Monitoring and Remediation Optimization System (MAROS) Software, Version 2.0

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Introduction

Long-term monitoring programs, whether applied for process control, performance measurement, or compliance purposes, require large-scale data collection effort and time commitment, making their cumulative costs very high. With the increasing use of risk-based goals and natural attenuation in recent years as well as the move toward long-term closure upon completion of cleanup activities, the need for better-designed long-term monitoring plans that are cost-effective, efficient, and protective of human and ecological health has greatly increased. AFCEE's 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 and efficiency.

The MAROS 2.0 software uses three strategies for managing and updating LTM plans: 1) streamlining data management; 2) conducting focused spatial and temporal analysis of the groundwater monitoring data; and 3) visualizing groundwater monitoring data and analysis results. Data management tools provide the capability for flexible data import and export, database update, and automated data cleaning and consolidation. Spatial and temporal analysis methods were designed to identify the redundant sampling locations, recommend new sampling locations and optimal sampling frequency, analyze plume migration patterns, and evaluate individual well or risk-based site cleanup status. Visualization tools provide graphical interpretation of monitoring data and analysis results using automated, updateable database software that can be integrated with a geographical information system (GIS). These features have been incorporated into a public-domain database management, statistical analysis, and data visualization tool, MAROS 2.0 (AFCEE 2003). The MAROS 2.0 software, developed for the Air Force Center for Environmental Excellence, is an integrated data management/data analysis software system designed to help site managers update existing long-term monitoring plans. This system can be used for a variety of ground water contaminants (e.g., fuels, solvents, metals), and is designed for continual modification of long-term monitoring plans as the plume or site conditions change over time. It can be downloaded at no cost from www.gsi-net.com.

The set of methods data management and visualization tools incorporated in the MAROS 2.0 software were designed to assess concentration trends, optimize the monitoring network and sampling frequency, analyze plume stability with spatial moment analysis, and evaluate risk-based site cleanup status using statistical power analysis. Data management tools provided within the software, have the capability of site database management and automated raw data filtering, reduction, and smoothing. Visualization tools facilitate the interpretation of monitoring data and analysis results using automated, updateable database software that can be integrated with a geographical information system (GIS). These methods and tools can help formulate an updated monitoring plan that is more effective and efficient.

At Fort Lewis Logistics Center, Washington, this system was applied to assess possible improvements in the current groundwater monitoring network for a chlorinated solvent plume. Preliminary monitoring optimization results reduced the monitoring well network as well as the sampling frequency which provided a basis to make more cost effective, scientifically based future long-term monitoring decisions.

Methods

In MAROS 2.0, two levels of analysis are used for optimizing long-term monitoring plans: 1) an overview statistical evaluation with interpretive trend analysis based on temporal trend analysis and plume stability information; and 2) a more detailed statistical optimization based on spatial and temporal redundancy reduction methods (see Figure 1 for further details). In general, the MAROS method applies to 2-D aquifers that have relatively simple site hydrogeology. However, for a multi-aquifer (3-D) system, the user could apply the statistical analysis layer-by-layer.

The overview statistics or interpretive trend analysis assesses the general monitoring system category by considering individual well concentration trends, overall plume stability, hydrogeologic factors (e.g., seepage velocity, and current plume length), and the location of potential receptors (e.g., property boundaries or drinking water wells). The analysis relies on temporal trend analysis to assess plume stability, which is then used to determine the general monitoring system category. The location and type of the individual wells allows further interpretation of the trend results, depending on what type of well is being analyzed (e.g., remediation well, leading plume edge well, or monitoring well). General recommendations for the monitoring network frequency and density are suggested based on heuristic rules applied to the source and tail trend results.

The detailed statistics level of analysis or sampling optimization, on the other hand, consists of a well redundancy analysis and well sufficiency analysis using the Delaunay method, a sampling frequency analysis using the Modified Cost Effective Sampling (CES) method and a data sufficiency analysis using power analysis. The well redundancy analysis is designed to minimize monitoring locations and the Modified CES method is designed to minimize the frequency of sampling. The data sufficiency analysis uses power analysis to assess the sampling record to determine if the current monitoring network and record is sufficient in terms of evaluating risk-based site target level status (Figure 1).

Results

Fort Lewis Logistics Center is located in Pierce County, Washington (Aziz et al. 2003). Trichloroethene (TCE) was used at the facility as a degreasing agent between early 1940s and mid-1970s and waste TCE was disposed of in several locations on site. In 1985, the Army identified traces of TCE in several monitoring wells installed in the shallow geologic units under the facility (known as the Upper Aquifer). The results of the RI showed that the ground water plume in the shallow Upper Aquifer principally contains TCE and the plume was over 2 miles long, between 3,000 to 4,000 feet wide and 60 to 80 feet thick. A pump-and-treat system installed at the site began operation in 1995. The objective of the remediation is to restore the Upper Aquifer to drinking water standards by reducing the TCE concentration to less than 5 ppb within 30~40 years at down-gradient compliance points.

The original groundwater long-term monitoring plan for the Upper Aquifer was completed in August 1995. It consisted of performance monitoring and compliance monitoring with the following goals: 1) plume containment monitoring to confirm that the TCE plume remains hydraulically controlled; and 2) plume reduction monitoring to verify progress toward achieving cleanup goals. As of 2001, 43 monitoring wells and 21 extraction wells were included in the Upper Aquifer long-term monitoring network. All monitoring wells, unless abandoned, have been sampled quarterly for TCE since the implementation of the long-term monitoring plan.

In applying the MAROS methods to develop a revised monitoring strategy for the Upper Aquifer, only wells included in the long-term monitoring plan as of September 2001 were considered. The following description will focus on the application of MAROS 2.0 new analysis methods, emphasizing data handling and visualization aspects of the MAROS software tool. A detailed description of the location and frequency optimization of the monitoring plan is available in Aziz et al. (2003).

The MAROS 2.0 sampling optimization software/methodology has been applied to the Fort Lewis Upper Aquifer's original RAM program as of September, 2001. An approximate cost savings estimate of $58,000 per year is projected while still maintaining adequate delineation of the plume as well as knowledge of the plume state over time. Results from the temporal trend analysis, moment analysis, sampling location determination, sampling frequency determination, and data sufficiency analysis indicate that:

Trend Analysis

- 6 out of 10 source wells and 15 out of 33 tail wells have a Probably Decreasing, Decreasing, or Stable trend. Both of the statistical methods used to evaluate trends (Mann-Kendall and Linear Regression) gave similar trend estimates for each well.
- 6 out of 6 source area extraction wells have a Probably Decreasing, or Decreasing trend. Both the Mann-Kendall and Linear Regression methods gave similar trend estimates for each well.
- 12 out of 15 plume containment extraction wells have Probably Decreasing, Decreasing, or Stable trend. Both the Mann-Kendall and Linear Regression methods gave similar trend estimates for each well.

Moment Analysis

- The dissolved mass shows an increase over time, whereas the center of mass has stayed stable and the plume spread shows a decrease over time. The increase in dissolved mass maybe due to either 1) the extraction system moving high concentration groundwater from source zones to nearby monitoring wells; or 2) the change in the wells sampled over the sampling period analyzed.
- Overall plume stability results indicate that a monitoring system of “Moderate” intensity is appropriate for this plume compared to “Limited” or “Extensive” systems due to a stable Upper Aquifer plume.

Redundancy Analysis

- The well redundancy optimization tool, using the Delaunay method, indicates that 8 existing monitoring wells may not be needed for plume monitoring and can be eliminated from the original monitoring network of 38 wells without compromising the accuracy of the monitoring network.

Well Sufficiency Analysis

- The well sufficiency optimization tool, using the Delaunay method, indicates that 6 new monitoring wells may help reduce uncertainty in selected areas within the original monitoring network.

Sampling Frequency Analysis

- The well sampling frequency tool, the Modified CES method, indicates the number of samples collected over time sampling can potentially be reduced by 56% by sampling at a less-than-quarterly frequency for most of the monitoring wells. A 57% reduction in sampling can potentially be achieved for the monitoring extraction wells using the sampling frequency recommended by the MAROS analysis.

Power Analysis

- 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 2000 feet downgradient of the most downgradient well at the site. As more sampling records accumulate, this hypothetical statistical compliance boundary will get closer and closer to the downgradient wells of the monitoring system.

The recommended long-term monitoring strategy, based on the analysis of the original monitoring plan, results in considerable 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 significant cost savings over the long-term at Fort Lewis.

References

Air Force Center for Environmental Excellence (AFCEE). (2003). Monitoring and Remediation Optimization System (MAROS) 2.0 Software Users Guide, Brooks AFB, San Antonio, Texas.

Aziz, J. J., Ling, M., Rifai, H. S., Newell, C. J., and Gonzales, J. R. (2003) MAROS: a Decision Support System for Optimizing Monitoring Plans, Ground Water, in press.

MAROS: Decision Support Tool

MAROS is a collection of tools in one software package that is used in an explanatory, non-linear fashion. The tool includes models, geostatistics, heuristic rules, and empirical relationships to assist the user in optimizing a groundwater monitoring network system while maintaining adequate delineation of the plume as well as knowledge of the plume state over time. Different users utilize the tool in different ways and interpret the results from a different viewpoint.

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Overview Statistics

What it is: Simple, qualitative and quantitative plume information can be gained through evaluation of monitoring network historical data trends both spatially and temporally. The MAROS Overview Statistics are the foundation the user needs to make informed optimization decisions at the site.

What it does: The Overview Statistics are designed to allow site personnel to develop a better understanding of the plume behavior over time and understand how the individual well concentration trends are spatially distributed within the plume. This step allows the user to gain information that will support a more informed decision to be made in the next level of optimization analysis.

What are the tools: Overview Statistics includes two analytical tools:

1) **Trend Analysis:** includes Mann-Kendall and Linear Regression statistics for individual wells and results in general heuristically-derived monitoring categories with a suggested sampling density and monitoring frequency.

2) **Moment Analysis:** includes dissolved mass estimation (0th Moment), center of mass (1st Moment), and plume spread (2nd Moment) over time. Trends of these moments show the user another piece of information about the plume stability over time.

What is the product: A first-cut blueprint for a future long-term monitoring program that is intended to be a foundation for more detailed statistical analysis.

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Detailed Statistics

What it is: The MAROS Detailed Statistics allows for a quantitative analysis for spatial and temporal optimization of the well network on a well-by-well basis.

What it does: The results from the Overview Statistics should be considered along side the MAROS optimization recommendations gained from the Detailed Statistical Analysis. The MAROS Detailed Statistics results should be reassessed in view of site knowledge and regulatory requirements as well as the Overview Statistics.

What are the tools: Detailed Statistics includes four analytical tools:

1) **Sampling Frequency Optimization:** uses the Modified CES method to establish a recommended future sampling frequency.

2) **Well Redundancy Analysis:** uses the Delaunay Method to evaluate if any wells within the monitoring network are redundant and can be eliminated without any significant loss of plume information.

3) **Well Sufficiency Analysis:** uses the Delaunay Method to evaluate areas where new wells are recommended within the monitoring network due to high levels of concentration uncertainty.

4) **Data Sufficiency Analysis:** uses Power Analysis to assess if the historical monitoring data record has sufficient power to accurately reflect the location of the plume relative to the nearest receptor or compliance point.

What is the product: List of wells to remove from the monitoring program, locations where monitoring wells may need to be added, recommended frequency of sampling for each well, analysis if the overall system is statistically powerful to monitor the plume.

Figure 1. MAROS 2.0 Decision Support Tool Flow Chart