen (accessed from the *Parameters for Risk-Based Power Analysis* screen by clicking *Analysis*) is used to display the results for the plume centerline concentration regression, grouped by COC.



Plume Centerline Regression Results

The regression coefficients from the plume centerline regression analysis are given below for sampling events selected by the user. The regression coefficient is equal to the slope of the regression line of log transformed centerline concentrations against the distance down the plume centerline. Projected concentrations using the results here will be calculated in the next step.

Sampling Event	Effective Date	No. of Wells	Regression Coefficient (1/ft)	Confidence in Coefficient
Sample Event 12	6/27/1997	4	-0.02605	67.0%
Sample Event 13	12/10/1997	4	-0.024076	67.0%
Sample Event 14	6/19/1998	4	-0.023664	73.3%
Sample Event 15	12/19/1998	4	-0.022742	67.0%
Sample Event 2	11/17/1989	3	-0.006948	53.7%
Sample Event 3	3/1/1990	3	-0.060229	95.8%
Sample Event 4	5/31/1990	4	-0.069423	94.0%
Sample Event 5	9/13/1990	3	-0.043764	95.8%

Note: when the number of wells is less than 3, no regression is performed and all values are set to 0.

No. of Wells: The number of plume centerline wells that are available for analysis in the sampling event. If this number is less than three, regression will not be performed.

Regression Coefficient: The first order coefficient (1/ft) of the exponential model where plume centerline concentrations are expressed as a function of the distance down the plume centerline. This regression coefficient is equivalent to the slope of the regression line of log-transformed centerline concentrations against the distance down the plume centerline. A negative coefficient indicates that the centerline concentrations drop with an increase in distance from the source. If the coefficient is positive, the user should go back to check if the flow angle or selected wells are correct.

Confidence in Coefficient: The statistical confidence that the estimated coefficient is different from 0. Refer to “Confidence in Trend" in *Linear Regression Analysis* for details.

Back: Returns the user to the *Parameters for Risk-Based Power Analysis* screen.

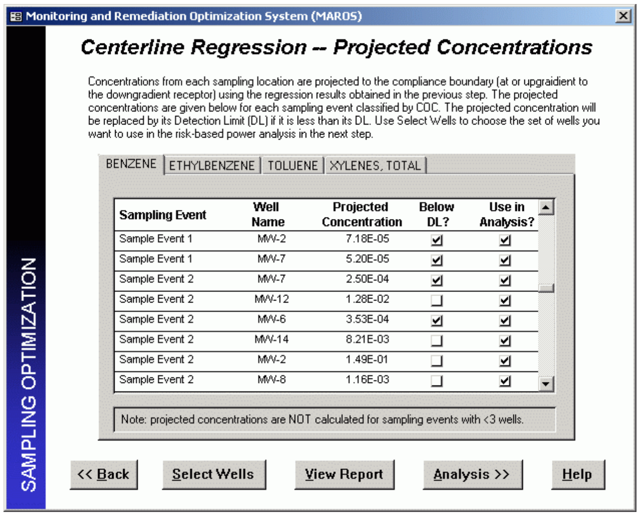
View Report: Generates a report with selected parameters and regression results for each COC. The user can go back to re-run the regression by selecting a different set of parameters.

Next: Proceeds to the *Centerline Regression – Projected Concentrations* screen.

Help: Provides information on the screen-specific input requirements.

Centerline Regression – Projected Concentrations

This screen (accessed from the *Plume Centerline Regression Results* screen by clicking *Next*) is used to display the projected concentrations calculated using regression coefficients obtained in the previous screen. Refer to Appendix A.6 for details.



Centerline Regression -- Projected Concentrations

Concentrations from each sampling location are projected to the compliance boundary (at or upgraidient to the downgradient receptor) using the regression results obtained in the previous step. The projected concentrations are given below for each sampling event classified by COC. The projected concentration will be replaced by its Detection Limit (DL) if it is less than its DL. Use Select Wells to choose the set of wells you want to use in the risk-based power analysis in the next step.

Sampling Event	Well Name	Projected Concentration	Below DL?	Use in Analysis?
Sample Event 1	MW-2	7.18E-05	☑	☑
Sample Event 1	MW-7	5.20E-05	☑	☑
Sample Event 2	MW-7	2.50E-04	☑	☑
Sample Event 2	MW-12	1.28E-02	☐	☑
Sample Event 2	MW-6	3.53E-04	☑	☑
Sample Event 2	MW-14	8.21E-03	☐	☑
Sample Event 2	MW-2	1.49E-01	☐	☑
Sample Event 2	MW-8	1.16E-03	☐	☑

Note: projected concentrations are NOT calculated for sampling events with <3 wells.

Projected Concentrations: Estimated concentrations (mg/L) projected to the compliance boundary, delineated based on the downgradient receptor. The distance to the compliance boundary is introduced into the exponential model to calculate the projected concentration. Data are not available for sampling events with less than three centerline wells.

Below DL: Indicates whether the projected concentration is below the user-provided detection limit for the COC. If true, a check mark is shown in the checkbox.

Use in Analysis: Indicates whether the projected concentration at this well will be used in the risk-based site cleanup evaluation. The user can make selections in screen *Well Selection Form* by clicking button *Select Wells*.

Back: Returns the user to the *Parameters for Risk-Based Power Analysis* screen.

Select Wells: Opens the *Well Selection Form* screen where the user can choose which wells (i.e., projected concentrations) to use in the risk-based power analysis.

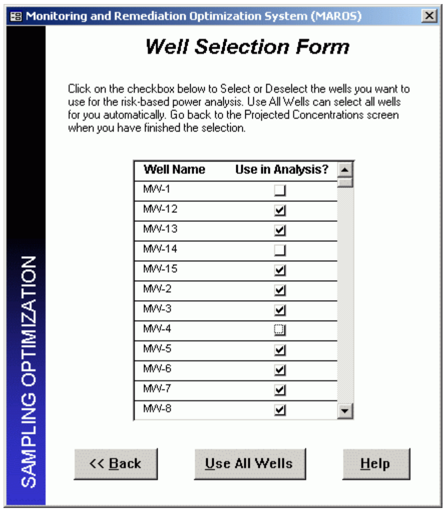
View Report: Generates a report with projected concentrations for the sampling events selected by the user for each COC. The user can go back to re-run the regression by selecting a different set of parameters.

Analysis: Determines the risk-based site cleanup status for the sampling events selected by the user. The *Risk-Based Power Analysis Results* screen will pop up.

Help: Provides information on the screen-specific input requirements.

Well Selection Form

This screen (accessed from the *Centerline Regression – Projected Concentrations* screen by clicking *Select Wells*) is for selecting the wells (i.e., the projected concentrations) that the user wants to use in the risk-based power analysis.



Well Selection Form

Click on the checkbox below to Select or Deselect the wells you want to use for the risk-based power analysis. Use All Wells can select all wells for you automatically. Go back to the Projected Concentrations screen when you have finished the selection.

Well Name	Use in Analysis?
MW-1	☐
MW-12	☑
MW-13	☑
MW-14	☐
MW-15	☑
MW-2	☑
MW-3	☑
MW-4	☐
MW-5	☑
MW-6	☑
MW-7	☑
MW-8	☑

Use in Analysis?: Indicates whether the well will be used in the risk-based site cleanup evaluation. If a well is selected, a check mark is displayed in the checkbox. The user can select/deselect a well by clicking on the checkbox.

Back: Returns the user to the *Centerline Regression – Projected Concentrations* screen.

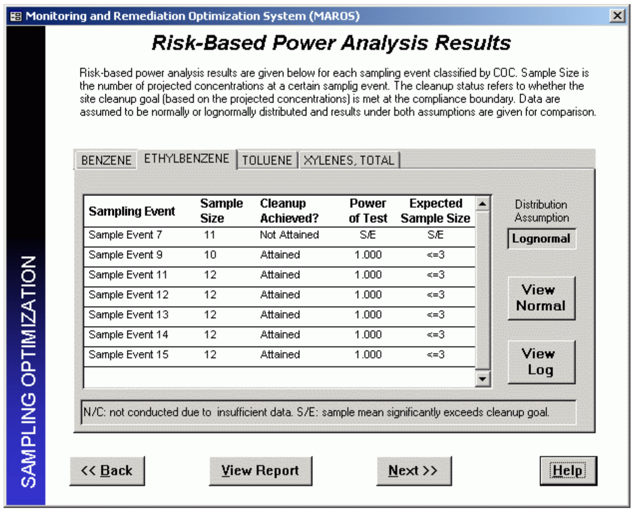
Use All Wells: Selects all wells for analysis.

Help: Provides additional information on software operation and screen-specific input requirements.

Note: if a well is selected/deselected here, it will be selected/deselected for all COCs.

Risk-Based Power Analysis Results

This screen (accessed from the *Centerline Regression – Projected Concentrations* screen by clicking *Analysis*) is used to display the results for risk-based site cleanup evaluations, grouped by COC.



Risk-Based Power Analysis Results

Risk-based power analysis results are given below for each sampling event classified by COC. Sample Size is the number of projected concentrations at a certain samplig event. The cleanup status refers to whether the site cleanup goal (based on the projected concentrations) is met at the compliance boundary. Data are assumed to be normally or lognormally distributed and results under both assumptions are given for comparison.

Sampling Event	Sample Size	Cleanup Achieved?	Power of Test	Expected Sample Size
Sample Event 7	11	Not Attained	S/E	S/E
Sample Event 9	10	Attained	1.000	<=3
Sample Event 11	12	Attained	1.000	<=3
Sample Event 12	12	Attained	1.000	<=3
Sample Event 13	12	Attained	1.000	<=3
Sample Event 14	12	Attained	1.000	<=3
Sample Event 15	12	Attained	1.000	<=3

N/C: not conducted due to insufficient data. S/E: sample mean significantly exceeds cleanup goal.

<u>Sample Size:</u> The number of projected concentrations (i.e., wells) available for analysis in the current sampling event.

<u>Cleanup Achieved?:</u> Indicates whether the cleanup goal is achieved for the entire site. Results could be *Attained*, *Not Attained*, or *N/C* (not conducted due to insufficient data). This evaluation is based on the estimated concentrations projected to the compliance boundary and therefore is a risk-based evaluation.

<u>Power of Test:</u> The probability that the correct conclusion can be made when the average projected concentrations at the site are truly below the cleanup level. The power values range from 0 to 1.0. *N/C* indicates the analysis is not conducted because of insufficient data (sample size < 4). *S/E* indicates the analysis is not conducted because the mean concentration significantly exceeds the cleanup goal.

<u>Expected Sample Size:</u> The number of data required to achieve the expected power with the observed variability of the projected concentrations. *<=3* indicates a very small data variability, leading to a high power. *>100* indicates the opposite. *N/C* indicates the analysis is not conducted because of insufficient data (sample size < 4). *S/E* indicates the analysis is not conducted because the mean concentration significantly exceeds the cleanup goal.

To facilitate the power analysis, projected concentration data are assumed to be normally or lognormally distributed. Results for both assumptions are calculated and provided for comparison. In most cases, they agree with each other. See Appendix A.6 for detailed explanations.

View Normal: Views results calculated under the assumption that data are normally distributed.

View Log: Views results calculated under the assumption that data are lognormally distributed.

Back: Returns the user to the *Centerline Regression – Projected Concentrations* screen.

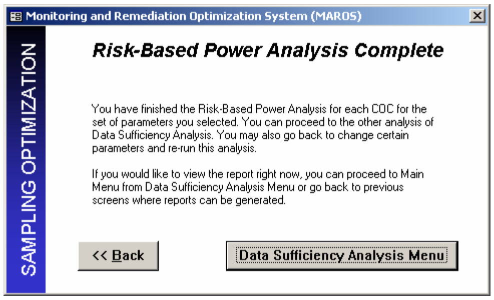
View Report: Generates a report with the risk-based power analysis results for the sampling events selected by the user. The user can go back to re-run the analysis by selecting a different time set of parameters.

Next: Proceeds to the *Risk-Based Power Analysis Complete* screen.

Help: Provides information on the screen-specific input requirements.

Risk-Based Power Analysis Complete

This screen (accessed from the *Risk-Based Power Analysis Results* screen by clicking *Next*) is a message screen indicating that risk-based power analysis has been completed and the user can proceed to other analyses.



You have finished the Risk-Based Power Analysis for each COC for the set of parameters you selected. You can proceed to the other analysis of Data Sufficiency Analysis. You may also go back to change certain parameters and re-run this analysis.

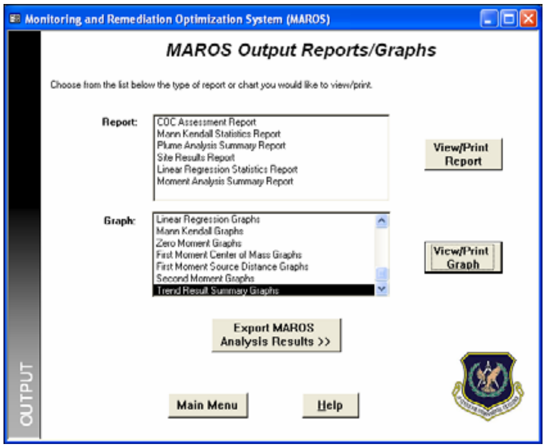
If you would like to view the report right now, you can proceed to Main Menu from Data Sufficiency Analysis Menu or go back to previous screens where reports can be generated.

Back: Returns to the *Risk-Based Power Analysis Results* screen. The user can go back to re-run the analysis by selecting a different set of parameters.

Data Sufficiency Analysis Menu: Returns the user to the *Data Sufficiency Analysis Menu* screen.

MAROS Output Reports/Graphs

MAROS Output Reports/Graphs (accessed from the *Main Menu* screen) allows the user to view/print reports and graphs from the site trend analyses as well as a preliminary Site Recommendation Report. Sample Reports are located in Appendix A.10.



MAROS Output Reports/Graphs

Choose from the list below the type of report or chart you would like to view/print.

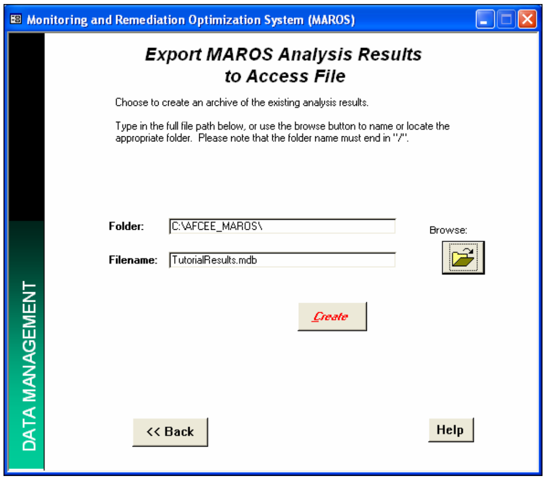
View/Print Report: To view/print reports choose the report of interest and click "View/Print Report".

View/Print Graph: To view/print a graph choose the graph of interest and click "View/Print Graph".

Export MAROS Analysis Results: Results can be exported to a Microsoft Access database. The user can then use the results, displayed in tables, to plot data in a GIS software or export data to other software programs. The database containing results can be compared against other MAROS runs for the same data set to evaluate the impact of changing parameters such as hydraulic characteristics, different methods of data consolidation and data time periods.

Main Menu: Returns the user to the *Main Menu*.

Help: Provides information on the screen-specific input requirements.



Export MAROS Analysis Results to Access File

Choose to create an archive of the existing analysis results.

Type in the full file path below, or use the browse button to name or locate the appropriate folder. Please note that the folder name must end in "/".

Folder: C:\AFCEE_MAROS\

Filename: TutorialResults.mdb

The *Export MAROS Analysis Results to Access File* (accessed from the *MAROS Output Reports* screen) allows the user to export MAROS analysis results to a Microsoft Access file.

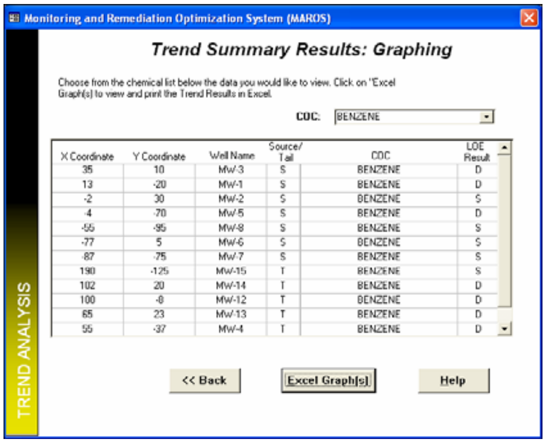
To export results into a database:

1) Enter the full file path and filename of the archived file to export (or click the browse button to find the archive file to overwrite). The Folder and File name you choose will appear in the top two boxes.

2) Click "Create" to proceed with exporting the data to a database file.

Back: Takes the user back to the *MAROS Output Reports/Graphs* screen.

Help: Provides information on the screen-specific input requirements.



Trend Summary Results: Graphing

Choose from the chemical list below the data you would like to view. Click on 'Excel Graph(s) to view and print the Trend Results in Excel.

COC: BENZENE

X Coordinate	Y Coordinate	Well Name	Source/ Tail	COC	LOE Result
35	10	MW-3	S	BENZENE	D
13	-20	MW-1	S	BENZENE	D
-2	30	MW-2	S	BENZENE	S
-4	-70	MW-5	S	BENZENE	D
-55	-95	MW-8	S	BENZENE	S
-77	5	MW-6	S	BENZENE	S
-87	-75	MW-7	S	BENZENE	S
190	-125	MW-15	T	BENZENE	S
102	20	MW-14	T	BENZENE	D
100	-8	MW-12	T	BENZENE	D
65	23	MW-13	T	BENZENE	D
55	-37	MW-4	T	BENZENE	D

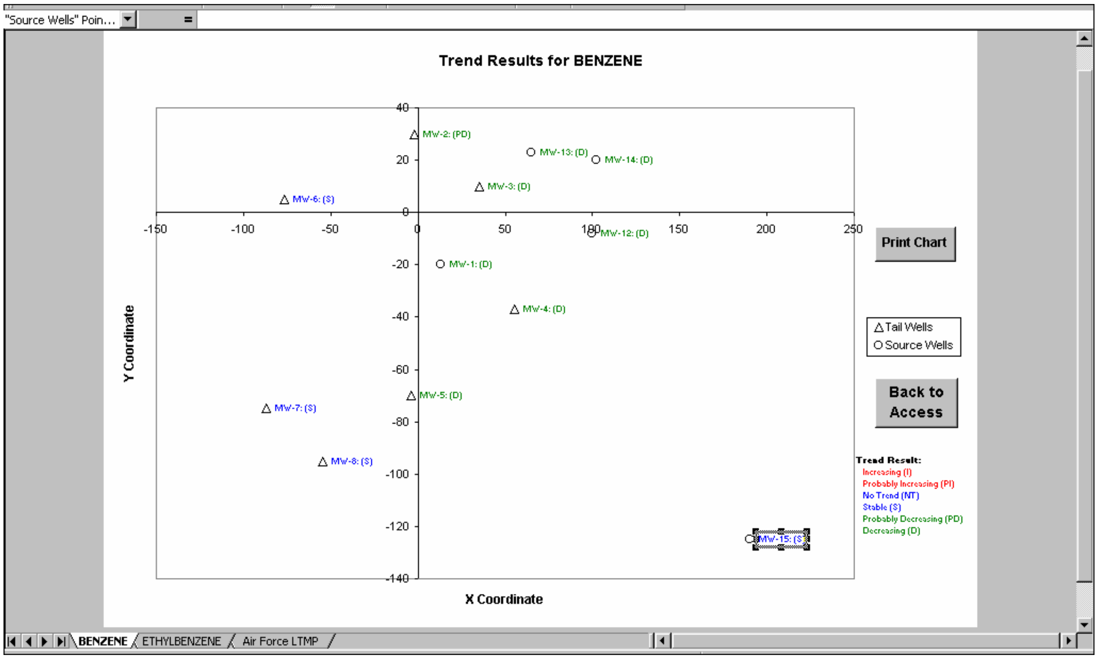
Trend Summary Results: Graphing (accessed from the *MAROS Output Reports* screen) allows the user to view/print graphical Trend summary results in Excel.

Excel Graph(s): Takes the user to the *Excel Graph* screens.

Back: Returns the user to the *MAROS Output Reports* screen.

Help: Provides information on the screen-specific input requirements.

Trend Summary Results: Graph (accessed from the *Trend Summary Results: Graphing* screen) allows the user to view/print graphical Trend summary results in Excel. This will open Excel on your computer to provide the trend result graphs.



Excel Graph(s): Takes the user to the *Excel Graph* screens.

Print Chart: Prints the current summary graph.

Back to Access: Returns the user to the *Trend Summary Results: Graphing* screen.

Note: Do not change the name or content of the worksheet *xlsLOETrendResults* or move it to other folders. Also, the *xlsLOETrendResults* worksheet will remain open until the user closes it. All the results and graph output are kept if the user chooses to save the file before closing it. The user should save the file under a different name by choosing "Save as…" under the Excel menu option "File."

DATABASE COMPACTION

To maintain performance, the database must be routinely compacted to remove unused space whenever data is added or changed, using the following procedures.

- Return to the *Main Menu* screen.
- On the "Tool" option of the upper toolbar, select "Database Utilities" and then select "Compact Database".

WARNING: It is good practice to keep a backup copy of the database before compacting. Should the compact process fail, the original database software will still be available.

Initial Database configuration

This software is an automated interface for an Access database containing groundwater data. An experienced Access user can work directly with the database at any time by clicking on the command "F11" or by choosing "Unhide" from the Windows Menu to reveal the Access database ("afcee_MAROS"). The advanced user can use the Access database tools to develop customized queries or reports which provide more detailed analysis and presentation of the dataset.

APPENDICES

APPENDIX A.1 — DATA IMPORT FILE FORMATS

A few words on data management

As a general rule, assembling site data for the analysis is the most difficult and time consuming step in the optimization protocol. The simple input file required by MAROS is the culmination of years of painstaking sampling and documentation. Often, the necessary data are not in database format, and may need to be entered into electronic format manually. Assembling the information with fidelity and clarity is the most important step in reaching an optimum well network solution. The following two suggestions may make the process easier:

1) *Limit your data at first*. Perform a preliminary analysis with a small file of the most recent data in electronic format to check for data format issues. Creating a small test file may highlight common problems with data such as misspellings of well names and COCs, numbers entered as text, and missing data. Finding and correcting these issues early can save considerable time.
2) *Precise data input*. All constituents must be spelled exactly as in the "MAROS_ConstituentList.xls" under the heading 'MAROS Constituent Names (see table A.1.6). For example 'BENZENE' is recognized by MAROS, but not 'benzene' or 'BZ'. Cutting and pasting names from the constituent list is a good strategy. Results and detection limits should be entered as numbers and not as text. Detailed data input formats are discussed below.

Excel and Access Formats

The following format for Microsoft Excel and Microsoft Access Table Files (Table A.1.1) should be used for importing files into MAROS from Excel and Access. The Well Name is a text field, and dashes and other symbols can be included in the name. The Well Name should be spelled consistently throughout the file. The X and Y Coordinates should be in feet. The coordinates can be in a geographic coordinate system such as State Plane or in a custom system such as plant coordinates.

The Constituent Naming convention follows ERPIMS. As described above, all constituent names must be spelled exactly as in the "MAROS_ConstituentList.xls" file under 'MAROS Constituent Names'. The sample date should be one date in short date format (i.e. 3/12/2004) with no ranges or partial year designations. For the input file, the Result field should have one number (no text) corresponding to the laboratory result. Non-detect results should be blank. Trace or 'J' flag values can be included as a number. The units should be included as indicated in Table A.1.1.

MAROS analysis requires detection limits for analytical data. Often, detection limits are uncertain or unknown for historic data. In the case of missing detection limits, a reasonable guess or setting one consistent detection limit for all data points is a good alternative. Data flags are limited to 'ND' for non-detect and 'TR' for trace detections. 'ND' should always be in the flag field for an empty Result cell. 'TR' corresponds to 'J' values.

The Excel template file "MAROS_ExcelImportTemplate.xls" or the Access template file "MAROS_AccessImportTemplate.mdb" should be used to create an import file for the MAROS software. Each row in the import file should contain one COC, for one well and date. Do not enter spike matrices or blanks. Use the Constituent list found in the "MAROS_ConstituentList.xls" file for naming conventions (contains about 2,100 constituents).

Example names for common constituents can be found in Table A.1.6. Note: if using the Access file for importing, the name of the Access table should be "ImportData", as in the "MAROS_AccessImportTemplate.mdb" file.

TABLE A.1.1 REQUIRED FIELD FORMAT FOR EXCEL AND ACCESS IMPORT FILES: SAMPLING RESULTS

Column Number	Field Name	Description
1	WellName	Name of the groundwater well sampled, be sure all wells are "spelled" the same.
2	XCoord	X coordinate of the well, although not mandatory, it is suggested that you enter this field, for graphing purposes
3	YCoord	Y coordinate of the well, although not mandatory, it is suggested that you enter this field, for graphing purposes
4	Constituent	Compound measured - mandatory entry: Follow the ERPIMS format of the naming convention found in the Excel template file (included with software).
5	SampleDate	Date Sample was collected: format mm/dd/yyyy
6	Result	Analytical result: enter result as a number, if non-detect then leave blank
7	Units	Measurement units for result: choices mg/L; ug/L; ng/L; g/L; pg/L
8	DetLim	Reporting Limit (detection limit) - same units as "Result"
9	Flags	Flag "ND" for non-detect (must enter the detection limit), or "TR" for trace amount (must enter both detection limit and the result), if there is a detect in the Result column, leave the flag blank.

ERPIMS Format

The following format for ERPIMS files in Microsoft Access (Table A.1.2-5) or ERPIMS text files should be used for importing files into MAROS. The Constituent Naming convention follows ERPIMS. The Access template file "MAROS_AccessTemplate.mdb" should be followed to import an ERPIMS Access import file for the MAROS software. Only the fields with an asterix (*) below are mandatory fields for the ERPIMS **Access** import file.

TABLE A.1.2 REQUIRED FIELD FORMAT FOR LDI IMPORT FILES: LOCATION RESULTS

Column Number	Field Name	Description
1	**AFIID**	* Air Force Installation
2	**LOCID**	* Location Identifier
3	LTCODE	Location Classification Code
4	LPRCODE	Location Proximity Code
5	**NCOORD**	* North State Plane Coordinate
6	**ECOORD**	* East State Plane Coordinate
7	**CRDTYPE**	* Coordinate System Type
8	CRDMETH	Coordinate System Method
9	CRDUHN	Precision of the Coordinates
10	**CRDUNITS**	* Coordinates Units of Measure
11	ESTDATE	Date Established
12	ESCCODE	Establishing Company Code
13	DRLCODE	Drilling Company Code
14	EXCCODE	Excavating Company Code
15	CMCCODE	Construction Method Code
16	ELEV	Surface Elevation
17	ELEVMETH	Elevation Determination Method
18	ELEVUN	Precision of the Elevation
19	ELEVUNITS	Elevation Units of Measure
20	ELFLAG	More Current Elevation Available in
21	WINTDEPTH	Borehole Depth
22	BHDIAM	Borehole Diameter
23	BHANGLE	Angle of Borehole Drilling
24	BHAZIM	Azimuth of Borehole Drilling
25	DATUM	Geodetic Datum Identifier
26	STPZONE	Coordinate Zone for Geodetic Datum attribute
27	STPPROJ	Geographic Projection
28	UTMZONE	Unit of Coordinate Zone for Geodetic Datum attribute
29	GEOLOG	References Drilling Logs
30	MAPID	Map Identifier
31	LOCDESC	Location Description

TABLE A.1.3 REQUIRED FIELD FORMAT FOR TES IMPORT FILES: TESTING RESULTS

Column Number	Field Name	Description
1	**SAMPLESEQ**	* Sample Sequence Number
2	**TESTSEQ**	* Test Sequence Number
3	LABCODE	Laboratory Company Code
4	ANMCODE	Analytical Method Code
5	EXMCODE	Extraction Method Code
6	RUN_NUMBER	Run Number
7	LABSAMPID	Laboratory Sample Identification
8	LABRECDATE	Date/time of Reception by Lab
9	LABRECTEMP	Sample Temperature at Reception
10	LABRECUNITS	Celsius or Fahrenheit
11	EXTDATE	Date/time of Extraction
12	LCHDATE	Date/time of Leaching
13	LCHMETH	Method of Leaching
14	LCHLOT	Designator of a Group of Samples Leachated Together
15	ANADATE	Date/time of Analysis
16	ANALOT	Designator of a Group of Samples Analyzed Together
17	LABLOTCTL	Laboratory Lot Control Number
18	LABLOT_SEQ	Sequence Number of Lab Lot
19	CALREFID	Reference Link Between Samples and Corresponding Calibration
20	RTTYPE	Remediation Technology Type
21	BASIS	Basis

TABLE A.1.4 REQUIRED FIELD FORMAT FOR SAM IMPORT FILES: SAMPLE RESULTS

Column Number	Field Name	Description
1	**SAMPLESEQ**	* Sample Sequence Number
2	**AFIID**	* Air Force Installation
3	CONTRACTSEQ	Contract Sequence Number
4	**LOCID**	* Location Identifier
5	**LOGDATE**	* Log Date (Note: the time of sampling should NOT be included)
6	**MATRIX**	* Sampling Matrix
7	SBD	Sample Beginning Depth
8	SED	Sample Ending Depth
9	**SACODE**	* Sample Type Code
10	**SAMPNO**	* Sample Number
11	LOGCODE	Logging Company Code
12	SMCODE	Sampling Method Code
13	WETCODE	Moisture Content
14	**FLDSAMPID**	* Field Sample Identifier
15	COOLER	Cooler Identifier
16	COCID	Chain of Custody Identifier
17	ABLOT	Ambient Blank Identifier
18	EBLOT	Equipment Blank Identifier
19	TBLOT	Trip Blank Identifier
20	SAPROG	Program Authorization
21	REMARKS	Comments About the Sample

TABLE A.1.5 REQUIRED FIELD FORMAT FOR RES IMPORT FILES: RESULTS

Column Number	Field Name	Description
1	**TESTSEQ**	* Tests Sequence Number
2	**RESULTSEQ**	* Results Sequence Number
3	**PARLABEL**	* Parameter Label
4	**PRCCODE**	* Parameter Classification Code
5	**PARVQ**	* Parameter Value Qualifier
6	**PARVAL**	* Parameter Value
7	PARUN	Parameter Value Uncertainty
8	PRESICION	Parameter Value Precision
9	EXPECTED	Expected Parameter Value
10	EVEXP	Integer Value of Expected Value
11	EVMAN	Decimal Value of Expected Value
12	EVPREC	Precision of Expected Value
13	**MDL**	* Method Detection Limit
14	**RL**	* AFCEE Reporting Limit
15	**UNITS**	* Units of Measure
16	VQ_1C	1st Column Value Qualifier
17	VAL_1C	1st Column Value
18	FCVALEXP	1st Column Value Integer Value
19	FCVALMAN	1st Column Value Decimal Value
20	FCVALPREC	Precision of 1st Column Value
21	VQ_CONFIRM	1st Column Value Qualifier
22	VAL_CONFIRM	Confirm Column Value
23	CNFVALEXP	Confirming Value Integer Value
24	CNFVALMAN	Confirming Value Decimal Value
25	CNFVALPREC	Precision of Confirming Value
26	DILUTION	Dilution Value
27	DILEXP	Dilution Value Integer Value
28	DILMAN	Dilution Value Decimal Value
29	DILPREC	Precision of Dilution Value
30	UNCVALEXP	Uncorrected Value Integer Value
31	UNCVALMAN	Uncorrected Value Decimal Value
32	CRVALEXP	Corrected Value Integer Value
33	CRVALMAN	Corrected Value Decimal Value
34	DQTYPE	Data Qualifier Type
35	**EPA_FLAGS**	* EPA Data Qualifier Codes

TABLE A.1.6 EXAMPLE MAROS CONSTITUENT NAME CONVENTION

CAS Number	Constituent	Abreviation or Synonym	ERPIMS Code	MAROS Constituent Name	Constituent Type
BTEX AND MTBE					
71-43-2	Benzene	B	BZ	BENZENE	ORG
100-41-4	Ethylbenzene	E	EBZ	ETHYLBENZENE	ORG
108-88-3	Toluene	T	BZME	TOLUENE	ORG
1330-20-7	Xylene (mixed isomers)	X	XYLENES	XYLENES, TOTAL	ORG
108-30-3	Xylene, m-	X	XYLENES1213	XYLENES, o & m	ORG
95-47-6	Xylene, o-	X	XYLENES1213	XYLENES, o & m	ORG
1634-04-4	Methyl t-Butyl Ether	MTBE	TBUTMEE	tert-BUTYL METHYL ETHER	ORG
CHLORINATED COMPOUNDS					
75-27-4	Bromodichloromethane		BDCME	BROMODICHLOROMETHANE	ORG
56-23-5	Carbon tetrachloride	CT	CTCL	CARBON TETRACHLORIDE	ORG
108-90-7	Chlorobenzene		CLBZ	CHLOROBENZENE	ORG
75-00-3	Chloroethane		CLEA	CHLOROETHANE	ORG
67-66-3	Chloroform	Trichloromethane	TCLME	CHLOROFORM	ORG
74-87-3	Chloromethane	Methyl Chloride	CLME	CHLOROMETHANE	ORG
95-57-8	Chlorophenol, 2-		CLPH2	2-CHLOROPHENOL	ORG
124-48-1	Dibromochloromethane		DBCME	DIBROMOCHLOROMETHANE	ORG
95-50-1	Dichlorobenzene (1,2) (-o)		DCBZ12	1,2-DICHLOROBENZENE	ORG
106-46-7	Dichlorobenzene, (1,4) (-p)		DCBZ14	1,4-DICHLOROBENZENE	ORG
75-71-8	Dichlorodifluoromethane		FC12	DICHLORODIFLUOROMETHANE	ORG
75-34-3	Dichloroethane, 1,1-	1,1 DCA	DCA11	1,1-DICHLOROETHANE	ORG
107-06-2	Dichloroethane, 1,2-	1, 2 DCA, EDC	DCA12	1,2-DICHLOROETHANE	ORG
156-59-2	Dichloroethene, cis-1,2-	1,2 cis DCE	DCE12C	cis-1,2-DICHLOROETHYLENE	ORG
156-60-5	Dichloroethene,1,2-trans-	1,2 trans DCE	DCE12T	trans-1,2-DICHLOROETHENE	ORG
75-09-2	Methylene chloride	Dichloromethane	MTLNCL	METHYLENE CHLORIDE	ORG
79-34-5	Tetrachloroethane, 1,1,2,2-		PCA	1,1,2,2-TETRACHLOROETHANE	ORG
127-18-4	Tetrachloroethene	PCE, Perc	PCE	TETRACHLOROETHYLENE(PCE)	ORG
120-82-1	Trichlorobenzene, 1,2,4-		TCB124	1,2,4-TRICHLOROBENZENE	ORG
71-55-6	Trichloroethane, 1,1,1-		TCA111	1,1,1-TRICHLOROETHANE	ORG
79-00-5	Trichloroethane, 1,1,2-	TCA	TCA112	1,1,2-TRICHLOROETHANE	ORG
79-01-6	Trichloroethene	TCE	TCE	TRICHLOROETHYLENE (TCE)	ORG
75-69-4	Trichlorofluoromethane		FC11	TRICHLOROFLUOROMETHANE	ORG
75-01-4	Vinyl chloride	VC	VC	VINYL CHLORIDE	ORG
PAH COMPOUNDS					
83-32-9	Acenaphthene		ACNP	ACENAPHTHENE	ORG
208-96-8	Acenaphthylene		ACNPY	ACENAPHTHYLENE	ORG
120-12-7	Anthracene		ANTH	ANTHRACENE	ORG
205-99-2	Benzo (b)Fluoranthene		BZBF	BENZO(b)FLUORANTHENE	ORG
191-24-2	Benzo (g,h,i)Perylene		BZGHIP	BENZO(g,h,i)PERYLENE	ORG

CAS Number	Constituent	Abreviation or Synonym	ERPIMS Code	MAROS Constituent Name	Constituent Type
207-08-9	Benzo (k) Fluoranthene		BZKF	BENZO(k)FLUORANTHENE	ORG
56-55-3	Benzo(a)Anthracene		BZAA	BENZO(a)ANTHRACENE	ORG
50-32-8	Benzo(a)Pyrene		BZAP	BENZO(a)PYRENE	ORG
218-01-9	Chrysene		CHRYSENE	CHRYSENE	ORG
53-70-3	Dibenzo(a,h) Anthracene		DBAHA	DIBENZ(a,h)ANTHRACENE	ORG
206-44-0	Fluoranthene		FLA	FLUORANTHENE	ORG
86-73-7	Fluorene		FL	FLUORENE	ORG
193-39-5	Indeno(1,2,3,c,d)Pyrene		INP123	INDENO(1,2,3-c,d)PYRENE	ORG
91-20-3	Naphthalene		NAPH	NAPHTHALENE	ORG
85-01-8	Phenanthrene		PHAN	PHENANTHRENE	ORG
129-00-0	Pyrene		PYR	PYRENE	ORG
OTHER COMPOUNDS					
67-64-1	Acetone		ACE	ACETONE	ORG
65-85-0	Benzoic acid		BZACID	BENZOIC ACID	ORG
71-36-3	Butanol, n-		BTOH	n-BUTANOL	ORG
75-15-0	Carbon disulfide		CDS	CARBON DISULFIDE	ORG
107-21-1	Ethylene glycol		ETEGLY	ETHYLENE GLYCOL	ORG
110-54-3	Hexane, n-		C6N	n-HEXANE	ORG
67-56-1	Methanol		MEOH	METHANOL	ORG
78-93-3	Methyl ethyl ketone	MEK	MEK	METHYL ETHYL KETONE (2-BUTANONE)	ORG
108-95-2	Phenol		PHENOL	PHENOL	ORG

APPENDIX A.2: STATISTICAL TREND ANALYSIS METHODS

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This appendix details the data evaluation and remedy selection procedures employed by the Monitoring and Remediation Optimization System (MAROS) Software. The procedures outlined below were developed to assess appropriate response measures for affected groundwater plumes based on scientifically sound quantitative analyses of current and historical site groundwater conditions.

Initial Site Investigation

Evaluation of groundwater plume conditions and appropriate response measures requires adequate site characterization, including plume delineation. Therefore, for the compliance monitoring evaluation, the minimum required site information includes:

- *Constituents of Concern (COCs):* Individual constituents must be identified along with their relevant source areas and transport mechanisms.
- *Site Hydrogeology:* Site stratigraphy and groundwater flow velocity and direction must be identified.
- *Affected Groundwater:* Plume must be completely delineated for each COC to ensure that the results of the compliance monitoring assessment are reliable and not erroneously influenced by a migrating plume.
- *Time-Series Groundwater Monitoring Data:* Historical record must be compiled for each COC and meet the minimum data requirements described below.
- *Actual and Potential Groundwater Receptors:* Well locations, groundwater-to-surface water discharge locations, underground utilities, or other points of exposure must be identified.
- *Current or Near-Term Impact?:* Any current or near-term receptor impact (defined for this evaluation as occurring in zero to two years) must be assessed. Plumes posing current or near-term impact on applicable receptors are referred for immediate evaluation of appropriate risk management measures.

Site Conceptual Model

The EPA recommends the use of conceptual site models to integrate data and guide both investigative and remedial actions (e.g., see EPA, 1999). A conceptual site model (CSM) is a three-dimensional representation that conveys what is known or suspected about contamination sources, release mechanisms, and the transport and fate of those contaminants. The conceptual model provides the basis for assessing potential remedial technologies at the site. In the context of the MAROS software, conceptual model development prior to software use would allow the user to better utilize the information gained through the various software modules as well as provide guidance for assessing the data that would best typify historical site conditions.

It is recommended that available site characterization data should be used to develop a conceptual model for the site prior to the use of the MAROS software. The conceptual model should include a three-dimensional representation of the source area as a NAPL or region of highly contaminated ground water, of the surrounding uncontaminated area, of ground water flow properties, and of the solute transport system based on available geological, biological, geochemical, hydrological, climatological, and analytical data for the site (EPA, 1998). Data on the contaminant levels and aquifer characteristics should be obtained from wells and boreholes which will provide a clear three-dimensional picture of the hydrologic and geochemical characteristics of the site. High concentrations of dissolved contaminants can be the result of leachates, rinse waters and rupture of water conveyance lines, and are not necessarily associated with NAPLs.

This type of conceptual model differs from the more generic conceptual site models commonly used by risk assessors that qualitatively consider the location of contaminant sources, release mechanisms, transport pathways, exposure points, and receptors. However, the conceptual model of the ground water system facilitates identification of these risk-assessment elements for the exposure pathways analysis. After development, the conceptual model can be used to help determine optimal placement of additional data collection points, as necessary, to aid in the natural attenuation investigation and to develop the solute fate and transport model. Contracting and management controls must be flexible enough to allow for the potential for revisions to the conceptual model and thus the data collection effort.

Successful conceptual model development involves (EPA, 1998):

- Definition of the problem to be solved (generally the three dimensional nature, magnitude, and extent of existing and future contamination).
- Identification of the core or cores of the plume in three dimensions. The core or cores contain the highest concentration of contaminants.
- Integration and presentation of available data, including:
    - Local geologic and topographic maps,
    - Geologic data,
    - Hydraulic data,
    - Biological data,
    - Geochemical data, and
    - Contaminant concentration and distribution data.
- Determination of additional data requirements, including:
    - Vertical profiling locations, boring locations and monitoring well spacing in three dimensions,
    - A sampling and analysis plan (SAP), and
    - Other data requirements.

Conceptual model development prior to use of the MAROS software will allow more accurate site evaluation through quality data input (i.e. identification of source and tail wells, etc.), as well as viewing the MAROS results in light of site-specific conditions. The conceptual model will also allow the user to gain insight into the type and extent of site data that is needed to fulfill minimum data requirements in order to fully utilize the MAROS software.

Minimum Data Requirements

Compliance Monitoring data evaluation must be based on data from a consistent set of wells over a series of periodic sampling events. Statistical validity of the constituent trend analysis requires constraints on the minimum data input. To ensure a meaningful comparison of COC concentrations over time and space, the following minimum requirements were imposed on the time-series groundwater monitoring data:

- *Number of Wells:* Evaluation should include data from at least four wells (ASTM , 1998) in which COCs have been detected. May include up to two wells which have not exhibited COCs during more recent sampling events being analyzed, but in which COCs were previously detected. As many wells should be included in the evaluation as possible, subject to the other minimum data requirements.
- *Minimum Data per Well:* Data for each well should include at least four measured concentrations over six sampling events during the time period being analyzed. For any well, data may not be missing from more than two consecutive sampling events. Guidelines given by ASTM, 1998 notes that a minimum of more than one year of quarterly monitoring data of 4 or 5 wells is needed to establish a trend.
- *Number of Sampling Events:* Evaluation should include at least six most-recent sampling events which satisfy the minimum groundwater data requirements specified above. For this evaluation, it is suggested that the user consolidate multiple sampling dates within a single quarter to consider them to be a single sampling event, with multiple measurements of the same constituent subject to a user defined consolidation (e.g. average). The sampling events do not need to be the same for each well.

Sufficient Data: At least four wells with four or more independent sampling events per well are available

Insufficient Data: Fewer than four wells or fewer than 4 independent sampling events per well are available.

Although the software will calculate trends for fewer than four wells and a minimum of 4 sampling events, the above criteria will ensure a meaningful evaluation of COC trends over time. The minimum requirements described would apply only to “well behaved” sites, for most sites more data is required to obtain an accurate representation of COC trends. Sites with significant variability in groundwater monitoring data (due to water table fluctuation, variations in groundwater flow direction, etc.) will require more data to obtain meaningful stability trends. Essentially, the plume you are evaluating should be delineated with adequate consecutive sampling data to accurately evaluate the concentration trend with time.

Plume Stability Analysis

Confirmation of the effective performance of monitored natural attenuation as a stand-alone remedial measure requires the demonstration of *primary lines of evidence,* i.e., actual measurement of stable or shrinking plume conditions based on evaluation of historical groundwater monitoring data. For a delineated plume, a stable or shrinking condition can be identified by a stable or decreasing concentration trends over time. For this analysis, an overall plume condition was determined for each COC based on a statistical trend analysis of concentrations at each well, as described below.

STATISTICAL TREND ANALYSIS: CONCENTRATION VS. TIME

Under optimal conditions, the natural attenuation of organic COCs at any site is expected to approximate a first-order exponential decay for compliance monitoring groundwater data. With actual site measurements, apparent concentration trends may often be obscured by data scatter arising from non-ideal hydrogeologic conditions, sampling and analysis conditions. However, even though the scatter may be of such magnitude as to yield a poor goodness of fit (typically characterized by a low correlation coefficient, e.g., $R^2 \ll 1$) for the first-order relationship, parametric and nonparametric methods can be utilized to obtain *confidence intervals* on the estimated first-order coefficient, i.e., the slope of the log-transformed data.

Nonparametric tests such as the Mann-Kendall test for trend are suitable for analyzing data that do not follow a normal distribution. Nonparametric methods focus on the location of the probability distribution of the sampled population, rather than specific parameters of the population. The outcome of the test is not determined by the overall magnitude of the data points, but depends on the ranking of individual data points. Assumptions on the distribution of the data are not necessary for nonparametric tests. The Mann-Kendall test for trend is a nonparametric test which has no distributional assumptions and irregularly spaced measurement periods are permitted. The advantage gained by this approach involves the cases where outliers in the data would produce biased estimates of the least squares estimated slope. Parametric tests such as first-order regression analysis make assumptions on the normality of the data distribution, allowing results to be affected by outliers in the data in some cases. However, the advantage of parametric methods involve more accurate trend assessments result from data where there is a normal distribution of the residuals. Therefore, when the data is normally distributed the nonparametric method, the Mann-Kendall test, is not as efficient. Both tests are utilized in the MAROS software.

Primary Line of Evidence 1: Mann-Kendall Analysis

GENERAL

The Mann-Kendall test is a non-parametric statistical procedure that is well suited for analyzing trends in data over time (Gilbert, 1987). The Mann-Kendall test can be viewed as a nonparametric test for zero slope of the first-order regression of time-ordered concentration data versus time. The AFCEE MAROS Tool includes this test to assist in the analysis of groundwater plume stability. The Mann-Kendall test does not require any assumptions as to the statistical distribution of the data (e.g. normal, lognormal, etc.) and can be used with data sets which include irregular sampling intervals and missing data. The Mann-Kendall test is designed for analyzing a single groundwater constituent, multiple constituents are analyzed separately.

For this evaluation, a decision matrix was used to determine the “Concentration Trend” category for each well, as presented on Table 2.

MANN-KENDALL STATISTIC (S)

The Mann-Kendall statistic (S) measures the trend in the data. Positive values indicate an increase in constituent concentrations over time, whereas negative values indicate a decrease in constituent concentrations over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend).

Data for performing the Mann-Kendall Analysis should be in time sequential order. The first step is to determine the sign of the difference between consecutive sample results. $\mathrm{Sgn}(x_j - x_k)$ is an indicator function that results in the values 1, 0, or –1 according to the sign of $x_j - x_k$ where $j > k$, the function is calculated as follows

$$\operatorname{sgn}(x_j - x_k) = 1 \qquad \text{if } x_j - x_k > 0$$

$$\operatorname{sgn}(x_j - x_k) = 0 \qquad \text{if } x_j - x_k = 0$$

$$\operatorname{sgn}(x_j - x_k) = -1 \qquad \text{if } x_j - x_k < 0$$

The Mann-Kendall statistic (S) is defined as the sum of the number of positive differences minus the number of negative differences or

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_j - x_k\right).$$

The ***confidence in the trend*** for the Mann-Kendall statistic is calculated using a Kendall probability table (e.g. Hollander, M. and Wolfe, D.A., 1973, incorporated into the software). By assessing the S result along with the number of samples, n, the Kendall table provides the probability of rejecting the null hypothesis (H_0 = no trend) for a given level of significance. MAROS calculates a 'confidence level' percentage by subtracting the probability from 1. Confidence of 90% represents a significance level of $\alpha = 0.1$ and 95% corresponds to $\alpha = 0.05$. The resulting confidence in the trend is applied in the Mann Kendall trend analysis as outlined in Table A.2.1. The Mann-Kendall test used in MAROS is limited to 40 sample events.

AVERAGE

The arithmetic mean of a sample of n values of a variable is the average of all the sample values written as

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

STANDARD DEVIATION

The standard deviation is the square root of the average of the square of the deviations from the sample mean written as

$$s = \sqrt{\frac{\sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2}{n-1}}\,.$$

The standard deviation is a measure of how the value fluctuates about the arithmetic mean of the data.

COEFFICIENT OF VARIATION (COV)

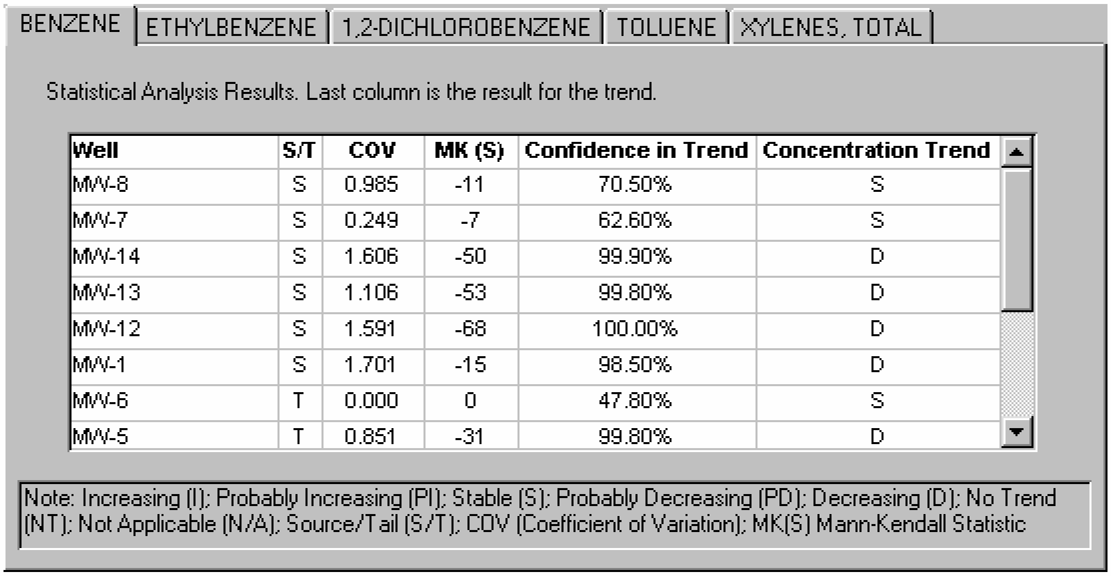
The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. The coefficient of variation, defined as the standard deviation divided by the average or

$$C.O.V. = \frac{s}{x}$$

Values less than or near 1.00 indicate that the data form a relatively close group about the mean value. Values larger than 1.00 indicate that the data show a greater degree of scatter about the mean.

RESULTS AND INTERPRETATION OF RESULTS: MANN-KENDALL ANALYSIS

The Constituent Trend Analysis results are presented in the *Mann-Kendall Analysis* Screen (accessed from the *Plume Analysis Menu*). The software uses the input data to calculate the Coefficient of Variation (COV) and the Mann-Kendall statistic (S) for each well with at least four sampling events (see Figure A.2.1). A "Concentration Trend" and "Confidence in Trend" are reported for each well with at least four sampling events. If there is insufficient data for the well trend analysis, N/A (Not Applicable) will be displayed in the "Concentration Trend" column.



Statistical Analysis Results. Last column is the result for the trend.

Well	S/T	COV	MK (S)	Confidence in Trend	Concentration Trend
MW-8	S	0.985	-11	70.50%	S
MW-7	S	0.249	-7	62.60%	S
MW-14	S	1.606	-50	99.90%	D
MW-13	S	1.106	-53	99.80%	D
MW-12	S	1.591	-68	100.00%	D
MW-1	S	1.701	-15	98.50%	D
MW-6	T	0.000	0	47.80%	S
MW-5	T	0.851	-31	99.80%	D

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T); COV (Coefficient of Variation); MK(S) Mann-Kendall Statistic

FIGURE A.2.1 MANN-KENDALL ANALYSIS RESULTS

- The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. Values less than or near 1.00 indicate that the data form a relatively close group about the mean value. Values larger than 1.00 indicate that the data show a greater degree of scatter about the mean.
- The Mann-Kendall statistic (MK (S) measures the trend in the data. Positive values indicate an increase in constituent concentrations over time, whereas negative values indicate a decrease in constituent concentrations over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend).
- The "Confidence in Trend" is the statistical probability that the constituent concentration is increasing ($S>0$) or decreasing ($S<0$).
- The "Concentration Trend" for each well is determined according to the following rules, where COV is the coefficient of variation:

TABLE A.2.1 MAROS MANN-KENDALL ANALYSIS DECISION MATRIX

Mann-Kendall Statistic	Confidence in Trend	Concentration Trend
$S > 0$	> 95%	Increasing
$S > 0$	90 - 95%	Probably Increasing
$S > 0$	< 90%	No Trend
$S \leq 0$	< 90% and COV ≥ 1	No Trend
$S \leq 0$	< 90% and COV < 1	Stable
$S < 0$	90 - 95%	Probably Decreasing
$S < 0$	95%	Decreasing

The MAROS Mann-Kendall Analysis Decision Matrix was developed in-house by Groundwater Services Inc. Strongly Increasing or Decreasing trends indicate a higher level of statistical significance. The confidence can be used as a qualitative measure of the statistical strength of the trend when evaluating the overall stability of the plume. The user can choose not to apply one of the two statistical plume analysis decision matrices. Choose "Not Used" in the Trend Result weighting screen. If the user would like to use another decision matrix to determine stability of the plume, they would need to do this outside the software.

Statistical Plume Analysis 2: Linear Regression Analysis

GENERAL

Linear Regression is a parametric statistical procedure that is typically used for analyzing trends in data over time. However, with the usual approach of interpreting the log slope of the regression line, concentration trends may often be obscured by data scatter arising from non-ideal hydrogeologic conditions, sampling and analysis conditions, etc. Even though the scatter may be of such magnitude as to yield a poor goodness of fit (typically characterized by a low correlation coefficient, e.g., $R^2 \ll 1$) for the first-order relationship, *confidence intervals* can nonetheless be constructed on the estimated first-order coefficient, i.e., the slope of the log-transformed data. Using this type of analysis, a higher degree of scatter simply corresponds to a wider confidence interval about the average log-slope. Assuming the *sign* (i.e., positive or negative) of the estimated log-slope is correct, a level of confidence that the slope is not zero can be easily determined. Thus, despite a poor goodness of fit, the overall *trend* in the data may still be ascertained, where low levels of confidence correspond to "Stable" or "No Trend" conditions (depending on the degree of scatter) and higher levels of confidence indicate the stronger likelihood of a trend. The coefficient of variation, defined as the standard deviation divided by the average, is used as a secondary measure of scatter to distinguish between "Stable" or "No Trend" conditions for negative slopes. The Linear Regression Analysis is designed for analyzing a single groundwater constituent, multiple constituents are analyzed separately. The MAROS software includes this test to assist in the analysis of groundwater plume stability.

For this evaluation, a decision matrix was used to determine the "Concentration Trend" category for each well, as presented on Table A.2.2.

LINEAR REGRESSION

The objective of linear regression analysis is to find the trend in the data through the estimation of the log slope as well as placing confidence limits on the log slope of the trend. Regression begins with the specification of a model to be fitted. A linear relationship is one expressed by a linear equation. The Linear Regression analysis in MAROS is performed on Ln (COC Concentration) versus Time. The regression model assumes that for a fixed value of x (sample date) the expected value of y (log COC concentration) is some function. For a particular value, x_i or sample date the predicted value for y (log COC concentration) is given by

$$\hat{y}_i = a + bx_i \, .$$

The fit of the predicted values to the observed values (x_i, y_i) are summarized by the difference between the observed value y_i and the predicted value $\hat{y}_i$ (the residual value.) A reasonable fit to the line is found by making the residual values as small as possible. The method of least squares is used to obtain estimates of the model parameters (a, b) that minimize the sum of the squared residuals, S^2 or the measure of the distance between the estimate and the values we want to predict (the y's).

$$S^2 = \sum_{i=1}^{n} \left(y_i - \hat{y}_i \right)^2$$

The values for the intercept (a) and the slope (b) of the line that minimize the sum of the squared residuals (S^2), are given by

$$b = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \qquad \text{and} \qquad a = \bar{y} - b\bar{x}$$

where $\bar{x}$ and $\bar{y}$ are the mean x and y (log COC concentration) values in the dataset.

In order to test the confidence on the regression trend, there is a need to place confidence limits on the slope of the regression line. In this stage of the trend analysis, it is assumed that for each x value, the y-distribution is normal. A t-test may be used to test that the true slope is different from zero. This t-test is preferentially used on data that is not serially correlated or seasonally cyclic or skewed.

The variance of y_i (σ^2) is estimated by the quantity $S_{y.x}^2$ where this quantity is defined as

$$S_{y|x}^2 = \frac{\sum_{i-1}^{n} (y_i - \hat{y}_i)^2}{n-2}$$

where n is the number of samples.

The estimation of the standard deviation or standard error of the slope (s.e.b.) is defined as

$$s.e.b. = \sqrt{\frac{S_{y|x}^{2}}{\sum_{i-1}^{n}\left(x_i - \bar{x}_i\right)^2}}\ .$$

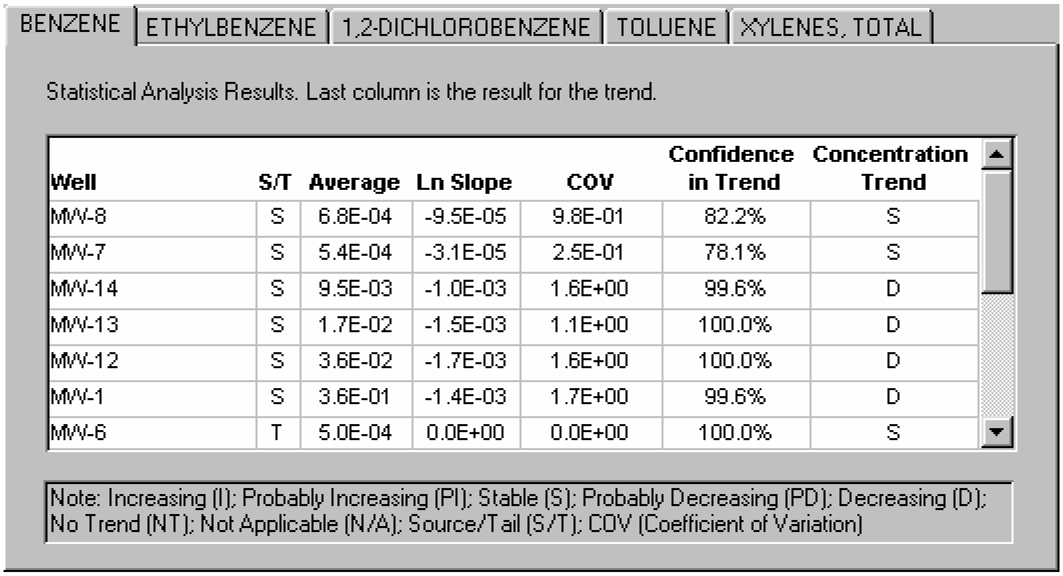
To test significance of the slope calculated, the following t-test result can be used to find the confidence interval for the slope.

$$t = \frac{b}{s.e.b.}$$

The t result along with the degrees of freedom (n-2) are used to find the confidence in the trend by utilizing a t-distribution table found in most statistical textbooks (e.g. Fisher, L.D. and van Belle, G., 1993). The resulting confidence in the trend is utilized in the linear regression trend analysis as outlined in Table A.2.2.

RESULTS AND INTERPRETATION OF RESULTS: LINEAR REGRESSION ANALYSIS

The Constituent Trend Analysis Results are presented in the Linear Regression Analysis Screen (accessed from the Mann-Kendall Analysis screen). The software uses the input data to calculate the Coefficient of Variation (COV) and the first-order coefficient (Ln Slope) for each well with at least four sampling events. A "Concentration Trend" and "Confidence in Trend" are reported for each well with at least four sampling events. If there is insufficient data for the well trend analysis, N/A (Not Applicable) will be displayed in the "Concentration Trend" column (Figure A.2.2)



Statistical Analysis Results. Last column is the result for the trend.

Well	S/T	Average	Ln Slope	COV	Confidence in Trend	Concentration Trend
MW-8	S	6.8E-04	-9.5E-05	9.8E-01	82.2%	S
MW-7	S	5.4E-04	-3.1E-05	2.5E-01	78.1%	S
MW-14	S	9.5E-03	-1.0E-03	1.6E+00	99.6%	D
MW-13	S	1.7E-02	-1.5E-03	1.1E+00	100.0%	D
MW-12	S	3.6E-02	-1.7E-03	1.6E+00	100.0%	D
MW-1	S	3.6E-01	-1.4E-03	1.7E+00	99.6%	D
MW-6	T	5.0E-04	0.0E+00	0.0E+00	100.0%	S

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T); COV (Coefficient of Variation)

FIGURE A.2.2 LINEAR REGRESSION ANALYSIS RESULTS

- The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. Values less than or near 1.00 indicate that the data form a relatively close group about the mean value. Values larger than 1.00 indicate that the data show a greater degree of scatter about the mean.

- The Log Slope (Ln Slope) measures the trend in the data. Positive values indicate an increase in constituent concentrations over time, whereas negative values indicate a decrease in constituent concentrations over time.
- The "Confidence in Trend" is the statistical probability that the constituent concentration is increasing (ln slope>0) or decreasing (ln slope<0).
- The "Concentration Trend" for each well is determined according to the following rules, where COV is the coefficient of variation:

TABLE A.2.2 MAROS LINEAR REGRESSION ANALYSIS DECISION MATRIX

Confidence in Trend	**Ln Slope**	
	Positive	**Negative**
<90%	No Trend	*COV < 1* Stable *COV > 1* No Trend
90% – 95%	Probably Increasing	Probably Decreasing
> 95%	Increasing	Decreasing

COV = Coefficient of Variation

The MAROS Linear Regression Analysis Decision Matrix was developed in-house by Groundwater Services Inc. The user can choose not to apply one of the two statistical plume analysis decision matrices. Choose "Not Used" in the Trend Results weighting screen. If the user would like to use another decision matrix to determine stability of the plume, they would need to do this outside the software.

Further Considerations

The results of a constituent concentration trend analysis form just one component of a plume stability analysis. Additional considerations in determining the over-all plume stability include:

- Multiple constituent concentration trend analyses;
- Time-frame over which the trend is evaluated;
- Adequate delineation of the plume;
- Status of the COC as a parent or daughter product;
- Proximity of monitoring wells with stable or decreasing constituent trends to the downgradient edge of the plume.

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APPENDIX A.3 — WELL REDUNDANCY/SUFFICIENCY ANALYSIS: DELAUNAY METHOD

Authors: Ling, M. and Rifai, H. S., University of Houston.

This appendix introduces the approach used in MAROS for well sufficiency analysis, the Delaunay method. The Delaunay method is designed to select the minimum number of sampling locations based on the spatial analysis of the relative importance of each sampling location in the monitoring network. The approach allows elimination of sampling locations that have little impact on the historical characterization of a contaminant plume. A well sufficiency analysis method (i.e., recommend new locations) based on the Delaunay method is also introduced.

Method Description

The Delaunay method is developed based on Delaunay triangulation, which is the triangulation of a point set with the property that no point in the point set falls in the interior of the circumcircle of any triangle in the triangulation. As seen in Figure A.3.1, all nodes (potential well locations) are joined by the blue lines, which form the edges of Delaunay triangles. The yellow lines form many polygons called Thiessen polygons or Voronoi diagrams, which are the dual parts of Delaunay triangles.

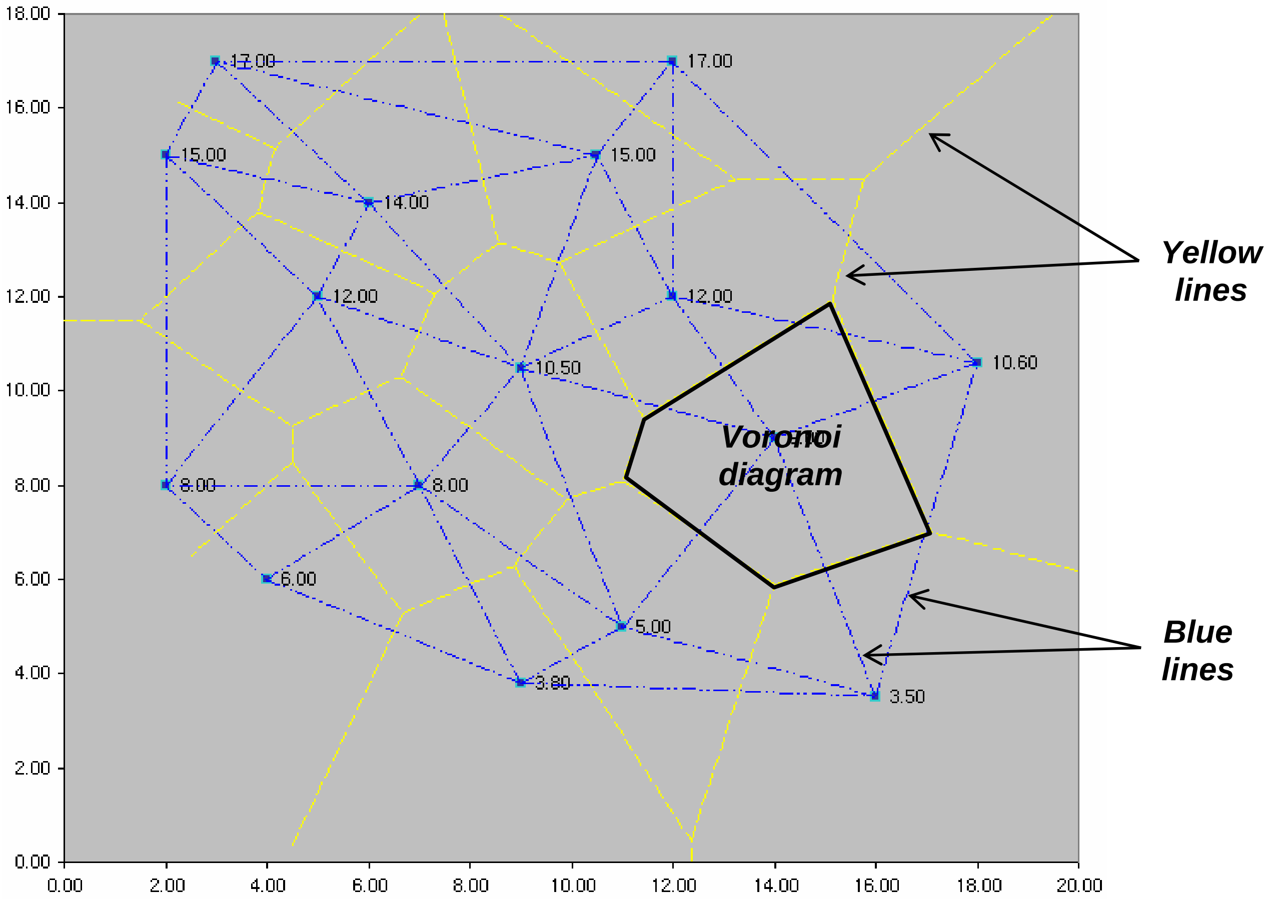


Figure A.3.1 Illustration of the Delaunay Triangulation

Delaunay triangles and Voronoi diagrams have been widely used for centuries for solving spatial distribution problems (Okabe et al. 1992, Watson 1994). In MAROS, Delaunay triangulation is first used to generate a grid for the studied site with potential sampling locations as its nodes. Then based on the formation of Delaunay triangles and Voronoi diagrams, spatial analyses are made to determine the relative importance of each sampling location. Finally, spatial-redundant locations are eliminated from the monitoring network.

To determine the relative importance of sample locations in the monitoring network, we define a *Slope Factor* (SF) for each potential location. The SF provides a measure of the importance of the information supplied by each sample location. Generally speaking, the SF is defined as the standardized difference between the concentration measured at a location and a concentration estimated from concentrations at its nearest neighbors.

The spatial distribution of groundwater quality data tends to follow lognormal distribution, but variance in the time-series data can be large due to artifacts of sampling and analysis and other issues. Using logarithmic scale of the concentrations smooths variance in the data, creating a more stationary data set. Using logarithmic transformations of the concentrations for estimating the average plume concentration were seen in some studies (Rice et al. 1995; Mace et al. 1997).

To be consistent, the SF calculation in MAROS is thus based on the logarithmic scale of the concentrations. In order to avoid performing calculations with negative values, concentration data is multiplied by a scaling factor (usually 10, 100 or 1000) before log transformation. The scaling factor is determined automatically in the software and is based on the magnitude of the minimum concentration result. In this way, all values are > 0 before log transformation. The following steps are used to calculate SF.

1) For a given node N_0, find its natural neighbors N_i, i.e., the set of nodes that are directly connected to this node by an edge of a Delaunay triangle (Figure A.3.2).

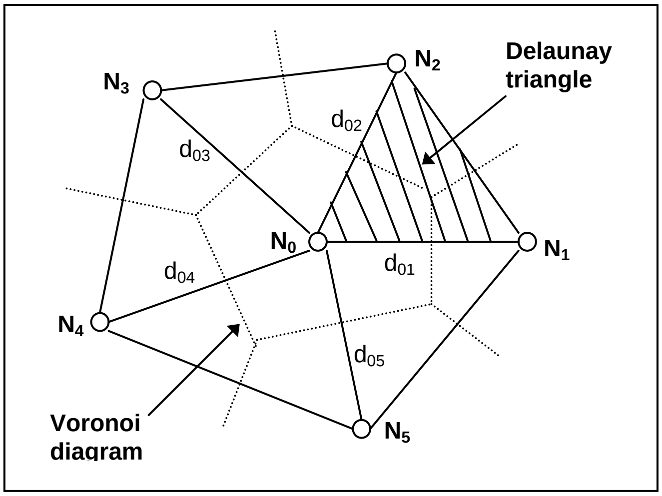


Figure A.3.2 Illustration of Natural Neighbors

2) The estimated logarithmic concentration, $EC_{0,}$ of node N_0 is computed as the inverse-distance-weighted average of logarithmic concentrations of its natural neighbors:

$$EC_0 = \sum_{i=1}^{n}\left(NC_i \cdot \frac{1}{d_{oi}}\right) \Bigg/ \sum_{i=1}^{n}\frac{1}{d_{oi}}$$

where:

n = number of natural neighbors
NC_i = measured concentration in logarithmic scale at node N_i, $i = 1, 2, \ldots, n$
d_{0i} = distance between node N_0 and its natural neighbor N_i

3) The SF is then calculated as:

$$SF = \left|\frac{EC_0 - NC_0}{Max(EC_0, NC_0)}\right|$$

where:

EC_0 = *estimated logarithmic concentration at node N0*
NC_0 = *measured concentration in logarithmic scale at node N0*

The magnitude of SF ranges from 0 to 1 (not including 1). Value 0 means that the concentration at a location can be exactly estimated by its surrounding locations, thus, sampling at this location provides no extra information influencing understanding of the plume. A value larger than '0' indicates the existence of estimation error. The larger is the estimation error, the larger the discrepancy would be between the estimated concentration and the measured concentration at a sampling location. SF values close to 1 indicate that the location provides unique information. Consequently, it is reasonable to keep sampling the location so that the plume can be better defined. In summary, the larger the SF value of a location is, the more important the location and vice versa.

One objective in spatial sampling is to accurately map a contaminant plume and track changes in this plume over time. It is clear that with more monitoring wells this objective can be achieved with a higher degree of accuracy. Unfortunately, there is always a trade-off between degree of accuracy and budget. The limitation of resources forces us to find a way to use as few monitoring wells as possible as far as certain degree of accuracy can be kept (no significant information loss).

To ensure that the elimination of sampling locations from a monitoring network will not cause significant information loss, two indicators are developed to measure the information loss. One is Average Concentration Ratio (CR) and the other is Area Ratio (AR), which are defined as:

$$CR = \frac{C_{avr,Current}}{C_{avr,Original}} \qquad AR = \frac{A_{Current}}{A_{Original}}$$

where:

$C_{avr,Current}$ = average plume concentration estimated after elimination of locations in the current step of optimization

$C_{avr,Original}$ = average plume concentration estimated from the potential locations (original network before elimination of any locations)

$A_{Current}$ = Triangulation area based on locations after elimination of locations in the current step of optimization

$A_{Original}$ = Triangulation area based on potential locations before any optimization (original network before elimination of any locations)

The average plume concentration is taken as the area-weighted average of the average concentrations of all Delaunay triangles:

$$C_{avr} = \sum_{i=1}^{N} TC_i \cdot TA_i \bigg/ \sum_{i=1}^{N} TA_i$$

where:

N = number of all Delaunay triangles in the triangulation

TA_j = area of each Delaunay triangle, $i = 1, 2, \ldots, N$

TC_i = average concentration of each Delaunay triangle, $i = 1, 2, \ldots, N$

TC_i is computed as (refer to Figure A.3.3):

$$TC_i = \frac{NC_1 \cdot A_1 + NC_2 \cdot A_2 + NC_3 \cdot A_3}{A_1 + A_2 + A_3}$$

where:

NC_1 = logarithmic concentration at vertex N_1

NC_2 = logarithmic concentration at vertex N_2

NC_3 = logarithmic concentration at vertex N_3

A_1 = *Area of sub-part* A_1

A_2 = *Area of sub-part* A_2

A_3 = *Area of sub-part* A_3

After elimination of "unimportant" locations (those with smallest SF values), the estimation of average plume concentration and triangulation area might be affected. By judging the values of CR and AR, information loss can be evaluated. CR and AR values close to 1 indicate that the information about the plume after elimination of locations is well kept. CR and AR values close to 0 represent a large estimation discrepancy and thus indicate greater information loss. By setting the acceptable level of information loss, we can judge when to stop eliminating locations.

Those eliminated locations are called "redundant" locations and the rest of potential locations are non-redundant ones and should be kept. An interpretation of the elimination decision process is given in Figure A.3.4.

The optimization process is iterative. It starts by eliminating the location(s) with smallest SF value(s), followed by a check of information loss. If information loss is not significant (within the acceptable range specified by the user), the process repeats until significant information loss happens.

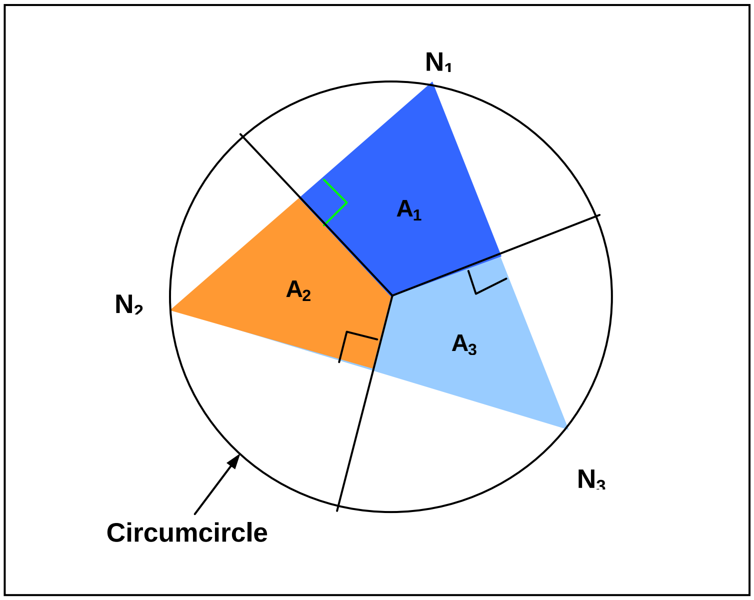
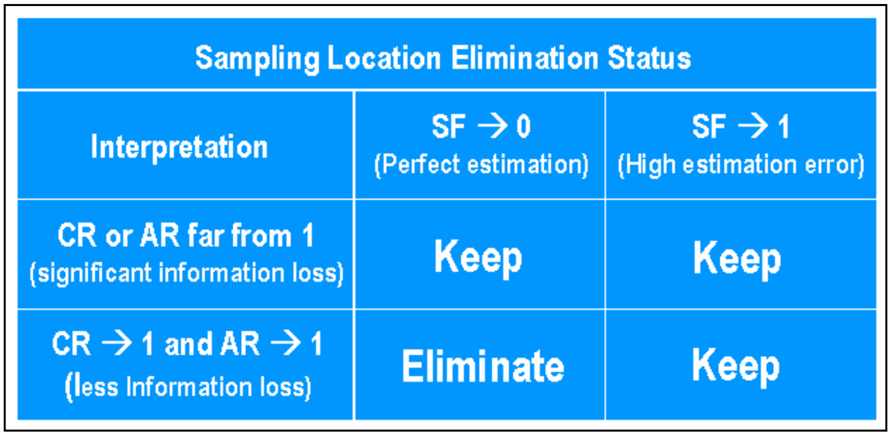


Figure A.3.3 Division of a Delaunay Triangle

Two kinds of thresholds are defined to judge whether or not to 1) eliminate a location or 2) to terminate the optimization. The SF threshold is defined for the first purpose. For example, if the SF threshold for all nodes is 0.10, those nodes with SF values less than 0.10 are potential nodes to be eliminated. CR and AR thresholds are defined for the second purpose. For example, if CR threshold is 0.95, elimination of locations is valid if the CR value is greater than 0.95. In this case, the acceptable level of information loss is 1 - 0.95 = 0.05, that is, 5%. If the CR value is less than 0.95, the optimization should be terminated and the locations eliminated at this step should be re-instated. Details about these thresholds will be discussed shortly.



Sampling Location Elimination Status		
Interpretation	SF → 0 (Perfect estimation)	SF → 1 (High estimation error)
CR or AR far from 1 (significant information loss)	Keep	Keep
CR → 1 and AR → 1 (less Information loss)	Eliminate	Keep

Figure A.3.4 Decision Process of the Elimination of a Location

Optimization Parameters

The User has the option of choosing the threshold levels for the SF and the area and concentration ratios. More detailed descriptions of the threshold parameters are discussed below. Choice of the parameter values should reflect what the User considers to be an acceptable level of information loss. Parameters should be determined after consideration of the overall monitoring objectives for the network.

Inside node Slope Factor: The SF threshold for nodes (locations) located inside the triangulation domain. When SF of an inside node is less than this threshold, and if the node is *Removable*, it will be eliminated from the monitoring network. The current default value for this parameter is 0.1. *Removable* stands for the elimination property of a location. If the *Removable* property of a location is False, optimization cannot eliminate it no matter how small its SF value is. This is important if you want to keep a location (e.g., a POC well) in the monitoring network. The default values for all potential locations are True.

Hull node Slope Factor: The SF threshold for nodes (locations) located on the edge (convex hull) of the triangulation domain. When SF of a hull node is less than this threshold, and if the node is *Removable*, it will be eliminated from the monitoring network. The current default value for this parameter is 0.01. The threshold for hull node is usually more stringent than that of the inside node, because the elimination of a hull node may cause reduction in the triangulation area, thereby causing greater information loss (reduction in AR). For contrast, the elimination of an inside node will only affect the average concentration ratio (CR).

Area Ratio (AR): The ratio of triangulation area (represents the area of a contaminant plume) at current optimization step to the original triangulation area before optimization. If the AR value in an optimization step is less than the threshold, the optimization will be stopped and locations eliminated in this step will be resumed. The default value is 0.95.

Concentration Ratio (CR): The ratio of average concentration of a contaminant plume at current optimization step to that of the original value before optimization. If the CR value in an optimization step is less than the threshold, the optimization will be stopped and locations eliminated in this step will be resumed. The default value is 0.95.

For the setting of these parameters, the user is referred to the corresponding parts in chapter *MAROS Detailed Screen Descriptions*.

Choice of Sampling Events

The Delaunay method performs the redundancy reduction by using an algorithm that considers all or a series of sampling events, of which optimization based on a single sampling event is a special case. Since each sampling event represents only one snapshot of the contaminant plume, we need to examine all sampling events (or parts of them) to reveal the general spatial pattern of the contaminant distribution in a specific site. This general spatial pattern is the underlying assumption for the spatial analysis. In the Delaunay method, we find the general pattern by averaging across sampling events. In addition, since the spatial patterns of COCs may be different from each other, the optimization is performed based on each COC. Therefore, results are given separately in terms of each COC. Finally, we provide the all-in-one results simply by considering the most conservative result from all COCs. The major steps of this algorithm are as follows:

1) Select a series of continuous sampling events for analysis. They could be all sampling events in the monitoring history. They could also be any segment of sampling events in the monitoring history, e.g., sampling events in the past five years.
2) Calculate SF values of potential locations for all sampling events selected by the users, and for each COC.
3) Average SF values of potential locations across the selected sampling events for each COC, weighted by the number of locations contained in each sampling event. The results are lumped SF values of potential locations for each COC.
4) Eliminate one location at a step from each COC starting from the location with smallest lumped SF value. Calculate CR and AR ratios for each sampling event and then average them across sampling events to provide sampling-events-averaged CR and AR values. Compare sampling-events-averaged CR or AR values to thresholds and if there is no significant information loss, repeat this step with the next available location.
5) Provide the COC-categorized results after eliminating all redundant locations from each COC. In this step, elimination of a location in a COC means to stop sampling for that COC at that well in the next round of sampling.
6) Provide the all-in-one results by eliminating only those locations that are eliminated from all COCs. Here elimination of a location is equivalent to abandoning it, i.e., to stop service of a well since no COC needs to be sampled at this well any more.

The user can also choose to analyze only one sampling event, e.g., the latest sampling event. In this case, the step of averaging across sampling events is skipped. Figure A.3.5 shows the detailed procedures of optimization in this simplified process.

In MAROS, two modules are developed based on the Delaunay Method. One is the *Access Module* starting with screen *Well Redundancy Analysis: Delaunay Method*, which is introduced in the chapter *MAROS Detailed Screen Descriptions*. The other one is the *Excel Module – xlsDelaunay2K*, which is a stand alone Microsoft Excel Worksheet, also discussed in chapter *MAROS Detailed Screen Descriptions*. The *Access Module* is designed to deal with multi-sampling-events analyses recognizing that a general spatial pattern may lie beneath what are revealed by each single sampling event. It can also be used to analyze a single sampling event, a special case of the multi-sampling-events analyses. The *Excel Module* is designed for one-sampling-event analyses, which provides the user with graphical interface and convenient controls to the optimization process, making the process of the Delaunay method better understood.

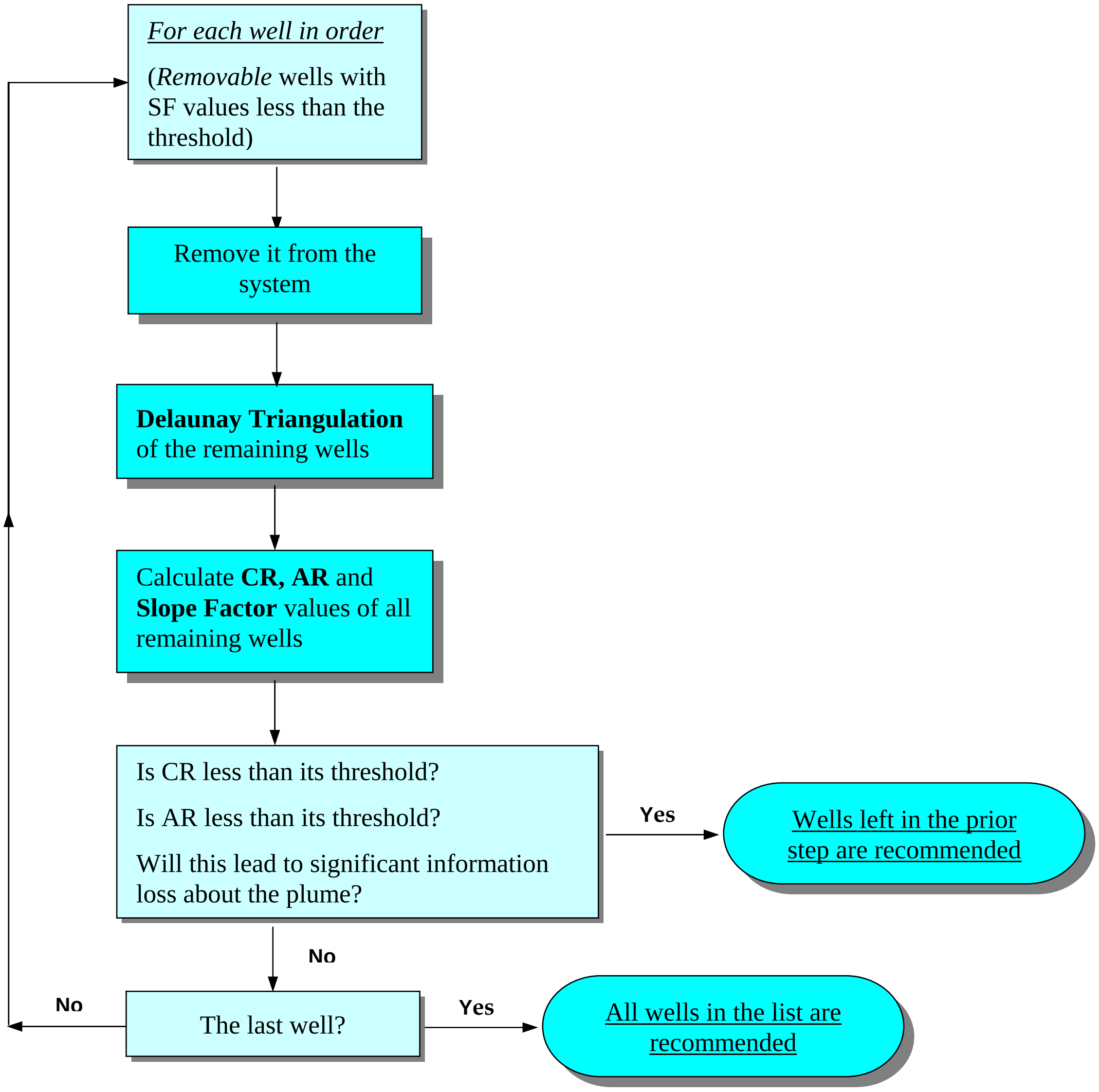


Figure A.3.5 Steps in Sampling Location Optiomization for One Sampling Event

Well Sufficiency Analysis

Augmentation of a monitoring network is needed when the existing network cannot achieve certain monitoring goals. Augmentation in this document means the addition of sampling locations and/or more frequent sampling. In this section, a method for determining new sampling locations is introduced, which is intended to enhance the spatial plume characterization. This method utilizes the SF values obtained from the previous analysis to assess the concentration estimation error or uncertainty in areas within the network. Among these potential areas, those with a high estimation error may be designated as regions for new sampling locations or increased monitoring intensity.

Conceptually, the method is to overlay a grid onto the study area and interpolate the SF values at existing sampling locations to grid cells that do not contain sampling locations. These grid cells serve as potential areas for new sampling locations. Those areas with a high estimated SF value (i.e., high estimation error) are therefore candidate regions for new sampling locations. This approach is further simplified in MAROS in order to adapt to the visualization limitations of Microsoft Access and Excel. In the simplified approach, Each Delaunay triangle in the triangulated monitoring network is used as a potential area for new sampling locations (Figure A.3.7).

The SF value at a Delaunay triangle is estimated as follows. Consider a Delaunay triangle with vertices N_1, N_2, and N_3 (Figure A.3.6). Assume A_1, A_2, and A_3 are sub-parts of the triangle divided based on the centroid of the triangle. The average SF value for this triangle is estimated as:

$$SF_{Avg} = \frac{SF_1 \cdot A_1 + SF_2 \cdot A_2 + SF_3 \cdot A_3}{A_1 + A_2 + A_3}$$

where:

SF_1 = the sampling-events-averaged SF value at vertex N_1

SF_2 = the sampling-events-averaged SF value at vertex N_2

SF_3 = the sampling-events-averaged SF value at vertex N_3

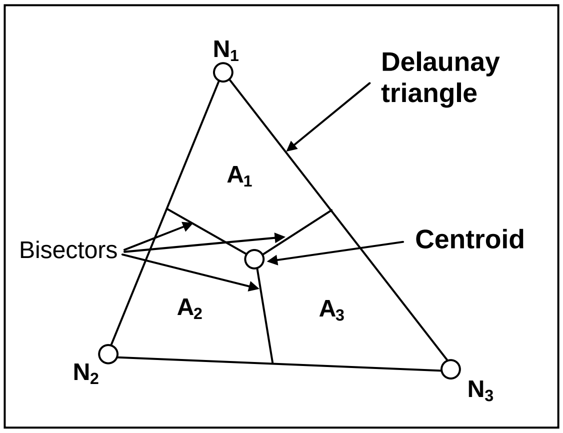
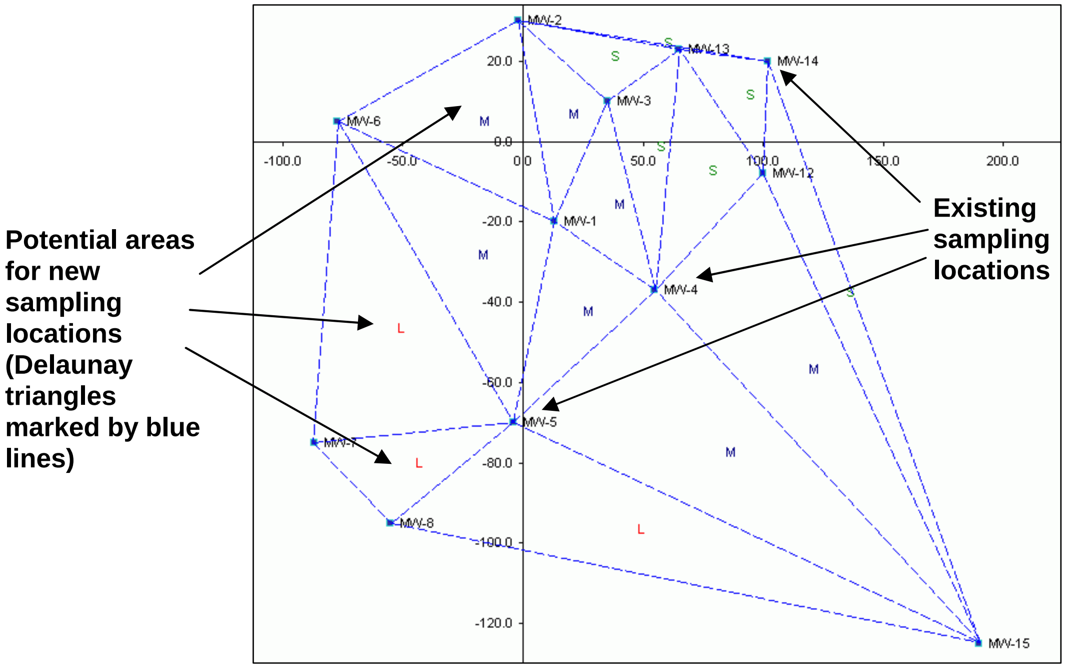


Figure A.3.6 Division of a Delaunay triangle for estimating its average SF value.

The estimated SF values at these potential areas reflect the concentration estimation error at these regions for the time period specified by the sampling events. For example, a value of 0.9 indicates the ratio of the estimated to measured concentration is 1:10 or 10:1, a large discrepancy. A value of 0.5 indicates the ratio of the estimated to measured concentration is only 1:2 or 2:1, a relatively small estimation error.

In MAROS, a Microsoft Excel module, *xlsNewLocation*, is developed to implement the method. To help visualize the analysis results in *xlsNewLocation*, potential areas (the triangles) for new sampling locations are marked by blue dash lines. A colored label is placed around the center of each triangle to indicate the estimated SF level at a potential area. The estimated SF values are classified into four levels: *S–Small* (<0.3), *M–Moderate* (0.3~0.6), *L–Large* (0.6~0.9), and *E–Extremely large* (>0.9). Those potential areas with the estimated SF value at the *Extremely large* or *Large* level are candidate regions for new sampling locations. New sampling locations can then be placed inside these regions, e.g., at the centroid of a triangle region. Refer to the *MAROS Detailed Screens Description* chapter for details on the usage of *xlsNewLocation*.

It is emphasized that recommendations from the well sufficiency analysis are derived solely from the spatial configuration of the monitoring network and the spatial pattern of the contaminant plume. No hydrogeologic conditions are considered in the analysis. Therefore, professional judgement and regulatory considerations must be used to decide whether an area for new sampling locations recommended using the above method is appropriate.



Potential areas for new sampling locations (Delaunay triangles marked by blue lines)

Existing sampling locations

Figure A.3.7 Illustration of the potential areas for new sampling locations.

Other Considerations

One thing to keep in mind is that if the coordinates of a sampling location are not available, this location will be excluded and will not be shown in the analysis. The potential locations for analysis are only those with coordinates from the raw set of locations in the original database (ERPIMS or others). The minimum number of wells valid for analysis is 6. If there are less than 6 sample locations with detected concentrations, the Delaunay method cannot be applied. (*Note: for datasets with less than 6 locations, the software will not function at the Moment Analysis step*).

Also, before applying the Delaunay method for spatial redundancy analysis, it is important to select the appropriate set of wells for analysis, i.e., only the wells that contribute to the spatial delineation of the plume. For example, if wells are far from the plume and contribute little or nothing to the delineation of the plume (e.g., some sentry wells or background wells far from the plume), they should be excluded from the analysis. One reason not to use these wells is that these wells usually are on the boundary of the triangulation and are hard to be eliminated since the Delaunay method protects boundary wells from being easily removed. The elimination status of these wells, in fact, should be determined from the regulatory standpoint. Another well type that could be excluded from analysis is one of a clustered well set because the Delaunay method is a two-dimensional method. Generally, only one well is picked from the clustered well set to represent the concentration at this point. This well can be the one that has the highest concentration or is screened in the representative aquifer interval with the geologic unit. Data from clustered wells can also be averaged to form a single sample and then used in the Delaunay method.

References

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Rice, D. W. et al., 1995, California Leaking Underground Fuel Tank (LUFT) Historical Analyses, UCRL-AR-122207, California State Water Resources Control Board.

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APPENDIX A.4 QUALITATIVE EVIDENCE: EMPIRICAL DATA

Authors: Newell, C.J. and Aziz, J. J., Groundwater Services, Inc.

Objective

There is a growing body of empirical knowledge about the general behavior of groundwater plumes that in **some cases** might be a **useful secondary line of evidence** for evaluating plume behavior. Webster's New Riverside Dictionary defines "*empirical*" as

> "Relying on or gained from observation or experiment rather than theory"

The idea behind using empirical data as a line of evidence is summarized by one of the conclusions from an extensive chlorinated solvent plume study performed by the Lawrence Livermore National Laboratory:

> "Statistical methods, such as general linear models and comparison of probability distributions of plume length indices are useful to quantify expected relationships between plume length and site and CVOC variables within a population of CVOC plumes. In addition, they provide population statistics that may be used to bound the uncertainty inherent in expected plume behaviors." McNab et al, 1999

The empirical data for groundwater plumes has been derived from a series of multiple-site statistical studies sometimes called "plume-a-thon" studies. These include: plume-a-thon studies of:

- BTEX plumes in California, Texas, Florida, and nationwide (four studies);
- MTBE plumes in California and Texas (two studies);
- Chlorinated solvent plumes nationwide (two studies)

In the MAROS system, the user has the **option**, but not the requirement, to use the body of empirical data on plume behavior to help design and optimize a monitoring system.

Key Points/Caveats

Key points regarding the use empirical data as a secondary line of evidence are summarized below:

- Use of empirical data as a line of evidence is optional to the user;
- The empirical data, if used, should be considered secondary evidence and not weighted as much as the primary evidence
- The application of the empirical data is subjective and controlled by the user; i.e., MAROS does not take data, compare to the empirical data, and make a conclusion.
- To use empirical data as a secondary line of evidence, the user

i) reviews the empirical data in this appendix;

ii) based on the user's judgement assigns a plume stability class for each COC (i.e., designates each COC plume in the source and tail as Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, or Decreasing;

iii) assigns a weighting where the importance of the empirical data (a secondary line of evidence) is compared to the importance of the other three lines of evidence (i.e., Mann-Kendall analysis, a primary line of evidence; Linear Regression, a primary line of evidence; and modeling results, a secondary line of evidence). (see "LTM Analysis" section for a discussion of weighting the different lines of evidence).

(Note that the default weighting system in the software is to weight the two Statistical Plume Analyses with a "medium" weight, while the two External Plume Information (including empirical rules) is weighted "low". Again, if the users does not want to use empirical rules as a secondary line of evidence then the user can select that option in the software, or select "Don't Use" in the weighting selection.)

Using Empirical Data as Secondary Evidence

APPROACH

Step 1. Determine if you have a plume in one of the following general categories:

a) BTEX Plumes, Small Releases: BTEX plume from a small fuel release (such as a gas station release) (SEE PAGE A.4-4)

b) BTEX Plumes, Larger Releases: BTEX plume from a larger fuel release (such as from a tank farm) (SEE PAGE A.4-8)

c) MTBE plumes from a small fuel release (such as a gas station release) (SEE PAGE A.4-9)

d) Chlorinated solvent plumes (SEE PAGE A.4-12)

Step 2. Compare the length of you plume to the statistical characteristics of the other plumes from its class by going to the appropriate section (A. B. C. or D. below)

Step 3. If your plume is **much shorter** than most of the other plumes in its class, there may be secondary evidence that your plume has a higher potential to expand. You should select "Increasing" or "Probably Increasing" and enter in software. (Of course if you feel the evidence is not strong enough to be significant, you have the option to not use empirical rules as a line of evidence.)

If your plume is **much longer** than most of the other plumes in its class, there may be secondary evidence that your plume has a lower potential to expand. You should select "Decreasing" or "Probably Decreasing" and enter in software. (Of course if you feel the evidence is not strong enough to be significant, you have the option to not use empirical rules as a line of evidence.)

If your plume is **about the same length** than most of the other plumes in its class, may be weak secondary evidence that your plume may neither increase or decrease in length. You should select "Stable" or "No Trend" and enter in software. (Of course if you feel the evidence is not strong enough to be significant, you have the option to not use empirical rules as a line of evidence.)

Step 4. If available, review the data about plume stability for your particular plume class of interest. For example, plume-a-thon studies of fuel plumes in California (Rice et al, 1995) and Texas (Mace et al., 1997) indicate that most BTEX plumes from small gasoline station releases are either stable, shrinking, or exhausted. If your plume is a BTEX plume from a small release such as a gas station, there may be additional secondary evidence that your plume is more likely “Stable” or “Probably Decreasing” or “Decreasing” as opposed to “Increasing.” It is important that the user’s experience about the site is used when applying the empirical rules.

For example, a very recent release has a much higher potential for expanding than most of the plumes in the plume-a-thon databases. In summary, the empirical data are designed to be supporting, External Plume Information that are used carefully based on the user’ s experience and site knowledge.

A. Empirical Data, BTEX Plumes – Small Releases

Recent studies of over 600 groundwater contamination sites throughout the U.S. provide important information regarding the fate and transport of petroleum hydrocarbons in the subsurface. An API research summary (Newell and Connor, 1998) examined the findings of four independent research studies and addressed several key technical issues regarding the assessment and remediation of BTEX (benzene, toluene, ethylbenzene, xylene) plumes. Each study involved detailed analysis of data from a large number of sites (primarily leaking underground storage tanks) to identify the salient characteristics of groundwater contaminant plumes caused by petroleum hydrocarbon releases. Two studies (California and Texas) evaluated the trends in dissolved petroleum hydrocarbon plumes.

PLUME LENGTH DATA (USED FOR STEP 3)

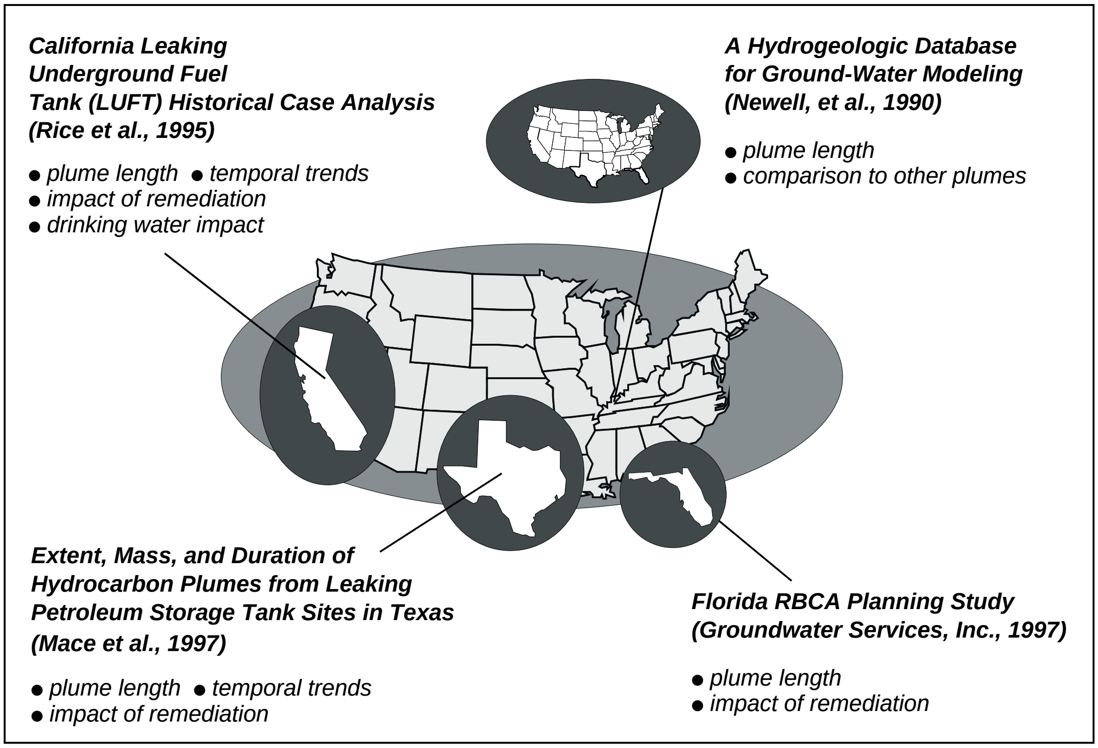
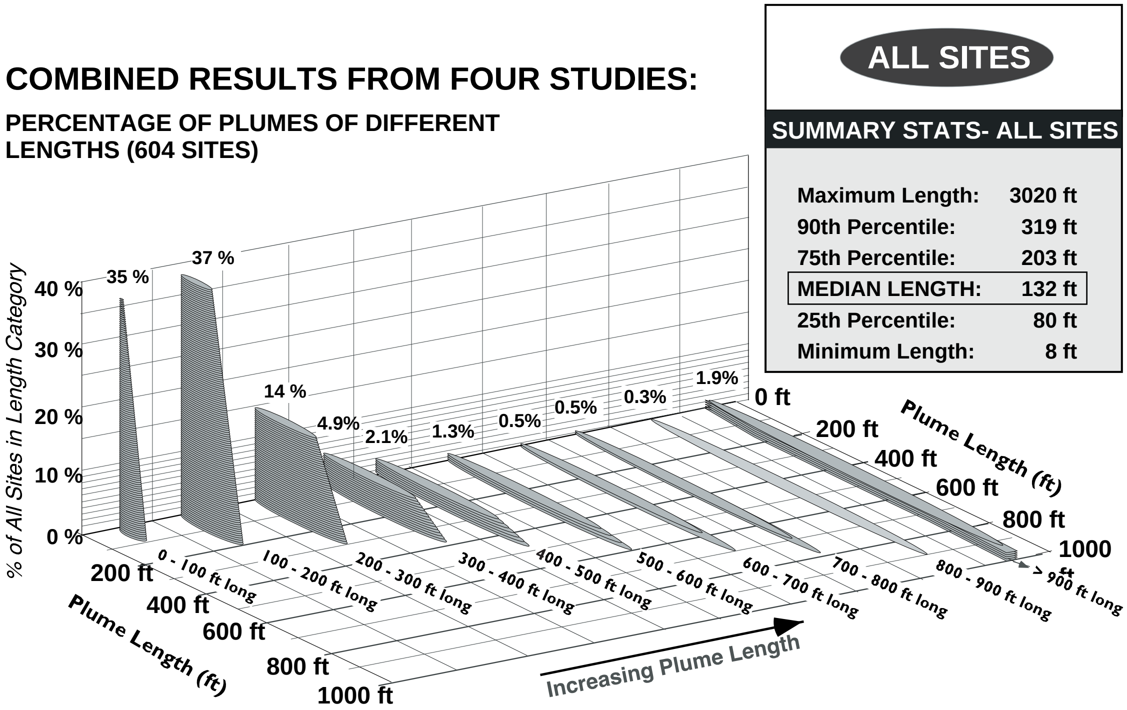


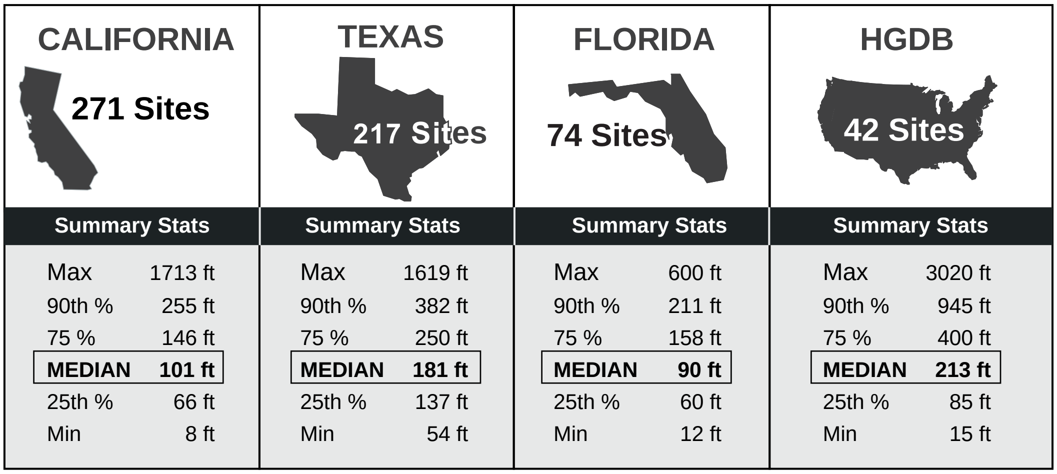
FIGURE A.4.1. LOCATION OF "BTEX PLUMES, SMALL RELEASE" STUDIES



SUMMARY STATS- ALL SITES

Maximum Length:	3020 ft
90th Percentile:	319 ft
75th Percentile:	203 ft
MEDIAN LENGTH:	**132 ft**
25th Percentile:	80 ft
Minimum Length:	8 ft

FIGURE A.4.2. LIMIT OF MIGRATION OF PETROLEUM HYDROCARBON PLUMES, BASED ON COMBINED RESULTS FROM FOUR STUDIES (NEWELL AND CONNOR, 1998). FOUR STUDIES INCLUDED THE LAWRENCE LIVERMORE STUDY (RICE ET AL. 1996), TEXAS BEG STUDY (MACE ET AL., 1997), FLORIDA RBCA STUDY (GSI, 1997), AND UNPUBLISHED DATA FROM THE HGDB DATABASE (NEWELL ET AL., 1990).



CALIFORNIA		TEXAS		FLORIDA		HGDB	
271 Sites		217 Sites		74 Sites		42 Sites	
Summary Stats		Summary Stats		Summary Stats		Summary Stats	
Max	1713 ft	Max	1619 ft	Max	600 ft	Max	3020 ft
90th %	255 ft	90th %	382 ft	90th %	211 ft	90th %	945 ft
75 %	146 ft	75 %	250 ft	75 %	158 ft	75 %	400 ft
MEDIAN	**101 ft**	**MEDIAN**	**181 ft**	**MEDIAN**	**90 ft**	**MEDIAN**	**213 ft**
25th %	66 ft	25th %	137 ft	25th %	60 ft	25th %	85 ft
Min	8 ft	Min	54 ft	Min	12 ft	Min	15 ft

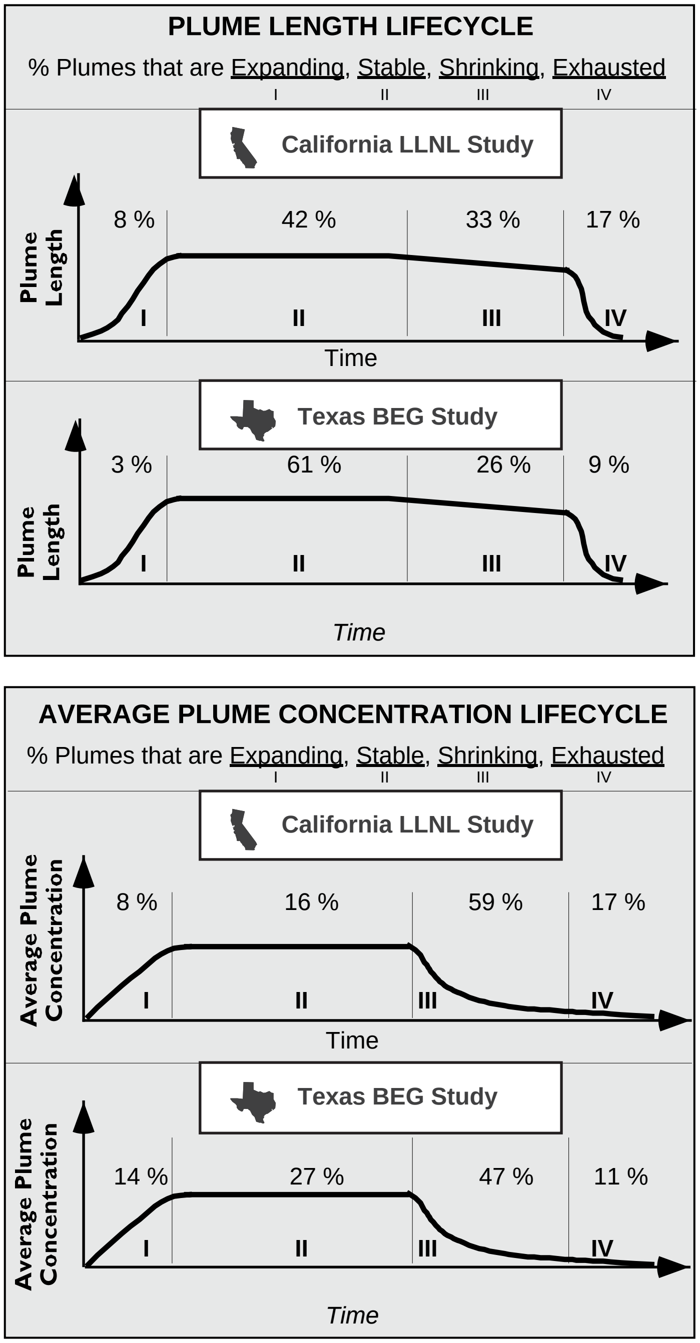
FIGURE A.4.3. SUMMARY STATISTICS FOR INDIVIDUAL PLUME-A-THON STUDIES. MOST STUDIES FOCUSED ON BENZENE OR BTEX RELEASES FROM SMALL FUEL RELEASES SUCH AS UNDERGROUND STORAGE TANKS (USTS) AT SERVICE STATIONS.

PLUME TREND DATA (USED FOR STEP 4)

Two studies (California and Texas) evaluated the trends in dissolved petroleum hydrocarbon plumes. Rice et al, (1995) developed the following classification system to evaluate BTEX plume trends:

- Expanding: Residual source present. Mass flux of contaminants exceeds assimilative capacity of aquifer.
- Stable: Insignificant changes. Active or passive remediation processes are controlling plume length.
- Shrinking: Residual source nearly exhausted, and active or passive remediation processes significantly reducing plume mass.
- Exhausted: Average plume concentration very low (e.g., 1 ppb) and unchanging over time. Final stages of source zone dissolution over a relatively small area at a site.

As shown in the conceptual plume lifecycle figure below (see Figure A.4.4), of the nearly 500 sites addressed by this analysis, nearly 75% were found to be in either a stable or shrinking condition, based on analyses of both plume length and concentration. Plume concentrations were predominantly shrinking (47 to 59%), whereas lengths were frequently stable (42 to 61%). These results suggest that dissolved hydrocarbon plumes tend to reduce more rapidly in concentration than in length.



Figures adapted from Rice et al., 1996.

FIGURE A.4.4 TEMPORAL TRENDS FOR PLUME LENGTH (TOP) AND AVERAGE PLUME CONCENTRATION (BOTTOM) FOR BTEX PLUMES, SMALL RELEASES.

B. Empirical Data, BTEX Plumes – Larger Releases

PLUME LENGTH DATA (USED FOR STEP 3)

Data from other releases besides UST sites suggests that longer BTEX plumes are possible. One data set, derived from a plume data compiled by Wiedemeier et al. (1999) shows 18 Air Force plumes with a median BTEX plume length of 530 ft (see Table A.4.1).

TABLE A.4.1. LENGTH OF BTEX PLUMES FROM LARGER FUEL RELEASES (DATA FROM WIEDEMEIER ET AL., 1999)

BTEX SITES , LARGER RELEASES	State	Plume Length (ft)
Elmendorf AFB	AK	3000
Dover AFB	DE	3000
Hill AFB	UT	1650
Myrtle Beach - POL Facility	SC	1150
Battle Creek	MI	900
King Salmon AFB	AK	850
Madison ANGB	WI	750
Pope AFB- FPTA #4	NC	720
Elmendorf AFB	AK	700
Griffis AFB	NY	360
Columbus AFB	MS	350
MacDill AFB	FL	350
Seymour Johnson AFB	NC	315
Eglin AFB- POL Facility	FL	300
MacDill AFB	FL	250
Westover AFB- Fire Training	MA	200
Fairchild AFB	WA	175
Langley AFB	VA	140
Maximum		3000
90% Percentile		2055
75% Percentile		888
MEDIAN		530
25% Percentile		304
Minimum		140
Number of Sites		18

PLUME LENGTH CORRELATION EQUATIONS (USED FOR STEP 3)

A second approach to compare your plume against empirical plume data is using correlation equations. One takes site data from your site, applies the correlation equation, and then obtains a **predicted plume length**. Then one uses the approach outlined in Step 3 to estimate plume behavior.

For example, if your plume is **much shorter** than **predicted plume length**, then there may be secondary evidence that your plume has a higher potential to expand. You should select "Increasing" or "Probably Increasing" and enter in software. On the other hand, if your plume is **much longer** than the **predicted plume length**, there may be secondary evidence that your plume has a lower potential to expand. You should select "Decreasing" or "Probably Decreasing" and enter in software.

Correlation Equations for BTEX Plumes

Some correlation equations for BTEX plumes are provided in Wiedemeier et al. (1999; see page 229-230).

A more detailed correlation analysis was performed for the American Petroleum Study by Nevin et al. analyzed plume length data UST and petroleum release sites taken from the four sources (the HGDB Air Force plumes, the Texas BEG study, and Florida RBCA study). The database includes sites ranging from small retail gas stations to large distribution sites covering thousands of square feet. This wide range of site sizes makes the study database different from the databases used in the Lawrence Livermore (LLNL, see Rice, et al., 1995) and Texas BEG (see Mace, et al., 1997) studies, which were almost entirely retail sites.

Using this database, correlations were performed on a number of hydrogeologic and source parameters. The correlation results agreed with results from the California and Texas plume-a-thon studies (Rice et al., 19995; Mace et al, 1997) that showed that plume length is not correlated with groundwater velocity or other hydrogeologic characteristics of the site.

The correlation study also confirmed that the source size is a major determining factor for plume length. Because transverse dispersion is a relatively weak process (Pankow and Cherry, 1996), the plume width was used as an approximation for the source width. As shown below, there is high degree of correlation ($R^2 = 0.67$) was found between plume length and plume width. Although this may appear to be self-evident, it is a key conclusion in that it supports the idea that BTEX plume length is largely driven by source factors, and much less by hydrogeologic factors.

The resulting plume length prediction equation is:

$$\text{Plume Length (ft)} = 2.0 \bullet \text{Plume Width (ft)} \quad R^2 = 0.67$$

This results is supported by qualitative conclusions by the California and Texas plume-a-thon studies. Rice et. al (1995) concluded "These hypothetical plume-length controlling variables may be source mass and passive bioremediation rate." Mace et al. (1997) identified other factors, such as the amount of spilled fuel and natural biodegradation rate, as having a greater influence than hydrogeology or previous remediation activities.

C. Empirical Data, MTBE Plumes

Two plume-a-thon studies have been conducted on MTBE plumes, one if California and one in Texas.

MTBE PLUME LENGTH DATA (USED FOR STEP 3)

California Study

Happel et al., 1998) performed a study of 63 MTBE sites in California. They concluded that:

"MTBE plumes were typically equivalent in length, or shorter than benzene plumes. On a site-by-site basis, this was also true in approximately 81% of the cases. Further at an individual LUFT site, the length of a benzene plume was only moderately correlated with the length of the corresponding MTBE plume; thus the length of a benzene plume cannot be used to predict the extent of MTBE impact."

TABLE A.4.2 CUMULATIVE DISTRIBUTIONS OF 1995/96 PLUME LENGTHS (IN FT) FOR BENZENE AND MTBE (SOURCE: FIGURE 4.1, HAPPEL ET AL., 1998).

Maximum	1000 ft
90% Percentile	325
75% Percentile	250
MEDIAN	120
25% Percentile	85
Minimum	0
Number of Sites	50

The median MTBE plume length was approximately 120 ft.

Mace and Choi studies 99 MBTE plumes in Texas, and compiled the following distribution for MTBE plume lengths:

TABLE A.4.3 CUMULATIVE DISTRIBUTIONS OF 10 PPB MTBE PLUME LENGTHS (IN FT) FOR 99 SITES IN TEXAS (SOURCE: FIGURE 3, MACE AND CHOI, 1998).

Maximum	750 ft
90% Percentile	386
75% Percentile	255
MEDIAN	174
25% Percentile	120
Minimum	0
Number of Sites	99

Mace and Choi found that MTBE plumes were, on average, only slightly longer than their companion benzene plumes.

MTBE PLUME TREND DATA (USED FOR STEP 4)

Caution should be take before using MTBE plume distributions as secondary evidence, as Happel et al. (1998) concluded that most of the MTBE plumes are not stable compared to the contaminant (e.g., BTEX) plumes:

> "Although our results using 1995/96 data indicate that, at the majority of sites, individual MTBE plumes were nearly equivalent or shorter than their corresponding benzene plumes (defined by action levels of 20 and 1 µg L -1 respectively), our results predict that at a portion of these sites this relationship will change over time as the contaminant plumes gradually dissociate." (Happel et al., 1998)

The Texas study arrived at the opposite conclusion, however:

> "Analysis of temporal data (83 percent of wells have stable, decreasing, or nondetection of MTBE concentration; co-occurrence with benzene has remained the same for the past several years; and limited plume length data shows sites with stable plumes) suggests that MTBE plumes may be naturally attenuated at many sites in Texas." (Mace and Choi, 1998).

More research is needed before MTBE plume-a-thon data can be used as adequate secondary evidence for determining plume stability.

D. Empirical Data, Chlorinated Solvent Plumes

Two chlorinated solvent plume-a-thons are available for use as secondary evidence, one performed for the Air Force Center for Environmental Excellence Tech Transfer Division by Groundwater Services, Inc., and one performed by the Lawrence Livermore National Laboratory.

CHLORINATED SOLVENT PLUME LENGTH DATA (USED FOR STEP 3)

AFCEE Study

The AFCEE database (Aziz et al., in review), used data from site investigation, treatability, and natural attenuation reports to compile the database. Questionnaires were completed using mean hydrogeologic property values extracted from the site reports for the most contaminated unit. Plume lengths were determined using isopleths for each chlorinated ethene or chlorinated ethane constituent included in the site report. The project developed several correlations to plume length and estimated first order biodegradation rates for both parent compounds and daughter products using the BIOCHLOR model (Aziz et al., 1999)

When comparing the chlorinated ethenes (i.e., PCE, TCE, c-DCE, t-DCE, and vinyl chloride), TCE and the DCE isomers have the longest median plume lengths, all in the 1200 ft range, as shown in Table A.5.4. Vinyl chloride has the shortest median plume length of 860 ft, followed by PCE with a plume length of 970 ft.

TABLE A.4.4 CUMULATIVE DISTRIBUTIONS OF CHLORINATED SOLVENT PLUME LENGTHS (IN FT) AND ASSOCIATED COMPOUNDS PLUME LENGTHS (IN FT) (SOURCE: TABLE 3, AZIZ ET AL, IN REVIEW).

			Plume Lengths (ft)				
	Minimum	**25th Percentile**	**Median**	**75th Percentile**	**Maximum**	**Mean**	**n**
PCE	100	228	**970**	1335	13700	1933	11
TCE	250	450	**1215**	2600	11900	2137	21
cis-DCE	200	540	**1205**	3100	9400	2046	20
trans-DCE	440	1190	**1200**	1890	2750	1494	5
VC	180	398	**860**	1310	3300	1084	15
Ethene	120	320	**600**	1045	1500	675	11
Chloride	270	863	**1418**	2900	4520	1848	14
BTEX	60	595	**750**	1270	3600	1183	15
TCA	130	365	**865**	2183	2700	1230	6
1,1-DCA	1040	1370	**1650**	1925	2500	1675	8
1,1-DCE	1000	1245	**1470**	1643	1820	1438	6

Key results from this study are (Aziz et al., in review):

- At sites contaminated with chlorinated ethenes only, TCE or c-DCE was the most likely constituent to have the longest plumes at the site. TCE and c-DCE had median plume lengths of 1215 ft and 1205 ft, respectively.
- VC had the shortest median plume length of 860 ft. Because the daughter product plumes were coincident or almost coincident with the parent plumes, these results indicate that vinyl chloride is unlikely to be the longest plume at a site. This is an encouraging result given the relatively high associated carcinogenicity of vinyl chloride.

- The plume width in the source area (or source area width) was used to represent the size of the NAPL-affected source area. The product of the source area width and the maximum dissolved phase solvent concentration was strongly correlated with plume length. This finding indicates that source characteristics, including the extent of DNAPL migration, are the most important factors impacting the maximum dissolved chlorinated solvent plume length.
- Chlorinated ethene plume lengths were moderately correlated with seepage velocity and groundwater travel distance, indicating that advection is also an important factor impacting chlorinated solvent plumes. Therefore, the seepage velocity should be accurately determined to predict plume lengths.
- Environmental factors, such as temperature, pH, dissolved oxygen, and redox potential were not strongly correlated with chlorinated ethene plume length. However, there was a strong trend of increasing PCE plume length with increasing redox potential, once the PCE plume length was normalized to remove the effects of advection. These results suggest that source width and strength and seepage velocity are more important factors impacting overall plume length than environmental conditions that are conducive to reductive dechlorination.

Lawrence Livermore Study

McNab et al. (1999) collected and analyzed data from 65 sites representing a variety of hydrogeologic settings and release scenarios (e.g., large industrial facilities, dry cleaners, and landfills). Data collection involved a variety of federal and state agencies and included participation from the U.S. Department of Defense, the Department of Energy, and private industry. The distribution of chlorinated solvent plume lengths from their database is shown in Table A.4.5:

TABLE A.4.5. SUMMARY OF FREQUENCY DISTRIBUTIONS OF MAXIMUM CVOC PLUME LENGTHS (FT) TO THE 10 PPB-DEFINED PLUME PER SITE, BASED ON THE INDICATED CONCENTRATION CONTOUR DEFINITION.

90% Percentile	6030 ft
75% Percentile	3210
MEDIAN	1600
25% Percentile	790
10% Percentile	120
Number of Sites	99

Key results from this study were:

- Statistical methods, such as general linear models and comparison of probability distributions of plume length indices are useful to quantify expected relationships between plume length and site and CVOC variables within a population of CVOC plumes. In addition, they provide population statistics that may be used to bound the uncertainty inherent in expected plume behaviors.
- An important conclusion of this study is that the presence of a vinyl chloride plume indicates that reductive dehalogenation may be playing a role in reducing the extent of CVOC plumes at approximately one-third of the sites examined. In contrast, the presence

of a cis-1,2-DCE plume in the absence of a vinyl chloride plume appears to indicate reductive dehalogenation rates that are insufficient to effectively reduce the extent of CVOC plumes at a site. Little evidence was found in the data to suggest that plume lengths and plume growth rates are substantially affected by reductive dehalogenation in these circumstances.

- There are no statistically significant differences between CVOC species with regard to their log-transformed 10-ppb plume lengths, including likely transformation daughter products such as cis-1,2-DCE and vinyl chloride. Plume lengths are positively correlated with maximum historical CVOC concentrations and mean groundwater velocity at each site. Large daughter product plumes do not commonly extend a large distance downgradient of the parent product plumes.

PLUME LENGTH CORRELATION GRAPHS (USED FOR STEP 3)

AFCEE Study

Aziz et al, (2000) also evaluated correlations to chlorinated solvent plume lengths. In general, the best correlation to log plume length (in ft) was log (Plume Width x Maximum Concentrations) as shown in Figure A.4.5.

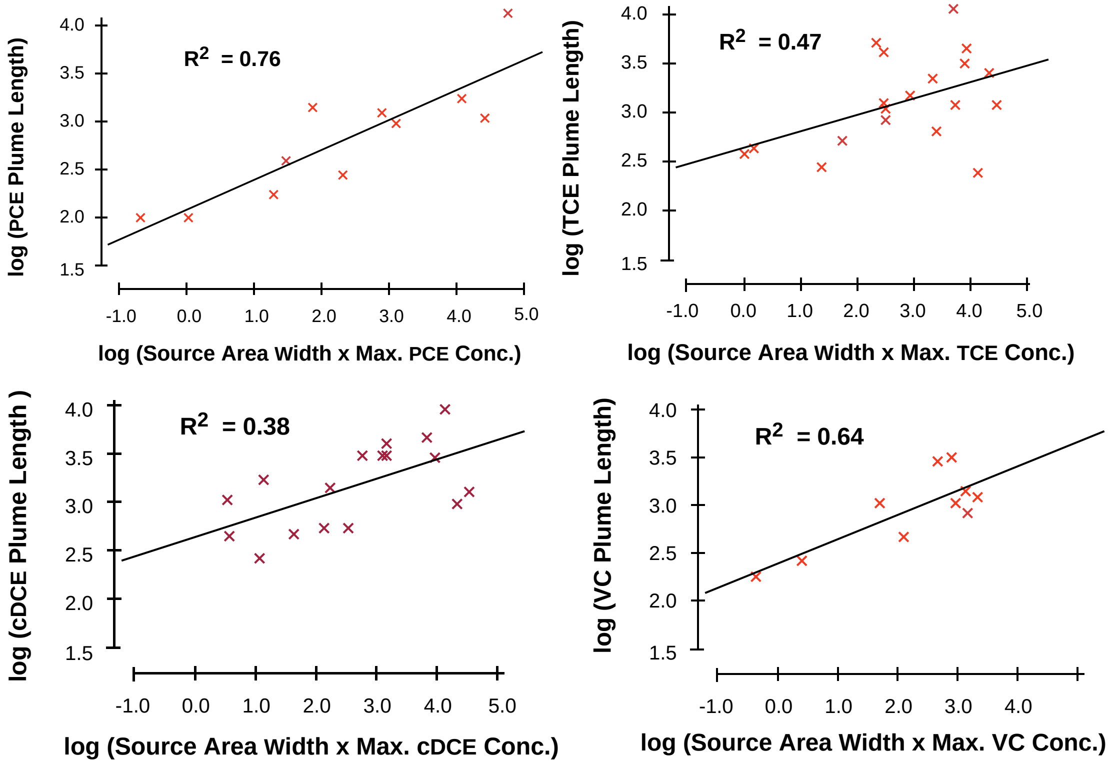


FIGURE A.4.5. CORRELATION OF LOG PLUME LENGTH WITH LOG (PLUME WIDTH X MAXIMUM CONCENTRATION) (AZIZ ET AL., 2000)

Lawrence Livermore Study

Numerous correlations were conducted as part of this chlorinated solvent plume study. The authors concluded that:

> Another important conclusion is that CVOC transformation rates through dehalogenation exert less impact on plume length than source strength and groundwater velocity. Thus, plumes with weaker source strength and slower groundwater velocities may be better candidates for the application of natural attenuation remedies.

CHLORINATED SOLVENT TREND DATA (USED FOR STEP 4)

Lawrence Livermore Study

As part of the Lawrence Livermore National Laboratory chlorinated solvent plume study (McNab et al, 1999), a time series analysis was performed. This analysis divided the chlorinated solvent plumes into two groups: a group with **Strong Reductive Dechlorination** processes (see Table A.4.6) and **No or Weak Reductive Dechlorination** processes (see Table A.4.7).

TABLE A.4.6. TEMPORAL TRENDS IN PLUME LENGTH FOR CVOC PLUMES FROM THE STRONG REDUCTIVE DECHLORINATION GROUP CHARACTERIZED BY MONITORING DATA FROM THREE OR MORE YEARS. SOURCE: MCNAB ET AL, 1999

p-value	**Plumes Decreasing In Length**		**Plumes Increasing In Length**		**Plumes With No Significant Trend**	
	% Sites	Number sites	% Sites	Number sites	% Sites	Number sites
0.01	9%	4	4%	2	87%	41
0.05	11%	5	13%	6	77%	36
0.1	13%	6	15%	7	72%	34
0.2	21%	10	19%	9	60%	28
0.3	21%	10	26%	12	53%	25
0.5	23%	11	28%	13	49%	23

TABLE A.4.7. TEMPORAL TRENDS IN PLUME LENGTH FOR CVOC PLUMES FROM THE NO REDUCTIVE DECHLORINATION AND WEAK REDUCTIVE DECHLORINATION GROUPS CHARACTERIZED BY MONITORING DATA FROM THREE OR MORE YEARS. SOURCE: MCNAB ET AL, 1999

p-value	**Plumes Decreasing In Length**		**Plumes Increasing In Length**		**Plumes With No Significant Trend**	
	% Sites	Number sites	% Sites	Number sites	% Sites	Number sites
0.01	9%	8	14%	13	78%	73
0.05	10%	9	21%	20	69%	65
0.1	12%	11	27%	25	62%	58
0.2	14%	13	34%	32	52%	49
0.3	17%	16	38%	36	45%	42
0.5	19%	18	44%	41	37%	35

The authors concluded that:

> "Regardless of the confidence level, the two populations of plumes do appear to differ from one another according to this analysis in that the plumes from the Strong RD group exhibit a diminished tendency toward increases in plume length than those plumes from the No RD and Weak RD groups. Previous historical case analyses of fuel hydrocarbon plumes (Rice et al., 1995, Mace et al., 1997) indicated that only a small minority of hydrocarbon plumes (on the order of 10%) were experiencing discernable plume growth, presumably as a result of the limiting effects of biotransformation processes. Thus, the differences in apparent CVOC plume growth rates provides an independent line of evidence to support the conclusion that reductive dehalogenation influences plume length behavior at sites where vinyl chloride plumes are present."

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APPENDIX A.5 SPATIAL MOMENT ANALYSIS

Authors: Aziz, J. J. and Newell, C. J., Groundwater Services, Inc.

This appendix details the moment analysis procedures employed by the Monitoring and Remediation Optimization System (MAROS) Software. The procedures outlined below were developed to assess plume stability for groundwater plumes based on scientifically sound quantitative analyses of current and historical site groundwater conditions. The moment analysis results can also be used to further assess possible information loss due to eliminating sample locations in the long-term monitoring network.

Plume Stability Analysis

Confirmation of the effective performance of monitored natural attenuation as a stand-alone remedial measure requires the demonstration of actual measurement of stable or shrinking plume conditions based on evaluation of historical groundwater monitoring data. For this analysis, an overall plume condition was determined for each COC based on a statistical trend analysis of moments for each sample event, as described below. The function that describes residence time of mass in a field is difficult to characterize exactly. An infinite set of parameters are needed to fully characterize the distribution and the mean residence time and variance are often inadequate, as well. It is more convenient to characterize the approximate distribution rather than the exact distribution, in terms of the moments. (Rasmuson 1985). The moment calculations can predict how the plume will change in the future if further statistical analysis is applied to the moments to identify a trend (in this case, Mann Kendall Trend Analysis is applied). The role of moment analysis in MAROS is to provide a relative measure of plume stability and condition, but can also assist the user in evaluating the impact on plume delineation in future sampling events by removing identified "redundant" wells from a long-term monitoring program.

Plume stability may vary by constituent, therefore the MAROS Moment analysis can be used to evaluate multiple COCs simultaneously which can be used to provide a quick way of comparing individual plume parameters to determine the size and movement of constituents relative to one another.

To estimate the mass, center of mass, and the spread of the plume at each sample event, spatial moment analysis of the discrete groundwater monitoring data was performed. The ijkth moment of the 2-D concentration distribution in space M_{ijk} (t) is defined as (Freyburg, 1986):

$$M_{ijk}(t) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \eta C(x,y,z,t) x^i y^j z^k \, dxdydz$$

where C(x,y,z) is the concentration at a monitoring point; η is the total porosity; and x, y, z are the spatial coordinates. The zeroth, first, and second moments (i+j+k = 0, 1, or 2, respectively) provide measures of the mass, location of the center of mass, and relative distribution of the plume.

The moment trends over time can be assessed by the Mann-Kendall test, which is a non-parametric statistical procedure that is well suited for analyzing trends in data over time (Gilbert, 1987). The Mann-Kendall test can be viewed as a nonparametric test for zero slope of the first-order regression of time-ordered concentration data versus time. The AFCEE MAROS Tool includes this test to assist in the analysis of groundwater plume stability and plume changes over time. The Mann-Kendall test does not require any assumptions as to the statistical distribution of the data (e.g. normal, lognormal, etc.) and can be used with data sets which include irregular sampling intervals and missing data. The Mann-Kendall test is designed for analyzing a single groundwater constituent, multiple constituents are analyzed separately. For more details on the Mann-Kendall Trend Analysis refer to Appendix A.2 *Statistical Trend Analysis Methods*.

ZEROTH MOMENT: SHOWS CHANGE IN MASS OVER TIME

The zeroth moment is the sum of concentrations for all monitoring wells and is an estimate of the total dissolved mass in the plume. The zeroth moment calculation can show high variability over time, largely due to the fluctuating concentrations at the most contaminated wells as well as the varying number and identity of wells in the network. Plume analysis and delineation based exclusively on concentration can exhibit temporal and spatial variability. The mass estimate is also sensitive to the extent of the site monitoring well network over time. Therefore, the plume should be adequately delineated for the mass estimates to be considered.

The 3-D Zeroth Moment or Mass estimate was calculated using the following formula:

$$M_{0,0,0} = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \eta C_i \, dx dy dz$$

where C_i is the concentration of the COC, η is the total porosity; and x, y, z are the spatial coordinates.

Because the data are spatially discontinuous, a numerical approximation to this equation is required. To conduct the numerical integration the horizontal plane (x,y) was divided into contiguous triangular regions with the apex of each triangle defined by a well sampling location with an associated COC concentration and saturated thickness at each sample location. A spatial interpolation method over these triangles allows the zeroth moment calculations using Delaunay Triangulation (see Appendix A.2 for methodology). An approximation of the mass is obtained from calculating:

$$Mass_{Estimated} \cong \sum \eta V_i C_{i\,avg}$$

where C_{iavg} is the geometric mean concentration of each triangle for a particular COC(i) , V_i is the volume of the triangle (calculated by d*A_i, where d is the averaged saturated thickness and A_i is the area of the triangle) and η is an estimate of the total porosity for the site.

Zeroth Moment Trend: The Zeroth Moment trend over time is determined by using the Mann-Kendall Trend Methodology. The "Zeroth Moment" Trend for each COC is determined according to the rules outlined in Appendix A.1. The Zeroth Moment trend test will allow the user to understand how the plume mass has changed over time. Results for the trend include: Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

Mann-Kendall Statistic (S): The Mann-Kendall Statistic (S) measures the trend in the data. Positive values indicate an increase in estimated mass over time, whereas negative values indicate a decrease in estimated mass over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend). However, the zeroth moment calculation can show high variability over time, largely due to the fluctuating concentrations at the most contaminated wells as well as varying monitoring well network sampling.

Confidence in Trend: The "Confidence in Trend" is the statistical confidence that the estimate of total dissolved mass is increasing (S>0) or decreasing (S<0) over time.

COV: The Coefficient of Variation (COV) is a statistical measure of how the individual data points (estimates of total dissolved mass) vary about the mean value. The coefficient of variation is defined as the standard deviation of mass estimates divided by the average. Values near 1.00 indicate that the data form a relatively close group about the mean value. Values either larger or smaller than 1.00 indicate that the data show a greater degree of scatter about the mean.

FIRST MOMENT: SHOWS CHANGE IN CENTER OF MASS OVER TIME

The first moment estimates the center of mass, coordinates (Xc and Yc) for each sample event and COC. The changing center of mass locations indicate the movement of the center of mass over time. Whereas, the distance from the original source location to the center of mass locations indicate the movement of the center of mass over time relative to the original source.

The 2-D coordinates for the center of mass of the plume for a given sample event can be calculated from:

$$X_c = \frac{M_{1,0,0}}{M_{0,0,0}} = \frac{\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \eta C_i x\,dx\,dy\,dz}{\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \eta C_i\,dx\,dy\,dz} \qquad Y_c = \frac{M_{0,1}}{M_{0,0}} = \frac{\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \eta C_i y\,dx\,dy\,dz}{\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \eta C_i\,dx\,dy\,dz}$$

where C_i is the concentration of the COC, η is the total porosity; and x, y are the spatial coordinates.

Similar to the Zeroth Moment calculation, the data are spatially discontinuous therefore a numerical approximation to this equation is required. To conduct the numerical integration the horizontal plane (x,y) was divided into contiguous triangular regions with the apex of each triangle defined by a well sampling location with an associated COC concentration at each sample location. A spatial interpolation method over these triangles allows the first moment calculations using Delaunay Triangulation (see Appendix A.3 for methodology). The Delaunay triangulation is a rough way to discretize the domain. The following formulas represent the 2-D approximation of the center of mass:

$$X_c \cong \frac{\sum X_i V_i C_{i\,avg}}{\sum V_i C_{iavg}} \qquad Y_c \cong \frac{\sum Y_i V_i C_{i\,avg}}{\sum V_i C_{iavg}}$$

where C_{iavg} is the geometric mean concentration of the each triangle for a particular COC(i) , X_i, Y_i are the spatial coordinates of the center of each triangle, V_i is the volume of the triangle (calculated by $d*A_i$, where d is the averaged saturated thickness and A_i is the area of the triangle) and Xc, Yc are the coordinates of the center of mass.

Calculation of the first moment normalizes the spread by the concentration indicating the center of mass. Analysis of the movement of mass should be viewed as it relates to 1) the original source location of contamination and 2) the direction of groundwater flow. Spatial and temporal trends in the center of mass can indicate spreading or shrinking or transient movement based on season variation in rainfall or other hydraulic considerations. No appreciable movement or a neutral trend in center of mass would indicate plume stability.

Distance from Source to Center of Mass:

To calculate the distance from the center of mass of the plume for a particular COC and sample event to the source location, the following formula is used:

$$D_{fromcenter} = \sqrt{\left(X_{source} - X_c\right)^2 + \left(Y_{source} - Y_c\right)^2}$$

where $D_{fromcenter}$ is the distance from the source location to the center of mass for a particular COC(i) and sample event , X_c, Y_c are the coordinates of the center of mass, X_{source}, Y_{source} are the coordinates of the source location for a particular COC.

First Moment Trend: The First Moment trend of the distance to the center of mass over time is determined by using the Mann-Kendall Trend Methodology. The "First Moment" trend for each COC is determined according to the rules outlined in Appendix A.1. Results for the trend include: Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

MK (S): The Mann-Kendall Statistic (S) measures the trend in the data, in this case the trend in the distance from the source area to the center of mass. Positive values indicate an increase in the distance from the source to the center of mass over time, whereas negative values indicate a decrease in the distance from the source to the center of mass over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend).

Confidence in Trend: The "Confidence in Trend" is the statistical confidence that the distance from the source to the center of mass is increasing ($S>0$) or decreasing ($S<0$).

COV: The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. The coefficient of variation, defined as the standard deviation divided by the average distance between the source and mass center. Values near 1.00 indicate that the data form a relatively close group about the mean value. Values either larger or smaller than 1.00 indicate that the data show a greater degree of scatter about the mean.

SECOND MOMENT: SHOWS SPREAD OF THE PLUME OVER TIME

The second moment indicates the distribution of the contaminant about the center of mass (σ_{xx} and σ_{yy} or equivalently S_{xx} and S_{yy}), or the distance of contamination from the center of mass for a particular COC and sample event. The Second Moment represents the spread of the plume over time in the x and y directions with x-axis representing its major migration direction. Freyberg (1986) describes the second moment about the center of mass as the "spatial covariance tensor".

The components of the covariance tensor are indicative of the spreading of the contaminant plume about the center of mass. The components of the covariance tensor can be described in terms of an ellipse (x the major axis and y the minor axis). The values of σ_{xx} and σ_{yy} represent the axes of the covariance ellipse.

The 2-D covariance or second moment equations (axial terms) are as follows:

$$\sigma_{xx} = \frac{M_{2,0,0}}{M_{0,0,0}} - X_c{}^2 \qquad \sigma_{yy} = \frac{M_{2,0,0}}{M_{0,0,0}} - Y_c{}^2$$

where σ_{xx} and σ_{yy} are the second moments for a particular COC (i) and sample event , X_c, Y_c are the coordinates of the center of mass.

Similar to the other Moment calculations, the data are spatially discontinuous therefore a numerical approximation to this equation is required. To conduct the numerical integration the horizontal plane (x, y) was divided into contiguous triangular regions with the apex of each triangle defined by a well sampling location with an associated COC concentration at each sample location. A spatial interpolation method over these triangles allows the first moment calculations using Delaunay Triangulation (see Appendix A.2 for methodology). The Delaunay triangulation is a rough way to discretize the domain. The following formulas represent the 2-D approximation of the spatial covariance tensors:

$$S_{xx} \cong \frac{\sum (X_i - X_c)^2 V_i C_{i\,avg}}{\sum V_i C_{iavg}} \qquad S_{yy} \cong \frac{\sum (Y_i - Y_c) V_i C_{i\,avg}}{\sum V_i C_{iavg}}$$

$$S_{xy} \cong \frac{\sum (X_i - X_c)(Y_i - Y_c) V_i C_{i\,avg}}{\sum V_i C_{iavg}}$$

Where S_{xx}, S_{yy}, and S_{xy} (the diagonal term) are the spatial covariance tensors for a particular COC(i) and sample event, where C_{iavg} is the geometric mean concentration of each triangle for a particular COC(i) , X_i and Y_i are the spatial coordinates (the easting-northing coordinates) of the center of each triangle, V_i is the volume of the triangle (calculated by $d*A_i$, where d is the averaged saturated thickness and A_i is the area of the triangle).

In order to analyze the behavior of the plume, the values of the spatial covariance tensors need to be adjusted relative to the orientation of the plume elliptical axes. It is assumed that the major elliptical axis (x′) is parallel to the estimated mean groundwater velocity vector and the minor elliptical axis (y′) is perpendicular to the groundwater direction. The components are estimated using the field coordinate system and then rotated counterclockwise using the standard Cartesian tensor rotational transformation with the following formulas:

$$S_{xx}' = S_{xx}(\cos\theta)^2 + 2S_{xy}\sin\theta\cos\theta + S_{yy}(\sin\theta)^2$$

$$S_{yy}' = S_{xx}(\sin\theta)^2 - 2S_{xy}\sin\theta\cos\theta + S_{yy}(\cos\theta)^2$$

where θ is the representative groundwater direction measured anti-clockwise from the X-axis field coordinate system. These are the actual values reported as second moments in MAROS.

Second Moment Trend: The Second Moment trend of the Spread of the Plume in the X or Y direction over time is determined by using the Mann-Kendall Trend Methodology. The "Second Moment" trend for each COC is determined according to the rules outlined in Appendix A.1. Results for the trend include: Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

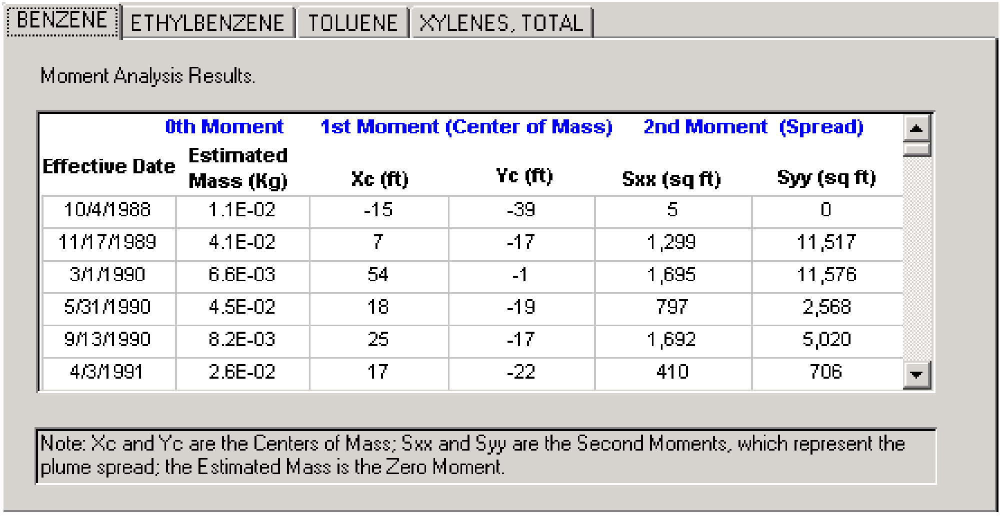
MK (S): The Mann-Kendall Statistic (S) measures the trend in the data. Positive values indicate an increase in the spread of the plume over time (expanding plume), whereas negative values indicate a decrease in the spread of the plume over time (shrinking plume). The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend).

Confidence in Trend: The "Confidence in Trend" is the statistical confidence that the spread of the plume in the x or y direction is increasing (S>0) or decreasing (S<0).

COV: The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. The coefficient of variation, defined as the standard deviation divided by the average. Values near 1.00 indicate that the data form a relatively close group about the mean value. Values either larger or smaller than 1.00 indicate that the data show a greater degree of scatter about the mean.

RESULTS AND INTERPRETATION OF RESULTS: MOMENT TREND ANALYSIS

The Moment Trend Analysis results are presented in the *Spatial Moment Analysis Results* screen (accessed from the *Moment Analysis Site Details* screen). The software uses the input data to calculate the Zeroth, First, and Second Moments for each sampling event (see Figure A-5.1).



	0th Moment	1st Moment (Center of Mass)		2nd Moment (Spread)	
Effective Date	Estimated Mass (Kg)	Xc (ft)	Yc (ft)	Sxx (sq ft)	Syy (sq ft)
10/4/1988	1.1E-02	-15	-39	5	0
11/17/1989	4.1E-02	7	-17	1,299	11,517
3/1/1990	6.6E-03	54	-1	1,695	11,576
5/31/1990	4.5E-02	18	-19	797	2,568
9/13/1990	8.2E-03	25	-17	1,692	5,020
4/3/1991	2.6E-02	17	-22	410	706

Note: Xc and Yc are the Centers of Mass; Sxx and Syy are the Second Moments, which represent the plume spread; the Estimated Mass is the Zero Moment.

Figure A.5.1 Moment Analysis Results

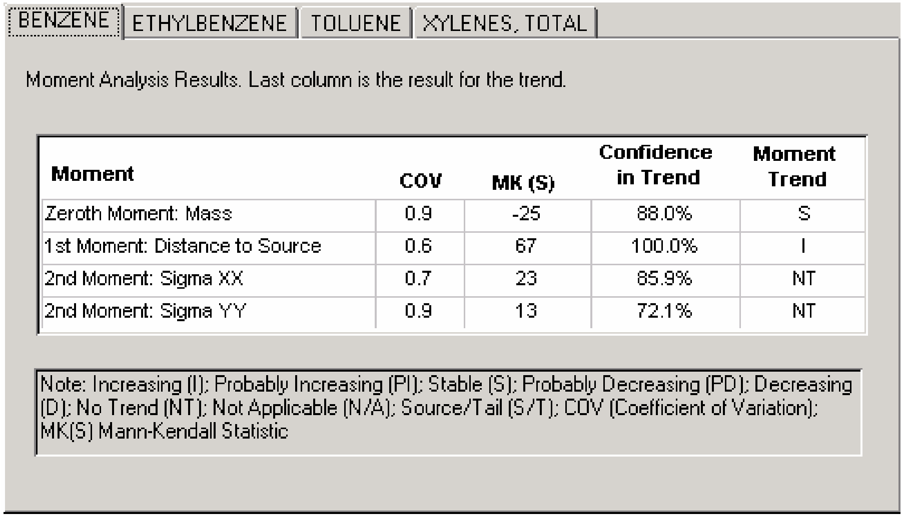
RESULTS AND INTERPRETATION:

The role of moment analysis in MAROS is to provide a relative measure of plume stability and condition over time, but can also assist the user in evaluating the impact on plume delineation in future sampling events by removing identified "redundant" wells from a long-term monitoring program.

Plume stability may vary by constituent, therefore the MAROS Moment analysis can be used to evaluate multiple COCs simultaneously which can be used to provide a quick way of comparing individual plume parameters to determine the size and movement of constituents relative to one another.

Zeroth Moment Trend: The Zeroth Moment trend over time will allow the user to understand how the plume mass has changed historically. A "Concentration Trend" and "Confidence in Trend" are reported for each sample event (see Figure A.5.2).

Zeroth moment calculations can show high variability over time, largely due to the fluctuating concentrations at the most contaminated wells. Field data can be highly variable due to changes in physical factors such as aquifer recharge and temperature. Plume analysis and delineation based exclusively on concentration can exhibit a large degree of temporal and spatial variability. When considering the results of the Zeroth moment trend, take into consideration the following factors which could effect the calculation and interpretation of the plume mass over time: 1) Change in the spatial distribution of the wells sampled historically 2) Different wells sampled within the well network over time (addition and subtraction of well within the network). 3) Adequate versus inadequate delineation of the plume over time



Moment Analysis Results. Last column is the result for the trend.

Moment	COV	MK (S)	Confidence in Trend	Moment Trend
Zeroth Moment: Mass	0.9	-25	88.0%	S
1st Moment: Distance to Source	0.6	67	100.0%	I
2nd Moment: Sigma XX	0.7	23	85.9%	NT
2nd Moment: Sigma YY	0.9	13	72.1%	NT

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T); COV (Coefficient of Variation); MK(S) Mann-Kendall Statistic

Figure A.5.2 Moment Analysis Mann-Kendall Trend Results

First Moment Trend: The First Moment trend of the distance to the center of mass over time is shows movement of the plume in relation to the original source location over time. Analysis of the movement of mass should be viewed as it relates to 1) the original source location of contamination 2) the direction of groundwater flow and/or 3) source removal or remediation. Spatial and temporal trends in the center of mass can indicate spreading or shrinking or transient movement based on season variation in rainfall or other hydraulic considerations. No appreciable movement or a neutral trend in the center of mass would indicate plume stability. However, changes in the first moment over time do not necessarily completely characterize the changes in the concentration distribution (and the mass) over time. Therefore, in order to fully characterize the plume the First Moment trend should be compared to the Zeroth moment trend (mass change over time), refer to Figures A.5.3 – A.5.5.

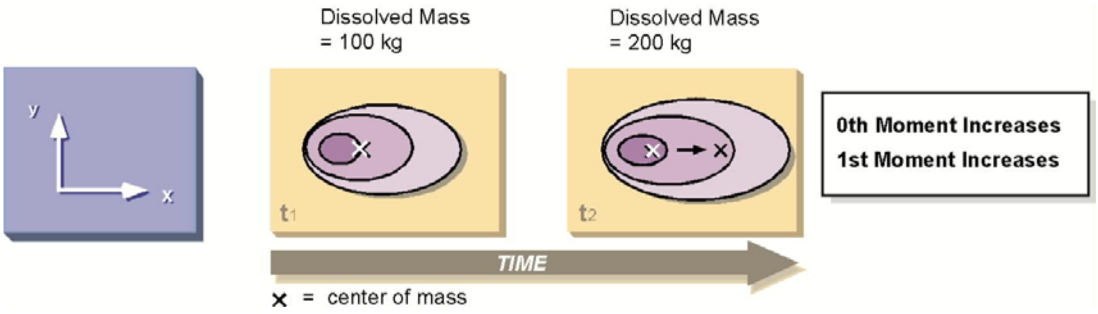


Figure A.5.3 Moment Analysis Mann-Kendall First Moment Trend Results: Zeroth Moment (Dissolved Mass) Increases over time and the First Moment Increases over time.

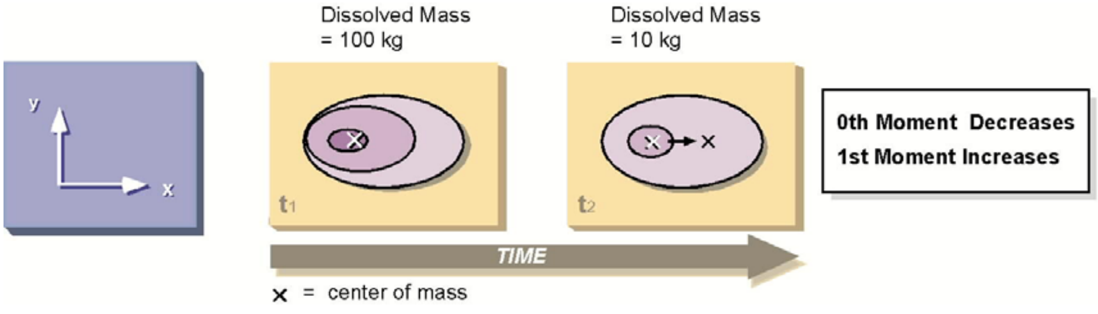


Figure A.5.4 Moment Analysis Mann-Kendall First Moment Trend Results: Zeroth Moment (Dissolved Mass) Decreases over time and the First Moment Increases over time.

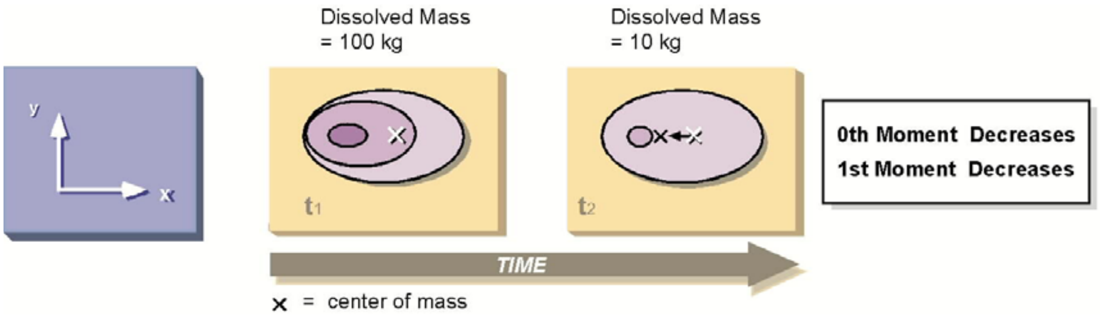


Figure A.5.5 Moment Analysis Mann-Kendall First Moment Trend Results: Zeroth Moment (Dissolved Mass) Decreases over time and the First Moment Decreases over time.

Second Moment Trend: The Second Moment trend indicates the spread of the plume about the center of mass. Analysis of the spread of the plume should be viewed as it relates to the direction of groundwater flow. An increasing trend in the second moment indicates an expanding plume, whereas a declining trend in the plume indicates a shrinking plume. No appreciable movement or a neutral trend in the center of mass would indicate plume stability. The second moment provides a measure of the spread of the concentration distribution about the plume's center of mass. However, changes in the second moment over time do not necessarily completely characterize the changes in the concentration distribution (and the mass) over time. Therefore, in order to fully characterize the plume the Second Moment trend should be compared to the Zeroth moment trend (mass change over time), refer to Figures A.5.6 – A.5.8.

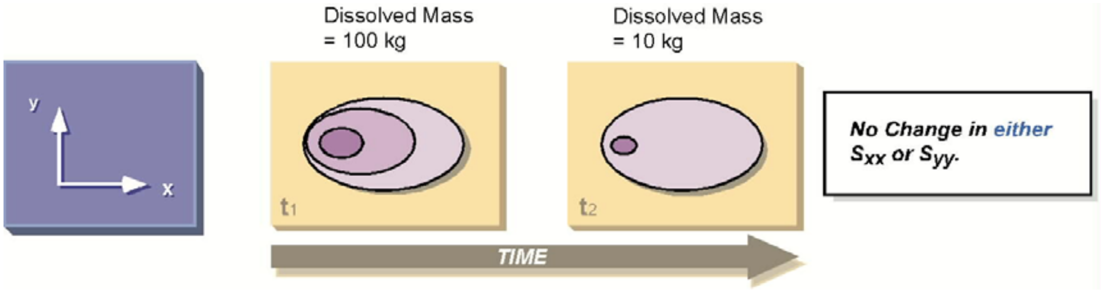


Figure A.5.6 Moment Analysis Mann-Kendall Second Moment Trend Results: No Change in trend of either Sxx or Syy (both parallel and perpendicular to the plume center line), Mass Decreases over time.

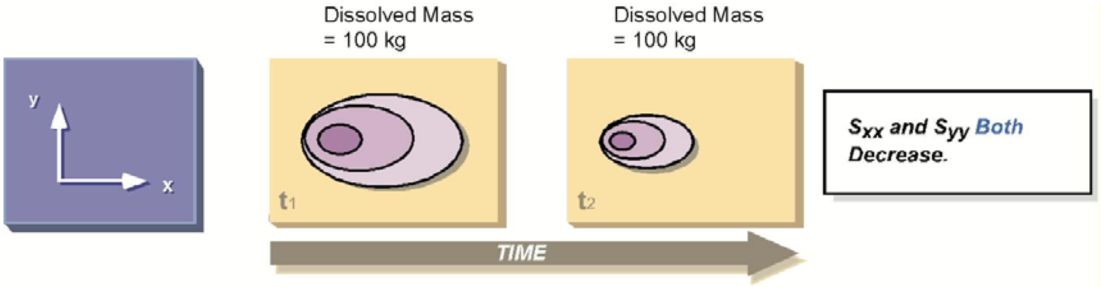


Figure A.5.7 Moment Analysis Mann-Kendall Second Moment Trend Results: Decreasing Trend in both Sxx and Syy (both parallel and perpendicular to the plume center line), no change in Mass over time.

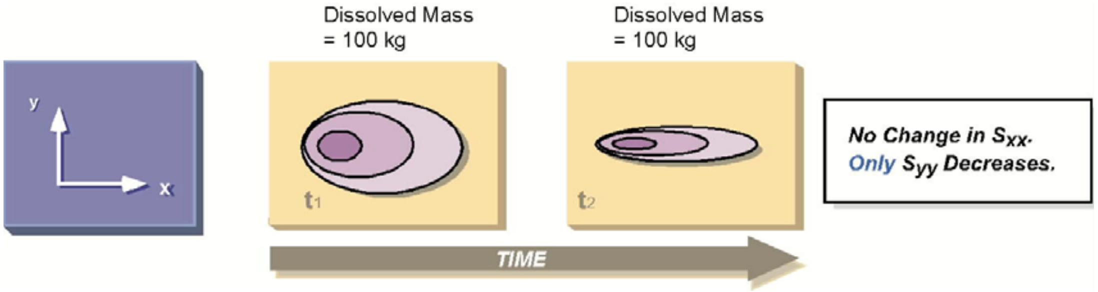


Figure A.5.8 Moment Analysis Mann-Kendall Second Moment Trend Results: Decreasing Trend in Syy (perpendicular to the plume center line), no change in mass over time.

Redundant Well Removal

Moment analysis can also be used to evaluate the effect of removing wells from a monitoring program. The question this analysis answers is whether or not removing a well from the well network will appreciably effect future plume delineation. The application of this technique involves analyzing how the moments would change if wells were removed from historical data sets.

Historical data used in plume delineation is evaluated for zeroth, first and second moments including all wells in a monitoring program and then again, excluding the wells proposed for elimination. The values determined for mass, center of mass and spread of mass can be compared to determine how plume delineation would change if wells are removed. If removal of a well has significant impact on plume delineation, then the well should be maintained in the monitoring program.

For example, if one were to choose a candidate (or several) well to remove from the monitoring program, you could go back into the historic data and perform moment analysis on the data set minus the candidate well. If similar zeroth, first and second moments were generated, then removing the wells would be not significantly effect the future delineation of the plume through a revised groundwater sampling network. Validation of removing a well from a monitoring program can be especially helpful when the water analysis alternates between non-detect and detection of very low concentrations.

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APPENDIX A.6 DATA SUFFICIENCY ANALYSIS

Authors: Ling, M. and Rifai, H. S., University of Houston; Vanderford, M., Groundwater Services, Inc..

The sufficiency of data, in the statistical context, refers to whether the observed data are adequate, both in quantity and in quality, for revealing changes in the variable of interest. In long-term groundwater monitoring, there are at least two conditions that require sufficiency analysis: 1) the need to increase confidence in individual well monitoring results or to detect subtle changes in contaminant concentrations at specific locations; and 2) an overall adequate monitoring program that is not adequate at specific sampling points (e.g., the sampling frequency in a well at the plume edge is too low to reflect a possible sudden change in concentrations). Statistical power analysis can be used to evaluate the sufficiency of data for groundwater LTM plans.

This appendix details the two posterior statistical power analysis methods employed in the *Data Sufficiency Analysis* module of the MAROS software. These statistical power analysis methods are designed to assess: 1) the cleanup status at individual wells; and 2) a risk-based cleanup status for the entire site. An example question arising from these evaluations is what to do next if cleanup cannot be confirmed due to large data variability. Results from these analyses provide hints that are helpful in answering these questions and suggestions for expansion or redundancy reduction of future sampling plans.

The two statistical power analysis methods are introduced in two different sections in this Appendix following a brief introduction of the technique itself.

The Basics of Statistical Power Analysis

Statistical hypothesis tests are widely used in monitoring evaluations such as the statistical tests involved in the three tasks mentioned above. For any statistical test, there are two types of error associated with the null hypothesis (H_0) and the alternative hypothesis (H_1): false positive (type I error) and false negative (type II error). These concepts are illustrated in Table A.6.1. False positive refers to the decision that the null hypothesis is rejected when in fact it is true; false negative is failing to reject the null hypothesis when it does not hold. Correspondingly, the false positive rate (denoted by α) is the probability of incorrectly declining the null hypothesis and the false negative rate (denoted by β) is the probability of incorrectly accepting the null hypothesis. Statistical power is equal to 1 - β, the probability of correctly rejecting the null hypothesis when it is not true.

Table A.6.1 Two types of error in a statistical test

True condition in the well	Decision based on a statistical sample	
	H_0: Site Not Contaminated	*H_1: Site Contaminated*
Not Contaminated	Correct Conclusion (Probability = 1- α)	False Positive (Probability = α)
Contaminated	False Negative (Probability = β)	Correct Conclusion (power) (Probability = 1- β)

The power of statistical tests is dependent upon the following design parameters: 1) the false positive rate (also called the significance level); 2) level of sampling effort (i.e., number of sampling points, frequency, and duration); 3) minimum detectable difference in the effect that can be detected; and 4) natural variability within the sampling environment. This relationship between the power of a statistical test and the design parameters makes several types of power analyses possible. The power of the test can be determined as a function of any of these design parameters. Alternatively, the value of any individual design parameter required to obtain a specified power of a statistical test can be determined as a function of the other parameters. With this type of approach, a relationship between the number of sampling locations, sampling frequency, the minimum difference that can be detected in the monitored variable, and the natural variability of the monitored variable can be established, and their trade-offs can be studied.

For example, Figure A.6.1 includes two power curves for the detection of changes in dissolved oxygen with a sample size of 8 and a significance level of 0.05. If the minimum detectable difference is 0.4 mg/L and the sample standard deviation is 0.5 mg/L, the power to detect this change is 0.7. If the sample standard deviation is 1.0 mg/L, the power to detect this change is dramatically reduced to less than 0.3. If the same level of power (0.7) is to be maintained, the minimum detectable difference doubles (0.8 versus 0.4) for the sample with a higher variability ($\sigma = 1.0$). Therefore, the sufficiency or power of a sampling plan can be evaluated in terms of the goal established in the sampling plan.

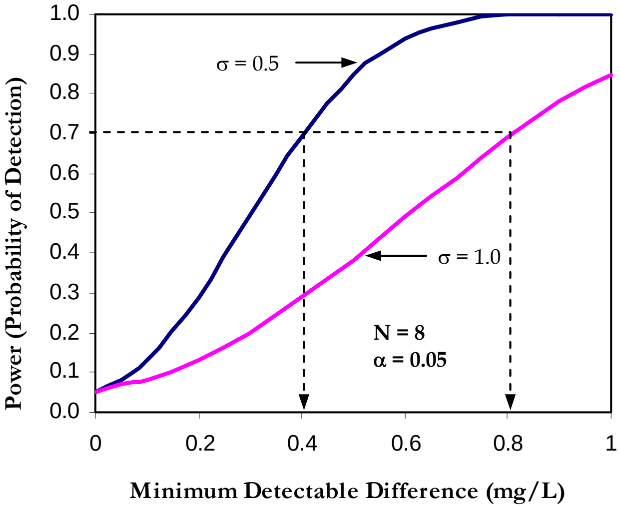


Figure A.6.1 Power curves for different variability

Statistical power analysis provides additional information for interpreting the results of statistical tests. The additional information includes: 1) the power of the statistical test (e.g., tests for trend or mean difference for individual wells or a group of wells); and 2) the expected sample size of a future sampling plan given the minimum detectable difference it is supposed to detect. Such information can assist users in modifying sampling plans to effectively achieve monitoring goals.

Power Analysis for Individual Well Cleanup Status

Before testing the cleanup status for individual wells, one important issue must be considered: the stability or trend of the contaminant plume. Only after the plume has reached or is reaching steady state can we conduct a test to examine the cleanup status of wells. Applying the analysis to wells in an expanding plume may cause incorrect conclusions and is less meaningful.

Although in long-term monitoring the site may require many years to attain site cleanup, individual wells become clean gradually, beginning with the tail wells and followed by the source wells. If we can show that the average concentration in a well is below the cleanup level with statistical significance, we can eliminate it from the monitoring network or at least reduce its frequency of sampling. If the average concentration is lower than the cleanup level but is not significant, we can find out by power analysis how many more samples need to be collected to confirm the cleanup (with data variability unchanged).

For cleanup status evaluation, a modified sequential t-test for assessing attainment of cleanup standards based on the mean contaminant levels is adopted (U.S. EPA 1992). The test procedures involve several steps. First, two statistics, δ and t, need to be calculated based on the yearly averages, i.e., the annual mean concentrations. When calculating δ and t, the untransformed yearly averages are used if they follow normal distribution (U.S. EPA 1992, p9-12). The log-transformed yearly averages are used if they are more likely to be lognormally distributed. Second, the likelihood ratio estimator LR is calculated as:

$$LR = \exp\left(\delta \frac{n-2}{n} t \sqrt{\frac{n}{n-1+t^2}}\right) \qquad \text{(Equation A.6-1)}$$

where n is the number of yearly averages or log-transformed yearly averages. LR is then compared with two critical statistics A and B to determine the cleanup status. A and B are defined as:

$$A = \frac{\beta}{1-\alpha} \text{ and } B = \frac{(1-\beta)}{\alpha} \qquad \text{(Equation A.6-2)}$$

where α is the type I error (i.e., significance level or false positive rate) and β is the type II error (i.e., false negative rate). When $LR < A$, cleanup standards have not been attained. When $LR > B$, cleanup standards have been attained (statistically significant). When LR is between A and B, future tests need to be performed when more sampling data become available (not statistically significant). In the MAROS *Data Sufficiency Analysis* module, a well is considered to have attained the cleanup standards only when LR > B and the concentration trend is not “Increasing” as defined in the Modified CES method.

The sequential t-test uses an easy-to-calculate approximation for the likelihood ratio. The use of log-transformed yearly averages improves the test performance with skewed data. It reduces the number of samples compared to that for an equivalent fixed sample size test, and has a low false positive rate and an acceptable false negative rate. According to the simulation results, for correlated data, skewed data, or correlated and skewed data, either normally distributed or lognormally distributed data, the log likelihood ratio method performs best among the other methods tested (U.S. EPA 1992).

This sequential t-test has several advantages. First, for assessing attainment, the objective is to test a hypothesis rather than to obtain an unbiased estimate of the mean or construct a confidence interval. Second, if the concentrations at the site are indeed below the cleanup standards, maintaining the expected power at the alternative hypothesis can protect against incorrectly concluding that additional cleanup or monitoring is required. Third, reducing the sampling size results in cost savings for the monitoring program. Fourth, a good estimate of the measurement variance for calculating the sample size for the fixed size test may not be available.

In cases where there are not enough yearly averages available for analysis, the original data from each sampling event (without being yearly-averaged) are also allowed for the sequential t-test. An option is provided in MAROS for the user to choose between the two types of data.

An optional power analysis to the cleanup status evaluation is also provided. This analysis uses the Student's t-test on mean difference to determine: 1) whether the mean concentration in a well is significantly below the cleanup goal; 2) the power associated with this test; and 3) the expected sample size in order to achieve the desired power. Because power analysis is difficult to perform for the sequential t-test but easy for the Student's t-test, the optional power analysis is provided in MAROS as an alternative for assessing data sufficiency associated with the cleanup status evaluation.

To determine if the mean concentration is statistically below the cleanup goal, a significance test based on the following statistic is used:

$$t = \frac{m - c}{\sqrt{s / n}} \qquad \text{(Equation A.6-3)}$$

where c is the cleanup goal (e.g., MCL), m and s are the sample mean and standard deviation respectively, n is the number of concentration data in the sample, and t is the test statistic following the Student's $\boldsymbol{t}$ distribution with n-1 degrees of freedom. When log-transformed data are used (i.e., under lognormal distribution assumption), c is the logarithmic cleanup goal, and m and s are the mean and standard deviation of the log-transformed data, respectively. Same as in the sequential t-test, both yearly averages and original data can be used in the optional analysis.

The significance of the test is found by comparing the test statistic t with the critical $\boldsymbol{t}$ value under significance level α. If t is less than the critical $\boldsymbol{t}$ value and both of them are negative, the test is *Significant* indicating the mean concentration is below the cleanup goal. Otherwise, the test is *Not Significant* indicating the mean concentration is not significantly below or is higher than the cleanup goal. The critical $\boldsymbol{t}$ value, or quantile, is obtained using the Microsoft Excel function *TINV()*.

In calculating statistical power and the expected sample size associated with the Student's t-test, an approximate power equation from Cohen (1988) is adopted in MAROS *Data Sufficiency Analysis*. The approximate power equation is:

$$Z_{1-\beta} = \frac{d(n-1)\sqrt{2n}}{2(n-1) + 1.21(Z_{1-a} - 1.06)} - Z_{1-a} \qquad \text{(Equation A.6-4)}$$

where α is the significance level, β is the type II error, n is the sample size, d is the effect size, and Z is the percentile of the standard normal distribution. The effect size d is calculated as:

$$d = \frac{m - c}{s}\sqrt{2} \qquad \text{(Equation A.6-5)}$$

where c is the cleanup level (e.g., MCL), m and s are sample mean and standard deviation, respectively. When log-transformed data are used, c is the logarithmic cleanup goal, and m and s are the mean and standard deviation of the log-transformed data, respectively.

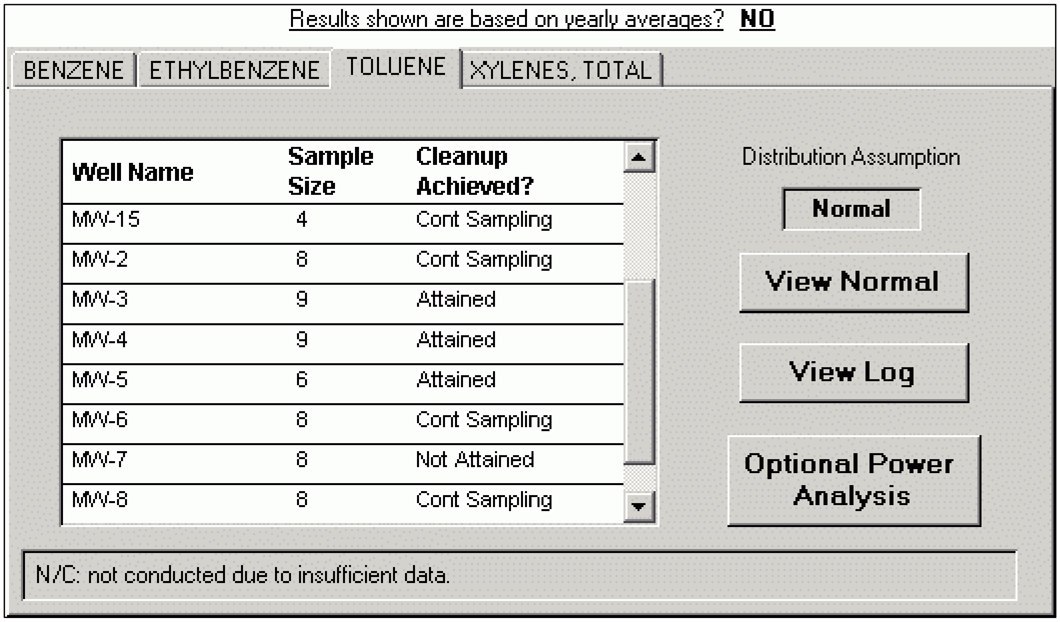
Statistical power (i.e., 1-β) is obtained by transforming $Z_{1-\beta}$ to probability using Microsoft Excel function *NORMSDIST()*. Given α, β (i.e., 1-power), and d of the sample, the expected sample size n can be solved from Equation A.6-4 using *Newton-Raphson* algorithm.

Two tests for the cleanup status evaluation are introduced above: the sequential t-test and the Student's t-test. Results from the two tests on a same dataset have the following relationships: 1) *Not Attained* always corresponds to *Not Significant*; 2) *Attained* always corresponds to *Significant*; and 3) *Cont. Sampling* may correspond to *Not Significant* or *Significant* because of the difference between the two tests. Significance result from the Student's t-test can be used as a secondary indication of cleanup status. Power and the expected sample size from the optional analysis can be used to indicate data sufficiency.

RESULTS AND INTERPRETATION OF RESULTS

The results of individual well cleanup status evaluation are presented in the *Individual Well Cleanup Status Results* and *Individual Well Cleanup Status – Optional Power Analysis* screens described in the *MAROS Detailed Screens Description* chapter. Power analysis parameters involved in the evaluation (see screen *Data Sufficiency Analysis – Options*) include:

Cleanup Goal: The cleanup standard for a COC, also called the primary remediation goal (PRG). The default cleanup goal for a COC is its MCL, if available in MAROS database.


Results shown are based on yearly averages? **NO**

Well Name	Sample Size	Cleanup Achieved?
MW-15	4	Cont Sampling
MW-2	8	Cont Sampling
MW-3	9	Attained
MW-4	9	Attained
MW-5	6	Attained
MW-6	8	Cont Sampling
MW-7	8	Not Attained
MW-8	8	Cont Sampling

Distribution Assumption: Normal

N/C: not conducted due to insufficient data.

Figure A.6.2 Individual well cleanup status – results based on the Sequential t-test.

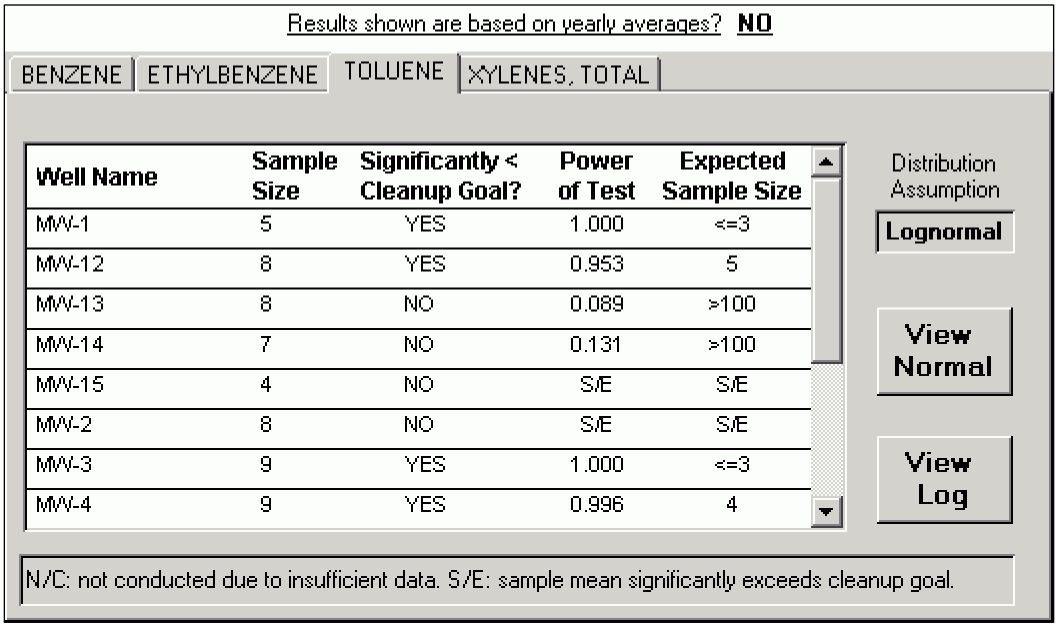
TargetLevel: The concentration level of COC in the well after attaining the cleanup goal. The default value for this parameter is set to 0.8 times the cleanup goal. This parameter is only used in the sequential t-test. The difference between the *Cleanup Goal* and the *TargetLevel* is the minimum detectable difference the sequential t-test is supposed to detect.

AlphaLevel: The significance level (type I error or false positive error rate) used for all statistical tests in MAROS *Data Sufficiency Analysis*. The default value for this parameter is 0.05.

TargetPower: The desired statistical power of all statistical tests in MAROS *Data Sufficiency Analysis*. The default value is 0.80.

Results from the sequential t-test and the optional power analysis are illustrated in Figure A.6.2 and A.6.3, respectively. Cleanup status, power, and expected sample size for each well with at least four samples (yearly averages or original data) are calculated for two distributional assumptions: normal and lognormal. When there are less than four data records, *NC* is displayed in result fields indicating the analysis is not performed due to insufficient data.

Cleanup Achieved? (Figure A.6.2) indicates whether the mean contaminant concentration at a well is below the cleanup goal with statistical significance using the sequential t-test. *Attained* indicates the mean concentration is significantly below the cleanup goal, and has achieved the *TargetLevel*. *Attained* is always supported by a sufficient power (equal to or greater than the expected power). Therefore, the cleanup goal has been attained and the well may be eliminated from the monitoring network. *Not Attained* indicates the mean concentration is higher than the cleanup goal. *Cont. Sampling* indicates although the mean concentration is below the cleanup goal, it is not statistically significant because 1) the mean concentration does not achieve the *TargetLevel* or 2) the existence of large data variability prevents the test from resulting in significance. The latter case corresponds to an inadequate power in the test. In the case of *Cont. Sampling*, more samples are to be collected for a future re-evaluation.



Results shown are based on yearly averages? **NO**

Well Name	Sample Size	Significantly < Cleanup Goal?	Power of Test	Expected Sample Size
MW-1	5	YES	1.000	<=3
MW-12	8	YES	0.953	5
MW-13	8	NO	0.089	>100
MW-14	7	NO	0.131	>100
MW-15	4	NO	S/E	S/E
MW-2	8	NO	S/E	S/E
MW-3	9	YES	1.000	<=3
MW-4	9	YES	0.996	4

Distribution Assumption: **Lognormal**

N/C: not conducted due to insufficient data. S/E: sample mean significantly exceeds cleanup goal.

Figure A.6.3 Individual well cleanup status – results from the optional analysis.

Yearly averages? indicates the type of data used in the evaluation (yearly averages or original data without being yearly-averaged). If there are many years of data, using yearly averages is recommended because it can reduce the influence of seasonal variation and serial correlation.

Distribution Assumption shows the assumption of data distribution for the results currently shown. Results for both normal and lognormal assumptions are given. Because normality tests for small size sample (e.g., <20) may not be accurate, presenting results under both assumptions provides a chance for comparison so that the conservative results may be used.

Significantly < Cleanup Goal? (Figure A.6.3) indicates whether the mean contaminant concentration at a well is below the cleanup goal with statistical significance using the Student's t-test in the optional analysis. *YES* indicates the mean concentration is significantly below the cleanup goal, supported by a power equal to or greater than 50%, although may not be as high as the expected power. Therefore, this result is also an indication of well cleanup but secondary to the sequential t-test. *NO* indicates the mean concentration is 1) higher than the cleanup goal or 2) below the cleanup goal but not statistically significant because the existence of large data variability prevents the test from resulting in significance. The latter case corresponds to an inadequate power in the test. In the case of *NO*, sampling should be continued. In the case of *YES*, the result from the sequential t-test should be consulted as to whether to continue sampling or stop sampling.

Power of Test (Figure A.6.3) is the probability (associated with the Student's t-test) that a well is confirmed to be clean when the mean contaminant concentration is truly below the cleanup goal. A value close to 1.0 may indicate that the data are distributed very close to the sample mean or the coefficient of variation is very small (a small variability). A value close to 0 indicates the opposite, requiring collecting more samples for a future re-evaluation. A value greater than the expected power indicates data in the well provide sufficient information.

Expected Sample Size (Figure A.6.3) is the number of samples (associated with the Student's t-test) required to achieve the expected power with the variability shown in the data. The smaller the value, the smaller the data variability and the higher the statistical power. If the expected sample size is smaller than the sample size, the sampling frequency at this well may be reduced. If the expected sample size is greater than the sample size, more samples are needed to confirm the cleanup status.

Risk-Based Power Analysis for Site Cleanup Evaluation

The use of risk-based goals in managing contaminated sites requires that cleanup standards be met at the compliance boundary. In order to perform a sufficiency analysis at the compliance boundary, a strategy was developed as follows. First, select monitoring wells along the plume centerline and regress concentrations from these centerline wells against their distances down the plume centerline with an exponential model. Second, for each monitoring well, project its concentration to the compliance boundary using the exponential model with its distance to the compliance boundary. Third, these projected concentrations at the compliance boundary constitute a group of estimated concentrations that can be evaluated by statistical power analysis. The result from this type of power analysis provides a statistical interpretation of whether the risk-based site cleanup goal has been met.

The exponential regression model is:

$$y = A \cdot EXP(Bx) \qquad \text{(Equation A.6-13)}$$

where A and B are regression coefficients, x is the distance from a plume centerline well to the plume source, and y is the concentration at this well. This regression follows the concept of bulk attenuation rate in natural attenuation, which assumes that the spatial change in plume concentrations can be modeled as exponentially decaying with distance downgradient from the source (ASTM 1998). Two types of data can be used for this regression: 1) data from monitoring wells points located on or close to the centerline; and 2) data estimated from hypothetical sampling points on the centerline through plume contouring. The first type of data yields more accurate results than the second type and therefore is used in the risk-based power analysis. The user should select at least three plume centerline wells for the regression analysis (see screen

Parameters for Risk-Based Power Analysis in chapter *Detailed Screen Description*). For convenience, linear regression with log-transformed concentrations is used in MAROS *Data Sufficiency Analysis* to estimate coefficients *A* and *B*. Note *B* should be a negative value indicating declining concentrations away from the source.

The compliance boundary is assumed to be a line perpendicular to the preferential ground flow direction that is located at or upgradient of the nearest downgradient receptor (Figure A.6.5). The user is asked to specify the whereabouts of the compliance boundary by providing the distance from the most downgradient well to the compliance boundary (see screen *Parameters for Risk-Based Power Analysis* in chapter *MAROS Detailed Screen Description*).

The projected concentrations are calculated by using Equation A.6-12 with the distance from each well to the compliance boundary. The projected concentrations from each sampling event are then used in the risk-based power analysis. Since there may be more than one sampling event selected by the user, the risk-based power analysis results are given on an event-by-event basis.

To determine the site cleanup status, a significance test based on the following statistic is used:

$$t = \frac{m - c}{\sqrt{s / n}} \qquad \text{(Equation A.6-14)}$$

where *c* is the cleanup goal, *m* and s are the mean and standard deviation estimated from the projected concentrations respectively, *n* is the number of projected concentrations, and *t* is the test statistic following ***t*** distribution with *n-1* degrees of freedom. When log-transformed data are used (i.e., under lognormal distribution assumption), *c* is the logarithmic cleanup level, and *m* and *s* are the mean and standard deviation of the projected concentrations, respectively.

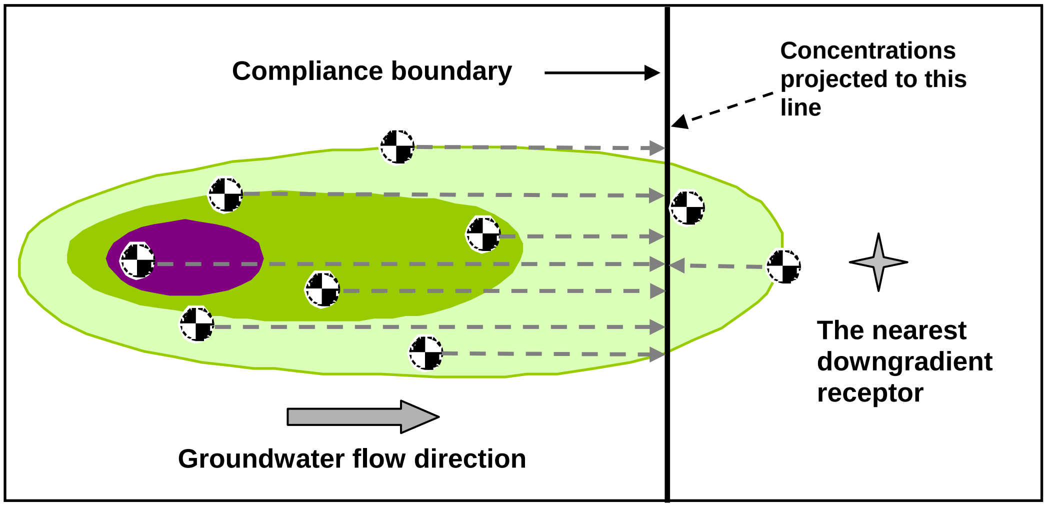


Figure A.6.5 Illustration of projected concentrations for risk-based power analysis.

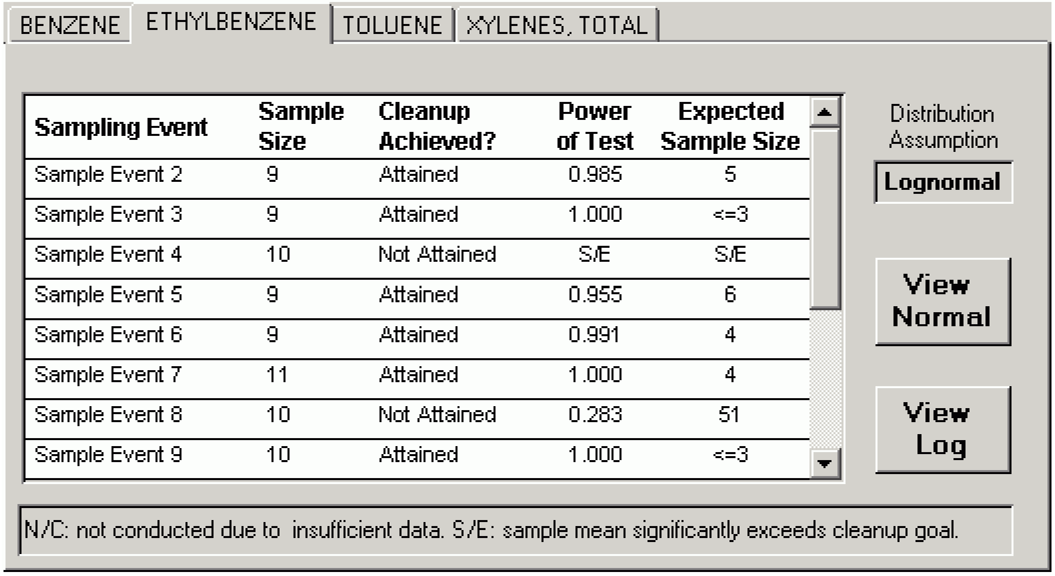
The significance of the site cleanup test is found by comparing the test statistic *t* with the critical ***t*** value under significance level α. In calculating statistical power and the expected sample size, Equation A.6-4 and Equation A.6-5 are used but with the statistics introduced in Equation A.6-14.

RESULTS AND INTERPRETATION OF RESULTS

The results of risk-based site cleanup evaluations are presented in the *Risk-Based Power Analysis Results* screen introduced in the *MAROS Detailed Screens Description* chapter. The site cleanup status, power, and expected sample size for each sampling event with at least six projected concentrations are calculated under both normal and lognormal assumptions (Figure A.6.6). When a sampling event has less than six projected concentrations (insufficient data) or the mean projected concentration is higher than the cleanup goal, *N/C* or *S/E*, respectively, are displayed in result fields indicating the analysis is not conducted.

<u>Cleanup Achieved?</u> presents the risk-based site cleanup status at the compliance boundary at the time when the sampling event was taken. The result indicates whether the mean projected concentration at the compliance boundary is below the cleanup level with statistical significance. Results could be *Attained* (cleanup goal achieved), *Not Attained* (cleanup goal not achieved), or *NC* (not conducted due to insufficient data). The results may be different over time (i.e., over sampling events selected). The results as a function of time can be used to evaluate the effectiveness of site remedial actions.

<u>Power of Test</u> is the probability that the site is confirmed to be clean when the projected mean concentration level at the compliance boundary is truly below the cleanup goal. A value close to 1.0 may indicate that the data are distributed very close to the sample mean or the coefficient of variation is very small (a small variability). A value close to 0 indicates the opposite, requiring more sampling locations for the analysis to reach a higher power. A value greater than the expected power means that data from the monitoring network provides sufficient information for the risk-based site cleanup evaluation.



Sampling Event	Sample Size	Cleanup Achieved?	Power of Test	Expected Sample Size
Sample Event 2	9	Attained	0.985	5
Sample Event 3	9	Attained	1.000	<=3
Sample Event 4	10	Not Attained	S/E	S/E
Sample Event 5	9	Attained	0.955	6
Sample Event 6	9	Attained	0.991	4
Sample Event 7	11	Attained	1.000	4
Sample Event 8	10	Not Attained	0.283	51
Sample Event 9	10	Attained	1.000	<=3

Distribution Assumption: Lognormal

N/C: not conducted due to insufficient data. S/E: sample mean significantly exceeds cleanup goal.

Figure A.6.6 Plume-level data sufficiency results

<u>Expected Sample Size</u> is the number of projected concentrations (i.e., the number of wells) required to achieve the expected power (e.g., 0.80) with the variability shown in the projected concentrations. The smaller the value, the smaller the data variability and the higher the statistical power. If the expected sample size is smaller than the sample size, the monitoring network has more than enough wells to detect the risk-based site cleanup status. If the expected sample size is greater than the sample size, more sampling locations are needed to confirm the cleanup status.

<u>Distribution Assumption</u> shows the assumption of data distribution for the results currently shown. Results for both normal and lognormal assumptions are given. Because normality tests

for small size sample (e.g., <20) may not be accurate, presenting results under both assumptions provides a chance for comparison so that the conservative results may be used.

In addition to *AlphaLevel* and *TargetPower*, power analysis parameters used in the risk-based site cleanup evaluation include:

Detection Limit: The uniform detection limit for a COC specified by the user. It is only used in the risk-based power analysis to indicate that the projected concentrations are below the detection limit. The detection limit for a COC is by default set to 20% of the MCL of a COC, if available in MAROS database.

References

ASTM, 1998, *Standard Guide for Remediation of Groundwater by Natural Attenuation at Petroleum Release Sites*, American Society of Test and Material, E1943-98.

Cohen, J., 1988, *Statistical Power Analysis for the Behavioral Sciences,* Lawrence Erlbaum Associates, Hillsdale, New Jersey.

U.S. EPA, 1992, *Methods for Evaluating the Attainment of Cleanup Standards Volume 2: Ground Water*, Environmental Statistics and Information Division, Office of Policy, Planning, and Evaluation, U.S. Environmental Protection Agency.

APPENDIX A.7 FALSE POSITIVE/NEGATIVE MINIMIZATION METHODOLOGY

Authors: Ling, M. and Rifai, H. S., University of Houston.

This appendix introduces the methods and strategies for minimizing false positive and false negative error rates in the statistical analysis of monitoring data. Most of the methods introduced in this appendix have not been implemented in the MAROS software. This appendix serves as a supplementary information source for those who have a deeper interest in this issue.

Introduction

Data evaluation is an essential part of a long-term monitoring program in that it aids in making decisions regarding plume conditions and the appropriate response measures. Uncertainty in the sample data can cause false positives and false negatives in the data evaluation procedure resulting in misleading or incorrect conclusions. False positive refers to falsely concluding the presence of a condition when it is in fact not present. False negative refers to the failure of recognizing the presence of a condition when it is present. In groundwater monitoring, for example, this condition could be the contamination of groundwater by petroleum hydrocarbons. The uncertainty that causes false positives and false negatives comes from three primary sources: (1) sampling uncertainty, which originates from sampling procedures; (2) analytical uncertainty, which governs the ability to detect and quantify the level of a particular contaminant; and (3) spatial and temporal variations, which control the ability to determine the significance of changes within a population using the sample data.

Sampling uncertainty is the result of field sampling procedures where systematic errors or random errors may exist in the processes of purging the well, collecting a sample, performing field tests, recording the test results, and preserving and transporting the sample. Designing appropriate sampling routines and employing an experienced sampling team can reduce sampling uncertainty.

Analytical uncertainty is caused by uncertainty associated with laboratory analysis of a sample. Lab analysis is affected by the detection and quantitation methods of a particular contaminant and the stability of laboratory performance. Using approved analytical methods and having samples analyzed by a laboratory with rigorous quality control protocols can reduce analytical uncertainty.

Spatial variation and temporal variation are caused by natural variability, which is inherent in any subsurface system. Spatial variation refers to the different level of contamination or different degree of uncertainty at different spatial locations. Temporal variation refers to systematic time effects in addition to random measurement errors. Unlike the first two kinds of uncertainty, which can be avoided or reduced by a well-planned sampling strategy and analytical protocols, uncertainty associated with natural variability can only be understood using appropriate statistical techniques.

The intent of this appendix is to develop data evaluation strategy using appropriate statistical techniques which will reduce the probability of making false positive and false negative decisions. Therefore only the last type of uncertainty (i.e., uncertainty due to natural variability) is considered in this study, assuming that the first two types have already been addressed. Problems involving spatial correlation or temporal correlation between measurements will also be considered. These correlations, if not addressed, cause violations of the statistical assumptions that underlie most statistical methods and cause excessive false positive and false negative rates during the statistical tests.

A thorough evaluation for optimization of a long-term monitoring program not only includes the development of an appropriate data evaluation strategy, but also requires a qualitative review of the program to determine the value of the information generated by monitoring each well. Factors such as the location of the screened intervals of monitoring wells in relation to water-bearing zones and the hydrogeologic position of each monitoring point in relation to the plume should be considered. For example, a well screened at an incorrect interval in relation to the water-bearing zone will provide misleading information regarding contaminant concentrations. The use of sample data from this well in the data evaluation process will lead to high false positive or false negative rates. Therefore, before proceeding with the details of this study we will briefly review major problems that affect the quality of sample data and ways to address them.

QUALITATIVE EVALUATION OF GROUNDWATER MONITORING PROBLEMS

Kufs (1994) has provided a comprehensive analysis of problems that may affect groundwater monitoring and has provided response measures for these problems. The identified problems include sample space, system implementation, program implementation, geologic uniformity, hydrologic uniformity, and geochemical interaction. The first three types of problems that are relatively important in terms of generating useful information are reviewed below.

Sample space problems occur when the wells in a system are inappropriately located for monitoring a specified volume of the aquifer. Typical sample space problems include:

- Inadequate arrangement of wells for evaluating the extent of contamination;
- Improper selection of screen setting or length;
- Inappropriate overall system design.

For example, well screens not set to span an appropriate hydrostratigraphic zone can cause sample problems. The remedies for sample space problems include installing additional wells, resampling the wells, or deleting anomalous data collected from the suspect wells. Details for the prevention, recognition and correction of typical sample space problems are presented in Table A.7.1.

System implementation problems refer to situations in which wells or other elements of the system do not perform as designed. Typical problems include:

- Well does not produce sufficient water;
- Well silts up after installation;
- Sand pack becomes clogged;
- Well seals leak;
- Well materials degrade;
- Well is poorly constructed.

For example, a well that dries or recharges too slowly to be sampled effectively is an indication of system implementation problems. The remedies for system implementation problems include redeveloping the well, redesigning a new well, or abandoning and replacing the well. Details for the prevention, recognition, and correction of typical system implementation problems are presented in Table A.7.2.

Program implementation problems refer to situations in which field data collection or laboratory analysis procedures fail to produce high quality data. Typical problems include:

- Well construction is not adequately documented;
- Field data collection procedures are inadequate;
- Sample collection procedures are inappropriate;
- Sample analysis procedures are inadequate or undocumented.

Examples of program implementation problems include missing or ambiguous data, different results for duplicated samples, and presence of chemicals in blanks. The remedies for program implementation problems include resampling using improved protocols, employing more experienced personnel, and employing a reputable laboratory for analysis. Details for the prevention, recognition, and correction of typical program implementation problems are presented in Table A.7.3.

A monitoring system with the above problems will appear to be functioning properly, but will actually be producing data that are misleading, uninterpretable, or incorrect. The qualitative evaluations described above should be the initial steps used to reduce false positive and false negative rates. These steps should be performed before any of the data analyses or statistical approaches presented later in this appendix are employed.

Table A.7.1 Prevention, Recognition and Correction of sample space problems*

Problem	Prevention	Recognition	Correction
1. Wells not positioned for identifying groundwater flow directions	Use basic hydrogeologic assumptions to estimate flow directions. Use ground-penetrating radar (GPR), if possible, to evaluate the validity of the assumptions.	Water elevations do not produce a unique contour pattern; too few wells screened in the same zone; wells installed essentially along a line.	Install additional wells or find existing wells screened in the same water-bearing zone.
2. Wells not positioned for evaluating the extent of contamination	Estimate the distance the contaminant plume may have migrated from the site based on site history, hydrogeology, and contaminant geochemistry. Use aerial images or electromagnetic conductivity (EM) and soil-gas surveys to check estimation.	Contaminant concentrations do not produce a unique contour pattern; the contamination plume does not appear to be related to the suspected source, or the contaminant pattern suggests undocumented sources.	Install additional wells or find existing wells screened in the same aquifer. In some cases, soil-gas or EM surveys can be used to augment monitoring well networks.
3. Screen settings not correctly selected	Use background geologic and geochemical information and geophysical surveys to project contaminant flow. Compare information to on-site soil samples collected from boreholes.	Water elevations appear to be anomalous; apparent flow directions seem illogical or overly complex; information for on-site soil samples lower than expected.	Install additional wells or find existing wells screened in the same aquifer. In some cases, packers can be used to test specific zones.
4. Screen length not correctly selected	Use background information and geophysical surveys to project correct screen length to meet study objectives. Confirm length using soil samples collected from boreholes.	Water elevations appear to be anomalous; contaminant concentrations lower than expected.	Use packers to isolate zones in open-hole wells. Install additional wells.
5. System not adequately designed to accomplish study	Identify ultimate use of data and methods of data analysis to estimate minimum sample size.	Groundwater flow or contaminant migration appears to be ambiguous or illogical.	Resample wells and/or install additional wells. Augment direct data with indirect data (e.g., geophysics and soil-gas). Delete anomalous data collected from suspect wells.

* Adapted from Table 1 in Kufs (1994).

Table A.7.2 Prevention, Recognition and Correction of System implementation problems*

Problem	Prevention	Recognition	Correction
1. Well does not produce sufficient amounts of water	If consistent with monitoring objectives, screen well in coarse granular or highly fractured medium.	Well is dry or recharges too slowly to sample effectively.	Redevelop well. Deepen bedrock well if consistent with study objectives. Redesign new well.
2. Well silts up after installation	Select screen opening size and sand pack gradation to be compatible with geologic materials to be screened. Add a sump below the well screen.	Water is murky or bottom of well feels "mushy" when sounded.	Redevelop well periodically.
3. Sand pack becomes clogged	Specify a well-sorted (poorly graded) coarse-grained, washed quartz sand or gravel consistent with the aquifer material.	Well recharges much more slowly than expected.	Redevelop well periodically. Redesign new well.
4. Well seals leak	Design seals to be compatible with projected use of well and site hydrogeology and geochemistry. Monitor installation of seals closely by repeatedly measuring the depth to the seal.	Water elevation and quality on either side of the seal are more similar than expected.	Abandon leaking wells to prevent inter-aquifer leakage, and replace well.
5. Well materials are degraded by contaminants or fail structurally	Specify stainless steel for areas of high organic contamination and PVC or Teflon in areas of extreme pH. Specify appropriate material strength based on expected loads. Screen or overdrill highly fractured bedrock wells.	Obstructions found in the well. Aquifer materials that are larger than screen slots enter the well. Well yields decrease over time. Phthalates or inorganics increase over time.	Abandon and replace well.
6. Well is poorly constructed	Hire a reliable driller. Have an experienced hydrogeologist monitor well installation.	Evidence of poor workmanship at surface. Well is not vertical and aligned. Water levels and quality appear anomalous.	Abandon and replace well.

* Adapted from Table 2 in Kufs (1994).

Table A.7.3 Prevention, Recognition and Correction of program implementation problems*

Problem	Prevention	Recognition	Correction
1. Well construction not adequately documented	Require contractors to produce boring logs and as-built diagrams for each well installed. Have an experienced hydrogeologist monitor installation.	Construction details are missing, confusing, or are not consistent with measurements taken for the well.	Use downhole sensors and geophysical logs to approximate well construction details.
2. Field data collection procedures are inadequate	Use trained field staff and detailed protocols. Adapt the protocols to the geologic conditions and contaminants expected.	Data are missing or are ambiguous.	If necessary, resample the well using improved protocols and/or more experienced personnel.
3. Sample collection procedures are inadequate	Use trained field staff and detailed protocols. Adapt the protocols to the geologic conditions and contaminants expected.	Water quality data are confusing; usually volatile chemicals are at lower concentrations than expected, and other chemicals are present when they were not projected, especially in blanks.	If necessary, resample the well using improved protocols and/or more experienced personnel.
4. Sample analysis procedures are inadequate or are undocumented	Work closely with a reputable laboratory to design an appropriate analytical program.	Documentation is poor; duplicate samples yield varied results; laboratory blanks are severely contaminated; spike recoveries are poor.	If necessary, resample the well and have analyses conducted by a reputable laboratory.

* Adapted from Table 3 in Kufs (1994).

Statistical Concerns Regarding False Positive and False Negative Rates

As mentioned previously, false positives and false negatives are the two types of errors existing in any statistical tests concerning the null hypothesis (denoted as H_0; the alternative hypothesis is denoted by H_1). From the statistical definition, false positive refers to the decision that the null hypothesis is rejected when in fact it is true; false negative is failing to reject the null hypothesis when it does not hold. Correspondingly, the false positive rate (type I error rate α) is the probability of incorrectly declining the null hypothesis and false negative rate (Type II error rate β) is the probability of incorrectly accepting the null hypothesis. α is also referred to as the significance level of a statistical test. $1-\beta$ is equivalent to the power or sensitivity of a statistical test, and is the probability of correctly rejecting the null hypothesis when it is not true. These concepts are illustrated in Table A.7.4 and Table A.7.5 for two types of groundwater monitoring programs, respectively.

Two questions arise regarding the control of false positive and false negative rates in groundwater monitoring: (1) is it possible to completely avoid false posititves and false negatives? and (2) to what level can we reduce false positive and false negative rates?

For the first question it is important to recognize that false positives and false negatives in groundwater monitoring are inevitable because of natural variability or uncertainty due to spatial and temporal variations. In addition, analytical determinations associated with method detection limits (MDL) and practical quantitation limits (PQL) have false positive rates by design. For example, the false positive rate associated with MDLs for rarely detected constituents such as volatile organic chemicals (VOCs), is intended to be 1% or larger (Clayton 1987).

In practice, limiting factors such as the monitoring budget control the levels to which the false positive and false negative rates can be reduced. A lower error rate is generally achieved by increasing monitoring which can be expressed as cost. The additional cost of lowering false positive rates comes from taking additional samples and using more precise analytical protocols. Lowering false negative rates and requiring a simultaneous reduction of false positive rate usually can only be achieved by increasing sample size. Therefore, if a sampling strategy is sufficiently sensitive to detecting changes in contaminant concentrations at regulatory levels, its false positive and false negative rates should be acceptable and need not be further reduced.

Table A.7.4 Two types of error in detection monitoring

True condition in the well	Decision based on a statistical sample	
	H_0: Site Not Contaminated	*H_1: Site Contaminated*
Not Contaminated	Correct Conclusion (Probability = 1- α)	False Positive Rate* (Probability = α)
Contaminated	False Negative Rate (Probability = β)	Correct Conclusion (power) (Probability = 1- β)

* The type of error that may cause facility-wide problems

Table A.7.5 Two types of error in corrective action monitoring

True condition in the well	Decision based on a statistical sample	
	H_0: Contaminated (Does not attain the cleanup standard)	*H_1: Clean (Attains the cleanup standards)*
Clean	False Negative Rate* (Probability = β)	Correct Conclusion (power) (Probability = 1- β)
Contaminated	Correct Conclusion (Probability = 1- α)	False Positive Rate (Probability = α)

* The type of error that may cause facility-wide problems

TYPES OF GROUNDWATER MONITORING IN A LONG-TERM MONITORING PROGRAM

The type of groundwater monitoring program used affects the development of strategies for the control of false positive and false negative rates. In long-term monitoring programs, three kinds of groundwater monitoring may be involved: detection monitoring, compliance or assessment monitoring, and corrective action monitoring. These three types of groundwater monitoring are mandated by the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA or Superfund). The purposes and relationships of these monitoring programs are listed in Table A.7.6.

As is shown in Table A.7.6, each of the monitoring programs addresses different problems and therefore requires different statistical methods for testing the corresponding hypothesis. Since each monitoring program has a different objective, definitions of null hypotheses and their implications are different.

Table A.7.4 and Table A.7.5 illustrate the differences in definition of the two types of error for detection monitoring and corrective action monitoring. In detection monitoring, the false positive refers to the decision that the contamination is present in the groundwater when in fact it is not. The false negative is the decision that there is no contamination when in fact contamination is present. However, in corrective action monitoring, where the site is undergoing active or passive remediation such as monitored natural attenuation, the definition of the null hypothesis turns to the opposite. The false positive is then the mistake of concluding that the groundwater is clean when contamination is still present. The false negative becomes the conclusion that the groundwater requires additional treatment when in fact it has attained the cleanup standards. For compliance monitoring, the definition of null hypothesis could take the form of the detection monitoring or the corrective action monitoring, depending on the statistical methods used.

Table A.7.6 Three types of groundwater monitoring programs*

Type	Purpose	Intensity	Implemented when
Detection monitoring	Detect a release to groundwater	Sampling and analysis of 15 inorganic and 47 organic compounds	No release to groundwater has been confirmed
Compliance monitoring	Determine if the groundwater impact is significant	Extended sampling of up to 17 inorganic and 213 organic compounds	Release to groundwater has been confirmed by *detection* monitoring
Corrective action monitoring	Document the effectiveness of remediation and the attainment of cleanup standards	Extensive sampling for site characterization combined with remedial actions	A statistically significant groundwater impact has been confirmed by *compliance* monitoring

* Adapted from Weber (1995)

STATISTICAL ANALYSIS: UNDERLYING ASSUMPTIONS

An important statistical assumption that underlies all statistical methods used in groundwater monitoring is the assumption that observations are **independently** and **identically** distributed. This can be clarified using the following three assumptions:

- **Independence** — Data values used in a statistical test are independent of each other. This assumption forms the basis of both parametric and nonparametric tests used in groundwater monitoring. Correlation between observations resulting from spatial or temporal correlation may violate this assumption.
- **Homogeneity of Variances** — Data values used in a statistical test have equal variances for all values of the independent variables. This assumption forms the basis of both parametric and nonparametric tests used in groundwater monitoring. Natural spatial variation tends to violate this assumption when performing inter-well analyses.

  Inter-well analysis refers to statistical tests performed using measurements from different wells, e.g., upgradient versus downgradient comparisons. Intra-well analysis refers to statistical tests or analyses performed using measurements from the same well, e.g., comparing new monitoring measurements to statistics computed from historical measurements from the same well. The use of intra-well analysis can eliminate the problem caused by spatial variability between wells in different locations and should be used whenever possible.

- **Identically distributed** — Samples used in a statistical test have the same population distributions. This assumption forms the basis of parametric and most nonparametric tests used in groundwater monitoring. Most parametric statistical methods assume data or their transformations are normally distributed. For nonparametric tests, the distribution of data does not have to be normal but need to be identical in most cases.

> Sometimes the normality of data can be achieved by transforming the original observations to make them normally distributed (e.g., lognormal). An algorithm for choosing the best transformation power is available in Neter et al. (1996). Usually parametric methods need a smaller sample size and have a higher power than their nonparametric counterparts. It is recommended that parametric methods be used for data evaluation whenever possible.

The use of any statistical method that fails to take the above assumptions into consideration may result in excessive false positive and false negative rates.

FACILITY-WIDE FALSE POSITIVE/NEGATIVE RATE

Another issue needing consideration is the facility-wide false positive rate (FWFPR), also called site-wide or experiment-wise false positive rate. This happens when the monitoring status of a facility or site depends on the probability of obtaining a false positive with any parameter at any well at the facility or site. For example, in detection monitoring when any of the constituents in any monitoring well indicates an exceedence over the background, the site is declared contaminated and must enter into more extensive compliance monitoring. Even if the comparison-wise false positive rate is very low, the FWFPR associated with a large program can be greatly exaggerated and can often lead to a declaration of contamination. For instance, assuming the significance level or false positive rate of an individual comparison is α, and all comparisons are independent, the probability of at least one of n comparisons being significant by chance alone is given by:

$$\alpha^* = 1 - (1-\alpha)^n \qquad \text{(Eq-1)}$$

If $\alpha = 0.05$ and n = 60, the FWFPR α^* is 0.95. This indicates the site is almost certain to be declared contaminated when in fact no contamination is present.

The most effective way to control FWFPR is the combined use of Bonferroni inequality and verification resampling (Davis et al. 1994, Gibbons 1994). Bonferroni inequality works by inversely specifying the comparison-wise significance level α with a fixed FWFPR α^*:

$$\alpha = \frac{\alpha^*}{n} \qquad \text{(Eq-2)}$$

However, when n is large, α becomes too small and results in a dramatic decrease in the statistical power of an individual comparison. For example if $\alpha^*=0.05$ and $n=50$, α is then 0.001. This is one tenth of the regulatory performance standard of RCRA Interim Final Guidance Document (EPA 1989), which requires that the comparison-wise false positive rate α should be no less than 0.01.

The use of verification resampling can solve this problem. Davis et al. (1987) found that the controlled use of verification resampling can control FWFPR while maintaining sensitivity to contamination. There are two types of widely used verification resampling strategies: 1 of m plans and California plans. 1 of m plans declare a statistically significant increase when an initial sample and all of m-1 resamples indicate exceedence. California plans declare a statistically significant increase when both the initial and any of the m-1 resamples indicate exceedence. An example of 1 of m plans illustrates the effects of verification resampling on the control of both FWFPR and the false negative rate. Assuming $\alpha=0.01$ and $n=50$ (future comparisons), for one verification resample the FWFPR is:

$$\begin{aligned}\alpha^* &= 1 - \text{Probability (all wells okay)}\\ &= 1 - (\text{Probability (one well okay)})^{n}\\ &= 1 - (1 - \alpha + \alpha\,(l - \alpha))^{n}\end{aligned}$$

$$= 1 - (1 - 0.01 + 0.01(1 - 0.01))\ 50$$
$$= 0.005 < 0.05$$

In this case the verification resample has limited the FWFPR to within 5%. In using α=0.01 instead of α=0.001 (0.05/50=0.001) with other conditions unchanged, the sensitivity of the individual comparison will be significantly increased.

However, in corrective action monitoring for evaluating the attainment of cleanup standards, the FWFPR no longer poses a threat. Assuming the site is declared clean only when all constituents of concern in all wells attain the cleanup standards, the FWFPR will always be less than or equal to the maximum comparison-wise false positive rate. For example, if the maximum comparison-wise false positive rate is α_{max}=0.2 for n=10 independent future comparisons, the FWFPR is given by:

$$\alpha* = \text{Probability (all wells clean)}$$
$$\leq \alpha_{max}^{\ n}$$
$$= 0.2^{10}$$
$$= 1 \times 10^{-7} << \alpha_{max}$$

However, the facility-wide false negative rate (FWFNR) may now cause problems if cleanup of the site is declared only when all constituents at all wells attain cleanup standards. In this case and for large monitoring programs, even if all wells have attained the cleanup standard, a non-attainment decision could still be reached due to FWFNR. The cause of the problem associated with FWFNR can be analyzed in the same way as that of detection monitoring.

Regardless of the strategy used, simultaneous analysis of more wells and more constituents will increase facility-wide false error rates, either FWFPR or FWFNR. Therefore, a non-statistical suggestion for reducing the FWFPR and FWFNR is to choose as few constituents and wells as possible. This will be valid and safe if the selected constituents are most likely to be different from their null hypotheses.

Using Appropriate Statistical Methods

This section details the statistical approaches that can be used in the data evaluation procedures for the control of false positive and false negative rates. First, scientifically sound statistical methods widely used for assessing the conditions of groundwater contamination and for making decisions about regulatory requirements are outlined. Second, procedures for dealing with problems that arise from violations of statistical assumptions will be presented.

In practice, the procedures for dealing with violations of statistical assumptions should be performed first. In this appendix, the statistical methods are presented first so that assumptions of these methods are understood and strategies dealing with violations of these assumptions can be developed.

METHOD 1 — COMBINED SHEWART-CUSUM CONTROL CHART

The combined Shewart-CUSUM control chart (ASTM 1996; EPA 1989; Gibbons 1994) is a statistical method for intra-well comparisons used in detection monitoring to determine if the groundwater at the well is contaminated. The combined Shewart-CUSUM control chart method is sensitive to both immediate and gradual releases. Also, since it is an intra-well comparison method, problems associated with spatial variations can be avoided.

Statistical Assumptions:

Data values are independent and normally distributed with mean μ and standard deviation of σ. If original measurements follow lognormal distribution, their logarithms will follow normal distribution and should be used in the computation.

Procedures:

Step 1. Estimate μ and σ by computing the mean $\overline{x}$ and standard deviation *s* of at least eight historical independent samples collected in a period of no less than one year.

Setp 2. Select the three Shewart-CUSUM parameters, *h* (the value against which the cumulative sum will be compared), *c* (a parameter related to the displacement that should be quickly detected), and *SCL* (the upper Shewart limit that is the number of standard deviation units for an immediate release). It is suggested that *c* = 1, *h* = 5, and *SCL* = 4.5 are most appropriate for groundwater monitoring applications. The false positive rate associated with these parameters is about 1%.

Step 3. Denote the new data value at time-point t_i as x_i and compute the standardized value z_i:

$$z_i = \frac{x_i - \overline{x}}{s}$$

Step 4. At each time period, t_i, compute the cumulative sum S_i, as:

$$S_i = \max[0, (z_i - c) + S_{i-1}]$$

where max[A, B] is the maximum of A and B, starting with $S_0 = 0$.

Step 5. Plot the values of S_i (y-axis) versus t_i (x-axis) on a time chart.

Step 6. Make decisions:

Declare an "out-of-control" situation for sampling period t_i if for the first time, $S_i \geq h$ (gradual release) or $z_i \geq SCL$ (immediate release). Any such designation must be verified on the next round of sampling before further investigation is deemed necessary. Once confirmed, the test results indicate that groundwater at the well is "contaminated".

As monitoring continues and no exceedence is found, the combined Shewart-CUSUM control charts should be updated periodically to incorporate these new data. Davis (1994) suggests that every two years all new data that are in control should be pooled with the initial samples to calculate the new background mean and variance.

Example:

Step 1. The data from Gibbons (1994), Example 8.1, page 165 are used and listed in Table A.7.7. The mean and standard deviation are estimated to be 50 μg/L and 10 μg/L, respectively, from eight previous background measurements in the same well.

Setp 2. The three Shewart-CUSUM parameters are selected as *h* = 5, *c* = 1, and *SCL* = 4.5, in units of standard deviation.

Step 3. The standardized value z_I for each new measurement is computed and presented in the fifth column of Table A7.7. For example, $z_3 = (60 - 50) / 10 = 1$.

Step 4. The quantity S_i is computed and presented in the seventh column of Table A.7.7. For example, S_6 = max [0, (3-1)+1] = max [0, 3] = 3.

Step 5. The control chat is presented in Figure 1 with S_i plotted verses t_i. From Figure A.7.1 and Table A.7.7 we can see the process is out of control both in terms of absolute value and trend on the third quarter of 1991. This result is confirmed in the fourth quarter of 1991.

Table A.7.7 Example dataset for constructing the Shewart-CUSUM charts

Quarter	Year	Period t_i	Concentration x_i	Standardized z_i	$z_i - c$	CUSUM S_i
1	90	1	50	0	-1	0
2	90	2	40	-1	-2	0
3	90	3	60	1	0	0
4	90	4	50	0	-1	0
1	91	5	70	2	1	1
2	91	6	80	3	2	3
3	91	7	100	5[a]	4	7[b]
4	91	8	120	7[a]	6	13[b]

[a] Shewart "out-of-control" limit exceeded ($z_i > SCL = 4.5$).

[b] CUSUM "out-of-control" limit exceeded ($S_i > h = 5$).

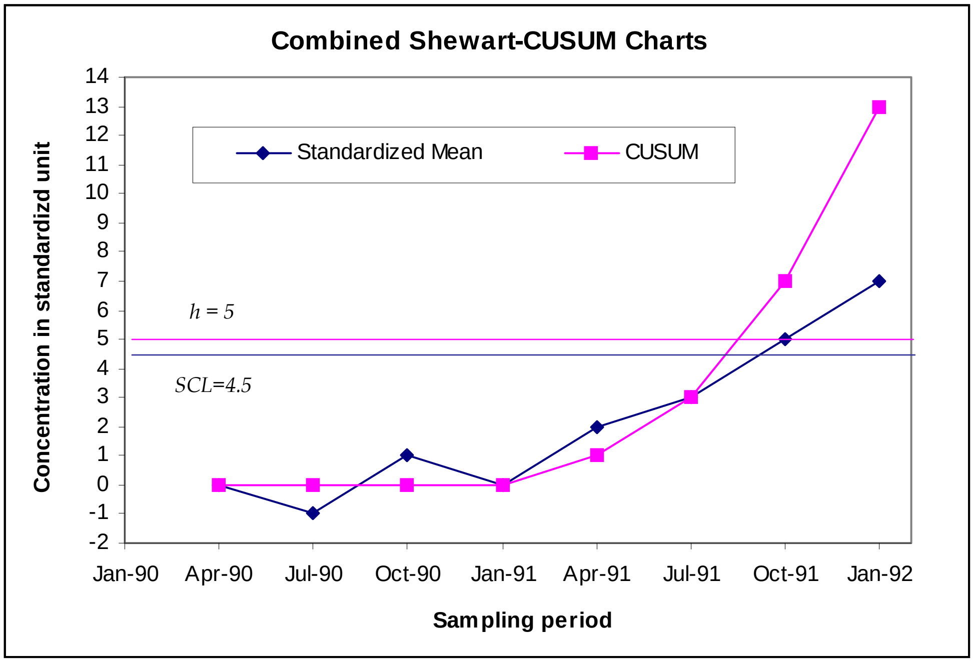


Figure A.7.1 Example Combined Shewart-cusum charts

METHOD 2 — PREDICTION LIMITS IN DETECTION MONITORING

Prediction limits are statistical estimates of the minimum or maximum concentration (or both) that will contain the next series of k measurements with a specified level of confidence (e.g., 99% confidence) based on a sample of n background measurements. In groundwater detection monitoring, we are concerned with the upper prediction limit, the limit with a known confidence of not being exceeded by the next k measurements. If any of the k measurements exceeds the limit, it is probable that contamination occurs and compliance monitoring may be initiated.

The Simultaneous Normal Prediction Limit for the Next r of m Measurements at Each of k Monitoring Wells presented by Davis and McNichols (1987) is recommended for both inter-well and intra-well comparisons. This method uses Bonferroni inequality to control the facility-wide false positive rate (FWFPR) and verification resampling to minimize the false positive and false negative rates associated with a single comparison. Furthermore, the dependence in multiple comparisons against the same background (inter-well comparisons) and the correlation due to repeated comparison of the re-samples to the same prediction limit (intra-well comparisons) are also handled.

Statistical Assumptions:

Data values are independent and normally distributed. If original measurements follow lognormal distribution, their logarithms will follow normal distribution and should be used in the computation. When spatial variations between wells are significant, the assumption of homogeneity of variances will be violated and the use of inter-well data should be avoided. In this case, intra-well prediction limits can be used instead.

Procedures (background verses downgradient comparisons):

Step 1. Determine the facility-wide false positive rate α that needs to be controlled for the site. For example, $\alpha = 0.05$, $\alpha = 0.005$, etc. If N constituents need to be tested simultaneously, use Bonferroni inequality to obtain α^*, the overall significance level for a single constituent as

$$\alpha^* = \frac{\alpha}{N}$$

Step 2. Determine the resampling plan that will be used: One of Two Samples in Bounds plan (exceedence is declared when both the initial sample and the resample exceed the limit), One of Three Samples in Bounds plan (exceedence is declared when both the initial sample and the two resamples exceed the limit), or First or Next Two Samples in Bounds plan (exceedence is declared when both the initial sample or any of the two resamples exceed the limit). Usually One of Two Samples in Bounds plan and One of Three Samples in Bounds plan are used (ASTM 1998).

Step 3. Compute the mean $\overline{x}$ and standard deviation s of the n background samples (at least 4) for the single constituent.

Step 4. Determine k, the number of monitoring wells that will be sampled for the single constituent.

Step 5. Consult the tables in Davis and McNichols (1987) or Gibbons (1994) with n, α^* and k to locate the factor K.

Step 6. Calculate the prediction limit as follows:

$$\bar{x} + Ks$$

Step 7. Make decisions:

For any downgradient well, if its initial sample exceeds the prediction limit and if the verifying resamples confirm this exceedence, then the groundwater is declared "contaminated". Note that different plans have different requirements.

For application in intra-well comparisons, the prediction limit is computed separately in each monitoring well for each constituent and the procedures will vary slightly.

Procedures (intra-well comparisons):

Step 1. Determine the facility-wide false positive rate α that needs to be controlled. Usually α = 0.05. Since the prediction limit is constructed separately for each well and each constituent, α^*, the significance level for each of the k comparisons (i.e., monitoring wells & constituents) can be calculated using the Bonferroni inequality:

$$\alpha^* = \frac{\alpha}{k}$$

Step 2. Determine the resampling plan that will be used.

Step 3. Compute the mean $\bar{x}$ and standard deviation s using the first available n measurements (at least 4) as background, for each well for each constituent.

Step 5. Consult the tables for intra-well comparisons in Davis and McNichols (1987) or Gibbons (1994) with n and α^* to locate the factor K.

Step 6. Calculate the prediction limit as follows for each well for each constituent:

$$\bar{x} + Ks$$

Step 7. Make decisions:

For any downgradient well for any constituent, if its initial sample exceeds the prediction limit and if the verifying resamples confirm this exceedence, then the groundwater is declared "contaminated". Note that different plans have different requirements.

The above two varieties of prediction limits not only control the facility-wide false positive rates at specified level but also minimize false negative rates for a certain number of n and k. For a fixed number of k, increasing n will increase the power of the test. For a fixed number of n, decreasing k will increase the power of the test.

Example:

Step 1. A set of hypothetical data representing a single constituent is presented in Table A.7.8 for demonstration. As in most cases of groundwater quality data, the eight independent background measurements are transformed by taking their natural logarithm. Then the background mean and standard deviation of the transformed data are computed as 1.029 and 0.672, respectively.

Step 2. The facility-wide false positive rate α of 0.05 is chosen and the One of Two Samples in Bounds plan (exceedence is declared when both the initial sample and the resample exceed the limit) is specified. Since only one constituent is considered, $\alpha^* = \alpha$.

Step 3. Assume there are ten monitoring wells ($k = 10$) for future comparison.

Step 4. Consulting the tables in Davis and McNichols (1987) or Gibbons (1994) with $n = 8$, $\alpha^* = 0.05$ and $k = 10$ and we find $K = 2.03$ (e.g., in Gibbons 1994, page 23, Table 1.5).

Step 5. Calculate the prediction limit as

$$\bar{x} + Ks = 1.029 + 2.03 \times 0.672 = 2.393.$$

Step 6. Make decisions:

Comparisons are made in logarithmic scale. Since the initial exceedence x_e is not confirmed by the verifying resample x_r, which is within the prediction limit, the conclusion of contamination cannot be drawn.

Table A.7.8 Example dataset for constructing prediction limits

Original background data (n=8)	Ln transformed data (x_i)	Mean $\bar{x}$	Standard deviation s	Prediction limit	Original exceedence[a] x_e	Verifying resample x_r
2.339	0.850				12.606	9.107
1.435	0.361					
3.071	1.122					
5.146	1.638				Ln(x_e)	Ln(x_r)
4.949	1.599	1.029	0.672	2.393	2.534	2.209
6.466	1.867					
0.912	-0.092					
2.418	0.883					

[a] Assume there is only one exceedence in the 10 "future" measurements.

METHOD 3 — CONFIDENCE LIMITS IN COMPLAINCE MONITORING

Confidence limits are statistical estimates of the minimum or maximum population parameter (e.g., mean concentration), or both, that will include the true parameter value with a specified level of confidence (e.g., 99% confidence) based on a sample of n measurements. In groundwater compliance monitoring, concern is with the lower confidence limit being exceeded by a predetermined standard such as the alternate concentration limit (ACL). If the lower confidence limit built from a compliance well exceeds the ACL, it may indicate that the groundwater contamination is significant and corrective action monitoring may be initiated.

The confidence limit should only be constructed from data collected during compliance monitoring and should be compared to the ACL computed from the average of background samples (EPA 1992). It should not be compared to the maximum concentration limits (MCLs). The use of tolerance limits in compliance monitoring is questioned by Gibbons (1994) and should be avoided. The method to construct a lower confidence limit for the mean concentration from EPA guidance (EPA 1992) is presented below.

Statistical Assumptions:

Data values are independent and normally distributed. If original measurements follow lognormal distribution, their logarithms will follow normal distribution and should be used in the computation.

Procedures:

Step 1. Use pre-determined ACL or estimate ACL from the average of background samples.

Step 2. Compute the mean $\bar{x}$ and standard deviation s from the n observations (at least four) at a compliance well for a constituent.

To reduce the false negative rate of the test (i.e., to increase the power of the test), a larger sample size n should be used.

Step 3. Calculate its lower 99% confidence limit as:

$$\bar{x} - \frac{t_{(n-1,\alpha)} s}{\sqrt{n}}$$

where $t_{(n-1,\ \alpha)}$ is the one-sided (1- α)100% point of Student's *t* distribution with *n-1* degrees of freedom.

Step 4. Make decisions:

If the lower confidence limit of any constituent in any compliance well exceeds the ACL, then there is statistically significant evidence of contamination. Otherwise, the site is within compliance.

Gibbons (1994) argues that when the ACL is estimated from the background mean and since the compliance monitoring is conditional on prior demonstration of a significant increase over background, the test is in fact a two-sample *t* test instead of the above confidence limit method which is a one-sample *t* test. The dependence due to repeated comparisons of multiple compliance well means to a single pooled background mean should also be considered. This suggests that a Dunnett-type test should be used. Readers can consult Gibbons (1994) and Dunnett (1955) for details.

Example:

Step 1. Example TOC concentration data (Table A.7.9) in three compliance wells are used to construct lower confidence limits and the result is compared to the ACL that is estimated from background samples as 5.00 mg/L.

Step 2. Calculate the mean and standard deviation of the concentrations for each monitoring well. They are shown in Table A.7.9.

Step 3. From EPA guidance (EPA 1989) the *t* value for 5 degrees of freedom and significance level of 1% is 3.365. The lower 99% confidence limit for each monitoring well is computed and presented in Table A.7.9. For example, the lower 99% confidence interval for MW-1 is

$$\bar{x} - t_{(6-1,0.01)} s / \sqrt{6} = 3.33 - 3.365 \times 0.70 / 2.45 = 2.36\,.$$

Step 4. Make decisions:

Although the confidence limits for both MW-1 and MW-2 are lower than the ACL, they represent different conditions. MW-1 is well within compliance since all of its concentrations are below the ACL. Even though all concentrations in MW-2 are above the ACL, no statistically significant evidence is available to conclude its non-compliance. More samples are needed in the future to verify whether this is a true non-compliance. For MW-3, it is statistically significant that the mean TOC level at this well is out of compliance.

Table A.7.9 Example TOC concentrations for confidence limits

Monitoring well	MW-1	MW-2	MW-3
Concentrations (mg/L)	4.19	6.97	6.97
	2.91	5.20	8.64
	4.26	5.03	8.69
	2.93	6.41	6.54
	2.32	6.79	10.12
	3.34	5.34	8.84
$\bar{x}$	3.33	5.96	8.30
s	0.70	0.79	1.21
$\bar{x} - t_{(n-1,\alpha)} s/\sqrt{n}$	2.36	4.87	6.64[a]
ACL		5.00	

[a] 99% lower confidence limit is below the ACL, indicating non-compliance.

METHOD 4 — THE SEQUENTIAL T-TEST IN CORRECTIVE ACTION MONITORING

One purpose of groundwater corrective action monitoring is to document the effectiveness of the remedial action. More specifically, the groundwater contamination should be cleaned up and this attainment should be proved by appropriate statistical tests. In *Methods for Evaluating the Attainment of Cleanup Standards Volume 2: Ground Water* (EPA 1992b), two methods for assessing the attainment of cleanup standards were given: a fixed sample size test based on a confidence limit, and a sequential t-test using a likelihood ratio. Both can be used to determine whether: (1) the mean concentration is below the cleanup standard; and (2) a selected percentile of all samples is below the cleanup standard.

The sequential t-test will be presented here as it has the following advantages:

- The number of samples required to reach a decision need not be known at the beginning of the sampling period.

  In a fixed sample size test, the number of samples required to reach a decision should be determined in advance based on specified false positive and false negative rates (e.g., α=0.05, β=0.20). This is to ensure for a known or presumed degree of uncertainty in the sample population, that the statistical test with the number of samples that will be collected will provide enough power (1-β) to detect the expected difference between the cleanup goal and the cleanup standard.
- On average and under the same levels of false positive and false negative rates, the sequential t-test will require fewer samples and therefore a shorter time to make the attainment decision than the fixed sample size test.

This method can be used to test wells individually or in a group and requires at least three years of data. Yearly averages of samples are used in the sequential t-test in order to reduce the effects of any serial correlation in the measurements. The test can only be performed after the termination of treatment (remedial action) and after the groundwater has returned back to steady state (i.e., after the disappearance of the post-effects of treatment).

Statistical Assumptions:

Yearly averages are independent and normally distributed. If yearly averages follow lognormal distribution, their logarithms will follow normal distribution and should be used in the computation. When spatial variations between wells are significant, joint testing of wells should be avoided.

Procedures (testing wells individually):

Step 1. Determine the false positive rate α and false negative rate β for control. Calculate parameters A and B as:

$$A = \frac{\beta}{1-\alpha}$$

$$B = \frac{1-\beta}{\alpha}$$

Since the facility-wide false negative rate (FWFNR) becomes important in corrective action monitoring, the β of single test should be controlled at a low level. For example, if $\beta = 0.2$ and there are 10 wells, the FWFNR could be as high as 0.89. So $\beta = 0.1$ or 0.05 can be used when the number of comparisons is large. By contrast, α of a single test can be moderately increased ($\alpha = 0.10$ or 0.05).

Step 2. Determine the cleanup standard Cs and the cleanup goal μ_1 ($\mu_1 < Cs$).

Step 3. Compute the yearly average $\bar{x}_k$ using n_k samples (at least four) in year k for the m years of data collected so far as:

$$\bar{x}_k = \frac{1}{n_k} \sum_{j=1}^{n_k} x_{jk} \quad (k = 1, 2, \ldots, m)$$

where x_{jk} is the jth measurement at year k.

Step 4. Compute the mean $\bar{x}$, and variance $s_{\bar{x}}^2$ of the yearly averages as:

$$\bar{x} = \frac{1}{m} \sum_{k=1}^{m} \bar{x}_k$$

$$s_{\bar{x}}^2 = \frac{\sum_{k=1}^{m} \left(\bar{x}_k - \bar{x}\right)^2}{m-1}$$

The restrictions of using yearly averages and at least four samples a year can be eased as long as there are no seasonal effects and no significant serial correlation between samples. For example, this test can be used for cases in which there are only two samples per year, or there are only a series of annual or biennial samples.

Step 5. Calculate the t and δ for the likelihood ratio as:

$$t = \frac{\bar{x} - \dfrac{Cs + \mu_1}{2}}{\sqrt{\dfrac{s_{\bar{x}}^2}{m}}}$$

$$\delta = \frac{\mu_1 - Cs}{\sqrt{\dfrac{s_{\bar{x}}^2}{m}}}$$

Step 6. Calculate the likelihood ratio as:

$$LR = \exp\left(\delta \frac{m-2}{m} t \sqrt{\frac{m}{m-1+t^2}} \right)$$

Step 7. Compare LR with parameters A and B to make decisions:

If $LR \leq A$, conclude that the groundwater at this well or site does not attain the cleanup standard. Reconsider treatment effectiveness.

If $LR > B$, conclude that the mean groundwater concentration in this well is less than the cleanup standard. If the yearly averages in this well do not show a statistically significant increasing trend, conclude that the groundwater at this well attains the cleanup standard. Otherwise, conclude that the groundwater at this well does not attain the cleanup standard and reconsider treatment effectiveness or resume sampling.

If $A < LR \leq B$, collect an additional year's worth of data and perform the test again.

If the groundwater from all wells or group of wells attain the cleanup standard, conclude that groundwater at this site attains the cleanup standard.

When testing a group of wells, data for the individual wells at each point in time should be used to produce a summary measure for the group as a whole. This summary measure may be an average, a maximum, or a median. These summary measures will be averaged over the yearly period. Then the same steps for testing wells individually can be followed to make the hypothetical test.

Example:

Step 1. Hypothetical arsenic measurements presented in Table A.7.10 are used in this example. Here we consider the false positive rate and false negative rate as equally important: $\alpha = \beta = 0.10$. Therefore, $A = \beta / (1 - \alpha) = 0.11$ and $B = (1 - \beta) / \alpha = 9$.

Step 2. The cleanup standard Cs is 5 ppb and the cleanup goal μ_1 is expected to be 4.5 ppb.

Step 3. Compute the yearly average $\bar{x}_k$ for each of the four years. The results are listed in the fourth column of Table A.7.10. For example, the yearly average of 1990 is

$$\bar{x} = (5.67 + 4.65 + 2.62 + 4.07) / 4 = 4.25$$

Step 4. The mean and variance of yearly averages are $\overline{x}$ = 4.58, and $s_{\overline{x}}^2$ = 0.107, respectively.

Table A.7.10 Example arsenic measurements for sequential test.

Year	Quarter	Measurements (ppb)	Yearly average $\overline{x}_k$	Mean[a] $\overline{x}$	Variance[b] $s_{\overline{x}}^2$
1990	1	5.67	4.25	4.58	0.107
1990	2	4.65			
1990	3	2.62			
1990	4	4.07			
1991	1	3.02	4.41		
1991	2	7.99			
1991	3	3.17			
1991	4	3.44			
1992	1	4.53	4.66		
1992	2	6.60			
1992	3	3.71			
1992	4	3.80			
1993	1	4.41	5.00		
1993	2	4.90			
1993	3	5.96			
1993	4	4.73			

[a] Mean of the yearly averages.

[b] Variance of the yearly averages.

Step 5. Calculate *t* and *δ*:

$$t = \frac{\overline{x} - \frac{Cs + \mu_1}{2}}{\sqrt{\frac{s_{\overline{x}}^2}{m}}} = \frac{4.25 - \frac{5 + 4.5}{2}}{\sqrt{\frac{0.107}{4}}} = -1.04$$

$$\delta = \frac{\mu_1 - Cs}{\sqrt{\frac{s_{\overline{x}}^2}{m}}} = \frac{4.5 - 5}{\sqrt{\frac{0.107}{4}}} = -3.06$$

Step 6. The likelihood ratio is

$$LR = \exp\left(\delta \frac{m-2}{m} t \sqrt{\frac{m}{m-1+t^2}}\right) = \exp\left(-3.06 \times \frac{4-2}{4} \times (-1.04) \times \sqrt{\frac{4}{4-1+(-1.04)^2}}\right) = 4.83$$

Step 7. Since $A < LR \leq B$ ($0.11 < 4.83 \leq 9$), more data need to be collected to perform the test again.

Inn the above test, we use $\alpha = \beta = 0.10$, which represents stringent control of error rates, especially in terms of false negative rate. If in the above test $\alpha = \beta = 0.20$ or $\alpha = 0.1$ *and* $\beta = 0.6$, then we will get $B = 4$. This may lead to a different conclusion since LR is greater than B in these two cases. Therefore, the test result is dependent on the levels of false error rates which we hope to control.

METHOD 5 — MANN-KENDALL TEST FOR TRENDS IN CONCENTRATION DATA

The Mann-Kendall test is a non-parametric statistical procedure that is well suited for analyzing trends in data over time (Gilbert, 1987). The Mann-Kendall test can be viewed as a nonparametric test for linear zero slope of the time-ordered concentration data versus time. The Mann-Kendall test does not require any assumptions as to the statistical distribution of the data (e.g. normal, lognormal, etc.) and can be used with data sets which include irregular sampling intervals and missing data. The Mann-Kendall test is designed for analyzing a single groundwater constituent in a single monitoring well; multiple constituents are analyzed separately.

The Mann-Kendall statistic (S) measures trends in the data. Positive values indicate an increase in constituent concentrations over time, whereas negative values indicate a decrease. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic, that is, large magnitudes indicate a strong trend.

A variation of the Mann-Kendall test developed by GSI (Groundwater Services Inc. 2000) is presented in this section for the characterization of both variability and the direction of the trend. This modified Mann-Kendall test evaluates the S statistic, confidence level of the S statistic, and the coefficient of variation (COV) of a time series in order to accurately characterize the concentration trend. This trend is classified in six categories: Decreasing, Probably Decreasing, Stable, No Trend, Probably Increasing, and Increasing.

Statistical Assumptions:

Observations in the time series must be mutually independent. Since a single constituent in a single monitoring well is tested, the homogeneity of variance is generally true.

Procedures (testing wells individually):

Step 1. Arrange measurements x_i (i = 1, 2, …, n) in time sequential order and determine the sign of the difference between consecutive measurements for all x_i as

$$\mathrm{sgn}(x_j - x_k) = 1 \qquad \text{if } x_j - x_k > 0$$

$$\mathrm{sgn}(x_j - x_k) = 0 \qquad \text{if } x_j - x_k = 0$$

$$\mathrm{sgn}(x_j - x_k) = -1 \qquad \text{if } x_j - x_k < 0$$

where $\mathrm{sgn}(x_j - x_k)$ is an indicator function that results in the values 1, 0, or –1 according to the sign of $x_j - x_k$ and $j > k$.

Step 2. Calculate the Mann-Kendall statistic S, which is defined as the sum of the number of positive differences minus the number of negative differences or

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}\left(x_j - x_k\right)$$

Step 3. Consult a Kendall probability table with the unsigned Mann-Kendall statistic *S* and the number of samples, *n*, to find the confidence in the trend (CT). The Kendall probability table can be found in many statistics textbooks (e.g. Hollander, M. and Wolfe, D.A., 1973).

Step 4. Calculate coefficient of variation (COV), which measures how individual data points vary about the mean value. The COV is defined as the standard deviation of the data divided by the mean or

$$COV = \frac{s}{\bar{x}}$$

A COV near 1.00 indicates that the data form a relatively close group about the mean value. A COV either larger or smaller than 1.00 indicates a greater degree of scatter about the mean.

Step 5. Determine the concentration trend by checking the decision matrix presented in Table A.7.11 with Mann-Kendall statistic (S), confidence in trend (CT), and coefficient of variation (COV). For example, if S > 0, and CT > 95%, the concentration trend is *Increasing*.

Table A.7.11 Mann-Kendall analysis decision matrix.

Mann-Kendall Statistic	Confidence in the Trend	Concentration Trend
S > 0	> 95%	Increasing
S > 0	90 - 95%	Probably Increasing
S > 0	< 90%	No Trend
S ≤ 0	< 90% and COV ≥ 1	No Trend
S ≤ 0	< 90% and COV < 1	Stable
S < 0	90 - 95%	Probably Decreasing
S < 0	95%	Decreasing

Example:

Step 1. Benzene concentrations from a monitoring well are presented in Table A.7.12. The signs of the difference between consecutive measurements are presented in the third to ninth rows of Table A.7.12. For example, the sign of the difference between the first and third measurements is

$$sgn(x_3-x_1) = sgn(0.034-0.026) = sgn(0.008) = 1.$$

Step 2. The Mann-Kendall statistic *S* is found to be -8. The calculations are shown in Table A.7.12.

Step 3. Consulting a Kendall probability table with $S = 8$ and $n = 8$ finds the confidence in the trend to be 0.801 or 80.1%. In fact, the Kendall probability table provides the probability that the unsigned Mann-Kendall statistic *S* equals or exceeds the specified value of the unsigned *S* when no trend is present. So the confidence in the trend is calculated as 1 minus this probability.

Step 4. The mean and standard deviation of this sample are 0.024 and 0.010, respectively. Therefore, the coefficient of variation is

$COV = 0.010 / 0.024 = 0.435$

Step 5. From Table A.7.11with $S \leq 0$, the confidence in the trend < 0, and the COV < 1, the concentration trend is *Stable*. Two meanings are thus indicated: 1) the slope of the times series is not statistically significantly different from zero; and 2) the fluctuation of benzene concentrations within the time period in this monitoring well is quite small.

Table A.7.12 Benzene data and computation of the Mann-Kendall statistic

Time	2/5/98	3/9/98	4/6/98	5/15/98	6/29/98	7/17/98	9/1/98	10/8/98	
Data (mg/L)	0.026	0.028	0.034	0.018	0.027	0.036	0.011	0.008	
Sign of difference between consecutive measurements		1	1	-1	1	1	-1	-1	
			1	-1	-1	1	-1	-1	
				-1	-1	1	-1	-1	
					1	1	-1	-1	
						1	-1	-1	
							-1	-1	
								-1	Total
No. of + signs		1	2	0	2	5	0	0	10
No. of - signs		0	0	3	2	0	6	7	18
					Mann-Kendall statistic S = 10 - 18 =				-8

METHOD 6 — METHODS FOR TESTING NORMALITY

There are many methods available for checking the normality of data, among which the normal probability plot is particularly useful for spotting irregularities (EPA 1992) within the data and the Shapiro Wilk test is superior to most other tests for testing normality of the data (EPA 2000).

In normal probability plots, an observed value is plotted on the x-axis and the proportion of observations less than or equal to each observed value is plotted as the y-coordinate. The scale of the plot is constructed so that, if the data are normally distributed, the plotted points will approximate a straight line. Visually apparent curves or bends indicate that the data do not follow a normal distribution. Evaluation by means of normal a probability plot is only qualitative.

As a quantitative test, the Shapiro Wilk test is based on the premise that if data are normally distributed, the ordered values should be highly correlated with corresponding quantiles taken from a normal distribution. The Shapiro Wilk test statistic (W) will be relatively high if the normal probability plot is approximately linear. When the normal probability plot contains significant bends or curves, the statistic will be relatively low. If the Shapiro Wilk test is applied to data from multiple wells (e.g., background wells), the spatial variability (both mean and variance differences among wells) exhibited in data from these wells must be negligible. Otherwise, one should use the multiple group version of the Shapiro Wilk test (ASTM 1998), which is suitable for the joint assessment of normality in multiple wells. Details about the multiple-group Shapiro Wilk test are available in Wilk and Shapiro (1968) and Gibbons (1994).

The Shapiro Wilk test can be used for sample sizes up to 50. When the sample size is larger than 50, a slight modification of the procedure called the Shapiro-Francia test can be used instead. The Probability Plot Correlation Coefficient (Filliben's statistic) test is roughly equivalent to these two tests. A brief evaluation is provided in EPA guidance (EPA 2000) as to the scope of use and performance of each of these alternatives. Since these test statistics (i.e., W statistic and Filliben's statistic) are difficult to compute manually, this section only presents the construction of a normal probability plot. Readers can refer to EPA guidance (EPA 1992, EPA 2000) for detailed procedures for these quantitative tests.

Procedures (Normal Probability Plot):

Step 1. Arrange data in order from smallest to largest and denote them as x_i, $i = 1, 2, \ldots, n$. The data can be measurements from a single well or from a group of wells.

Step 2. The cumulative probability corresponding to each measurement is computed as

$\phi_i = \frac{i}{n+1}$, where i is the order of the ith smallest measurement.

Step 3. Compute the normal quantiles corresponding to the cumulative probabilities obtained from Step 2 as

$y_i = \Phi^{-1}(\phi_i)$, where Φ^{-1} denotes the inverse of the cumulative normal distribution.

Step 4. Plot the normal quantiles verses the concentration of each measurement, i.e., y_i verses x_i. If these points approximate a straight line, it is evidence that the data are normally distributed. Significant bends or curves in the plot indicate departures from a normal distribution.

Example:

Step 1. Hypothetical arsenic data from four wells are presented in Table A.7.13. These measurements are ordered from smallest to largest in the fourth column of Table A.7.13. The order of each measurement is listed in the fifth column of Table A.7.13.

Step 2. The cumulative probability corresponding to each measurement is given in the sixth column of Table A.7.13. For example for the third smallest measurement

$$\phi_3 = \frac{3}{n+1} = \frac{3}{16+1} = 0.18 \cdot$$

Step 3. The normal quantile corresponding to each of the cumulative probabilities is listed in the last column of Table A.7.13. In this example, they are calculated with the function *NORMINV()* in Microsoft® Excel.

Step 4. The normal probability plot is presented in Figure A.7.2. The points do not approximate a straight line very well but bends in the plot are not significant, indicating the data are approximately normally distributed.

Table A .7.13 Example arsenic data for normal probability plot.

Well	Quarter	Original data (ppb)	Ordered data (x_i)	Order (i)	Cumulative probability (ϕ_i)	Normal quantile (y_i)
MW-1	1	13.96	3.87	1	0.06	-1.56
	2	12.77	5.15	2	0.12	-1.19
	3	9.66	7.00	3	0.18	-0.93
	4	8.46	8.16	4	0.24	-0.72
MW-2	1	8.77	8.46	5	0.29	-0.54
	2	3.87	8.56	6	0.35	-0.38
	3	5.15	8.68	7	0.41	-0.22
	4	10.11	8.77	8	0.47	-0.07
MW-3	1	8.56	8.84	9	0.53	0.07
	2	8.16	8.97	10	0.59	0.22
	3	8.97	9.66	11	0.65	0.38
	4	8.84	10.11	12	0.71	0.54
MW-4	1	11.05	10.82	13	0.76	0.72
	2	10.82	11.05	14	0.82	0.93
	3	8.68	12.77	15	0.88	1.19
	4	7.00	13.96	16	0.94	1.56

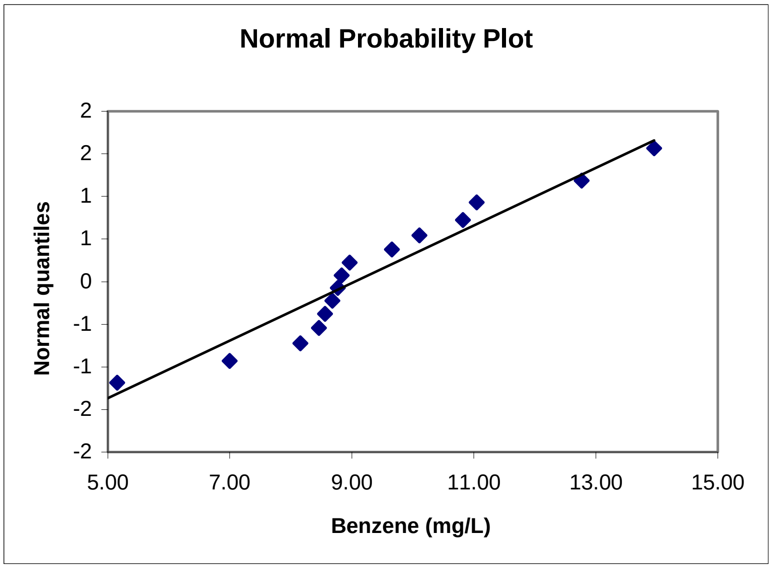


Figure A.7.2 Example normal probability plot.

METHOD 7 — METHODS FOR TESTING HOMOGENEITY OF VARIANCE

The assumption that variances of different groups of data are approximately equal is required for many statistical methods that make references from different groups of data, such as the analysis of variance (ANOVA, parametric or non-parametric) presented in EPA guidance (EPA 1989, EPA

1992) for detection monitoring. Violation of this assumption when using these kinds of statistical methods may result in excessive false positive rate or false negative rate (Davis and McNichols 1994). Natural spatial variability inherent in a site is the reason for unequal variances in different spatial locations.

Bartlett's test and Levene's test (EPA 1992, EPA 2000) are most widely used for checking the assumption of equal variances. Levene's test is less sensitive to departures from normality than Bartlett's test and has power superior to Bartlett's test for non-normal data. In addition, Levene's test has power nearly as great as Bartlett's test for normally distributed data. Therefore, we introduce Levene's test in this section. An exploratory method worth mentioning is the Box Plots, through which one can visualize the spread or dispersion within a dataset and compare across groups to see if the assumption of equal variances is reasonable. Details for Box Plots can be found in EPA guidance (EPA 1992).

Procedures (Levene's test):

Step 1. For each of the k groups, calculate the group mean as

$$\bar{x}_i = \frac{1}{n_i}\sum_{j=1}^{n_i} x_{ij} \text{ , where } i = 1, 2, \ldots, k;\ n_j = \text{number of data in group } i.$$

Step 2. Compute the absolute residuals as $z_{ij} = \left| x_{ij} - \bar{x}_i \right|$ and calculate the group means of these absolute residuals as

$$\bar{z}_i = \frac{1}{n_i}\sum_{j=1}^{n_i} z_{ij}$$

Also calculate the overall mean of he absolute residuals as

$$\bar{z} = \frac{1}{N}\sum_{i=1}^{k}\sum_{j=1}^{n_i} z_{ij} \text{ , where } N = n_1 + n_2 + \ldots + n_k.$$

Step 3. Compute the following sums of squares for the absolute residuals:

$$SS_{TOTAL} = \sum_{i=1}^{k}\sum_{j=1}^{n_i} {z_{ij}}^2 - N\bar{z}^2 \text{ , } SS_{GROUPS} = \sum_{i=1}^{k} n_i \bar{z}_i^2 - N\bar{z}^2 \text{, and } SS_{ERROR} = SS_{TOTAL} - SS_{GROUPS}$$

Step 4. Compute the F-statistic as

$$f = \frac{SS_{GROUPS}/(k-1)}{SS_{ERROR}/(N-k)}$$

Step 5. Consult an F-distribution table with the desired significance level α, (k-1) numerator degrees of freedom, and (N-k) denominator degrees of freedom to find the critical F value. If f is greater than F, reject the assumption of equal variances.

Example:

Step 1. The arsenic data presented in Table A.7.13 are used again in Table A.7.14 (second column) to illustrate the Levene's test. Assuming MW-1 and MW-2 are upgradient wells and MW-3 and MW-4 are downgradient wells, we want to test the assumption of equal variances before using a parametric ANOVA test. Each group mean is calculated and presented in the fourth column of Table A.7.14. For example,

$$\bar{x}_1 = \frac{1}{n_1}\sum_{j=1}^{n_1} x_{1j} = \frac{1}{4}(13.96 + 12.77 + 9.66 + 8.46) = 11.21$$

Step 2. The absolute residuals are listed in the fifth column of Table A.7.14. Group means of these absolute residuals are 2.15, 2.46, 0.27, and 1.55 and the overall mean is 1.61 (presented in the sixth and seventh columns of Table A.7.14, respectively). For example,

$$z_{23} = |x_{23} - \bar{x}_2| = |5.15 - 6.97| = |-1.82| = 1.82$$

$$\bar{z} = \frac{1}{N}\sum_{i=1}^{k}\sum_{j=1}^{n_i} z_{ij} = \frac{1}{16}\sum(2.75 + 1.56 + \ldots + 0.70 + 2.39) = 1.61$$

Step 3. The sums of squares for the absolute residuals are

$$SS_{TOTAL} = \sum_{i=1}^{k}\sum_{j=1}^{n_i} z_{ij}^{\;2} - N\bar{z}^2 = \sum\left(2.75^2 + 1.56^2 + \ldots + 2.39^2\right) - 16\times 1.61^2 = 15.95$$

$$SS_{GROUPS} = \sum_{i=1}^{k} n_i \bar{z}_i^2 - N\bar{z}^2 = \sum\left(4\times 2.15^2 + 4\times 2.46^2 + 4\times 0.27^2 + 4\times 1.55^2\right) - 16\times 1.61^2 = 11.28$$

$$SS_{ERROR} = SS_{TOTAL} - SS_{GROUPS} = 15.95 - 11.28 = 4.67$$

Step 4. The F-statistic, *f*, is

$$f = \frac{SS_{GROUPS}/(k-1)}{SS_{ERROR}/(N-k)} = \frac{11.28/(4-1)}{4.67/(16-4)} = \frac{3.76}{0.39} = 9.65$$

Step 5. The critical value *F* for *F*-distribution with $\alpha = 0.01$, *3* numerator degrees of freedom, and *12* denominator degrees of freedom is *5.95*. Therefore, $f = 9.65 > F = 5.95$, the assumption of equal variances is rejected.

Table A.7.14 Example calculation for Levene's test

Well	Original data (x_{ij})	Group mean ($\bar{x}_i$)	Absolute residuals (z_{ij})	Residual group mean ($\bar{z}_i$)	Overall residual mean ($\bar{z}$)
MW-1	13.96	11.21	2.75	2.15	1.61
	12.77		1.56		
	9.66		1.55		
	8.46		2.75		
MW-2	8.77	6.97	1.79	2.46	
	3.87		3.11		
	5.15		1.82		
	10.11		3.14		
MW-3	8.56	8.63	0.07	0.27	
	8.16		0.47		
	8.97		0.34		
	8.84		0.21		
MW-4	11.05	9.39	1.66	1.55	
	10.82		1.43		
	8.68		0.70		
	7.00		2.39		

If we are confident that the variability estimated from the above set of data is true, the parametric ANOVA test for detecting differences among the group means is not advisable. Approaches that account for unequal variances, such as data transformation to stabilize variances, intra-well Shewart-CUSUM control charts, or intrawell prediction limits, should be used instead. Conversely, the conclusion of unequal variances might not be true if we consider the effect of small sample size (4 observations per well), which is far from adequate to characterize the real spatial variability.

METHOD 8 — METHODS FOR TESTING SERIAL CORRELATION

Most statistical methods are based on the assumption of independence between observations. This assumption is violated if serial correlation, or autocorrelation, exists in observations separated in time (a time series). This is common for groundwater quality data that are measured in high frequency such as weekly or monthly sampling. To check if a time series dataset is significantly correlated, the Durbin-Watson test recommended in EPA guidance (EPA 1992b) can be used.

The Durbin-Watson test is based on the first order (or lag 1) autocorrelation model (Box et al. 1994), or AR(1) model, which states that the residual of an observation is dependent on the residual of its previous observation by a factor of ρ ($1 > \rho > -1$), or correlation coefficient. The residuals are obtained from de-trended and de-seasonalized observations, if any. The AR(1) model can be expressed as

$e_t = \rho e_{t-1} + \varepsilon_t$, where e_t (e_{t-1}) is the residual, or error term, at time t ($t-1$), and ε_t is a random shock which is independent and normally distributed at time t.

If there is no serial correlation between observations, the expected value of ρ will be close to zero. However, the estimated value of ρ is unlikely to be zero even if the actual serial correlation is zero. The Durbin-Watson statistic can be used to test whether the observed value of ρ, denoted as ϕ, is significantly different from zero. The procedures below introduce how to calculate ϕ, the observed value of ρ, followed by the Durbin-Watson test.

Procedures:

Step 1. List the observations measured consecutively at a constant interval ordered by time, denoting them as x_i, $i=1,2,\dots,N$, where N is the number of total observations. Estimate the trend and/or seasonality from this set of data. The trend is commonly estimated by the least square method and expressed as a linear trend:

$\hat{y}_i = b_0 + b_1 t_i$, where b_0 and b_1 are the intercept and slope of the regression line, respectively; $\hat{y}$ is the estimate of the observation at time t_i.

In the case of no obvious trend in the time series, the model is $\hat{y} = b_0$, where b_0 is the overall mean of the observations.

Seasonal variability is generally indicated by a regular pattern that is repeated every year. The seasonal mean or median is usually used to characterize the average concentration level of a season. This average level is simply the mean or median of the de-trended observations in a certain season, denoted as μ_j, $j = 1, 2,\dots, k$, where j represents a season and k is the total number of seasons in a year.

Step 2. Calculate the residuals, e_i, by subtracting the observations from their trend and/or respective seasonal means or medians as

$e_i = x_i - \hat{y}_i - \mu_j$, where the observation at time i must be in the season j.

Step 3. Estimate ϕ, the observed serial correlation as

$$\phi = \frac{\sum_{i=2}^{N} e_i e_{i-1}}{\sum_{i=1}^{N} {e_i}^2}$$

Step 4. Calculate D, the Durbin-Watson statistic as

$$D = \frac{\sum_{i=2}^{N} (e_i - e_{i-1})^2}{\sum_{i=1}^{N} {e_i}^2}$$

Step 5. Consult the Durbin-Watson table (Neter et al. 1996) for test bounds with desired significance level (α, usually 0.05) and the number of observations (n). Use the first column ($p-1=1$) in this table to find d_u, the upper critical value for the test. If $D < d_u$, conclude that there is a significant serial correlation and keep ϕ, the observed serial correlation, for future use. If $D > d_u$, conclude that there is no serial correlation, or a serial correlation that is negligible.

Example:

Step 1. A hypothetical dataset containing quarterly measurements of manganese concentration from a monitoring well during a four years period is presented in Table A.7.15. The time series plot of this dataset is given in Figure A.7.3, from which no obvious trend or seasonal effects can be inferred. Therefore, we calculate the sample mean of this time series, which is 4.97, as the estimate of the overall mean from which the residuals can be obtained.

Step 2. Calculate residuals by subtracting the overall mean (4.97) from each observation. They are listed in the third column of Table A.7.15. For example, $e_2 = 5.51 - 4.97 = 0.54$.

Step 3. The observed serial correlation, ϕ, is

$$\phi = \frac{\sum_{i=2}^{N} e_i e_{i-1}}{\sum_{i=1}^{N} e_i^{\,2}} = \frac{\sum\left((-0.151) + 0.318 + \ldots + (-1.035)\right)}{\sum (0.076 + 0.297 + \ldots + 0.986)} = \frac{2.03}{15.17} = 0.13$$

Step 4. The Durbin-Watson statistic, D, is

$$D = \frac{\sum_{i=2}^{N} (e_i - e_{i-1})^2}{\sum_{i=1}^{N} e_i^{\,2}} = \frac{\sum\left(0.674 + 0.002 + \ldots + 4.142\right)}{15.17} = 1.66$$

Step 5. Consulting the Durbin-Watson table (Neter et al. 1996, page 1349) with $\alpha = 0.05$ and $n = 16$ in the column titled $p-1=1$, we find $d_u = 1.37$. Since $D = 1.66 > d_u = 1.37$, conclude that there is no serial correlation in this set of manganese measurements. Therefore, in future use of this time series data, independence between data can be assumed true.

The serial correlation between successive observations, computed from the above procedures, depends on the time interval between collecting groundwater samples. For the AR(1) process, the serial correlation between successive observations decays exponentially with the increase of separation interval: $\rho_{kt} = \rho_t^k$, where ρ_t is the serial correlation for time interval t and ρ_{kt} is the serial correlation for the time interval that is k times as long as time interval t. The inverse of this relation also holds. As the time interval becomes longer (e.g., from monthly to semiannual sampling), the serial correlation between successive observations approximates zero. This is the theoretical basis for achieving serially independent observations in a sampling design. When data are strongly correlated, methods like collapsing and averaging data over a longer interval (Ward et al., 1988 and 1990) can be applied to remove serial correlation.

Table A .7.15 Example calculation for test of serial correlation

Quarter	Data (mg/L)	Residuals (e_i)	e_ie_{i-1}	e_i^2	$(e_i-e_{i-1})^2$
1	4.69	-0.28		0.076	
2	5.51	0.54	-0.151	0.297	0.674
3	5.55	0.58	0.318	0.342	0.002
4	5.09	0.13	0.074	0.016	0.210
5	6.08	1.11	0.141	1.241	0.974
6	4.59	-0.37	-0.414	0.138	2.206
7	3.73	-1.24	0.460	1.535	0.753
8	3.10	-1.87	2.314	3.486	0.394
9	4.93	-0.04	0.068	0.001	3.352
10	5.28	0.32	-0.012	0.102	0.126
11	3.23	-1.74	-0.555	3.024	4.236
12	5.94	0.97	-1.692	0.946	7.354
13	6.22	1.26	1.224	1.584	0.082
14	5.52	0.56	0.704	0.313	0.488
15	6.01	1.04	0.583	1.086	0.233
16	3.97	-0.99	-1.035	0.986	4.142
Mean =	4.97	Σ =	2.03	15.17	25.23
		ϕ =	0.13	D =	1.66

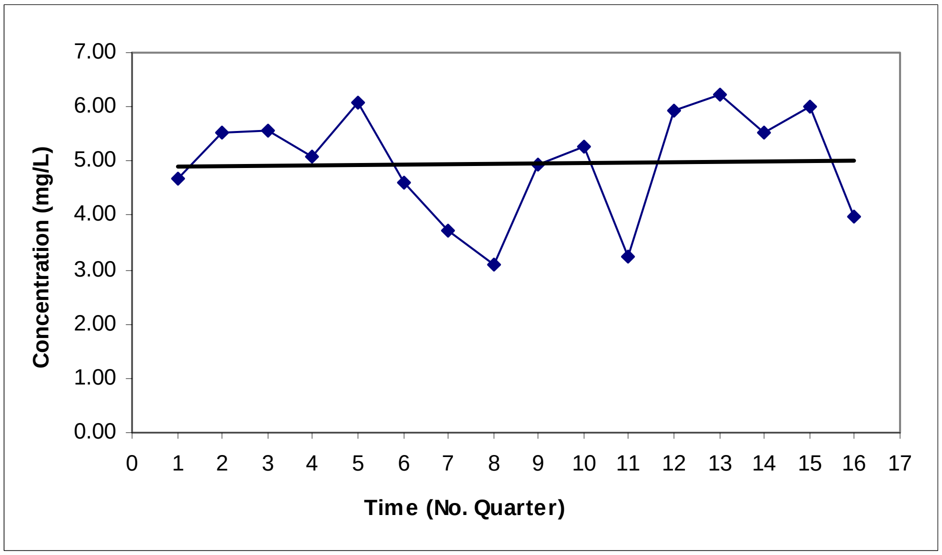


Figure A.7 3 Time series plot of quarterly manganese concentrations

METHOD 9 — METHODS FOR DEALING WITH NONDETECTS

If data generated from chemical analysis contains nondetects, i.e., measurements that are below the detection limit (DL) of the analytical procedure, the traditional statistical methods based on all quantified values do not work. Special procedures must be used to handle these nondetects.

Nondetects are usually reported with the appropriate limit of detection and refer to concentrations that lie somewhere between zero and the detection limit. Data that include both detect and non-detect results are called censored data in statistical literature. General guidelines (EPA 1992, ASTM 1998) that usually prove adequate in handling data with nondetects are introduced below.

If less than 15% percent of all samples are nondetects, replace nondetects by half their detection limit (or DL, or a fraction of DL, or zero) and proceed with a parametric analysis, such as prediction limits or confidence limits. It is shown that the results of parametric tests will not be substantially affected by this simple substitution (EPA 1992).

If the percent of nondetects is between 15 and 50, use Cohen's adjustment (EPA 1989) or Aitchison's adjustment (EPA 1992) to the sample mean and variance, followed by a parametric analysis. Aitchison's method imputes nondetects as zero concentration. Cohen's method assumes nondetects are below detection limit but not necessarily zero. Both methods require that data without nondetects be normally distributed. A useful approach to selecting between the two methods is described in the EPA guidance (EPA 2000). Davis et al. (1994) point out that Aitchison's adjustment is not appropriate for log-transformed data and that there is a substantial amount of spatial variation involved. This section only introduces Cohen's adjustment.

If the percent of nondetects is between 50 and 90, use nonparametric versions of statistical interval estimates. For detection monitoring, the nonparametric prediction limits developed by Davis et al. (1992) can be used. The nonparametric prediction limit is simply the largest or next to largest concentration found in the background, or upgradient, measurements. Complete tabulations of confidence levels for these nonparametric prediction limits for different combinations of background sample size, number of future comparisons, and resample plans are available in Gibbons (1994). For compliance monitoring or corrective action monitoring, the nonparametric confidence interval presented in the EPA document (EPA 1989) or test of proportion from other sources (EPA 1992b, EPA 2000) can be used. This section introduces the nonparametric prediction limit.

If the percent of nondetects is greater than 90, a situation that is not uncommon in detection monitoring, use either the Poisson prediction limits (ASTM 1998) or the nonparametric prediction limits discussed above. Detailed discussion of Poisson prediction limits is provided in Gibbons (1994). Loftis et al. (1999) doubted the validity of using the Poisson model for modeling concentration data because the variance of distribution varies with changing units of measurement. Therefore, we suggest that the Poisson prediction limits should be used only for counts of analytical hits, usually for VOCs. In the case of 100% nondetects, i.e., detection frequency equals zero, one can also use the laboratory-specific quantitation limit or limits required by the applicable regulatory agency (ASTM 1998) as the nonparametric prediction limits. In this case, one should question whether the constituent is a useful indicator of contamination and if not, statistical testing of the constituent should not be performed.

Statistical independence of data is still the underlying assumption of all of the above-suggested procedures. Note that the above-suggested percentages are not hard and fast rules, and should be based on judgement (EPA 2000).

Procedures (Cohen's Adjustment):

Step 1. Let n be the total number of measurements and denote them as x_i, $i = 1, 2, \ldots, n$, among which m measurements are above detection limit (DL). Thus, there are $(n-m)$ measurements that are below the DL (nondetects).

Step 2. Compute the sample mean from the data above the DL as:

$$\bar{x}_d = \frac{1}{m}\sum_{i=1}^{m} x_i$$

Step 3. Compute the sample variance from the data above the DL as:

$$s_d^{\;2} = \frac{\sum_{i=1}^{m}\left(x_i - \bar{x}_d\right)^2}{m-1}$$

Step 4. Compute two parameters h and γ as:

$$h = \frac{(n-m)}{n} \quad \text{and} \quad \gamma = \frac{s_d^{\;2}}{(\bar{x}_d - DL)^2}$$

Step 5. Consult Cohen's table (e.g., EPA 2000, Table A-10 of Appendix A) with h and γ to determine the value of the parameter $\hat{\lambda}$. If the exact value of h and γ do not appear in the table, use double linear interpolation to estimate $\hat{\lambda}$.

Step 6. Estimate the corrected sample mean, $\bar{x}$, and sample variance, s^2, which account for the data below the DL, as

$$\bar{x} = \bar{x}_d - \hat{\lambda}(\bar{x}_d - DL) \quad \text{and} \quad s^2 = s_d^{\;2} + \hat{\lambda}(\bar{x}_d - DL)^2$$

An example of this adjustment is available in EPA guidance (EPA 2000), pages 4-44.

Procedures (Nonparametric Prediction Limit):

Step 1. Let n be the total number of background measurements and denote the number of monitoring wells for future comparison as r.

Step 2. Determine the resample plan (e.g., One of Two Samples in Bounds plan or One of Three Samples in Bounds plan) and use the largest or next to largest background measurement as the nonparametric prediction limit.

Step 3. Use n, r, and choices from step 2 in the tables from Davis and McNichols (1994) or Gibbons (1994) to determine the Per-Constituent significance level (α) or Per-Constituent confidence level ($1-\alpha$), respectively.

Step 4. Inverse problems can be solved by fixing the desired Per-Constituent significance level (α) and using the tables to inversely determine the number of background measurements (n), or the number of wells for future comparison (r). If N constituents are involved, the Per-Constituent significance level (α) should be calculated as

$\alpha = \dfrac{a*}{N}$, where α* is the desired facility-wide false positive rate.

Step 5. The use of this nonparametric prediction limit for future comparisons is the same as in the parametric prediction limit described in **METHOD 2**.

Procedures (Poisson Prediction Limit):

Step 1. Let *y* be the total number of detections (analytical hits) from multiple-constituent scans (e.g., for VOCs) of *n* background samples. Denote the number of future measurements (i.e., number of monitoring wells or number of measurements in one well) as *k*.

Step 2. Determine the resample plan and the facility-wide false positive rate (α*). Calculate the significance level (α) associated with each individual test as the minimum of 0.01 or one of the following:

$\alpha = (1-(1-\alpha^*)^{1/k})^{1/2}$ for One of Two Samples in Bounds plan;

$\alpha = (1-(1-\alpha^*)^{1/k})^{1/3}$ for One of Three Samples in Bounds plan;

$\alpha = \sqrt{1-(1-\alpha^*)^{1/k}}\sqrt{1/2}$ for First or Next Two Samples in Bounds plan.

Step 3. Compute the Poisson prediction limit as:

$$PoissonPL = \frac{y}{n} + \frac{z^2}{2n} + \frac{z}{n}\sqrt{y(1+n)+\frac{z^2}{4}} \text{ (detections per scan)}$$

where z is the (1-α) 100 upper percentage point of the standard normal distribution.

Step 4. If the average number of detections per scans of the *k* future samples is greater than this prediction limit, it may indicate exceedence but must be verified by resamples. The verification procedure is same as in the parametric prediction limit described in **METHOD 2**.

Example (Nonparametric Prediction Limit):

Step 1. Consider developing a nonparametric prediction limit for a facility with $r = 15$ monitoring wells. In $n = 10$ background measurements of benzene concentrations, two were above the detection limit (percentage of nondetects is greater than 50). These detects are, 5 ppb, and 8 ppb. Nondetects are reported as "< 2 ppb".

Step 2. Plan I: use One of Two Samples in Bounds plan. Plan II: use One of Three Samples in Bounds plan. Use the largest background measurement, 8 ppb, as the nonparametric prediction limit for both plans.

Step 3. For Plan I, in Table 2a on page 164 of Davis and McNichols (1994), for $n = 10$ and $r = 15$, the Per-Constituent significance level is 0.159, which is much higher than 5%. For Plan II, in Table 3a on page 165 of Davis and McNichols (1994), for $n = 10$ and $r = 16$, the Per-Constituent significance level is 0.0428, which is within 5%.

Therefore Plan II is an eligible plan if the facility-wide false positive rate (α*) is to be controlled at 5%, and only one constituent, benzene, is considered.

Step 4. If Plan I must be used to control the Per-Constituent significance level (α) at 5%, then in Table 2a on page 164 of Davis and McNichols (1994), for $r = 15$, we find $\alpha = 0.388$ if $n = 25$. This means 25 background measurements are needed to meet the 5% requirement.

Example (Poisson Prediction Limit):

Step 1. Consider developing a Poisson prediction limit for a facility with $k = 15$ monitoring wells. In $n = 12$ background samples for which a 32-constituent VOC scan was conducted, there were $y = 6$ detections. The percentage of nondetects in this case is far less than 10% ($6/12/32 = 0.016 = 1.6\%$).

Step 2. Use the One of Two Samples in Bounds plan and set the facility-wide false positive rate $\alpha^* = 0.05$. The α for this resample plan is:

$$\alpha = (1-(1-\alpha^*)^{1/k})^{1/2} = (1-(1-0.95)^{1/15})^{1/2} = 0.058$$

Since the minimum of 0.01 and 0.058 is 0.01, the significance level associated with each individual test is therefore $\alpha = 0.01$. The z value associated with $\alpha = 0.01$ is 2.236.

Step 3. The Poisson prediction limit is:

$$PoissonPL = \frac{6}{12} + \frac{2.236^2}{2\times 12} + \frac{2.236}{12}\sqrt{6(1+12)+\frac{2.236^2}{4}} = 2.452 \text{ (detections per scan)}$$

This Poisson detection limit can also be translated into a total of 2.452 × 15 ≈ 36 detections out of scans of 15 future samples. For comparison, the background samples have only 6/12 = 0.5 detections per scan.

METHOD 10 — METHODS FOR DEALING WITH SEASONAL EFFECTS AND SERIAL CORRELATION

When the data exhibit regular seasonal patterns or significant serial correlation, the assumption of independence is violated and adjustments must be taken to remove these effects. As is described in **METHOD 8**, adjusting for seasonal effects is usually achieved by removing the seasonal means from the data. While the methods of calculating and testing the significance of the serial correlation coefficient are given in **METHOD 8**, procedures for adjusting serial correlation are not provided. In this section, approaches from EPA guidance (1992b) for dealing with seasonal effects and serial correlation are presented. These adjustments aid in determining the standard error of the mean and degrees of freedom associated with it when seasonal effects and/or serial correlation exist. Standard error of the mean is crucial in constructing confidence limits that are widely used in compliance monitoring and corrective action monitoring. Recall in **METHOD 3**, the lower confidence limit is calculated as

$\bar{x} - \frac{t_{(n-1,\alpha)}s}{\sqrt{n}}$, where $\frac{s}{\sqrt{n}}$ is the standard error of a sample mean and the degrees of freedom associated with $\frac{s}{\sqrt{n}}$ is $n-1$.

Now we denote the standard error of the mean as $s_{\bar{x}}$ and thus a lower confidence limit is generally in the form of $\bar{x} - t_{(Df,\alpha)}s_{\bar{x}}$ and an upper confidence limit in the form of $\bar{x} + t_{(Df,\alpha)}s_{\bar{x}}$, where Df is the degrees of freedom associated with $s_{\bar{x}}$. The following procedures provide for calculating $s_{\bar{x}}$ in the presence of seasonal effects or serial correlation or both, assuming that no obvious trend exists in the data. In the presence of trends in the data, detrend the data first the method described in **METHOD 8** before using the following procedures.

Procedures (Seasonal Effects Only):

Step 1. Consider a time series of N observations that exhibit m seasonal patterns. The jth ($j = 1, 2, \ldots, m$) seasonal average is:

$\bar{x}_j = \frac{1}{n_j}\sum_{k=1}^{n_j} x_{jk}$, where n_j is the number of non-missing observations for season j.

Step 2. Calculate the sample residuals after correcting for the seasonal means as:

$$e_{jk} = x_{jk} - \bar{x}_j$$

Step 3. Compute the mean square error as:

$$s_e^2 = \frac{\sum_{j=1}^{m}\sum_{k=1}^{n_j} e_{jk}^2}{N - m}$$

Step 4. The standard error of the mean is

$s_{\bar{x}} = \sqrt{\frac{s_e^2}{N}}$ and the Df associated with it is N-m.

Procedures (Serial Correlation Only):

Step 1. Consider a time series of N observations that exhibit serial correlation but no seasonal effects. The observed serial correlation coefficient is ϕ, which has been proved as statistically significant using the Durbin-Watson test presented in **METHOD 8**.

Step 2. Assume the variance estimated from this time series is s^2. The standard error of the mean when N is large is approximately

$s_{\bar{x}} = \sqrt{\frac{s^2}{N}\frac{(1+\phi)}{(1-\phi)}}$ and the Df associated with it is approximately $\frac{N-1}{3}$, rounded to the nearest smaller integer.

Procedures (Seasonal Effects and Serial Correlation):

Step 1. Consider a time series of N observations that exhibit m seasonal patterns and serial correlation. The mean square error calculated from this set of data is s_e^2, which is estimated by using ***Procedures (Seasonal Effects Only)***. The observed serial correlation coefficient is ϕ, which has been proven to be statistically significant using the Durbin-Watson test presented in **METHOD 8**.

Step 2. The standard error of the mean when N is large is approximately

$s_{\bar{x}} = \sqrt{\frac{s_e^{\,2}}{N}\frac{(1+\phi)}{(1-\phi)}}$ and the *Df* associated with it is approximately $\frac{N-m}{3}$, rounded to the nearest smaller integer.

Example:

Step 1. A hypothetical dataset containing quarterly measurements of a contaminant from a monitoring well during a four year period (*N = 16*) is presented in Table A.7.16. The time series plot of this dataset is given in Figure A.7.4, which shows clear seasonal patterns (*m = 4*). To determine whether this well is in compliance, a lower confidence limit on the sample mean needs to be constructed to compare to the background standard, which is 6.5 mg/L.

Step 2. The four seasonal means are 6.52, 9.85, and 8.08, and 4.87 mg/L, respectively. For example, the first seasonal mean $\bar{x}_1 = (6.74 + 7.64 + 5.30 + 6.40) / 4 = 6.52$. The de-seasonalized residuals, e_i, are listed in the fourth column of Table A.7.16.

Step 3. Based on the de-seasonalized residuals, the observed serial correlation coefficient is

$$\phi = \frac{\sum_{i=2}^{N} e_i e_{i-1}}{\sum_{i=1}^{N} e_i^{\,2}} = \frac{4.084}{12.261} = 0.33$$, and the Durbin-Watson statistic is

$$D = \frac{\sum_{i=2}^{N} (e_i - e_{i-1})^2}{\sum_{i=1}^{N} e_i^{\,2}} = \frac{16.027}{12.261} = 1.31\cdot$$

Step 4. Consulting the Durbin-Watson table given (Neter et al. 1996, page 1349) with $\alpha = 0.05$ and $n = 16$ in the column titled $p\text{-}1=1$, we find $d_u = 1.37$. Since $D = 1.31 < d_u = 1.37$, there is significant serial correlation in this time series and procedures adjusting for seasonal effects and serial correlation must be used as shown in the following steps.

Step 5. The mean square error of the de-seasonalized residuals is

$$s_e^{\,2} = \frac{\sum_{j=1}^{m}\sum_{k=1}^{n_j} e_{jk}^{\,2}}{N-m} = \frac{12.261}{16-4} = 1.022$$. Thus the standard error of the mean is

$$s_{\bar{x}} = \sqrt{\frac{s_e^{\,2}}{N}\frac{(1+\phi)}{(1-\phi)}} = \sqrt{\frac{1.022}{16}\frac{(1+0.33)}{(1-0.33)}} = 0.357$$ and the *Df* associated with it is

$$\frac{N-m}{3} = \frac{16-4}{3} = 4.$$

Step 6. The lower confidence limit on the sample mean is therefore

$$\bar{x} - t_{(Df,\alpha)} s_{\bar{x}} = 7.33 - t_{(4,0.05)} \times 0.357 = 7.33 - 2.78 \times 0.357 = 6.34 \text{ mg/L.}$$

Since this lower confidence limit contains the background standard, which is 6.5 mg/L, it can be concluded that the contaminant concentration at this well is within compliance.

Table A.7.16 Example data for adjusting seasonal effects and serial correlation

Quarter	Data (mg/L)	Seasonal average	Deseasonalized Residuals (e_i)	e_i^2	$e_i e_{i-1}$	$(e_i-e_{i-1})^2$
1	6.74	1st = 6.52	0.22	0.048		
2	9.11	2nd = 9.85	-0.74	0.543	-0.162	0.916
3	7.25	3rd = 8.08	-0.82	0.678	0.607	0.007
4	5.99	4th = 4.87	1.13	1.268	-0.927	3.801
5	7.64		1.12	1.247	1.257	0.000
6	10.79		0.94	0.885	1.050	0.031
7	9.94		1.86	3.455	1.749	0.843
8	4.53		-0.34	0.114	-0.627	4.823
9	5.30		-1.22	1.484	0.411	0.776
10	9.13		-0.72	0.519	0.878	0.248
11	8.21		0.14	0.019	-0.098	0.734
12	4.60		-0.26	0.069	-0.036	0.158
13	6.40		-0.12	0.014	0.031	0.021
14	10.36		0.52	0.267	-0.061	0.403
15	6.91		-1.17	1.373	-0.606	2.851
16	4.34		-0.53	0.278	0.618	0.415
Overall mean = 7.33			Σ =	12.261	4.084	16.027
			ϕ =	0.33	D =	1.31

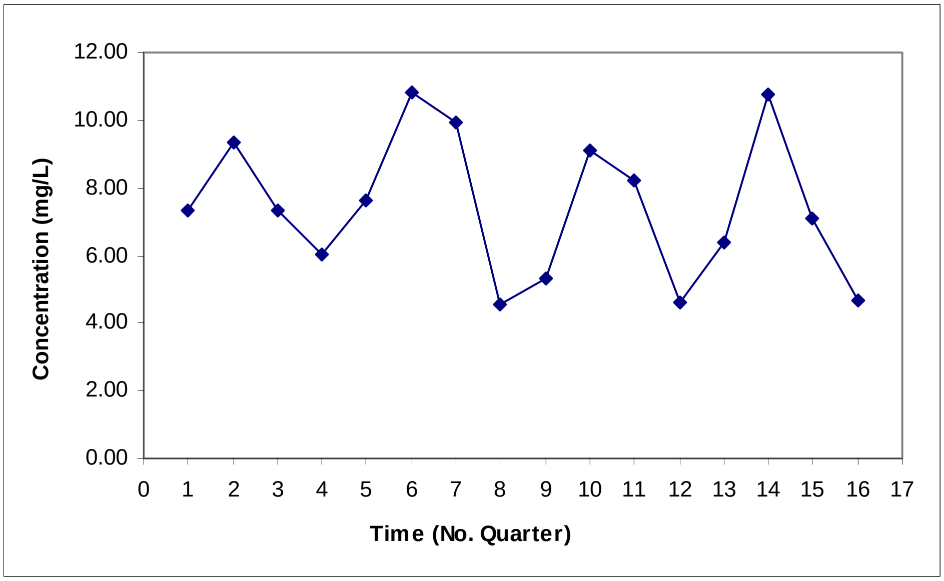


Figure A.7.4 Time series plot of quarterly contaminant concentrations

The Strategy for Data Evaluation

The use of an appropriate data evaluation strategy in a long-term monitoring program will result in reduction or better control of false positive and false negative rates. In this study, the strategies for assessing data before testing are presented and appropriate statistical methods for testing the data are recommended. A summary of these methods and strategies are presented in tables A.7.17 through A.7.20. The general data evaluation procedures are described below. This is a general outline and is not intended to be a guidance-style flowchart.

Table A.7.17 Appropriate statistical methods used in long-term monitoring programs

Method	Scope of Use	Objective	Method Description
Method **1**: Combined Shewart-CUSUM control chart	Detection monitoring	To determine if groundwater is contaminated and if compliance monitoring is required.	The control chart method is sensitive to both immediate and gradual releases. As an intra-well comparison method, problems associated spatial variations can be completely avoided.
Method **2**: Inter-well and intra-well prediction limits.	Detection monitoring	To determine if groundwater is contaminated and if compliance monitoring is required.	The method is capable of controlling the facility-wide false positive rate (FWFPR) and minimizing the false positive and false negative rates associated with a single comparison.
Method **3**: Confidence limits	Compliance monitoring	To find if there is statistically significant evidence of contamination and if corrective action monitoring is required.	The method is easy to perform. The requirement that the confidence limit be compared to the ACL from background samples instead of the MCL is protective of human health or the environment (EPA 1992a).
Method **4**: Sequential test method	Corrective action monitoring	To test if groundwater has attained the cleanup standards.	The method requires fewer samples and a corresponding shorter time to make the attainment decision than the fixed sample size test, under the same levels of false positive and false negative rates.
Method **5**: Mann-Kendall test for trends	Where needed	To determine whether the trend of concentration data vs. time is increasing, decreasing, or stable, etc.	This method does not require a test for normality of data. Test results of the GSI style Mann-Kendall test are classified more reasonably.

Procedures:

1. Distinguish the type of monitoring program in which the statistical tests will be used and set up the correct null hypothesis. Refer to tables A.7.4, A.7.5, and A.7.6.
2. Estimate the percentage of nondetects in the observations and choose the correct "category" of statistical approach based on the percentage of nondetects. Refer to Table A.7.19. This may need to be done on a well-by-well basis.

3. Adjust for seasonal patterns and serial correlation, if needed, before testing for the distributional assumption. Refer to tables A.7.20 and A.7.18. This may need to be done on a well-by-well basis.
4. Evaluate the possibility of using intra-well analysis to avoid the influence of spatial variability based on the sufficiency of data from the historical database. Tests for homogeneity of variance (refer to Table A.7.18, Method 17) can be performed to determine the significance of spatial variation.
5. Choose the appropriate statistical approaches from the correct "category" based on considerations from the first four steps. Refer to Table A.7.17. This may need to be done on a well-by-well basis.

Note: If any of the above conditions change during the process of long-term monitoring, re-evaluate the above steps. For example, if the monitoring requirement in the site changes from compliance monitoring to corrective action monitoring, all above steps should be re-evaluated.

Considerations:

Methods that control FWFPR or FWFNR should be used if FWFPR or FWFNR is critical to making a monitoring decision. Sensitivity or power of a statistical approach should always be evaluated and in some cases compared to EPA references. When more than one method is eligible, the one with highest power at the range of observed variability is preferred as long as it meets the requirement of the false positive rate.

Table A.7.18 Methods for testing statistical assumptions

Method	Objective	Method Description
Method **6**: Shapiro Wilk test	To test the normality of data.	The method is a superior alternative to the Chi-Square test and is widely used (EPA 1992a, 1992b).
Method **7**: Levene's test	To test the homogeneity of variances between data from different wells.	The method is a more formal procedure than Box Plots visual method. It has a high power that Bartlett's test for non-normal data.
Method **8**: Durbin-Watson test	To test if there is significant serial correlation in data	This test is a widely used method (EPA 1992b, Neter et al. 1996)

Table A.7.19 Methods for dealing with non-detects

% Non-detects	METHOD **9**	Distributional Assumption	Method Description
< 15%	Sub Method 1: Simple replacement	Normal or Lognormal	The method replaces nondetects with half of their MDLs for "undetected" measurements, or PQLs for "detected but not quantified" measurements.
15% ~ 50%	Sub Method 2: Cohen's adjustment	Normal or Lognormal	The method makes Cohen's adjustments by including nondetects in the calculation.
50% ~ 90%	Sub Method 3: Nonparametric methods	Not known	The method uses a nonparametric version of statistical interval estimates (e.g., prediction limit and confidence limit).
90% ~ 100%	Sub Method 4: Poisson model	Poisson	The method uses the Poisson prediction limit or tolerance limit constructed from counts of analytical hits only.
100%	Sub Method 5: Specified limits	Not known	The method uses laboratory-specific QL or limits required by applicable regulatory agency.

Table A.7.20 Methods for dealing with serial correlation and seasonal effects

Condition	METHOD **10**	Method Description
No seasonal patterns but may be serially correlated	Sub Method 1: Lag 1 adjustment	The method adjusts for serial correlation based on AR(1) model (first order autoregressive model)
Seasonal patterns but no serial correlation	Sub Method 2: Seasonal adjustment	The method makes inferences out of seasonally adjusted residuals (remove seasonal mean)
Seasonally-adjusted residuals exhibit serial correlation	Sub Method 3: Combined adjustment	The method adjusts for serial correlation of seasonally adjusted residuals

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APPENDIX A.8 — MAROS SITE RESULTS

Authors: Newell, C.J. and Aziz, J. J., Groundwater Services, Inc.

The preliminary monitoring system optimization results are based on site classification, source treatment and monitoring system category (Figure A.8.1). The decision matrices below are heuristic rules based on the judgment of the authors. Users are expected to review and modify as necessary to reflect site specific hydrogeology, contaminants, risks and regulatory considerations. General recommendations by more rigorous statistical methods can be obtained by using the more detailed optimization approaches outlined in Appendices A.2 and A.3. General site results are outlined by for Sampling Frequency, Well Sample Density and Duration of Sampling. These criteria take into consideration: plume stability, type of plume, and groundwater velocity. The results are specific to only one COC. Each COC considered in the MAROS software is assigned a result based on the criteria outlined here.

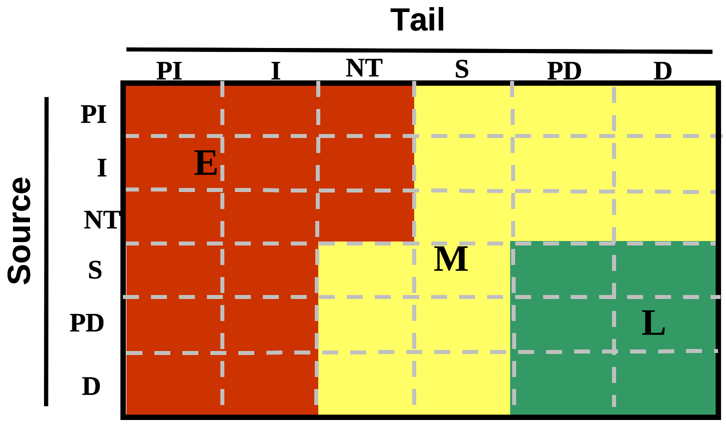


Figure A.8.1 Decision Matrix for Assigning Monitoring System Categories: Moderate (M); Extensive (E); Limited (L); Plume Stability: Increasing (I); Probably Increasing (PI); No Trend (NT); Stable(S); Probably Decreasing (PD); Decreasing(D).

Weighted Average

Two types of weighting are available within the MAROS Analysis software (i.e. LOE weighting and well weighting). The weighting for these analyses follow a simple weighted average defined as:

$$\text{Weighted Average} = \frac{\sum_{i=1}^{n} W_i X_i}{\sum_{i=1}^{n} W_i}, \text{ where } W_i \geq 0.$$

W_i is the weight of the value, X_i, in the MAROS software, high, medium, and low weight correspond to values 3, 2 and 1 respectively.

No Current Site Treatment Or Monitored Natural Attenuation

Sites not currently undergoing site treatment (i.e. no current site remediation method other than monitored natural attenuation) have separate decision matrices applied (Tables A.8.1 to A.8.3)

FREQUENCY

MAROS uses a simple decision matrix to indicate how often wells at the site should be sampled to be sufficient for adequate groundwater monitoring. Users can compare the frequency of the sampling at their site to the suggested frequency of monitoring evaluated based on the decision matrix below. If their site has wells being sampled at a significantly higher interval, then some reduction in the sampling frequency could be applied. Note that user can apply the sampling optimization (Sample Frequency) wing of the software to perform a more rigorous analysis of the sampling frequency required for monitoring for individual well sampling frequency recommendations.

Another possibility for sites with slow moving groundwater (higher TTR) involves a comparison study of trends for a complete dataset and a censored dataset. For example, the user can choose to analyze all existing monitoring data, then censor the data (consistently choose 1 quarter's worth of data, e.g. the first sample event for each year) and run the trend analysis again. Run the MAROS trend results on both the sets of data and then compare the results. If both trend results are the same, then the trend results could have been obtained from using only annual sampling. Similarly, if you would like to be able to sample at a frequency greater than biennial, this same type of analysis could be applied. You could choose to monitor the well greater than every 2 years if the trend results are consistent with less data. This type of analysis is only appropriate with adequately characterized plumes and long time period sample datasets (> 8 years).

The sampling frequency at the site is determined by the Monitoring System Category assigned by the results from the Source and Tail Stability as well as the "Time to Receptor". Sites with both decreasing Source and Tail Results are recommended for closure.

Table A.8.1 Frequency Determination for sites with no groundwater fluctuations and Monitored natural Attenuation.

TTR	**Monitoring System Category**		
	E	**M**	**L**
Close (TTR < 2 yrs)	Quarterly	Biannually (6 months)	Annually
Medium (2 < TTR < 5 yrs)	Biannually (6 months)	Annually	Annually
Far (TTR > 5 yrs)	Annually	Annually	Biennially (2 year interval)
TTR: time to receptor (distance to receptor/seepage velocity)			

Table A.8.2 Frequency Determination for sites with groundwater fluctuations and Monitored natural attenuation.

TTR	Monitoring System Category		
	E	M	L
Close (TTR < 2 yrs)	Quarterly	Quarterly	Biannually
Medium (2 < TTR < 5 yrs)	Quarterly	Biannually	Biannually
Far (TTR > 5 yrs)	Biannually	Biannually	Annually
TTR: time to receptor (distance to receptor/seepage velocity)			

DURATION

MAROS uses a simple decision matrix to assess when the design of the groundwater monitoring network should be reassessed for reducing the scope of the system or to stop monitoring altogether. Users can compare the projected duration of the sampling at their site to the suggested duration of monitoring evaluated based on the decision matrix below. The matrix was developed based on engineering judgment and experience of the authors. It is not based on any kind of statistical analysis. If their site has groundwater monitoring planned for a significantly longer time period, then some reduction in the monitoring duration could be applied, subject to local and federal regulations.

The sampling duration at the site is determined by the Monitoring System Category assigned by the results from the combined Source and Tail Stability Category as well as the length of the sampling record available. Sites with both decreasing Source and Tail Results are suggested to end the sampling.

Table A.8.3 duration Determination for sites with Monitored Natural Attenuation.

Sampling Record	Source or Tail Trend Category			
	I or PI Trends	NT or N/A	S Trends	PD or D Trends
Small (< 2 yrs)	Consider reassessment of network if concentrations begin to decrease.	Insufficient Data, continue sampling	6 more years	3 more years
Medium (2 < TTR < 10 yrs)	Consider reassessment of network if concentrations begin to decrease.	Insufficient Data, continue sampling	4 more years	2 more years
Large (> 10 yrs)	Consider reassessment of network if concentrations begin to decrease.	Insufficient Data, continue sampling	2 more years	1 more year

SAMPLING DENSITY

MAROS uses a simple rule of thumb to indicate how many wells at the site may be sufficient for groundwater monitoring. Users can compare the number of wells at their site to the number of wells from the rule of thumb. If their site has significantly more wells being sampled, then some reduction in the number of wells is possible. Note that users can use the sampling optimization (Sample Location) wing of the software to perform a more rigorous analysis of the number of wells required for monitoring.

The simple rule of thumb is based on two large databases of historical plume data were considered when evaluating the minimum well density reflecting both BTEX and chlorinated solvent plume information (Mace, 1997 and McNab, 1999). Mace (1997) used data from 138 BTEX plumes while McNab (1999) presented data from 37 the chlorinated solvent plumes. These data were combined, plotted, and then used to develop the following equation:

$$\text{sampling density (number of wells)} = 1.5(plumelength)^{0.4}$$

= where plume length is in units of feet and the sampling density is the number of wells for the entire plume.

In other words, this equation indicates the monitoring well density actually in use at the sites in the database and is based on plumes of different sizes (roughly 50 ft to 5000 ft).

MAROS uses this equation to indicate a well density that is typical at many sites. Based on recommendations developed by ASTM (1998), a minimum of four wells is specified for all plumes. User should also consider the well density in light of adequately defining/characterizing the plume through gathering sufficient site information.

Current Site Treatment

Sites currently undergoing site treatment (i.e. pump and treat system, etc.) have separate site suggestions for sampling frequency, duration and density applied.

FREQUENCY

No recommendation is given for the sampling frequency at a site that is currently undergoing remediation.

DURATION

MAROS uses a simple decision matrix to assess when the design of the groundwater monitoring network should be reassessed for reducing the scope of the system or to stop monitoring altogether. Users can compare the projected duration of the sampling at their site to the suggested duration of monitoring evaluated based on the decision matrix below. The matrix was developed based on engineering judgment and experience of the authors. It is not based on any kind of statistical analysis. If their site has groundwater monitoring planned for a significantly longer time period, then some reduction in the monitoring duration could be applied, subject to local and federal regulations.

Table A.8.4 duration Determination for sites with current site treatment.

Source or Tail Trend Category			
I or PI Trends	**NT or N/A**	**S Trends**	**D or PD Trends**
Remediate indefinitely or consider increasing performance or remediation mechanism.	Insufficient Data, continue sampling.	Stop treatment if PRG met. Consider stopping treatment if plume has been stable for extended period.	Consider stopping treatment if decreasing trends have been occurring for extended period.

The sampling duration at the site is determined by the Source and Tail Stability results. Sites with both decreasing Source and Tail trends are suggested to consider stopping treatment if decreasing trends have been occurring for an extended period or PRG's have been met. Sites with Source or Tail results that indicate an increasing plume size are recommended for indefinite remediation or consider increasing performance or remediation mechanism. Sites with Stable in the Source and Tail suggest to consider removing the treatment system if previously reducing concentration or PRG met.

SAMPLING DENSITY

The sampling density determination for a site currently undergoing remediation is identical to that not currently undergoing site treatment. However, the results should be considered in the context of evaluating both regulatory compliance as well as remediation method performance evaluation.

References

Mace, R.E., R.S. Fisher, D.M. Welch, and S.P. Parra, Extent, Mass, and Duration of Hydrocarbon Plumes from Leaking Petroleum Storage Tank Sites in Texas, Bureau of Economic Geology, University of Texas at Austin, Austin, Texas. Geologic Circular 97-1, 1997.

McNab, W.W., D.W.R.J. Bear, R. Ragaini, C. Tuckfield, and C. Oldenburg, 1999. Historical Case Analysis of Chlorinated Volatile Organic Compound Plumes, Lawrence Livermore Laboratory, University of California, Livermore, Ca, 1999. http://searchpdf.adobe.com/proxies/0/5/69/6.html

APPENDIX A.9 — SAMPLING FREQUENCY ANALYSIS: MODIFIED CES METHOD

Authors: Ling, M. and Rifai, H. S., University of Houston; Vanderford, M., Groundwater Services, Inc.

In MAROS, the Modified CES method is used to determine the sampling frequencies at all sampling locations for each COC. The Modified CES method has been developed based on the Cost Effective Sampling algorithm (CES, Ridley et. al. 1995) developed at Lawrence Livermore National Laboratory (LLNL). The Modified CES method is designed to set the sampling frequency for a well based on the analysis of time series concentration data at each sampling location, considering both recent trends and long-term trends of the concentration data. In contrast to the spatially-based Delaunay Method used in the MAROS sample location optimization, the Modified CES method is an approach based on temporal analysis. Its use, combined with the Delaunay Method and trend analyses, leads to a complete process of sampling optimization.

Cost Effective Sampling

Regulatory guidance on choosing appropriate intervals for groundwater sampling is somewhat limited. General guidelines suggest that sampling intervals should be related to issues such as the variability in contaminant concentrations, distance and travel time of contaminants relative to potential receptors and the attenuation of contaminant concentration required to meet regulatory criteria (AFCEE, 2000). Cost Effective Sampling (CES) is a methodology developed to estimate the lowest-frequency sampling schedule for a given groundwater monitoring location providing stakeholders the needed information for regulatory and remedial decision-making.

The CES method evaluates the frequency of well sampling based on statistics describing the trend, variability and magnitude of contaminant concentrations. The central premise of the CES method is that sampling frequency should be based on the *rate of change* of constituents at the well rather than well location within the plume. The CES method recommends three steps for determining the sampling frequencies.

Step 1. Set frequency based on recent trends. Initial sampling of monitoring wells is usually quarterly, so the definition of ‘recent’ is usually 2 years or 8 data collection events. Based on the trends determined by rates of change from linear regression analysis, a location is routed along one of four paths. The lowest rate of change, 0-10 ppb per year, leads to an annual frequency schedule. The highest rate, 30+ ppb per year, leads to a quarterly schedule. Rates of change in between these two extremes are qualified by variability information, with higher variability leading to a higher sampling frequency. Variability is characterized by a distribution-free version of the coefficient of variation: the range divided by the median concentration with 1.0 as the cut-off.

Step 2. Adjust frequency based on overall trends. If the long-term history of change is significantly greater than the recent trend, the frequency may be reduced by one level. If this is not so, no change could be made.

Step 3. Reduce frequency based on risk. Since not all compounds in the target list are equally harmful, frequency is reduced by one level if recent maximum concentration for compound of high risk is less than one half of the MCL.

It was stated that the evaluation by CES should be performed at the end of each year's monitoring. All the target chemicals should be evaluated to make the final decision. Latest updates by LLNL include biennial sampling of the well if three successive annual recommendations are made, and the cut-off value of variability at high concentrations.

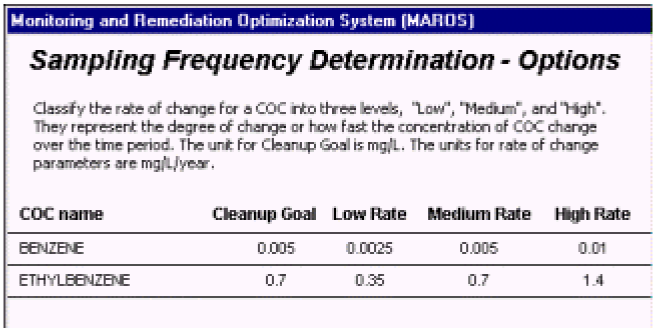
The adoption of minimum frequency of "quarterly" sampling is referred to by Barcelona et. al (1989). The use of the quarterly interval can be useful during the characterization phase of groundwater monitoring to evaluate seasonality, rate of change and variability, especially for fast moving plumes. However, for more stable plumes, the default adoption of quarterly monitoring can be excessive. The use of sampling intervals from Quarterly, Semi-Annual, Annual to Biennial levels is very common in long-term groundwater monitoring (AFCEE 1997, NFESC 2000) and has been adopted in MAROS method.

Details of the Modified CES Method

The sampling frequency method MAROS employs is based on the CES method, with some modifications to integrate with the overall MAROS approach. The resulting Modified CES method has three major steps that correlate with those of the original CES method. The details of the decision procedures for the three major steps are given in the following sub-sections.

In the Modified CES method, Concentration Trend (**CT**) determined by Mann-Kendall analysis is used instead of the distribution-free version of the coefficient of variation for the characterization of the variability. The GSI style Mann-Kendall trend results (Groundwater Services, Inc.) fall into 6 categories: Decreasing (**D**), Probably Decreasing (**PD**), Stable **(S)**, No Trend **(NT)**, Probably Increasing (**PI**), and Increasing (**I**). The result of nonparametric Mann-Kendall analysis is judged with Coefficient of Variation (standard deviation divided by sample mean) and Confidence in Trend to determine the trend category. Details of this statistical method can be found in Appendix A.2 of this User Guide.

The Rate of Change (ROC) parameters used for determining the linear trends of COC were generalized to include all possible ranges. The ROC parameters fall into five categories: Low (**L**), Low-Medium (**LM**), Medium (**M**), Medium-High (**MH**), and High (**H**). The ROC is simply the slope of the fitted line by linear regression. The User is required to define three ROC parameters, the Low rate, Medium rate, and High rate in the software. The other two rates, Low-Medium and Medium-High will be automatically determined. The term *Cleanup Goal* or *PRG* (Primary Remediation Goal) is used in MAROS to stand for MCL. By default, the Low rate is defined as 0.5*PRG*/year, the Medium rate is defined as 1.0*PRG*/year and the High rate is defined as 2.0*PRG*/year, for all COCs. The Low-Medium rate is defined as the half way between the Low rate and the Medium rate, as is the same for Medium-High rate. The User should provide more accurate values for these ROC values, if accurate classification is available from the hydrogeologic setting in the studied site. The unit of the ROC parameters is mg/L/year.



Sampling Frequency Determination - Options

Classify the rate of change for a COC into three levels, "Low", "Medium", and "High". They represent the degree of change or how fast the concentration of COC change over the time period. The unit for Cleanup Goal is mg/L. The units for rate of change parameters are mg/L/year.

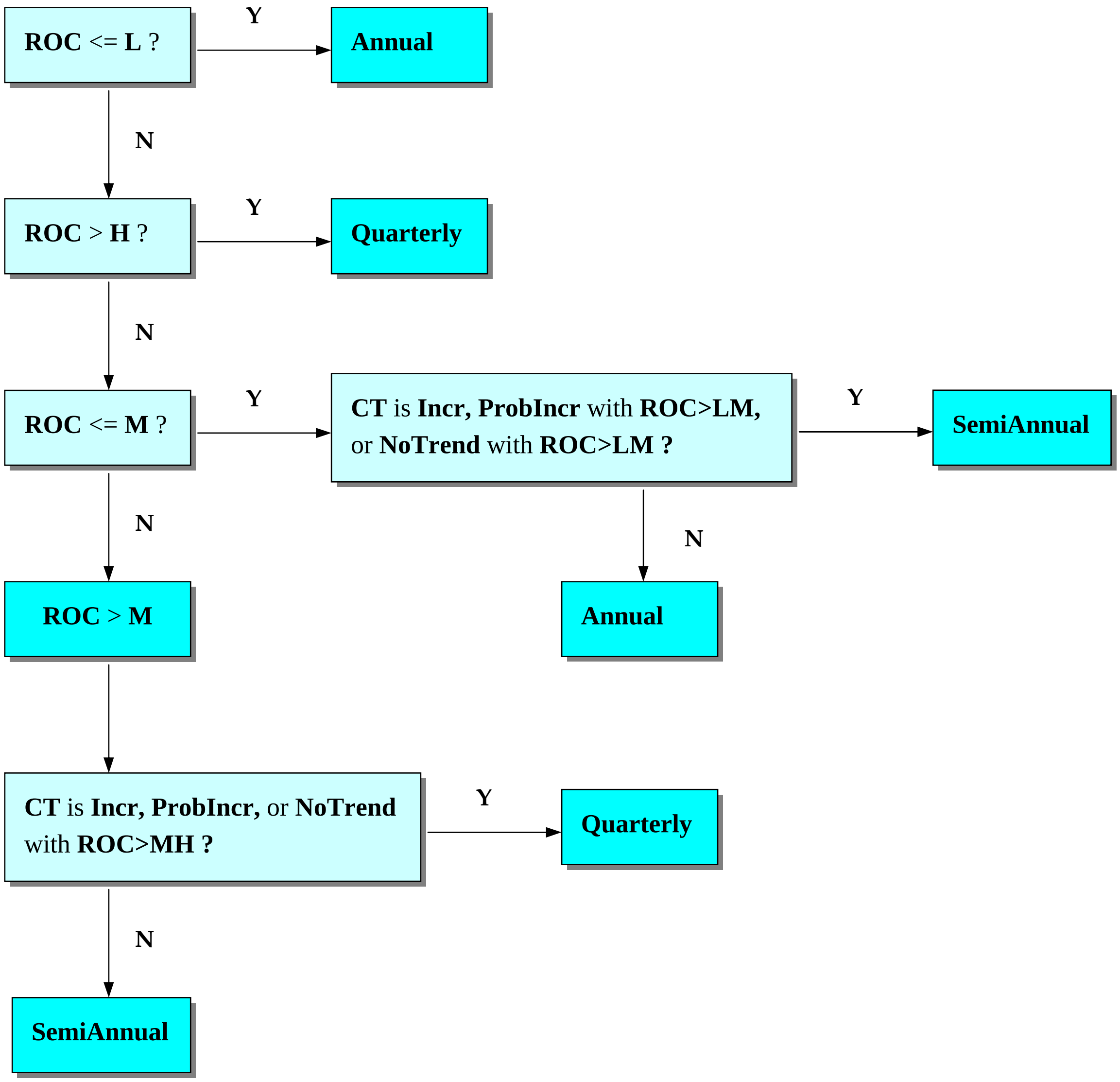
COC name	Cleanup Goal	Low Rate	Medium Rate	High Rate
BENZENE	0.005	0.0025	0.005	0.01
ETHYLBENZENE	0.7	0.35	0.7	1.4

For example, in the screen displayed to the right, the Cleanup Goal for Benzene is 0.005 mg/L. Then the default Low rate is 0.5 × 0.005 = 0.0025 mg/L/year, unless the User provides a site-specific value. According to the definition, the default Medium rate is 0.005 mg/L/year, and the default Low-Medium rate is (L+M)/2 = (0.0025+0.005)/2 = 0.00375, etc. For details on how to set these parameters, refer to the corresponding section under *MAROS Detailed Screen Descriptions*.

In MAROS, the determination of sampling frequencies using the Modified CES method starts with the *Sampling Frequency Analysis* screen, detailed under *MAROS Detailed Screen Descriptions*.

1) DETERMINE FREQUENCY BY RECENT TRENDS

Sampling frequency can be determined by results from both recent trends and overall trends. In the initial step, we need to determine the sampling frequency based on recent trends using the decision logic shown below.

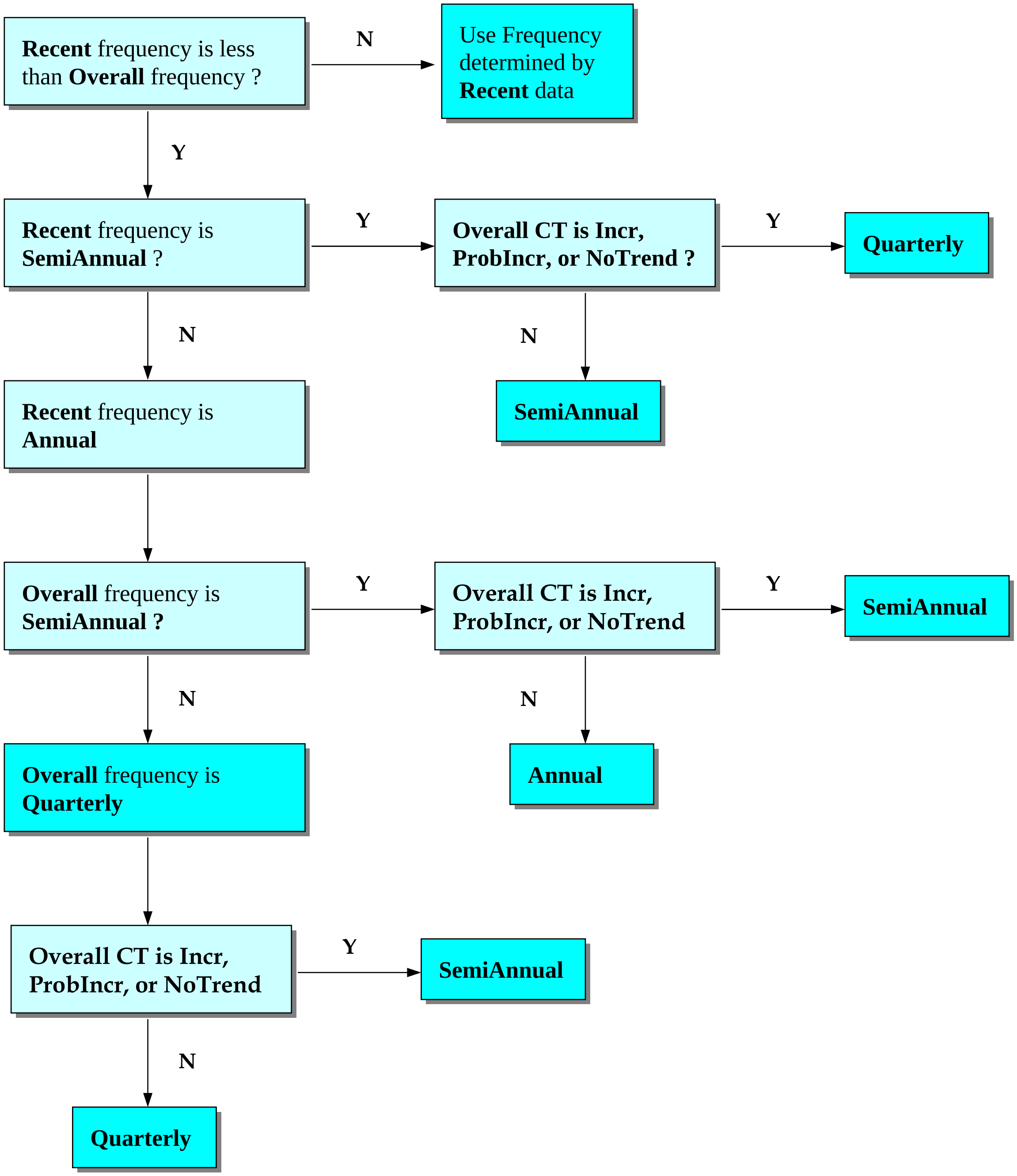


For wells with sufficient data to determine a trend and low rates of change, Annual sampling is recommended. Wells without a sufficient data set (<4 sample events) are assigned a default Quarterly sampling frequency. Wells with high rates of change are assigned default quarterly monitoring as well. For wells with moderate rates of change, the concentrations trend results from the Mann-Kendall analysis are evaluated and wells are assigned either Quarterly, Semi-annual or Annual monitoring frequencies.

A similar procedure is used to determine the sampling frequency based on overall trends. In this step, the sampling frequency can be one of three possible outcomes: Annual, Semi-Annual, or Quarterly. An adjustment based on the recent/overall ratio will be performed in the next step. Figure A.9.1 gives a quick decision matrix that is similar to the above flowchart but is more illustrative of the results.

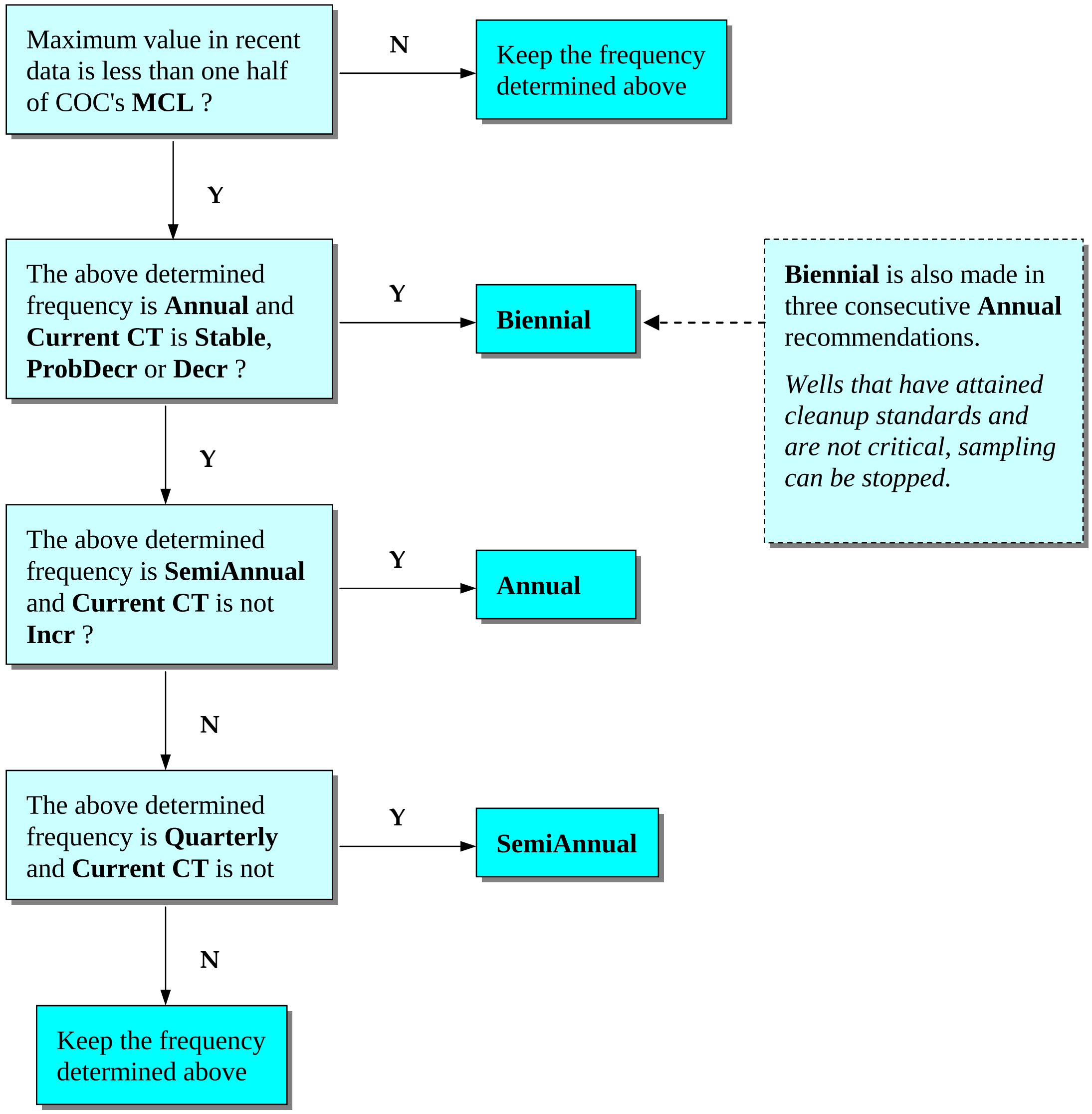
2) ADJUSTMENT BASED ON RECENT/OVERALL RATIO

If the frequency determined from overall trend is greater than that from the recent trend, e.g., the overall frequency is Quarterly while the current frequency is Annual, we might need to adjust the recent frequency by one level. When the recent trend is significantly lower than the long-term trend, reducing the sampling frequency gradually will ensure safety. Additionally, as more data is collected the confidence in the concentrations trends should increase. The steps used in evaluating recent versus overall trends are illustrated in the chart below.



3) ADJUSTMENT BASED ON MCL

If the maximum concentration in the sample is less than one half of the MCL, and if the trend of COC in this well is not increasing, we can reduce the sampling frequency by one level. Because at such a low concentration level and with confidence that it will not increase, the adjustment will not result in higher risk. The steps to be followed are shown in the following flow chart. In addition, wells that have attained cleanup standards (their long-term concentrations were far less than MCL) can be eliminated from the monitoring network to further optimize the monitoring program. Some of the empirical rules are referred to NFESC (2000).



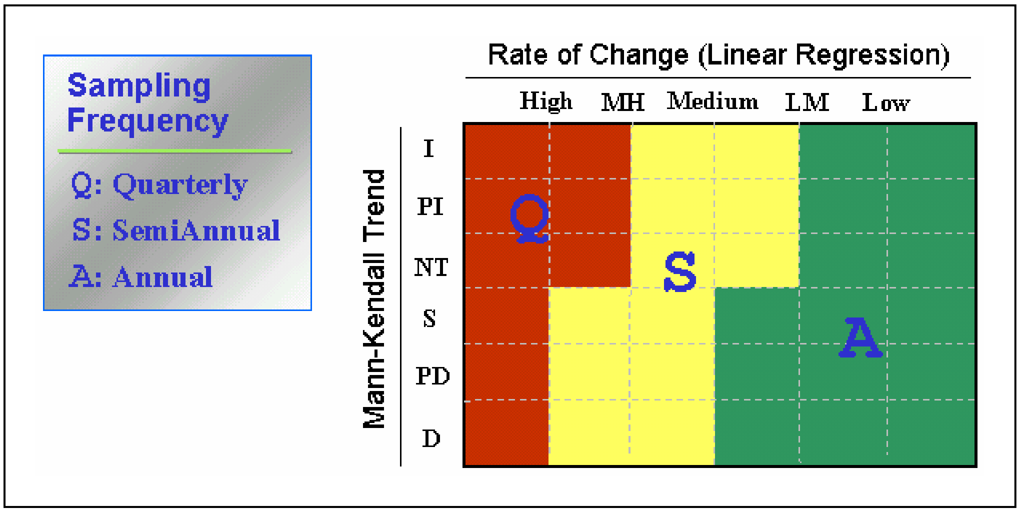
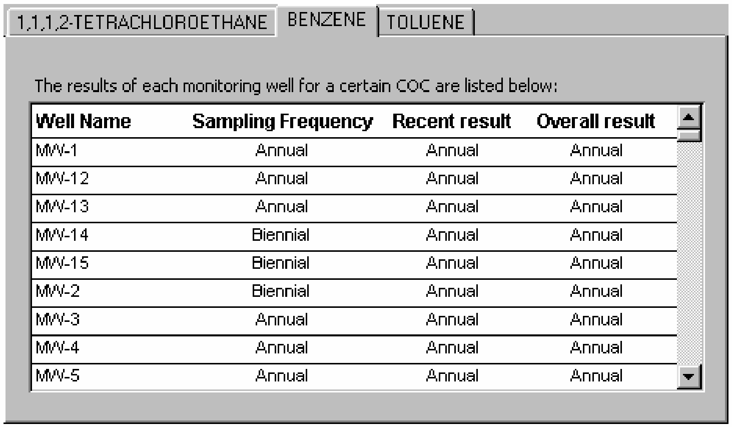


Figure A.9.1 Decision Matrix for Determining Frequency.

As illustrated above, the Modified CES method has three major steps centered on the magnitude of ROC, and the direction of change. The GSI style Mann-Kendall analysis is adopted because it can perform distribution-free test and provides a good measure of the direction of change. Most Users will be more concerned with an increasing trend rather than a decreasing trend, assuming they have the same ROC. Regulators tend to impose more stringent sampling plans if the trend is increasing. An increasing trend can result in future exceedences of the MCL and increased threats to potential receptors. By contrast, a decreasing trend may drop the concentration below MCL and bring the well into compliance. These examples illustrate the importance of both the magnitude and direction of the concentration trend. As discussed above, the modified CES method incorporateds these considerations into the decision process.



The results of each monitoring well for a certain COC are listed below:

Well Name	Sampling Frequency	Recent result	Overall result
MW-1	Annual	Annual	Annual
MW-12	Annual	Annual	Annual
MW-13	Annual	Annual	Annual
MW-14	Biennial	Annual	Annual
MW-15	Biennial	Annual	Annual
MW-2	Biennial	Annual	Annual
MW-3	Annual	Annual	Annual
MW-4	Annual	Annual	Annual
MW-5	Annual	Annual	Annual

The final results displayed in MAROS include the recent result (based on the analysis of the 'recent' time period chosen by the User), overall result (based on the analysis of overall data) and the recommendation after two steps are adjusted (*Sampling Frequency*) As is shown in the right screen, the *Sampling Frequency* for MW-15 is Biennial. Both the *Current* and *Overall* results for MW-15 are Annual. Its recommended frequency can be used in the future round of sampling. The final recommendation for sampling frequency should be made only after evaluating the Sampling Frequency recommendation for each well in light of site specific conditions. Wells used as sentry or compliance points may, by regulation, require more frequent monitoring. Other wells, with concentrations below MCLs, limited data sets with low concentrations or wells with suspicious data points can have their frequency intervals increased.

Both parts of the sampling optimization — sampling location determination (based on the Delaunay Method) and sampling frequency determination (based on Modified CES method) can be performed periodically to ensure continued quality of the groundwater monitoring program. Re-analysis is particularly important when newer monitoring wells have been included in the program. Changes in sampling location and frequency can evolve when wells gain sufficient data to determine a concentration trend.

References

AFCEE, 1997, Long-Term Monitoring Optimization Guide - Version 1.1, HQ Air Force Center for Environmental Excellence, Consultant Operations Division, Brooks Air Force Base, TX.

AFCEE, 2000, Designing Monitoring Programs to Effectively Evaluate the Performance of Natural Attenuation. Technology Transfer Division, Brooks Air Force Base, TX.

Barcelona, M. J. et al., 1989, Sampling Frequency for Ground-water Quality Monitoring, EPA/600/4-89/032, Environmental Monitoring Systems Laboratory, U.S. EPA.

NFESC, 2000, Guide to Optimal Groundwater Monitoring - Interim Final, Naval Facilities Engineering Service Center, Port Hueneme, California.

Ridley, M. N. et al., 1995, Cost-Effective Sampling of Groundwater Monitoring Wells, the Regents of UC/LLNL, Lawrence Livermore National Laboratory.

APPENDIX A.10 — MAROS SAMPLE REPORTS

1. COC Assessment Summary
2. Linear Regression Statistics Graph
3. Linear Regression Statistics Summary
4. Mann-Kendall Statistics Graph
5. Mann-Kendall Statistics Summary
6. Spatial Moment Analysis Summary
7. Zeroth, First, and Second Moment Graphs
8. Plume Analysis Summary
9. Site Results Summary
10. Sampling Location Optimization Results
11. Sampling Location Optimization Results – Summary
12. Sampling Location Optimization Graph
13. Sampling Frequency Optimization Results
14. Power Analysis – Individual Well Cleanup Status
15. Power Analysis – Individual Well Cleanup Status Graph
16. Power Analysis – Individual Well Cleanup Status Optional
17. Risk-Based Power Analysis – Regression Results
18. Risk-Based Power Analysis – Projected Concentrations
19. Risk-Based Power Analysis – Site Cleanup Status

MAROS COC Assessment

Project:

User Name:

Location: Service Station

State: Texas

Toxicity:

Contaminant of Concern	Representative Concentration (mg/L)	PRG (mg/L)	Percent Above PRG
LEAD	1.0E+01	1.5E-02	67296.0%
BENZENE	2.1E-01	5.0E-03	4073.5%
1,1,1,2-TETRACHLOROETHANE	3.8E-01	1.1E-01	241.2%
1,2-DICHLOROBENZENE	9.8E-01	6.0E-01	64.1%
TOLUENE	1.5E+00	1.0E+00	50.4%
BARIUM	3.2E+00	2.3E+00	37.4%
COPPER	1.7E+00	1.3E+00	30.4%
PERCHLORATE	1.2E-01	9.2E-02	27.6%

Note: Top COCs by toxicity were determined by examining a representative concentration for each compound over the entire site. The compound representative concentrations are then compared with the chosen PRG for that compound, with the percentage excedence fror the PRG determining the compound's toxicity. All compounds above exceed the PRG.

Prevalence:

Contaminant of Concern	Class	Total Wells	Total Excedences	Percent Excedences	Total detects
LEAD	MET	12	10	83.3%	10
BENZENE	ORG	12	8	66.7%	10
BARIUM	MET	12	7	58.3%	12
TOLUENE	ORG	12	5	41.7%	12
COPPER	MET	12	4	33.3%	12
1,2-DICHLOROBENZENE	ORG	12	4	33.3%	12
1,1,1,2-TETRACHLOROETHANE	ORG	12	3	25.0%	9
PERCHLORATE	INO	12	2	16.7%	10

Note: Top COCs by prevalence were determined by examining a representative concentration for each well location at the site. The total excedences (values above the chosen PRGs) are compared to the total number of wells to determine the prevalence of the compound.

Mobility:

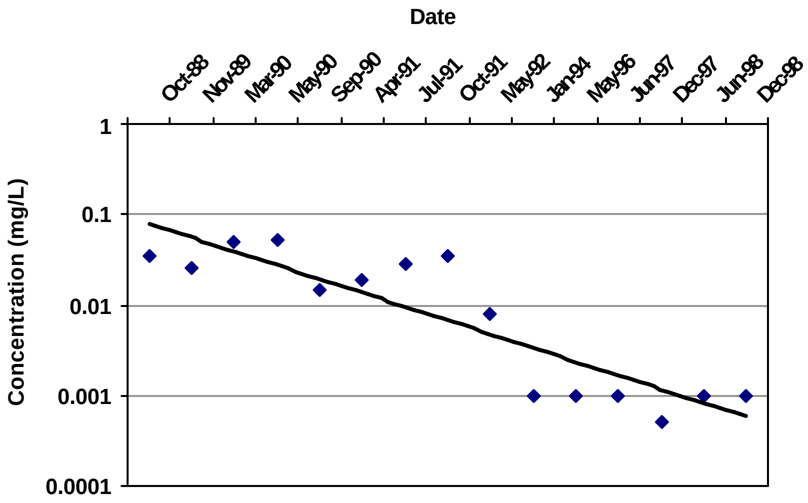
Contaminant of Concern	Kd
PERCHLORATE	
BENZENE	0.0984
TOLUENE	0.347
1,1,1,2-TETRACHLOROETHANE	0.857
1,2-DICHLOROBENZENE	1.91
LEAD	10
BARIUM	11
COPPER	40

Note: Top COCs by mobility were determined by examining each detected compound in the dataset and comparing their mobilities (Koc's for organics, assume foc = 0.001, and Kd's for metals).

MAROS Linear Regression Statistics

Well: MW-13
Well Type: T
COC: BENZENE

Time Period 10/4/1988 **to** 12/19/1998
Consolidation Period No Time Consolidation
Consolidation Type Median
Duplicate Consolidation Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



COV: 1.01

Confidence in Trend: 100.0%

Ln Slope: -1.3E-03

LR Concentration Trend: D

Consolidation Data Table:

Well	Well Type	Consolidation Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
MW-13	T	10/4/1988	BENZENE	3.5E-02		1	1
MW-13	T	11/17/1989	BENZENE	2.6E-02		1	1
MW-13	T	3/1/1990	BENZENE	4.9E-02		1	1
MW-13	T	5/31/1990	BENZENE	5.2E-02		1	1
MW-13	T	9/13/1990	BENZENE	1.5E-02		1	1
MW-13	T	4/3/1991	BENZENE	1.9E-02		1	1
MW-13	T	7/10/1991	BENZENE	2.9E-02		1	1
MW-13	T	10/3/1991	BENZENE	3.5E-02		1	1
MW-13	T	5/2/1992	BENZENE	8.0E-03		1	1
MW-13	T	1/11/1994	BENZENE	1.0E-03	ND	1	0
MW-13	T	5/28/1996	BENZENE	1.0E-03	ND	1	0
MW-13	T	6/27/1997	BENZENE	1.0E-03	ND	1	0
MW-13	T	12/10/1997	BENZENE	5.2E-04		1	1
MW-13	T	6/19/1998	BENZENE	1.0E-03	ND	1	0
MW-13	T	12/19/1998	BENZENE	1.0E-03	ND	1	0

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - Due to insufficient Data (< 4 sampling events); ND = All Samples are Non-detect

MAROS Linear Regression Statistics Summary

Project:

User Name:

Location: Service Station

State: Texas

Time Period: 10/4/1988 **to** 12/19/1998

Consolidation Period: No Time Consolidation

Consolidation Type: Median

Duplicate Consolidation: Average

ND Values: 1/2 Detection Limit

J Flag Values : Actual Value

Well	Source/ Tail	Average Conc (mg/L)	Median Conc (mg/L)	Standard Deviation	All Samples "ND" ?	Ln Slope	Coefficient of Variation	Confidence in Trend	Concentration Trend
BENZENE									
MW-8	S	6.7E-04	5.0E-04	6.5E-04	No	-9.6E-05	0.97	83.5%	S
MW-7	S	5.3E-04	5.0E-04	1.3E-04	No	-3.2E-05	0.24	79.3%	S
MW-6	S	5.0E-04	5.0E-04	0.0E+00	Yes	0.0E+00	0.00	100.0%	S
MW-5	S	1.2E+00	1.2E+00	8.2E-01	No	-8.6E-04	0.67	100.0%	D
MW-3	S	6.9E-02	6.0E-02	7.3E-02	No	-1.3E-03	1.05	99.9%	D
MW-2	S	2.0E-02	5.0E-04	6.9E-02	No	-5.2E-04	3.52	92.6%	PD
MW-1	S	1.0E+00	8.0E-01	9.7E-01	No	-1.6E-03	0.92	100.0%	D
MW-4	T	5.8E-02	1.8E-02	8.6E-02	No	-8.5E-04	1.47	99.7%	D
MW-15	T	5.0E-04	5.0E-04	0.0E+00	Yes	0.0E+00	0.00	100.0%	S
MW-14	T	1.1E-02	5.0E-04	1.6E-02	No	-1.1E-03	1.50	99.9%	D
MW-13	T	1.8E-02	1.5E-02	1.9E-02	No	-1.5E-03	1.03	100.0%	D
MW-12	T	4.7E-02	2.2E-02	7.0E-02	No	-1.7E-03	1.48	100.0%	D

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - Due to insufficient Data (< 4 sampling events); COV = Coefficient of Variation

MAROS Mann-Kendall Statistics Summary

Project:

User Name:

Location: Service Station

State: Texas

Time Period 10/4/1988 **to** 12/19/1998

Consolidation Period No Time Consolidation

Consolidation Type Median

Duplicate Consolidation Average

ND Values: 1/2 Detection Limit

J Flag Values : Actual Value

Well	Source/ Tail	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples "ND" ?	Concentration Trend
BENZENE								
MW-8	S	15	1	0.97	-12	70.4%	No	S
MW-7	S	15	1	0.24	-8	63.3%	No	S
MW-6	S	15	0	0.00	0	48.0%	Yes	S
MW-5	S	15	15	0.67	-55	99.7%	No	D
MW-3	S	15	12	1.05	-69	100.0%	No	D
MW-2	S	15	7	3.52	-27	89.9%	No	NT
MW-1	S	15	15	0.92	-90	100.0%	No	D
MW-4	T	15	14	1.47	-59	99.9%	No	D
MW-15	T	15	0	0.00	0	48.0%	Yes	S
MW-14	T	15	7	1.50	-68	100.0%	No	D
MW-13	T	15	10	1.03	-62	99.9%	No	D
MW-12	T	15	11	1.48	-82	100.0%	No	D

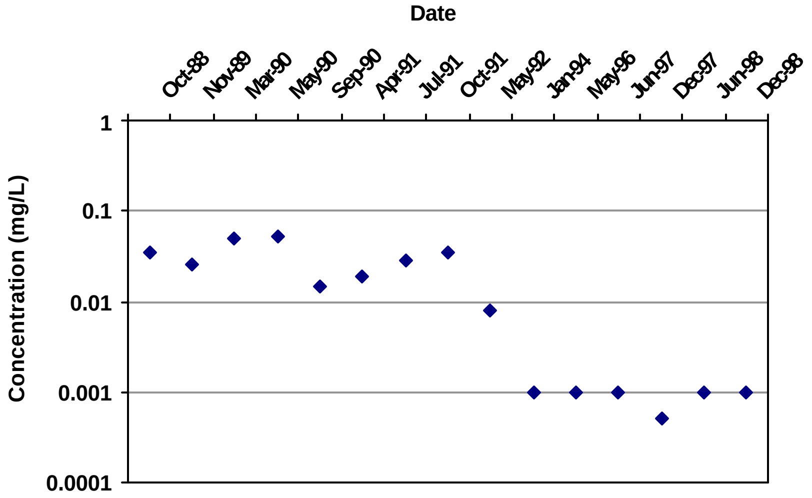
Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A)-Due to insufficient Data (< 4 sampling events); Source/Tail (S/T)

The Number of Samples and Number of Detects shown above are post-consolidation values.

MAROS Mann-Kendall Statistics Summary

Well: MW-13
Well Type: T
COC: BENZENE

Time Period: 10/4/1988 **to** 12/19/1998
Consolidation Period No Time Consolidation
Consolidation Type Median
Duplicate Consolidation Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic:

-64

Confidence in Trend:

100.0%

Coefficient of Variation

1.01

Mann Kendall Concentration Trend: (See Note)

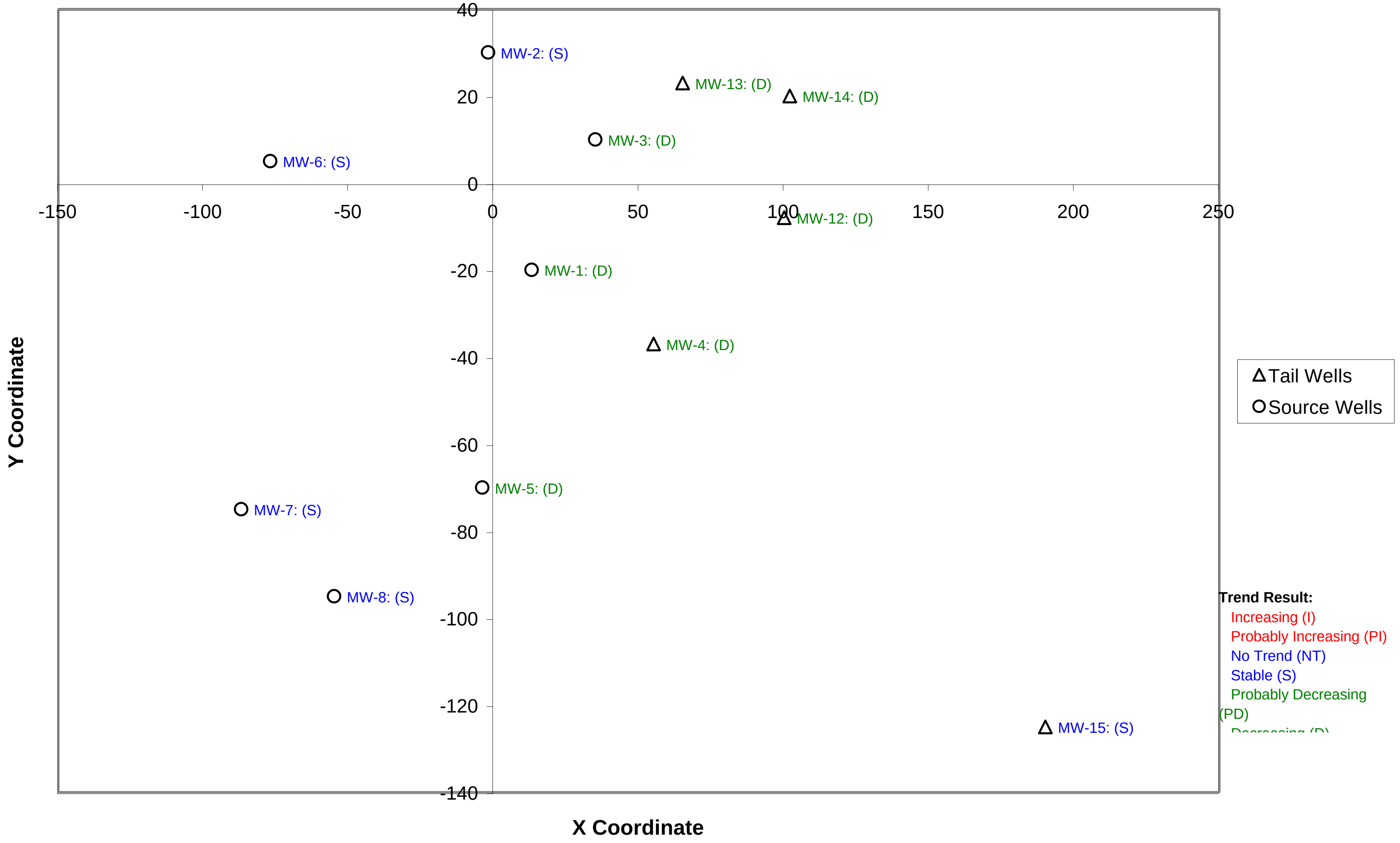
D

Data Table:

Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
MW-13	T	10/4/1988	BENZENE	3.5E-02		1	1
MW-13	T	11/17/1989	BENZENE	2.6E-02		1	1
MW-13	T	3/1/1990	BENZENE	4.9E-02		1	1
MW-13	T	5/31/1990	BENZENE	5.2E-02		1	1
MW-13	T	9/13/1990	BENZENE	1.5E-02		1	1
MW-13	T	4/3/1991	BENZENE	1.9E-02		1	1
MW-13	T	7/10/1991	BENZENE	2.9E-02		1	1
MW-13	T	10/3/1991	BENZENE	3.5E-02		1	1
MW-13	T	5/2/1992	BENZENE	8.0E-03		1	1
MW-13	T	1/11/1994	BENZENE	1.0E-03	ND	1	0
MW-13	T	5/28/1996	BENZENE	1.0E-03	ND	1	0
MW-13	T	6/27/1997	BENZENE	1.0E-03	ND	1	0
MW-13	T	12/10/1997	BENZENE	5.2E-04		1	1
MW-13	T	6/19/1998	BENZENE	1.0E-03	ND	1	0
MW-13	T	12/19/1998	BENZENE	1.0E-03	ND	1	0

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - Due to insufficient Data (< 4 sampling events); ND = Non-detect

Trend Results for BENZENE



MAROS Spatial Moment Analysis Summary

Project:

Location: Service Station

User Name:

State: Texas

Effective Date	0th Moment Estimated Mass (Kg)	1st Moment (Center of Mass) Xc (ft)	Yc (ft)	Source Distance (ft)	2nd Moment (Spread) Sigma XX (sq ft)	Sigma YY (sq ft)	Number of Wells
BENZENE							
10/4/1988	1.7E-01	46	-49	67	980	2,591	12
11/17/1989	1.2E-01	38	-48	61	1,165	5,923	12
3/1/1990	1.0E-01	47	-61	77	1,234	2,769	12
5/31/1990	6.4E-02	48	-48	68	1,369	3,937	12
9/13/1990	6.2E-02	43	-59	73	987	3,106	12
4/3/1991	4.8E-02	41	-53	68	849	2,891	12
7/10/1991	5.5E-02	41	-59	72	860	3,080	12
10/3/1991	7.4E-02	43	-60	74	896	3,269	12
5/2/1992	2.6E-02	42	-70	82	1,254	5,210	12
1/11/1994	2.5E-02	44	-80	91	1,164	3,844	12
5/28/1996	2.8E-02	41	-75	85	909	3,386	12
6/27/1997	1.6E-02	49	-94	106	1,118	4,164	12
12/10/1997	6.8E-03	48	-103	113	1,486	5,578	12
6/19/1998	6.1E-03	57	-96	112	1,540	5,138	12
12/19/1998	1.4E-03	56	-109	122	2,534	9,481	12

Project:

Location: Service Station

User Name:

State: Texas

Moment Type	Consituent	Coefficient of Variation	Mann-Kendall S Statistic	Confidence in Trend	Moment Trend
Zeroth Moment: Mass					
	BENZENE	0.88	-91	100.0%	D
1st Moment: Distance to Source					
	BENZENE	0.23	83	100.0%	I
2nd Moment: Sigma XX					
	BENZENE	0.35	35	95.4%	I
2nd Moment: Sigma YY					
	BENZENE	0.42	53	99.6%	I

Note: The following assumptions were applied for the calculation of the Zeroth Moment:

Porosity: 0.30 **Saturated Thickness:** Uniform: 12 ft

Mann-Kendall Trend test performed on all sample events for each constituent. Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A)-Due to insufficient Data (< 4 sampling events).

Note: The Sigma XX and Sigma YY components are estimated using the given field coordinate system and then rotated to align with the estimated groundwater flow direction. Moments are not calculated for sample events with less than 6 wells.

MAROS Zeroth Moment Analysis

Project: Tutorial

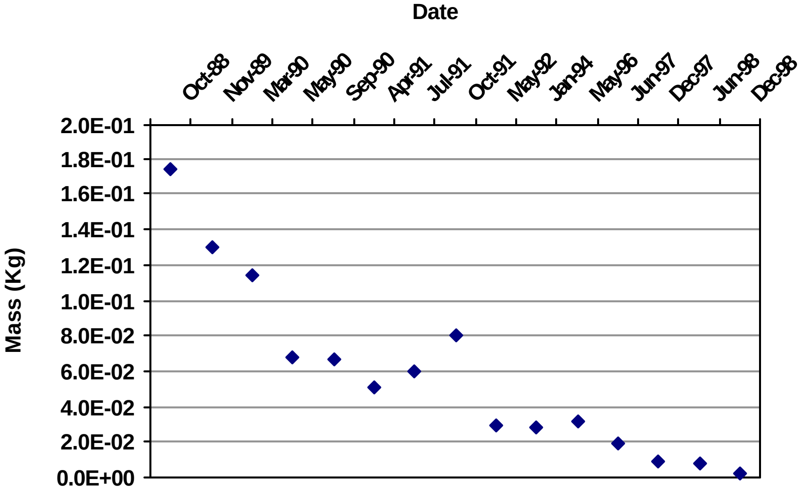
User Name: Charles Newell

Location: Service Station

State: Texas

COC: BENZENE

Change in Dissolved Mass Over Time



Porosity: 0.30

Saturated Thickness:

Uniform: 12 ft

Mann Kendall S Statistic:

-91

Confidence in Trend:

100.0%

Coefficient of Variation

0.85

Zeroth Moment Trend:

D

Data Table:

Effective Date	Constituent	Estimated Mass (Kg)	Number of Wells
10/4/1988	BENZENE	1.7E-01	12
11/17/1989	BENZENE	1.3E-01	12
3/1/1990	BENZENE	1.1E-01	12
5/31/1990	BENZENE	6.8E-02	12
9/13/1990	BENZENE	6.6E-02	12
4/3/1991	BENZENE	5.1E-02	12
7/10/1991	BENZENE	5.9E-02	12
10/3/1991	BENZENE	8.0E-02	12
5/2/1992	BENZENE	2.9E-02	12
1/11/1994	BENZENE	2.8E-02	12
5/28/1996	BENZENE	3.2E-02	12
6/27/1997	BENZENE	1.9E-02	12
12/10/1997	BENZENE	8.5E-03	12
6/19/1998	BENZENE	7.5E-03	12
12/19/1998	BENZENE	2.4E-03	12

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - Due to insufficient Data (< 4 sampling events); ND = Non-detect. Moments are not calculated for sample events with less than 6 wells.

MAROS First Moment Analysis

Project: Tutorial

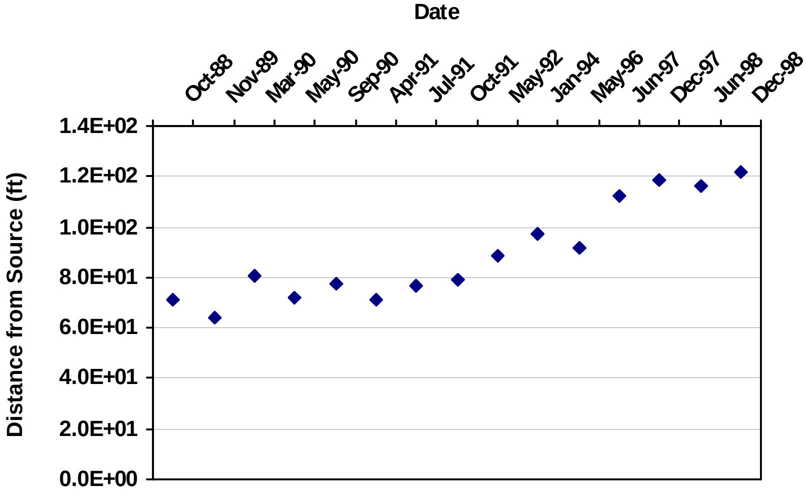
User Name: Charles Newell

Location: Service Station

State: Texas

COC: BENZENE

Distance from Source to Center of Mass



Mann Kendall S Statistic:

83

Confidence in Trend:

100.0%

Coefficient of Variation:

0.22

First Moment Trend:

I

Data Table:

Effective Date	Constituent	Xc (ft)	Yc (ft)	Distance from Source (ft)	Number of Wells
10/4/1988	BENZENE	48	-53	71	12
11/17/1989	BENZENE	39	-51	64	12
3/1/1990	BENZENE	49	-64	81	12
5/31/1990	BENZENE	50	-52	72	12
9/13/1990	BENZENE	44	-64	77	12
4/3/1991	BENZENE	42	-58	71	12
7/10/1991	BENZENE	42	-64	76	12
10/3/1991	BENZENE	45	-65	79	12
5/2/1992	BENZENE	43	-77	89	12
1/11/1994	BENZENE	46	-86	98	12
5/28/1996	BENZENE	44	-81	92	12
6/27/1997	BENZENE	52	-100	113	12
12/10/1997	BENZENE	49	-108	119	12
6/19/1998	BENZENE	58	-101	116	12
12/19/1998	BENZENE	59	-106	122	12

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - Due to insufficient Data (< 4 sampling events). Moments are not calculated for sample events with less than 6 wells.

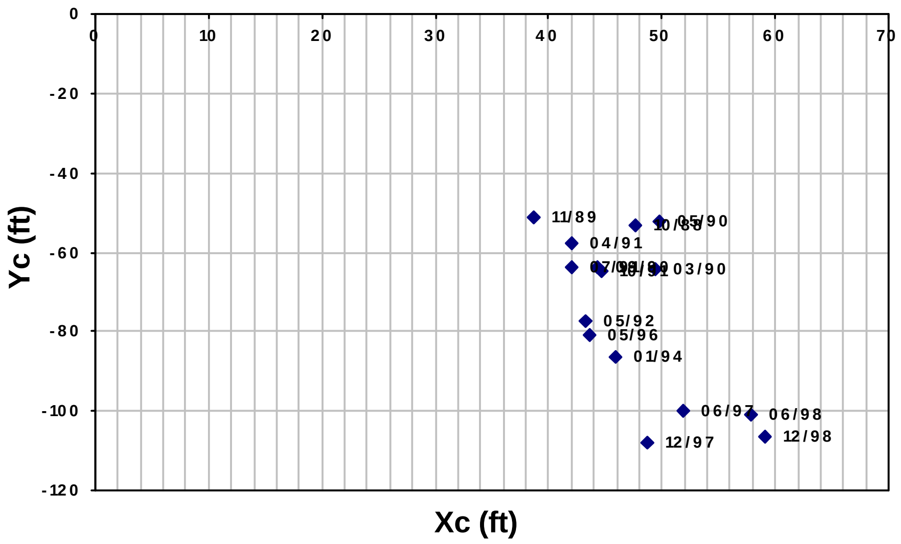
MAROS First Moment Analysis

Project: Tutorial **User Name:** Charles Newell

Location: Service Station **State:** Texas

COC: BENZENE

Change in Location of Center of Mass Over Time



Groundwater Flow Direction:

Source Coordinate:

X: 0

Y: 0

Effective Date	Constituent	Xc (ft)	Yc (ft)	Distance from Source (ft)	Number of Wells
10/4/1988	BENZENE	48	-53	71	12
11/17/1989	BENZENE	39	-51	64	12
3/1/1990	BENZENE	49	-64	81	12
5/31/1990	BENZENE	50	-52	72	12
9/13/1990	BENZENE	44	-64	77	12
4/3/1991	BENZENE	42	-58	71	12
7/10/1991	BENZENE	42	-64	76	12
10/3/1991	BENZENE	45	-65	79	12
5/2/1992	BENZENE	43	-77	89	12
1/11/1994	BENZENE	46	-86	98	12
5/28/1996	BENZENE	44	-81	92	12
6/27/1997	BENZENE	52	-100	113	12
12/10/1997	BENZENE	49	-108	119	12
6/19/1998	BENZENE	58	-101	116	12
12/19/1998	BENZENE	59	-106	122	12

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - Due to insufficient Data (< 4 sampling events). Moments are not calculated for sample events with less than 6 wells.

MAROS Second Moment Analysis

Project: Tutorial

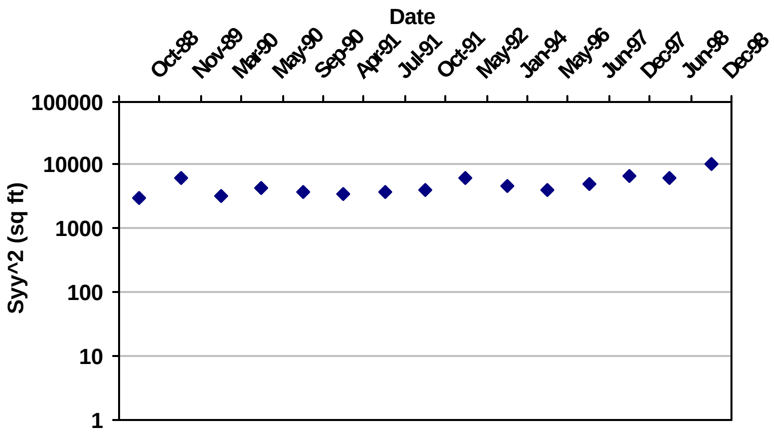
User Name: Charles Newell

Location: Service Station

State: Texas

COC: BENZENE

Change in Plume Spread Over Time



Mann Kendall S Statistic:

59

Confidence in Trend:

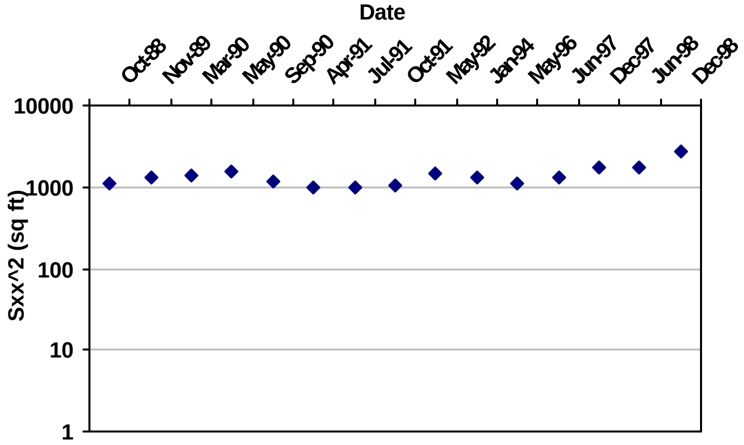
99.9%

Coefficient of Variation

0.38

Second Moment Trend:

I



Mann Kendall S Statistic:

33

Confidence in Trend:

94.3%

Coefficient of Variation

0.31

Second Moment Trend:

PI

Data Table:

Effective Date	Constituent	Sigma XX (sq ft)	Sigma YY (sq ft)	Number of Wells
10/4/1988	BENZENE	1,104	2,893	12
11/17/1989	BENZENE	1,329	6,063	12
3/1/1990	BENZENE	1,366	3,215	12
5/31/1990	BENZENE	1,533	4,347	12
9/13/1990	BENZENE	1,142	3,694	12
4/3/1991	BENZENE	1,007	3,502	12
7/10/1991	BENZENE	1,008	3,718	12
10/3/1991	BENZENE	1,025	3,824	12
5/2/1992	BENZENE	1,436	6,019	12
1/11/1994	BENZENE	1,308	4,493	12
5/28/1996	BENZENE	1,076	3,962	12
6/27/1997	BENZENE	1,294	4,735	12

MAROS Second Moment Analysis

Effective Date	Constituent	Sigma XX (sq ft)	Sigma YY (sq ft)	Number of Wells
12/10/1997	BENZENE	1,749	6,327	12
6/19/1998	BENZENE	1,711	5,988	12
12/19/1998	BENZENE	2,676	10,095	12

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - Due to insufficient Data (< 4 sampling events)

The Sigma XX and Sigma YY components are estimated using the given field coordinate system and then rotated to align with the estimated groundwater flow direction. Moments are not calculated for sample events with less than 6 wells.

MAROS Plume Analysis Summary

Project:

User Name:

Location: Service Station

State: Texas

Time Period: 10/4/1988 **to** 12/19/1998

Consolidation Period No Time Consolidation

Consolidation Type Median

Duplicate Consolidation Average

ND Values: 1/2 Detection Limit

J Flag Values : Actual Value

Constituent	Well	Source/ Tail	Number of Samples	Number of Detects	Average (mg/L)	Median (mg/L)	All Samples "ND" ?	Mann-Kendall	Linear Regression	Modeling	Empirical
BENZENE											
	MW-8	S	15	1	6.7E-04	5.0E-04	No	S	S	N/A	N/A
	MW-7	S	15	1	5.3E-04	5.0E-04	No	S	S	N/A	N/A
	MW-6	S	15	0	5.0E-04	5.0E-04	Yes	S	S	N/A	N/A
	MW-5	S	15	15	1.2E+00	1.2E+00	No	D	D	N/A	N/A
	MW-3	S	15	12	6.9E-02	6.0E-02	No	D	D	N/A	N/A
	MW-2	S	15	7	2.0E-02	5.0E-04	No	NT	PD	N/A	N/A
	MW-1	S	15	15	1.0E+00	8.0E-01	No	D	D	N/A	N/A
	MW-4	T	15	14	5.8E-02	1.8E-02	No	D	D	N/A	N/A
	MW-15	T	15	0	5.0E-04	5.0E-04	Yes	S	S	N/A	N/A
	MW-14	T	15	7	1.1E-02	5.0E-04	No	D	D	N/A	N/A
	MW-13	T	15	10	1.8E-02	1.5E-02	No	D	D	N/A	N/A
	MW-12	T	15	11	4.7E-02	2.2E-02	No	D	D	N/A	N/A

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - Due to insufficient Data (< 4 sampling events); Source/Tail (S/T)

The Number of Samples and Number of Detects shown above are post-consolidation values.

MAROS Site Results

Project:

User Name:

Location: Service Station

State: Texas

User Defined Site and Data Assumptions:

Hydrogeology and Plume Information:

Groundwater Seepage Velocity:	92 ft/yr
Current Plume Length:	270 ft
Current Plume Widt	150 ft
Number of Tail Wells:	5
Number of Source Wells:	7

Down-gradient Information:

Distance from Edge of Tail to Nearest:

Down-gradient receptor:	1000 ft
Down-gradient property:	1000 ft

Distance from Source to Nearest:

Down-gradient receptor:	1000 ft
Down-gradient property:	1000 ft

Source Information:

Source Treatment: No Current Site Treatment

NAPL is not observed at this site.

Data Consolidation Assumptions:

Time Period: 10/4/1988 **to** 12/19/1998

Consolidation Period: No Time Consolidation

Consolidation Type: Median

Duplicate Consolidation: Average

ND Values: 1/2 Detection Limit

J Flag Values : Actual Value

Plume Information Weighting Assumptions:

Consolidation Step 1. Weight Plume Information by Chemical

Summary Weighting: Weighting Applied to All Chemicals Equally

Consolidation Step 2. Weight Well Information by Chemical

Well Weighting: No Weighting of Wells was Applied.

Chemical Weighting: No Weighting of Chemicals was Applied.

Note: These assumptions were made when consolidating the historical montoring data and lumping the Wells and COCs.

1. Compliance Monitoring/Remediation Optimization Results:

Preliminary Monitoring System Optimization Results: Based on site classification, source treatment and Monitoring System Category the following suggestions are made for site Sampling Frequency, Duration of Sampling before reassessment, and Well Density. These criteria take into consideration: Plume Stability, Type of Plume, and Groundwater Velocity.

COC	Tail Stability	Source Stability	Level of Effort	Sampling Duration	Sampling Frequency	Sampling Density
BENZENE	D	PD	L	Sample 1 more year	Biannually (6 months)	15

Note:

Plume Status: (I) Increasing; (PI)Probably Increasing; (S) Stable; (NT) No Trend; (PD) Probably Decreasing; (D) Decreasing

Design Categories: (E) Extensive; (M) Moderate; (L) Limited (N/A) Not Applicable, Insufficient Data Available

Level of Monitoring Effort Indicated by Analysi Limited

2. Spatial Moment Analysis Results:

Moment Type	Consituent	Coefficient of Variation	Mann-Kendall S Statistic	Confidence in Trend	Moment Trend
Zeroth Moment: Mass					
	BENZENE	0.88	-91	100.0%	D
1st Moment: Distance to Source					
	BENZENE	0.23	83	100.0%	I
2nd Moment: Sigma XX					
	BENZENE	0.35	35	95.4%	I
2nd Moment: Sigma YY					
	BENZENE	0.42	53	99.6%	I

Note: The following assumptions were applied for the calculation of the Zeroth Moment

Porosity: 0.30 **Saturated Thickness:** Uniform: 12 ft

Mann-Kendall Trend test performed on all sample events for each constituent. Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A)-Due to insufficient Data (< 4 sampling events).

MAROS Sampling Location Optimization

Results by Considering All COCs

Project: Example **User Name:** Meng

Location: Service Station **State:** Texas

Sampling Events Analyzed: **From** Sample Event 10 **to** Sample Event 15

1/11/1994 12/19/1998

Well	X (feet)	Y (feet)	Number of COCs	COC-Averaged Slope Factor*	Abandoned?
MW-1	13.00	-20.00	1	0.259	☐
MW-12	100.00	-8.00	1	0.165	☑
MW-13	65.00	23.00	1	0.254	☐
MW-14	102.00	20.00	1	0.064	☐
MW-15	190.00	-125.00	1	0.421	☐
MW-2	-2.00	30.00	1	0.308	☐
MW-3	35.00	10.00	1	0.117	☑
MW-4	55.00	-37.00	1	0.165	☑
MW-5	-4.00	-70.00	1	0.532	☐
MW-6	-77.00	5.00	1	0.526	☐
MW-7	-87.00	-75.00	1	0.417	☐
MW-8	-55.00	-95.00	1	0.645	☐

Note: the COC-Averaged Slope Factor is the value calculated by averaging those "Average Slope Factor" obtained earlier across COCs; to be conservative, a location is "abandoned" only when it is eliminated from all COCs; "abandoned" doesn't necessarily mean the abandon of well, it can mean that NO samples need to be collected for any COCs.
* When the report is generated after running the Excel module, SF values will NOT be shown above.

MAROS Sampling Frequency Optimization Results

Project: Example **User Name:** Meng

Location: Service Station **State:** Texas

The Overall Number of Sampling Events: 15

"Recent Period" defined by events: **From** Sample Event 10 **To** Sample Event 15

1/11/1994 12/19/1998

"Rate of Change" parameters used:

Constituent	Cleanup Goal	Low Rate	Medium Rate	High Rate
BENZENE	0.005	0.0025	0.005	0.01

Units: Cleanup Goal is in mg/L; all rate parameters are in mg/L/year.

Well	Recommended Sampling Frequency	Frequency Based on Recent Data	Frequency Based on Overall Data
BENZENE			
MW-1	Annual	Annual	Annual
MW-12	Annual	Annual	Annual
MW-13	Biennial	Annual	Annual
MW-14	Biennial	Annual	Annual
MW-15	Biennial	Annual	Annual
MW-2	Biennial	Annual	Annual
MW-3	Annual	Annual	Annual
MW-4	Annual	Annual	Annual
MW-5	Annual	Annual	Annual
MW-6	Biennial	Annual	Annual
MW-7	Biennial	Annual	Annual
MW-8	Biennial	Annual	Annual

Note: Sampling frequency is determined considering both recent and overall concentration trends. Sampling Frequency is the final recommendation; Frequency Based on Recent Data is the frequency determined using recent (short) period of monitoring data; Frequency Based on Overall Data is the frequency determined using overall (long) period of monitoring data. If the "recent period" is defined using a different series of sampling events, the results could be different.

MAROS Risk-Based Power Analysis for Site Cleanup

Project: Example

User Name Meng

Location: Service Station

State: Texas

Parameters:

Groundwater Flow Direction: 0 degrees

Distance to Receptor: 1000 feet

From Period: Sample Event 1 10/4/1988 **to** Sample Event 15 12/19/1998

Selected Plume Centerline Wells:

Well	Distance to Receptor (feet)
MW-12	1090.0
MW-4	1135.0
MW-1	1177.0

The distance is measured in the Groundwater Flow Angle from the well to the compliance boundary.

				Normal Distribution Assumption			Lognormal Distribution Assumption				
Sample Event	**Sample Szie**	**Sample Mean**	**Sample Stdev.**	**Cleanup Status**	**Power**	**Expected Sample Size**	**Celanup Status**	**Power**	**Expected Sample Size**	**Alpha Level**	**Expected Power**
BENZENE				Cleanup Goal = 0.005							
Sample Event 1	12	1.30E-15	1.76E-15	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 2	12	1.41E-22	1.41E-22	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 3	12	5.12E-17	7.09E-17	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 4	12	3.84E-15	5.90E-15	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 5	12	1.14E-23	1.50E-23	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 6	12	1.52E-26	3.16E-26	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 7	12	3.25E-24	4.71E-24	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 8	12	1.09E-20	1.30E-20	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 9	12	1.82E-19	3.12E-19	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 10	12	2.01E-23	4.38E-23	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 11	12	3.64E-34	1.24E-33	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 12	12	5.62E-24	1.54E-23	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 13	12	1.61E-22	4.50E-22	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 14	12	7.73E-17	1.41E-16	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8
Sample Event 15	12	4.58E-07	6.70E-07	Attained	1.000	<=3	Attained	1.000	<=3	0.05	0.8

Note: #N/C means "not conducted" due to a small sample size (N<4) or that the mean concentration is much greater than the cleanup level Sample Size is the number of sampling locations used in the power analysis; Expected Sample Size is the number of concentration data needed to reach the Expected Power under current sample variability.

Regression of Plume Centerline Concentrations

Project: Example **User Name** Meng

Location: Service Station **State:** Texas

Groundwater Flow Direction: 0 degrees **Distance to Receptor:** 1000 feet

From Period: 10/4/1988 **to** 12/19/1998

Selected Plume Centerline Wells:

Well	Distance to Receptor (feet)
MW-12	1090.0
MW-4	1135.0
MW-1	1177.0

The distance is measured in the Groundwater Flow Angle from the well to the compliance boundary.

	Sample Event	Effective Date	Number of Centerline Wells	Regression Coefficient (1/ft)	Confidence in Coefficient
BENZENE					
	Sample Event 1	10/4/1988	3	-2.88E-02	87.0%
	Sample Event 2	11/17/1989	3	-4.25E-02	90.7%
	Sample Event 3	3/1/1990	3	-3.14E-02	87.6%
	Sample Event 4	5/31/1990	3	-2.77E-02	66.1%
	Sample Event 5	9/13/1990	3	-4.45E-02	84.4%
	Sample Event 6	4/3/1991	3	-5.06E-02	80.8%
	Sample Event 7	7/10/1991	3	-4.57E-02	78.0%
	Sample Event 8	10/3/1991	3	-3.83E-02	88.8%
	Sample Event 9	5/2/1992	3	-3.53E-02	77.9%
	Sample Event 10	1/11/1994	3	-4.33E-02	93.5%
	Sample Event 11	5/28/1996	3	-6.76E-02	96.4%
	Sample Event 12	6/27/1997	3	-4.44E-02	87.8%
	Sample Event 13	12/10/1997	3	-4.10E-02	92.4%
	Sample Event 14	6/19/1998	3	-2.83E-02	81.7%
	Sample Event 15	12/19/1998	3	-7.29E-03	82.7%

Note: when the number of plume centerline wells is less than 3, no analysis is performed and all related values are set to ZERO; Confidence in Coefficient is the statistical confidence that the estimated coefficient is different from ZERO (for details, please refer to "Conference in Trend" in Linear Regression Analysis).

Risk-Based Power Analysis -- Projected Concentrations

Project: Example

User Name: Meng

Location: Service Station

State: Texas

From Period 10/4/1988 **to** 12/19/1998 **Distance from the most downgradient well to recep** 1000 feet

Sampling Event	Effective Date	Well	Observed Concentration (mg/L)	Distance Down Centerline (ft)	Regression Coefficient (1/ft)	Projected Concentration (mg/L)	Below Detection Limit?	Used in Analysis?
BENZENE								
Sample Event 1	10/4/1988	MW-1	2.500E+00	1177.0	-2.88E-02	4.835E-15	Yes	Yes
Sample Event 1	10/4/1988	MW-12	2.000E-01	1090.0	-2.88E-02	4.732E-15	Yes	Yes
Sample Event 1	10/4/1988	MW-13	3.500E-02	1125.0	-2.88E-02	3.024E-16	Yes	Yes
Sample Event 1	10/4/1988	MW-14	4.000E-02	1088.0	-2.88E-02	1.002E-15	Yes	Yes
Sample Event 1	10/4/1988	MW-15	1.000E-03	1000.0	-2.88E-02	3.156E-16	Yes	Yes
Sample Event 1	10/4/1988	MW-2	2.000E-03	1192.0	-2.88E-02	2.511E-18	Yes	Yes
Sample Event 1	10/4/1988	MW-3	2.000E-01	1155.0	-2.88E-02	7.286E-16	Yes	Yes
Sample Event 1	10/4/1988	MW-4	2.900E-01	1135.0	-2.88E-02	1.879E-15	Yes	Yes
Sample Event 1	10/4/1988	MW-5	1.500E+00	1194.0	-2.88E-02	1.778E-15	Yes	Yes
Sample Event 1	10/4/1988	MW-6	1.000E-03	1267.0	-2.88E-02	1.450E-19	Yes	Yes
Sample Event 1	10/4/1988	MW-7	1.000E-03	1277.0	-2.88E-02	1.087E-19	Yes	Yes
Sample Event 1	10/4/1988	MW-8	1.000E-03	1245.0	-2.88E-02	2.731E-19	Yes	Yes
Sample Event 2	11/17/1989	MW-1	1.900E+00	1177.0	-4.25E-02	3.522E-22	Yes	Yes
Sample Event 2	11/17/1989	MW-12	4.600E-02	1090.0	-4.25E-02	3.445E-22	Yes	Yes
Sample Event 2	11/17/1989	MW-13	2.600E-02	1125.0	-4.25E-02	4.397E-23	Yes	Yes
Sample Event 2	11/17/1989	MW-14	2.600E-02	1088.0	-4.25E-02	2.120E-22	Yes	Yes
Sample Event 2	11/17/1989	MW-15	1.000E-03	1000.0	-4.25E-02	3.437E-22	Yes	Yes
Sample Event 2	11/17/1989	MW-2	2.700E-01	1192.0	-4.25E-02	2.645E-23	Yes	Yes
Sample Event 2	11/17/1989	MW-3	1.800E-01	1155.0	-4.25E-02	8.501E-23	Yes	Yes
Sample Event 2	11/17/1989	MW-4	1.200E-01	1135.0	-4.25E-02	1.326E-22	Yes	Yes
Sample Event 2	11/17/1989	MW-5	1.700E+00	1194.0	-4.25E-02	1.530E-22	Yes	Yes
Sample Event 2	11/17/1989	MW-6	1.000E-03	1267.0	-4.25E-02	4.039E-27	Yes	Yes
Sample Event 2	11/17/1989	MW-7	1.000E-03	1277.0	-4.25E-02	2.640E-27	Yes	Yes
Sample Event 2	11/17/1989	MW-8	3.000E-03	1245.0	-4.25E-02	3.087E-26	Yes	Yes
Sample Event 3	3/1/1990	MW-1	2.200E+00	1177.0	-3.14E-02	1.947E-16	Yes	Yes
Sample Event 3	3/1/1990	MW-12	1.400E-01	1090.0	-3.14E-02	1.904E-16	Yes	Yes
Sample Event 3	3/1/1990	MW-13	4.900E-02	1125.0	-3.14E-02	2.220E-17	Yes	Yes
Sample Event 3	3/1/1990	MW-14	3.400E-02	1088.0	-3.14E-02	4.924E-17	Yes	Yes
Sample Event 3	3/1/1990	MW-15	1.000E-03	1000.0	-3.14E-02	2.297E-17	Yes	Yes
Sample Event 3	3/1/1990	MW-2	1.000E-03	1192.0	-3.14E-02	5.526E-20	Yes	Yes
Sample Event 3	3/1/1990	MW-3	1.000E-03	1155.0	-3.14E-02	1.766E-19	Yes	Yes
Sample Event 3	3/1/1990	MW-4	2.200E-01	1135.0	-3.14E-02	7.282E-17	Yes	Yes

Project: Example **User Name:** Meng

Location: Service Station **State:** Texas

Sampling Event	Effective Date	Well	Observed Concentration (mg/L)	Distance Down Centerline (ft)	Regression Coefficient (1/ft)	Projected Concentration (mg/L)	Below Detection Limit?	Used in Analysis?
BENZENE								
Sample Event 3	3/1/1990	MW-5	1.200E+00	1194.0	-3.14E-02	6.227E-17	Yes	Yes
Sample Event 3	3/1/1990	MW-6	1.000E-03	1267.0	-3.14E-02	5.242E-21	Yes	Yes
Sample Event 3	3/1/1990	MW-7	1.000E-03	1277.0	-3.14E-02	3.829E-21	Yes	Yes
Sample Event 3	3/1/1990	MW-8	1.000E-03	1245.0	-3.14E-02	1.046E-20	Yes	Yes
Sample Event 4	5/31/1990	MW-1	2.300E+00	1177.0	-2.77E-02	1.655E-14	Yes	Yes
Sample Event 4	5/31/1990	MW-12	1.900E-01	1090.0	-2.77E-02	1.517E-14	Yes	Yes
Sample Event 4	5/31/1990	MW-13	5.200E-02	1125.0	-2.77E-02	1.577E-15	Yes	Yes
Sample Event 4	5/31/1990	MW-14	4.400E-02	1088.0	-2.77E-02	3.714E-15	Yes	Yes
Sample Event 4	5/31/1990	MW-15	1.000E-03	1000.0	-2.77E-02	9.634E-16	Yes	Yes
Sample Event 4	5/31/1990	MW-2	1.000E-03	1192.0	-2.77E-02	4.750E-18	Yes	Yes
Sample Event 4	5/31/1990	MW-3	1.400E-01	1155.0	-2.77E-02	1.851E-15	Yes	Yes
Sample Event 4	5/31/1990	MW-4	1.600E-02	1135.0	-2.77E-02	3.679E-16	Yes	Yes
Sample Event 4	5/31/1990	MW-5	1.300E+00	1194.0	-2.77E-02	5.843E-15	Yes	Yes
Sample Event 4	5/31/1990	MW-6	1.000E-03	1267.0	-2.77E-02	5.963E-19	Yes	Yes
Sample Event 4	5/31/1990	MW-7	1.000E-03	1277.0	-2.77E-02	4.522E-19	Yes	Yes
Sample Event 4	5/31/1990	MW-8	1.000E-03	1245.0	-2.77E-02	1.096E-18	Yes	Yes
Sample Event 5	9/13/1990	MW-1	1.500E+00	1177.0	-4.45E-02	2.707E-23	Yes	Yes
Sample Event 5	9/13/1990	MW-12	3.000E-02	1090.0	-4.45E-02	2.598E-23	Yes	Yes
Sample Event 5	9/13/1990	MW-13	1.500E-02	1125.0	-4.45E-02	2.737E-24	Yes	Yes
Sample Event 5	9/13/1990	MW-14	1.400E-02	1088.0	-4.45E-02	1.325E-23	Yes	Yes
Sample Event 5	9/13/1990	MW-15	1.000E-03	1000.0	-4.45E-02	4.749E-23	Yes	Yes
Sample Event 5	9/13/1990	MW-2	1.000E-03	1192.0	-4.45E-02	9.258E-27	Yes	Yes
Sample Event 5	9/13/1990	MW-3	6.000E-02	1155.0	-4.45E-02	2.882E-24	Yes	Yes
Sample Event 5	9/13/1990	MW-4	3.800E-02	1135.0	-4.45E-02	4.444E-24	Yes	Yes
Sample Event 5	9/13/1990	MW-5	1.500E+00	1194.0	-4.45E-02	1.270E-23	Yes	Yes
Sample Event 5	9/13/1990	MW-6	1.000E-03	1267.0	-4.45E-02	3.290E-28	Yes	Yes
Sample Event 5	9/13/1990	MW-7	1.000E-03	1277.0	-4.45E-02	2.109E-28	Yes	Yes
Sample Event 5	9/13/1990	MW-8	1.000E-03	1245.0	-4.45E-02	8.757E-28	Yes	Yes
Sample Event 6	4/3/1991	MW-1	1.900E+00	1177.0	-5.06E-02	2.735E-26	Yes	Yes
Sample Event 6	4/3/1991	MW-12	2.200E-02	1090.0	-5.06E-02	2.575E-26	Yes	Yes
Sample Event 6	4/3/1991	MW-13	1.900E-02	1125.0	-5.06E-02	3.790E-27	Yes	Yes
Sample Event 6	4/3/1991	MW-14	1.000E-03	1088.0	-5.06E-02	1.295E-27	Yes	Yes
Sample Event 6	4/3/1991	MW-15	1.000E-03	1000.0	-5.06E-02	1.108E-25	Yes	Yes
Sample Event 6	4/3/1991	MW-2	1.000E-03	1192.0	-5.06E-02	6.744E-30	Yes	Yes
Sample Event 6	4/3/1991	MW-3	1.500E-01	1155.0	-5.06E-02	6.567E-27	Yes	Yes
Sample Event 6	4/3/1991	MW-4	1.600E-02	1135.0	-5.06E-02	1.925E-27	Yes	Yes

Project: Example

User Name: Meng

Location: Service Station

State: Texas

BENZENE

Sampling Event	Effective Date	Well	Observed Concentration (mg/L)	Distance Down Centerline (ft)	Regression Coefficient (1/ft)	Projected Concentration (mg/L)	Below Detection Limit?	Used in Analysis?
Sample Event 6	4/3/1991	MW-5	9.100E-01	1194.0	-5.06E-02	5.547E-27	Yes	Yes
Sample Event 6	4/3/1991	MW-6	1.000E-03	1267.0	-5.06E-02	1.521E-31	Yes	Yes
Sample Event 6	4/3/1991	MW-7	1.000E-03	1277.0	-5.06E-02	9.177E-32	Yes	Yes
Sample Event 6	4/3/1991	MW-8	1.000E-03	1245.0	-5.06E-02	4.627E-31	Yes	Yes
Sample Event 7	7/10/1991	MW-1	1.700E+00	1177.0	-4.57E-02	7.852E-24	Yes	Yes
Sample Event 7	7/10/1991	MW-12	3.000E-02	1090.0	-4.57E-02	7.354E-24	Yes	Yes
Sample Event 7	7/10/1991	MW-13	2.900E-02	1125.0	-4.57E-02	1.438E-24	Yes	Yes
Sample Event 7	7/10/1991	MW-14	1.000E-03	1088.0	-4.57E-02	2.686E-25	Yes	Yes
Sample Event 7	7/10/1991	MW-15	1.000E-03	1000.0	-4.57E-02	1.492E-23	Yes	Yes
Sample Event 7	7/10/1991	MW-2	1.000E-03	1192.0	-4.57E-02	2.329E-27	Yes	Yes
Sample Event 7	7/10/1991	MW-3	1.100E-01	1155.0	-4.57E-02	1.387E-24	Yes	Yes
Sample Event 7	7/10/1991	MW-4	1.400E-02	1135.0	-4.57E-02	4.399E-25	Yes	Yes
Sample Event 7	7/10/1991	MW-5	2.500E+00	1194.0	-4.57E-02	5.314E-24	Yes	Yes
Sample Event 7	7/10/1991	MW-6	1.000E-03	1267.0	-4.57E-02	7.589E-29	Yes	Yes
Sample Event 7	7/10/1991	MW-7	1.000E-03	1277.0	-4.57E-02	4.807E-29	Yes	Yes
Sample Event 7	7/10/1991	MW-8	1.000E-03	1245.0	-4.57E-02	2.072E-28	Yes	Yes
Sample Event 8	10/3/1991	MW-1	8.000E-01	1177.0	-3.83E-02	2.234E-20	Yes	Yes
Sample Event 8	10/3/1991	MW-12	2.800E-02	1090.0	-3.83E-02	2.181E-20	Yes	Yes
Sample Event 8	10/3/1991	MW-13	3.500E-02	1125.0	-3.83E-02	7.145E-21	Yes	Yes
Sample Event 8	10/3/1991	MW-14	1.000E-03	1088.0	-3.83E-02	8.407E-22	Yes	Yes
Sample Event 8	10/3/1991	MW-15	1.000E-03	1000.0	-3.83E-02	2.436E-20	Yes	Yes
Sample Event 8	10/3/1991	MW-2	5.000E-03	1192.0	-3.83E-02	7.867E-23	Yes	Yes
Sample Event 8	10/3/1991	MW-3	1.100E-01	1155.0	-3.83E-02	7.127E-21	Yes	Yes
Sample Event 8	10/3/1991	MW-4	5.500E-02	1135.0	-3.83E-02	7.659E-21	Yes	Yes
Sample Event 8	10/3/1991	MW-5	2.700E+00	1194.0	-3.83E-02	3.935E-20	Yes	Yes
Sample Event 8	10/3/1991	MW-6	1.000E-03	1267.0	-3.83E-02	8.930E-25	Yes	Yes
Sample Event 8	10/3/1991	MW-7	1.000E-03	1277.0	-3.83E-02	6.091E-25	Yes	Yes
Sample Event 8	10/3/1991	MW-8	1.000E-03	1245.0	-3.83E-02	2.072E-24	Yes	Yes
Sample Event 9	5/2/1992	MW-1	2.500E-01	1177.0	-3.53E-02	2.216E-19	Yes	Yes
Sample Event 9	5/2/1992	MW-12	1.100E-02	1090.0	-3.53E-02	2.106E-19	Yes	Yes
Sample Event 9	5/2/1992	MW-13	8.000E-03	1125.0	-3.53E-02	4.449E-20	Yes	Yes
Sample Event 9	5/2/1992	MW-14	1.000E-03	1088.0	-3.53E-02	2.054E-20	Yes	Yes
Sample Event 9	5/2/1992	MW-15	1.000E-03	1000.0	-3.53E-02	4.596E-19	Yes	Yes
Sample Event 9	5/2/1992	MW-2	1.000E-02	1192.0	-3.53E-02	5.218E-21	Yes	Yes
Sample Event 9	5/2/1992	MW-3	6.400E-02	1155.0	-3.53E-02	1.234E-19	Yes	Yes
Sample Event 9	5/2/1992	MW-4	6.000E-03	1135.0	-3.53E-02	2.344E-20	Yes	Yes

Project: Example **User Name:** Meng

Location: Service Station **State:** Texas

Sampling Event	Effective Date	Well	Observed Concentration (mg/L)	Distance Down Centerline (ft)	Regression Coefficient (1/ft)	Projected Concentration (mg/L)	Below Detection Limit?	Used in Analysis?
BENZENE								
Sample Event 9	5/2/1992	MW-5	2.200E+00	1194.0	-3.53E-02	1.070E-18	Yes	Yes
Sample Event 9	5/2/1992	MW-6	1.000E-03	1267.0	-3.53E-02	3.692E-23	Yes	Yes
Sample Event 9	5/2/1992	MW-7	1.000E-03	1277.0	-3.53E-02	2.593E-23	Yes	Yes
Sample Event 9	5/2/1992	MW-8	1.000E-03	1245.0	-3.53E-02	8.029E-23	Yes	Yes
Sample Event 10	1/11/1994	MW-1	2.200E-01	1177.0	-4.33E-02	1.585E-23	Yes	Yes
Sample Event 10	1/11/1994	MW-12	5.000E-03	1090.0	-4.33E-02	1.560E-23	Yes	Yes
Sample Event 10	1/11/1994	MW-13	1.000E-03	1125.0	-4.33E-02	6.851E-25	Yes	Yes
Sample Event 10	1/11/1994	MW-14	1.000E-03	1088.0	-4.33E-02	3.403E-24	Yes	Yes
Sample Event 10	1/11/1994	MW-15	1.000E-03	1000.0	-4.33E-02	1.539E-22	Yes	Yes
Sample Event 10	1/11/1994	MW-2	2.000E-03	1192.0	-4.33E-02	7.522E-26	Yes	Yes
Sample Event 10	1/11/1994	MW-3	1.100E-02	1155.0	-4.33E-02	2.055E-24	Yes	Yes
Sample Event 10	1/11/1994	MW-4	1.800E-02	1135.0	-4.33E-02	7.996E-24	Yes	Yes
Sample Event 10	1/11/1994	MW-5	1.200E+00	1194.0	-4.33E-02	4.139E-23	Yes	Yes
Sample Event 10	1/11/1994	MW-6	1.000E-03	1267.0	-4.33E-02	1.460E-27	Yes	Yes
Sample Event 10	1/11/1994	MW-7	1.000E-03	1277.0	-4.33E-02	9.467E-28	Yes	Yes
Sample Event 10	1/11/1994	MW-8	1.000E-03	1245.0	-4.33E-02	3.786E-27	Yes	Yes
Sample Event 11	5/28/1996	MW-1	3.540E-01	1177.0	-6.76E-02	9.695E-36	Yes	Yes
Sample Event 11	5/28/1996	MW-12	1.000E-03	1090.0	-6.76E-02	9.824E-36	Yes	Yes
Sample Event 11	5/28/1996	MW-13	1.000E-03	1125.0	-6.76E-02	9.216E-37	Yes	Yes
Sample Event 11	5/28/1996	MW-14	1.000E-03	1088.0	-6.76E-02	1.125E-35	Yes	Yes
Sample Event 11	5/28/1996	MW-15	1.000E-03	1000.0	-6.76E-02	4.317E-33	Yes	Yes
Sample Event 11	5/28/1996	MW-2	1.000E-03	1192.0	-6.76E-02	9.933E-39	Yes	Yes
Sample Event 11	5/28/1996	MW-3	1.000E-02	1155.0	-6.76E-02	1.212E-36	Yes	Yes
Sample Event 11	5/28/1996	MW-4	3.700E-02	1135.0	-6.76E-02	1.734E-35	Yes	Yes
Sample Event 11	5/28/1996	MW-5	6.780E-01	1194.0	-6.76E-02	5.883E-36	Yes	Yes
Sample Event 11	5/28/1996	MW-6	1.000E-03	1267.0	-6.76E-02	6.233E-41	Yes	Yes
Sample Event 11	5/28/1996	MW-7	1.000E-03	1277.0	-6.76E-02	3.170E-41	Yes	Yes
Sample Event 11	5/28/1996	MW-8	1.000E-03	1245.0	-6.76E-02	2.759E-40	Yes	Yes
Sample Event 12	6/27/1997	MW-1	4.600E-02	1177.0	-4.44E-02	9.666E-25	Yes	Yes
Sample Event 12	6/27/1997	MW-12	1.000E-03	1090.0	-4.44E-02	9.970E-25	Yes	Yes
Sample Event 12	6/27/1997	MW-13	1.000E-03	1125.0	-4.44E-02	2.110E-25	Yes	Yes
Sample Event 12	6/27/1997	MW-14	1.000E-03	1088.0	-4.44E-02	1.090E-24	Yes	Yes
Sample Event 12	6/27/1997	MW-15	1.000E-03	1000.0	-4.44E-02	5.405E-23	Yes	Yes
Sample Event 12	6/27/1997	MW-2	1.000E-03	1192.0	-4.44E-02	1.080E-26	Yes	Yes
Sample Event 12	6/27/1997	MW-3	3.000E-03	1155.0	-4.44E-02	1.673E-25	Yes	Yes
Sample Event 12	6/27/1997	MW-4	2.800E-02	1135.0	-4.44E-02	3.792E-24	Yes	Yes

Project: Example **User Name:** Meng

Location: Service Station **State:** Texas

Sampling Event	Effective Date	Well	Observed Concentration (mg/L)	Distance Down Centerline (ft)	Regression Coefficient (1/ft)	Projected Concentration (mg/L)	Below Detection Limit?	Used in Analysis?
BENZENE								
Sample Event 12	6/27/1997	MW-5	6.230E-01	1194.0	-4.44E-02	6.158E-24	Yes	Yes
Sample Event 12	6/27/1997	MW-6	1.000E-03	1267.0	-4.44E-02	3.876E-28	Yes	Yes
Sample Event 12	6/27/1997	MW-7	1.000E-03	1277.0	-4.44E-02	2.487E-28	Yes	Yes
Sample Event 12	6/27/1997	MW-8	1.000E-03	1245.0	-4.44E-02	1.029E-27	Yes	Yes
Sample Event 13	12/10/1997	MW-1	3.600E-02	1177.0	-4.10E-02	4.013E-23	Yes	Yes
Sample Event 13	12/10/1997	MW-12	1.000E-03	1090.0	-4.10E-02	3.944E-23	Yes	Yes
Sample Event 13	12/10/1997	MW-13	5.200E-04	1125.0	-4.10E-02	4.885E-24	Yes	Yes
Sample Event 13	12/10/1997	MW-14	1.000E-03	1088.0	-4.10E-02	4.280E-23	Yes	Yes
Sample Event 13	12/10/1997	MW-15	1.000E-03	1000.0	-4.10E-02	1.578E-21	Yes	Yes
Sample Event 13	12/10/1997	MW-2	1.000E-03	1192.0	-4.10E-02	6.027E-25	Yes	Yes
Sample Event 13	12/10/1997	MW-3	1.000E-03	1155.0	-4.10E-02	2.746E-24	Yes	Yes
Sample Event 13	12/10/1997	MW-4	3.000E-03	1135.0	-4.10E-02	1.870E-23	Yes	Yes
Sample Event 13	12/10/1997	MW-5	3.630E-01	1194.0	-4.10E-02	2.016E-22	Yes	Yes
Sample Event 13	12/10/1997	MW-6	1.000E-03	1267.0	-4.10E-02	2.786E-26	Yes	Yes
Sample Event 13	12/10/1997	MW-7	1.000E-03	1277.0	-4.10E-02	1.849E-26	Yes	Yes
Sample Event 13	12/10/1997	MW-8	1.000E-03	1245.0	-4.10E-02	6.864E-26	Yes	Yes
Sample Event 14	6/19/1998	MW-1	1.140E-02	1177.0	-2.83E-02	3.732E-17	Yes	Yes
Sample Event 14	6/19/1998	MW-12	1.000E-03	1090.0	-2.83E-02	3.852E-17	Yes	Yes
Sample Event 14	6/19/1998	MW-13	1.000E-03	1125.0	-2.83E-02	1.429E-17	Yes	Yes
Sample Event 14	6/19/1998	MW-14	1.000E-03	1088.0	-2.83E-02	4.077E-17	Yes	Yes
Sample Event 14	6/19/1998	MW-15	1.000E-03	1000.0	-2.83E-02	4.936E-16	Yes	Yes
Sample Event 14	6/19/1998	MW-2	1.000E-03	1192.0	-2.83E-02	2.140E-18	Yes	Yes
Sample Event 14	6/19/1998	MW-3	2.000E-03	1155.0	-2.83E-02	1.221E-17	Yes	Yes
Sample Event 14	6/19/1998	MW-4	1.400E-02	1135.0	-2.83E-02	1.507E-16	Yes	Yes
Sample Event 14	6/19/1998	MW-5	6.800E-02	1194.0	-2.83E-02	1.375E-16	Yes	Yes
Sample Event 14	6/19/1998	MW-6	1.000E-03	1267.0	-2.83E-02	2.555E-19	Yes	Yes
Sample Event 14	6/19/1998	MW-7	1.000E-03	1277.0	-2.83E-02	1.925E-19	Yes	Yes
Sample Event 14	6/19/1998	MW-8	1.000E-03	1245.0	-2.83E-02	4.767E-19	Yes	Yes
Sample Event 15	12/19/1998	MW-1	1.900E-03	1177.0	-7.29E-03	3.568E-07	Yes	Yes
Sample Event 15	12/19/1998	MW-12	1.000E-03	1090.0	-7.29E-03	3.541E-07	Yes	Yes
Sample Event 15	12/19/1998	MW-13	1.000E-03	1125.0	-7.29E-03	2.743E-07	Yes	Yes
Sample Event 15	12/19/1998	MW-14	1.000E-03	1088.0	-7.29E-03	3.593E-07	Yes	Yes
Sample Event 15	12/19/1998	MW-15	1.000E-03	1000.0	-7.29E-03	6.824E-07	Yes	Yes
Sample Event 15	12/19/1998	MW-2	1.000E-03	1192.0	-7.29E-03	1.683E-07	Yes	Yes
Sample Event 15	12/19/1998	MW-3	1.000E-03	1155.0	-7.29E-03	2.204E-07	Yes	Yes
Sample Event 15	12/19/1998	MW-4	1.000E-03	1135.0	-7.29E-03	2.550E-07	Yes	Yes

Project: Example **User Name:** Meng

Location: Service Station **State:** Texas

Sampling Event	Effective Date	Well	Observed Concentration (mg/L)	Distance Down Centerline (ft)	Regression Coefficient (1/ft)	Projected Concentration (mg/L)	Below Detection Limit?	Used in Analysis?
BENZENE								
Sample Event 15	12/19/1998	MW-5	1.520E-02	1194.0	-7.29E-03	2.522E-06	Yes	Yes
Sample Event 15	12/19/1998	MW-6	1.000E-03	1267.0	-7.29E-03	9.743E-08	Yes	Yes
Sample Event 15	12/19/1998	MW-7	1.000E-03	1277.0	-7.29E-03	9.058E-08	Yes	Yes
Sample Event 15	12/19/1998	MW-8	1.000E-03	1245.0	-7.29E-03	1.144E-07	Yes	Yes

Note: Projected Concentrations that are below the user-specified detection limit are indicated by a check mark to its right; for sampling events with less than 3 selected plume centerline wells, NO projected concentrations are calculated because no regression coefficient is available.

APPENDIX A.11 — MAROS TUTORIAL

Authors: Aziz, J. J. and Vanderford, M., Groundwater Services, Inc.; Ling, M., University of Houston

Objectives

This tutorial has been developed to illustrate some of the most commonly used features of the MAROS software. The general objective of the tutorial is to use the MAROS 2.1 statistical and decision support methodology to optimize a simple, hypothetical long-term monitoring network and sampling plan.

The key objectives of the tutorial include familiarizing the user with typical applications, implementation and interpretation of the MAROS 2.1 modules: The MAROS methodology is explained in general terms during this tutorial. More detailed information is provided in the MAROS Manual and in references listed at the end of this tutorial.

Upon completing this tutorial, the user should be able to:

- Enter data into the software from both Excel files and Access archive files;
- Rank and choose COCs that control long-term monitoring decisions;
- Select time ranges to analyze data and consolidate large data sets;
- Determine the overall plume stability through trend analysis;
- Evaluate plume stability using moment analysis (total mass, center of mass and spread of mass estimates);
- Evaluate individual well concentration trends over time;
- Reduce, where possible, redundant wells without information loss;
- Suggest locations for new wells for future sampling;
- Provide future sampling frequency recommendations while maintaining sufficient plume stability information;
- To evaluate risk-based site cleanup status using data sufficiency analysis.

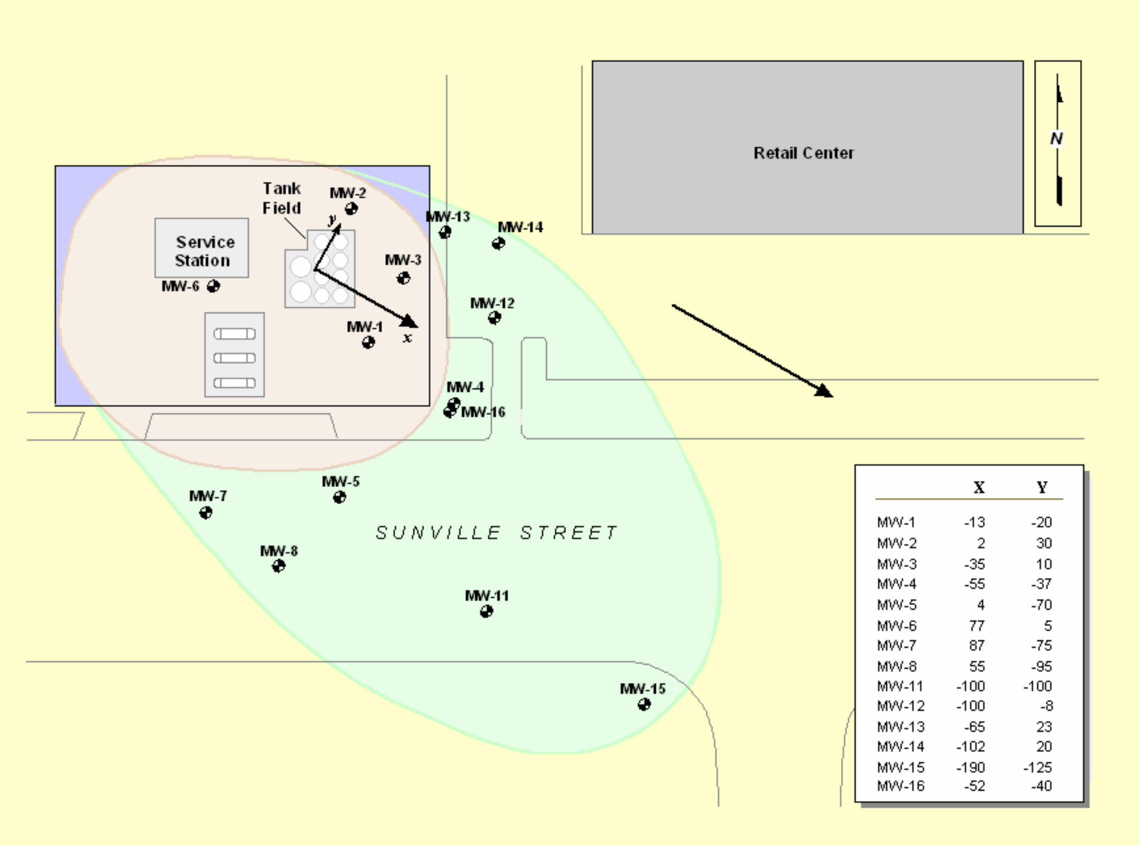
MAROS is a collection of tools in one software package that is used in an explanatory, non-linear fashion. The tool includes models, statistics, heuristic rules, and empirical relationships to assist the user in optimizing a groundwater monitoring network system while maintaining adequate delineation and knowledge of the plume state over time. Different users utilize the tool in different ways and interpret the results from a different viewpoint. Therefore, it is important to not only have a conceptual model for the site before beginning the MAROS analysis, but to also assess all of the MAROS results in conjunction with knowledge of site conditions, regulatory framework, community issues, and other site specific situations. Also, the MAROS methodology assumes that the current sampling network adequately delineates the plume (bounding wells have non-detect values) and that if a hydraulic containment system and/or remediation system is currently in operation, this will continue. For a more detailed description of the structure of the software and further utilities, refer to the Appendices 1 - 10.

The goal of the tutorial is to show the user tips and pitfalls when applying MAROS at a typical site. The tutorial example has been used only to illustrate the utilities of the MAROS software, it is by no means a complete site analysis.

Note: The MAROS software can be used to analyze sites more complex than this example, with many more wells, more COCs, more sampling data and more complex geology. However, the analysis may be more difficult to set up and interpret. For instance, if a site has co-mingled plumes, typically the plume networks should be analyzed separately for the different constituents. If the site has more than one aquifer affected by contaminants, the well networks for each groundwater unit should be analyzed separately. Results for multiple COCs can be interpreted side by side and weighted based on toxicity, mobility and prevalence of the compound. In general, the MAROS method applies to 2-D systems that have relatively simple site hydrogeology. However, for a multi-layered (3-D) system, the user should apply the statistical analysis layer-by-layer.

Site Background and Conceptual Model

The example site is a Service Station where shallow groundwater has been affected by leaking underground gasoline storage tanks. Site characterization activities have delineated the plume boundaries, vertically and horizontally. The primary constituent of concern at the Service Station site is benzene, which is analyzed at 14 monitoring wells in the Upper Aquifer well network (Figure A.11.1). The site has 10 years of approximately semi-annual sampling data. Monitored natural attenuation has been chosen as the remedial response, and stakeholders are in the process of reviewing a long-term monitoring plan for the site. The historical benzene data for all, or in some cases, a subset of wells will be analyzed using the MAROS 2.1 software in order to: 1) determine plume stability, and 2) recommend changes in sampling frequency and sampling locations without compromising the effectiveness of the long-term monitoring network.



	X	Y
MW-1	-13	-20
MW-2	2	30
MW-3	-35	10
MW-4	-55	-37
MW-5	4	-70
MW-6	77	5
MW-7	87	-75
MW-8	55	-95
MW-11	-100	-100
MW-12	-100	-8
MW-13	-65	23
MW-14	-102	20
MW-15	-190	-125
MW-16	-52	-40

FIGURE A.11.1 EXAMPLE SITE: SERVICE STATION MONITORING WELL LOCATIONS

Geology/Hydrogeology

The shallow geologic unit under the Service Station (known as the Upper Aquifer) consists primarily of sand and gravel. The Upper Aquifer has an approximate saturated thickness of 12 feet. The groundwater flow direction is predominantly toward the southeast and the groundwater seepage velocity is approximately 92 ft/yr.

Parameter	Value
Seepage Velocity	92 ft/yr
Porosity	30%
Approximate Zone A Source Location	Coordinates -1, -1
Approximate Saturated Thickness	12 ft
General Groundwater Flow Direction	Southeast

TABLE A.11.1 EXAMPLE SITE: SERVICE STATION SITE PARAMETERS

Remedial Action and Long-Term Monitoring

A site investigation of the service station was performed in 1986 and the results showed that the groundwater plume in the shallow Upper Aquifer principally contains benzene and is 270 ft long, approximately 150 feet wide. The plume also contains ethylbenzene, toluene, and xylenes at concentrations above the MCL level. According to the results of the site investigation, a leaking underground storage tank is the source of benzene. Nonaqueous-phase liquid (NAPL) was found in the "source area" and the leaking tank was removed along with excavating the contaminated soil. The area that extends from the edge of the property across Sunnyville Street (MW-15) is designated as the "down-gradient area".

Well	Well Type	Well Category
MW-1	MW	S
MW-2	MW	S
MW-3	MW	S
MW-4	MW	T
MW-5	MW	S
MW-6	MW	S
MW-7	MW	S
MW-8	MW	S
MW-9	MW	T
MW-10	MW	T
MW-11	MW	T
MW-12	MW	T
MW-13	MW	T
MW-14	MW	T
MW-15	MW	T
MW-16	MW	T

Note: MW = Monitoring Well, S = Source Zone Well; T = Tail Zone Well

TABLE A.11.2 EXAMPLE SITE: SERVICE STATION WELL CATEGORIES

The regulatory agency involved with the site concluded that site characterization activities to date have fully delineated the extent of contamination. Lower groundwater units have not been affected by site constituents. Monitored Natural Attenuation has been approved as a site remedy, due to the size of the plume and its distance from any receptors. The original long-term groundwater monitoring plan was completed in 1998. It consisted of compliance monitoring with the goal of plume reduction monitoring to verify progress toward achieving cleanup goals over a 30 year period. The number of monitoring wells that were sampled in the original Upper Aquifer monitoring network is 14 (Figure A.11.1). All monitoring wells have been sampled semi-annually in the Upper Aquifer for BTEX since the implementation of the original long-term monitoring plan. Between 1988 and 1998, 16 sampling events had been carried out at the site.

Start Using MAROS

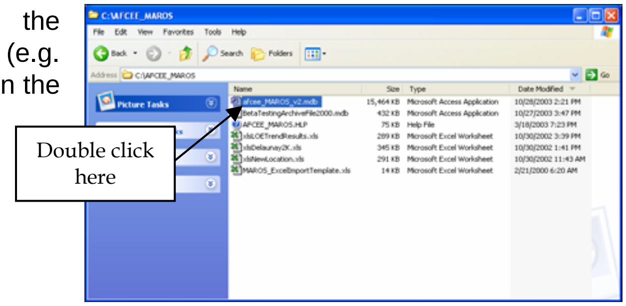
STEP 1: INSTALLATION

If the MAROS software is not already installed on your computer, follow the instructions on page 3 of the User Manual.

STEP 2: START MAROS

To start using the software, go to the subdirectory where MAROS is installed (e.g. C:\AFCEE_MAROS\) and double click on the "afcee_MAROS_v2.mdb" file.

The *Start* Screen will be displayed.



Name	Size	Type	Date Modified
afcee_MAROS_v2.mdb	15,464 KB	Microsoft Access Application	10/28/2003 2:21 PM
BetaTestingArchiveFile2000.mdb	432 KB	Microsoft Access Application	10/27/2003 3:47 PM
AFCEE_MAROS.HLP	75 KB	Help File	3/18/2003 7:23 PM
xlsLOETrendResults.xls	289 KB	Microsoft Excel Worksheet	10/30/2002 3:39 PM
xlsDelaunay2K.xls	345 KB	Microsoft Excel Worksheet	10/30/2002 1:41 PM
xlsNewLocation.xls	291 KB	Microsoft Excel Worksheet	10/30/2002 11:43 AM
MAROS_ExcelImportTemplate.xls	14 KB	Microsoft Excel Worksheet	2/21/2000 6:20 AM

Double click here

STEP 3: ENTER USER INFORMATION

The *Start* Screen gives the user access to the software system.

User Name: Charles Newell
Project Name: Tutorial

Enter details here

Click here

Enter the following information as User Name and Project Name in the boxes to the left of the Start Button:

- User Name: *Enter your name*
- Project Name: “Tutorial”

Click the “Start” button when finished.

Importing Data

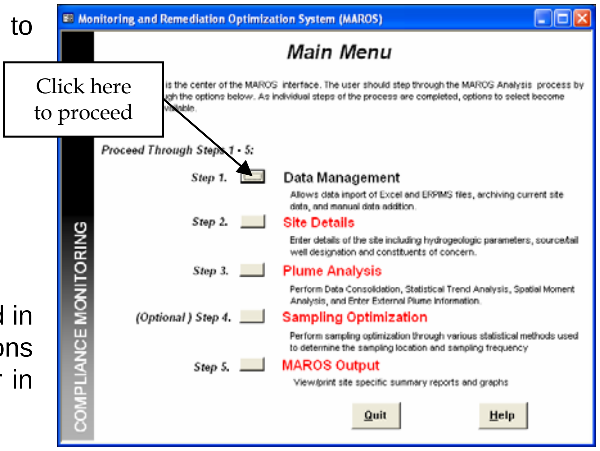
STEP 1: MAIN MENU

The *Main* screen serves at the center of the user interface. The user progressively steps through the Compliance Monitoring Trend Analysis and Optimization Evaluation process by navigating through the options displayed. As individual steps of the process are completed, options to select become successively available.

The *Main Menu* screen allows the user to choose between performing:

- Step 1: Data Management
- Step 2: Site Details
- Step 3: Plume Analysis
- Step 4: Sampling Optimization
- Step 5: MAROS Output

Options that are not available are displayed in red. As steps are completed and options become available choices, text will appear in black.



Click here to proceed

is the center of the MAROS interface. The user should step through the MAROS Analysis process by
gh the options below. As individual steps of the process are completed, options to select become
vailable.

Proceed Through Steps 1 - 5:

Step 1. Data Management
Allows data import of Excel and ERPIMS files, archiving current site data, and manual data addition.

Step 2. Site Details
Enter details of the site including hydrogeologic parameters, source/tail well designation and constituents of concern.

Step 3. Plume Analysis
Perform Data Consolidation, Statistical Trend Analysis, Spatial Moment Analysis, and Enter External Plume Information.

(Optional) Step 4. Sampling Optimization
Perform sampling optimization through various statistical methods used to determine the sampling location and sampling frequency

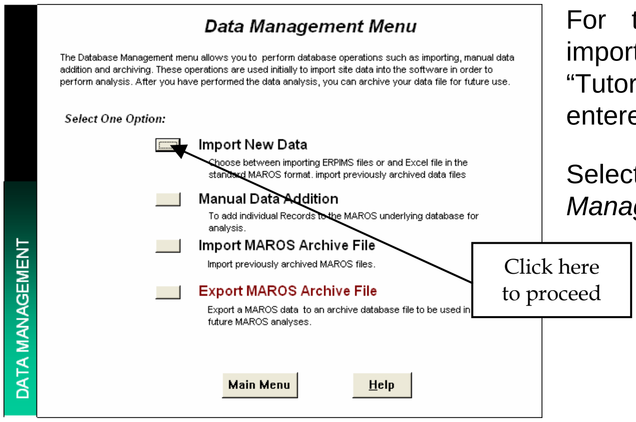
Step 5. MAROS Output
View/print site specific summary reports and graphs

Click on the “Data Management” button to continue.

The *Data Management Menu* will appear.

STEP 2: DATA MANAGEMENT MENU

The *Data Management Menu* is used to perform database operations such as importing, manual data addition and archiving. These operations are used initially to import site data into the software in order to perform the analysis.



The Database Management menu allows you to perform database operations such as importing, manual data addition and archiving. These operations are used initially to import site data into the software in order to perform analysis. After you have performed the data analysis, you can archive your data file for future use.

Select One Option:

Import New Data
Choose between importing ERPIMS files or and Excel file in the standard MAROS format. import previously archived data files

Manual Data Addition
To add individual Records to the MAROS underlying database for analysis.

Import MAROS Archive File
Import previously archived MAROS files.

Export MAROS Archive File
Export a MAROS data to an archive database file to be used in future MAROS analyses.

Click here to proceed

For this tutorial analytical data will be imported from an Excel spreadsheet “TutorialExampleData.xls”. Site details will be entered manually in later screens.

Select “Import New Data” from the *Data Management Menu*.

Note: Typically the first time through the MAROS software the user will have to utilize the “Import New Data” option, where you can import raw electronic data from an Excel File or Access File. The first time the data is entered, the user can save the data as an archive file for future use. The archive file can store analytical data and site details. Refer to Appendix A.1 for import file formats. Also, see example import file MAROS_ExcelImportTemplate.xls.

STEP 3: IMPORT NEW DATA

The *Import New Data* screen is used to import electronic data files.

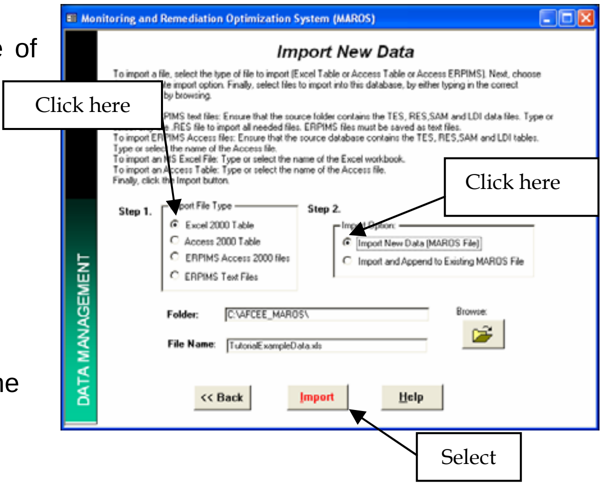
To import archived data into the full database:

1) Enter the full file path and the filename of the archived file to import:

   Note: The “Browse” button can also be used to locate the import file.

   Folder: “C:\AFCEE_MAROS\”
   File Name: “TutorialExampleData.xls”

   Choose ‘Import New Data’ (rather than the append option).


Monitoring and Remediation Optimization System (MAROS)

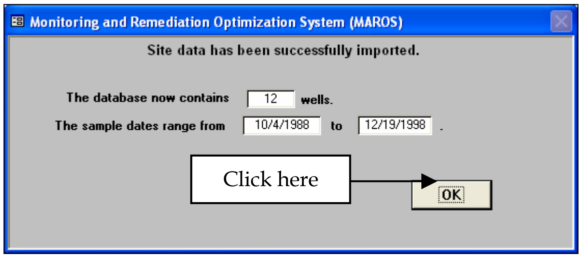
Import New Data

Step 1. Import File Type
● Excel 2000 Table
○ Access 2000 Table
○ ERPIMS Access 2000 files
○ ERPIMS Text Files

Step 2. Import Option:
● Import New Data (MAROS File)
○ Import and Append to Existing MAROS File

Folder: C:\AFCEE_MAROS\
File Name: TutorialExampleData.xls

2) Click the “Import” button to proceed with importing the file to the existing database.


Monitoring and Remediation Optimization System (MAROS)

Site data has been successfully imported.

The database now contains 12 wells.

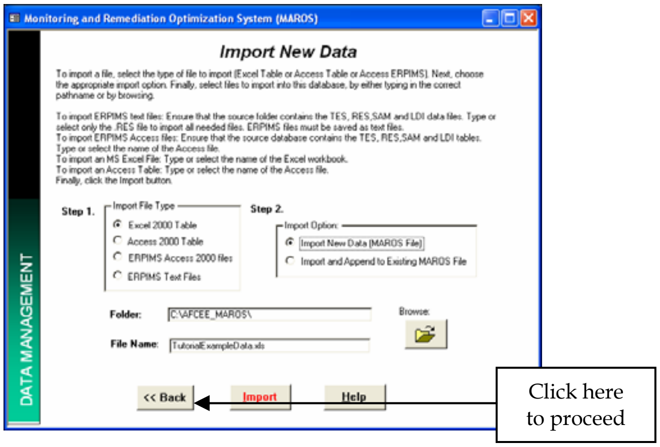
The sample dates range from 10/4/1988 to 12/19/1998 .

A screen will be displayed showing the total number of wells and the dates range of sample events.

Check numbers to see if they accurately reflect your dataset. Wells with all non-detect values located outside of the network are often not imported.
Click “OK” to proceed.

The *Import New Data* screen will be displayed again.

3) From *Import New Data* screen, click “Back” to return to the *Data Management Menu* screen.


Monitoring and Remediation Optimization System (MAROS)

Import New Data

To import a file, select the type of file to import (Excel Table or Access Table or Access ERPIMS). Next, choose the appropriate import option. Finally, select files to import into this database, by either typing in the correct pathname or by browsing.

To import ERPIMS text files: Ensure that the source folder contains the TES, RES,SAM and LDI data files. Type or select only the .RES file to import all needed files. ERPIMS files must be saved as text files.
To import ERPIMS Access files: Ensure that the source database contains the TES, RES,SAM and LDI tables. Type or select the name of the Access file.
To import an MS Excel File: Type or select the name of the Excel workbook.
To import an Access Table: Type or select the name of the Access file.
Finally, click the Import button.

Step 1. Import File Type
● Excel 2000 Table
○ Access 2000 Table
○ ERPIMS Access 2000 files
○ ERPIMS Text Files

Step 2. Import Option:
● Import New Data (MAROS File)
○ Import and Append to Existing MAROS File

Folder: C:\AFCEE_MAROS\
File Name: TutorialExampleData.xls

4) From the *Data Management Menu* screen, click on “Main Menu” to return to the *Main Menu* screen.

Data Management Menu

The Database Management menu allows you to perform database operations such as importing, manual data addition and archiving. These operations are used initially to import site data into the software in order to perform analysis. After you have performed the data analysis, you can archive your data file for future use.

Select One Option:

Import New Data
Choose between importing ERPIMS files or and Excel file in the standard MAROS format. import previously archived data files

Manual Data Addition
To add individual Records to the MAROS underlying database for analysis.

Import MAROS Archive File
Import previously archived MAROS files.

Export MAROS Archive File
Export a MAROS data to an archive database file to be used in future MAROS analyses.

Click here to proceed

The site data file will now have been imported from the Excel file. The next stage is to define the site details.

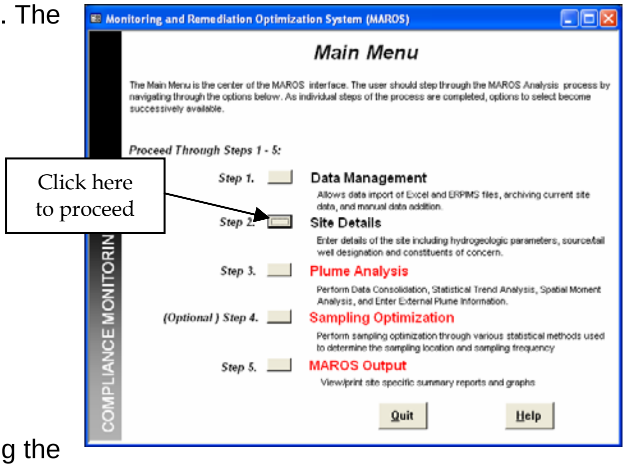
The Data Management Menu can also be used to import data manually and from MAROS Archive files, created in previous sessions. Details of these operations can be found in the MAROS 2.1 Users Guide.

Site Details

Step 2, Site Details allows initial definition of site specific data including choosing the “Source” and “Tail” wells, sample events and providing site-specific Constituents of Concern (COC’s).

STEP 1: MAIN MENU

Select “Site Details” from the *Main Menu*. The *Site Information* screen will be displayed.



The Main Menu is the center of the MAROS interface. The user should step through the MAROS Analysis process by navigating through the options below. As individual steps of the process are completed, options to select become successively available.

Proceed Through Steps 1 - 5:

Step 1. Data Management
Allows data import of Excel and ERPIMS files, archiving current site data, and manual data addition.

Step 2. Site Details
Enter details of the site including hydrogeologic parameters, source/tail well designation and constituents of concern.

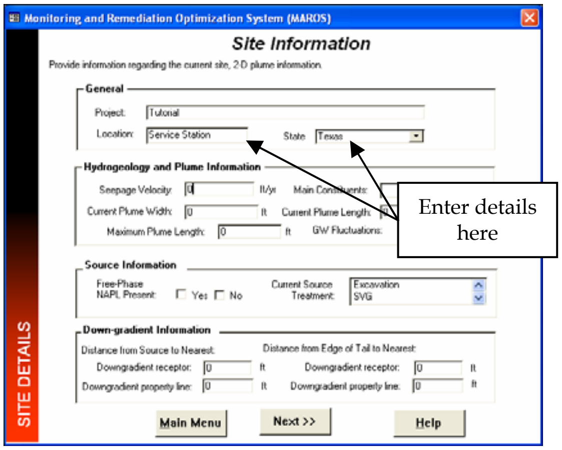
Step 3. Plume Analysis
Perform Data Consolidation, Statistical Trend Analysis, Spatial Moment Analysis, and Enter External Plume Information.

(Optional) Step 4. Sampling Optimization
Perform sampling optimization through various statistical methods used to determine the sampling location and sampling frequency

Step 5. MAROS Output
View/print site specific summary reports and graphs

STEP 2: SITE INFORMATION

Site Information is the first step in defining the site type as well as parameters unique to the site. Site details were outlined at the start of the tutorial.



Provide information regarding the current site, 2-D plume information.

General
Project: Tutorial
Location: Service Station
State: Texas

Hydrogeology and Plume Information
Seepage Velocity: 0 ft/yr
Main Constituents:
Current Plume Width: 0 ft
Current Plume Length:
Maximum Plume Length: 0 ft
GW Fluctuations:

Source Information
Free-Phase NAPL Present: ☐ Yes ☐ No
Current Source Treatment: Excavation SVG

Down-gradient Information
Distance from Source to Nearest:
Downgradient receptor: 0 ft
Downgradient property line: 0 ft
Distance from Edge of Tail to Nearest:
Downgradient receptor: 0 ft
Downgradient property line: 0 ft

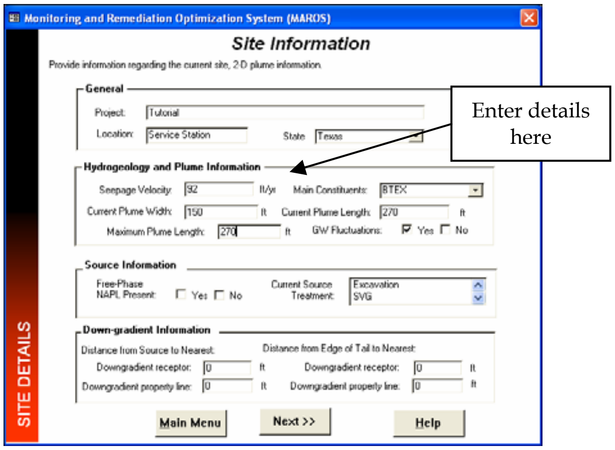
The following information will need to be entered on the *Site Information* screen:

Under ***General*** enter:

- Location: “Service Station”
- State: “Texas”

Under ***Hydrogeology and Plume Information*** enter:

- Seepage Velocity: “92” ft/yr
- Main Constituents: “BTEX”
- Current Plume Width: “150” ft
- Current Plume Length: “270” ft
- Maximum Plume Length: “270” ft
- GW Fluctuations: Select “Yes”



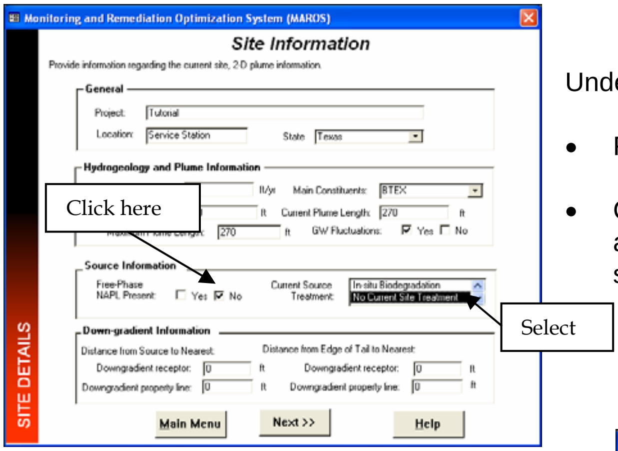
Provide information regarding the current site, 2-D plume information.

General
Project: Tutorial
Location: Service Station
State: Texas

Hydrogeology and Plume Information
Seepage Velocity: 92 ft/yr
Main Constituents: BTEX
Current Plume Width: 150 ft
Current Plume Length: 270 ft
Maximum Plume Length: 270 ft
GW Fluctuations: ☑ Yes ☐ No

Source Information
Free-Phase NAPL Present: ☐ Yes ☐ No
Current Source Treatment: Excavation SVG

Down-gradient Information
Distance from Source to Nearest:
Downgradient receptor: 0 ft
Downgradient property line: 0 ft
Distance from Edge of Tail to Nearest:
Downgradient receptor: 0 ft
Downgradient property line: 0 ft



Site Information

Provide information regarding the current site, 2-D plume information.

General

Project: Tutorial
Location: Service Station
State: Texas

Hydrogeology and Plume Information

ft/yr
Main Constituents: BTEX
ft
Current Plume Length: 270 ft
Maximum Plume Length: 270 ft
GW Fluctuations: ☑ Yes ☐ No

Source Information

Free-Phase NAPL Present: ☐ Yes ☑ No
Current Source Treatment: In-situ Biodegradation / No Current Site Treatment

Down-gradient Information

Distance from Source to Nearest:
Downgradient receptor: 0 ft
Downgradient property line: 0 ft
Distance from Edge of Tail to Nearest:
Downgradient receptor: 0 ft
Downgradient property line: 0 ft

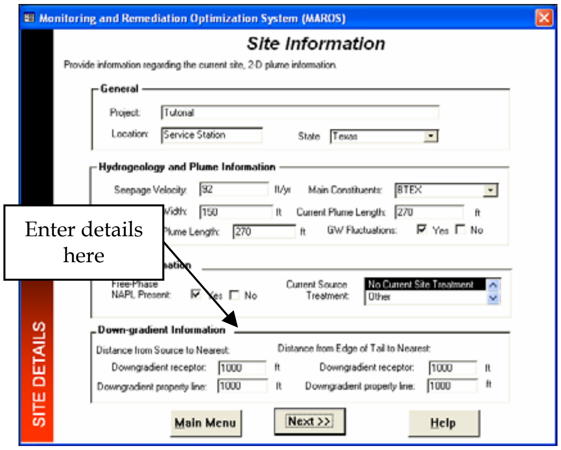
Under ***Source Information*** select:

- Free Phase NAPL Present: “No”
- Current Source Treatment: Click on down arrow to obtain list of choices. Scroll down to select “No Current Site Treatment”.

Under ***Down-gradient Information*** enter:

- “1000” ft for all 4 boxes

Select “Next” to continue. The *Sample Events* screen will appear.



Site Information

Provide information regarding the current site, 2-D plume information.

General

Project: Tutorial
Location: Service Station
State: Texas

Hydrogeology and Plume Information

Seepage Velocity: 92 ft/yr
Main Constituents: BTEX
Width: 150 ft
Current Plume Length: 270 ft
Plume Length: 270 ft
GW Fluctuations: ☑ Yes ☐ No

Free-Phase NAPL Present: ☑ Yes ☐ No
Current Source Treatment: No Current Site Treatment / Other

Down-gradient Information

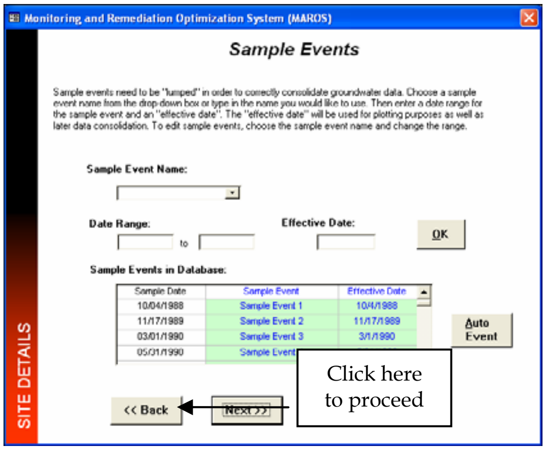
Distance from Source to Nearest:
Downgradient receptor: 1000 ft
Downgradient property line: 1000 ft
Distance from Edge of Tail to Nearest:
Downgradient receptor: 1000 ft
Downgradient property line: 1000 ft

STEP 3: SAMPLE EVENTS

Sample Events allows the user to define sample events and dates to be used for graphing and data consolidation. This grouping of individual sample days is important for the MAROS analysis to be performed. Typically a sample event will last 2 days to 2 weeks, depending on how long it takes to sample all the wells at a site. Sampling is usually performed on a quarterly, semi-annual, or annual basis.

The **Effective Date** is selected by the user as representative of the sample event, e.g. sample event start date.

The **Auto Event** option is used to automatically set up sample events as unique for each sample date. This is appropriate only for a small site where all sampling can be completed on one day, i.e. one date per sampling event.



Sample Events

Sample events need to be "lumped" in order to correctly consolidate groundwater data. Choose a sample event name from the drop-down box or type in the name you would like to use. Then enter a date range for the sample event and an "effective date". The "effective date" will be used for plotting purposes as well as later data consolidation. To edit sample events, choose the sample event name and change the range.

Sample Event Name:

Date Range: to

Effective Date:

Sample Events in Database:

Sample Date	Sample Event	Effective Date
10/04/1988	Sample Event 1	10/4/1988
11/17/1989	Sample Event 2	11/17/1989
03/01/1990	Sample Event 3	3/1/1990
05/31/1990	Sample Event	

To define sample events, to the right of the heading ***Sample Events in Database*** click on “Auto Event”.

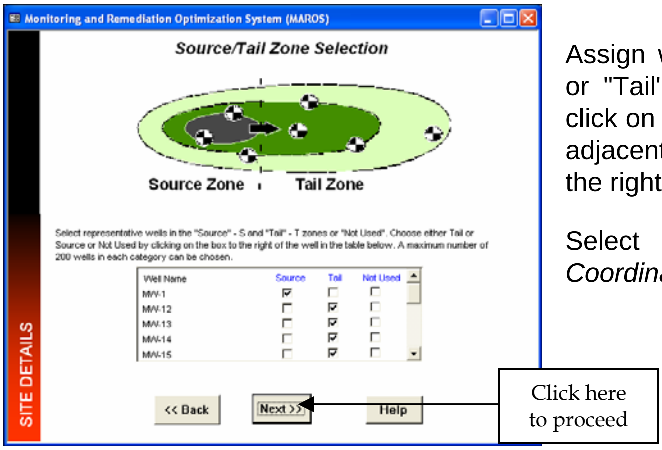
A list of all the sample events in the dataset will appear in the green boxes. To consolidate sample dates, choose a ***Sample Event Name*** (i.e. March 2000) and enter it in the box. Under ***Date Range***, enter the first and last date of the sample event, (using 2 digits for day and month and 4 for year) and then assign an effective date for the sample event. Assign dates for each sample event. Click “OK” to save choices. Click the “Next” button to proceed to the *Source Tail Selection* screen.

STEP 4: SOURCE/TAIL ZONE SELECTION

Source/Tail Zone Selection allows the user to define the well type for the wells in the database. The MAROS software divides the wells for the site into two different zones (e.g. “Source” zone and “Tail” zone).

The “**Source**” area is generally the location with the highest groundwater concentrations of constituents of concern or the area closes to the original release. The source can include zones with free-phase NAPLs, residual NAPL, contaminated vadose zone soils, and/or other typical source materials. The source zone wells for this site include MW-1, MW-2, MW-3, MW-5, MW-6, MW-7, and MW-8 (Figure A.11.1).

The downgradient groundwater plume (“**Tail**”) zone is the area downgradient of the contaminant source zone. The Tail only contains contaminants in the dissolved phase and the sorbed phase, but contains no sources of contamination. The tail wells for this site include, MW-4, MW-11, MW-12, MW-13, MW-14, MW-15 and MW-16 (Figure A.11.1).



Select representative wells in the "Source" - S and "Tail" - T zones or "Not Used". Choose either Tail or Source or Not Used by clicking on the box to the right of the well in the table below. A maximum number of 200 wells in each category can be chosen.

Well Name	Source	Tail	Not Used
MW-1	☑	☐	☐
MW-12	☐	☑	☐
MW-13	☐	☑	☐
MW-14	☐	☑	☐
MW-15	☐	☑	☐

Click here to proceed

Assign well categories as being in "Source" or "Tail" zones (Table A.11.2). To do this click on the appropriate “Source” or “Tail” box adjacent to each well. Use the scroll bar to the right of the box to view all wells.

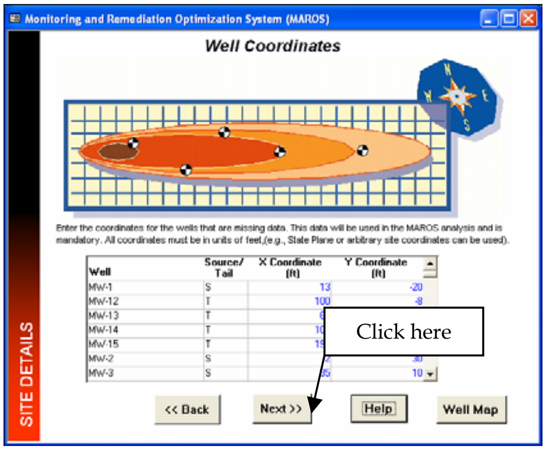
Select “Next” to continue. The *Well Coordinates* screen will appear.

STEP 5: WELL COORDINATES

Well Coordinates allows the user to define and/or revise the well coordinates if they were not defined in the import file. Well coordinates are mandatory and should be in feet (e.g. State Plane coordinates or arbitrary site coordinates).

Well coordinates will have already been specified.

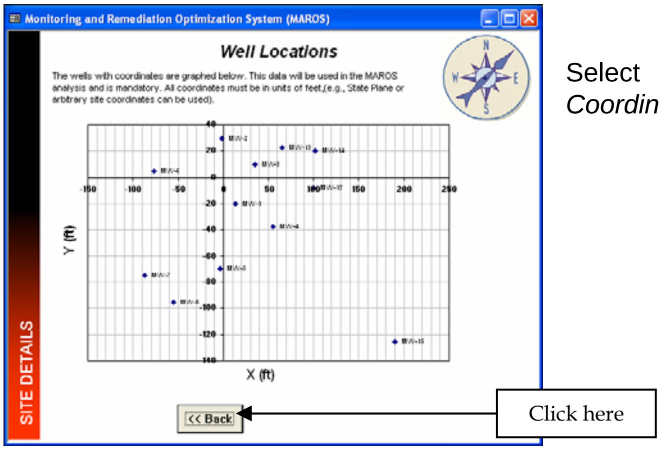
Select the button “Well Map” to view the well location map.



Enter the coordinates for the wells that are missing data. This data will be used in the MAROS analysis and is mandatory. All coordinates must be in units of feet,(e.g., State Plane or arbitrary site coordinates can be used).

Well	Source/ Tail	X Coordinate (ft)	Y Coordinate (ft)
MW-1	S	13	-20
MW-12	T	100	-8
MW-13	T	[illegible]	[illegible]
MW-14	T	[illegible]	[illegible]
MW-15	T	[illegible]	[illegible]
MW-2	S	[illegible]	[illegible]
MW-3	S	35	10

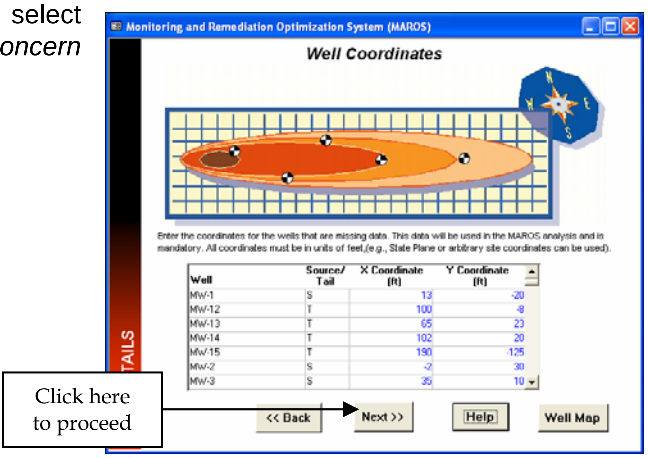
Well Locations allows the user to review the well coordinates in their relative locations.



The wells with coordinates are graphed below. This data will be used in the MAROS analysis and is mandatory. All coordinates must be in units of feet,(e.g., State Plane or arbitrary site coordinates can be used).

Select “Back” to continue. The *Well Coordinates* screen will re-appear.

From the *Well Coordinates* screen, select “Next” to continue. The *Constituents of Concern Decision* screen will appear.



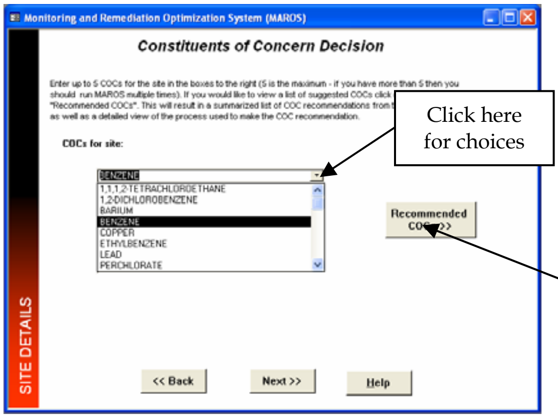
Enter the coordinates for the wells that are missing data. This data will be used in the MAROS analysis and is mandatory. All coordinates must be in units of feet,(e.g., State Plane or arbitrary site coordinates can be used).

Well	Source/ Tail	X Coordinate (ft)	Y Coordinate (ft)
MW-1	S	13	-20
MW-12	T	100	-8
MW-13	T	65	23
MW-14	T	102	20
MW-15	T	190	-125
MW-2	S	-2	30
MW-3	S	35	10

STEP 6: CONSTITUENTS OF CONCERN

Constituents of Concern Decision allows the user to define up to five constituents to be evaluated at the site. Typically the User should choose 1-2 priority constituents for the site, which will be used to lead the analysis.

The site used for this tutorial has several COCs (lead, benzene, ethylbenzene, toluene and xylenes), of which benzene will be used as the priority indicator compound for the plume.



Constituents of Concern Decision

Enter up to 5 COCs for the site in the boxes to the right (5 is the maximum - if you have more than 5 then you should run MAROS multiple times). If you would like to view a list of suggested COCs click "Recommended COCs". This will result in a summarized list of COC recommendations from as well as a detailed view of the process used to make the COC recommendation.

COCs for site: BENZENE

- 1,1,1,2-TETRACHLOROETHANE
- 1,2-DICHLOROBENZENE
- BARIUM
- BENZENE
- COPPER
- ETHYLBENZENE
- LEAD
- PERCHLORATE

Click here for choices

Select for COC Risk Ranking

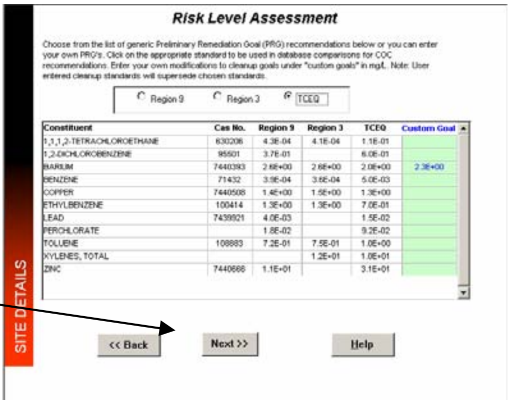
All boxes will initially be blank.

Click on the arrow to the right of the top box to display a list of COCs.

Select benzene by clicking on “benzene”. The top box should now have “benzene” displayed as shown.

If a priority constituent has not already been identified, choose “Recommended COCs”.

The *Risk Level Assessment* screen allows the User to choose the regulatory limits associated with COCs in the input file. For example, the user can choose a preliminary remediation goal (PRG) to screen representative concentrations from the dataset. The user can either select the appropriate clean-up standard (Region 3, Region 9 or TCEQ) or custom goals can be specified.


Risk Level Assessment

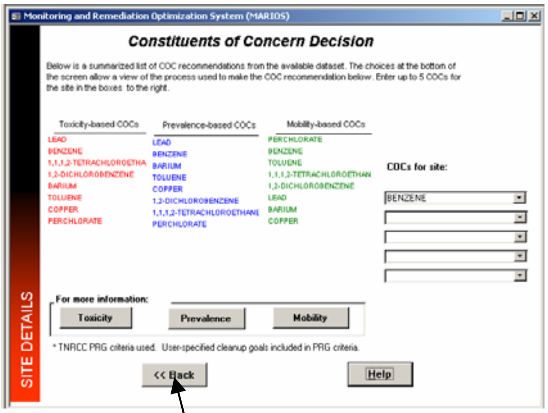
Choose from the list of generic Preliminary Remediation Goal (PRG) recommendations below or you can enter your own PRG's. Click on the appropriate standard to be used in database comparisons for COC recommendations. Enter your own modifications to cleanup goals under "custom goals" in mg/L. Note: User entered cleanup standards will supersede chosen standards.

○ Region 9 ○ Region 3 ● TCEQ

Constituent	Cas No.	Region 9	Region 3	TCEQ	Custom Goal
1,1,1,2-TETRACHLOROETHANE	630206	4.3E-04	4.1E-04	1.1E-01	
1,2-DICHLOROBENZENE	95501	3.7E-01		6.0E-01	
BARIUM	7440393	2.6E+00	2.6E+00	2.0E+00	2.3E+00
BENZENE	71432	3.5E-04	3.6E-04	5.0E-03	
COPPER	7440508	1.4E+00	1.5E+00	1.3E+00	
ETHYLBENZENE	100414	1.3E+00	1.3E+00	7.0E-01	
LEAD	7439921	4.0E-03		1.5E-02	
PERCHLORATE		1.8E-02		9.2E-02	
TOLUENE	108883	7.2E-01	7.5E-01	1.0E+00	
XYLENES, TOTAL			1.2E+01	1.0E+01	
ZINC	7440666	1.1E+01		3.1E+01	

Click here to proceed

Choose “Next” to proceed with Risk Ranking of COC’s.



Constituents of Concern Decision

Below is a summarized list of COC recommendations from the available dataset. The choices at the bottom of the screen allow a view of the process used to make the COC recommendation below. Enter up to 5 COCs for the site in the boxes to the right.

Toxicity-based COCs	Prevalence-based COCs	Mobility-based COCs
LEAD	LEAD	PERCHLORATE
BENZENE	BENZENE	BENZENE
1,1,1,2-TETRACHLOROETHA	BARIUM	TOLUENE
1,2-DICHLOROBENZENE	TOLUENE	1,1,1,2-TETRACHLOROETHAN
BARIUM	COPPER	1,2-DICHLOROBENZENE
TOLUENE	1,2-DICHLOROBENZENE	LEAD
COPPER	1,1,1,2-TETRACHLOROETHANE	BARIUM
PERCHLORATE	PERCHLORATE	COPPER

COCs for site: BENZENE

* TNRCC PRG criteria used. User-specified cleanup goals included in PRG criteria.

Click here to proceed

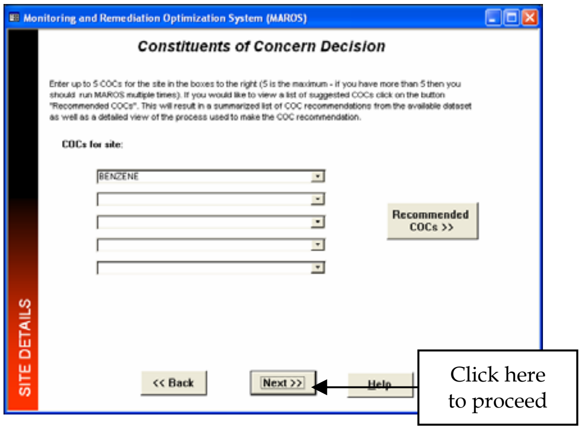
The *Constituents of Concern Decision* screen ranks site COCs based on toxicity, prevalence and mobility. Details of the analysis can be found by choosing the buttons associated with each criterion.

The User can decide, on the basis of these criteria, which site COCs to prioritize in the analysis.

Click “Back” to return to the main program.

From the *Constituents of Concern* window, click “Next” to proceed.

Note: The other drop down boxes can be used to change the COC or to select up to 4 additional COCs.

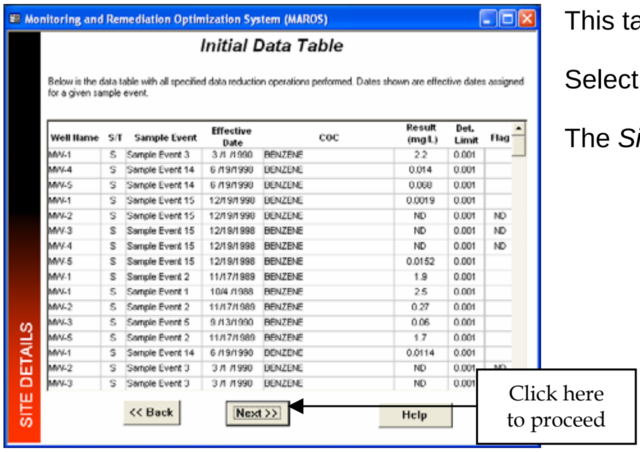


Enter up to 5 COCs for the site in the boxes to the right (5 is the maximum - if you have more than 5 then you should run MAROS multiple times). If you would like to view a list of suggested COCs click on the button "Recommended COCs". This will result in a summarized list of COC recommendations from the available dataset as well as a detailed view of the process used to make the COC recommendation.

COCs for site: BENZENE

STEP 7: VIEWING DATA

The *Initial Data Table* allows the user to view the initial data table with the COCs chosen as well as the sample events defined and effective dates.



Initial Data Table

Below is the data table with all specified data reduction operations performed. Dates shown are effective dates assigned for a given sample event.

Well Name	S/T	Sample Event	Effective Date	COC	Result (mg/L)	Det. Limit	Flag
MW-1	S	Sample Event 3	3 /1 /1990	BENZENE	2.2	0.001	
MW-4	S	Sample Event 14	6 /19/1990	BENZENE	0.014	0.001	
MW-5	S	Sample Event 14	6 /19/1990	BENZENE	0.068	0.001	
MW-1	S	Sample Event 15	12/19/1990	BENZENE	0.0019	0.001	
MW-2	S	Sample Event 15	12/19/1990	BENZENE	ND	0.001	ND
MW-3	S	Sample Event 15	12/19/1998	BENZENE	ND	0.001	ND
MW-4	S	Sample Event 15	12/19/1998	BENZENE	ND	0.001	ND
MW-5	S	Sample Event 15	12/19/1998	BENZENE	0.0152	0.001	
MW-1	S	Sample Event 2	11/17/1989	BENZENE	1.9	0.001	
MW-1	S	Sample Event 1	10/4 /1988	BENZENE	2.5	0.001	
MW-2	S	Sample Event 2	11/17/1989	BENZENE	0.27	0.001	
MW-3	S	Sample Event 5	9 /13/1990	BENZENE	0.06	0.001	
MW-5	S	Sample Event 2	11/17/1989	BENZENE	1.7	0.001	
MW-1	S	Sample Event 14	6 /19/1990	BENZENE	0.0114	0.001	
MW-2	S	Sample Event 3	3 /1 /1990	BENZENE	ND	0.001	ND
MW-3	S	Sample Event 3	3 /1 /1990	BENZENE	ND	0.001	

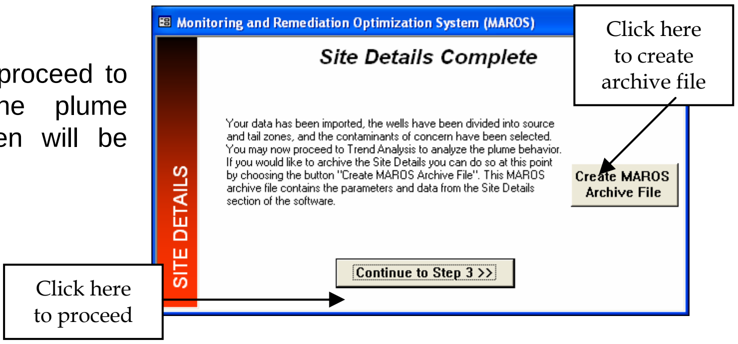
This table is not available for editing.

Select “Next” to continue.

The *Site Details Complete* screen will appear.

At this point your data has been imported, sample events have been identified, the wells have been divided into source and tail zones, and the constituents of concern have been selected.

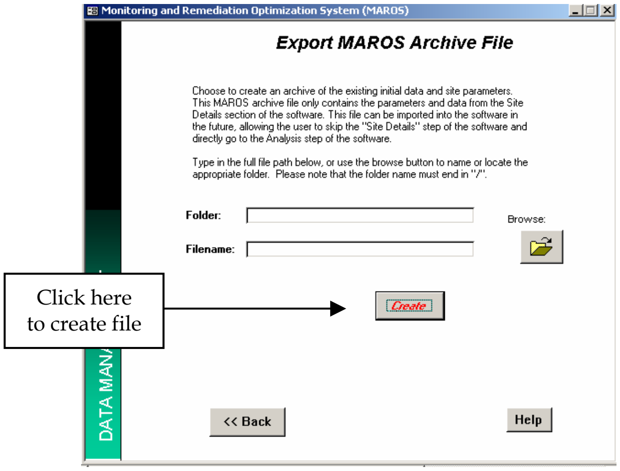
Click on “Continue to Step 3” to proceed to Trend Analysis to analyze the plume behavior. The *Main Menu* screen will be displayed.



Site Details Complete

Your data has been imported, the wells have been divided into source and tail zones, and the contaminants of concern have been selected. You may now proceed to Trend Analysis to analyze the plume behavior. If you would like to archive the Site Details you can do so at this point by choosing the button "Create MAROS Archive File". This MAROS archive file contains the parameters and data from the Site Details section of the software.

Note: This screen provides the option to create an archive file of the site details which have been entered. The archive file contains all imported data and Site Details entered to this point. Creation of an archive file is strongly suggested, as the archive file can be re-imported for further data analysis without having to re-enter site details.



Export MAROS Archive File

Choose to create an archive of the existing initial data and site parameters. This MAROS archive file only contains the parameters and data from the Site Details section of the software. This file can be imported into the software in the future, allowing the user to skip the "Site Details" step of the software and directly go to the Analysis step of the software.

Type in the full file path below, or use the browse button to name or locate the appropriate folder. Please note that the folder name must end in "/".

Folder:

Filename:

Choose “Create MAROS Archive File”

Type in full path and file name or choose “Browse”.

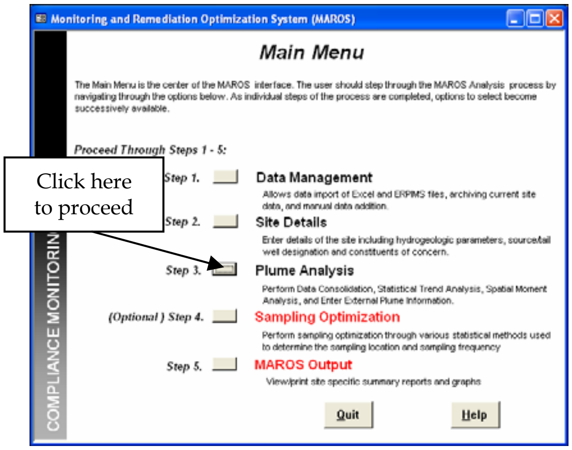
Click on “Create” to complete the archive file.

Choose “Back” to return to Site Details Complete window..

Plume Analysis

Step 3, Plume Analysis allows the user to perform data reduction as well as trend analysis through Statistical Plume Analysis, Spatial Moment Analysis, and External Plume Information. It also allows the user to apply final Analysis Consolidation to the trend results.

STEP 1: PLUME ANALYSIS



Main Menu

The Main Menu is the center of the MAROS interface. The user should step through the MAROS Analysis process by navigating through the options below. As individual steps of the process are completed, options to select become successively available.

Proceed Through Steps 1 - 5:

Step 1. ☐ **Data Management**
Allows data import of Excel and ERPIMS files, archiving current site data, and manual data addition.

Step 2. ☐ **Site Details**
Enter details of the site including hydrogeologic parameters, source/tail well designation and constituents of concern.

Step 3. ☐ **Plume Analysis**
Perform Data Consolidation, Statistical Trend Analysis, Spatial Moment Analysis, and Enter External Plume Information.

(Optional) Step 4. ☐ **Sampling Optimization**
Perform sampling optimization through various statistical methods used to determine the sampling location and sampling frequency

Step 5. ☐ **MAROS Output**
View/print site specific summary reports and graphs

Click here to proceed

Select “Plume Analysis” from the *Main Menu*.

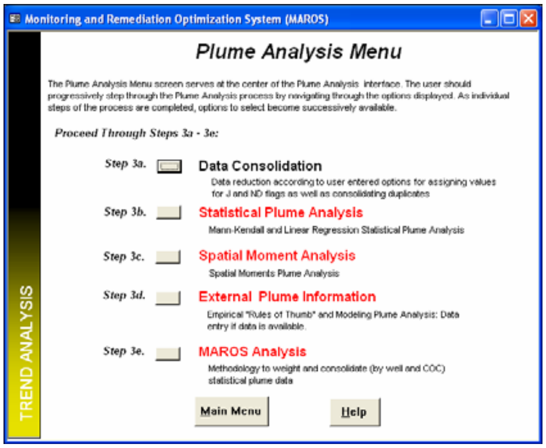
The *Plume Analysis Menu* will be displayed.

The *Plume Analysis Menu* screen serves at the center of the trend analysis user interface. The user progressively steps through the Long Term Monitoring Plume Analysis process by navigating through the options displayed. As individual steps of the process are completed, options to select become successively available.

The *Plume Analysis Menu* screen allows the user to choose between performing:

- Step 3a: Data Consolidation
- Step 3b: Statistical Plume Analysis
- Step 3c: Spatial Moment Analysis
- Step 3d: External Plume Information
- Step 3e: MAROS Analysis

Available choices are displayed in black text.



Plume Analysis Menu

The Plume Analysis Menu screen serves at the center of the Plume Analysis interface. The user should progressively step through the Plume Analysis process by navigating through the options displayed. As individual steps of the process are completed, options to select become successively available.

Proceed Through Steps 3a - 3e:

Step 3a. ☐ **Data Consolidation**
Data reduction according to user entered options for assigning values for J and ND flags as well as consolidating duplicates

Step 3b. ☐ **Statistical Plume Analysis**
Mann-Kendall and Linear Regression Statistical Plume Analysis

Step 3c. ☐ **Spatial Moment Analysis**
Spatial Moments Plume Analysis

Step 3d. ☐ **External Plume Information**
Empirical "Rules of Thumb" and Modeling Plume Analysis: Data entry if data is available.

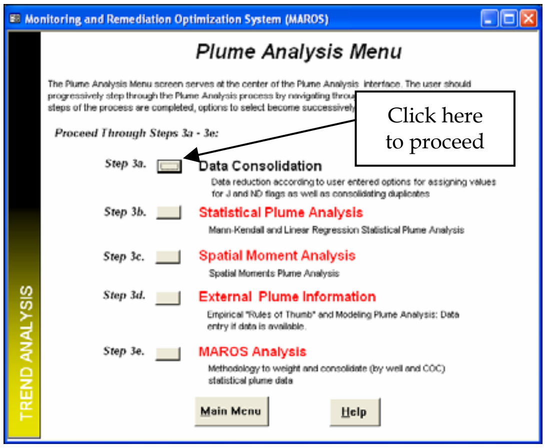
Step 3e. ☐ **MAROS Analysis**
Methodology to weight and consolidate (by well and COC) statistical plume data

STEP 2: DATA CONSOLIDATION

Data consolidation allows the reduction of data based on dates as well as consolidating duplicates based on statistical functions (i.e. average, median, etc.). This step also allows for assigning values to non-detects and J flag data.

1) From the *Plume Analysis Menu*, select the “Step 3a: Data Consolidation” option.

   The *Data Reduction: Part 1 of 2* menu will appear.



The Plume Analysis Menu screen serves at the center of the Plume Analysis interface. The user should progressively step through the Plume Analysis process by navigating throu steps of the process are completed, options to select become successively

Proceed Through Steps 3a - 3e:

Step 3a. Data Consolidation
Data reduction according to user entered options for assigning values for J and ND flags as well as consolidating duplicates

Step 3b. Statistical Plume Analysis
Mann-Kendall and Linear Regression Statistical Plume Analysis

Step 3c. Spatial Moment Analysis
Spatial Moments Plume Analysis

Step 3d. External Plume Information
Empirical "Rules of Thumb" and Modeling Plume Analysis: Data entry if data is available.

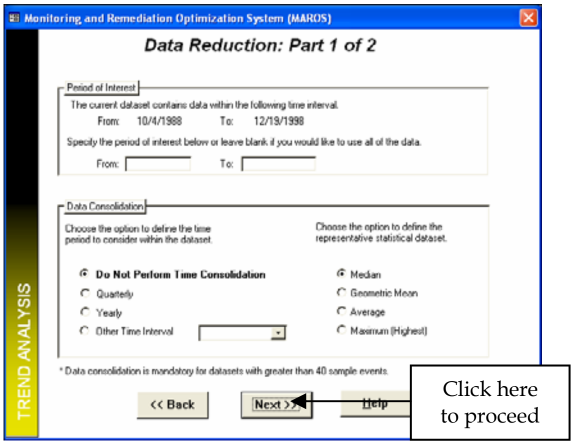
Step 3e. MAROS Analysis
Methodology to weight and consolidate (by well and COC) statistical plume data

2) The *Data Reduction*: *Part 1 of 2* menu allows the user to consolidate the data based on time intervals and parameters chosen.

   The “**Period of Interest**” option allows the user to specify which time frame will be considered. For example, if the User wishes to limit the analysis to data collected between 1/1/1988 and 12/30/1995, these dates should be entered here.

   The “**Data Consolidation**” option is used to define the time period to consolidate the dataset and to define the representative statistical dataset within the consolidated time interval. Data consolidation is highly recommended for datasets with greater than 40 wells or for datasets with a long history.

   For this tutorial, the full dataset will be used and no data consolidation will be performed. This is appropriate for the small size of the dataset.



The current dataset contains data within the following time interval.
From: 10/4/1988 To: 12/19/1998
Specify the period of interest below or leave blank if you would like to use all of the data.
From: ☐ To: ☐

Choose the option to define the time period to consider within the dataset.
● Do Not Perform Time Consolidation
○ Quarterly
○ Yearly
○ Other Time Interval

Choose the option to define the representative statistical dataset.
● Median
○ Geometric Mean
○ Average
○ Maximum (Highest)

* Data consolidation is mandatory for datasets with greater than 40 sample events.

Under the heading “Period of Interest” the two empty text boxes should be left blank. This means that the full dataset will be used.

Under the heading “Data Consolidation” the first option “Do Not Perform Time Consolidation” should remain selected.

Select “Next” to proceed to the *Data Reduction*: *Part 2 of 2* screen.

Note: If the user wishes to perform time consolidation, one of the options in the bottom right of the screen (median, average, etc) needs to be selected to define the representative statistical dataset within the consolidated time interval. If the user decides to consolidate the data yearly, for instance, the statistic chosen (e.g. average) will be the representative result for the year.

3) *Data Reduction*: *Part 2 of 2* allows the user to consolidate the data based on concentration parameters chosen.

The "**Non-Detect (ND)**" option allows the user to choose the number value to represent a non-detect result in the data. To apply a specific detection limit for each chemical choose "Uniform Detection Limit". The suggested detection limit is the minimum detection limit.

The **"Duplicates"** option is used to consolidate duplicates. Note that duplicates are samples that have the same constituent, date, and well name. Samples with the same "effective date" will be consolidated as duplicates.

The "**Trace (TR)**" option is used to specify the number value which will be used to represent a Trace result in the data. (The "TR" flag is equivalent to the "J" flag used by most labs, to indicate a result that is reported but is below the method detection limit).

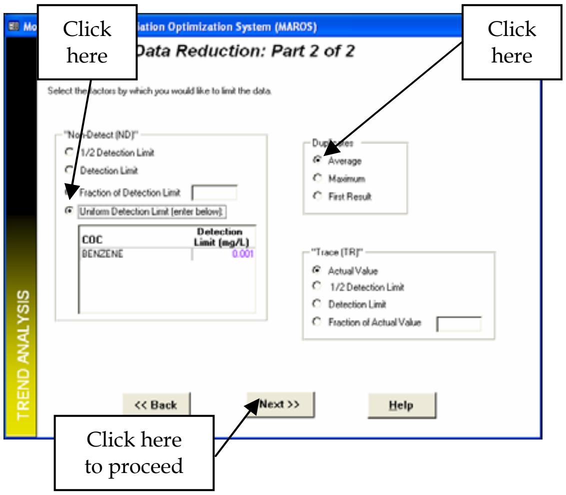
This particular tutorial will use a uniform detection limit of 0.001 mg/L to represent non-detect results, duplicates will be consolidated using the average value and trace results will be analyzed based on the actual value. The following steps outline how this is implemented:

Under the heading "Non-Detect (ND)", click in the middle of the circle next to the option "Uniform Detection Limit".

Under the heading "Duplicates" click in the middle of the circle next to the option "Average".

Under the heading "Trace" click in the middle of the circle next to the option "Actual Value".

Select "Next" to proceed. The *Reduced Data Table* will be displayed.



Data Reduction: Part 2 of 2

Select the factors by which you would like to limit the data.

"Non-Detect (ND)"
○ 1/2 Detection Limit
○ Detection Limit
○ Fraction of Detection Limit
● Uniform Detection Limit (enter below):

COC	Detection Limit (mg/L)
BENZENE	0.001

Duplicates
● Average
○ Maximum
○ First Result

"Trace (TR)"
● Actual Value
○ 1/2 Detection Limit
○ Detection Limit
○ Fraction of Actual Value

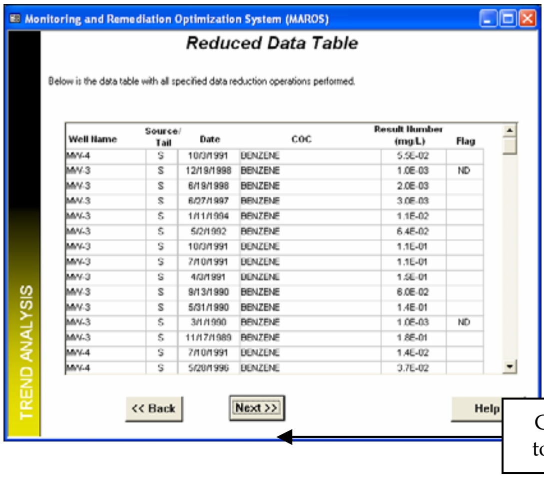
Click here

Click here

Click here to proceed

Note: Typically when applying statistics, half the detection limit could be used. However where there the detection varies historically, then setting a uniform detection limit will reduce the possibility of false trends.

4) The *Reduced Data Table* allows the user to view the reduced data table with the COCs chosen as well as the data consolidation performed.



Reduced Data Table

Below is the data table with all specified data reduction operations performed.

Well Name	Source/ Tail	Date	COC	Result Number (mg/L)	Flag
MW-4	S	10/3/1991	BENZENE	5.5E-02	
MW-3	S	12/19/1998	BENZENE	1.0E-03	ND
MW-3	S	6/19/1998	BENZENE	2.0E-03	
MW-3	S	6/27/1997	BENZENE	3.0E-03	
MW-3	S	1/11/1994	BENZENE	1.1E-02	
MW-3	S	5/2/1992	BENZENE	6.4E-02	
MW-3	S	10/3/1991	BENZENE	1.1E-01	
MW-3	S	7/10/1991	BENZENE	1.1E-01	
MW-3	S	4/3/1991	BENZENE	1.5E-01	
MW-3	S	9/13/1990	BENZENE	6.0E-02	
MW-3	S	5/31/1990	BENZENE	1.4E-01	
MW-3	S	3/1/1990	BENZENE	1.0E-03	ND
MW-3	S	11/17/1989	BENZENE	1.8E-01	
MW-4	S	7/10/1991	BENZENE	1.4E-02	
MW-4	S	5/20/1996	BENZENE	3.7E-02	

Click here to proceed

This table is not available for editing.

Select "Next" to proceed to the *Reduced Data Plot* screen.

5) The *Reduced Data Plot* screen allows the user to view the reduced data in graphical form.

To display data for MW-1:

Click the down arrow in the first text box ("Well"), to display the options, and select MW-1.

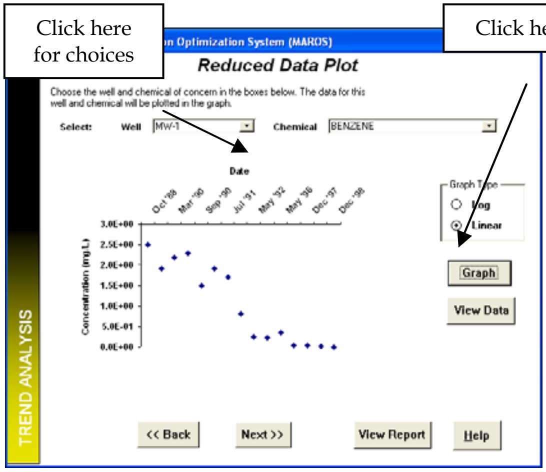
Click the down arrow in the second text box ("Chemical"), to display the options, and select benzene.

Under the heading "Graph Type" click on the circle next to "Linear".

Select the "Graph" button to display the graph for MW-1.

Click here for choices

Click here

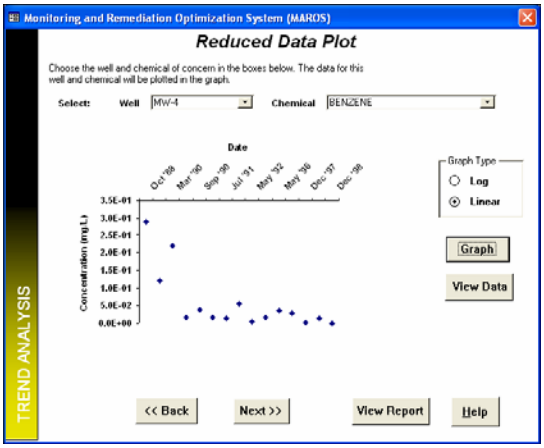


Reduced Data Plot

Choose the well and chemical of concern in the boxes below. The data for this well and chemical will be plotted in the graph.

Select: Well MW-1 Chemical BENZENE

Graph Type
○ Log
● Linear



Reduced Data Plot

Choose the well and chemical of concern in the boxes below. The data for this well and chemical will be plotted in the graph.

Select: Well MW-4 Chemical BENZENE

Graph Type
○ Log
● Linear

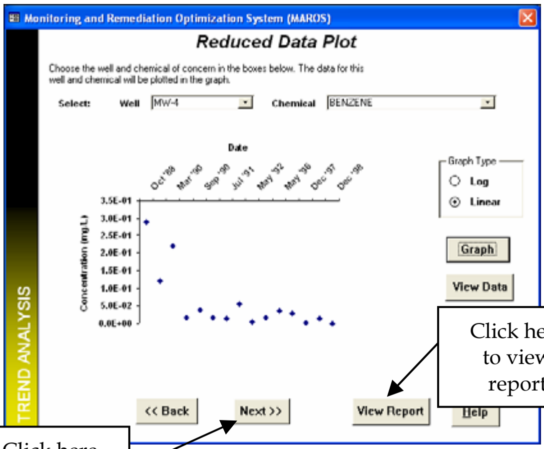
To view data for a well "MW-4", click the down arrow in the first text box ("Well"), where "MW-1" is displayed. A list of choices will appear. Click on "MW-4" to select well MW-4.

Select the "Graph" button to display the graph for MW-4.

A graph of benzene concentrations for well MW-4 is displayed.

Note: If more than one COC was being used data for other chemicals can be displayed by clicking on the down arrow of the second text box ("Chemical"). The graph type can be changed from Linear to Logarithmic by selecting the “Log” option under “Graph Type”. After any change, click the “Graph” button to display the graph.

6) Use the *View Report* option to print the current graph and data.



Reduced Data Plot

Choose the well and chemical of concern in the boxes below. The data for this well and chemical will be plotted in the graph.

Select: Well MW-4 Chemical BENZENE

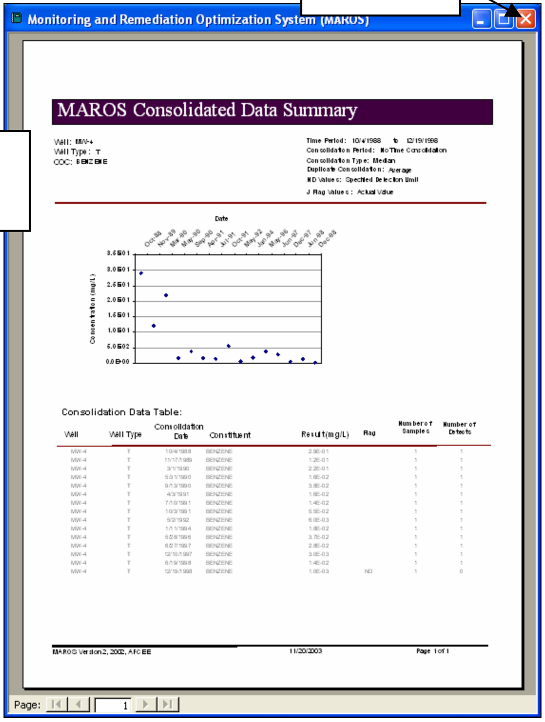
Graph Type ○ Log ● Linear

Click here to proceed

Click here to view report

Click “View Report” to proceed.

Click here to close



MAROS Consolidated Data Summary

Well: MW-4
Well Type: T
COC: BENZENE

Time Period: 10/4/1988 to 12/19/1998
Consolidation Period: No Time Consolidation
Consolidation Type: Median
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values: Actual Value

Consolidation Data Table:

Well	Well Type	Consolidation Date	Constituent	Result(mg/L)	Flag	Number of Samples	Number of Detects
MW-4	T	10/4/1988	BENZENE	2.9E-01		1	1
MW-4	T	11/17/1989	BENZENE	1.2E-01		1	1
MW-4	T	3/1/1990	BENZENE	2.2E-01		1	1
MW-4	T	5/31/1990	BENZENE	1.6E-02		1	1
MW-4	T	9/13/1990	BENZENE	3.8E-02		1	1
MW-4	T	4/3/1991	BENZENE	1.6E-02		1	1
MW-4	T	7/10/1991	BENZENE	1.4E-02		1	1
MW-4	T	10/3/1991	BENZENE	5.5E-02		1	1
MW-4	T	5/2/1992	BENZENE	6.0E-03		1	1
MW-4	T	1/11/1994	BENZENE	1.8E-02		1	1
MW-4	T	5/28/1996	BENZENE	3.7E-02		1	1
MW-4	T	6/27/1997	BENZENE	2.8E-02		1	1
MW-4	T	12/10/1997	BENZENE	3.0E-03		1	1
MW-4	T	6/19/1998	BENZENE	1.4E-02		1	1
MW-4	T	12/19/1998	BENZENE	1.0E-03	ND	1	0

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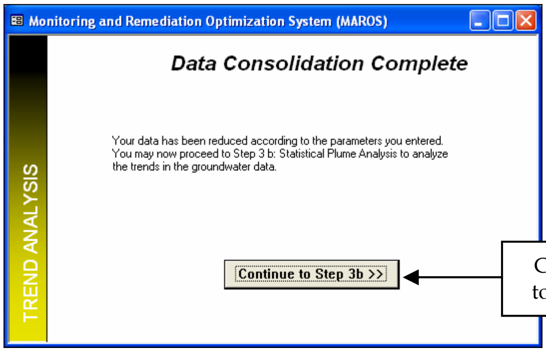
The report displays the data in graphical and tabular format. This report can also be printed.

Close the report by clicking on the red button in the top right hand corner of the screen. The *Reduced Data Plot* screen will return.

Select the “Next” button to proceed. The *Data Reduction Complete* screen will appear.

7) The *Data Reduction Complete* screen indicates that the data has been reduced according to the parameters entered. The user may now proceed to the Statistical Plume Analysis and analyze the trends in the groundwater data.



Data Consolidation Complete

Your data has been reduced according to the parameters you entered. You may now proceed to Step 3 b: Statistical Plume Analysis to analyze the trends in the groundwater data.

Click here to proceed

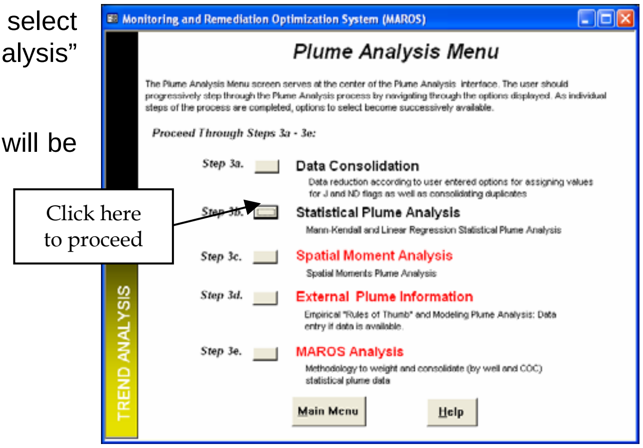
Select the “Trends Analysis” button to return to the *Main Menu*.

STEP 3: STATISTICAL PLUME ANALYSIS

The Statistical Plume Analysis option allows the user to perform Mann-Kendall Analysis and Linear Regression Analysis.

1) From the *Plume Analysis Menu*, select the “Step 3b: Statistical Plume Analysis” option.

   The *Mann-Kendall Statistics* menu will be displayed.



Plume Analysis Menu

The Plume Analysis Menu screen serves at the center of the Plume Analysis interface. The user should progressively step through the Plume Analysis process by navigating through the options displayed. As individual steps of the process are completed, options to select become successively available.

Proceed Through Steps 3a - 3e:

Step 3a. Data Consolidation
Data reduction according to user entered options for assigning values for J and ND flags as well as consolidating duplicates

Step 3b. Statistical Plume Analysis
Mann-Kendall and Linear Regression Statistical Plume Analysis

Step 3c. Spatial Moment Analysis
Spatial Moments Plume Analysis

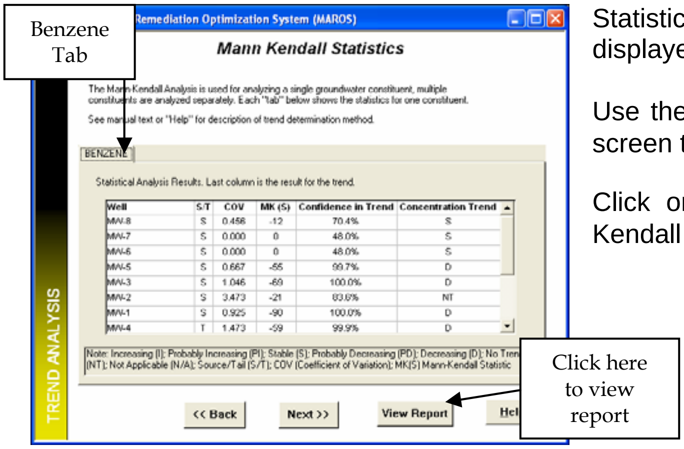
Step 3d. External Plume Information
Empirical "Rules of Thumb" and Modeling Plume Analysis: Data entry if data is available.

Step 3e. MAROS Analysis
Methodology to weight and consolidate (by well and COC) statistical plume data

2) The *Mann-Kendall Statistics* screen is used to view the Mann-Kendall Trend Analysis results by well and constituent. Statistical analysis results displayed include:

   - The **Coefficient of Variation** “COV” - a statistical measure of how the individual data points vary about the mean value.
   - The **Mann-Kendall Statistic** “MK (S)” measures the trend in the data.
   - The “**Confidence in Trend**” is the statistical confidence that the constituent concentration is increasing (S>0) or decreasing (S<0).
   - The “**Concentration Trend**” for each well - Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

   Further details on this methodology are provided on Page 32 and Appendix A.2 of the User Manual.



Mann Kendall Statistics

The Mann-Kendall Analysis is used for analyzing a single groundwater constituent, multiple constituents are analyzed separately. Each "tab" below shows the statistics for one constituent.

See manual text or "Help" for description of trend determination method.

Statistical Analysis Results. Last column is the result for the trend.

Well	S/T	COV	MK (S)	Confidence in Trend	Concentration Trend
MW-8	S	0.456	-12	70.4%	S
MW-7	S	0.000	0	48.0%	S
MW-6	S	0.000	0	48.0%	S
MW-5	S	0.667	-55	99.7%	D
MW-3	S	1.046	-69	100.0%	D
MW-2	S	3.473	-21	83.6%	NT
MW-1	S	0.925	-90	100.0%	D
MW-4	T	1.473	-59	99.9%	D

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Tren
(NT); Not Applicable (N/A); Source/Tail (S/T); COV (Coefficient of Variation); MK(S) Mann-Kendall Statistic

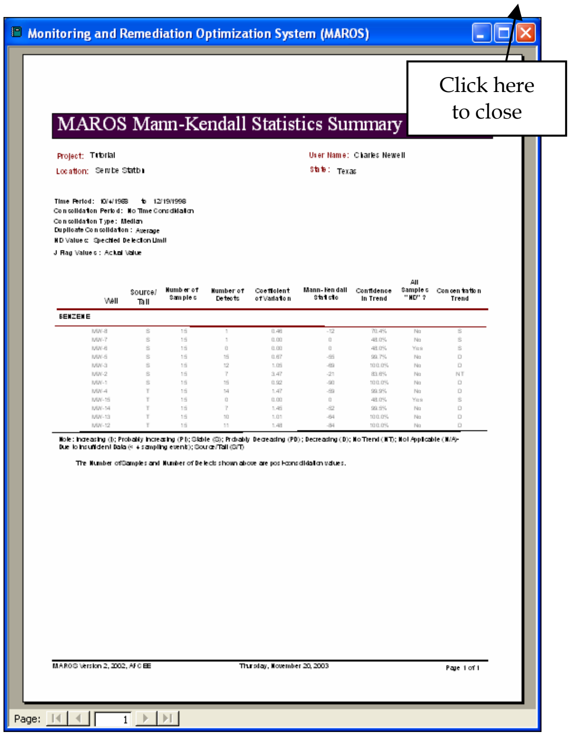
Statistical analysis for the benzene data is displayed.

Use the scroll-down arrow on the right of the screen to view results for wells not displayed.

Click on “View Report” to print the “Mann-Kendall Statistics Report”.

Note: If more than one COC was being used, the user would navigate the results for individual constituents by clicking on the tabs at the top of the screen.

The “Mann-Kendall Statistics Report” displays consolidated data and results of the Mann Kendall analysis. This report can also be printed or printed to the Adobe Acrobat application in electronic pdf file format.



MAROS Mann-Kendall Statistics Summary

Project: Tutorial
Location: Service Station
User Name: Charles Newell
State: Texas

Time Period: 10/4/1988 to 12/19/1998
Consolidation Period: No Time Consolidation
Consolidation Type: Median
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values: Actual Value

Well	Source/ Tail	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples "ND" ?	Concentration Trend
BENZENE								
MW-8	S	15	1	0.46	-12	70.4%	No	S
MW-7	S	15	1	0.00	0	48.0%	No	S
MW-6	S	15	0	0.00	0	48.0%	Yes	S
MW-5	S	15	15	0.67	-55	99.7%	No	D
MW-3	S	15	12	1.05	-69	100.0%	No	D
MW-2	S	15	7	3.47	-21	83.6%	No	NT
MW-1	S	15	15	0.92	-90	100.0%	No	D
MW-4	T	15	14	1.47	-59	99.9%	No	D
MW-15	T	15	0	0.00	0	48.0%	Yes	S
MW-14	T	15	7	1.45	-62	99.9%	No	D
MW-13	T	15	10	1.01	-84	100.0%	No	D
MW-12	T	15	11	1.48	-84	100.0%	No	D

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A)-Due to insufficient Data (< 4 sampling events); Source/Tail (S/T)

The Number of Samples and Number of Detects shown above are post-consolidation values.

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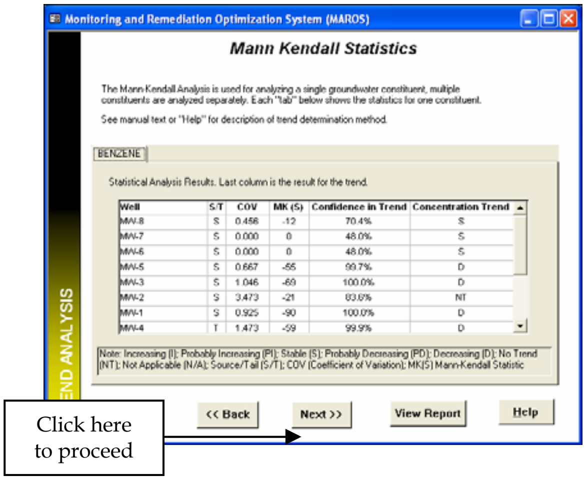
Page: 1

Close the report by clicking on the close button in the top right hand corner of the screen. The *Mann-Kendall Statistics* screen will return.



Mann Kendall Statistics

The Mann-Kendall Analysis is used for analyzing a single groundwater constituent, multiple constituents are analyzed separately. Each "tab" below shows the statistics for one constituent.

See manual text or "Help" for description of trend determination method.

Statistical Analysis Results. Last column is the result for the trend.

Well	S/T	COV	MK (S)	Confidence in Trend	Concentration Trend
MW-8	S	0.456	-12	70.4%	S
MW-7	S	0.000	0	48.0%	S
MW-6	S	0.000	0	48.0%	S
MW-5	S	0.667	-55	99.7%	D
MW-3	S	1.046	-69	100.0%	D
MW-2	S	3.473	-21	83.6%	NT
MW-1	S	0.925	-90	100.0%	D
MW-4	T	1.473	-59	99.9%	D

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T); COV (Coefficient of Variation); MK(S) Mann-Kendall Statistic

Select the “Next” button on the *Mann-Kendall Statistics* to proceed.

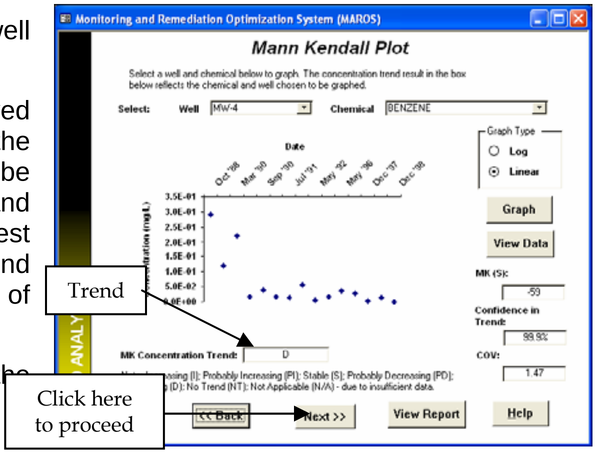
The *Mann-Kendall Plot* screen will appear.

3) The *Mann Kendall Plot* screen allows the user to view the Mann-Kendall Trend Analysis results by well and constituent.

Graph of benzene concentrations for well MW-4 is displayed.

The Mann Kendall statistics are displayed for this well. For example, the Concentration Trend is shown to be decreasing “D” in the box in the left hand bottom corner. The Mann-Kendall test statistic (S), the confidence in the trend and COV are also shown to the right of the window.

Select the “Next” button to continue to the *Linear Regression Statistics* screen.



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-4 Chemical BENZENE

Graph Type
○ Log
● Linear

MK (S): -59

Confidence in Trend: 99.9%

COV: 1.47

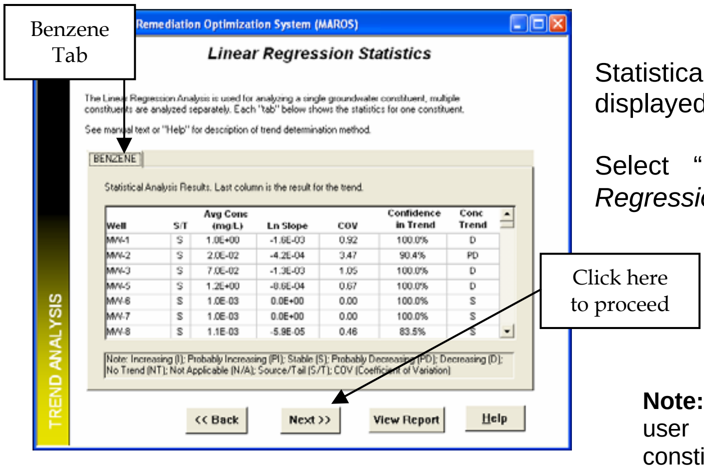
MK Concentration Trend: D

asing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD);
(D); No Trend (NT); Not Applicable (N/A) - due to insufficient data.

Note: As discussed above, plots of other wells and chemicals can be obtained using the Well or Chemical drop down boxes in the top of the screen, followed by selecting the “Graph” button. The graph type can be specified as Log or Linear. The graph can be printed by selecting the “View Report” button.

4) *Linear Regression Statistics* allows the user to view the Linear Regression Analysis results by well and constituent. The Linear Regression analysis is another statistical method with similar output as the Mann-Kendall method. Statistical analysis results displayed include:

- The **Coefficient of Variation** “COV” - a statistical measure of how the individual data points vary about the mean value.
- “**Slope**” - the slope of the least square fit through the given data indicates the trend in the data.
- The “**Confidence in Trend**” is the statistical confidence that the constituent concentration is increasing (S>0) or decreasing (S<0).
- The “**Concentration Trend**” for each well - Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).



Linear Regression Statistics

The Linear Regression Analysis is used for analyzing a single groundwater constituent, multiple constituents are analyzed separately. Each "tab" below shows the statistics for one constituent.

See manual text or "Help" for description of trend determination method.

Statistical Analysis Results. Last column is the result for the trend.

Well	S/T	Avg Conc (mg/L)	Ln Slope	COV	Confidence in Trend	Conc Trend
MW-1	S	1.0E+00	-1.6E-03	0.92	100.0%	D
MW-2	S	2.0E-02	-4.2E-04	3.47	90.4%	PD
MW-3	S	7.0E-02	-1.3E-03	1.05	100.0%	D
MW-5	S	1.2E+00	-8.6E-04	0.67	100.0%	D
MW-6	S	1.0E-03	0.0E+00	0.00	100.0%	S
MW-7	S	1.0E-03	0.0E+00	0.00	100.0%	S
MW-8	S	1.1E-03	-5.9E-05	0.46	83.5%	S

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T); COV (Coefficient of Variation)

Statistical analysis for the benzene data is displayed.

Select “Next” to proceed to the *Linear Regression Plot* screen.

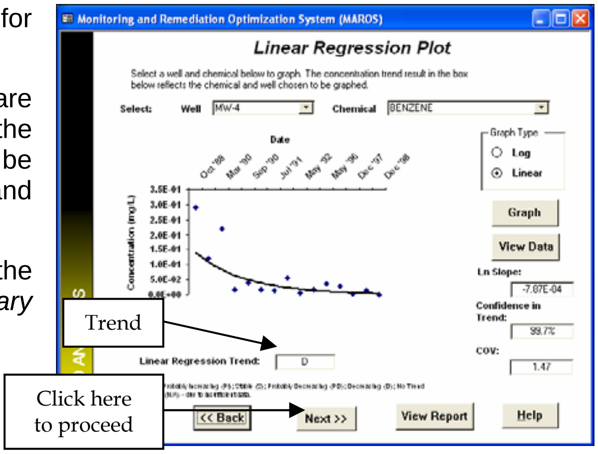
Note: If more than one COC is being used, the user will navigate the results for individual constituents by clicking on the tabs at the top of the screen. The information displayed can also be viewed in report form, “Linear Regression Statistics Report” from the *MAROS Output* Screen.

5) *Linear Regression Plot* allows the user to view the linear regression data in graphical form.

A graph of benzene concentrations for well MW-4 is displayed.

The Linear Regression statistics are displayed for this well. For example, the Linear Regression Trend is shown to be decreasing “D” in the box in the left hand bottom corner.

Select the “Next” button to continue to the *Trend Analysis Statistics Summary* screen.



Linear Regression 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-4 Chemical BENZENE

Ln Slope: -7.87E-04

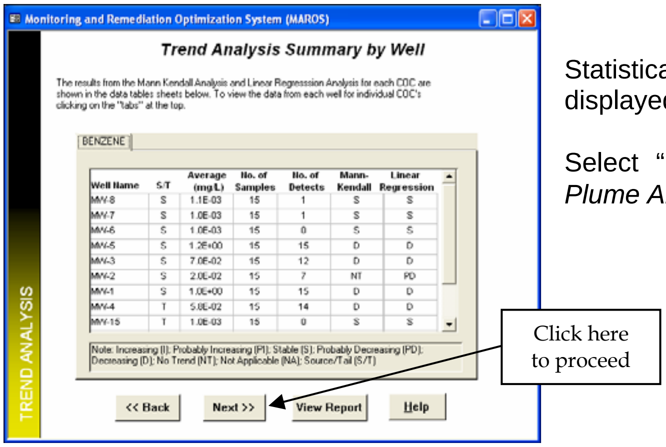
Confidence in Trend: 99.7%

COV: 1.47

Linear Regression Trend: D

Note: As discussed previously, plots of other wells and chemicals can be obtained using the Well or Chemical drop down boxes in the top of the screen, followed by selecting the “Graph” button. The graph type can be specified as Log or Linear. The graph can be printed by selecting the “View Report” button.

6) *Trend Analysis Statistics Summary by Well* allows the user to view the Mann-Kendall Trend Analysis and Linear Regression Analysis results by well and constituent.



Trend Analysis Summary by Well

The results from the Mann Kendall Analysis and Linear Regresssion Analysis for each COC are shown in the data tables sheets below. To view the data from each well for individual COC's clicking on the "tabs" at the top.

Well Name	S/T	Average (mg/L)	No. of Samples	No. of Detects	Mann-Kendall	Linear Regression
MW-8	S	1.1E-03	15	1	S	S
MW-7	S	1.0E-03	15	1	S	S
MW-6	S	1.0E-03	15	0	S	S
MW-5	S	1.2E+00	15	15	D	D
MW-3	S	7.0E-02	15	12	D	D
MW-2	S	2.0E-02	15	7	NT	PD
MW-1	S	1.0E+00	15	15	D	D
MW-4	T	5.8E-02	15	14	D	D
MW-15	T	1.0E-03	15	0	S	S

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (NA); Source/Tail (S/T)

Click here to proceed

Statistical analysis for the benzene data is displayed.

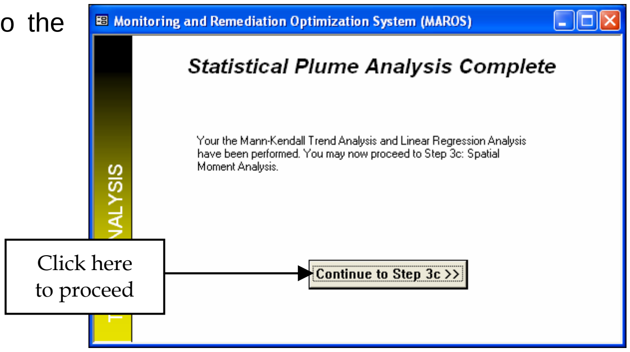
Select "Next" to proceed to the *Statistical Plume Analysis Complete* screen.

Note: If more than one COC is being used, the user will navigate the results for individual constituents by clicking on the tabs at the top of the screen.

The information displayed in this screen can also be viewed in report form, "Statistical Plume Analysis Summary Report" from the *MAROS Output* Screen or by clicking on "View Report". In this particular example, the Mann-Kendall results are the same as the Linear Regression results for all wells.

7) The *Statistical Plume Analysis Complete* screen indicates that the Mann-Kendall Trend Analysis and Linear Regression Analysis have been performed. The next stage will be Spatial Moment Analysis.

Select "Plume Analysis" to return to the *Plume Analysis Menu*.



Statistical Plume Analysis Complete

Your the Mann-Kendall Trend Analysis and Linear Regression Analysis have been performed. You may now proceed to Step 3c: Spatial Moment Analysis.

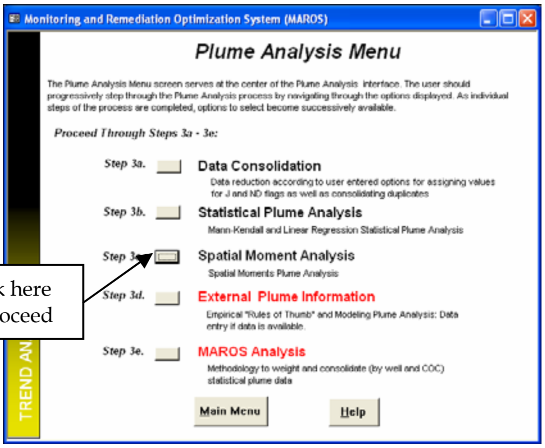
Click here to proceed

STEP 4: SPATIAL MOMENT ANALYSIS

The Spatial Moment Analysis option is used to perform Moment Analysis (Zero, First, and Second Moments calculated).

1) From the *Plume Analysis Menu*, select the “Step 3c: Spatial Moment Analysis” option.

   The *Moment Analysis Site Details* screen will be displayed.



Plume Analysis Menu

The Plume Analysis Menu screen serves at the center of the Plume Analysis interface. The user should progressively step through the Plume Analysis process by navigating through the options displayed. As individual steps of the process are completed, options to select become successively available.

Proceed Through Steps 3a - 3e:

Step 3a. **Data Consolidation**
Data reduction according to user entered options for assigning values for J and ND flags as well as consolidating duplicates

Step 3b. **Statistical Plume Analysis**
Mann-Kendall and Linear Regression Statistical Plume Analysis

Step 3c. **Spatial Moment Analysis**
Spatial Moments Plume Analysis

Step 3d. **External Plume Information**
Empirical "Rules of Thumb" and Modeling Plume Analysis: Data entry if data is available.

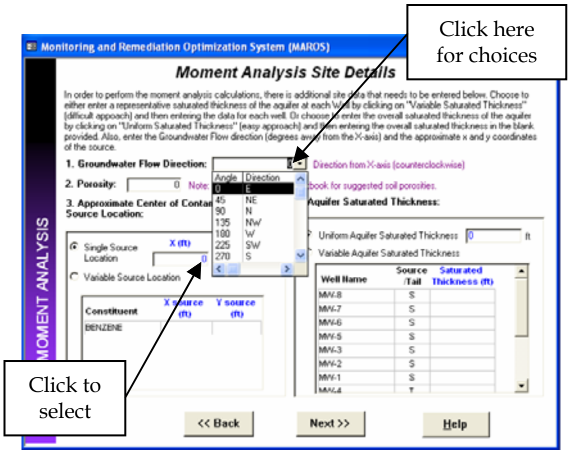
Step 3e. **MAROS Analysis**
Methodology to weight and consolidate (by well and COC) statistical plume data

Click here to proceed

2) *Moment Analysis Site Details* allows the user to enter the additional site data required in the Moment Analysis. Data required includes porosity, groundwater flow direction, approximate contaminant source location, and aquifer saturated thickness.

   The following parameters are to be entered for this tutorial:

   - Groundwater flow direction: Southeast (shown on Figure A.11.1) enter 315 degrees as groundwater flow direction is defined in degrees from the x-axis in a counter clockwise direction.
   - Porosity: 30% (enter as 0.3).
   - Source Location: X = -1 and Y = -1 (i.e. at the edge of Tank Field, near MW-1– see Figure A.11.1)
   - Uniform Saturated Aquifer, 12 ft thick



Moment Analysis Site Details

In order to perform the moment analysis calculations, there is additional site data that needs to be entered below. Choose to either enter a representative saturated thickness of the aquifer at each Well by clicking on "Variable Saturated Thickness" (difficult appoach) and then entering the data for each well. Or choose to enter the overall saturated thickness of the aquifer by clicking on "Uniform Saturated Thickness" (easy approach) and then entering the overall saturated thickness in the blank provided. Also, enter the Groundwater Flow direction (degrees away from the X-axis) and the approximate x and y coordinates of the source.

1. Groundwater Flow Direction: Direction from X-axis (counterclockwise)

Angle	Direction
0	E
45	NE
90	N
135	NW
180	W
225	SW
270	S

2. Porosity: 0 Note: …book for suggested soil porosities.

3. Approximate Center of Conta… Source Location:

● Single Source Location X (ft) 0
○ Variable Source Location

Constituent	X source (ft)	Y source (ft)
BENZENE		

Aquifer Saturated Thickness:

○ Uniform Aquifer Saturated Thickness 0 ft
○ Variable Aquifer Saturated Thickness

Well Name	Source /Tail	Saturated Thickness (ft)
MW-8	S	
MW-7	S	
MW-6	S	
MW-5	S	
MW-3	S	
MW-2	S	
MW-1	S	
MW-4	T	

Click here for choices

Click to select

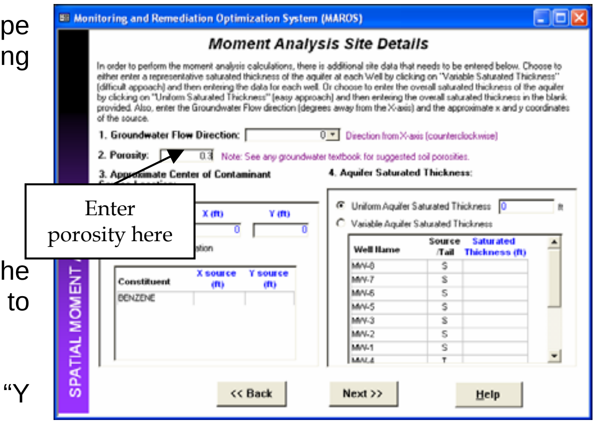
To enter the groundwater flow direction, click on the down arrow in the first text box under “Groundwater Flow Direction”.

A list of choices will appear. Use the scroll bar to see all the choices. Click “315 - E” to select.

To enter the porosity value 30%, type “0.3” in the text box next to the heading “Porosity”.

Enter the x and y coordinates of the source in using the text boxes adjacent to “Single Source Location”.

In the “X (ft)” box type “-1” and in the “Y (ft)” box type “-1”.



Moment Analysis Site Details

In order to perform the moment analysis calculations, there is additional site data that needs to be entered below. Choose to either enter a representative saturated thickness of the aquifer at each Well by clicking on "Variable Saturated Thickness" (difficult appoach) and then entering the data for each well. Or choose to enter the overall saturated thickness of the aquifer by clicking on "Uniform Saturated Thickness" (easy approach) and then entering the overall saturated thickness in the blank provided. Also, enter the Groundwater Flow direction (degrees away from the X-axis) and the approximate x and y coordinates of the source.

1. Groundwater Flow Direction: 0 Direction from X-axis (counterclockwise)

2. Porosity: 0.3 Note: See any groundwater textbook for suggested soil porosities.

3. Approximate Center of Contaminant

X (ft): 0 Y (ft): 0

Constituent	X source (ft)	Y source (ft)
BENZENE		

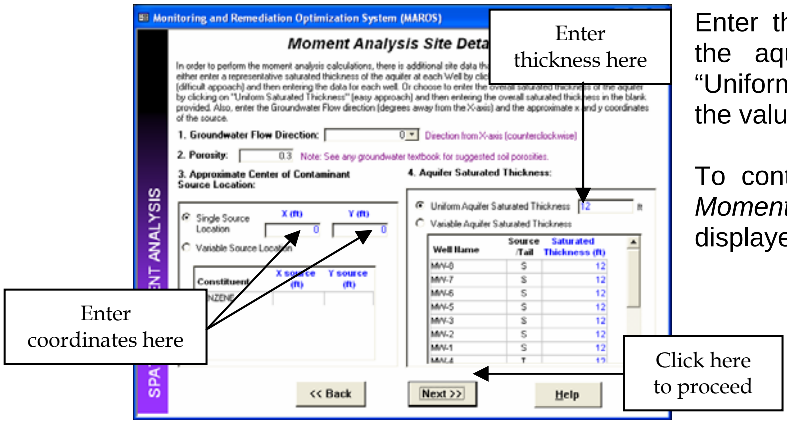
4. Aquifer Saturated Thickness:

● Uniform Aquifer Saturated Thickness 0 ft

○ Variable Aquifer Saturated Thickness

Well Name	Source /Tail	Saturated Thickness (ft)
MW-8	S	
MW-7	S	
MW-6	S	
MW-5	S	
MW-3	S	
MW-2	S	
MW-1	S	
MW-4	T	

Enter porosity here



Moment Analysis Site Details

In order to perform the moment analysis calculations, there is additional site data that needs to be entered below. Choose to either enter a representative saturated thickness of the aquifer at each Well by clicking on "Variable Saturated Thickness" (difficult appoach) and then entering the data for each well. Or choose to enter the overall saturated thickness of the aquifer by clicking on "Uniform Saturated Thickness" (easy approach) and then entering the overall saturated thickness in the blank provided. Also, enter the Groundwater Flow direction (degrees away from the X-axis) and the approximate x and y coordinates of the source.

1. Groundwater Flow Direction: 0 Direction from X-axis (counterclockwise)

2. Porosity: 0.3 Note: See any groundwater textbook for suggested soil porosities.

3. Approximate Center of Contaminant Source Location:

● Single Source Location X (ft): 0 Y (ft): 0

○ Variable Source Location

Constituent	X source (ft)	Y source (ft)
BENZENE		

4. Aquifer Saturated Thickness:

● Uniform Aquifer Saturated Thickness 12 ft

○ Variable Aquifer Saturated Thickness

Well Name	Source /Tail	Saturated Thickness (ft)
MW-8	S	12
MW-7	S	12
MW-6	S	12
MW-5	S	12
MW-3	S	12
MW-2	S	12
MW-1	S	12
MW-4	T	12

Enter thickness here

Enter coordinates here

Click here to proceed

Enter the overall saturated thickness of the aquifer in the text box next to “Uniform Saturated Thickness”. Type in the value “12”.

To continue, select “Next”. The *Spatial Moment Analysis Results* screen will be displayed.

Note: Where the thickness of the saturated aquifer varies according to well location, representative saturated thickness of the aquifer at each well can be entered by clicking on “Variable Saturated Thickness” and then entering the data for each well.

3) *Moment Analysis Statistics* allows the user to view the Spatial Moment Analysis results by well and constituent.

The **zeroth moment** is a total plume mass estimate for each sample event and COC. The mass result for each date will indicate the change in total estimated mass of the plume over time.

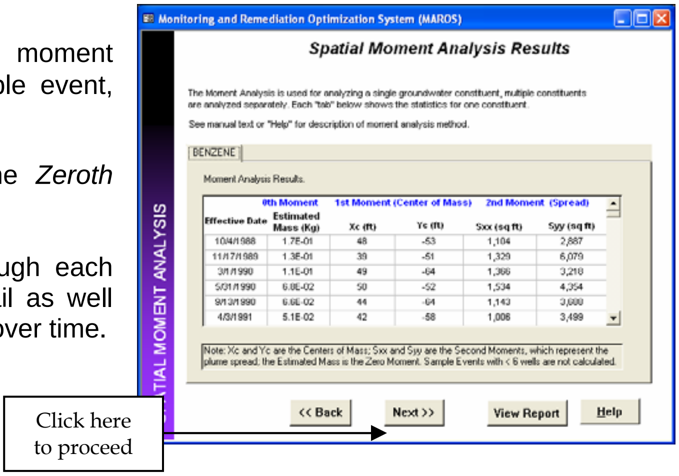
The **first moment** estimates the center of mass of the plume coordinates (Xc and Yc) for each sample event and COC. The center of mass locations indicate the movement of the center of mass over time.

The **second moment** indicates the spread of the contaminant about the center of mass (Sxx and Syy), or the distance of contamination from the center of mass. The Second Moment represents the spread of the plume over time.

Displayed are the spatial moment analysis results for each sample event, for the constituent benzene.

Click “Next” to proceed to the *Zeroth Moment Plot* screen.

The next screens will go through each moment analysis result in detail as well as looking at trends in the data over time.



Monitoring and Remediation Optimization System (MAROS)

Spatial Moment Analysis Results

The Moment Analysis is used for analyzing a single groundwater constituent, multiple constituents are analyzed separately. Each "tab" below shows the statistics for one constituent.

See manual text or "Help" for description of moment analysis method.

BENZENE

Moment Analysis Results.

	0th Moment	1st Moment (Center of Mass)		2nd Moment (Spread)	
Effective Date	Estimated Mass (Kg)	Xc (ft)	Yc (ft)	Sxx (sq ft)	Syy (sq ft)
10/4/1988	1.7E-01	48	-53	1,104	2,887
11/17/1989	1.3E-01	39	-51	1,329	6,079
3/1/1990	1.1E-01	49	-64	1,366	3,218
5/31/1990	6.8E-02	50	-52	1,534	4,354
9/13/1990	6.6E-02	44	-64	1,143	3,600
4/3/1991	5.1E-02	42	-58	1,008	3,499

Note: Xc and Yc are the Centers of Mass; Sxx and Syy are the Second Moments, which represent the plume spread; the Estimated Mass is the Zero Moment. Sample Events with < 6 wells are not calculated.

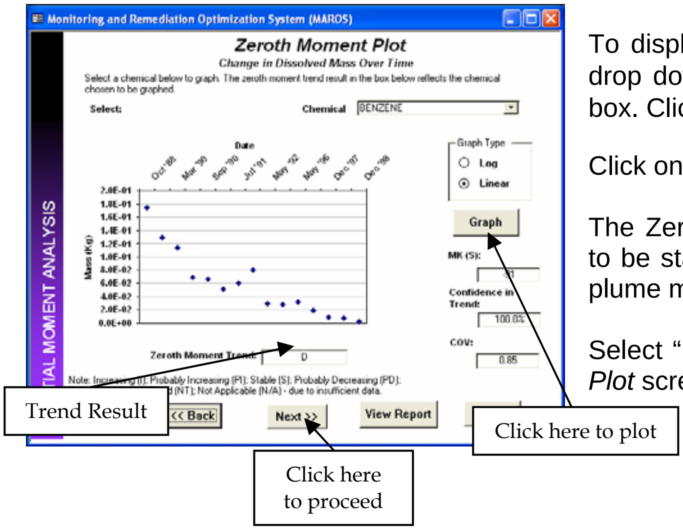
Click here to proceed

Note: If more than one COC is being used, the user will navigate the results for individual constituents by clicking on the tabs at the top of the screen. The results can be printed by selecting the “View Report” button.

4) *Zeroth Moment Plot* allows the user to view the Zeroth Moment Analysis results by constituent over time. The zeroth moment is a total plume mass estimate for each sample event and COC.

The **Zeroth Moment** trend over time is determined by applying the Mann-Kendall Trend Methodology to the mass estimates. The “Zeroth Moment” Trend for each COC is determined according to the rules outlined in Appendix A.2. Results for the trend include: Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

Other statistics displayed include the Mann-Kendall Statistic (S), the Confidence in Trend and the Coefficient of Variation (COV). Refer to Appendix A.2 and A.5 for further details.



Zeroth Moment Plot

Change in Dissolved Mass Over Time

Select a chemical below to graph. The zeroth moment trend result in the box below reflects the chemical chosen to be graphed.

Select: Chemical: BENZENE

MK (S): -91

Confidence in Trend: 100.0%

COV: 0.85

Zeroth Moment Trend: D

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); d (NT); Not Applicable (N/A) - due to insufficient data.

To display results for benzene, click on the drop down arrow next to the "Chemical" text box. Click on "benzene" to select.

Click on "graph" to plot the data.

The Zero Moment Trend over time is shown to be stable "D". This indicates the dissolved plume mass is decreasing over time

Select "Next" to proceed to the *First Moment Plot* screen.

Note: If more than one COC is being used, plots of other chemicals can be obtained using the "Chemical" drop down box at the top of the screen, followed by selecting the "Graph" button. The graph type can be specified as Log or Linear. The graph can be printed by selecting the "View Report" button.

5) *First Moment Plot: Distance from Source to Center of Mass* is used to view the First Moment Analysis results by constituent over time. The first moment calculation estimates the center of mass for the plume using site coordinates (Xc and Yc) for each sample event and COC. The distance from the original source location to the center of mass location for each sample event is plotted in the *First Moment Plot* window. The trend indicates the movement of the center of mass over time relative to the original source.

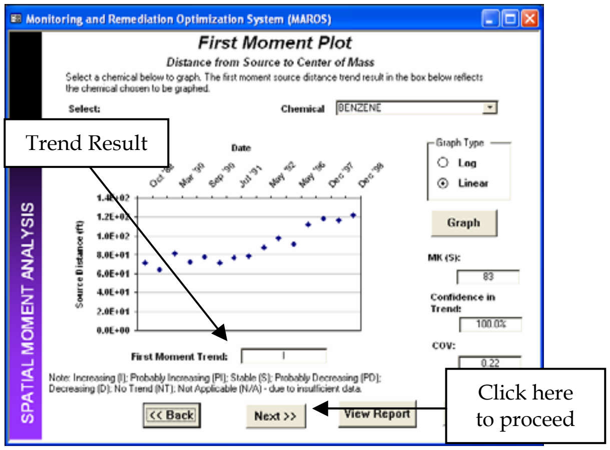
An evaluation of the **First Moment** trend for the distance to the center of mass over time is determined by using the Mann-Kendall Trend Methodology. The "First Moment" trend for each COC is calculated according to the rules outlined in Appendix A.2. Results for the trend include: Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

Other statistics displayed include the Mann-Kendall Statistic (S), the Confidence in Trend and the Coefficient of Variation (COV). Refer to Appendix A.2 and A.5 for further details.

The First Moment analysis results are displayed for benzene.

The First Moment Trend of the distance to the center of mass over time is shown to be increasing "I". This means the center of mass has been moving farther from the original source area over the time period considered.

Select "Next" to proceed to the First Moment Plot: Change in Location of Mass Over Time screen.



First Moment Plot

Distance from Source to Center of Mass

Select a chemical below to graph. The first moment source distance trend result in the box below reflects the chemical chosen to be graphed.

Select: Chemical: BENZENE

MK (S): 83

Confidence in Trend: 100.0%

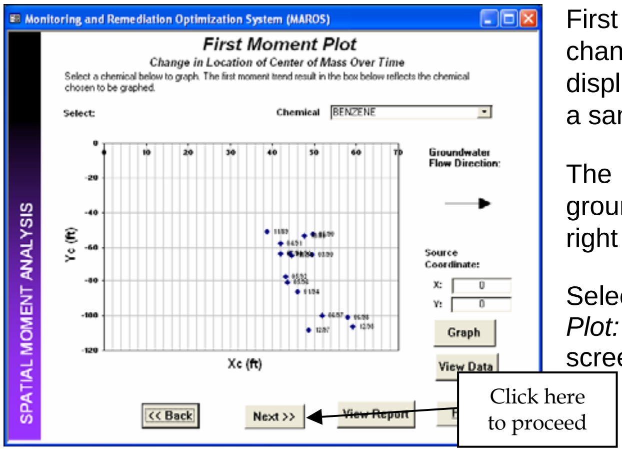
COV: 0.22

First Moment Trend: I

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - due to insufficient data.

Note: If more than one COC is being used, plots of other chemicals can be obtained using the "Chemical" drop down box at the top of the screen, followed by selecting the "Graph" button. The graph type can be specified as Log or Linear. The graph can be printed by selecting the “View Report” button.

6) *First Moment Plot: Change in Location of Mass Over Time* is used to visualize the movement of First Moments by constituent over time. The first moment estimates the center of mass for the plume for each sample event and COC. The center of mass locations indicate the movement of the center of mass over time.


Monitoring and Remediation Optimization System (MAROS)

First Moment Plot

Change in Location of Center of Mass Over Time

Select a chemical below to graph. The first moment trend result in the box below reflects the chemical chosen to be graphed.

Select: Chemical: BENZENE

Source Coordinate: X: 0 Y: 0

Click here to proceed

First Moment analysis results showing the change in location of mass over time are displayed for benzene. Each point represents a sample event.

The results can be compared to the groundwater flow direction displayed to the right of the screen.

Select “Next” to proceed to the *First Moment Plot: Change in Location of Mass Over Time* screen.

Note: If more than one COC is being used, plots of other chemicals can be obtained using the “Chemical” drop down box at the top of the screen, followed by selecting the “Graph” button. The graph type can be specified as Log or Linear. The graph can be printed by selecting the “View Report” button. Data values can be viewed by selecting “View Data”. This option shows a table with the First Moment coordinates and Source Distance for all sample events.

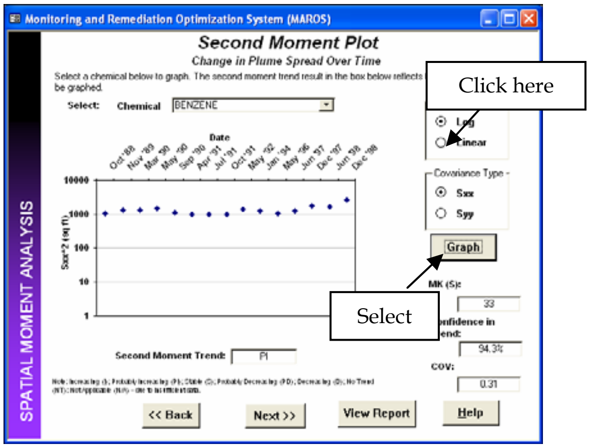
7) *Second Moment Plot: Change in Plume Spread Over Time* allows the user to view the Second Moment Analysis results by constituent over time. The second moment indicates the spread of the contaminant about the center of mass (Sxx and Syy), or the distance of contamination from the center of mass. Analysis of the spread of the plume should be viewed as it relates to the direction of groundwater flow. The Second Moment represents the spread of the plume over time in both the x and y directions.

The **Second Moment** trend of the Spread of the Plume in the X or Y direction over time is determined by using the Mann-Kendall Trend Methodology using the rules outlined in Appendix A.2. Results for the trend include: Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

Other statistics displayed include the Mann-Kendall Statistic (S), the Confidence in Trend and the Coefficient of Variation (COV). Refer to Appendix A.2 and A.5 for further details.

Second Moment analysis results showing the spread of the plume over time are displayed for benzene. The scale shown is logarithmic (Log).

Change graph type to Linear by clicking on the open circle next to “Linear”. Click on “Graph” to display.


Monitoring and Remediation Optimization System (MAROS)

Second Moment Plot

Change in Plume Spread Over Time

Select a chemical below to graph. The second moment trend result in the box below reflects be graphed.

Select: Chemical: BENZENE

● Log
○ Linear

Covariance Type
● Sxx
○ Syy

MK (S): 33

onfidence in end: 94.3%

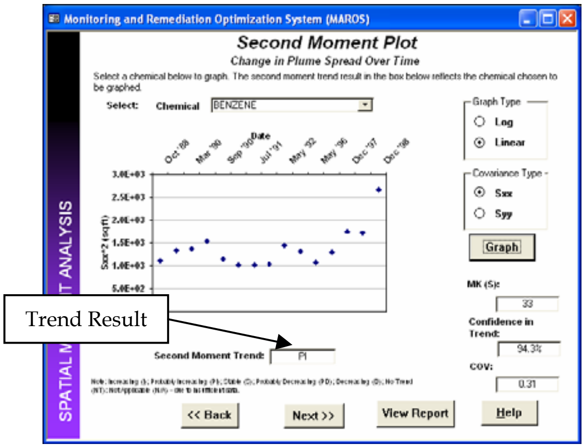
COV: 0.31

Second Moment Trend: PI

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - due to insufficient data.

Click here

Select


Monitoring and Remediation Optimization System (MAROS)

Second Moment Plot

Change in Plume Spread Over Time

Select a chemical below to graph. The second moment trend result in the box below reflects the chemical chosen to be graphed.

Select: Chemical: BENZENE

Graph Type: ○ Log ● Linear

Covariance Type: ● Sxx ○ Syy

MK (S): 33

Confidence in Trend: 94.3%

COV: 0.31

Second Moment Trend: PI

Trend Result

The graph displays covariance type "Sxx", representing spreading of the plume in the direction of groundwater flow.

The Second Moment Trend of the spread of the plume over time is No Trend--"NT". This indicates that the concentrations are too variable to indicate a definite trend.

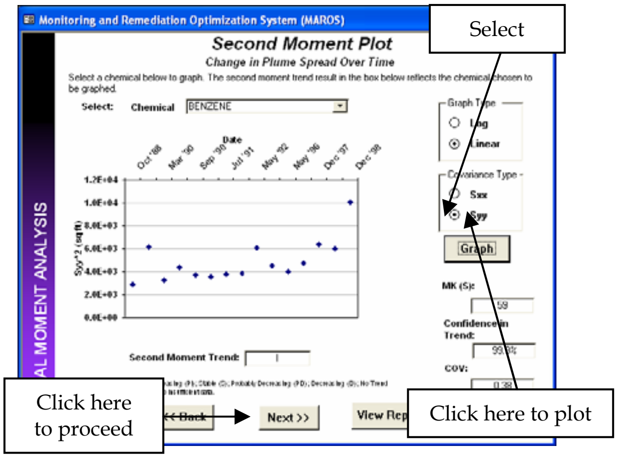
To view the results for covariance type "Syy" click on the circle labeled "Syy" under Covariance Type.

Then click on the "Graph" button.

The graph now displays covariance type "Syy", representing spreading of the plume in the direction perpendicular to groundwater flow.

The Second Moment Trend of the spread of the plume over time is shown to be stable "S".

Select "Next" to proceed to the *Spatial Moment Analysis Summary* screen.


Monitoring and Remediation Optimization System (MAROS)

Second Moment Plot

Change in Plume Spread Over Time

Select a chemical below to graph. The second moment trend result in the box below reflects the chemical chosen to be graphed.

Select: Chemical: BENZENE

Graph Type: ○ Log ● Linear

Covariance Type: ○ Sxx ● Syy

MK (S): 59

Confidence in Trend: 99.9%

COV: 0.38

Second Moment Trend: I

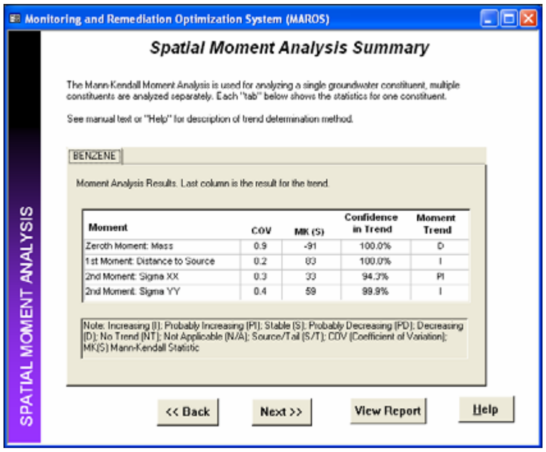
Select

Click here to proceed

Click here to plot

Note: If more than one COC is being used plots of other chemicals can be obtained using the "Chemical" drop down box at the top of the screen, followed by selecting the "Graph" button. The graph type can be specified as Log or Linear. The graph can be printed by selecting the "View Report" button.

8) *Spatial Moment Analysis Summary* allows the user to view the Moment Analysis Trend (Mann-Kendall) results by constituent.


Monitoring and Remediation Optimization System (MAROS)

Spatial Moment Analysis Summary

The Mann-Kendall Moment Analysis is used for analyzing a single groundwater constituent, multiple constituents are analyzed separately. Each "tab" below shows the statistics for one constituent.

See manual text or "Help" for description of trend determination method.

BENZENE

Moment Analysis Results. Last column is the result for the trend.

Moment	COV	MK (S)	Confidence in Trend	Moment Trend
Zeroth Moment: Mass	0.9	-91	100.0%	D
1st Moment: Distance to Source	0.2	83	100.0%	I
2nd Moment: Sigma XX	0.3	33	94.3%	PI
2nd Moment: Sigma YY	0.4	59	99.9%	I

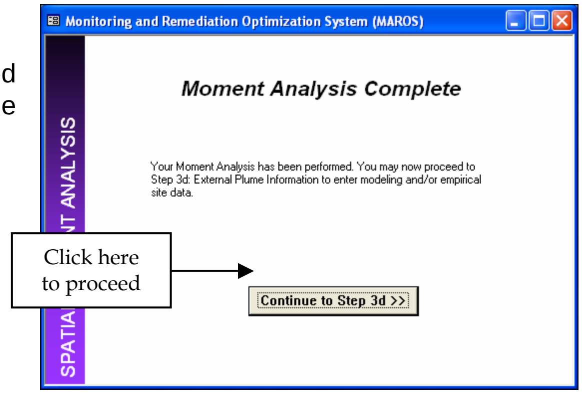
Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T); COV (Coefficient of Variation); MK(S) Mann-Kendall Statistic

Displayed are the spatial moment analysis results for benzene.

Click "Next" to proceed to the *Moment Analysis Complete* screen.

9) *Moment Analysis Complete* screen indicates that the Spatial Moment Analysis has been performed.

Click on “Continue to Step 3d” to proceed to the External Plume Information. The *Plume Analysis Menu* will appear.



Your Moment Analysis has been performed. You may now proceed to Step 3d: External Plume Information to enter modeling and/or empirical site data.

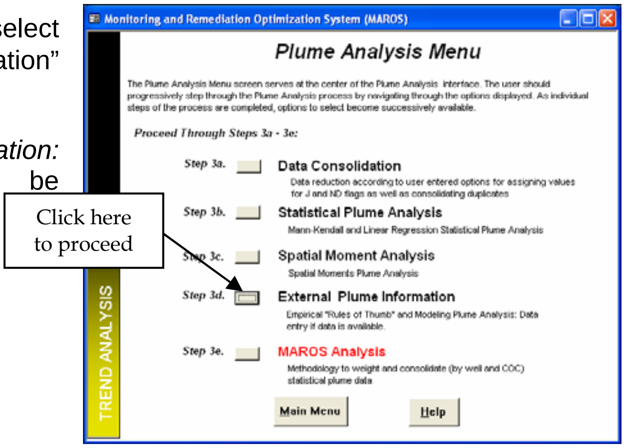
Click here to proceed

STEP 5: EXTERNAL PLUME INFORMATION

The external plume information module is used when applicable modeling data and/or empirical data have been generated using an analysis external to MAROS. This portion of the software is an optional utility, which will not be used in this tutorial.

1) From the *Plume Analysis Menu*, select the "Step 3d: External Plume Information" option.

   The *External Plume Information: Modeling Results* screen will be displayed.



Plume Analysis Menu

The Plume Analysis Menu screen serves at the center of the Plume Analysis interface. The user should progressively step through the Plume Analysis process by navigating through the options displayed. As individual steps of the process are completed, options to select become successively available.

Proceed Through Steps 3a - 3e:

Step 3a. **Data Consolidation**
Data reduction according to user entered options for assigning values for J and ND flags as well as consolidating duplicates

Step 3b. **Statistical Plume Analysis**
Mann-Kendall and Linear Regression Statistical Plume Analysis

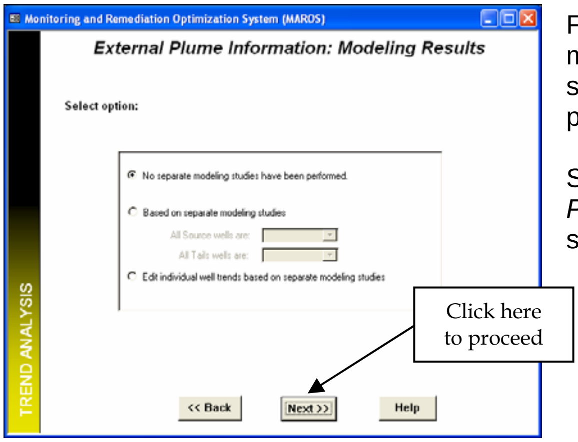
Step 3c. **Spatial Moment Analysis**
Spatial Moments Plume Analysis

Step 3d. **External Plume Information**
Empirical "Rules of Thumb" and Modeling Plume Analysis: Data entry if data is available.

Step 3e. **MAROS Analysis**
Methodology to weight and consolidate (by well and COC) statistical plume data

2) *External Plume Information: Modeling Results* allows the user to enter external modeling results by well and constituent or for all source or all tail wells (e.g. Increasing (I), Stable (S), etc.).

   Modeling results should be taken from fate and transport models that take site specific data and predict the ultimate extent of constituent migration (either for natural attenuation process or site undergoing remediation).



External Plume Information: Modeling Results

Select option:

● No separate modeling studies have been performed.

○ Based on separate modeling studies

All Source wells are:

All Tails wells are:

○ Edit individual well trends based on separate modeling studies

For this tutorial there are no additional modeling results. The option "No separate modeling studies have been performed" should be already selected.

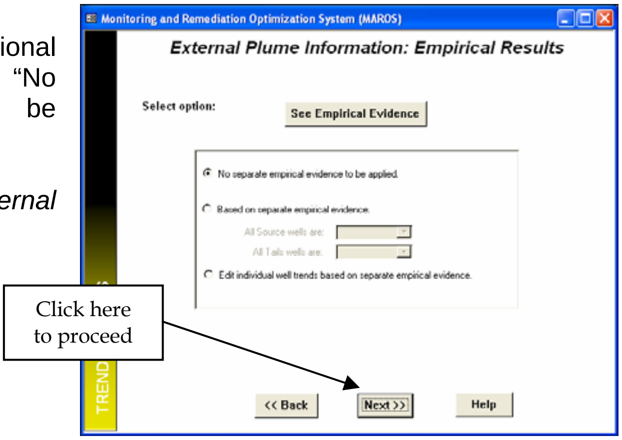
Select "Next" to proceed to the *External Plume Information: Empirical Results* screen.

3) *External Plume Information: Empirical Results* allows the user to enter empirical trend information by well and constituent or for all source or all tail wells. The rationale and limitations to this approach is outlined in Appendix A.4. This portion of the software is an optional utility, which will not be used in this tutorial.

Empirical results should be developed on the basis of data from previous similar site studies (e.g. “plume-a-thon” studies such as the Lawrence Livermore study, the BEG studies and the AFCEE chlorinated database).

For this tutorial there are no additional modeling results. The option “No separate empirical evidence to be applied” should be already selected.

Select “Next” to proceed to the *External Plume Information Complete* screen.



● No separate empirical evidence to be applied.

○ Based on separate empirical evidence.

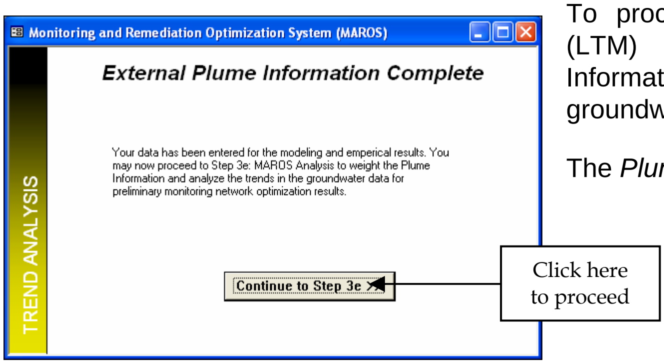
All Source wells are:

All Tails wells are:

○ Edit individual well trends based on separate empirical evidence.

Click here to proceed

4) *External Plume Information Complete* Screen indicates that the Modeling and Empirical Trend results have been entered. This portion of the software is an optional utility, which will not be used in this tutorial.



Your data has been entered for the modeling and emperical results. You may now proceed to Step 3e: MAROS Analysis to weight the Plume Information and analyze the trends in the groundwater data for preliminary monitoring network optimization results.

Click here to proceed

To proceed to the Long Term Monitoring (LTM) Analysis to weight the Plume Information and analyze the trends in the groundwater data, select “Trends Analysis”.

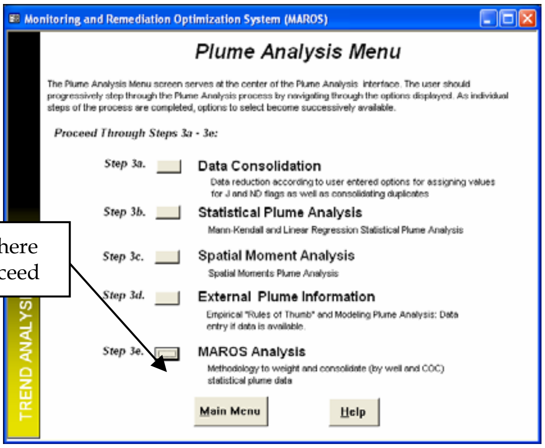
The *Plume Analysis Menu* will appear.

STEP 6: MAROS ANALYSIS

MAROS analysis allows user to weight the trend analysis data and weight well data. Final suggested generic monitoring system categories for each COC are displayed.

1) From the *Plume Analysis Menu*, select the “Step 3e: MAROS analysis” option.

   The *Statistical and Plume Information Summary by Well* screen will be displayed.



Plume Analysis Menu

The Plume Analysis Menu screen serves at the center of the Plume Analysis interface. The user should progressively step through the Plume Analysis process by navigating through the options displayed. As individual steps of the process are completed, options to select become successively available.

Proceed Through Steps 3a - 3e:

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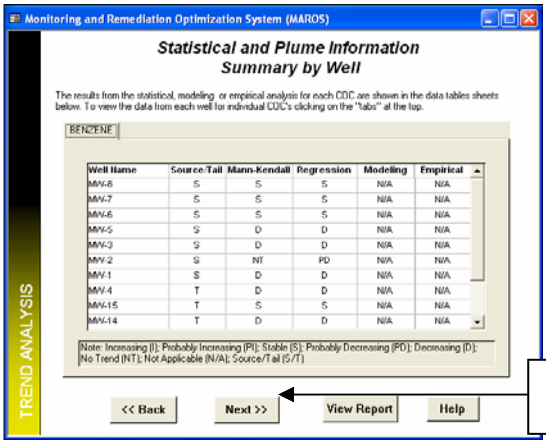
Step 3c. Spatial Moment Analysis
Spatial Moments Plume Analysis

Step 3d. External Plume Information
Empirical "Rules of Thumb" and Modeling Plume Analysis: Data entry if data is available.

Step 3e. MAROS Analysis
Methodology to weight and consolidate (by well and COC) statistical plume data

Click here
to proceed

2) *Statistical and Plume Information Summary by Well* allows the user to view the Mann-Kendall Trend Analysis, Linear Regression Analysis, Modeling and Empirical results by well and constituent.



Statistical and Plume Information Summary by Well

The results from the statistical, modeling or empirical analysis for each COC are shown in the data tables sheets below. To view the data from each well for individual COC's clicking on the "tabs" at the top.

Well Name	Source/Tail	Mann-Kendall	Regression	Modeling	Empirical
MW-8	S	S	S	N/A	N/A
MW-7	S	S	S	N/A	N/A
MW-6	S	S	S	N/A	N/A
MW-5	S	D	D	N/A	N/A
MW-3	S	D	D	N/A	N/A
MW-2	S	NT	PD	N/A	N/A
MW-1	S	D	D	N/A	N/A
MW-4	T	D	D	N/A	N/A
MW-15	T	S	S	N/A	N/A
MW-14	T	D	D	N/A	N/A

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T)

Click here
to proceed

Results for benzene are displayed.

Select “Next” to proceed to the *Statistical and Plume Information Summary Weighting* screen.

Note: If more than one COC is being considered, the user will navigate to the results for individual constituents by clicking on the tabs at the top of the screen. The results can be printed by selecting the “View Report” button.

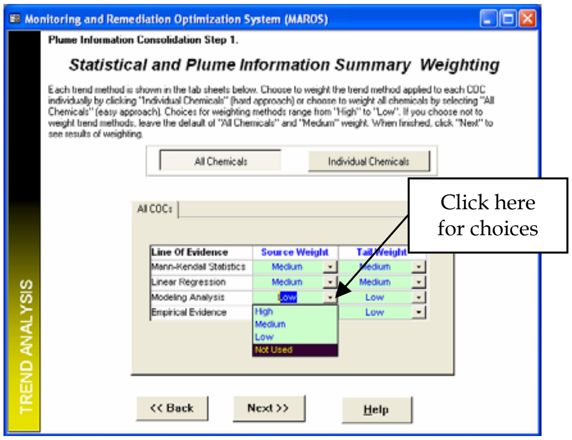
3) *Statistical and Plume Information Summary Weighting* allows the user to weight the individual lines of evidence (i.e. Mann-Kendall Trend Analysis, Linear Regression Analysis, Modeling and Empirical results).

   Choices for weighting trend methods are "High", “Medium”, "Low" and “Not Used”. If you choose not to weight trend methods, leave the default of "All Chemicals" and "Medium" weight.

Since no modeling analysis or empirical evidence is being used, the weighting for these trends should be changed to “Not Used”.

Click on the drop down arrow under the “Source Weight” text box to the right of “Modeling Analysis”. A list of choices will appear. Select “Not Used”.

Repeat for the text box to the right (“Tail Weight”) and for the two text boxes adjacent to “Empirical Evidence”.

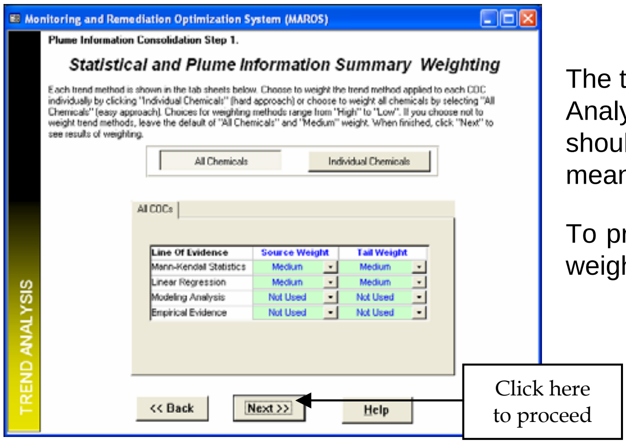


Plume Information Consolidation Step 1.

Statistical and Plume Information Summary Weighting

Each trend method is shown in the tab sheets below. Choose to weight the trend method applied to each COC individually by clicking "Individual Chemicals" (hard approach) or choose to weight all chemicals by selecting "All Chemicals" (easy approach). Choices for weighting methods range from "High" to "Low". If you choose not to weight trend methods, leave the default of "All Chemicals" and "Medium" weight. When finished, click "Next" to see results of weighting.

Line Of Evidence	Source Weight	Tail Weight
Mann-Kendall Statistics	Medium	Medium
Linear Regression	Medium	Medium
Modeling Analysis	Low	Low
Empirical Evidence		Low



Plume Information Consolidation Step 1.

Statistical and Plume Information Summary Weighting

Each trend method is shown in the tab sheets below. Choose to weight the trend method applied to each COC individually by clicking "Individual Chemicals" (hard approach) or choose to weight all chemicals by selecting "All Chemicals" (easy approach). Choices for weighting methods range from "High" to "Low". If you choose not to weight trend methods, leave the default of "All Chemicals" and "Medium" weight. When finished, click "Next" to see results of weighting.

Line Of Evidence	Source Weight	Tail Weight
Mann-Kendall Statistics	Medium	Medium
Linear Regression	Medium	Medium
Modeling Analysis	Not Used	Not Used
Empirical Evidence	Not Used	Not Used

The top two rows for Mann-Kendall Trend Analysis and Linear Regression Analysis should have “Medium” weighting. This means that weighting will not be applied.

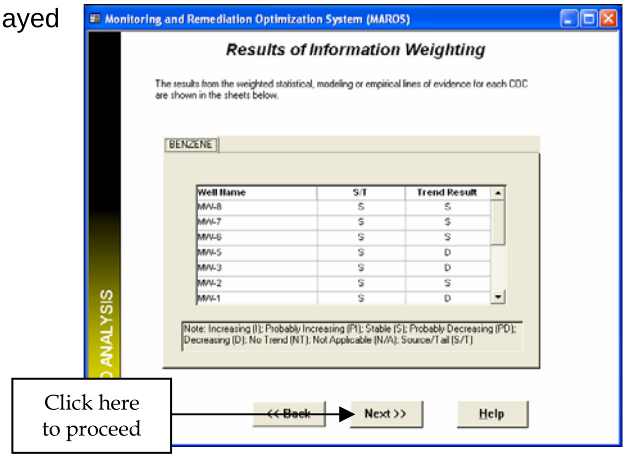
To proceed, click "Next" to see results of weighting.

Note: If more than one COC is being used, the User could choose to weight the trend methods applied to each COC individually (select "Individual Chemicals") or to weight all chemicals (select "All Chemicals").

4) *Results of Information Weighting* allows the user to view the weighted statistical, modeling and empirical lines of evidence for each COC.

Trend results for benzene are displayed for each well.

Select “Next” to proceed.



Results of Information Weighting

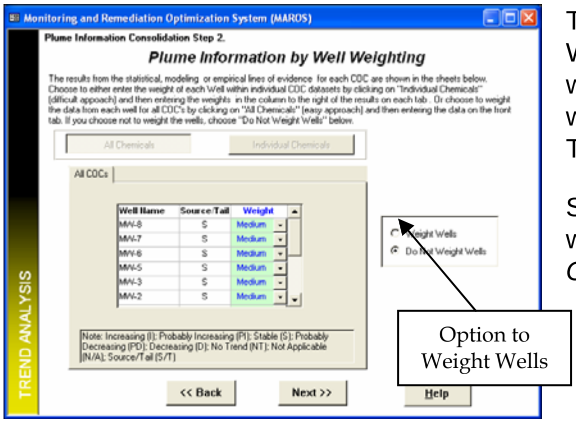
The results from the weighted statistical, modeling or empirical lines of evidence for each COC are shown in the sheets below.

Well Name	S/T	Trend Result
MW-8	S	S
MW-7	S	S
MW-6	S	S
MW-5	S	D
MW-3	S	D
MW-2	S	S
MW-1	S	D

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T)

5) *Plume Information by Well Weighting* screen allows the user to weight individual wells by all chemicals or by constituent.

To weigh individual wells, the option “Weight Wells” could be selected on the right of the screen. Choices for weighting methods range from "High" to "Low".



Plume Information Consolidation Step 2.

Plume Information by Well Weighting

The results from the statistical, modeling or empirical lines of evidence for each COC are shown in the sheets below. Choose to either enter the weight of each Well within individual COC datasets by clicking on "Individual Chemicals" (difficult appoach) and then entering the weights in the column to the right of the results on each tab . Or choose to weight the data from each well for all COC's by clicking on "All Chemicals" (easy approach) and then entering the data on the front tab. If you choose not to weight the wells, choose "Do Not Weight Wells" below.

Well Name	Source/Tail	Weight
MW-8	S	Medium
MW-7	S	Medium
MW-6	S	Medium
MW-5	S	Medium
MW-3	S	Medium
MW-2	S	Medium

○ Weight Wells
● Do Not Weight Wells

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T)

Option to Weight Wells

The screen displays “Do Not Weight Wells” as default. This means that the weighting applied to the trend methods will be applied equally to all the wells. This is the option required for this tutorial.

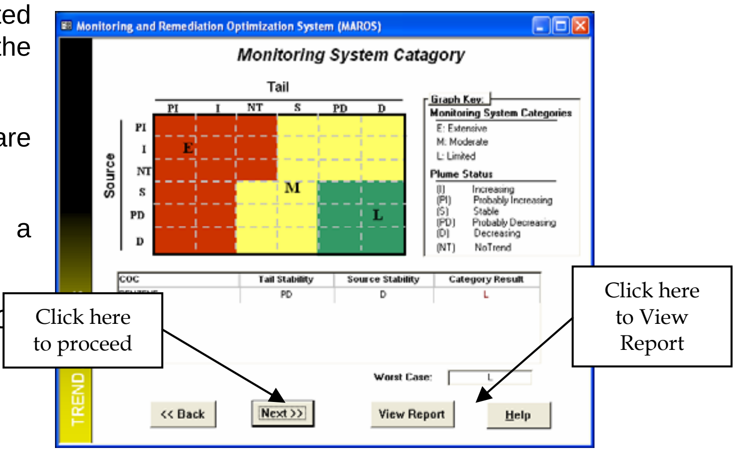
Select “Next” to see the results of the weighting. The *Monitoring System Category* screen will be displayed.

6) *Monitoring System Category* screen allows the User to view the suggested design category for each COC. Overall Trend results for both tail and source wells are given. From these results a generic monitoring system category, based on heuristic rules, that characterizes the site for each individual constituent is shown. Design categories include Extensive (E), Moderate (M), and Limited (L) long term monitoring required for the site.

The benzene results for the site are displayed.

Select “View Report” to obtain a summary of the results for the analysis.

Select “Next” to proceed to the *MARO Analysis Complete* screen.

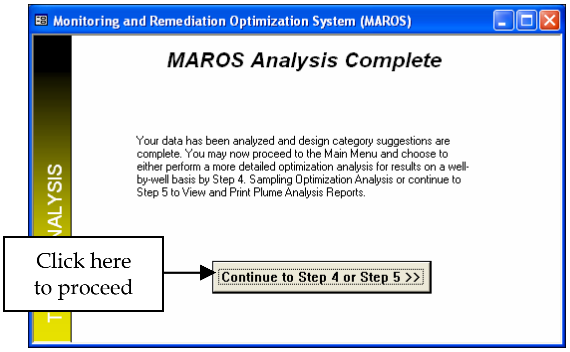


COC	Tail Stability	Source Stability	Category Result
BENZENE	PD	D	L

Worst Case: L

Click here to proceed

Click here to View Report



MAROS Analysis Complete

Your data has been analyzed and design category suggestions are complete. You may now proceed to the Main Menu and choose to either perform a more detailed optimization analysis for results on a well-by-well basis by Step 4. Sampling Optimization Analysis or continue to Step 5 to View and Print Plume Analysis Reports.

Click here to proceed

At this point, the data has been analyzed and design category suggestions are complete. Proceed to the *Main Menu* and choose to either perform *Sampling Optimization Analysis* or choose *MAROS Output*. Select “Continue to Step 4 or Step 5” to proceed.

Typical Overview Statistics: Plume Trend Analysis Results

At this point in the software the user should assess the overall statistical trend results for the site where they can gain information on the plume stability as well as the distribution of individual well trends. Again, the goal of the tutorial is to show the user tips and pitfalls when applying MAROS at a typical site. The tutorial example has been used only to illustrate the utilities of the MAROS software and it is by no means a complete site analysis.

(For a description of the Detailed statistical modules including Sampling Optimization modules, see below.)

MANN-KENDALL/LINEAR REGRESSION ANALYSIS

All 14 monitoring wells had sufficient data within the time period of October, 1988 to December, 1998 (greater than three years of semi-annual data) to assess the trends in the wells. Trend results from the Mann-Kendall and Linear Regression temporal trend analysis for both Upper Aquifer monitoring wells are given in Table A.11.3.

TABLE A.11.3 SERVICE STATION BENZENE WELL TREND RESULTS

Well	Well Type [2]	Well Category [3]	Mann-Kendall Trend [4]	Linear Regression Trend [4]	Overall Trend [5]	Number of Samples	Number of Detects	Comments of Detects
MW-1	MW	Source	D	D	D	15	15	Consistent detect, but decreasing trend
MW-2	MW	Source	NT	PD	S	15	7	Inconsistent pattern on detects and NDs
MW-3	MW	Source	D	D	D	15	12	Consistent detect, but decreasing trend
MW-4	MW	Tail	D	D	D	15	14	Consistent detect, but decreasing trend. Most recent ND.
MW-5	MW	Source	D	D	D	15	15	Consistent detect, but decreasing trend since 1994
MW-6	MW	Source	S - ND	S - ND	S – ND	15	0	All samples ND
MW-7	MW	Source	S - ND	S - ND	S – ND	15	1	Almost all samples ND
MW-8	MW	Source	S – ND	S - ND	S - ND	15	1	Almost all samples ND
MW-11	MW	Tail	I	NT	PI	13	12	Increasing concentrations
MW-12	MW	Tail	D	D	D	15	11	Consistent detect until 1994
MW-13	MW	Tail	D	D	D	15	10	Consistent detect until 1992
MW-14	MW	Tail	D	D	D	15	7	Consistent detect until 1991
MW-15	MW	Tail	S - ND	S - ND	S – ND	15	0	All samples ND
MW-16	MW	Tail	D	D	D	15	14	Consistent low levels

Notes:

1. Consolidation of data included non-detect (ND) values set to the detection limit (0.001 mg/L) and the maximum value of duplicate data was used.
2. MW = Monitoring Well
3. Source = Source Zone Well; Tail = Tail Zone Well
4. Decreasing (D), Probably Decreasing (PD), Stable (S), No Trend (NT), Probably Increasing (PI), and Increasing (I)
5. Overall Trend is calculated from a weighted average of the Linear Regression and Mann-Kendall Trends.

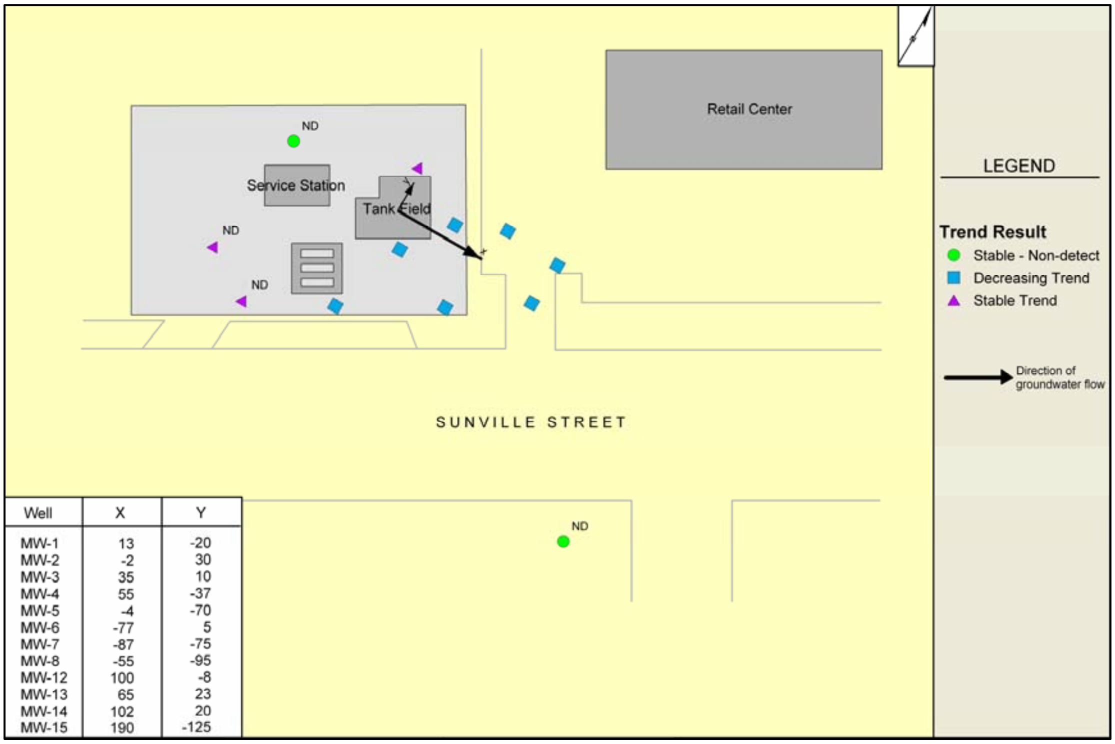
For further details on this methodology refer to Appendix A.8.

The monitoring well trend results show that 5 out of 5 source wells and all 7 tail wells have a Probably Decreasing, Decreasing, or Stable trends. Both methods gave similar trend estimates for each well.

Well Type	*MAROS Trend Analysis*	
	PD, D, S	**I, PI**
Source	5 of 5 (100%)	0 of 5 (0%)
Tail	6 of 7 (86%)	1 of 7 (14%)

Note: Decreasing (D), Probably Decreasing (PD), Stable (S), Probably Increasing (PI), and Increasing (I)

When considering the spatial distribution of the trend results (Figure A.11.2– map created in ArcGIS from MAROS results), the majority of the decreasing or stable trend results are located near the Tanks (source area), indicating a decreasing source.



Well	X	Y
MW-1	13	-20
MW-2	-2	30
MW-3	35	10
MW-4	55	-37
MW-5	-4	-70
MW-6	-77	5
MW-7	-87	-75
MW-8	-55	-95
MW-12	100	-8
MW-13	65	23
MW-14	102	20
MW-15	190	-125

FIGURE A.11.2 SERVICE STATION BENZENE TREND RESULTS

Note: If extraction or recovery wells are present in a well network, these well trend results need to be treated differently for the purpose of individual trend analysis interpretation primarily due to the different course of action possible for the two types of wells. For monitoring wells, strongly decreasing concentration trends may lead the site manager to decrease their monitoring frequency, as well look at the well as possibly attaining its remediation goal. Conversely, strongly decreasing concentration trends in extraction wells may indicate ineffective or near-asymptotic contamination extraction, which may in turn lead to either the shutting down of the well or a drastic change in the extraction scheme. Other reasons favoring the separation of these two types of wells in the trend analysis interpretation is the fact that they produce very different types of samples. On average, the extraction wells possess screens that are twice as large and extraction wells pull water from a much wider area than the average monitoring well. Therefore, the potential for the dilution of extraction well samples is far greater than monitoring well samples.

MOMENT ANALYSIS

Moment Trend results from the Zeroth, First, and Second Moment analyses for the Upper Aquifer monitoring well network were varied. Moment Trend results from a selected Upper Aquifer monitoring well dataset are given in the Moment Analysis Report, Appendix 10. All 12 wells were used in the moment analysis.

Moment Type	***Mann-Kendall Trend Analysis***	
	Trend	**Comment**
Zeroth	Decreasing	The decrease in dissolved mass is most likely due to biodegradation of benzene and removal of the source materials.
First	Increasing	The center of mass is moving down-gradient relative to the approximate source location (MW-1) through time in a South-Easterly direction, perpendicular to groundwater flow.
Second	No Trend/ Stable	The plume shows No Trend in the direction of groundwater flow and a Stable trend perpendicular to groundwater flow. This indicates that there is variability in the spread in the direction of groundwater flow and very little spread orthogonal to the flow direction.

Note: The zeroth moment (or dissolved mass) estimate can show high variability over time, due to the fluctuating concentrations at the most contaminated wells as well as a varying monitoring well network. This may result in an unexpected increasing trend of mass over time. To investigate the influence of fluctuating factors over time, data can be consolidated to annual sampling and the zeroth moment trend re-evaluated. Another factor to consider when interpreting the mass increase over time is the change in the spatial distribution of the wells sampled historically. If the service station site network had changes in the well distribution over time, due to addition and subtraction of wells from the well network, this could cause moment trends to be incorrect. Also, an observed mass increase could also stem from more mass being dissolved from the NAPL while a remediation system is operating.

The spatial and temporal trends in the center of mass distance from the source location (first moment results) can indicate transient movement based on season variation in rainfall or other hydraulic considerations. The Service Station results that the source area concentration is decreasing faster than the tail area of the plume, therefore the “increasing” trend in the first moment. Even though the center of mass is moving, the plume itself is still decreasing in concentration over time and the direction of movement is in the groundwater flow direction.

The second moment provides a measure of the spread of the concentration distribution about the plume’s center of mass. The second moment, or spread of the plume over time in the x direction for each sample event, shows an increasing trend over time. Analysis of the spread of the plume indicates a shrinking to stable plume, where wells representing very large areas both on the tip and the sides of the plume show decreasing concentrations. This increasing trend in the spread of the plume shows that, although the concentrations are decreasing over time, the plume is moving down-gradient.

OVERVIEW STATISTICS: PLUME ANALYSIS

In evaluating overall plume stability, the trend analysis results and all monitoring wells were assigned "Medium" weights within the MAROS software, assuming equal importance for each well and each trend result in the overall analysis.

Overview Statistics Results:

- Overall trend for Source region: Decreasing,
- Overall trend for Tail region: Probably decreasing,
- Overall results from moment analysis indicate a decreasing dissolved mass of the plume,
- Overall monitoring intensity needed: Limited.

These results matched with the judgment based on the visual comparison of benzene plumes over time, as well as the Moment Analysis. The benzene plume concentrations observed in 1991 was very similar to that of 1994, indicating that the benzene plume is relatively stable to decreasing over time.

For a generic plume, the MAROS software indicates to:

- Continue semi-annual sampling frequency.
- May need up to 15 wells

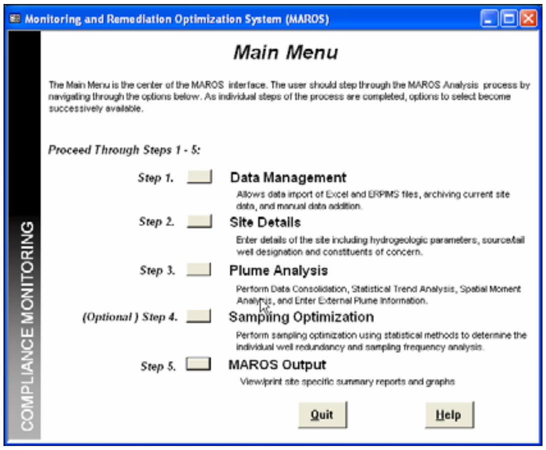
These MAROS results are for a generic site, and are based on knowledge gained from applying the MAROS Overview Statistics. The frequency recommendation is for the whole monitoring network and the number of wells seems high. Therefore, a more detailed analysis for both the well redundancy and sampling frequency utilizing the detailed statistics analysis in the MAROS 2.1 software is needed to allow for reductions and recommendations on a well-by-well basis. These overview statistics were also used when evaluating a final recommendation for each well after the detailed statistical analysis was applied.

Sampling Optimization

Step 4, Sampling Optimization allows the user to perform detailed sampling optimization with modules to optimize sampling location by the Delaunay method and sampling frequency by the Modified CES method or to evaluate data sufficiency by statistical power analysis.

Select "Sampling Optimization" from the Main Menu and the *Sampling Optimization Menu* screen will appear.

The *Sampling Optimization Menu* screen serves as the center of the sampling optimization user interface. The User can choose to perform either sampling location analysis or sampling frequency analysis first. Data sufficiency analysis will become available after the sampling frequency analysis is completed.



The Main Menu is the center of the MAROS interface. The user should step through the MAROS Analysis process by navigating through the options below. As individual steps of the process are completed, options to select become successively available.

Proceed Through Steps 1 - 5:

Step 1. ☐ **Data Management**
Allows data import of Excel and ERPIMS files, archiving current site data, and manual data addition.

Step 2. ☐ **Site Details**
Enter details of the site including hydrogeologic parameters, source/tail well designation and constituents of concern.

Step 3. ☐ **Plume Analysis**
Perform Data Consolidation, Statistical Trend Analysis, Spatial Moment Analysis, and Enter External Plume Information.

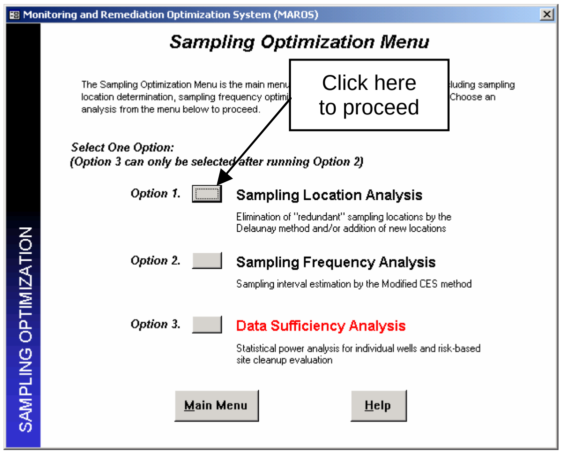
(Optional) Step 4. ☐ **Sampling Optimization**
Perform sampling optimization using statistical methods to determine the individual well redundancy and sampling frequency analysis.

Step 5. ☐ **MAROS Output**
View/print site specific summary reports and graphs

OPTION 1: SAMPLING LOCATION ANALYSIS

The Sampling Location Analysis module uses the Delaunay method to recommend wells that may be removed from the sampling program and to identify locations within the well network that may require more data collection effort.

Select "Sampling Location Analysis" from the *Sampling Optimization Menu*.



The Sampling Optimization Menu is the main menu … luding sampling location determination, sampling frequency optimi… Choose an analysis from the menu below to proceed.

Select One Option:
(Option 3 can only be selected after running Option 2)

Option 1. ☐ **Sampling Location Analysis**
Elimination of "redundant" sampling locations by the Delaunay method and/or addition of new locations

Option 2. ☐ **Sampling Frequency Analysis**
Sampling interval estimation by the Modified CES method

Option 3. ☐ **Data Sufficiency Analysis**
Statistical power analysis for individual wells and risk-based site cleanup evaluation

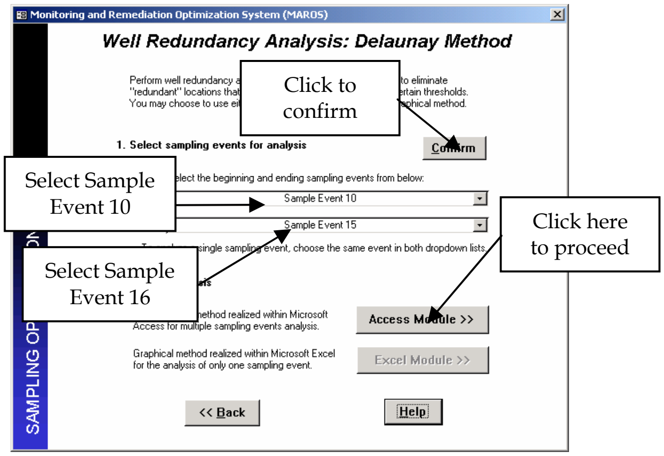
The *Well Redundancy Analysis: Delaunay Method* screen will appear.

The first step is to select the sampling events/time period to be included in the analysis. Sample events are chosen using the "To" and "From" drop down menus.

1) Select "Sampling Event 10" from the "From" dropdown list and "Sampling Event 16" from the "To" dropdown list. The latest five years of data will be used.

Click "Confirm" to confirm the selection and the "Access Module" button will be activated.

Click "Access Module" and the *Access Module – Potential Locations Setup* screen will appear.



Perform well redundancy a… to eliminate "redundant" locations that… ertain thresholds. You may choose to use ei… aphical method.

1. Select sampling events for analysis

…elect the beginning and ending sampling events from below:

Sample Event 10

Sample Event 15

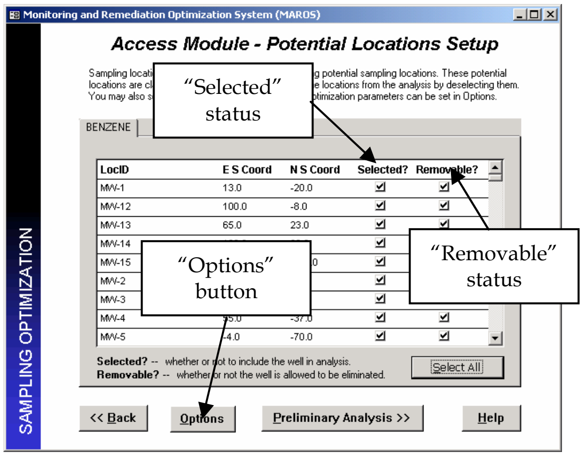
… single sampling event, choose the same event in both dropdown lists.

…method realized within Microsoft Access for multiple sampling events analysis.

Graphical method realized within Microsoft Excel for the analysis of only one sampling event.

When multiple sampling events are selected, only the “Access Module” button will be activated. If only one sampling event is selected (i.e., select the same event from both the “From” and “To” dropdown lists), the “Excel Module” button will also be activated. The Excel Module illustrates graphically how the Delaunay method works and gives the user more control of the optimization process.

Usually multiple sampling events are used to detect the sampling locations that are redundant throughout a period rather than at a single point in time. In this case study, multiple sampling events and the Access Module will be used to illustrate the sampling location optimization. For optimization with the Excel Module, please refer to “Sampling Location Determination – Excel Module” in the *MAROS Detailed Screen Descriptions* section of the User’s Guide.



Access Module - Potential Locations Setup

Sampling locati g potential sampling locations. These potential locations are cl e locations from the analysis by deselecting them. You may also s ptimization parameters can be set in Options.

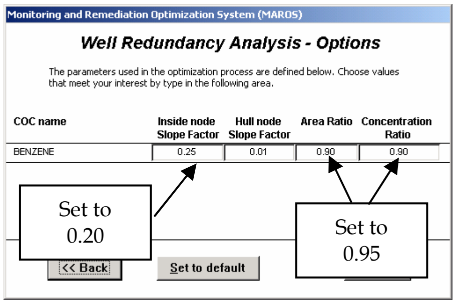
LocID	E S Coord	N S Coord	Selected?	Removable?
MW-1	13.0	-20.0	☑	☑
MW-12	100.0	-8.0	☑	☑
MW-13	65.0	23.0	☑	☑
MW-14	[illegible]	[illegible]	☑	[illegible]
MW-15	[illegible]	[illegible]	☑	[illegible]
MW-2	[illegible]	[illegible]	☑	[illegible]
MW-3	[illegible]	[illegible]	☑	[illegible]
MW-4	55.0	-37.0	☑	☑
MW-5	-4.0	-70.0	☑	☑

Selected? -- whether or not to include the well in analysis.
Removable? -- whether or not the well is allowed to be eliminated.

2) The *Access Module – Potential Locations Setup* screen allows the user to select the sampling locations for analysis and set the optimization parameters.

In this case study, all wells will be used in the analysis and all wells are assumed to be removable. Therefore, both the “Selected?” and “Removable” checkboxes are checked for each well. In practice, if not all wells are suitable for analysis, the User can deselect them. Similarly, if not all wells are removable (e.g., sentry wells), deselect the checkboxes in the “Removable?” column.

If the user deselects some of the wells and then wants to reselect them all, click the “Select All” button to facilitate this process.

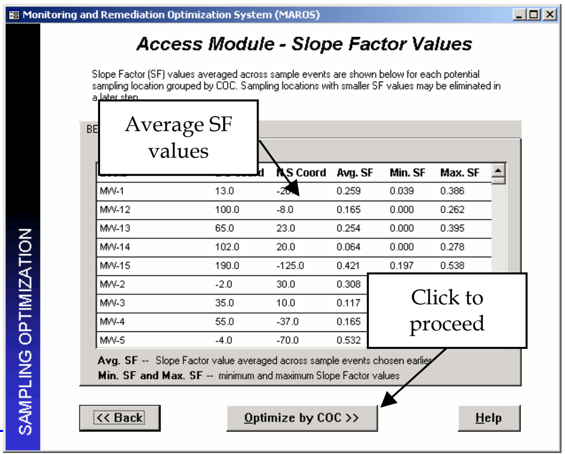


Well Redundancy Analysis - Options

The parameters used in the optimization process are defined below. Choose values that meet your interest by type in the following area.

COC name	Inside node Slope Factor	Hull node Slope Factor	Area Ratio	Concentration Ratio
BENZENE	0.25	0.01	0.90	0.90

3) Click the “Options” button and the *Well Redundancy Analysis – Options* screen will appear. Here the User can set the Slope Factor (SF) thresholds for wells inside and on the periphery of the benzene plume. Wells that have SF values smaller than the thresholds will become potential candidates for elimination. The Area Ratio (AR) and Concentration Ratio (CR) are thresholds constraining the information loss after elimination of wells. For example, 0.95 for Concentration Ratio means the acceptable information loss in plume average concentration estimation is 5% at most.



Access Module - Slope Factor Values

Slope Factor (SF) values averaged across sample events are shown below for each potential sampling location grouped by COC. Sampling locations with smaller SF values may be eliminated in a later step.

[illegible]	[illegible]	N S Coord	Avg. SF	Min. SF	Max. SF
MW-1	13.0	-20	0.259	0.039	0.386
MW-12	100.0	-8.0	0.165	0.000	0.262
MW-13	65.0	23.0	0.254	0.000	0.395
MW-14	102.0	20.0	0.064	0.000	0.278
MW-15	190.0	-125.0	0.421	0.197	0.538
MW-2	-2.0	30.0	0.308	[illegible]	[illegible]
MW-3	35.0	10.0	0.117	[illegible]	[illegible]
MW-4	55.0	-37.0	0.165	[illegible]	[illegible]
MW-5	-4.0	-70.0	0.532	[illegible]	[illegible]

Avg. SF -- Slope Factor value averaged across sample events chosen earlier
Min. SF and Max. SF -- minimum and maximum Slope Factor values

In this example, set the “Inside node Slope Factor” to 0.20, the “Hull node Slope Factor to 0.01”, and both the “Area Ratio” and “Concentration Ratio” to 0.95. Click the “<<Back” button to return to the *Access Module – Potential Locations Setup* screen. Click “Preliminary Analysis >>” to proceed and the *Access Module – Slope Factor Values* screen will appear.

3) The *Access Module – Slope Factor Values* screen shows a summary of the SF values

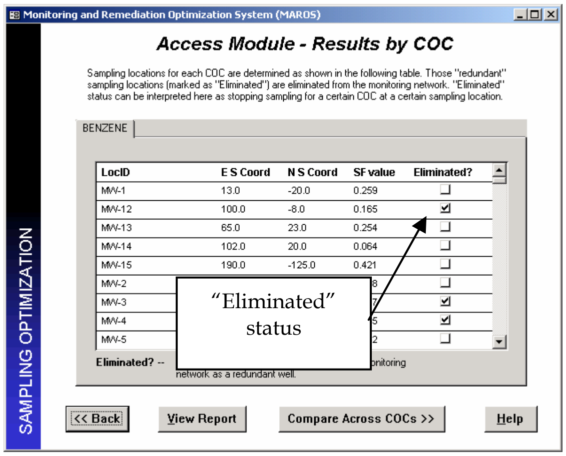
for each well. The “Min. SF”, “Max. SF” and “Ave. SF” columns list the summary statistics for the Slope Factor calculations for selected sample events during the time period. The average SF value is used to determine the overall redundancy of a well. The smaller it is, the less significant the well.

Note that there are several wells with average SF values less than 0.2. Click “Optimize by COC >>” to proceed. The *Access Module – Results by COC* screen will appear.

4) The *Access Module – Results by COC* screen shows the optimization results for each COC. Wells that can be eliminated are identified with a check mark in the “Eliminated?” column.

   It is seen from the table that wells MW-16, MW-3, and MW-4 can be eliminated for benzene.

   Note: When multiple COCs are analyzed, MAROS will produce Slope Factor results for each constituent. Frequently, the MAROS analysis will recommend different wells for removal for each COC. In this case, the final results should be evaluated across COCs, keeping the priority of the COC, the number of detections, detection limits and regulatory standards in mind. MAROS will always default to the most conservative result, i.e. retaining the well in the network.



Access Module - Results by COC

Sampling locations for each COC are determined as shown in the following table. Those "redundant" sampling locations (marked as "Eliminated") are eliminated from the monitoring network. "Eliminated" status can be interpreted here as stopping sampling for a certain COC at a certain sampling location.

BENZENE

LocID	E S Coord	N S Coord	SF value	Eliminated?
MW-1	13.0	-20.0	0.259	☐
MW-12	100.0	-8.0	0.165	☑
MW-13	65.0	23.0	0.254	☐
MW-14	102.0	20.0	0.064	☐
MW-15	190.0	-125.0	0.421	☐
MW-2	[illegible]	[illegible]	[illegible]	☐
MW-3	[illegible]	[illegible]	[illegible]	☑
MW-4	[illegible]	[illegible]	[illegible]	☑
MW-5	[illegible]	[illegible]	[illegible]	☐

Eliminated? -- [illegible] onitoring network as a redundant well.

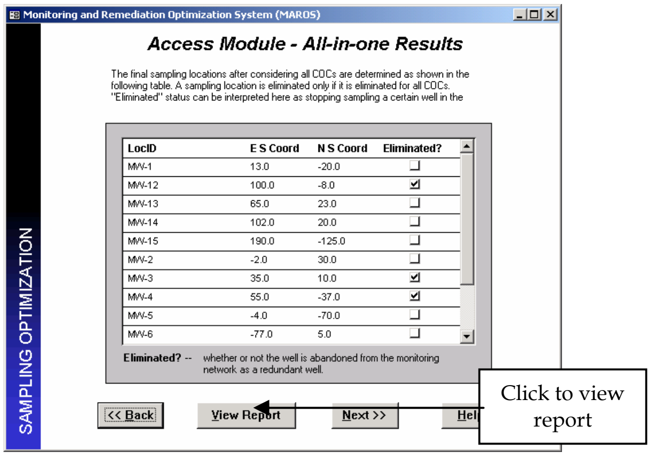
The User can choose to view the report where results are categorized by COC by clicking the “View Report” button.

Click the “Compare Across COCs >>” to proceed and the *Access Module – All-in-one Results* screen will appear.

5) The *Access Module – All-in-one Results* screen shows the optimization results for each well after considering all COCs. In this step, a well is eliminated only if it is elimnated for all COCs.

   As only benzene is analyzed, the result at this step is the same as from the previous step.

   A summary report is available for review by clicking the “View Report” button. Click “Next >>” to proceed and the *Well Sufficiency Analysis – New Locations* screen will appear.



Access Module - All-in-one Results

The final sampling locations after considering all COCs are determined as shown in the following table. A sampling location is eliminated only if it is eliminated for all COCs. "Eliminated" status can be interpreted here as stopping sampling a certain well in the

LocID	E S Coord	N S Coord	Eliminated?
MW-1	13.0	-20.0	☐
MW-12	100.0	-8.0	☑
MW-13	65.0	23.0	☐
MW-14	102.0	20.0	☐
MW-15	190.0	-125.0	☐
MW-2	-2.0	30.0	☐
MW-3	35.0	10.0	☑
MW-4	55.0	-37.0	☑
MW-5	-4.0	-70.0	☐
MW-6	-77.0	5.0	☐

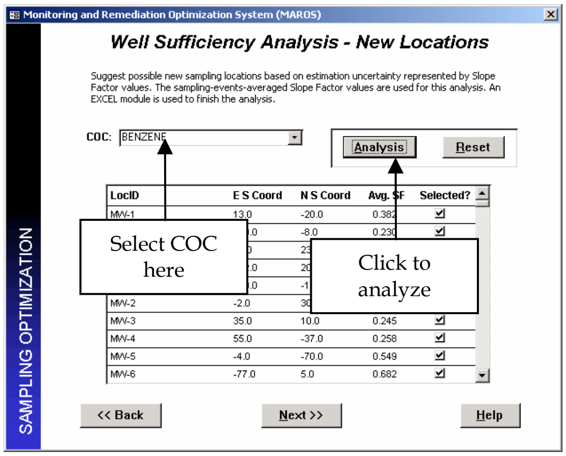
Eliminated? -- whether or not the well is abandoned from the monitoring network as a redundant well.

Note: The decision to terminate sampling for one COC or all COCs at a well may require further considerations, more than just recommendations from the above-described optimization. The above recommendations are based solely on one statistical analysis. In practice, decisions are always made out of the scope of technical considerations. Regulatory considerations, for example, need to be incoprated into the decision process. Also, if some of the parameters were changed in the above analysis, the reults could be a little different. To better understand the influence of parameters on optimization results, the user can try several runs with different parameters each time.

6) The *Well Sufficiency Analysis – New Locations* screen allows the user to perform a sufficiency analysis to determine potential new sampling locations. This analysis utilizes the SF values obtained from the Well Redundancy analysis to predict the concentration estimation uncertainty in unsampled regions. The regions where uncertainty is high are the potentail locations for adding new sampling points.

The analysis is performed for each COC individually..

The "Selected?" column shows the status of whether a well is used in the analysis. The User can exclude wells from analysis by unchecking the checkbox. In this example, all wells are used in the analysis. The "Reset" button can be used to reselect all wells.



Well Sufficiency Analysis - New Locations

Suggest possible new sampling locations based on estimation uncertainty represented by Slope Factor values. The sampling-events-averaged Slope Factor values are used for this analysis. An EXCEL module is used to finish the analysis.

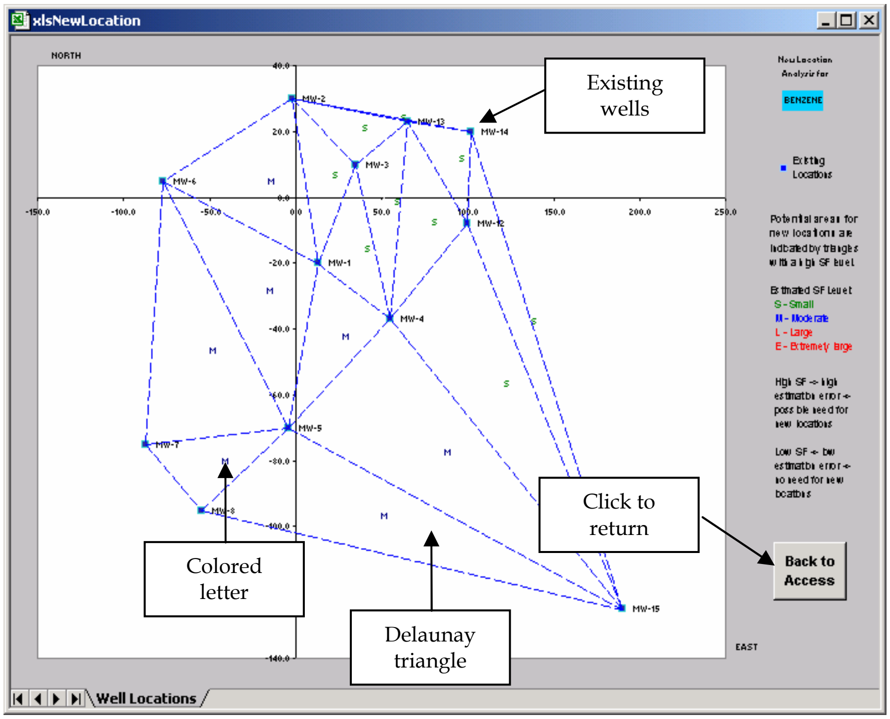
COC: BENZENE

LocID	E S Coord	N S Coord	Avg. SF	Selected?
MW-1	13.0	-20.0	0.382	☑
	.0	-8.0	0.230	☑
	0	23		
	.0	20		
	.0	-1		
MW-2	-2.0	30		
MW-3	35.0	10.0	0.245	☑
MW-4	55.0	-37.0	0.258	☑
MW-5	-4.0	-70.0	0.549	☑
MW-6	-77.0	5.0	0.682	☑

Select the COC from the "COC:" dropdown list. In this example, select benzene. Then click the "Analysis" button to proceed. An Excel chart called *xlsNewLocation* will pop up.

Note: The Excel worksheet illustrating the results of well sufficiency analysis is programmed with Macros. If the level of security in Excel is set on High, the worksheet will not open. Set security to medium (in Excel under 'Tools', 'Macro', and 'Security'). At this level, a dialog box will appear warning the User of the presence of macros. Choose 'Enable Macros' from the dialog box.

7) The *xlsNewLocation* Excel chart indicates the concentration estimation uncertainty at the center of each Delaunay triangle with a colored letter: "S" represents small, "M" represents moderate, "L" represents large, and "E" represents extremely large. The interpretations of the results are also provided on the chart. The areas with "L" or "E"



code can be considered for new sampling locations.

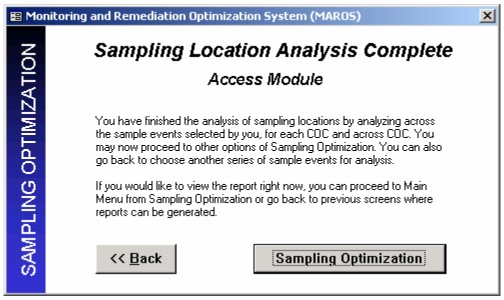
In this example, there are no triangles having “L” or “E” letters. Since the plume is stable to decreasing over time (see results from Plume Analysis), therefore no new locations need to be recommended. After viewing the results, the user can print out this chart or save it with a different name (Save As option) for future use.

Press “Back to Access” to return to the *Well Sufficiency Analysis – New Locations* screen or simply switch back by selecting the MAROS application.

In the *Well Sufficiency Analysis – New Locations* screen, click “Next >>” to proceed. The *Sampling Location Analysis Complete Access Module* screen will appear.

8) The Sampling Location Analysis is complete. The User may proceed to sampling frequency optimization analyses by selecting “Sampling Optimization”.

If the User wished to return to the location analysis for further modification and analysis choose “<< Back”.



Sampling Location Analysis Complete

Access Module

You have finished the analysis of sampling locations by analyzing across the sample events selected by you, for each COC and across COC. You may now proceed to other options of Sampling Optimization. You can also go back to choose another series of sample events for analysis.

If you would like to view the report right now, you can proceed to Main Menu from Sampling Optimization or go back to previous screens where reports can be generated.

Note: The redundancy reduction results based on the Delaunay method are provided in Table A.11.1. The user may notice that both the MAROS recommendation and qualitative evaluation were used in making the final recommendations. The reasoning in the table is only used to illustrate the importance of further considerations. In practice, the User may choose to do this for each module.

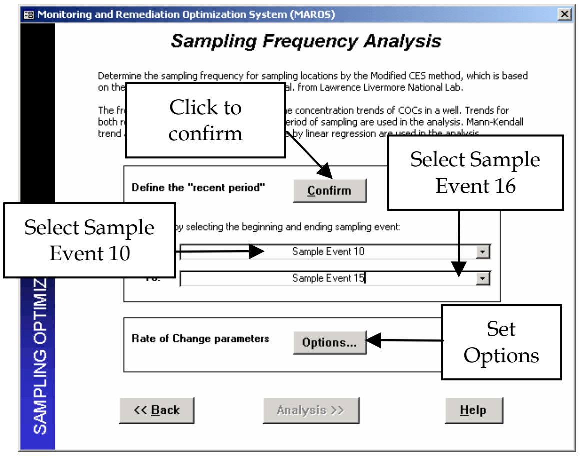
OPTION 2: SAMPLING FREQUENCY ANALYSIS

Select “Sampling Frequency Analysis” from the *Sampling Optimization Menu*. The *Sampling Frequency Analysis* screen will appear.

1) Define the “recent period” by selecting the beginning and ending sampling events. Select the starting sampling event from the “From” dropdown list and the final sampling event from the “To” dropdown list. The “From” sampling event must not be later than the “To” sampling event.

   The “recent period” is defined in order to calculate the recent concentration trend. This period should be shorter than the overall sampling history, if possible. The total sampling period should be greater than six sampling events for a meaningful result. The latest two or three years can be defined as the “recent period” as opposed to a total sampling time.

   Note: The sampling frequency analysis requires that at least six monitoring events be used. If less than six records are used in the analysis, the accuracy of the results may be significantly affected. Correspondingly, at least six sampling events are to be selected. For example, a period of two years will contain eight samples for a quarterly sampling while a three-year period is needed to generate six samples with a semiannual sampling. The analysis will still proceed with less than six samples but the recommended results may be inaccurate. Be aware that six sampling events do not necessarily lead to six samples because sampling could be skipped at certain events for some wells.



Monitoring and Remediation Optimization System (MAROS)

Sampling Frequency Analysis

Determine the sampling frequency for sampling locations by the Modified CES method, which is based on the al. from Lawrence Livermore National Lab.

The fr e concentration trends of COCs in a well. Trends for both r eriod of sampling are used in the analysis. Mann-Kendall trend by linear regression are used in the analysis.

Define the "recent period"

by selecting the beginning and ending sampling event:

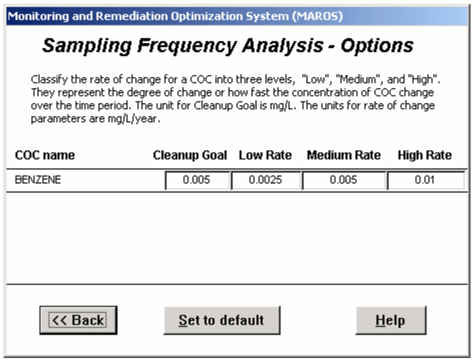
Sample Event 10

Sample Event 15

Rate of Change parameters

   In this example, select “Sample Event 10” from the “From” dropdown list and “Sample Event 16” from the “To” dropdown list. Click the “Confirm” button to confirm the selection. Notice that the “Analysis >>” button is now activated.

2) View or modify the Rate of Change (ROC) parameters by selecting “Options…” The *Sampling Frequency Analysis – Options* screen will appear.



Monitoring and Remediation Optimization System (MAROS)

Sampling Frequency Analysis - Options

Classify the rate of change for a COC into three levels, "Low", "Medium", and "High". They represent the degree of change or how fast the concentration of COC change over the time period. The unit for Cleanup Goal is mg/L. The units for rate of change parameters are mg/L/year.

COC name	Cleanup Goal	Low Rate	Medium Rate	High Rate
BENZENE	0.005	0.0025	0.005	0.01

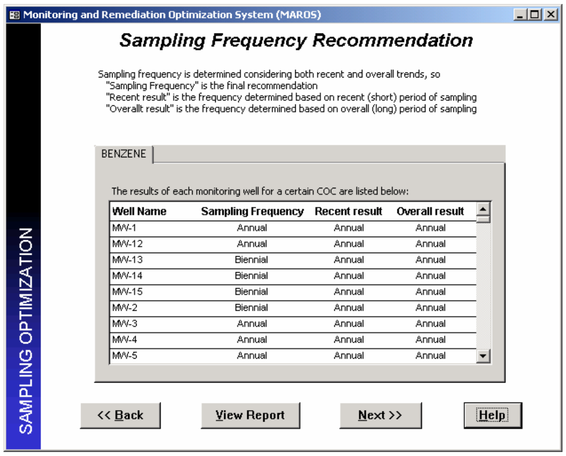
   The “Cleanup Goal” is generally the site-specific (or risk-based) cleanup goal for a COC. If the user does not provide this value, the software will use the maximum contaminant level (MCL) for that COC (Set under the COC Decision screen). The “Low Rate”, “Medium Rate”, and “High Rate” are threshold values used to classify the rate of change (i.e., the linear slope from concentrations vs. time regression). By default, the “Low Rate” is defined as 50% change of the “Cleanup Goal” per year, the “Medium Rate” as 100% change of the “Cleanup Goal” per year, and “High Rate” as 200% change of the “Cleanup Goal” per year. In this example, the default values will be used. Click the “Back” button to return to the *Sampling Frequency Analysis* screen.

   Note: The ROC parameters should be modified according to site-specific conditions and needs. For example, higher ROC parameters can be applied to sites/wells where concentration levels are consistently high and the ratio of ROC to concentration level is very small. Conversely, for sites/wells where concentration levels are around the cleanup goal, small ROC parameters need to be used to provide high sensitivity.

3) Click the “Analysis >>” button to perform the analysis. The *Sampling Frequency Recommendation* screen will appear. The “Recent Result” and the “Overall Result” represent the frequency determined from the recent data and the overall data, respectively. The “Sampling Frequency” is the final recommendation after balancing the results obtained from both recent and overall data.

Click the “View Report” button to view a result report where the recommended sampling frequency and other details are listed for each well and each COC. The user can print this report or export it in different formats.

Note: The frequency recommendations given by the MAROS software should be reviewed in light of the number of samples considered, number of non-detects, etc (see Table A.11.2 for example). For example, if all measurements at a well are non-detects and the detection levels are consistently low, a uniform value should be used to quantify the non-detects to avoid a false concentration trend, which may lead to an erroneous sampling frequency. Regulatory framework, community issues, and other site-specific situations must also be considered in the final decision-making (see Table A.11.2 for example). For example, if a sentry well provides early warning for a downgradient receptor, its sampling frequency may need to be set based on regulatory criteria even if all the measurements are non-detects and the recommendation is biennial.



Sampling Frequency Recommendation

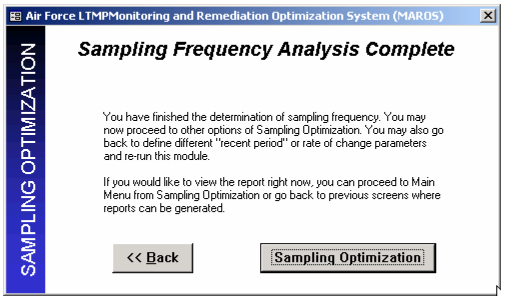
Sampling frequency is determined considering both recent and overall trends, so
"Sampling Frequency" is the final recommendation
"Recent result" is the frequency determined based on recent (short) period of sampling
"Overallt result" is the frequency determined based on overall (long) period of sampling

The results of each monitoring well for a certain COC are listed below:

Well Name	Sampling Frequency	Recent result	Overall result
MW-1	Annual	Annual	Annual
MW-12	Annual	Annual	Annual
MW-13	Biennial	Annual	Annual
MW-14	Biennial	Annual	Annual
MW-15	Biennial	Annual	Annual
MW-2	Biennial	Annual	Annual
MW-3	Annual	Annual	Annual
MW-4	Annual	Annual	Annual
MW-5	Annual	Annual	Annual

Click the “Next >>” button to proceed.

The *Sampling Frequency Analysis Complete* screen will appear. The User may now choose to perform the Data Sufficiency analysis by selecting “Sampling Optimization” or go back to modify the frequency analysis parameters by choosing “<< Back”.



Sampling Frequency Analysis Complete

You have finished the determination of sampling frequency. You may now proceed to other options of Sampling Optimization. You may also go back to define different "recent period" or rate of change parameters and re-run this module.

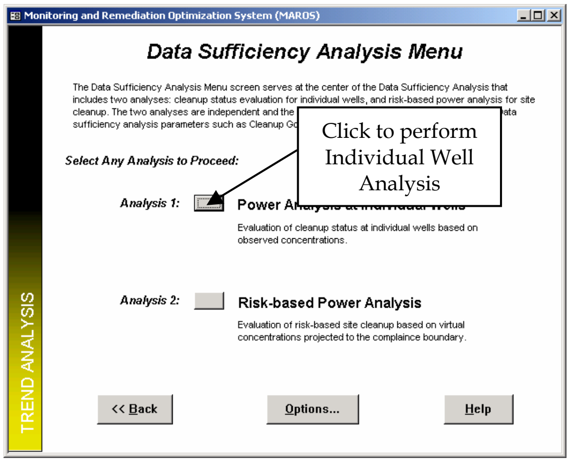
If you would like to view the report right now, you can proceed to Main Menu from Sampling Optimization or go back to previous screens where reports can be generated.

Click the “Sampling Optimization” button to proceed.

OPTION 3: DATA SUFFICIENCY ANALYSIS

Select "Data Sufficiency Analysis" from the *Sampling Optimization Menu*. The *Data Sufficiency Analysis Menu* screen will appear.

From the *Data Sufficiency Analysis Menu* screen the User can choose to perform the power analysis at individual wells and/or risk-based power analysis.



Data Sufficiency Analysis Menu

The Data Sufficiency Analysis Menu screen serves at the center of the Data Sufficiency Analysis that includes two analyses: cleanup status evaluation for individual wells, and risk-based power analysis for site
cleanup. The two analyses are independent and the
sufficiency analysis parameters such as Cleanup Go

Select Any Analysis to Proceed:

Power A

Evaluation of cleanup status at individual wells based on observed concentrations.

Risk-based Power Analysis

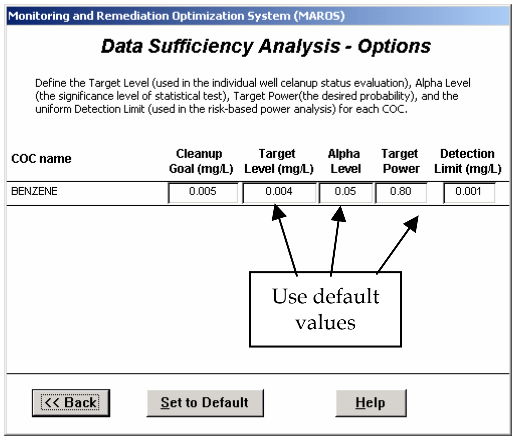
Evaluation of risk-based site cleanup based on virtual concentrations projected to the complaince boundary.

Click to perform Individual Well Analysis

1) View or modify analysis parameters by clicking the "Options…" button. The *Data Sufficiency Analysis – Options* screen will appear.

   The "Cleanup Goal" is the site-specific (or risk-based) cleanup goal for a COC, as described earlier. The "Target Level" is the statistical concentration level the remediation is aimed to achieve, which should be smaller than the "Cleanup Goal", indicating that the concentration level after remediation is below the cleanup level. The "Target Level" is set by default to 80% of the "Cleanup Goal". The "Alpha Level" is the type I error (or significance level) used in a statistical test.

   The "Target Power" is the probability of detecting a true change in the concentration level before and after the remediation. It is equal to 1 minus type II error (1-β). The default values for the "Alpha Level" and "Target Power" are 0.05 and 0.80, respectively. The "Detection Limit" is used in the risk-based power analysis to indicate that a projected concentration is below the detection limit.



Data Sufficiency Analysis - Options

Define the Target Level (used in the individual well celanup status evaluation), Alpha Level (the significance level of statistical test), Target Power(the desired probability), and the uniform Detection Limit (used in the risk-based power analysis) for each COC.

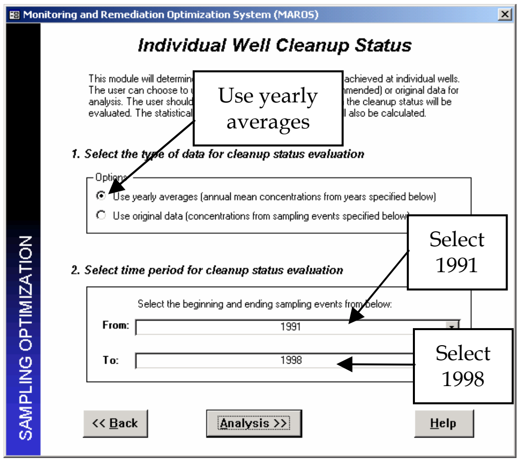
COC name	Cleanup Goal (mg/L)	Target Level (mg/L)	Alpha Level	Target Power	Detection Limit (mg/L)
BENZENE	0.005	0.004	0.05	0.80	0.001

Use default values

   In this example, all default parameters will be used. Click the "<< Back" button to return to the *Data Sufficiency Analysis Menu* screen.

2) Select "Power Analysis at Individual Wells" from the *Data Sufficiency Analysis Menu* screen to perform the individual well power analysis. The *Individual Well Cleanup Status* screen will appear.

   First, select the type of data for analysis by clicking on one of the options buttons. One choice is to use yearly averages and the other is to use original data. Using yearly averages can avoid potential seasonal effects in the monitoring data and may also remove autocorrelation. If there are many years of data available, using yearly averages is recommended. In this example, select "Use yearly averages".



Individual Well Cleanup Status

This module will determin | achieved at individual wells.
The user can choose to | mmended) or original data for
analysis. The user should | the cleanup status will be
evaluated. The statistical | l also be calculated.

1. Select the type of data for cleanup status evaluation

Options
● Use yearly averages (annual mean concentrations from years specified below)
○ Use original data (concentrations from sampling events specified below)

2. Select time period for cleanup status evaluation

Select the beginning and ending sampling events from below:

From: 1991

To: 1998

Use yearly averages

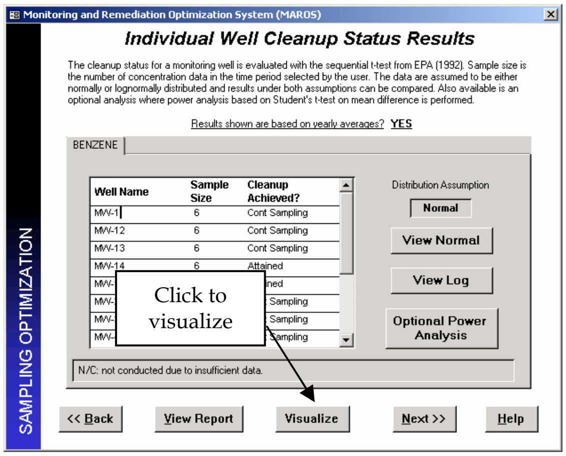
Select 1991

Select 1998

Select the beginning and ending sampling events from the “From” and “To” dropdown lists to define the period to be used in the analysis. Select 1991 from the “From” dropdown list and 1998 from the “To” dropdown list.

Click the “Analysis >>” button to proceed. The *Individual Well Cleanup Status Results* screen will appear.

3) The *Individual Well Cleanup Status Results* screen shows the analysis results in a table format and allows the user to visualize the results spatially.



Individual Well Cleanup Status Results

The cleanup status for a monitoring well is evaluated with the sequential t-test from EPA (1992). Sample size is the number of concentration data in the time period selected by the user. The data are assumed to be either normally or lognormally distributed and results under both assumptions can be compared. Also available is an optional analysis where power analysis based on Student's t-test on mean difference is performed.

Results shown are based on yearly averages? YES

BENZENE

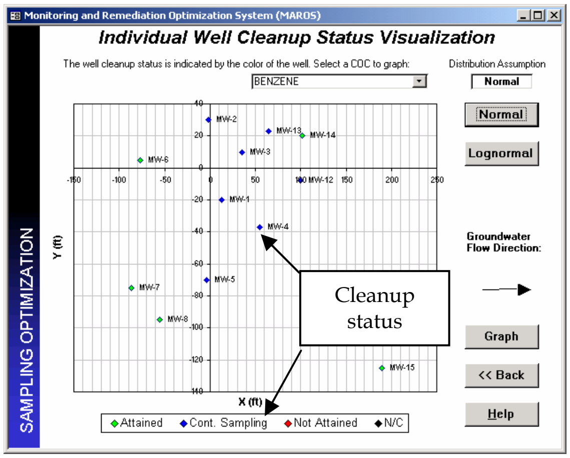
Well Name	Sample Size	Cleanup Achieved?
MW-1	6	Cont Sampling
MW-12	6	Cont Sampling
MW-13	6	Cont Sampling
MW-14	6	Attained
MW-		ned
MW-		Sampling
MW-		Sampling
MW-		Sampling

Distribution Assumption: Normal

N/C: not conducted due to insufficient data.

The “Sample Size” column contains the number of yearly averages used in the analysis. The “Cleanup Achieved?” column shows the cleanup status at each well. There are four types of results: Attained, Not Attained, Cont Sampling (continue sampling), and N/C (not conducted). The detailed results of the analysis are given in a report that can be accessed by clicking the “View Report” button.

The “View Normal” and “View Lognormal” buttons allow the user to view results calculated assuming that the data are normally distributed and lognormally distributed, respectively. The “Optional Power Analysis” button allows the User to enter another screen where detailed power analysis results are provided (refer to the Appendix A.6 in the User’s Guide for details of the analysis).



The well cleanup status is indicated by the color of the well. Select a COC to graph: BENZENE

Distribution Assumption: Normal

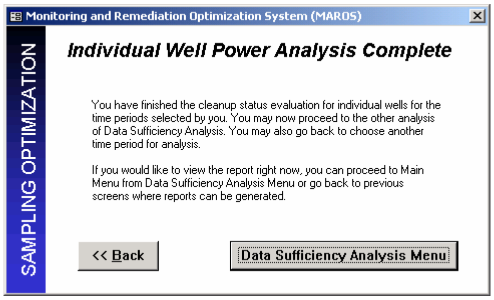
To visualize the cleanup status spatially, click the “Visualize” button and the *Individual Well Cleanup Status Visualization* screen will appear.

The cleanup status of each well is indicated with colored symbols on a scatter plot. The plot allows the User to have a better understanding of the spatial distribution of individual wells’ cleanup status over the site.

Click the “<< Back” button to return and then click “Next >>” on the *Individual Well Cleanup Status Results* screen to proceed.

The *Individual Well Power Analysis Complete* screen will appear.

Click the “Data Sufficiency Analysis Menu” button to return to the *Data Sufficiency Analysis Menu* screen.



Individual Well Power Analysis Complete

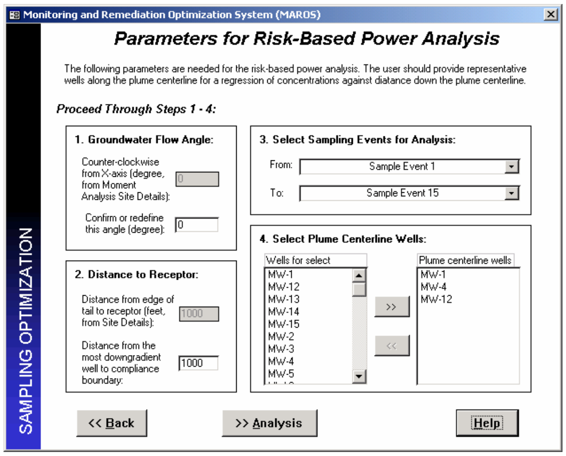
You have finished the cleanup status evaluation for individual wells for the time periods selected by you. You may now proceed to the other analysis of Data Sufficiency Analysis. You may also go back to choose another time period for analysis.

If you would like to view the report right now, you can proceed to Main Menu from Data Sufficiency Analysis Menu or go back to previous screens where reports can be generated.

4) Select “Risk Based Power Analysis” from the *Data Sufficiency Analysis Menu* screen to perform the risk-based (site-scale or plume-level) power analysis. The *Parameters for Risk-Based Power Analysis* screen will appear.

Under “Groundwater Flow Angle”, input the groundwater flow angle—315, if it is not already present.

For the “Distance to Receptor”, input 1000 to confirm the distance. This distance is then used to locate the hypothetical statistical compliance boundary (HSCB). In this example, the HSCB is 1000 ft downgradient from the tail of the monitoring network. Then select “Sample Event 1” from the “From” dropdown list and “Sample Event 16” from the “To” dropdown list. The software will calculate the risk-based cleanup status for all sample events.



Parameters for Risk-Based Power Analysis

The following parameters are needed for the risk-based power analysis. The user should provide representative wells along the plume centerline for a regression of concentrations against diatance down the plume centerline.

Proceed Through Steps 1 - 4:

1. Groundwater Flow Angle:

Counter-clockwise from X-axis (degree, from Moment Analysis Site Details): 0

Confirm or redefine this angle (degree): 0

2. Distance to Receptor:

Distance from edge of tail to receptor (feet, from Site Details): 1000

Distance from the most downgradient well to compliance boundary: 1000

3. Select Sampling Events for Analysis:

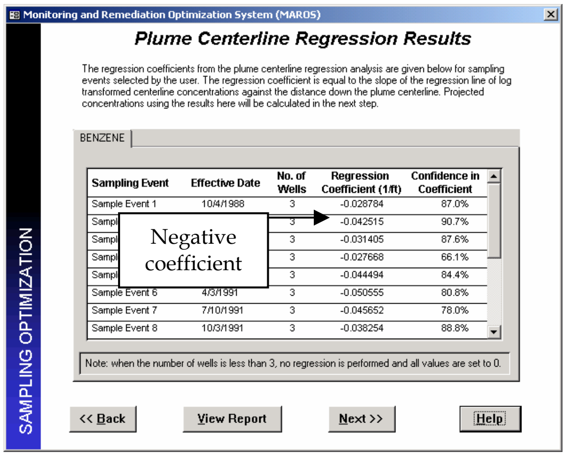
From: Sample Event 1

To: Sample Event 15

4. Select Plume Centerline Wells:

Wells for select	Plume centerline wells
MW-1 MW-12 MW-13 MW-14 MW-15 MW-2 MW-3 MW-4 MW-5	MW-1 MW-4 MW-12

To select plume centerline wells (at least three wells are required for the analysis), consult the plume contour map and pick wells that are located on or close to the plume centerline. In this example, MW-1, MW-4, MW-11 and MW-15 can be used for an approximate analysis. Use the “>>” button to add the three wells into the “Plume centerline wells” group. Use the “”<<” button to delete a well from the “Plume centerline wells” group.



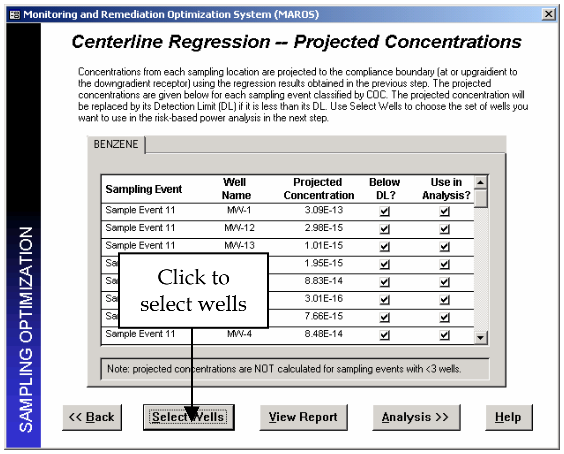
Plume Centerline Regression Results

The regression coefficients from the plume centerline regression analysis are given below for sampling events selected by the user. The regression coefficient is equal to the slope of the regression line of log transformed centerline concentrations against the distance down the plume centerline. Projected concentrations using the results here will be calculated in the next step.

Sampling Event	Effective Date	No. of Wells	Regression Coefficient (1/ft)	Confidence in Coefficient
Sample Event 1	10/4/1988	3	-0.028784	87.0%
Sampl		3	-0.042515	90.7%
Sampl		3	-0.031405	87.6%
Sampl		3	-0.027668	66.1%
Sampl		3	-0.044494	84.4%
Sample Event 6	4/3/1991	3	-0.050555	80.8%
Sample Event 7	7/10/1991	3	-0.045652	78.0%
Sample Event 8	10/3/1991	3	-0.038254	88.8%

Note: when the number of wells is less than 3, no regression is performed and all values are set to 0.

After inputting the above information, click the “>> Analysis” button to proceed. The *Plume Centerline Regression Results* screen will appear. The regression coefficient (from the exponential regression of centerline concentrations vs. distance down centerline) and the confidence associated with the coefficient are displayed for each sample event. The regression analysis is performed only for events in which at least three centerline wells were sampled. Note the regression coefficients are all negative, indicating the concentration is decaying along the plume centerline.



Centerline Regression -- Projected Concentrations

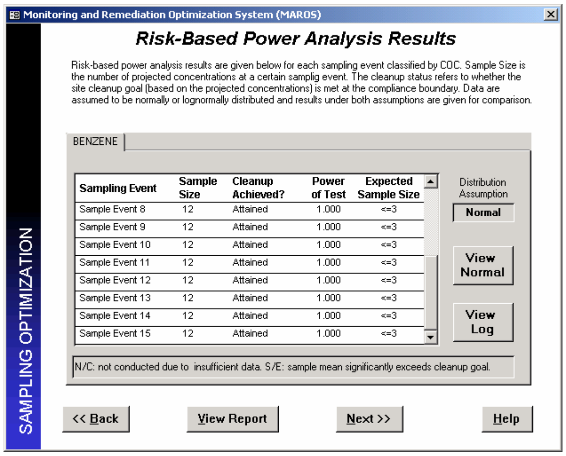
Concentrations from each sampling location are projected to the compliance boundary (at or upgraidient to the downgradient receptor) using the regression results obtained in the previous step. The projected concentrations are given below for each sampling event classified by COC. The projected concentration will be replaced by its Detection Limit (DL) if it is less than its DL. Use Select Wells to choose the set of wells you want to use in the risk-based power analysis in the next step.

Sampling Event	Well Name	Projected Concentration	Below DL?	Use in Analysis?
Sample Event 11	MW-1	3.09E-13	☑	☑
Sample Event 11	MW-12	2.98E-15	☑	☑
Sample Event 11	MW-13	1.01E-15	☑	☑
Sa		1.95E-15	☑	☑
Sa		8.83E-14	☑	☑
Sa		3.01E-16	☑	☑
Sa		7.66E-15	☑	☑
Sample Event 11	MW-4	8.48E-14	☑	☑

Note: projected concentrations are NOT calculated for sampling events with <3 wells.

Click the “Next >>” button to proceed. The *Centerline Regression – Projected Concentrations* screen will appear. The “Projected Concentration” is the concentration projected to the HSCB. If this value is less than the previously defined detection limit, a check mark will appear in the box besides it. In this example, since all projected concentrations are below the detection limit, intuitively the risk-based cleanup status should be “Attained”.

If some wells need to be excluded from the analysis, click the “Select Wells” button and finish the selection in the *Well Selection Form* screen. In this screen, deselect a well by unchecking the checkbox in the “Used in Analysis?” column. The deselected well will be excluded from analysis for all sample events. In this example, all wells will be used in the analysis. Click the “<< Back” button to return.



Risk-Based Power Analysis Results

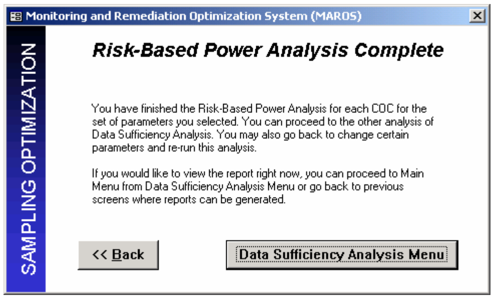
Risk-based power analysis results are given below for each sampling event classified by COC. Sample Size is the number of projected concentrations at a certain samplig event. The cleanup status refers to whether the site cleanup goal (based on the projected concentrations) is met at the compliance boundary. Data are assumed to be normally or lognormally distributed and results under both assumptions are given for comparison.

Sampling Event	Sample Size	Cleanup Achieved?	Power of Test	Expected Sample Size
Sample Event 8	12	Attained	1.000	<=3
Sample Event 9	12	Attained	1.000	<=3
Sample Event 10	12	Attained	1.000	<=3
Sample Event 11	12	Attained	1.000	<=3
Sample Event 12	12	Attained	1.000	<=3
Sample Event 13	12	Attained	1.000	<=3
Sample Event 14	12	Attained	1.000	<=3
Sample Event 15	12	Attained	1.000	<=3

N/C: not conducted due to insufficient data. S/E: sample mean significantly exceeds cleanup goal.

Click the “Analysis >>” button on the *Centerline Regression – Projected Concentrations* screen to proceed. The *Risk-Based Power Analysis Results* screen will appear. In this screen, the risk-based cleanup status, power and expected sample size for each sample event are listed over time. The cleanup status as a function of time may reflect the progress in remediation (e.g., from Not Attained → Attained).

In this example, the cleanup status is “Attained” for all sample events at the HSCB. The “View Normal” and “View Lognormal” buttons allow the User to view results calculated assuming that the data are normally distributed and lognormally distributed, respectively. A detailed result report can be generated by clicking the “View Report” button. Click the “Next >>” button to proceed.



Risk-Based Power Analysis Complete

You have finished the Risk-Based Power Analysis for each COC for the set of parameters you selected. You can proceed to the other analysis of Data Sufficiency Analysis. You may also go back to change certain parameters and re-run this analysis.

If you would like to view the report right now, you can proceed to Main Menu from Data Sufficiency Analysis Menu or go back to previous screens where reports can be generated.

The *Risk-Based Power Analysis Complete* screen will appear. To modify the analysis parameters and re-run the analyses, click the “<< Back” button.

Click the “Data Sufficiency Analysis Menu” button to return to the *Data Sufficiency Analysis Menu* screen.

Note: The above-described data sufficiency analyses have some implicit assumptions. For the correct use and a better understanding of the power analysis method, refer to Appendix A.6 of the User’s Guide.

To print report/graphs after all analyses are finished, click “<< Back” on the *Data Sufficiency Analysis Menu* screen and then click the “Main Menu” button on the *Sampling Optimization Menu* screen.

From the *Main Menu* screen, select “MAROS output Reports/Graphs” to view or print reports and graphs.

TABLE A.11.1 SAMPLING LOCATION OPTIMIZATION RESULTS BASED ON THE DELAUNAY METHOD

Well	Used in analysis?	MAROS Results	Final Recommendation	Reasoning
MW-1	Yes	Keep	Keep	
MW-11	Yes	Keep	Keep	
MW-12	Yes	**Eliminate**	**Keep**	A downgradient well on the plume centerline, providing important information for plume delineation and stability calculation. It needs to be kept.
MW-13	Yes	Keep	Keep	
MW-14	Yes	Keep	Keep	
MW-15	Yes	Keep	Keep	
MW-16	Yes	**Eliminate**	**Eliminate**	Redundant with well MW-4.
MW-2	Yes	Keep	Keep	
MW-3	Yes	**Eliminate**	**Eliminate**	In the source area of the plume where well density is high. It can be eliminated without significantly affect the plume characterization.
MW-4	Yes	**Eliminate**	**Keep**	A down/cross gradient well close to the plume centerline, used to monitor the lateral migration plume. *If the plume is proved to be shrinking and falls to below detection level at this area, this well can be eliminated*.
MW-5	Yes	Keep	Keep	
MW-6	Yes	Keep	Keep	
MW-7	Yes	Keep	Keep	
MW-8	Yes	Keep	Keep	

Sample events 10 to 15 were used in the above analysis. The analysis parameters are 0.20, 0.01, 0.95, and 0.95 for Inside Node Slope Factor, Hull Node Slope Factor, Area Ratio and the Concentration Ratio, respectively.

TABLE A.11.2 SAMPLING FREQUENCY OPTIMIZATION RESULTS BASED ON THE MCES METHOD

Well	Original Frequency	MAROS Recommended Frequency	Final Recommendation	Reasoning
MW-1	Semiannual since 96	Annual	Annual	
MW-12	Semiannual since 96	Annual	**Semiannual**	Most downgradient along the plume centerline and serve as a sentry well
MW-13	Semiannual since 96	Biennial	Biennial	Non-detects or below MCL since 94 & in the central part of the plume
MW-14	Semiannual since 96	Biennial	**Annual**	Non-detects since 91 but monitors the downgradient part of plume
MW-15	Semiannual since 96	Biennial	**Biennial**	All historical concentrations are Non-detects and far from plume
MW-2	Semiannual since 96	Biennial	**Annual**	Non-detects or below MCL since 94 but it monitors the lateral migration of plume near the source
MW-3	Semiannual since 96	Annual	Annual	Recommended for elimination
MW-4	Semiannual since 96	Annual	Annual	
MW-5	Semiannual since 96	Annual	Annual	
MW-6	Semiannual since 96	Biennial	Biennial	All historical concentrations are nondetects & an upgradient well
MW-7	Semiannual since 96	Biennial	Biennial	All historical concentrations are nondetects or below MCL & an upgradient well
MW-8	Semiannual since 96	Biennial	Biennial	All historical concentrations are nondetects or below MCL & a cross-gradient well in the upgradient section of the plume
The default ROC parameters were used in the above analysis, i.e., 0.5MCL/year, 1.0MCL/year, and 2.0MCL/year for the Low, Medium, and High thresholds, respectively.				

MAROS Output

At this point in the software the user has gone through all of the optimization utilities and can begin to consolidate the knowledge of the site with the MAROS analysis results to make a final determination of the site optimization. The goal of the tutorial is to show the user tips and pitfalls when applying MAROS at a typical site. The tutorial example has been used only to illustrate the utilities of the MAROS software and it is by no means a complete site analysis.

Step 5, *MAROS Output Reports/Graphs* allows the user to view/print reports and graphs from the site trend analyses as well as a preliminary Site Recommendation Report.

This allows production of standard Reports, including the one-page heuristic approach to sampling optimization based on plume stability and site parameters with results for sampling frequency, duration and density. Samples of MAROS Reports are located in Appendix A.10.

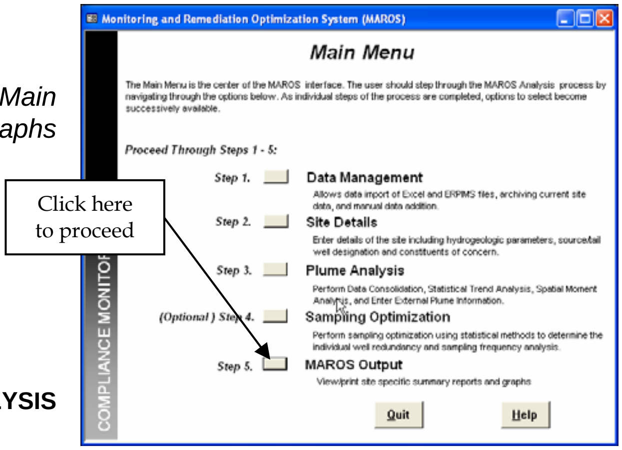
The Reports can be used to review results and assess the project objectives defined at the start of the tutorial.

The MAROS output results should also be reviewed before proceeding to a final decision on optimization of the monitoring network to ensure that the trends in the data are fully understood. Spend time reviewing the data and trend results, both spatially and temporally. Try to identify any spurious data or “outliers”. Here are some examples of questions to be asked:

- Which wells have actual trends for benzene concentration and which do not (see Graph *Trend Summary Results: Graphing* and Report *MAROS Plume Analysis summary*).
- From the trend analysis results, is the plume increasing or decreasing? (see Report *MAROS Spatial Moment Analysis Summary*, Zero Moment)
- Is the plume moving? (see Report *MAROS Spatial Moment Analysis Summary*, First Moment)
- What are the trends in benzene concentrations over time? (see Graphs *Linear Regression Graphs* and *Mann Kendall Graphs*)
- Review the Mann-Kendall and Linear Regression Trends. Are there any differences for different wells? (See Report *MAROS Plume Analysis summary* and Mann-Kendall and Linear Regression plots for individual wells)
- Are there wells on the outside of the monitoring network with increasing concentrations? (see Graph *Trend Summary Results: Graphing* and Report *MAROS Plume Analysis summary*)
- Review data based on qualitative knowledge of the site, for example, is there a reason for one well to be showing a sudden detected concentration having been persistently non-detect?
- Review the parameters selected for the data consolidation and the analysis (see Report *MAROS Site Results*).

STEP 1: MAIN MENU

Select Step 5 “MAROS Output” from the *Main Menu*. The *MAROS Output Reports/Graphs* screen will be displayed.



The Main Menu is the center of the MAROS interface. The user should step through the MAROS Analysis process by navigating through the options below. As individual steps of the process are completed, options to select become successively available.

Proceed Through Steps 1 - 5:

Allows data import of Excel and ERPIMS files, archiving current site data, and manual data addition.

Enter details of the site including hydrogeologic parameters, source/tail well designation and constituents of concern.

Perform Data Consolidation, Statistical Trend Analysis, Spatial Moment Analysis, and Enter External Plume Information.

Perform sampling optimization using statistical methods to determine the individual well redundancy and sampling frequency analysis.

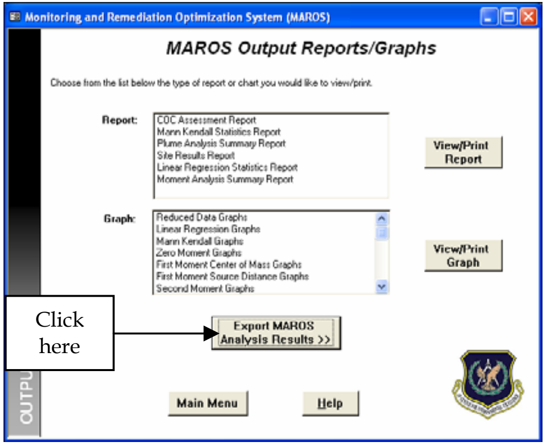
View/print site specific summary reports and graphs

OPTION1: EXPORT MAROS ANALYSIS RESULTS

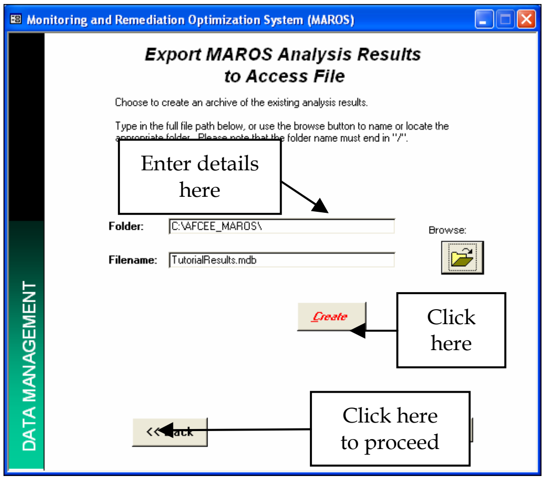
1) Save the output results before you close the software. Results from the current analysis should be exported to a database file for future use or comparison with other analyses. The exported file is an Access database (mdb) and will not contain the report formats above. Reports to be saved should be printed as hard copies or printed to pdf files before the software is closed. The MAROS output file will be in database table format, which can be exported to Excel or imported as database files into GIS and other software, but cannot be used to quickly generate the MAROS reports.

   Select “Export MAROS Analysis Results”.

   The *Export MAROS Analysis Results to Access File* screen is displayed.



Choose from the list below the type of report or chart you would like to view/print.



Choose to create an archive of the existing analysis results.

Type in the full file path below, or use the browse button to name or locate the appropriate folder. Please note that the folder name must end in "/".

Folder: C:\AFCEE_MAROS\

Filename: TutorialResults.mdb

Enter or Browse to the folder name and the name of the file to create:

The file name should clearly indicate that it is a MAROS *output* file. The User may want to include a date or other indicator of when or how the analysis was conducted. MAROS output files should not be confused with MAROS archive files (importing output files causes MAROS to crash, and the software must be re-loaded).

- Folder: “C:\AFCEE_MAROS\”
- Filename: “TutorialOutput.mdb”

Select “Create”.

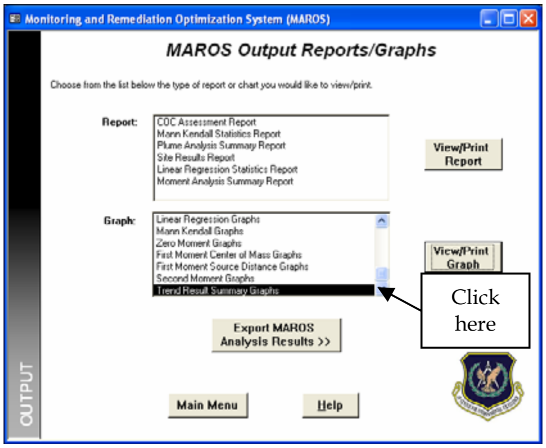
Click “Back” to return to the *MAROS Output Reports/Graphs* screen.

OPTION 2: MAROS OUTPUT REPORTS/GRAPHS

MAROS Output Reports/Graphs allows the user to view/print reports and graphs from the site trend analyses as well as a preliminary Site Recommendation Report. Reports and graphs are not saved along with either the Archive or Output mdb files. Reports containing results of the current analysis must be printed before closing the MAROS application. Electronic copies of the reports can be saved by printing the report to Adobe Acrobat and saving the file in pdf format. Only Reports generated from completed modules are displayed in the MAROS Output dialog box. If the User has not completed a module, such as the Data Sufficiency Analysis, results for this option will not be available in the window.

To select a report or graph, click on the title, then select “View/Print Report” or “View/Print Graph”.

1) To view the MAROS trend summary results in tabular and graphical format:



Choose from the list below the type of report or chart you would like to view/print.

Under “Graph”, click on the arrow at the bottom right hand corner of the text box. The option “Trend Summary Graphs” should be visible.

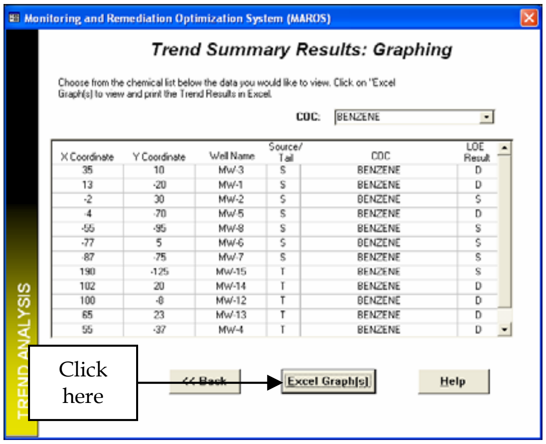
Select “Trend Summary Graphs”.

Click on “View/Print Graph” to display a table of data.

Trend Summary Results: Graphing allows the user to view/print graphical summary results in Excel.

Select “Excel Graph(s)” to spatially display the data. This will open Excel on your computer to provide the trend result graphs.

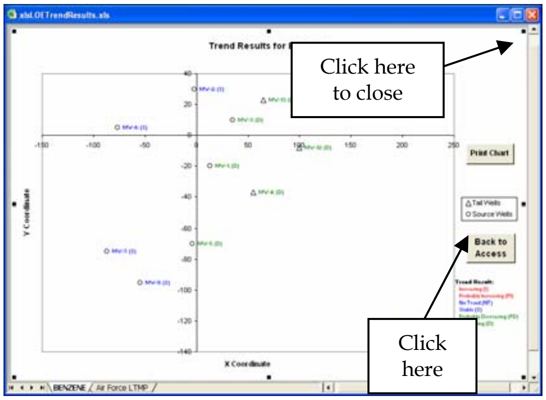
Trend Summary Result: allows the user to view/print graphical Trend Summary Results in Excel.



Choose from the chemical list below the data you would like to view. Click on 'Excel Graph(s) to view and print the Trend Results in Excel.

X Coordinate	Y Coordinate	Well Name	Source/ Tail	COC	LOE Result
35	10	MW-3	S	BENZENE	D
13	-20	MW-1	S	BENZENE	D
-2	30	MW-2	S	BENZENE	S
-4	-70	MW-5	S	BENZENE	D
-55	-95	MW-8	S	BENZENE	S
-77	5	MW-6	S	BENZENE	S
-87	-75	MW-7	S	BENZENE	S
190	-125	MW-15	T	BENZENE	S
102	20	MW-14	T	BENZENE	D
100	-8	MW-12	T	BENZENE	D
65	23	MW-13	T	BENZENE	D
55	-37	MW-4	T	BENZENE	D

Trend results should be reviewed for all wells to check for reasonable results.



Click here to close

Click here

Select "Print Chart" to print the current summary graph.

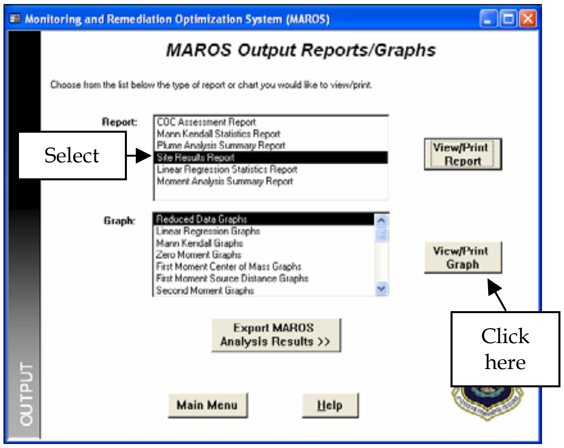
Click on the close button ("X" at the top right hand corner of the screen) to close the window or select "Back to Access" to return to the Trend Summary Results.

Select "Back to Access" to return to the *MAROS Output Reports/Graphs* screen.

Note: The *xlsLOETrendResults* file must remain in the same folder as the MAROS 2.1 application file. Do not change the name or content of the worksheet *xlsLOETrendResults* or move it to other folders. The results can be saved by using the 'Save As' option under the Excel File menu, and saving the file under a different name for later use. The *xlsLOETrendResults* worksheet will remain open until the user closes it. All the results and graph output are kept if the user chooses to save the file before closing it.

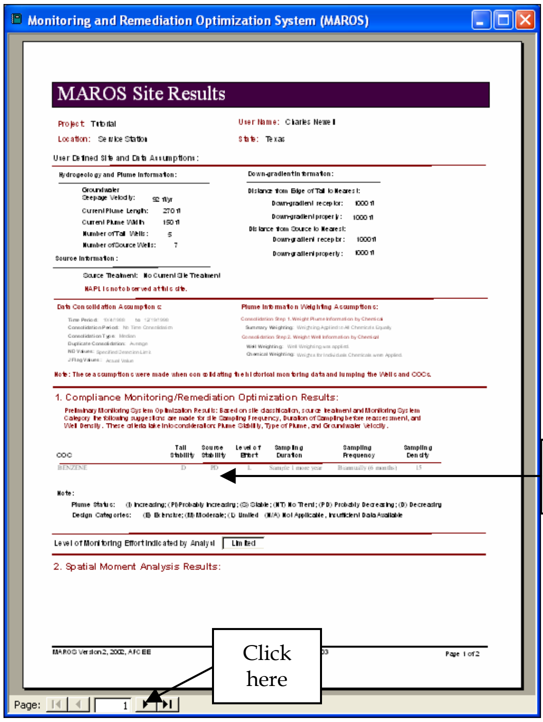
2) To view the *Site Report*, select "Site Report" from the first list of options under the heading "Report".

Select "View/Print Report" to display the MAROS Site Results report.



Select

Click here



MAROS Site Results

Project: Tutorial
Location: Service Station
User Name: Charles Newell
State: Texas

User Defined Site and Data Assumptions:

Hydrogeology and Plume Information:
Groundwater Seepage Velocity: 92 ft/yr
Current Plume Length: 270 ft
Current Plume Width: 150 ft
Number of Tail Wells: 5
Number of Source Wells: 7

Down-gradient Information:
Distance from Edge of Tail to Nearest:
Down-gradient receptor: 1000 ft
Down-gradient property: 1000 ft
Distance from Source to Nearest:
Down-gradient receptor: 1000 ft
Down-gradient property: 1000 ft

Source Information:
Source Treatment: No Current Site Treatment
NAPL is not observed at this site.

Data Consolidation Assumptions:
Time Period: [illegible] to [illegible]
Consolidation Period: No Time Consolidation
Consolidation Type: Median
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values: Actual Value

Plume Information Weighting Assumptions:
Consolidation Step 1. Weight Plume Information by Chemical
Summary Weighting: Weighting Applied to All Chemicals Equally
Consolidation Step 2. Weight Well Information by Chemical
Well Weighting: Well Weighting was applied.
Chemical Weighting: Weights for Individuals Chemicals were Applied.

Note: These assumptions were made when consolidating the historical monitoring data and lumping the Wells and COCs.

1. Compliance Monitoring/Remediation Optimization Results:

Preliminary Monitoring System Optimization Results: Based on site classification, source treatment and Monitoring System Category the following suggestions are made for site Sampling Frequency, Duration of Sampling before reassessment, and Well Density. These criteria take into consideration: Plume Stability, Type of Plume, and Groundwater Velocity.

COC	Tail Stability	Source Stability	Level of Effort	Sampling Duration	Sampling Frequency	Sampling Density
BENZENE	D	PD	L	Sample 1 more year	Biannually (6 months)	15

Note:
Plume Status: (I) Increasing; (PI) Probably Increasing; (S) Stable; (NT) No Trend; (PD) Probably Decreasing; (D) Decreasing
Design Categories: (E) Extensive; (M) Moderate; (L) Limited (N/A) Not Applicable, Insufficient Data Available

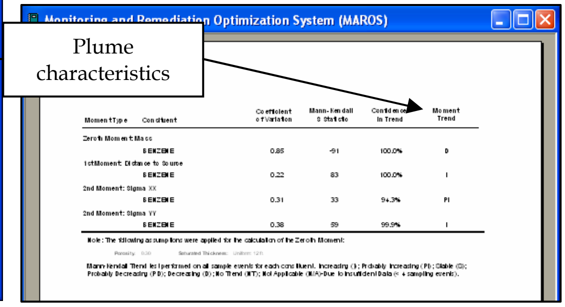
Level of Monitoring Effort Indicated by Analysis: Limited

2. Spatial Moment Analysis Results:

MAROS Version 2, 2002, AFCEE
Page 1 of 2

Click here

Page 1 of the report is displayed. To select Page 2, click on the arrow next to "1" at the bottom of the screen.



Plume characteristics

Moment Type	Constituent	Coefficient of Variation	Mann-Kendall S Statistic	Confidence in Trend	Moment Trend
Zeroth Moment: Mass					
	BENZENE	0.85	-91	100.0%	D
1st Moment: Distance to Source					
	BENZENE	0.22	83	100.0%	I
2nd Moment: Sigma XX					
	BENZENE	0.31	33	94.3%	PI
2nd Moment: Sigma YY					
	BENZENE	0.38	59	99.9%	I

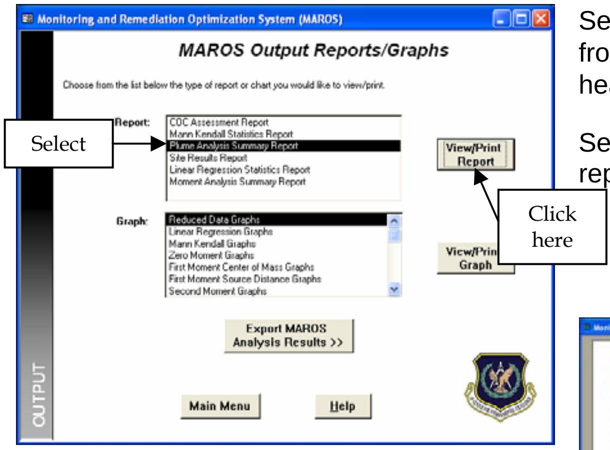
Note: The following assumptions were applied for the calculation of the Zeroth Moment:

Mann-Kendall Trend test performed on all sample events for each constituent. Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A)-Due to Insufficient Data (< 4 sampling events).

The plume characteristics are displayed on this report. The source is classified as "PD", probably decreasing and the plume tail as "PD", decreasing.

The plume mass is decreasing (zeroth moment result "D") and the plume is moving from away from the source (first moment result "I"). The plume is not spreading appreciably (second moment result "NT" and "S").

3) To view the trend results for individual wells, select the report *Plume Analysis Summary Report*.



Choose from the list below the type of report or chart you would like to view/print.

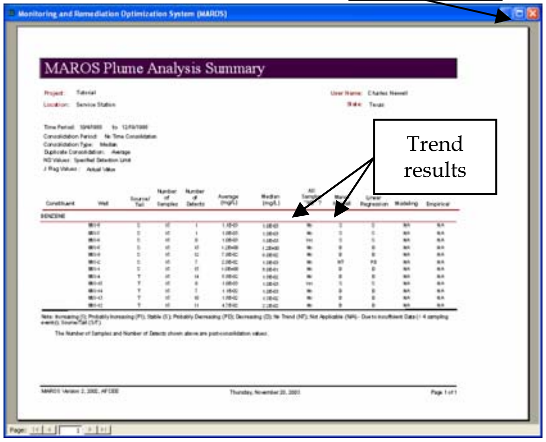
Select

Click here

Select "Plume Analysis Summary Report" from the first list of options under the heading "Report".

Select "View/Print Report" to display the report.

Click here to close

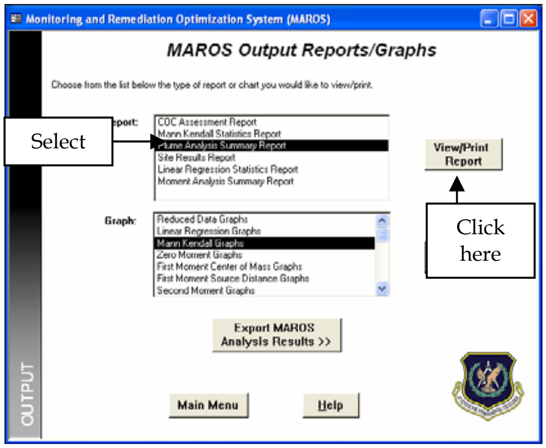


Trend results

The Mann Kendall and Linear Regression trend results for each well are consistent except for well MW-2.

For this well review the data spatially.

(All trend results are also stored in the exported mdb output file, which can conveniently be exported to Excel.)



Choose from the list below the type of report or chart you would like to view/print.

Select

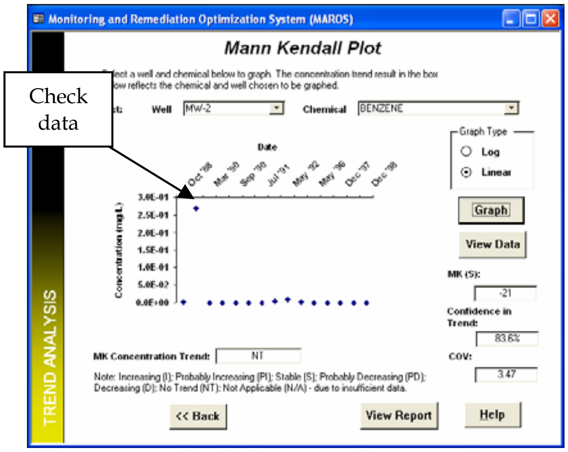
Click here

Select "Mann Kendall Graphs" from the main menu.

Click on "View/Print Graph" to display a plot of data.

A plot of data for MW-1 will be displayed. Select MW-2 from the drop down box in the top right hand corner of the screen, then click on "Graph" to plot.

The plot for MW-2 shows that one data point may be erroneous. The single detection may be a true value or it may be an artifact of sampling, a result of poor sample labeling or a laboratory artifact. The source of this data should be reviewed.



lect a well and chemical below to graph. The concentration trend result in the box ow reflects the chemical and well chosen to be graphed.

Well: MW-2
Chemical: BENZENE
Graph Type: ○ Log ● Linear
MK (S): -21
Confidence in Trend: 83.6%
MK Concentration Trend: NT
COV: 3.47

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - due to insufficient data.

If this point was not included in the data set, the trend results may be different.

It is generally useful to identify wells with all non-detect results. Non-detect wells will often appear as having ‘Stable’ trends when a uniform detection limit is chosen. However, if actual detection limits are chosen, non-detect wells can indicate spurious trends.

Select “Back” to return to the *MAROS Output Reports/Graphs* screen.

Tutorial Site Conclusions

At this point in the software the user has gone through all of the optimization utilities and can consolidate the knowledge of the site with the MAROS analysis results to make a final determination of the site optimization. **The goal of the tutorial is to show the user tips and pitfalls when applying MAROS at a typical site. The tutorial example has been used only to illustrate the utilities of the MAROS software and it is by no means a complete site analysis.**

Results from the temporal trend analysis, moment analysis, sampling location determination, sampling frequency determination, and data frequency analysis indicate that:

- The 7 site monitoring source wells are located near the Tank Field. These have historically elevated benzene concentrations. There are 7 tail wells.
- 3 out of 7 source wells and 5 out of 7 tail wells have a “Decreasing” trend. 4 out of 7 source wells and 1 out of 7 tail wells have a “Stable” trend. One tail well has a Probably Increasing trend. Both the statistical methods used to evaluate trends (Mann-Kendall and Linear Regression) gave similar trend estimates for each well.
- 1 source well appears to have a suspect data point which should be investigated further (MW-2).
- The dissolved mass is decreasing over time, whereas the center of mass shows an increase in distance over time in relation to the source location. The plume shows variable spreading the direction of groundwater flow and a stable trend in the direction perpendicular to groundwater flow. However, the trend results do show overall decreasing concentrations in individual wells.
- Overall plume stability results indicate that a monitoring system of “Limited” intensity is appropriate for this monitoring network due to a stable Upper Aquifer plume.
- The well redundancy optimization tool, using the Delaunay method, indicates that 3 existing monitoring wells may not be needed for plume monitoring and can be eliminated from the original monitoring network of 14 wells without compromising the accuracy of the monitoring network. Further analysis indicates that only 2 of these wells could be comfortably removed.
- The well sufficiency optimization tool, using the Delaunay method, indicates that no new monitoring wells are needed for the existing monitoring network.
- The well sampling frequency tool, the Modified CES method, indicates the number of samples collected over time can potentially be reduced by 56% by sampling at a less-than-quarterly frequency for most of the monitoring wells, considering the sampling frequency reduction only.
- The MAROS Data Sufficiency (Power Analysis) application indicates that the monitoring record has sufficient statistical power at this time to say that the plume will not cross a “hypothetical statistical compliance boundary” located 1000 feet downgradient of the most downgradient well at the site. With the progress of remediation, this hypothetical statistical compliance boundary will get closer and closer to the downgradient wells of the monitoring system.

The MAROS optimized plan consists of 12 wells: 1 sampled semiannually, 5 sampled annually, and 5 sampled biennially and one sampled quarterly. The MAROS optimized plan would result in 13.5 samples per year, compared to 24 samples per year in the original monitoring program. Implementing these recommendations could lead to a **60% reduction** in samples from the original plan in terms of the samples to be collected per year.

The recommended long-term monitoring strategy based on the analysis of the original monitoring plan, results in a moderate reduction in sampling costs and allows site personnel to develop a better understanding of plume behavior over time. A reduction in the number of redundant wells, an increase in the number of wells in areas with inadequate information, as well as reduction in sampling frequency is expected to results in a moderate cost savings over the long-term at this BTEX site. An approximate cost savings of 60% per year is projected for the tutorial site, while still maintaining adequate delineation of the plume as well as knowledge of the plume state over time. At more complex sites with many more wells and more sampling data, cost savings would be greatly increased.