Groundwater Monitoring Network Optimization Frontier Hard Chrome Superfund Site, Vancouver, Washington

Solid Waste and
Emergency Response
(5203P)

EPA 542-R-07-021
December 2007
www.epa.gov

Groundwater Monitoring Network Optimization Frontier Hard Chrome Superfund Site, Vancouver, Washington

GROUNDWATER MONITORING NETWORK OPTIMIZATION
FRONTIER HARD CHROME SUPERFUND SITE

EXECUTIVE SUMMARY

The following report reviews and provides recommendations for instituting a long-term groundwater monitoring network for Frontier Hard Chrome Superfund Site in Vancouver, Washington (FHC Site). The FHC Site consists of a former chrome plating facility in the floodplain of the Colombia River. Shallow groundwater in the FHC area has been impacted by residual hexavalent chromium from chrome-plating operations conducted between 1958 and 1983. Affected groundwater migrated downgradient from the source under the influence of industrial groundwater pumping south of the FHC site.

Extensive site remediation activities were completed at the FHC Site in 2003. The area around FHC is currently undergoing rapid urban redevelopment to residential and commercial property use. The primary goal of developing an optimized groundwater monitoring strategy at the FHC Site is to create a dataset that fully supports site management decisions while minimizing time and expense associated with collecting and interpreting data. The long-term groundwater monitoring network for the FHC Site should be designed to support site management decisions while accommodating on-going redevelopment.

In the following report, the current FHC groundwater monitoring network has been evaluated using a formal qualitative approach as well as statistical tools found in the Monitoring and Remediation Optimization System software (MAROS). Recommendations are made for groundwater sampling frequency and location based on current hydrogeologic conditions and long-term monitoring (LTM) goals for the system. The following report evaluates the monitoring system using analytical and hydrogeologic data collected after installation of the remedy to the present, a time-frame between October 2003 and June 2007. The following report outlines recommendations based on a formal evaluation, but final determination of sampling locations and frequencies are to be decided by the overseeing regulatory agencies.

Current Site Conditions

The broad area of shallow groundwater contamination associated with chrome plating operations at FHC was discovered in the 1980’s and investigated and delineated through the 1990’s. The Record of Decision (ROD) (USEPA, 2001) for groundwater at FHC produced in 2001, detailed an *in-situ* chemical reduction of mobile hexavalent chromium (Cr(VI)) as the final remedy. The regulatory screening level for total chromium for the Site was determined to be 50 µg/L, based on the State of Washington Department of Ecology Model Toxics Control Act (MTCA) Standard A value.

As a result of aggressive remedial treatments and cessation of industrial pumping, total chromium concentrations across the site have dropped below the regulatory screening level. It should be noted that for the past 3 years, total chromium levels in groundwater at FHC have consistently been measured below the clean-up level of 50 µg/L. The FHC groundwater plume, that is the extent of groundwater affected above the regulatory screening level, has largely disappeared. However, for the purpose of the following analysis, the term “plume” is used to describe the historic extent of groundwater affected by chromium originating from the FHC site. In this document, the term ‘plume’ describes all chromium concentrations at any detectible level within the current FHC Site groundwater monitoring network. Analytical results for total chromium were used in the analysis of the groundwater network as a conservative surrogate for assessing the concentration of soluble hexavalent chromium.

Site Groundwater Monitoring Goals and Objectives

Primary monitoring goals for the FHC Site groundwater include defining the extent and magnitude of residual contamination and evaluating the efficacy of the chosen remedy. The specific groundwater monitoring objective for FHC is to “ensure dilution and dispersion of affected groundwater” until site groundwater meets state cleanup standards (USEPA, 2001). Shallow groundwater in the FHC area is protected by institutional controls prohibiting construction of water-supply wells in groundwater that may be affected by industrial contaminants. Monitoring data will provide support for institutional controls by delineating the extent of affected groundwater. Data from the network will provide evidence of concentration stability and indicate if constituents begin to remobilize. Analytical data collected from the network will document continued efficacy of the remedy and attenuation of chemical constituents confirming that the remedy is achieving site clean-up goals.

Project Goals and Objectives

The goal of the long-term monitoring optimization (LTMO) process is to review the current groundwater monitoring program and provide recommendations for improving the efficiency and accuracy of the network in supporting site monitoring objectives. Specifically, the LTMO process provides information on the site characterization, stability of constituent concentrations, sufficiency and redundancy of monitoring locations and the appropriate frequency of network sampling. Tasks involved in the LTMO process include:

- Evaluate well locations and screened intervals within the context of the hydrogeologic regime to determine if the site is well characterized;
- Evaluate overall ‘plume’ stability through trend and moment analysis;
- Evaluate individual well concentration trends over time for target constituents of concern (COCs);
- Develop sampling location recommendations based on an analysis of spatial uncertainty;
- Develop sampling frequency recommendations based on qualitative and quantitative statistical analysis results;
- Evaluate individual well analytical data for statistical sufficiency and identify locations that have achieved clean-up goals.

The end product of the LTMO process at the FHC Site is a recommendation for specific sampling locations and frequencies that best address site monitoring goals and objectives while providing sufficient flexibility for site redevelopment.

Results

Statistical and qualitative evaluations of FHC Site analytical data have been conducted and the following general conclusions have been drawn based on the results of these analyses:

- After a qualitative evaluation of well locations, screened intervals and hydrogeologic characteristics, affected groundwater at the FHC Site is delineated to the relevant regulatory standards established for the site (Washington State Department of Ecology MTCA A Standards, 50 µg/L for total chromium). Groundwater areas where concentrations occasionally exceed regulatory standards are bounded by wells where results are below the standard. No major data gaps in site characterization were found.

- The historic area of affected groundwater evaluated shows overall stable to decreasing concentration trends for total chromium. None of the well data reviewed show increasing concentration trends. Many “no trend’ findings result from intermittent detections, data outliers or apparently cyclical variation in concentrations, especially in Zone B wells.

- Moment trend analysis indicated that total dissolved mass measured within the monitoring network is decreasing over time. The center of mass in Zone B is retreating toward the source.

- Results from the spatial redundancy analysis indicate that several wells could be removed from the program, as they do not provide unique information. Wells identified as redundant are listed in Table 5.

- No areas of high concentration uncertainty were found; therefore no new monitoring locations are recommended.

- The sampling frequency analysis recommended a reduced sampling frequency for the majority of wells. Annual to biennial sampling frequencies were recommended by the MAROS algorithm based on the rate of change and trend of well concentrations.

- Many locations evaluated were statistically below the screening level for chromium using both the student’s T-test with a power analysis and the sequential T-test. Approximately two-thirds of monitoring locations have achieved the cleanup goals with 80% or greater statistical power, given the current dataset.

Recommendations

The following general recommendations are made based on the findings summarized above and those described in Section 4 below.

- Several areas of spatial redundancy were identified. 10 wells are recommended for exclusion from the monitoring program.

- No new monitoring locations are recommended.

- Reduce the frequency of monitoring to annual sampling.

- Monitoring data show fairly high variance. In most cases, variance in the data can be explained by site characteristics and geochemical processes. Continue monitoring concentration trends for both total chromium and hexavalent chromium and potentiometric water levels to determine how the hydraulic influence of the Columbia River may be contributing to underlying variance in the data.

- The majority of the analysis above was completed before several wells in the network were damaged as a result of site redevelopment. Some wells may need to be replaced or rehabilitated in order to achieve stated site monitoring objectives. The recommendation that no new monitoring locations are needed does not imply that monitoring wells damaged or destroyed during site redevelopment do not need to be replaced. New wells may be required, but their placement near 'old' locations identified as important is recommended.

- Continue development and updating of the comprehensive site database. Results for both total chromium and hexavalent chromium concentrations should be added to the database. Validated analytical data for all wells in the area should be added to database within a reasonable time after sampling. Each well should have a complete record of historic sampling events.

- Survey location coordinates and elevations for all wells. Share data with all stakeholders. A common set of coordinates should be used by planners, regulators, and construction and development companies.

1.0 INTRODUCTION

The Frontier Hard Chrome Superfund Site (FCH Site) is a National Priorities Listed (NPL) site administered under the Comprehensive Environmental Response, Compensation and Liability Act (Superfund). The site is located in Vancouver, Washington in Clark, County near the Columbia River (see Figure 1). The FHC site is currently administered by the Washington Department of Ecology (Ecology) with support from the US Environmental Protection Agency (EPA) Region 10. The original FHC property is a 1/2-acre historic chrome-plating facility, built and operated between 1958 and 1983. The Site has traditionally been organized into soil and groundwater operable units (OU). Only the groundwater OU will be considered in this report.

Groundwater monitoring plays a critical role in long-term restoration of the FHC Site. The purpose of the following LTMO evaluation is to review the current groundwater monitoring network and provide recommendations for improving the efficiency and accuracy of the network for supporting site management decisions during and after site redevelopment.

At the FHC Site, monitoring goals define why and how data collected from the site will be used. The primary groundwater monitoring goal for the site is to "ensure dilution and dispersion of affected groundwater", with monitoring to continue until "all remaining groundwater meets state standards for groundwater cleanup" (USEPA, 2001). Monitoring data from the site network are used to support institutional controls, by identifying areas of affected groundwater and to document continued attenuation of site constituents.

In order to recommend an optimized network that addresses the stated monitoring objectives, spatial and analytical data from the site were analyzed using a series of quantitative and qualitative tools. Tasks performed during LTMO analyses include:

- Evaluate well locations and screened intervals within the context of the hydrogeologic regime to determine if the site is well characterized;
- Evaluate overall 'plume stability' through concentration trend and moment analysis;
- Evaluate individual well concentration trends over time for target constituents of concern (total chromium);
- Develop sampling location recommendations based on an analysis of spatial uncertainty;
- Develop sampling frequency recommendations based on both qualitative and quantitative statistical analysis results;
- Evaluate individual well analytical data for statistical sufficiency and identify locations that have achieved clean-up goals.

A discussion of site background and regulatory context for the FHC Site is provided below. Section 2 of the report details the analytical and statistical approach taken during the LTMO evaluation. A detailed discussion of results is provided in Section 3. Summary conclusions and recommendations are presented in Section 4.

1.1 Site Background and Regulatory History

The FHC Site is located in a former industrial area in the city of Vancouver in southwestern Washington near the Columbia River. The site is located within the greater Portland, Oregon/Vancouver, Washington metropolitan area. Because of Vancouver's location along the Columbia River and proximity to the Pacific Ocean, the region has historically been the home to several shipyards and supporting industrial activity.

As the regional economy has changed in recent years, the Vancouver shipyards have been redeveloped into residential and commercial property to support rapid increases in population. The area to the south of the FHC Site has been redeveloped, and the industrial water supply wells that contributed to the spread of chromium-affected groundwater to the southwest have been removed from service. The FHC Site is scheduled for redevelopment into commercial properties in the near future.

The FHC Site is located in a floodplain, approximately one-half mile north of the Columbia River. One-quarter mile north of the site, a steep rise in elevation marks an area of residential land use. In the mid-1950's, much of the floodplain, including the FHC Site, was filled with hydraulic dredge material and construction rubble. East of the FHC Site, a topographic depression exists at the original level of the floodplain where the City of Vancouver operates two groundwater well fields to provide public water supply. The Pioneer Plating Company operated a chrome plating facility on the one-half acre FHC site from 1958 through 1970. Chrome plating operations continued under Frontier Hard Chrome management until 1983.

During much of its operational history, liquid wastes from chrome-plating operations were discharged directly to the public sanitary sewer system. By 1975, the City of Vancouver determined that chromium in wastewater was impacting the operation of its secondary waste water treatment systems. FHC was directed to find an alternate disposal method for liquid wastes. In 1976, FHC received a permit to discharge untreated wastes to a drywell behind the facility. The permit included a schedule for the installation of a treatment system for chromium-affected waste water; however, no treatment systems were installed between 1976 and 1981.

By 1982, Ecology found FHC in violation of state waste disposal regulations. During the same time period, chromium contamination was discovered in an industrial water supply well southwest of the site, near the Columbia River. A broad area of shallow groundwater contamination associated with chrome plating operations at FHC was discovered. In December 1982, the FHC Site was proposed for inclusion on the NPL under the CERCLA. In 1983, FHC closed all operations and the site was officially placed on the NPL. Under a cooperative agreement with EPA, Ecology began the Remedial Investigation and Feasibility Study (RI/FS) process. Records of Decision (ROD's) for the site have been published in 1987 (for the soil OU) and 1988 (for the groundwater OU) (USEPA, 1987 and 1988).

The 1987 ROD for soil called for excavation, stabilization and replacement of affected soils with concentrations over 550 mg/Kg total chromium. Subsequently, the proposed method of soil stabilization as a means of preventing leaching of chromium was found to be ineffective. The 1988 ROD for groundwater recommended extraction and treatment of groundwater from areas where concentrations of total chromium exceeded 50,000 µg/L. However, groundwater monitoring indicated that the area of affected groundwater was shrinking after the downgradient industrial supply wells were removed from service. The combination of changing site conditions and the development of new cost-effective technologies motivated the EPA to reevaluate the proposed remedies for FHC.

An amended ROD was completed in 2001 (USEPA, 2001) detailing the final remedial action planned for the site. The selected groundwater remedy included treatment of mobile hexavalent chromium (Cr(VI)) through *in-situ* reduction to relatively insoluble trivalent chromium (Cr(III)). An In-situ Redox Manipulation (ISRM) technology was chosen as the groundwater OU remedy (see Figure 1 for approximate location of groundwater and soil ISRM treatment areas). An area downgradient from the source was injected with reducing agents, resulting in the reduction of naturally occurring iron in the subsurface. The area of reduced iron forms an *in-situ* permeable reactive barrier, reducing soluble Cr(VI) in groundwater to Cr(III). The purpose of the reactive barrier was to 1) provide containment and prevent downgradient transport of affected groundwater, 2) reduce mass of Cr(VI) in high concentration areas; and 3) provide long-term protection against future leaching of Cr(VI) (USEPA, 2001).

An ISRM technology was also chosen for the soil OU. The area of the former chrome-plating tank and main building of FHC was treated with reducing agents, applied directly to the soil. Aggressive treatment of the source area was anticipated to prevent further Cr(VI) inputs to site groundwater.

Remedial activities for soil and groundwater were completed in September 2003. Regular monitoring of site groundwater was included in the ROD to “ensure dilution and dispersion of affected groundwater”, with monitoring to continue until “all remaining groundwater meets state standards for groundwater cleanup” (USEPA, 2001). The groundwater cleanup standard for the FHC site has been established at 50 µg/L. Site groundwater has been monitored quarterly between 2003 and 2007.

Analytical data for total dissolved chromium have been collected and used in the following report, as this chemical analysis reflects concentrations of the more toxic and soluble oxidation state of Cr(VI). Chromium solubility and mobility are strongly influenced by redox reactions, chemical speciation, adsorption/desorption phenomena, and precipitation/dissolution reactions. The reduced form of chromium (Cr(III)) is significantly less soluble in water than Cr(VI). Areas of the FHC site shallow subsurface have been chemically treated with reducing agents, converting Cr(VI) to Cr(III). Groundwater samples at certain monitoring well locations are under low reducing conditions due to the continued presence of reducing agents.

During the process of groundwater sampling some water samples may appear clear (indicating Cr in the dissolved phase), and subsequently form a precipitate when exposed to the atmosphere. When groundwater samples are removed from the subsurface, Cr (III) compounds can precipitate as amorphous hydroxides. When sample turbidity exceeds 10 Nephelometric Turbidity Units (NTUs), samples are filtered removing the Cr(III) species, but for samples with relatively low turbidity, the samples are not filtered even though they may contain suspended Cr(III). The data that are derived after adjusting for the interfering precipitation are below clean-up standards for the site. However, the redox changes introduced during sampling may introduce a higher level of variance in samples collected in the region of the ISRM remedy.

1.2 Geology and Hydrogeology

The FHC Site is underlain by several geologic units, with the upper two being of interest for this report. The top unit consists of hydraulic fill and construction debris used to elevate the adjacent floodplain in the 1940's and1950's. Fill materials are largely silt and sand and heterogeneous, poorly-compacted construction waste. Fill extends approximately 12 to 20 feet below ground surface (ft bgs) across the site. The fill unit is generally unsaturated, but localized areas of perched groundwater may be present. (USEPA, 2001)

Underlying the fill is an alluvial unit, consisting of a clayey silt subunit and a sand-and-ground unit. Groundwater in the alluvial unit is hydraulically connected to the Columbia River. The clayey silt is heterogeneous in character and is 3 to 7 feet thick, thinning to the north of the site. The clayey silt unit separates the lower sand-and-ground unit from the fill. The sand-and-ground unit consists of poorly sorted sandy gravels, silty sandy gravels and sandy silts with scattered large cobbles. Deposits in this unit resulted from overbank deposition during flooding of the Columbia River and from channel deposition that resulted in more particle sorting than the overbank deposits. The alluvial unit is approximately 70 feet in thickness and is highly heterogeneous and anisotropic.

During initial site characterization, the alluvial unit was considered to have three layers. Upper and lower permeable zones (Zones A and B) separated by an aquitard were described in the RI/FS (issued in 1987). Zone A was described as a sand and gravel layer beginning about 20 ft bgs and extending to about 35 ft bgs. A confining "lower aquitard" below Zone A is described in the 1988 ROD (USEPA, 1988) and was the basis for separating groundwater in the alluvial unit into A and B zones. Currently, this silt zone is seen as semi-continuous fine-grained unit of dense sandy silt to silty sand. The layer is now thought to be semi-confining and not a significant hydraulic barrier within the alluvial aquifer.

Zone B, or the deeper alluvial unit, is also made up of sands and gravel, but with higher permeability than Zone A. The lower alluvial unit extends from approximately 35 ft bgs down to 80 to 100 ft bgs. Groundwater velocity in this zone is about 2.25 ft/d to the south-southwest. There is no distinct vertical gradient between A and B Zones. Wells in the FHC network are designated as either A or B Zone wells based on the depth of the screened interval. During the LTMO analysis, the zone designations were used to separate the data into two analysis groups to evaluate groundwater in zones based on permeability. This is done with the understanding that Zones A and B are most likely hydraulically connected.

Groundwater flow in the region of the FHC site is generally to the south/southwest as the potentiometric surface data indicate a shallow slope to the south. Historically, groundwater flow direction has been influenced by pumping at downgradient industrial water supply wells, but when these wells were deactivated, groundwater flow returned to a generally southerly flow direction. The average hydraulic gradient is 0.00015 ft/ft and groundwater velocity is between 0.5 and 5 ft/d. Recharge to site groundwater occurs from local infiltration of precipitation and from the recharge from another alluvial aquifer north of the site near the topographic rise. Downgradient from the Site, groundwater discharges to the Columbia River and area potentiometric surfaces are influenced by Columbia River stage. Groundwater parameters used in the LTMO analysis are listed in Table 2.

2.0 ANALYTICAL APPROACH

Evaluation of the groundwater monitoring network in the vicinity of the FHC Site consisted of both quantitative and qualitative methods. A quantitative statistical evaluation of the site was conducted using tools in the MAROS software. The qualitative evaluation reviewed hydrogeologic conditions, well construction and placement. Both quantitative statistical and qualitative evaluations were combined using a 'lines of evidence' approach to recommend a final groundwater monitoring strategy to support site monitoring objectives.

2.1 MAROS Method

The MAROS 2.2 software was used to evaluate the LTM network at the FHC Site. MAROS is a collection of tools in one software package that is used in an explanatory, non-linear but linked fashion to statistically evaluate groundwater monitoring programs. The tool includes models, statistics, heuristic rules, and empirical relationships to assist in optimizing a groundwater monitoring network system. Results generated from the software tool can be used to develop lines of evidence, which, in combination with professional judgment, can be used to inform regulatory decisions for safe and economical long-term monitoring of affected groundwater. A summary description of each tool used in the analysis is provided in Appendix A of this report. For a detailed description of the structure of the software and further utilities, refer to the MAROS 2.2 Manual (AFCEE, 2003; http://www.gsi-net.com/software/MAROS_V2_2Manual.pdf) and Aziz et al., 2003.

In MAROS 2.2, two levels of analysis are used for optimizing long-term monitoring plans: 1) an overview statistical evaluation based on temporal trend analysis resulting in 'plume stability' information; and 2) a more detailed statistical optimization based on spatial and temporal redundancy reduction methods (see Appendix A or the MAROS Users Manual (AFCEE, 2003)).

2.1.1 COC Choice

MAROS includes a short module that provides recommendations on prioritizing COCs for the entire network based on toxicity, prevalence, and mobility of the compounds dissolved in groundwater. However, the priority constituent at the FHC site is total dissolved chromium, analyzed as a surrogate for Cr(VI). Volatile organic compounds (VOCs) are present in small amounts in site groundwater from off-site sources, but these compounds are not risk-drivers for site management. The COC choice module was not used for the FHC site.

2.1.2 Plume Stability

Within MAROS, time-series concentration data are analyzed to develop a conclusion about 'plume stability'. For the MAROS analysis, a plume is defined as the extent of groundwater within the monitoring network affected by any concentration of the target contaminant over time. Practically, the 'plume' area is defined as the maximum extent of affected groundwater over the time-frame of the investigation. The definition of 'plume' used in this document is distinct from the regulatory definition in that concentrations do not need to exceed the regulatory screening limit in order to be considered part of the 'plume'.

For the purpose of this analysis, a groundwater plume is said to be stable when constituent concentrations at individual monitoring locations as well as moments estimated from the entire network are not changing rapidly. If a plume is found to be stable, in many cases, the number of locations and monitoring frequency can be reduced without loss of information.

Individual well concentrations are evaluated using both Mann-Kendall and Linear Regression trend tools. The Mann-Kendall nonparametric evaluation is considered one of the best methods to evaluate concentration trend as it does not assume the data fit a particular distribution (Gilbert, 1987). Individual well concentration trends were calculated for chromium for the time period 2003 to 2007. Individual well Mann-Kendall trends were also used in the sampling frequency analysis, where trends determined for the 2006 to 2007 interval were compared with trends calculated using the entire dataset for each well. During the final 'lines of evidence' evaluation, individual well concentration trends are considered along with summary statistics such as percent detection and historic maximum concentration to make recommendations for the final sampling network.

Moment analysis algorithms in MAROS are simple approximations of complex calculations and are meant to estimate the total dissolved mass (zeroth moment), center of mass (first moment) and spread of mass (second moment) within the monitoring network and the trend for each of these estimates over time. Trends for the first moment indicate the relative amount of mass upgradient vs. downgradient and the change in the distance of the center of mass from the source over time. Trends in the second moment indicate relative dispersivity by evaluating the spread of mass about the center of mass over time.

2.1.3 Well Redundancy and Sufficiency

Spatial analysis modules in MAROS recommend elimination of sampling locations that have little impact on the historical characterization of contaminant concentrations while identifying areas within the monitoring network where additional data are needed. For details on the redundancy and sufficiency analyses, see Appendix A or the MAROS Users Manual (AFCEE, 2003).

Sample locations are evaluated in MAROS for their importance in providing information to define concentrations within the area of affected groundwater. Wells identified as providing information redundant with surrounding wells are recommended for elimination from the program. (Note: 'elimination' from the program does not necessarily mean plugging and abandoning the well. See Section 2.3 below.)

Well sufficiency is evaluated in MAROS using the same spatial analysis method as that for redundancy. Areas identified as having unacceptably high levels of concentration uncertainty are recommended for additional monitoring locations.

The well redundancy and sufficiency analyses use the Delaunay method and are designed to select the minimum number of sampling locations based on the relative importance of information supplied at each sampling location in the monitoring network. The importance of each sampling location is assessed by calculating a slope factor (SF) and concentration and area ratios (CR and AR respectively). Sampling locations with a high SF provide unique information and are retained in the network. Locations with low SF are considered for removal. Areas ringed by wells with high SF's may be candidates for new well locations. SF's were calculated for all wells at the FHC Site and the results were used to determine the importance of each well in the network for defining chromium concentrations.

The results from the Delaunay method and the method for determining new sampling locations are derived solely from the spatial configuration of the monitoring network and the spatial pattern of the contaminant plume based on a two-dimensional assumption. No parameters such as the hydrogeologic conditions are considered in the analysis. Therefore, professional judgment and regulatory considerations must be used to confirm final decisions.

2.1.4 Sampling Frequency

MAROS uses a Modified Cost Effective Sampling (MCES) method to optimize sampling frequency for each location based on the magnitude, direction, and uncertainty of its concentration trends. The MCES method is based on the Cost Effective Sampling (CES) method developed by Ridley et al. (1995). The MCES method estimates a conservative lowest-frequency sampling schedule for a given groundwater monitoring location that still provides needed information for regulatory and remedial decision-making.

The MAROS algorithm recommended a preliminary location sampling frequency (PLSF) for each monitoring location at the FHC Site based on a combination of recent (2006-2007) and long-term (2003-2007) trends and the magnitude and rate of concentration change. The PLSF has been reviewed qualitatively and a final optimal sampling frequency has been recommended consistent with monitoring objectives and regulatory requirements.

2.1.5 Data Sufficiency

The MAROS Data Sufficiency module employs simple statistical methods to evaluate whether analytical data are adequate both in quantity and in quality for revealing changes in constituent concentrations. Statistical tests for the MAROS module were taken from the USEPA *Methods for Evaluating the Attainment of Cleanup Standards Volume 2: Groundwater* statistical guidance document (USEPA, 1992).

Two types of statistical analyses have been performed on analytical samples from each individual well. First, hypothesis testing using a Sequential T-test has been performed to determine if groundwater concentration is statistically below the screening level for total chromium (screening levels were set to Ecology MTCA Standard A of 50 µg/L). The Sequential T-test indicates if the well has a sufficient number of samples at low enough concentrations to be categorized as having "attained" groundwater cleanup goals (confidently below the screening level concentration). The statistical standard set by the Sequential T-test is quite high, and if the well data indicate the groundwater concentration has 'attained' cleanup, then there is high confidence that the groundwater is statistically below the regulatory limit. If measured concentrations are high or there are an insufficient number of data points, then the well is recommended for further sampling.

A Student's T-test followed by statistical power analysis was also performed in the Data Sufficiency module to assess the reliability of the hypothesis test and to suggest the number of additional samples that may be required to reach statistical significance. The power analysis uses the number of samples (n), the variance of the samples, the minimum detectible difference and the significance (α) of the test to determine if the well is below the screening level with very high confidence. The power analysis provides a higher level of certainty that the well is not affected above risk-based levels. Locations that pass the power test are considered "statistically clean".

The Data Sufficiency module is designed to evaluate 6 years of sampling data. While quarterly sampling for the past 3 years has provided a sufficient number of events to evaluate the data using most techniques, 3 more years of sampling is necessary before wells at the FHC Site can be confidently evaluated using this module. The analysis was conducted with the current dataset and results are reported, but the results should be considered preliminary, at this point.

At the FHC Site, locations that monitor groundwater areas "statistically below screening levels" or "statistically clean" may be considered for reduced sampling frequency or elimination from the program. Statistically 'clean' ring locations can be retained in the program to help bound the areas of affected groundwater, set institutional control boundaries or function as surrogate point of compliance locations.

2.2 Data Input, Consolidation and Site Assumptions

Groundwater analytical data from the FHC Site were supplied by Region 10 EPA and from the *Frontier Hard Chrome Event 11 Long-Term Monitoring Report* (Weston, 2007). Site data were supplemented with information from historic site reports including the RODs. Groundwater monitoring locations included in the evaluation are listed in Table 1, with additional aquifer and site details provided in Table 2.

Chemical analytical data collected between October 2003 and June 2007 and well information data were organized in a database, from which summary statistics were calculated. In all, 33 sample locations were considered in the network evaluation for the FHC Site. Wells are described in Table 1, and well locations are illustrated on Figure 1.
Groundwater monitoring data collected prior to 2003 are available for a subset of FHC wells; however, the installation of the remedy changed the nature and distribution of dissolved constituents as well as groundwater geochemistry. Therefore, data collected before 2003 are not comparable with those collected after installation of the remedy. In order to provide reasonable consistency in statistical comparisons, analyses have been limited to the 2003 – 2007 time-frame. Individual well trend evaluations were performed

for data collected between 2003 and 2007. The data represent a roughly 3 year record for many wells, and provide an indication of long-term, post-remediation trends in site constituent concentrations. Spatial analyses and recent sampling frequency analyses were conducted for data collected 2006-2007. Duplicate samples in the dataset were averaged to develop one analytical result for each quarter. No other data consolidation was performed.

It should be noted that only total chromium concentrations in groundwater were used for this evaluation. Analytical data for total chromium concentrations were collected as a conservative surrogate for Cr(VI), which is the soluble form of the metal. Groundwater samples at certain monitoring well locations were under low reducing conditions in the subsurface due to the injection of the reductant. During the process of groundwater sampling, the clear water samples would form a precipitate when exposed to the atmosphere and filtering of the sample was necessary because turbidity was greater the 10 NTUs. Use of total chromium results should be considered conservative as the method will over-predict soluble chromium concentrations by including residual suspended Cr(III) in the result. Using total chromium analysis at all sites should improve consistency in evaluating groundwater under a variety of subsurface redox conditions.

2.3 Qualitative Evaluation

Multiple factors should be considered in developing recommendations for monitoring at sites undergoing long-term groundwater restoration. The LTMO process for the FHC Site includes developing a 'lines of evidence' approach, combining statistical analyses with qualitative review to recommend an improved monitoring network. Results from the statistical analyses in combination with a qualitative review were used to determine continuation or cessation of monitoring at each well location along with a proposed frequency of monitoring for those locations retained in the network.

The primary consideration in developing any monitoring network is to ensure that information collected efficiently supports site management decisions. Site information needs are reflected in the monitoring objectives for the network. For this reason, any proposed changes to the network are reviewed to be consistent with and supportive of the stated monitoring objectives. The qualitative review process begins with evaluating each monitoring location for the role it plays supporting site monitoring objectives. For example, a location may provide vertical or horizontal delineation of affected groundwater or may provide information on decay rates in the source area. Each well in the FHC Site network was evaluated for its contribution to site monitoring objectives. Qualitatively, redundant locations are those where multiple wells address the same monitoring objective in approximately the same location.

A recommendation to eliminate chemical analytical monitoring at a particular location based on the data reviewed does not necessarily constitute a recommendation to physically abandon (plug) the well. A change in site conditions might warrant resumption of monitoring at some time in the future at wells that are not currently recommended for continued sampling. In some cases, stakeholders may pursue a comprehensive monitoring event for all historic wells every five to ten years to provide a broad view of plume changes over time. In general, continuation of water level measurements in all site wells is recommended. Data on hydraulic gradients and potentiometric surfaces are often relatively inexpensive to collect and can be used to support model development and resource planning. However, when site redevelopment is an issue, optimization of the network can be used to identify redundant locations that can be plugged without loss of information.

Qualitative evaluation for sampling frequency recommendations includes consideration of factors such as the rate of change of concentrations, the groundwater flow velocity, and the type and frequency of decisions that must be made about the site. Additionally, consideration is given to the concentration at a particular location relative to the regulatory screening level, the length of the monitoring history and the location relative to potential receptors.

A summary of the lines of evidence used to develop a final monitoring network recommendation is presented below.

Key Point: *Several lines of evidence were used to develop recommendations for the monitoring network.*

Lines of Evidence	Method
▪ Individual well trend	▪ Mann-Kendall (Linear regression)
▪ Plume-Wide Trends	▪ Moment Analysis: Total dissolved mass, center of mass and distribution of mass trends.
▪ Well Redundancy and Sufficiency	▪ Delaunay triangulation and slope factor calculation, along with area ratios and concentration ratios.
▪ Sampling Frequency	▪ Modified Cost Effective Sampling
▪ Data Sufficiency	▪ Sequential T-Test, Student's T-Test and Power Analysis
▪ Qualitative Evaluation	▪ Hydrogeologic factors, monitoring objectives, stakeholder concerns and all statistical results to develop final recommendation.

3.0 SITE RESULTS

Data from 33 monitoring wells at depths corresponding to Zones A and B were included in the quantitative network analysis for the FHC Site. Summary statistics for the wells (including percent detections and maximum concentrations) are shown on Table 3. Qualitative considerations are discussed alongside statistical interpretations below.

3.1 Plume Stability

3.1.1 Concentration Trends

Individual well chromium concentration trends using the Mann-Kendall method are summarized in the table below. Trends were evaluated for data collected between 2003 and 2007. Detailed results of the trend evaluations performed are summarized on Table 3. Results of the individual well Mann-Kendall trends are also illustrated on Figure 2 and Figures 7 and 8. Detailed Mann-Kendall reports for each well in the network are located in Appendix B.

Alluvial Aquifer Zone	Total Wells	Number and Percentage of Wells for Each Trend Category				
		Non Detect	PD, D	S	I, PI	No Trend
Zone A	16	0	5 (31%)	7 (44%)	0	4 (25%)
Zone B	17	0	7 (41%)	2 (12%)	0	8 (47%)
All Wells	33	0	12 (36%)	9 (27%)	0	12 (36%)

Note: Number and percentage of total wells in each category shown. Decreasing trend (D), Probably Decreasing trend (PD), Stable (S), Probably Increasing trend (PI), and Increasing trend (I).

All wells had sufficient analytical data to evaluate trends. Because chromium is present naturally at low levels in the aquifer, all wells groundwater analyzed showed detectable quantities. None of the sampling locations showed increasing or probably increasing trends for total chromium. The site cleanup standard for chromium is 50 µg/L. Overall, two-thirds of well datasets showed stable to decreasing concentration trends.

Several wells with historic high concentrations near the ISRM zone indicate no trend or high variance in the data. Overall most of the measured concentrations at these locations are quite low, but occasional spikes in concentration are seen (see MW-12A and MW-15A and B in Appendix B). Data variability may be a result of artifacts due to changing redox environment during sampling and subsequent filtering of samples (see discussion above). Many of these wells monitor former “hot spots” or areas with possibly high residual chromium concentrations. Greater variability in the analytical data was found in data from Zone B wells, as indicated by the relatively large number of No Trend (NT) results.

3.1.1.2 Moments

Moment analysis was used to estimate the total dissolved mass (Zeroth Moment), center of mass (First Moment) and distribution of mass (Second Moment) for total chromium in the Zones A and B. The values were determined using the current well configuration. The Mann-Kendall trends of the moments were determined for data between 2004 and 2007 (4th quarter 2003 data did not include all sampling locations). Estimates of the zeroth and first moments for the FHC Site are shown in Table 4. Moment trends are summarized in the table below, and first moments over time are illustrated on Figure 2.

Total mass values are rough estimates of mass in the dissolved phase, assuming a constant porosity and uniform saturated thickness across the site. The mass estimates are best interpreted as metrics for determining the trend of dissolved mass within the network. For both A and B zone groundwater, mass estimates decreased strongly between 2004 and 2007. Mass estimates are greater for Zone B as the saturated thickness is greater.

First moments, indicating the trend in center of mass, show No Trend in Zone A. Concentrations measured in Zone A wells are low, and minor fluctuations in concentration are seen in concentration vs. time graphs (Appendix B). The alluvial aquifer is influenced by stages of the Columbia River, and the fluctuations in both first moments and concentrations in Zone A may result from hydraulic influence of the river. First moments for Zone B indicate that the center of mass is regressing toward the source, indicating decreasing concentrations in the tail area relative to the source.

Moment Type	Moment Analysis	Comment
	Zone A	**Zone B**
Zeroth	***Decreasing***: Total mass of chromium showed a strongly decreasing trend 2004-2007	***Decreasing***: Total mass of chromium showed a strongly decreasing trend 2004-2007.
First	***No Trend***: The movement of center of mass in Zone A shows no trend over time.	***Decreasing***: The center of mass in Zone B is moving closer to the source, supporting the conclusion of a shrinking plume.
Second	***No Trend*** in both X and Y directions	***Probably Increasing*** in the X direction (direction of groundwater flow). ***Increasing*** in the Y direction (orthogonal to groundwater flow).

Second moments indicate the pattern of dilution and dispersion of mass as it moves from the center of the network to the edges. No clear trend in second moments was found for Zone A. Zone B second moments indicate relatively more mass is moving to the edges relative to the center. Increasing second moments support the conclusion that total chromium in Zone B is dispersing in both the X (direction of groundwater flow) and Y (orthogonal to groundwater flow) directions.

3.2 Well Redundancy and Sufficiency

The spatial redundancy analysis was performed using data collected between 2006 and 2007. Spatial redundancy results include slope factor (SF) and area (AR) and concentration ratio (CR) calculations to rank the importance of the well in the network. Summary results for the redundancy analysis as well as a summary of the data sufficiency results (identifying wells where groundwater is statistically below the screening level) are presented on Table 5.

Of the 16 wells screened in the Zone A depth range, eight were identified as possibly redundant based on SF and AR and CR results. Interior well locations with SF below 0.3 were considered for removal, while hull wells were retained if SF was above 0.1. The average SF for each well is shown on Table 5. Wells identified by the MAROS algorithm as redundant include B85-4, MW-14A, MW-15A, MW-16A, W85-6A, W85-7A, W-92-16A and W98-20A.

Seventeen Zone B locations were evaluated and six were identified as redundant based on the criteria described above. Wells B87-8, MW-11B, MW-12B and C, MW-13C and W85-6B were identified as not providing unique information to characterize the affected or potentially affected groundwater.

The decision to remove a well from routine monitoring is based on a combination of spatial statistical analyses and qualitative review of the function of the well in supporting site monitoring objectives. The spatial statistics for Zone A and B wells were considered along with other lines of evidence including whether the well monitors groundwater below the screening level, trend results, detection frequencies and overall monitoring objectives before a final recommendation was made.

In the case of FHC, location of wells should be compatible with site redevelopment while still meeting the objectives of the program. Proposed plans for site redevelopment were received from stakeholders, and well locations were reviewed to try to accommodate proposed development (see Figures 7 and 8). In the case of nested well locations (locations where multiple wells monitor several depths), if one well was very important for monitoring one depth profile the other well is recommended for retention in the program as well. Final recommendations for wells to retain in the monitoring program are summarized below and shown on Table 5.

	Final Network Recommendation	
	Zone A	**Zone B**
Wells Retained	***B85-4, MW-16A, W85-6A, W92-16A MW-12A, MW-17A, W97-18A, MW-15A, W97-19A, W98-21A, W99-5A,***	***B85-3, B87-8, MW-12B, MW-12C, MW-15B MW-16B, W85-6B, W92-16B, W97-18B, W97-19B, W98-21B, W99-R5B***
Wells Excluded	***MW-11A, MW-13A, MW-14A, W85-7A, W98-20A***	***MW-11B, MW-13B, MW-13C, MW-14B, W85-7B***

The graphical well sufficiency analyses for Zones A and B are illustrated in Figures 3 and 4, respectively. MAROS uses the Delaunay triangulation and SF calculations to identify areas with high concentration uncertainties. Graphical results illustrate polygons created by the triangulation method and indicate areas of high uncertainty with an “L” or an “E” in the center of the triangle. For both Zones A and B, no areas of high concentration uncertainty were found; all areas show an “S” (for small uncertainty) or an “M” (medium). Overall, the networks have very low spatial uncertainty. Some areas of moderate spatial uncertainty were identified near the source “hot spots”, but these areas do not require additional well locations. No new well locations are recommended for the monitoring networks.

Site data excluding the wells recommended for elimination were re-run in the MAROS data sufficiency module to determine if eliminating wells from the program would increase concentration uncertainty. Figures 5 and 6 illustrate the concentration uncertainty found after elimination of redundant locations in Zones A and B. No increase in statistical uncertainty was found when wells listed above were eliminated, supporting the redundancy of locations recommended for exclusion from the program.

3.3 Sampling Frequency

Table 6 summarizes the results of the MAROS preliminary sampling frequency recommendation. The MCES method evaluates overall and recent temporal trends, and recommends an optimized sampling frequency based on the rate of concentration change. As with the redundancy analysis, a qualitative review of all data is conducted before recommending a final sampling frequency.

The rate of change of chromium concentrations for FHC wells is very low. The majority of well locations have decreasing to stable concentration trends for the period analyzed. For the recent data, many wells show stable trends, indicating that the rate of concentration reduction at most locations has slowed. Many wells show some fluctuation in the data that may be consistent with hydraulic influence from the Columbia River or redox conditions during sampling.

The majority of wells in both Zones A and B have preliminary recommendations for annual to biennial (every two years) sampling. The current sampling frequency is quarterly. Quarterly monitoring has already provided a statistically significant dataset (sufficient number of sample points to perform statistical analyses). After a qualitative review, annual sampling frequency is recommended for all wells remaining in the network during long-term groundwater monitoring. Annual sampling is consistent with the very low rate of change seen over the past 3 years, and relatively low groundwater flow velocities and limited number of site management decisions to be made.

One well, MW-12A, had a PLSF recommendation for quarterly sampling, based on the ‘no trend’ concentration trend result and the presence of one outlying sample result. With the exception of one possible data outlier, the well shows a fairly low overall rate of change, so the MW-12A is also recommended for annual sampling.

The table below summarizes the current monitoring frequency and the recommended sampling frequency after the lines of evidence evaluation.

Monitoring Wells	Well Sampling frequency Analysis Source OU		
	Sampling Frequency	**Current Sampling Frequency**	**Sampling Frequency Recommendation**
	Quarterly	33	0
	Semi-annual	0	0
	Annual	0	23
	Biennial	0	0
Total Samples (average per year)		**99**	**23**
Total Wells		**33**	**23**

3.4 Data Sufficiency

The Data Sufficiency module was used to identify wells monitoring groundwater that has statistically achieved site cleanup goals with >80% statistical power and those that have attained cleanup using the Sequential T-test method (even more stringent). Statistical power increases with the number of samples taken and with reduction in both the concentration and detection limits for the dataset. For the FHC data set, the data were assumed to be log-normally distributed and the statistics were performed using this assumption. The groundwater cleanup goal for the FHC Site is 50 µg/L and the majority of detection limits are 0.5 µg/L for most samples.

The Data Sufficiency tools are normally run on datasets with greater than 6 years of data, but quarterly data for the past 3 years provides enough data to perform a preliminary analysis. Preliminary results for all sampling locations are reported in Table 5. Achievement of “clean” status was considered along with other lines of evidence when considering elimination of wells from the program and for reduction in sample frequency. Data sufficiency should be revisited when 3 more years of data have been collected.

Results of the data sufficiency indicate that the majority of wells in the network are at or approaching cleanup goals and have a sufficient number of sample events to provide confidence in the statistical outcome (although the number of sample *years* since source remediation is insufficient).

The data support the conclusion that the ISRM groundwater treatment in combination with removal of the industrial supply wells has reduced site-wide concentrations. The groundwater network indicates groundwater is approaching and may have achieved cleanup goals and that a reduction in monitoring effort may be appropriate at this time. The table below summarizes the results of the Data Sufficiency analysis. Identification of specific wells that have achieved cleanup can be found on Table 5.

Groundwater Zone	Total Wells	Data Sufficiency Results	
		Wells Statistically Below MTCA with >80% Power	Wells Statistically “Attained” Clean-up Goals
A	16	15 (94%)	4 (25%)
B	17	12 (71%)	1 (5%)
Total	33	27 (82%)	5 (15%)

MTCA = Washington State Model Toxics Control Act Standard A = 50µg/L.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 General Conclusions

The primary goal of developing an optimized monitoring strategy at the FHC Site is to create a dataset that fully supports site management decisions while minimizing time and expense associated with collecting and interpreting the data. A summary of the final recommended monitoring network is presented in Table 7. The recommended network reduces monitoring effort and cost by reducing both the frequency of groundwater sampling and the number of locations sampled.

Tasks identified in the Section 1 were performed for each of the groundwater zones. A summary of general results and recommendations resulting from each task is presented below:

- *Evaluate well locations and screened intervals within the context of the hydrogeologic regime to determine if the site is well characterized.*

  Result: Part of the network optimization process is to identify possible gaps in site characterization that may require additional sampling locations or site investigation. Based on well locations, screened intervals and hydrogeologic characteristics, affected groundwater at the FHC Site is delineated to the specified screening levels (MTCAs Standard A, 50µg/L). Groundwater areas where concentrations historically exceed screening levels (hot spots) are bounded by wells where results are below MTCAs. Monitoring locations in the tail of the network have average concentrations below the screening levels for both Zone A and Zone B. A “hot spot” was identified in Zone A near location MW-12A, while the “hot spot” in Zone B is shifted to the south near wells MW-15B and B87-8. All wells in the network have a sufficiently large data set to perform statistical calculations. No major data gaps were identified during the qualitative evaluation.

  Recommendation: LTMO is appropriate for the site at this time. No additional fundamental site investigation is recommended at this time. In order to comply with stated monitoring objectives, future groundwater monitoring should include historic “hot spot” wells as well as regulatory compliance points.

- *Evaluate overall plume stability through trend and moment analysis.*

  Result: Total chromium concentrations evaluated are largely decreasing to stable, even though some concentration trends (for both individual wells and plume moments) show no trend. Many ‘no trend’ findings result from occasional outliers in the dataset (see MW-14B) or from wells where the concentration fluctuates at very low to non-detect concentrations (see W97-18B, W97-19B). Another source of data variance includes possible influence of Columbia River stages on the aquifer and conservative sampling artifacts resulting from monitoring total chromium from a highly reduced geochemical regime. Overall, total dissolved mass estimates (zeroth moment) within the monitoring networks are strongly decreasing. Center of mass estimates show some variation, but are consistent with shrinking extent of affected groundwater. The distribution of mass within the Zone B network indicates that dilution and dispersion of dissolved chromium is ongoing.

Recommendation: Reduced monitoring effort is appropriate for stable or shrinking plumes. Monitoring frequency can be reduced where groundwater concentrations are not changing rapidly. After an initial steep drop in concentrations (2003-2004), groundwater concentrations are not changing rapidly at the FHC Site and concentrations within the network appear to have stabilized at a low level, largely below the 50µg/L screening level. This finding is consistent with reduced monitoring effort.

- *Evaluate individual well concentration trends over time for target constituents of concern (total chromium);*

  Result: For 33 wells evaluated at the FHC Site, approximately two-thirds of locations showed stable to decreasing concentration trends (63%). No increasing or probably increasing trends were calculated. No statistically significant trend was found at roughly one-third of locations.

  Recommendation: Individual well trend evaluations at the FHC Site provide support for the conclusion that total chromium concentrations are largely stable. Monitoring frequency can be reduced for locations where concentrations are not changing rapidly or are decreasing below screening levels. Some variation in concentrations is seen at “hot spot” locations, where occasional spikes in concentration have been recorded. “Hot spot” locations should be monitored periodically to develop a longer-term dataset (>6 years).

  In the future, both dissolved and total chromium analytical data should be collected at the appropriate locations. The dissolved chromium concentrations in groundwater should be used instead of or along side total chromium for the evaluations in order to reduce variance in the data introduced through sampling artifacts and variable redox conditions. The appropriate locations to use the dissolved data in the evaluations include monitoring well locations where the groundwater samples have greater then 10 NTUs turbidity readings.

  Wells in the tail area of the network (south and west of W85-6A/B) are largely stable to decreasing with very low concentrations; these locations should be monitored in the future as delineation or compliance points to confirm the absence of affected groundwater in this area.

- *Develop sampling location recommendations based on an analysis of spatial uncertainty;*

  Result: The spatial redundancy analysis indicated that several wells could be removed from the routine monitoring program, as they do not provide unique information.

The spatial analysis did not identify any areas of high spatial uncertainty.

Recommendation: 10 wells are recommended for exclusion from routine monitoring. The wells include locations near the remedy and some downgradient locations. A spatial analysis was conducted for the reduced network and no increase in spatial concentration uncertainty was found for data between 2006 and 2007. The resulting network of 23 locations should provide adequate information to monitor "dilution and dispersion" of dissolved chromium until all areas achieve cleanup goals with statistical confidence.

No new monitoring locations are recommended.

- *Develop sampling frequency recommendations based on both qualitative and quantitative statistical analysis results;*

  Result: The sampling frequency analysis recommended a dramatically reduced sampling frequency for the majority of wells. Annual to biennial sampling frequencies were recommended by the algorithm based on the rate of change and trend of well concentrations.

  Recommendation: Reduce the frequency of monitoring. An annual sampling frequency was recommended for future monitoring. While quarterly sampling has been effective to characterize the success of the remedy, long-term data over a period of years are required to achieve the stated monitoring objectives. These long-term objectives are not achieved by frequent sampling events, but rather by sampling a consistent set of wells at a frequency comparable to the rate of change of concentrations. The recommendation is to collect annual data for approximately six more years, and re-evaluate the plume for statistical attainment of site cleanup objectives.

- *Evaluate individual well analytical data for statistical sufficiency and identify locations that have achieved clean-up goals.*

  Result: 82% of wells are statistically below cleanup standards with greater than 80% power. 15% of locations have achieved cleanup using the Sequential T-test, a very rigorous statistical test.

  Recommendation: Data sufficiency should be revisited when 3 more years of data have been collected. Preliminary results indicate that remedial actions and management decisions at the FHC site have resulted in a reduction in groundwater concentrations with groundwater concentrations achieving or close to cleanup objectives. The high number of sampling locations currently achieving cleanup objectives is consistent with a reduced monitoring effort. All locations recommended for removal from routine monitoring have achieved the cleanup goal based on the Student's T-test and power analysis.

Additional Recommendations:

- The majority of the analysis above was completed before several wells in the network were damaged as a result of site redevelopment. Some wells may need to be replaced or rehabilitated in order to achieve stated site monitoring objectives. The general recommendations for the network are to: 1) monitor "hot spots" in Zones A and B, and 2) monitor sufficient delineation points down and cross-gradient to confirm contaminant containment.

  The recommendation that no new monitoring locations are needed does not imply that monitoring wells damaged or destroyed during site redevelopment do not need to be replaced. New wells may be required, but their placement near 'old' locations identified as important is recommended.

- Monitoring data at the FHC Site show some variance relative to concentrations (resulting in no trend). In most cases, variance in the data can be explained by site characteristics and geochemical processes. Continue monitoring for concentration trends and potentiometric water levels to determine how the hydraulic influence of the Columbia River may be contributing to underlying variance in the data. Additionally, area redevelopment may cause changes in recharge patterns (new paved areas, installation of permeable paving), which may be reflected in aquifer characteristics and concentration trends.

- Collect analytical data on total chromium as well as dissolved (Cr(VI)) chromium. Monitor turbidity in groundwater samples to ensure that only dissolved chromium is being measured in the sample. Flag samples that have been filtered.

- Continue development and updating of the comprehensive site database including both total and dissolved chromium analytical results. Validated analytical data for all wells in the area should be added to database within a reasonable time after sampling. Each well should have a complete record of historic sampling events.

- Survey location coordinates and elevations for all wells. Make data available to all stakeholders.

5.0 CITED REFERENCES

AFCEE. (2003). Monitoring and Remediation Optimization System (MAROS) 2.2 Software Users Guide. Air Force Center for Environmental Excellence. http://www.gsi-net.com/software/MAROS_V2_1Manual.pdf

AFCEE. (1997). Air Force Center for Environmental Excellence, AFCEE Long-Term Monitoring Optimization Guide, http://www.afcee.brooks.af.mil.

Aziz, J. A., C. J. Newell, M. Ling, H. S. Rifai and J. R. Gonzales (2003). "MAROS: A Decision Support System for Optimizing Monitoring Plans." Ground Water 41(3): 355-367.

Gilbert, R. O. (1987). Statistical Methods for Environmental Pollution Monitoring. New York. Van Norstrand Reinhold.

Ridley, M.N., Johnson, V. M and Tuckfield, R. C. (1995). Cost-Effective Sampling of Ground Water Monitoring Wells. HAZMACON. San Jose, California.

USEPA. (2001) *Frontier Hard Chrome Superfund Site Amended Record of Decision*. USEPA Region X. August, 2001.

USEPA (1988) *Frontier Hard Chrome Superfund Site Record of Decision: Groundwater Operable Unit.* USEPA Region X. July 1988.

USEPA (1987) *Frontier Hard Chrome Superfund Site Record of Decision: Soil Operable Unit.* USEPA Region X. December, 1987.

USEPA (1992). Methods for Evaluating the Attainment of Cleanup Standards: Volume 2 Ground Water. Washington, D.C., United States Environmental Protection Agency Office of Policy Planning and Evaluation.

Weston (2007). *Frontier Hard Chrome Event 11 Long-Term Monitoring Report* (June 2007 Results). Weston Solutions, Inc. August, 2007.

GROUNDWATER MONITORING NETWORK OPTIMIZATION
FRONTIER HARD CHROME

Vancouver, Washington

TABLES

TABLE 1
MONITORING WELL NETWORK SUMMARY

LONG-TERM MONITORING OPTIMIZATION
FRONTIER HARD CHROME SUPERFUND SITE
VANCOUVER, WASHINGTON

Well Name	Hydrologic Zone	Screened Interval [ft bgs]	Source or Tail (for MAROS)	Minimum Sample Date	Maximum Sample Date	Number of Samples (2003-2007)	Current Sampling Frequency	Well Description
Zone A								
B85-4	A	21.5-26.5	S	2/5/2004	6/5/2007	11	Quarterly	Historic high concentrations, monitors central area downgradient of plume.
RA-MW-11A	A	22.9-27.6	S	10/16/2003	6/5/2007	12	Quarterly	Monitors northern edge of plume, near area of historic high, area of remedy barrier, paired with Zone B well.
RA-MW-12A	A	23.2-27.9	S	10/17/2003	6/5/2007	12	Quarterly	Monitors area of historic highest concentrations and permeable reactive barrier, nested with Zone B wells.
RA-MW-13A	A	22.5-27.1	T	10/15/2003	6/5/2007	12	Quarterly	Very low concentration area near permeable reactive barrier, nested with Zone B wells.
RA-MW-14A	A	20.3-25.1	T	10/15/2003	6/5/2007	12	Quarterly	Monitors area of historic high concentrations and eastern permeable reactive barrier, nested with Zone B well.
RA-MW-15A	A	22.1-26.6	S	10/15/2003	6/5/2007	12	Quarterly	Monitors center plume between remedy and B85-4, low Cr in Zone A, paired with high Cr well in Zone B.
RA-MW-16A	A	22.2-26.7	T	10/14/2003	6/5/2007	12	Quarterly	Monitors center plume between remedy and B85-4, low Cr in Zone A, paired with high Cr well in Zone B.
RA-MW-17A	A	21.7-26.2	T	10/14/2003	6/5/2007	12	Quarterly	Northeastern edge in remedy zone, not paired with Zone B well.
W85-6A	A	17-27	T	2/9/2004	6/5/2007	9	Quarterly	Downgradient, center of plume, paired with Zone B well.
W85-7A	A	16.5-26.5	T	2/6/2004	6/5/2007	11	Quarterly	Downgradient, center-west of plume, paired with Zone B well.
W92-16A	A	24-34	T	2/5/2004	6/5/2007	11	Quarterly	Delineates western edge of plume near-downgradient of remedy, low detection frequency, paired with Zone B well.
W97-18A	A	22.5-27.5	T	2/5/2004	6/5/2007	11	Quarterly	Delineates far eastern edge of plume, paired with Zone B well.
W97-19A	A	20-25	T	2/6/2004	6/5/2007	11	Quarterly	Delineates far western downgradient edge of plume, paired wit Zone B well.
W98-20A	A	22-27	T	2/7/2004	6/5/2007	11	Quarterly	Monitors downgradient, center of plume, not paired with Zone B well.
W98-21A	A	21-26	T	2/9/2004	6/5/2007	11	Quarterly	Monitors downgradient, eastern edge of plume, paired with Zone B well.
W99-R5A	A	22-32	T	2/7/2004	6/5/2007	11	Quarterly	Monitors farthest downgradient tail, historic edge of plume, paired with Zone B well.

TABLE 1
MONITORING WELL NETWORK SUMMARY

LONG-TERM MONITORING OPTIMIZATION
FRONTIER HARD CHROME SUPERFUND SITE
VANCOUVER, WASHINGTON

Well Name	Hydrologic Zone	Screened Interval [ft bgs]	Source or Tail (for MAROS)	Minimum Sample Date	Maximum Sample Date	Number of Samples (2003-2007)	Current Sampling Frequency	Well Description
Zone B								
B85-3	B	24-29	T	2/5/2004	6/5/2007	11	Quarterly	Monitors upgradient northwest corner, near former FHC building, west of reducing zone.
B87-8	B	24.5-29.5	S	2/4/2004	6/5/2007	11	Quarterly	Monitors high concentration area immediately downgradieent of remedy, not paired with Zone A well.
RA-MW-11B	B	28.3-32.9	S	10/16/2003	6/5/2007	12	Quarterly	Monitors northern edge of plume, near area of historic high groundwater concentrations, paired wit A Zone well.
RA-MW-12B	B	28.3-32.8	T	10/17/2003	6/5/2007	12	Quarterly	Monitors northern edge of upper Zone B, near area of historic high groundwater concentrations, paired with Zone A well.
RA-MW-12C	B	34.5-39	T	10/17/2003	6/5/2007	12	Quarterly	Monitors northern edge of lower Zone B, near area of historic high groundwater concentrations, paired with Zone A well.
RA-MW-13B	B	27.3-31.9	T	10/16/2003	6/5/2007	12	Quarterly	Monitors upper Zone B near reactive barrier, area of low concentrations.
RA-MW-13C	B	34.6-39.5	T	2/3/2004	6/5/2007	11	Quarterly	Monitors lower Zone B near reactive barrier, area of low concentrations.
RA-MW-14B	B	25.5-30.1	T	10/15/2003	6/5/2007	12	Quarterly	Monitors eastern edge of Zone B near remedy, paired with Zone A well.
RA-MW-15B	B	27.7-32.5	S	10/15/2003	6/5/2007	12	Quarterly	Monitors immediately downgradient of permeable barrier, 'hot spot' in Zone B.
RA-MW-16B	B	27.9-32.5	S	10/14/2003	6/5/2007	12	Quarterly	Monitors center plume between remedy and downgradient area, low Cr in Zone A, paired with high Cr in Zone B.
W85-6B	B	44-49	T	2/9/2004	6/5/2007	9	Quarterly	Downgradient, center of plume, paired with Zone A well.
W85-7B	B	44-49	T	2/6/2004	6/5/2007	11	Quarterly	Downgradient center of plume, paired with Zone A well.
W92-16B	B	35-45	S	10/14/2003	6/5/2007	12	Quarterly	Delineates western edge of plume near-downgradient of remedy, variable concentrations, paired with Zone A well.
W97-18B	B	39.5-44.5	T	2/6/2004	6/5/2007	11	Quarterly	Delineates far eastern edge of plume, paired with Zone A well.
W97-19B	B	40-45	T	2/6/2004	6/5/2007	11	Quarterly	Delineates far western downgradient edge of plume, paired wit Zone A well.
W98-21B	B	39-44	T	2/9/2004	6/5/2007	11	Quarterly	Monitors downgradient, eastern edge of plume, paired with Zone A well.
W99-R5B	B	44-49	T	2/7/2004	6/5/2007	11	Quarterly	Downgradient tail edge of plume, paired with Zone A well.

Notes:
1. Wells listed are in current monitoring program. Data from USEPA Region 10, Sept. 2007. Well locations illustrated on Figure 1.
2. Groundwater zones are based on the depth of the well screened interval. Zone A is in the upper alluvial aquifer; Zone B is in the more transmissive lower depth of the alluvial aquifer.
3. Number of samples is the number of quarters the well has been sampled 2003-2007.

TABLE 2
AQUIFER INPUT PARAMETERS

LONG-TERM MONITORING OPTIMIZATION
FRONTIER HARD CHROME SUPERFUND SITE
VANCOUVER, WASHINGTON

Parameter	Value	Units
Current Plume[5] Length	1000	ft
Maximum Plume[5] Length	2500	ft
Plume[5] Width	1000	ft
SeepageVelocity (ft/yr) [3]		
Zone A	182.5	ft/yr
Zone B	821.25	ft/yr
Distance to Receptors (Columbia River)	3000	ft
GWFluctuations	Yes	--
SourceTreatment	Permeable reactive barrier/chemical reductant	--
Contaminant Type	Metals	--
NAPLPresent	No	--
Priority Constituent	**Cleanup Goals**	
Chromium (total)	50	ug/L
Parameter	**Value**	
Groundwater flow direction	S/SW	225 degrees
Porosity	0.3	--
Source Location near Well	North of RA-MW-11	--
Source X-Coordinate	1091615.515	ft
Source Y-Coordinate	112599.082	ft
Coordinate System	NAD 83 SP Washington South	
Saturated Thickness		
Zone A	15	ft
Zone B	50	ft

Notes:

1. Aquifer data from ROD and ROD Amendment (USEAPA, 1988; USEPA, 2001).
2. Source coordinates estimated to center of historic FHC building.
3. * = a wide range of transmissivites are present in the aquifer, and groundwater velocity calculations result in a range, with values shown being the best estimate.
4. Cleanup objectives are Model Toxics Control Act Method A promulgated by the Washington State Department of Ecology for property with unrestricted use.
5. 'Plume' as used in this report descripes the extent of groundwater affected by source-associated chromium at any concentration; rather than groundwater above the regulatory screening limit.

TABLE 3
WELL TREND SUMMARY RESULTS: 2003-2007

LONG-TERM MONITORING OPTIMIZATION
FRONTIER HARD CHROME SUPERFUND SITE
VANCOUVER, WASHINGTON

WellName	Number of Samples	Number of Detects	Percent Detection	Maximum Result [ug/L]	Max Result Above Standard?	Average Result [ug/L]	Average Result Above Standard?	Mann-Kendall Trend	Linear Regression Trend	Overall Trend Result
Zone A Wells										
B85-4	11	10	91%	37.7	No	8.3	No	D	D	D
RA-MW-11A	12	10	83%	**50.1**	Yes	9.7	No	D	D	D
RA-MW-12A	12	12	100%	**5260**	Yes	**682.0**	Yes	NT	NT	NT
RA-MW-13A	12	10	83%	4.4	No	1.4	No	S	S	S
RA-MW-14A	12	9	75%	5.4	No	1.8	No	S	NT	S
RA-MW-15A	12	11	92%	37	No	6.2	No	NT	NT	NT
RA-MW-16A	12	11	92%	9.2	No	3.3	No	D	D	D
RA-MW-17A	12	11	92%	10.2	No	5.1	No	S	S	S
W85-6A	9	8	89%	14.3	No	4.6	No	S	S	S
W85-7A	11	9	82%	3.6	No	1.8	No	S	S	S
W92-16A	11	7	64%	6.3	No	1.6	No	NT	PD	S
W97-18A	11	6	55%	0.6	No	0.5	No	S	D	PD
W97-19A	11	10	91%	7.9	No	2.7	No	PD	D	D
W98-20A	11	10	91%	5.1	No	2.1	No	S	D	PD
W98-21A	11	10	91%	7.1	No	2.6	No	PD	D	D
W99-R5A	11	4	36%	4.1	No	0.8	No	NT	NT	NT
Zone B Wells										
B85-3	11	8	73%	6.3	No	2.84	No	NT	NT	NT
B87-8	11	11	100%	**241**	Yes	**61.8**	Yes	NT	NT	NT
RA-MW-11B	12	11	92%	**69.2**	Yes	9.9	No	D	D	D
RA-MW-12B	12	10	83%	26	No	5.3	No	D	NT	S
RA-MW-12C	12	12	100%	12.2	No	4.0	No	S	S	S
RA-MW-13B	12	6	50%	7.1	No	1.4	No	NT	NT	NT
RA-MW-13C	11	10	91%	7.3	No	2.6	No	S	S	S
RA-MW-14B	12	9	75%	7	No	1.5	No	NT	NT	NT
RA-MW-15B	12	12	100%	**192**	Yes	**78.1**	Yes	NT	NT	NT
RA-MW-16B	12	12	100%	**225**	Yes	46.4	No	NT	NT	NT
W85-6B	9	8	89%	13	No	4.5	No	D	D	D
W85-7B	11	4	36%	18	No	3.7	No	D	D	D
W92-16B	12	12	100%	**225**	Yes	46	No	NT	NT	NT
W97-18B	11	8	73%	1.3	No	0.881	No	NT	NT	NT
W97-19B	11	9	82%	12.5	No	3.41	No	D	D	D
W98-21B	11	10	91%	6.6	No	2.77	No	D	D	D
W99-R5B	11	10	91%	9.9	No	3.99	No	D	D	D

Notes

1. Trends were evaluated for data collected between 2003 and 2007.
2. Number of Samples is the number of quarterly samples for the compound at this location.
   Number of Detects is the number of times the compound has been detected for data at this location.
3. Maximum Result is the maximum concentration for the COC analyzed between 2003 and 2007.
4. Screening level Standard from Washington Department of Ecology = 50ug/L. Values above the Standard indicated in **Bold**.
5. D = Decreasing; PD = Probably Decreasing; S = Stable; PI = Probably Increasing; I = Increasing; N/A = Insufficient Data to determine trend;
   NT = No Trend; ND = well has all non-detect results for COC; ND* = Non-detect except for one trace value.
6. Mann-Kendall trend results are illustrated on Figure 2.

TABLE 4
MOMENT ESTIMATES AND TRENDS

LONG-TERM MONITORING OPTIMIZATION
FRONTIER HARD CHROME SUPERFUND SITE
VANCOUVER, WASHINGTON

Zone	Effective Sample Event Date	Number of wells in network	Dissolved Cr Mass Estimate [Kg]	Distance of Center of Mass from Source [ft]
Zone A	2/10/2004	16	0.32	830
	4/5/2004	16	0.63	1192
	8/15/2004	16	0.59	957
	5/5/2005	16	0.26	1038
	12/12/2005	15	0.37	753
	3/8/2006	15	0.25	931
	6/15/2006	16	0.18	962
	9/25/2006	16	0.26	912
	12/15/2006	16	0.08	1058
	3/30/2007	16	0.25	984
	6/5/2007	16	0.25	1010
	Trend		**D**	**NT**
Zone B	2/10/2004	17	5.66	901
	4/5/2004	17	3.34	1092
	8/15/2004	17	2.70	1026
	5/5/2005	17	2.76	817
	12/12/2005	16	1.91	709
	3/8/2006	16	1.41	878
	6/15/2006	17	1.16	831
	9/25/2006	17	1.74	792
	12/15/2006	17	0.58	673
	3/30/2007	17	1.68	737
	6/5/2007	17	1.44	881
	Trend		**D**	**D**

Notes:
1. Input parameters for the moment analysis are listed in Table 2.
2. Moments are based on all wells sampled during the quarter including the effective date indicated.
3. Number of wells is the total number of locations sampled for the plume during the year indicated.
4. Estimated mass is the total dissolved mass of total chromium within the network indicated.
5. Trends are Mann Kendall trends on the moments, S=Stable, D = Decreasing, NT = No Trend.
6. First moments are illustrated on Figure 2.

TABLE 5
WELL REDUNDANCY AND CLEAN-UP STATUS SUMMARY RESULTS

LONG-TERM MONITORING OPTIMIZATION
FRONTIER HARD CHROME SUPERFUND SITE
VANCOUVER, WASHINGTON

WellName	Mann-Kendall Trend 2003-2007	Maximum Concentration Cr (ug/L)	Cr Average Slope Factor	Statistically Below Screening Level >80% Power	Sequential T-Test Result	MAROS Statistically Redundant	Recommendation After Qualitative Review
Zone A							
B85-4	D	37.70	0.12	YES		**Yes**	Retain
RA-MW-11A	D	**50.10**	0.43	YES		No	**Exclude**
RA-MW-12A	NT	**5260.00**	0.58	*NO*		No	Retain
RA-MW-13A	S	4.40	0.40	YES	Attained	No	**Exclude**
RA-MW-14A	S	5.40	0.09	YES		**Yes**	**Exclude**
RA-MW-15A	NT	37.00	0.12	YES		**Yes**	Retain
RA-MW-16A	D	9.20	0.08	YES		**Yes**	Retain
RA-MW-17A	S	10.20	0.15	YES		No	Retain
W85-6A	S	14.30	0.20	YES		**Yes**	Retain
W85-7A	S	3.60	0.07	YES	Attained	**Yes**	**Exclude**
W92-16A	NT	6.30	0.27	YES		**Yes**	Retain
W97-18A	S	0.60	0.41	YES	Attained	No	Retain
W97-19A	PD	7.90	0.10	YES		No	Retain
W98-20A	S	5.10	0.09	YES		**Yes**	**Exclude**
W98-21A	PD	7.10	0.04	YES		No	Retain
W99-R5A	NT	4.10	0.32	YES	Attained	No	Retain
Zone B							
B85-3	NT	6.30	0.26	YES		No	Retain
B87-8	NT	**241.00**	0.17	*NO*		**Yes**	Retain
RA-MW-11B	D	**69.20**	0.17	YES		**Yes**	**Exclude**
RA-MW-12B	D	26.00	0.17	YES		**Yes**	Retain
RA-MW-12C	S	12.20	0.22	YES		**Yes**	Retain
RA-MW-13B	NT	7.10	0.42	YES		No	**Exclude**
RA-MW-13C	S	7.30	0.23	YES		**Yes**	**Exclude**
RA-MW-14B	NT	6.50	0.46	YES		No	**Exclude**
RA-MW-15B	NT	**192.00**	0.39	*NO*		No	Retain
RA-MW-16B	NT	**225.00**	0.35	*NO*		No	Retain
W85-6B	D	12.90	0.21	--		**Yes**	Retain
W85-7B	D	17.70	0.52	YES		No	**Exclude**
W92-16B	NT	**225.00**	0.33	*NO*		No	Retain
W97-18B	NT	1.30	0.45	YES	Attained	No	Retain
W97-19B	D	12.50	0.23	YES		No	Retain
W98-21B	D	6.60	0.08	YES		No	Retain
W99-R5B	D	9.90	0.05	YES		No	Retain

Notes:
1. Slope Factor is the difference between the actual concentration and the concentration estimated from nearest neighbors normalized by the actual concentration. Slope factors close to 1 show the concentrations cannot be estimated from the nearest neighbors, and the well is important in the network.
2. Slope factors were calculated using data between January 2006 and June 2007.
3. Locations with slope factors below 0.3 and area ratios below 0.8 were considered for elimination.
4. Wells statistically below the cleanup level (50 ug/L) by Student's-T Test and >80% Power indicated. "Attained" indicates wells statistically below cleanup level assuming log-normal distribution using sequential T-test.
5. MAROS identified wells that are statistically redundant were reviewed using qualitative factors, and the final recommendation reflects both statistical findings and regulatory and site specific factors.

TABLE 6
MCES SAMPLING FREQUENCY ANALYSIS RESULTS

LONG-TERM MONITORING OPTIMIZATION
FRONTIER HARD CHROME SUPERFUND SITE
VANCOUVER, WASHINGTON

Well Name	Recent Concentration Rate of Change [mg/yr]	Recent MK Trend (2006-2007)	Frequency Based on Recent Data (2006-2007)	Overall Concentration Rate of Change [mg/yr]	Overall MK Trend (2003 - 2007)	Frequency Based on Overall Data (2003 - 2007)	MAROS Recommended Frequency	Current Sampling Frequency	Final Recommended Frequency
Zone A Wells									
B85-4	-4.00E-06	S	Annual	-1.48E-05	D	Annual	Biennial	Quarterly	Annual
RA-MW-11A	1.31E-06	S	Annual	-1.75E-05	D	Annual	Biennial	Quarterly	Annual
RA-MW-12A	-1.27E-03	NT	Annual	5.99E-04	NT	Quarterly	Quarterly	Quarterly	Annual
RA-MW-13A	-1.42E-06	S	Annual	-7.25E-07	S	Annual	Biennial	Quarterly	Annual
RA-MW-14A	-1.84E-07	S	Annual	-3.91E-07	S	Annual	Biennial	Quarterly	Annual
RA-MW-15A	-3.69E-06	S	Annual	1.17E-06	NT	Annual	Biennial	Quarterly	Annual
RA-MW-16A	-2.06E-06	S	Annual	-2.56E-06	D	Annual	Biennial	Quarterly	Annual
RA-MW-17A	-7.68E-06	S	Annual	-1.45E-06	S	Annual	Biennial	Quarterly	Annual
W85-6A	1.71E-06	S	Annual	-4.82E-06	S	Annual	Biennial	Quarterly	Annual
W85-7A	5.67E-07	S	Annual	-2.96E-07	S	Annual	Biennial	Quarterly	Annual
W92-16A	-2.46E-07	NT	Annual	-2.35E-06	NT	Annual	Biennial	Quarterly	Annual
W97-18A	-1.49E-07	PD	Annual	-4.89E-09	S	Annual	Annual	Quarterly	Annual
W97-19A	1.84E-06	NT	Annual	-3.38E-06	PD	Annual	Biennial	Quarterly	Annual
W98-20A	1.66E-06	NT	Annual	-2.23E-06	S	Annual	Biennial	Quarterly	Annual
W98-21A	-1.20E-07	S	Annual	-2.70E-06	PD	Annual	Biennial	Quarterly	Annual
W99-R5A	-3.32E-07	S	Annual	-1.12E-06	NT	Annual	Biennial	Quarterly	Annual
Zone B Wells									
B85-3	-7.10E-06	S	Annual	5.25E-07	NT	Annual	Biennial	Quarterly	Annual
B87-8	9.07E-05	S	Annual	-4.39E-05	NT	Annual	Annual	Quarterly	Annual
RA-MW-11B	-1.35E-05	NT	Annual	-2.08E-05	D	Annual	Biennial	Quarterly	Annual
RA-MW-12B	-9.87E-06	S	Annual	-6.41E-06	D	Annual	Biennial	Quarterly	Annual
RA-MW-12C	-8.58E-07	NT	Annual	-5.10E-07	S	Annual	Biennial	Quarterly	Annual
RA-MW-13B	-5.49E-07	S	Annual	-7.81E-07	NT	Annual	Biennial	Quarterly	Annual
RA-MW-13C	-8.67E-07	S	Annual	-5.17E-07	S	Annual	Biennial	Quarterly	Annual
RA-MW-14B	-2.35E-07	S	Annual	-8.40E-07	NT	Annual	Biennial	Quarterly	Annual
RA-MW-15B	-2.64E-04	S	Annual	4.74E-06	NT	Annual	Annual	Quarterly	Annual
RA-MW-16B	3.04E-05	NT	Annual	1.01E-05	NT	Annual	Annual	Quarterly	Annual
W85-6B	-7.12E-06	S	Annual	-5.15E-06	D	Annual	Biennial	Quarterly	Annual
W85-7B	0.00E+00	S	Annual	-1.13E-05	D	Annual	Biennial	Quarterly	Annual
W92-16B	2.55E-05	NT	Annual	8.99E-06	NT	Annual	Annual	Quarterly	Annual
W97-18B	3.45E-07	NT	Annual	2.61E-07	NT	Annual	Biennial	Quarterly	Annual
W97-19B	1.74E-06	NT	Annual	-5.83E-06	D	Annual	Biennial	Quarterly	Annual
W98-21B	-2.01E-06	S	Annual	-3.20E-06	D	Annual	Biennial	Quarterly	Annual
W99-R5B	-2.71E-06	S	Annual	-5.94E-06	D	Annual	Biennial	Quarterly	Annual

Notes:

1. Concentration rate of change is from linear regression calculations. 'Recent' concentration rate of change and MK trends are calculated from data collected 2006 - 2007.
2. MK trend = Mann Kendall trend. D = Decreasing, PD = Probably Decreasing, S = Stable, NT = No Trend.
3. Recent data frequency is the estimated sample frequency based on the recent trend.
4. Overall rate of change and MK trend are for the full data set (2003-2007) for each well. The overall result is the estimated sample frequncy based on the full data record.
6. MAROS Recommended Frequency is the final frequency from the MAROS calculations based on both recent and overall trends.
7. Current frequency is the approximate sampling frequency currently implemented.
8. The final recommended sampling frequency is based on a combination of qualitative and statistical evaluations.

TABLE 7
FINAL RECOMMENDED MONITORING NETWORK FRONTIER HARD CHROME

LONG-TERM MONITORING OPTIMIZATION
FRONTIER HARD CHROME SUPERFUND SITE
VANCOUVER, WASHINGTON

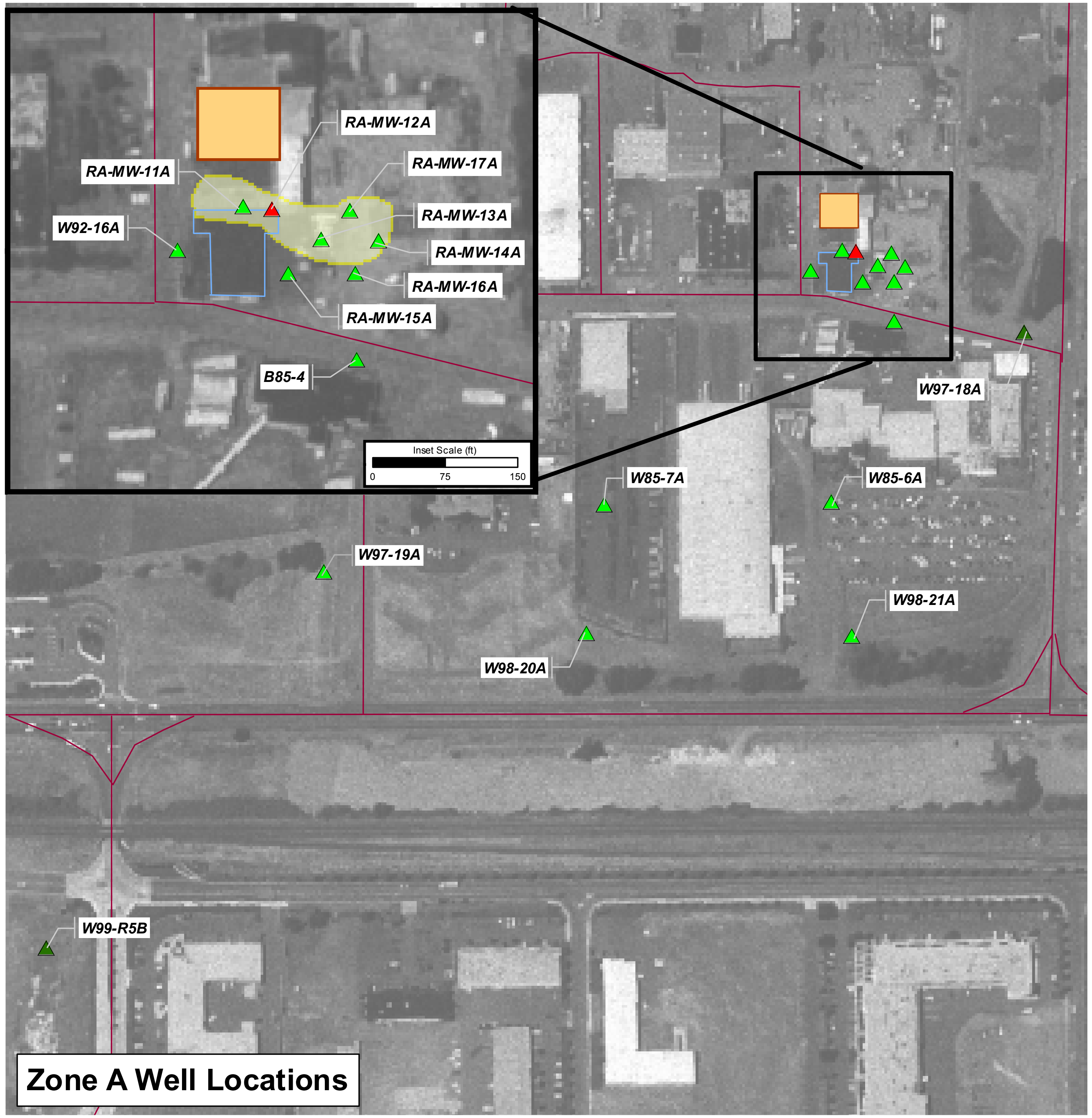
	Total Chromium					
WellName	**Percent Detection**	**Mann Kendall Trend**	**Statistically Below Standard?**	**MAROS Redundancy Determination**	**Recommendation After Qualitative Review**	**Final Recommended Frequency**
Zone A Wells						
B85-4	91%	D	√	√	Retain	Annual
RA-MW-11A	83%	D	√		**Exclude**	**Exclude**
RA-MW-12A	100%	NT			Retain	Annual
RA-MW-13A	83%	S	√		**Exclude**	**Exclude**
RA-MW-14A	75%	S	√	√	**Exclude**	**Exclude**
RA-MW-15A	92%	NT	√	√	Retain	Annual
RA-MW-16A	92%	D	√	√	Retain	Annual
RA-MW-17A	92%	S	√		Retain	Annual
W85-6A	89%	S	√	√	Retain	Annual
W85-7A	82%	S	√	√	**Exclude**	**Exclude**
W92-16A	64%	NT	√	√	Retain	Annual
W97-18A	55%	S	√		Retain	Annual
W97-19A	91%	PD	√		Retain	Annual
W98-20A	91%	S	√	√	**Exclude**	**Exclude**
W98-21A	91%	PD	√		Retain	Annual
W99-R5A	36%	NT	√		Retain	Annual
Zone B Wells						
B85-3	73%	NT	√		Retain	Annual
B87-8	100%	NT		√	Retain	Annual
RA-MW-11B	92%	D	√	√	**Exclude**	**Exclude**
RA-MW-12B	83%	D	√	√	Retain	Annual
RA-MW-12C	100%	S	√	√	Retain	Annual
RA-MW-13B	50%	NT	√		**Exclude**	**Exclude**
RA-MW-13C	91%	S	√	√	**Exclude**	**Exclude**
RA-MW-14B	75%	NT	√		**Exclude**	**Exclude**
RA-MW-15B	100%	NT			Retain	Annual
RA-MW-16B	100%	NT			Retain	Annual
W85-6B	89%	D	√	√	Retain	Annual
W85-7B	36%	D	√		**Exclude**	**Exclude**
W92-16B	100%	NT			Retain	Annual
W97-18B	73%	NT	√		Retain	Annual
W97-19B	82%	D	√		Retain	Annual
W98-21B	91%	D	√		Retain	Annual
W99-R5B	91%	D	√		Retain	Annual

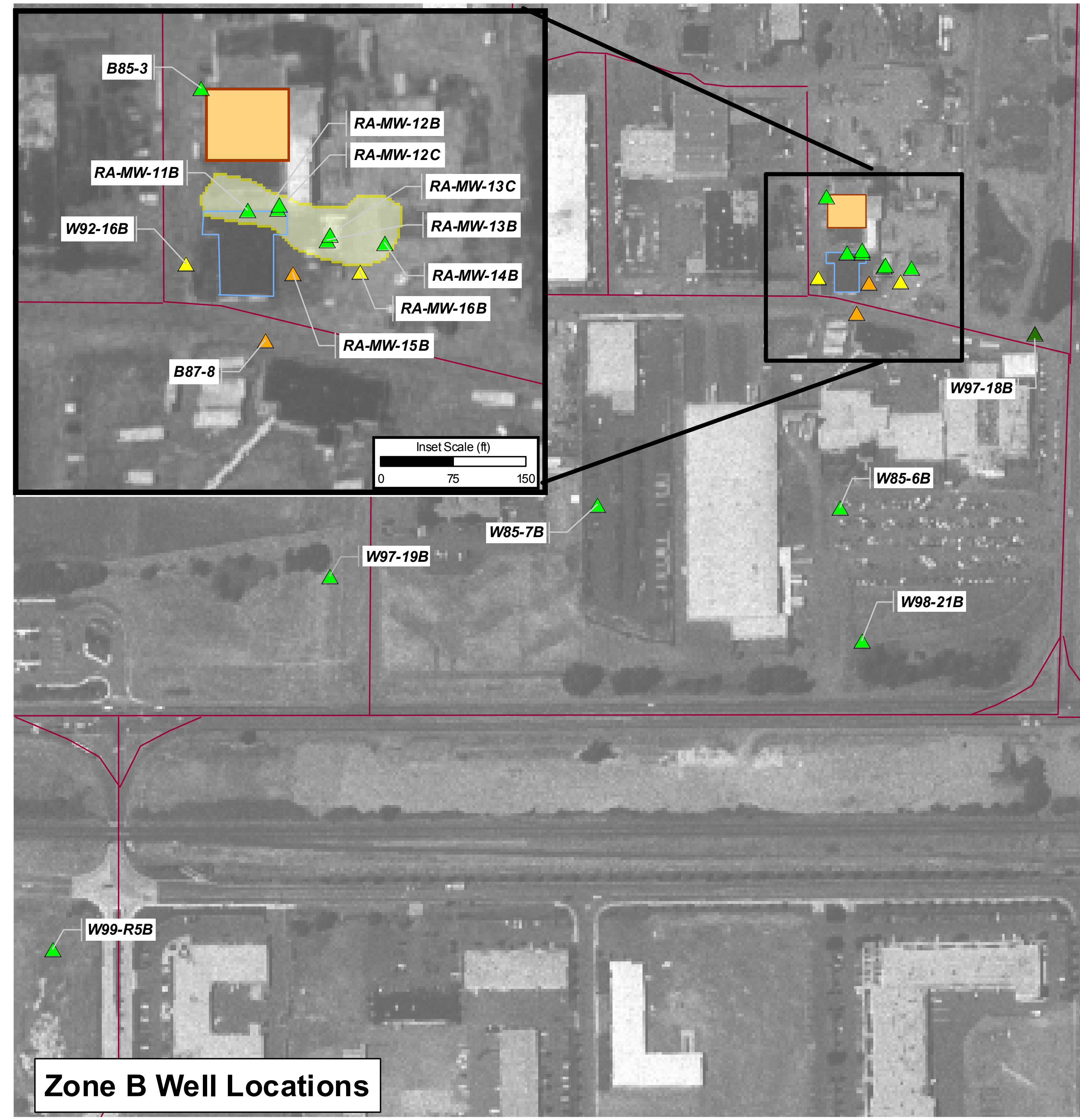
Notes:
1. Mann Kendall Trends: D = Decreasing; PD = Probably Decreasing; S = Stable; PI = Probably Increasing; I = Increasing; NT = No Trend; ND = well has all non-detect.
2. Mann-Kendall trends 2003 - 2007 are shown.
3. Statistically below standard based Student's T-Test with >80% statistical power for data between 2003-2007. Cleanup standard is Washington Ecology MTCA A = 50ug/L Total Chromium.
4. MAROS redundancy indicates well has low SF and high AR and CR.
5. Final Recommendation based on statistical as well as qualitative evaluation.

GROUNDWATER MONITORING NETWORK OPTIMIZATION
FRONTIER HARD CHROME

Vancouver, Washington

FIGURES





Legend

Average [Cr] [mg/L]

- ND - 0.001
- 0.001 - 0.01
- 0.01 - 0.05
- 0.05 - 0.5
- > 0.5

- Roads
- Cassidy Mfg.
- Soil Treatment Area (Approximate)
- ISRM Groundwater Treatment Zone (Approximate)

Notes:

1. Aerial map from 1994 shows historic site features and road locations. FHC buildings and industrial area to the south have been demolished.
2. The Soil Remedy and ISRM Groundwater Remedy are approximate areas based on USEPA maps.
3. Groundwater monitoring locations for each Zone are indicated. Average Cr concentrations 2003 - 2007 at each location are indicated by color.
4. Total Cr MTCA Standard A cleanup level = 0.05 mg/L.

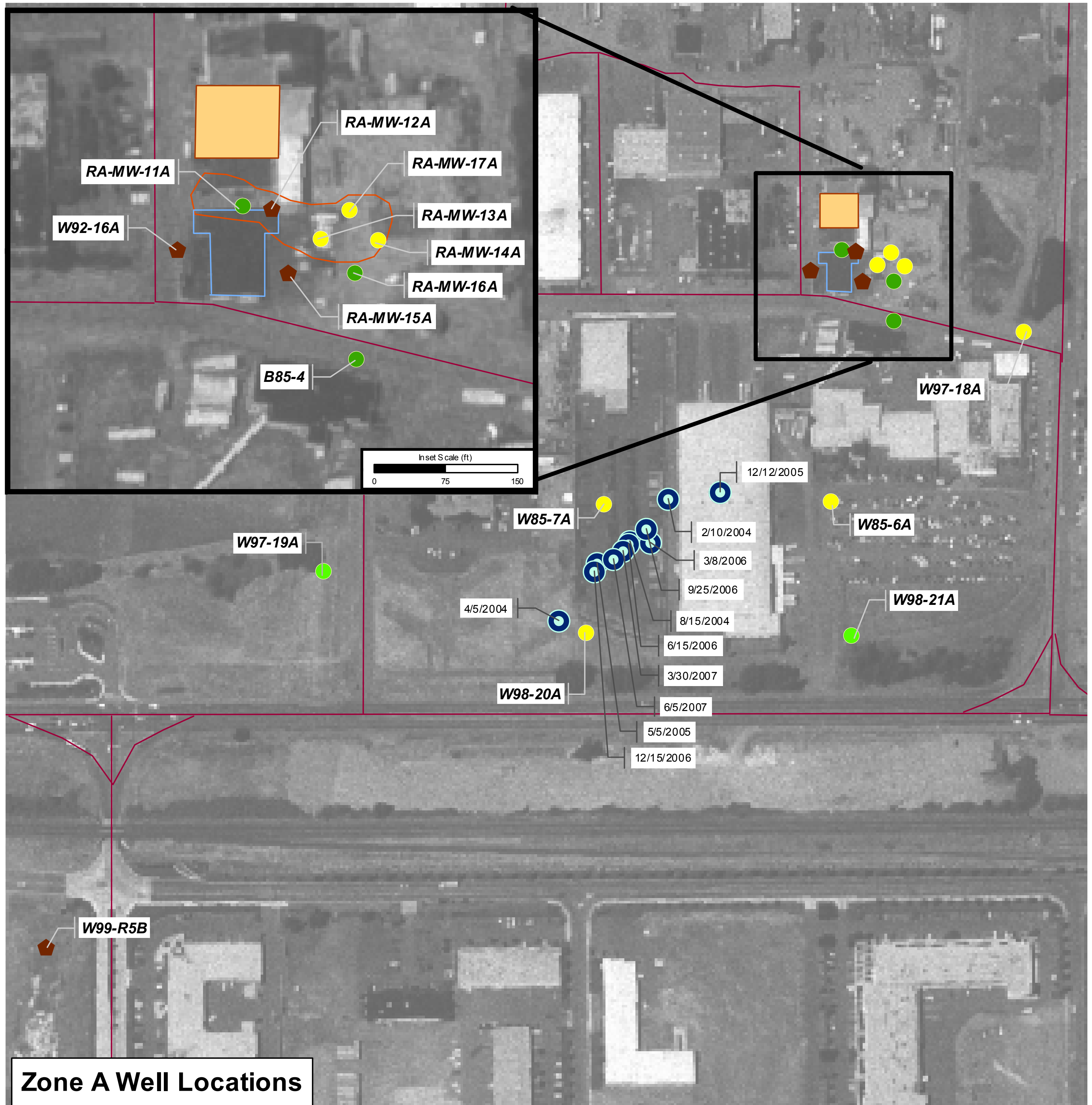
Large Map Scale (ft)
0 150 300

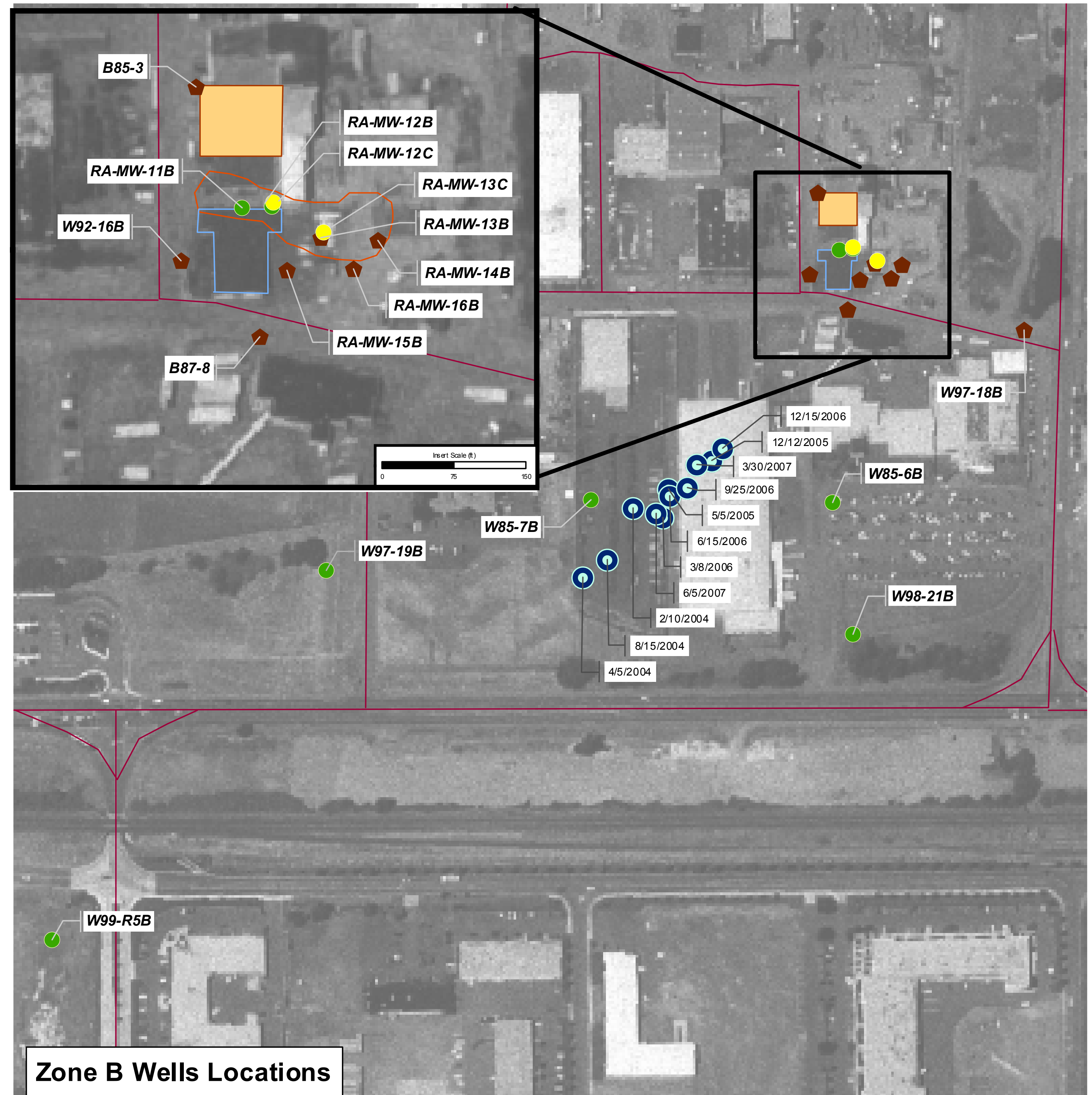
N

FRONTIER HARD CHROME GROUNDWATER MONITORING NETWORK

Vancouver, Washington

Coord. Sys. NAD 83 SP Wash. S. FT.	Issued: 21-DEC-2007
Drawn By: MV	Revised: ----
Chk'd By: MV	Map ID: ----
Appv'd By: MV	**FIGURE 1**





Legend

Mann Kendall Trend Cr

- Decreasing
- Probably Decreasing
- Stable
- Probably Increasing
- Increasing

- Non Detect (2003-2007)
- No Trend
- Insufficient Data
- First Moment (Effective Date Shown)

- Soil Remedy Area
- ISRMTreatment
- Cassidy Mfg.
- Roads

Notes:

1. Aerial map from 1994 shows historic site features and road locations. FHC buildings and industrial area to the south have been demolished.
2. Mann-Kendall trends were determined for data collected between 2003-2007.
3. First moments were determined using quarterly data. An effective date of the quarterly sampling event is indicated.
4. Total Cr MTCA Standard A cleanup level = 0.05 mg/L.

Scale (ft)
0 150 300

N

FRONTIER HARD CHROME

CONCENTRATION TREND AND FIRST MOMENT RESULTS

Vancouver, Washington

Coord. Sys. NAD 83 SP Wash. S. FT.	Issued: 21-DEC-2007
Drawn By: MV	Revised: ----
Chk'd By: MV	Map ID: ----
Appv'd By:	**FIGURE 2**

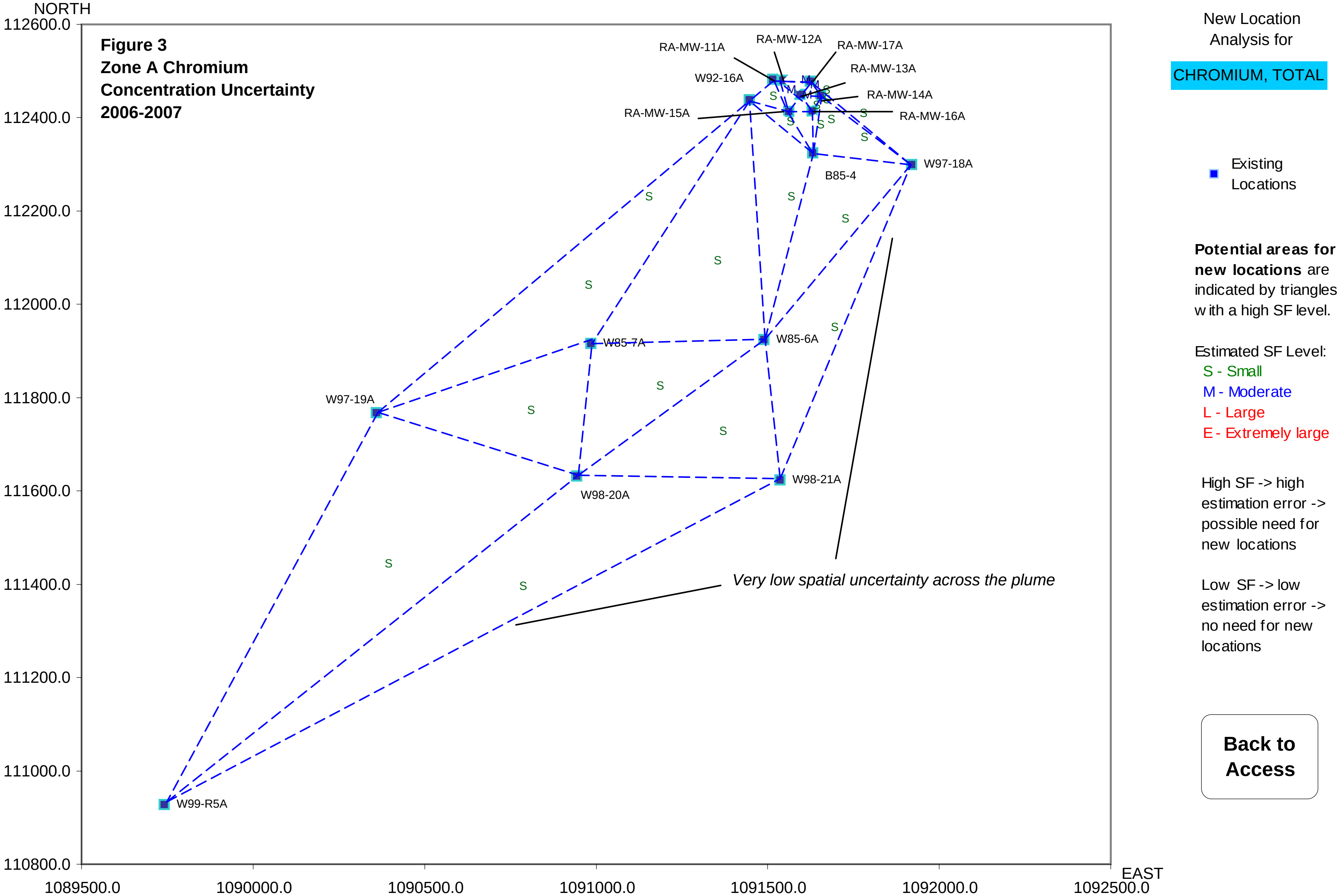
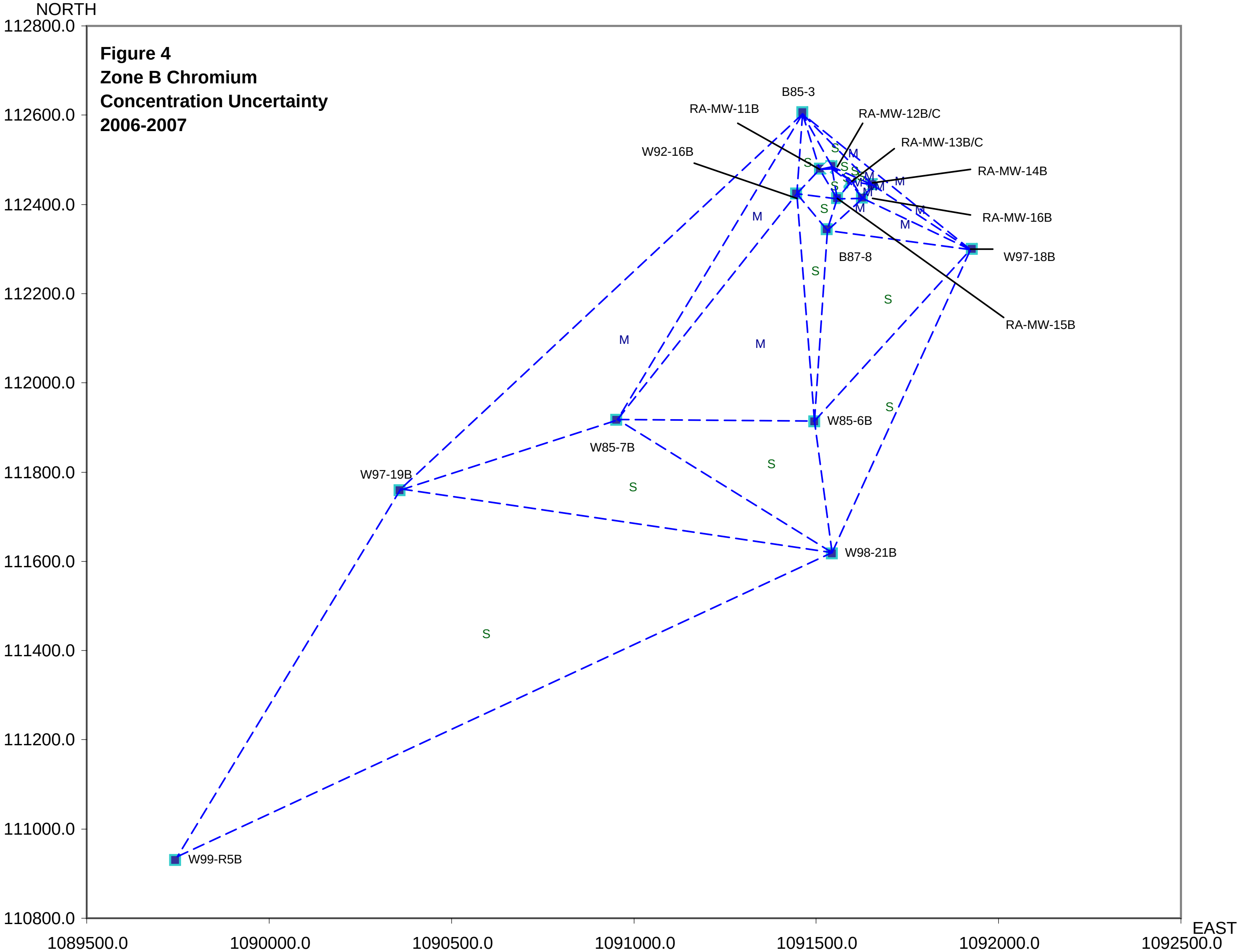


Figure 3
Zone A Chromium
Concentration Uncertainty
2006-2007
NORTH
EAST
112600.0
112400.0
112200.0
112000.0
111800.0
111600.0
111400.0
111200.0
111000.0
110800.0
1089500.0
1090000.0
1090500.0
1091000.0
1091500.0
1092000.0
1092500.0
RA-MW-11A
RA-MW-12A
RA-MW-17A
RA-MW-13A
RA-MW-14A
RA-MW-15A
RA-MW-16A
W92-16A
W97-18A
B85-4
W85-7A
W85-6A
W97-19A
W98-20A
W98-21A
W99-R5A
Very low spatial uncertainty across the plume
New Location Analysis for
CHROMIUM, TOTAL
Existing Locations
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 -> possible need for new locations
Low SF -> low estimation error -> no need for new locations
Back to Access



New Location Analysis for

CHROMIUM, TOTAL

Existing Locations

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 -> possible need for new locations

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

Back to Access

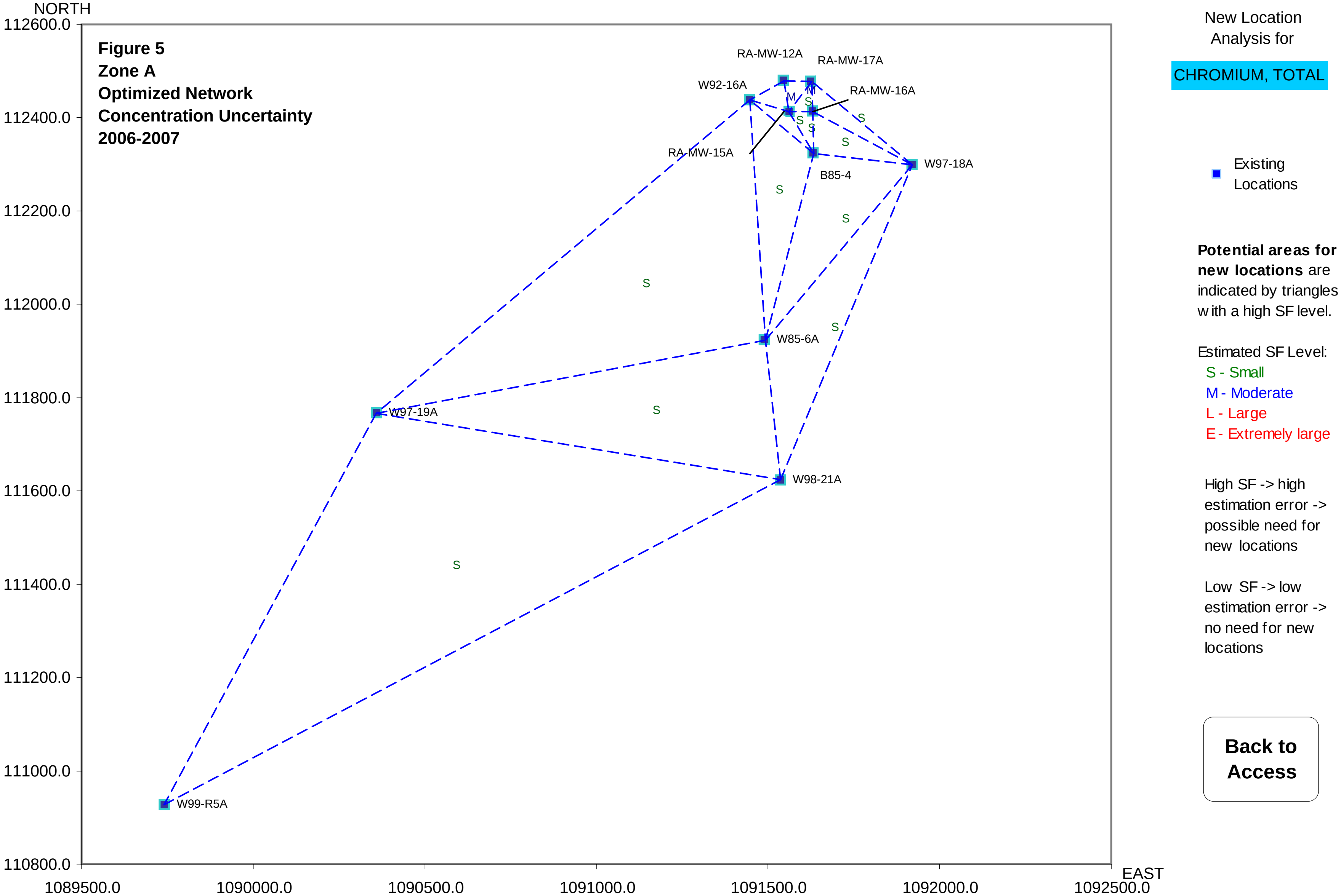
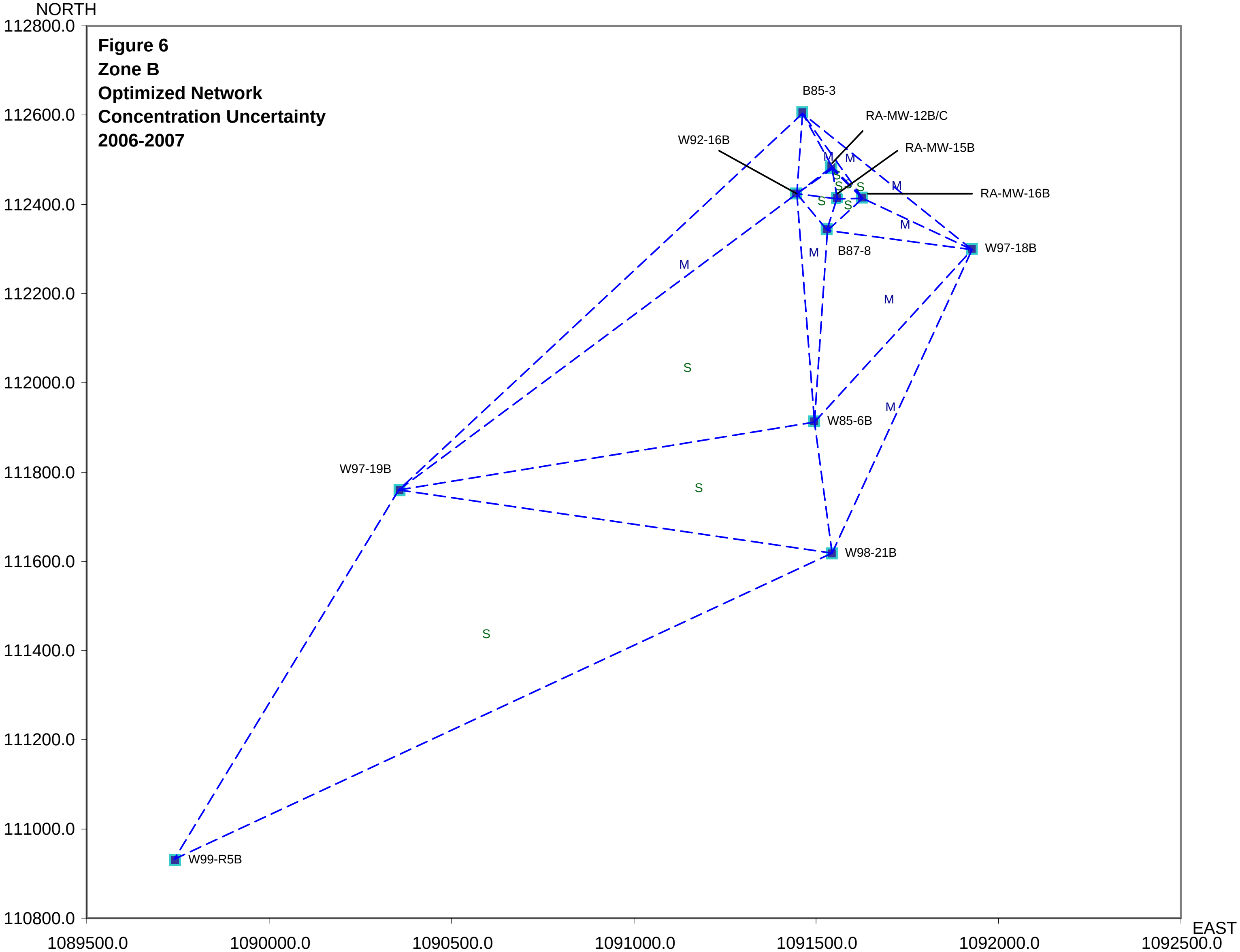


Figure 5
Zone A
Optimized Network
Concentration Uncertainty
2006-2007
NORTH
112600.0
112400.0
112200.0
112000.0
111800.0
111600.0
111400.0
111200.0
111000.0
110800.0
1089500.0
1090000.0
1090500.0
1091000.0
1091500.0
1092000.0
1092500.0
EAST
RA-MW-12A
RA-MW-17A
W92-16A
RA-MW-16A
RA-MW-15A
B85-4
W97-18A
W85-6A
W97-19A
W98-21A
W99-R5A
M
M
S
New Location
Analysis for
CHROMIUM, TOTAL
Existing
Locations
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 -> possible need for new locations
Low SF -> low estimation error -> no need for new locations
Back to
Access



New Location Analysis for

CHROMIUM, TOTAL

Existing Locations

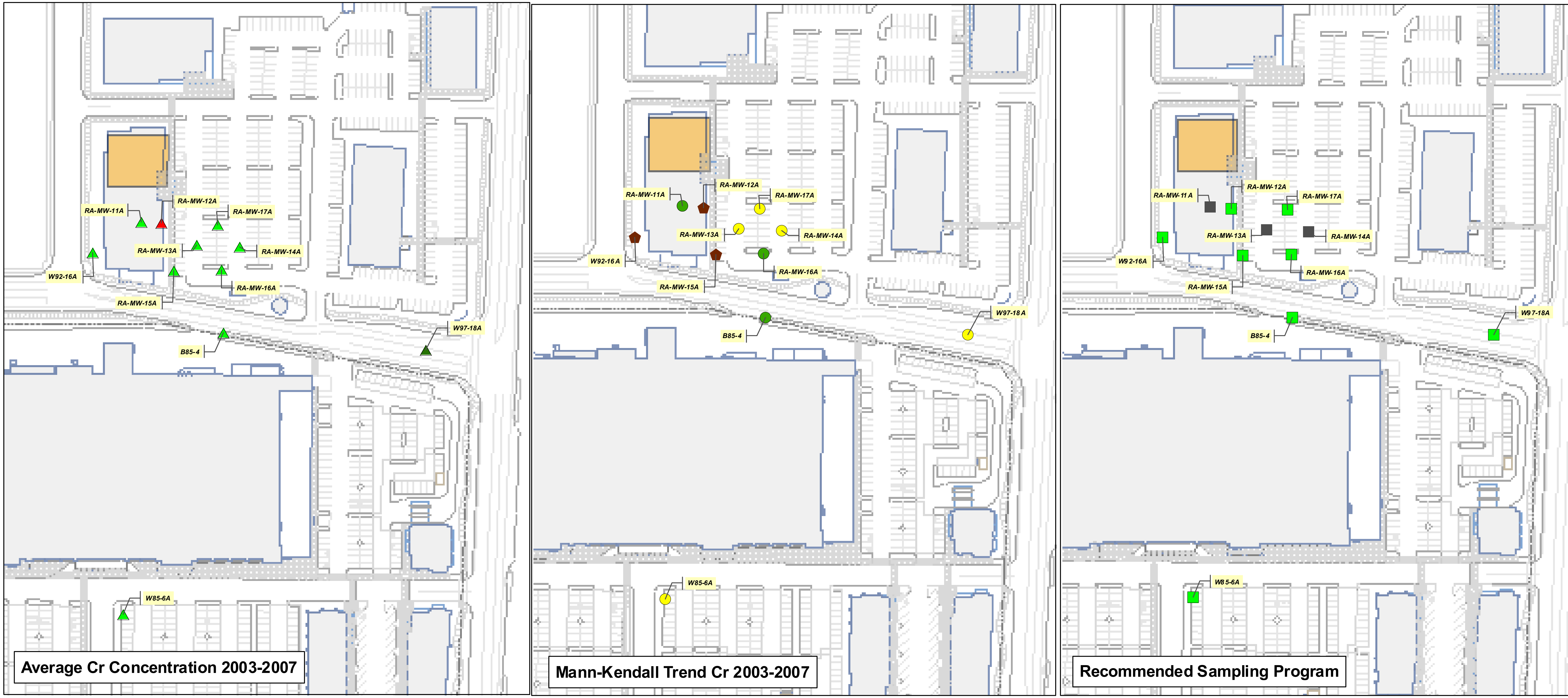
Potential areas for new locations are indicated by triangles with a high SF level.

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

High SF -> high estimation error -> possible need for new locations

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

Back to Access



Legend

Average Cr Concentration [mg/L]

- ND - 0.001
- 0.001 - 0.01
- 0.01 - 0.05
- 0.05 - 0.5
- > 0.5

Cr Screening Level = 0.05 mg/L

Mann Kendall Trend Cr

- Decreasing
- Probably Decreasing
- Stable
- Probably Increasing
- Increasing
- Non Detect (2003-2007)
- No Trend
- Insufficient Data

- Soil Remedy Area
- Proposed Development

Recommended Sampling Frequency

- Annual Sampling
- Eliminate from routine monitoring

Notes:
1. Average Total Cr concentrations calculated for data 2003-2007.
2. Mann Kendall trends were determined for Total Cr 2003-2007.
3. All built structures are proposed for the property redevelopment. Drawings for development received from developer October, 2007.

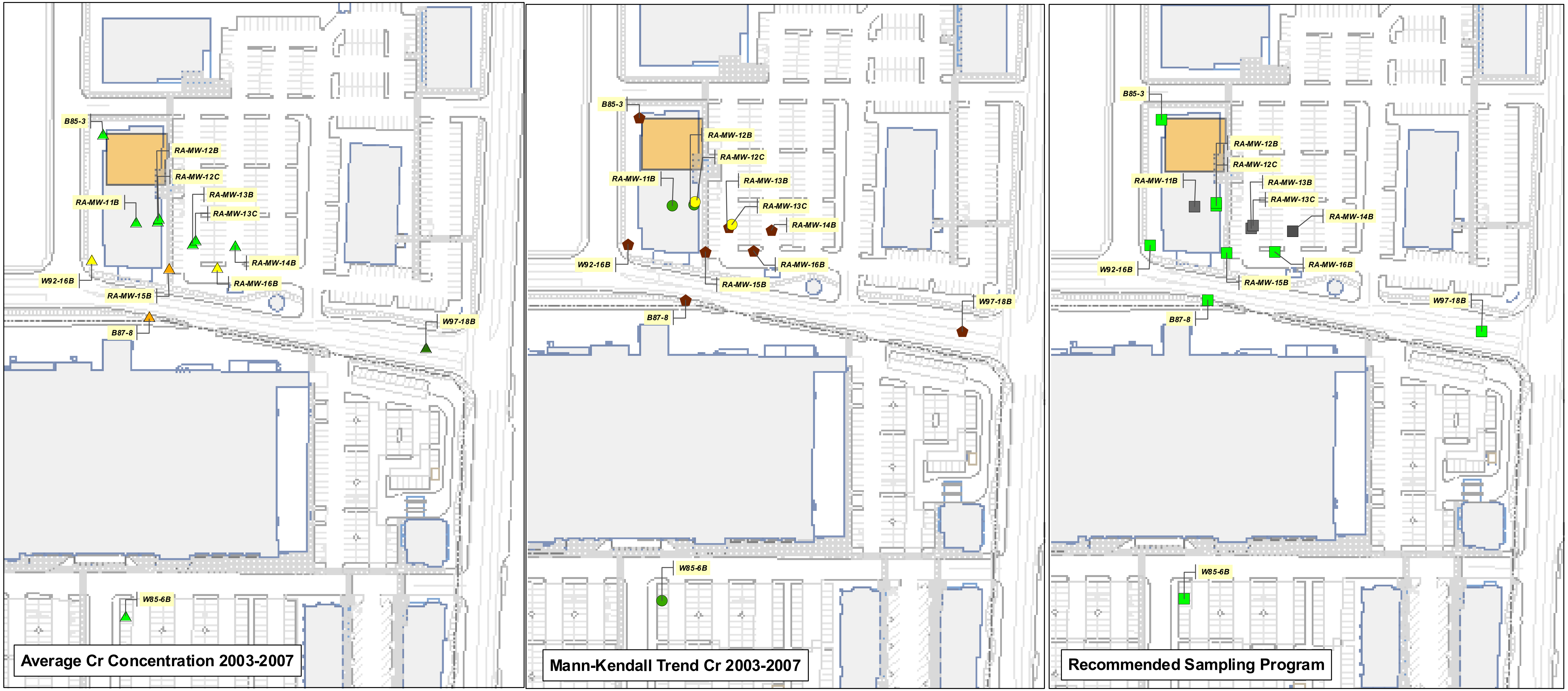
N

Scale (ft)
0 75 150

FRONTIER HARD CHROME
ZONE A SOURCE AREA
SUMMARY

Vancouver, Washington

Coord. Sys. NAD 83 SP Wash. S. FT.	Issued: 21-DEC-2007
Drawn By: MV	Revised: ----
Chk'd By: MV	Map ID: ----
Appv'd By: MV	**FIGURE 7**



Legend

Average Cr Concentration [mg/L]

- ND - 0.001
- 0.001 - 0.01
- 0.01 - 0.05
- 0.05 - 0.5
- > 0.5

Cr Screening Level = 0.05 mg/L

Mann Kendall Trend Cr

- Decreasing
- Probably Decreasing
- Stable
- Probably Increasing
- Increasing
- Non Detect (2003-2007)
- No Trend
- Insufficient Data
- Soil Remedy Area
- Proposed Development

Recommended Sampling Frequency

- Annual Sampling
- Eliminate from routine monitoring

Notes:
1. Average Total Cr concentrations calculated for data 2003-2007.
2. Mann Kendall trends were determined for Total Cr 2003-2007.
3. All built structures are proposed for the property redevelopment. Drawings for development received from developer October, 2007.

N

Scale (ft)
0 75 150

FRONTIER HARD CHROME
ZONE B SOURCE AREA
SUMMARY

Vancouver, Washington

Coord. Sys. NAD 83 SP Wash. S. FT.	Issued: 21-DEC-2007
Drawn By: MV	Revised: ----
Chk'd By: MV	Map ID: ----
Appv'd By:	**FIGURE 8**

GROUNDWATER MONITORING NETWORK OPTIMIZATION
FRONTIER HARD CHROME

Vancouver, Washington

APPENDIX A:

MAROS 2.2 Methodology

APPENDIX A
MARROS 2.2 METHODOLOGY

Contents

MAROS METHODOLOGY

MAROS is a collection of tools in one software package that is used in an explanatory, non-linear but linked fashion. The tool includes models, statistics, heuristic rules, and empirical relationships to assist the user in optimizing a groundwater monitoring network system. The final optimized network maintains adequate delineation while providing information on plume dynamics over time. Results generated from the software tool can be used to develop lines of evidence, which, in combination with expert opinion, can be used to inform regulatory decisions for safe and economical long-term monitoring of groundwater plumes. For a detailed description of the structure of the software and further utilities, refer to the MAROS 2.2 Manual (AFCEE, 2003; http://www.gsi-net.com/software/MAROS_V2_1Manual.pdf) and Aziz et al., 2003.

1.0 MAROS Conceptual Model

In MAROS 2.2, 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 Figures A.1 and A.2 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 has the option to 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 method relies on temporal trend analysis to assess plume stability, which is then used to determine the general monitoring system category. Since the monitoring system category is evaluated for both source and tail regions of the plume, the site wells are divided into two different zones: the source zone and the tail zone.

Source zone monitoring wells could include areas with non-aqueous phase liquids (NAPLs), contaminated vadose zone soils, and areas where aqueous-phase releases have been introduced into ground water. The source zone generally contains locations with historical high ground water concentrations of the COCs. The tail zone is usually the area downgradient of the contaminant source zone. Although this classification is a simplification of the plume conceptual model, this broadness makes the user aware on an individual well basis that the concentration trend results can have a different interpretation depending on the well location in and around the plume. 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 consists of well redundancy and well sufficiency analyses using the Delaunay method, a sampling frequency analysis using the Modified Cost Effective Sampling (MCES) method and a data sufficiency analysis including statistical 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 simple statistical methods to assess the sampling record to determine if groundwater concentrations are statistically below target levels and if the current monitoring network and record is sufficient in terms of evaluating concentrations at downgradient locations.

2.0 Data Management

In MAROS, ground water monitoring data can be imported from simple database-format Microsoft® Excel spreadsheets, Microsoft Access tables, previously created MAROS database archive files, or entered manually. Monitoring data interpretation in MAROS is based on historical analytical data from a consistent set of wells over a series of sampling events. The analytical data is composed of the well name, coordinate location, constituent, result, detection limit and associated data qualifiers. Statistical validity of the concentration trend analysis requires constraints on the minimum data input of at least four wells (ASTM 1998) in which COCs have been detected. Individual sampling locations need to include data from at least six most-recent sampling events. To ensure a meaningful comparison of COC concentrations over time and space, both data quality and data quantity need to be considered. Prior to statistical analysis, the user can consolidate irregularly sampled data or smooth data that might result from seasonal fluctuations or a change in site conditions. Because MAROS is a terminal analytical tool designed for long-term planning, impacts of seasonal variation in the water unit are treated on a broad scale, as they relate to multi-year trends.

Imported ground water monitoring data and the site-specific information entered in Site Details can be archived and exported as MAROS archive files. These archive files can be appended as new monitoring data becomes available, resulting in a dynamic long-term monitoring database that reflects the changing conditions at the site (i.e. biodegradation, compliance attainment, completion of remediation phase, etc.). For wells with a limited monitoring history, addition of information as it becomes available can change the frequency or identity of wells in the network.

3.0 Site Details

Information needed for the MAROS analysis includes site-specific parameters such as seepage velocity and current plume length and width. Information on the location of potential receptors relative to the source and tail regions of the plume is entered at this point. Part of the trend analysis methodology applied in MAROS focuses on where the monitoring well is located, therefore the user needs to divide site wells into two different zones: the source zone or the tail zone. Although this classification is a simplification of the well function, this broadness makes the user aware on an individual well basis that the concentration trend results can have a different interpretation depending on the well location in and around the plume. It is up to the user to make 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). The Site Details section of MAROS contains a preliminary map of well locations to confirm well coordinates.

4.0 Constituent Selection

A database with multiple COCs can be entered into the MAROS software. MAROS allows the analysis of up to 5 COCs concurrently and users can pick COCs from a list of compounds existing in the monitoring data. MAROS runs separate optimizations for each compound. For sites with a single source, the suggested strategy is to choose one to three priority COCs for the optimization. If, for example, the site contains multiple chlorinated volatile organic compounds (VOCs), the standard sample chemical analysis will evaluate all VOCs, so the sample locations and frequency should based on the concentration trends of the most prevalent, toxic or mobile compounds. If different chemical classes are present, such as metals and chlorinated VOCs, choose and evaluate the priority constituent in each chemical class.

MAROS includes a short module that provides recommendations on prioritizing COCs based on toxicity, prevalence, and mobility of the compound. The toxicity ranking is determined by examining a representative concentration for each compound for the entire site. The representative concentration is then compared to the screening level (PRG or MCL) for that compound and the COCs are ranked according to the representative concentrations percent exceedence of the screening level. The evaluation of prevalence is performed by determining a representative concentration for each well location and evaluating the total exceedences (values above screening levels) compared to the total number of wells. Compounds found over screening levels are ranked for mobility based on Kd (sorption partition coefficient). The MAROS COC assessment provides the relative ranking of each COC, but the user must choose which COCs are included in the analysis.

5.0 Data Consolidation

Typically, raw data from long-term monitoring have been measured irregularly in time or contain many non-detects, trace level results, and duplicates. Therefore, before the data can be further analyzed, raw data are filtered, consolidated, transformed, and possibly smoothed to allow for a consistent dataset meeting the minimum data requirements for statistical analysis mentioned previously.

MAROS allows users to specify the period of interest in which data will be consolidated (i.e., monthly, bi-monthly, quarterly, semi-annual, yearly, or a biennial basis). In computing the representative value when consolidating, one of four statistics can be used: median, geometric mean, mean, and maximum. Non-detects can be transformed to one half the reporting or method detection limit (DL), the DL, or a fraction of the DL. Trace level results can be represented by their actual values, one half of the DL, the DL, or a fraction of their actual values. Duplicates are reduced in MAROS by one of three ways: assigning the average, maximum, or first value. The reduced data for each COC and each well can be viewed as a time series in a graphical form on a linear or semi-log plot generated by the software.

6.0 Overview Statistics: Plume Trend Analysis

Within the MAROS software there are historical data analyses that support a conclusion about plume stability (e.g., increasing plume, etc.) through statistical trend analysis of historical monitoring data. Plume stability results are assessed from time-series concentration data with the application of three statistical tools: Mann-Kendall Trend analysis, linear regression trend analysis and moment analysis. The two trend methods are used to estimate the concentration trend for each well and each COC based on a statistical trend analysis of concentrations versus time at each well. These trend analyses are then consolidated to give the user a general plume stability estimate and general monitoring frequency and density recommendations (see Figures A.1 through A.3 for further step-by-step details). Both qualitative and quantitative plume information can be gained by these evaluations 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. 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 or detailed statistics optimization analysis.

6.1 Mann-Kendall Analysis

The Mann-Kendall test is a statistical procedure that is well suited for analyzing trends in data over time. The Mann-Kendall test can be viewed as a non-parametric test for zero slope of the first-order regression of time-ordered concentration data versus time. One advantage of the Mann-Kendall test is that it 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. The Mann-Kendall S statistic measures the trend in the data: positive values indicate an increase in concentrations over time and negative values indicate a decrease in concentrations over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall statistic (i.e., a large value indicates a strong trend). The confidence in the trend is determined by consulting the S statistic and the sample size, n, in a Kendall probability table such as the one reported in Hollander and Wolfe (1973).

The concentration trend is determined for each well and each COC based on results of the S statistic, the confidence in the trend, and the Coefficient of Variation (COV). The decision matrix for this evaluation is shown in Table 3. A Mann-Kendall statistic that is greater than 0 combined with a confidence of greater than 95% is categorized as an Increasing trend while a Mann-Kendall statistic of less than 0 with a confidence between 90% and 95% is defined as a probably Increasing trend, and so on.

Depending on statistical indicators, the concentration trend is classified into six categories:

- Decreasing (D),
- Probably Decreasing (PD),
- Stable (S),
- No Trend (NT),
- Probably Increasing (PI)
- Increasing (I).

These trend estimates are then analyzed to identify the source and tail region overall stability category (see Figure 2 for further details).

6.2 Linear Regression Analysis

Linear Regression is a parametric statistical procedure that is typically used for analyzing trends in data over time. 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 linear regression analysis is based on the first-order linear regression of the log-transformed concentration data versus time. The slope obtained from this log-transformed regression, the confidence level for this log-slope, and the COV of the untransformed data are used to determine the concentration trend. The decision matrix for this evaluation is shown in Table 4.

To estimate the confidence in the log-slope, the standard error of the log-slope is calculated. 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, (up to five COCs simultaneously). For this evaluation, a decision matrix developed by Groundwater Services, Inc. is also used to determine the “Concentration Trend” category (plume stability) for each well.

Depending on statistical indicators, the concentration trend is classified into six categories:

- Decreasing (D),
- Probably Decreasing (PD),
- Stable (S),
- No Trend (NT),
- Probably Increasing (PI)
- Increasing (I).

The resulting confidence in the trend, together with the log-slope and the COV of the untransformed data, are used in the linear regression analysis decision matrix to determine the concentration trend. For example, a positive log-slope with a confidence of less than 90% is categorized as having No Trend whereas a negative log-slope is considered Stable if the COV is less than 1 and categorized as No Trend if the COV is greater than 1.

6.3 Overall Plume Analysis

General recommendations for the monitoring network frequency and density are suggested based on heuristic rules applied to the source and tail trend results.

Individual well trend results are consolidated and weighted by the MAROS according to user input, and the direction and strength of contaminant concentration trends in the source zone and tail zone for each COC are determined. Based on

- **i)** the consolidated trend analysis,
- **ii)** hydrogeologic factors (e.g., seepage velocity), and
- **iii)** location of potential receptors (e.g., wells, discharge points, or property boundaries),

the software suggests a general optimization plan for the current monitoring system in order to efficiently but effectively monitor groundwater in the future. A flow chart utilizing the trend analysis results and other site-specific parameters to form a general sampling frequency and well density recommendation is outlined in Figure 2. For example, a generic plan for a shrinking petroleum hydrocarbon plume (BTEX) in a slow hydrogeologic environment (silt) with no nearby receptors would entail minimal, low frequency sampling of just a few indicators. On the other hand, the generic plan for a chlorinated solvent plume in a fast hydrogeologic environment that is expanding but has very erratic concentrations over time would entail more extensive, higher frequency sampling. The generic plan is based on a heuristically derived algorithm for assessing future sampling duration, location and density that takes into consideration plume stability. For a detailed description of the heuristic rules used in the MAROS software, refer to the MAROS 2.2Manual (AFCEE, 2003).

6.4 Moment Analysis

An analysis of moments can help resolve plume trends, where the zeroth moment shows change in dissolved mass vs. time, the first moment shows the center of mass location vs. time, and the second moment shows the spread of the plume vs. time. 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 trend analysis of moments can be summarized as:

- Zeroth Moment: An estimate of the total mass of the constituent for each sample event
- First Moment: An estimate of the center of mass for each sample event
- Second Moment: An estimate of the spread of the plume around the center of mass

The role of moment analysis in MAROS is to provide a relative estimate of plume stability and condition within the context of results from other MAROS modules. The Moment analysis algorithms in MAROS are simple approximations of complex calculations and are meant to estimate changes in total mass, center of mass and spread of mass for complex well networks. The Moment Analysis module is sensitive to the number and arrangement of wells in each sampling event, so, changes in the number and identity of wells during monitoring events, and the parameters chosen for data consolidation can cause changes in the estimated moments.

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. Moment analysis in the MAROS software can also be used to 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 (this analysis was not performed as part of this study, for more details on this application of moment analysis refer to the MAROS Users Manual (AFCEE, 2003)).

The **zeroth moment** is the sum of concentrations for all monitoring wells and is a mass estimate. 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. Plume analysis and delineation based exclusively on concentration can exhibit fluctuating temporal and spatial values. The mass estimate is also sensitive to the extent of the site monitoring well network over time. The zeroth moment trend over time is determined by using the Mann-Kendall Trend Methodology. The zeroth Moment trend test allows 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 (N/A) (Insufficient Data). When considering the results of the zeroth moment trend, the following factors should be considered 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

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. Calculation of the first moment normalizes the spread by the concentration indicating the center of mass. The first moment trend of the distance to the center of mass over time 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).

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 for a particular COC and sample event. The Second Moment represents the spread of the plume over time in both the x and y directions. 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 second moment 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).

7.0 Detailed Statistics: Optimization Analysis

Although the overall plume analysis shows a general recommendation regarding sampling frequency reduction and a general sampling density, a more detailed analysis is also available with the MAROS 2.2 software in order to allow for further reductions on a well-by-well basis for frequency, well redundancy, well sufficiency and sampling sufficiency. The MAROS Detailed Statistics allows for a quantitative analysis for spatial and temporal optimization of the well network on a well-by-well basis. The results from the Overview Statistics should be considered along with the MAROS optimization recommendations gained from the Detailed Statistical Analysis described previously. The MAROS Detailed Statistics results should be reassessed in view of site knowledge and regulatory requirements as well as in consideration of the Overview Statistics (Figure 2).

The Detailed Statistics or Sampling Optimization MAROS modules can be used to determine the minimal number of sampling locations and the lowest frequency of sampling that can still meet the requirements of sampling spatially and temporally for an existing monitoring program. It also provides an analysis of the sufficiency of data for the monitoring program.

Sampling optimization in MAROS consists of four parts:

- Well redundancy analysis using the Delaunay method
- Well sufficiency analysis using the Delaunay method
- Sampling frequency determination using the Modified CES method
- Data sufficiency analysis using statistical power analysis.

The well redundancy analysis using the Delaunay method identifies and eliminates redundant locations from the monitoring network. The well sufficiency analysis can determine the areas where new sampling locations might be needed. The Modified CES method determines the optimal sampling frequency for a sampling location based on the direction, magnitude, and uncertainty in its concentration trend. The data sufficiency analysis examines the risk-based site cleanup status and power and expected sample size associated with the cleanup status evaluation.

7.1 Well Redundancy Analysis – Delaunay Method

The well redundancy analysis using 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. An extended method or wells sufficiency analysis, based on the Delaunay method, can also be used for recommending new sampling locations.

Details about the Delaunay method can be found in Appendix A.2 of the MAROS Manual (AFCEE, 2003).

Sampling Location determination uses the Delaunay triangulation method to determine the significance of the current sampling locations relative to the overall monitoring network. The Delaunay method calculates the network Area and Average concentration of the plume using data from multiple monitoring wells. A slope factor (SF) is calculated for each well to indicate the significance of this well in the system (i.e. how removing a well changes the average concentration.)

The Sampling Location optimization process is performed in a stepwise fashion. Step one involves assessing the significance of the well in the system, if a well has a small SF (little significance to the network), the well may be removed from the monitoring network. Step two involves evaluating the information loss of removing a well from the network. If one well has a small SF, it may or may not be eliminated depending on whether the information loss is significant. If the information loss is not significant, the well can be eliminated from the monitoring network and the process of optimization continues with fewer wells. However if the well information loss is significant then the optimization terminates. This sampling optimization process allows the user to assess "redundant" wells that will not incur significant information loss on a constituent-by-constituent basis for individual sampling events.

<u>7.2 Well Sufficiency Analysis – Delaunay Method</u>

The well sufficiency analysis, using the Delaunay method, is designed to recommend new sampling locations in areas *within* the existing monitoring network where there is a high level of uncertainty in contaminant concentration. Details about the well sufficiency analysis can be found in Appendix A.2 of the MAROS Manual (AFCEE, 2003).

In many cases, new sampling locations need to be added to the existing network to enhance the spatial plume characterization. If the MAROS algorithm calculates a high level of uncertainty in predicting the constituent concentration for a particular area, a new sampling location is recommended. The Slope Factor (SF) values obtained from the redundancy evaluation described above are used to calculate the concentration estimation error for each triangle area formed in the Delaunay triangulation. The estimated SF value for each area is then classified into four levels: Small, Moderate, Large, or Extremely large (S, M, L, E) because the larger the estimated SF value, the higher the estimation error at this area. Therefore, the triangular areas with the estimated SF value at the Extremely large or Large level can be candidate regions for new sampling locations.

The results from the Delaunay method and the method for determining new sampling locations are derived solely from the spatial configuration of the monitoring network and the spatial pattern of the contaminant plume. No parameters such as the hydrogeologic conditions are considered in the analysis. Therefore, professional judgment and regulatory considerations must be used to make final decisions.

<u>7.3 Sampling Frequency Determination - Modified CES Method</u>

The Modified CES method optimizes sampling frequency for each sampling location based on the magnitude, direction, and uncertainty of its concentration trend derived from its recent and historical monitoring records. The Modified Cost Effective Sampling (MCES) estimates a conservative lowest-frequency sampling schedule for a given groundwater monitoring location that still provides needed information for regulatory and remedial decision-making. The MCES method was developed on the basis of the Cost Effective Sampling (CES) method developed by Ridley et al (1995). Details about the MCES method can be found in Appendix A.9 of the MAROS Manual (AFCEE, 2003).

In order to estimate the least frequent sampling schedule for a monitoring location that still provides enough information for regulatory and remedial decision-making, MCES employs three steps to determine the sampling frequency. The first step involves analyzing frequency based on recent trends. A preliminary location sampling frequency (PLSF) is developed based on the rate of change of well concentrations calculated by linear regression along with the Mann-Kendall trend analysis of the most recent monitoring data (see Figure 3). The variability within the sequential sampling data is accounted for by the Mann-Kendall analysis. The rate of change vs. trend result matrix categorizes wells as requiring annual, semi-annual or quarterly sampling. The PLSF is then reevaluated and adjusted 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.

The final step in the analysis involves reducing frequency based on risk, site-specific conditions, regulatory requirements or other external issues. Since not all compounds in the target being assessed are equally harmful, frequency is reduced by one level if recent maximum concentration for a compound of high risk is less than 1/2 of the Maximum Concentration Limit (MCL). The result of applying this method is a suggested sampling frequency based on recent sampling data trends and overall sampling data trends and expert judgment.

The final sampling frequency determined from the MCES method can be Quarterly, Semiannual, Annual, or Biennial. Users can further reduce the sampling frequency to, for example, once every three years, if the trend estimated from Biennial data (i.e., data drawn once every two years from the original data) is the same as that estimated from the original data.

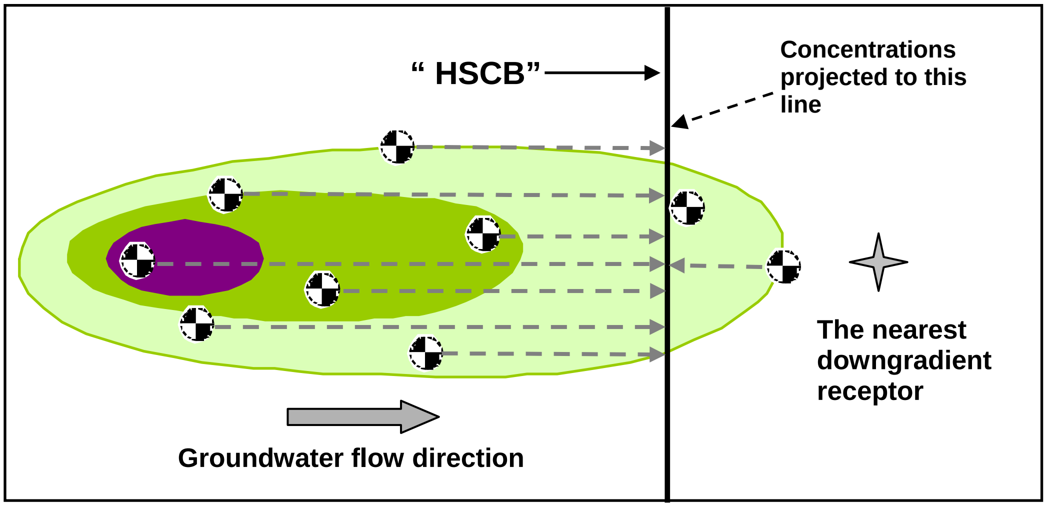
7.4 Data Sufficiency Analysis – Power Analysis

The MAROS Data Sufficiency module employs simple statistical methods to evaluate whether the collected data are adequate both in quantity and in quality for revealing changes in constituent concentrations. The first section of the module evaluates individual well concentrations to determine if they are statistically below a target screening level. The second section includes a simple calculation for estimating projected groundwater concentrations at a specified point downgradient of the plume. A statistical Power analysis is then applied to the projected concentrations to determine if the downgradient concentrations are statistically below the cleanup standard. If the number of projected concentrations is below the level to provide statistical significance, then the number of sample events required to statistically confirm concentrations below standards is estimated from the Power analysis.

Before testing the cleanup status for individual wells, the stability or trend of the contaminant plume should be evaluated. Only after the plume has reached stability or is reliably diminishing 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.

Statistical power analysis is a technique for interpreting the results of statistical tests. The Power of a statistical test is a measure of the ability of the test to detect an effect given that the effect actually exists. The method provides additional information about a statistical test: 1) the power of the statistical test, i.e., the probability of finding a difference in the variable of interest when a difference truly exists; and 2) the expected sample size of a future sampling plan given the minimum detectable difference it is supposed to detect. For example, if the mean concentration is lower than the cleanup goal but a statistical test cannot prove this, the power and expected sample size can tell the reason and how many more samples are needed to result in a significant test. The additional samples can be obtained by a longer period of sampling or an increased sampling frequency. Details about the data sufficiency analysis can be found in Appendix A.6 of the MAROS Manual (AFCEE, 2003).

When applying the MAROS power analysis method, a hypothetical statistical compliance boundary (HSCB) is assigned to be a line perpendicular to the groundwater flow direction (see figure below). Monitoring well concentrations are projected onto the HSCB using the distance from each well to the compliance boundary along with a decay coefficient. The projected concentrations from each well and 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. This power analysis can then indicate if target are statistically achieved at the HSCB. For instance, at a site where the historical monitoring record is short with few wells, the HSCB would be distant; whereas, at a site with longer duration of sampling with many wells, the HSCB would be close. Ultimately, at a site the goal would be to have the HSCB coincide with or be within the actual compliance boundary (typically the site property line).



In order to perform a risk-based cleanup status evaluation for the whole site, a strategy was developed as follows.

- Estimate concentration versus distance decay coefficient from plume centerline wells.
- Extrapolate concentration versus distance for each well using this decay coefficient.
- Comparing the extrapolated concentrations with the compliance concentration using power analysis.

Results from this analysis can be *Attained* or *Not Attained*, providing a statistical interpretation of whether the cleanup goal has been met on the site-scale from the risk-based point of view. The results as a function of time can be used to evaluate if the monitoring system has enough power at each step in the sampling record to indicate certainty of compliance by the plume location and condition relative to the compliance boundary. For example, if results are *Not Attained* at early sampling events but are *Attained* in recent sampling events, it indicates that the recent sampling record provides a powerful enough result to indicate compliance of the plume relative to the location of the receptor or compliance boundary.

CITED REFERENCES

AFCEE 2003. Monitoring and Remediation Optimization System (MAROS) 2.1 Software Users Guide. Air Force Center for Environmental Excellence. http://www.gsi-net.com/software/MAROS_V2_1Manual.pdf

AFCEE. 1997. Air Force Center for Environmental Excellence, AFCEE Long-Term Monitoring Optimization Guide, http://www.afcee.brooks.af.mil.

Aziz, J. A., C. J. Newell, M. Ling, H. S. Rifai and J. R. Gonzales (2003). "MAROS: A Decision Support System for Optimizing Monitoring Plans." Ground Water **41**(3): 355-367.

Gilbert, R. O., 1987, Statistical Methods for Environmental Pollution Monitoring, Van Nostrand Reinhold, New York, NY, ISBN 0-442-23050-8.

Hollander, M. and Wolfe, D. A. (1973). Nonparametric Statistical Methods, Wiley, New York, NY.

Ridley, M.N. et al., 1995. Cost-Effective Sampling of Groundwater Monitoring Wells, the Regents of UC/LLNL, Lawrence Livermore National Laboratory.

U.S. Environmental Protection Agency, 1992. Methods for Evaluating the Attainment of Cleanup Standards Volume 2: Ground Water.

Weight, W. D. and J. L. Sonderegger (2001). Manual of Applied Field Hydrogeology. New York, NY, McGraw-Hill.

TABLE 1 Mann-Kendall Analysis Decision Matrix (Aziz, et. al., 2003)		
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

TABLE 2 Linear Regression Analysis Decision Matrix (Aziz, et. al., 2003)		
Confidence in the Trend	**Log-slope**	
	Positive	**Negative**
< 90%	No Trend	COV < 1 Stable COV > 1 No Trend
90 - 95%	Probably Increasing	Probably Decreasing
> 95%	Increasing	Decreasing

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.

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 (0^{th} Moment), center of mass (1^{st} Moment), and plume spread (2^{nd} 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.

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 Decision Support Tool Flow Chart

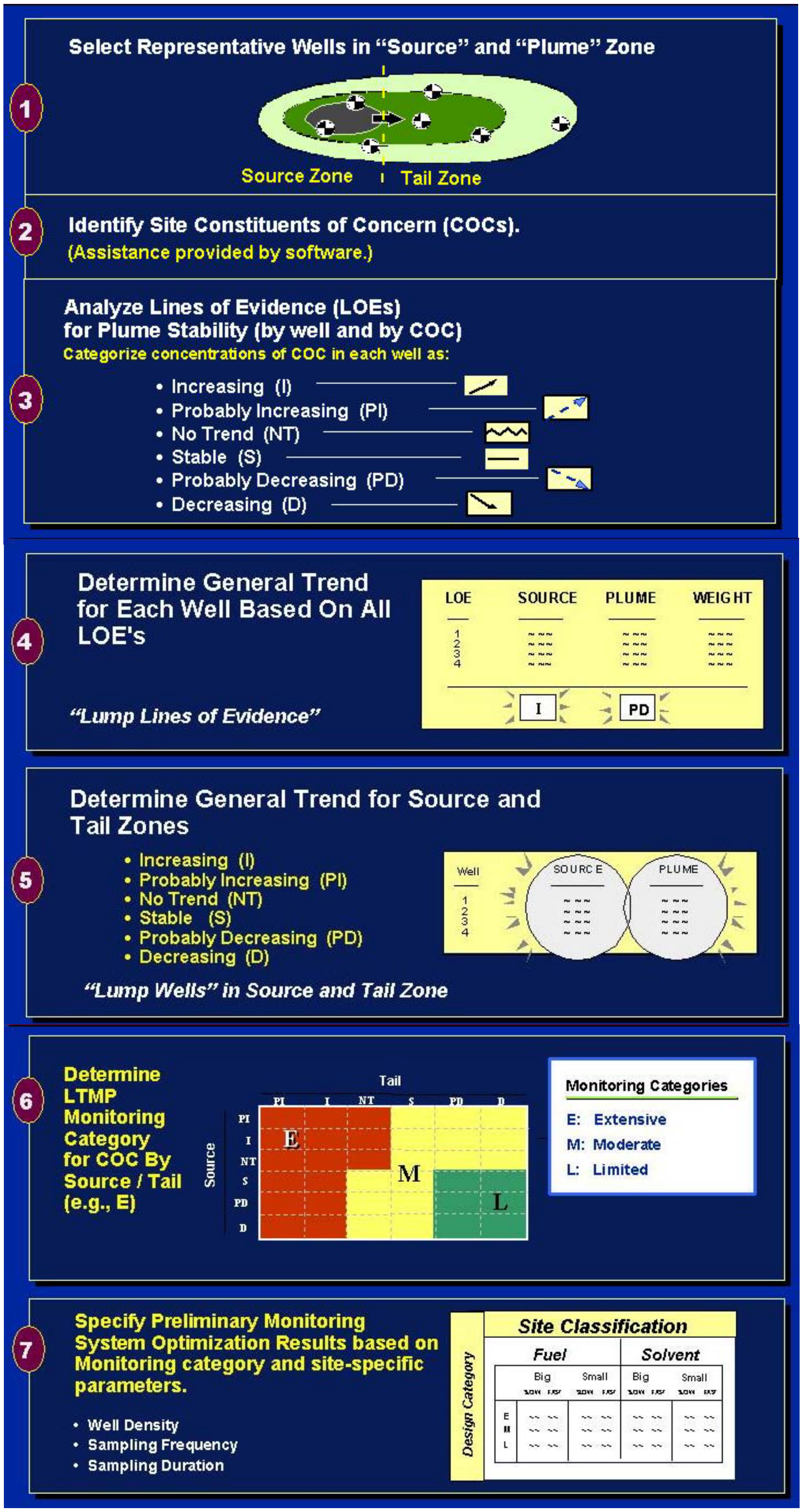


Figure 2:
MAROS Overview Statistics Trend Analysis Methodology

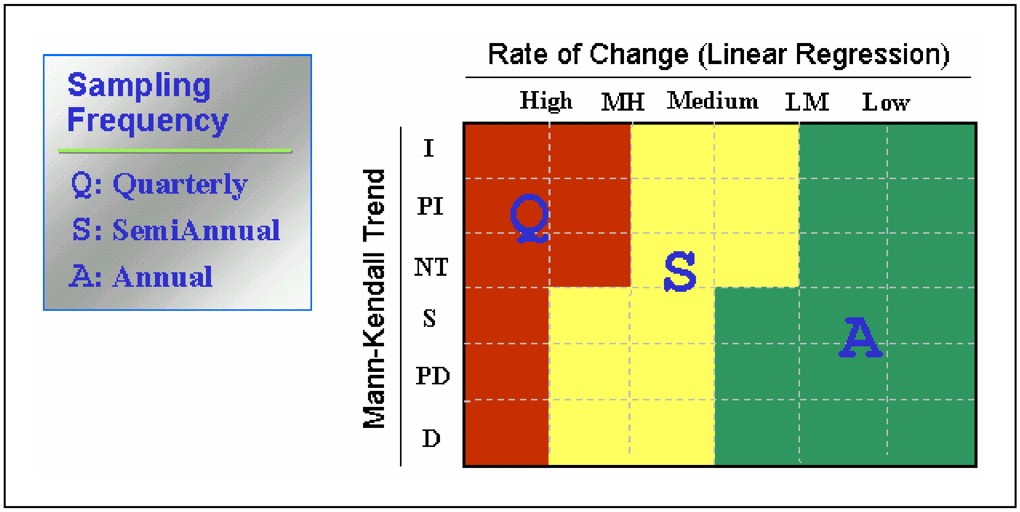


Figure 3. Decision Matrix for Determining Provisional Frequency (*Figure A.3.1 of the MAROS Manual (AFCEE 2003*)

GROUNDWATER MONITORING NETWORK OPTIMIZATION
FRONTIER HARD CHROME

Vancouver, Washington

APPENDIX B:

MAROS Reports

Zone A
- Mann-Kendall Reports
- Moment Reports

Zone B
- Mann-Kendall Reports
- Moment Reports

MAROS Mann-Kendall Statistics Summary

Project: FHC

User Name: MV

Location: Vancouver

State: Washington

Time Period: 10/15/2003 **to** 6/5/2007
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
CHROMIUM, TOTAL								
RA-MW-11A	S	12	10	1.23	-43	99.9%	No	D
RA-MW-12A	S	12	12	2.18	-18	87.5%	No	NT
RA-MW-15A	S	12	11	1.61	-2	52.7%	No	NT
B85-4	S	11	10	1.48	-25	97.0%	No	D
W85-6A	T	9	8	0.96	-6	69.4%	No	S
RA-MW-13A	T	12	10	0.75	-9	70.4%	No	S
RA-MW-14A	T	12	9	0.78	0	47.3%	No	S
RA-MW-17A	T	12	11	0.57	-17	86.0%	No	S
W99-R5A	T	11	4	1.29	0	46.9%	No	NT
W85-7A	T	11	9	0.51	-14	84.0%	No	S
W92-16A	T	11	7	1.17	-5	61.9%	No	NT
W97-18A	T	11	6	0.07	-9	72.9%	No	S
W97-19A	T	11	10	0.81	-21	94.0%	No	PD
W98-20A	T	11	10	0.74	-17	89.1%	No	S
W98-21A	T	11	10	0.73	-21	94.0%	No	PD
RA-MW-16A	T	12	11	0.65	-26	95.7%	No	D

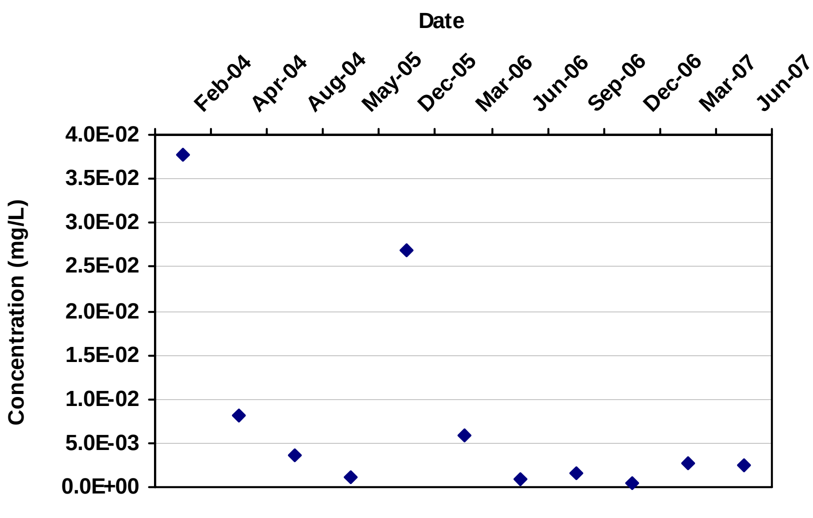
Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A)-Due to insufficient Data (< 4 sampling events); Source/Tail (S/T)

The Number of Samples and Number of Detects shown above are post-consolidation values.

MAROS Mann-Kendall Statistics Summary

Well: B85-4
Well Type: S
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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: -25

Confidence in Trend: 97.0%

Coefficient of Variation: 1.48

Mann Kendall Concentration Trend: (See Note) D

Data Table:

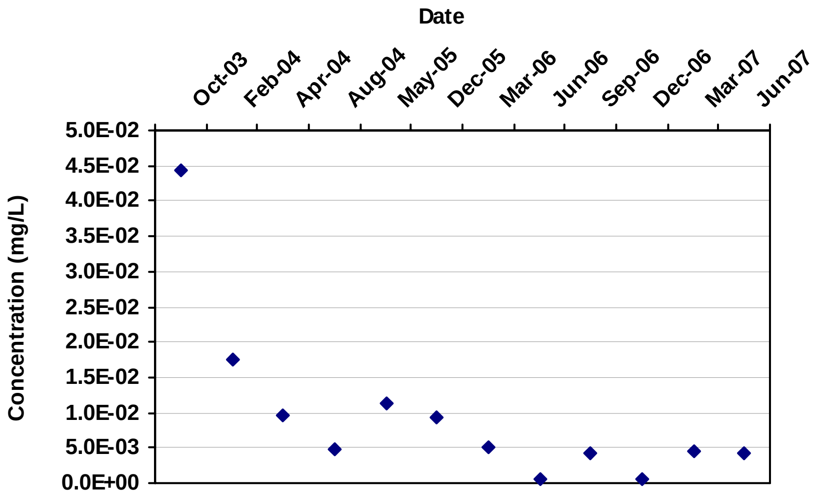
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
B85-4	S	2/10/2004	CHROMIUM, TOTAL	3.8E-02		1	1
B85-4	S	4/5/2004	CHROMIUM, TOTAL	8.1E-03		1	1
B85-4	S	8/15/2004	CHROMIUM, TOTAL	3.7E-03		1	1
B85-4	S	5/5/2005	CHROMIUM, TOTAL	1.1E-03		1	1
B85-4	S	12/12/2005	CHROMIUM, TOTAL	2.7E-02		1	1
B85-4	S	3/8/2006	CHROMIUM, TOTAL	5.8E-03		1	1
B85-4	S	6/15/2006	CHROMIUM, TOTAL	9.0E-04		1	1
B85-4	S	9/25/2006	CHROMIUM, TOTAL	1.5E-03		1	1
B85-4	S	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
B85-4	S	3/30/2007	CHROMIUM, TOTAL	2.8E-03		1	1
B85-4	S	6/5/2007	CHROMIUM, TOTAL	2.4E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-11A
Well Type: S
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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: -43

Confidence in Trend: 99.9%

Coefficient of Variation: 1.23

Mann Kendall Concentration Trend: (See Note) D

Data Table:

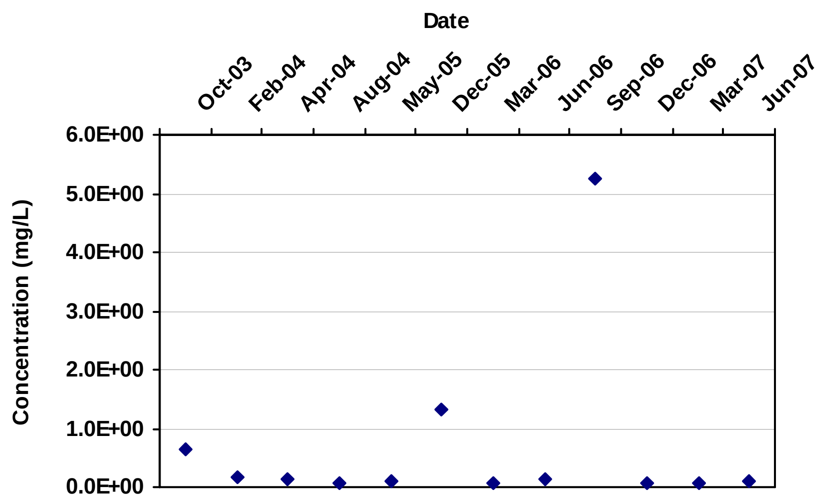
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-11A	S	10/15/2003	CHROMIUM, TOTAL	4.4E-02		2	2
RA-MW-11A	S	2/10/2004	CHROMIUM, TOTAL	1.7E-02		1	1
RA-MW-11A	S	4/5/2004	CHROMIUM, TOTAL	9.7E-03		1	1
RA-MW-11A	S	8/15/2004	CHROMIUM, TOTAL	4.8E-03		1	1
RA-MW-11A	S	5/5/2005	CHROMIUM, TOTAL	1.1E-02		1	1
RA-MW-11A	S	12/12/2005	CHROMIUM, TOTAL	9.3E-03		1	1
RA-MW-11A	S	3/8/2006	CHROMIUM, TOTAL	5.2E-03		1	1
RA-MW-11A	S	6/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-11A	S	9/25/2006	CHROMIUM, TOTAL	4.1E-03		1	1
RA-MW-11A	S	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-11A	S	3/30/2007	CHROMIUM, TOTAL	4.6E-03		1	1
RA-MW-11A	S	6/5/2007	CHROMIUM, TOTAL	4.3E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-12A
Well Type: S
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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: -18

Confidence in Trend: 87.5%

Coefficient of Variation: 2.18

Mann Kendall Concentration Trend: (See Note) NT

Data Table:

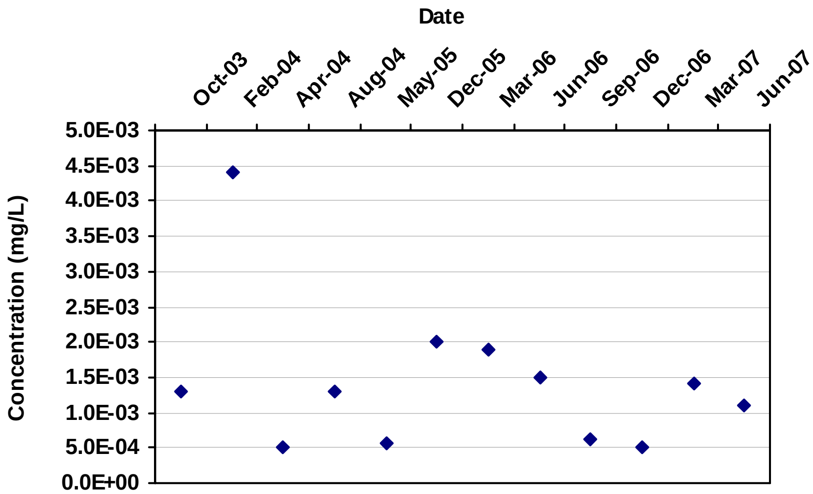
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-12A	S	10/15/2003	CHROMIUM, TOTAL	6.4E-01		2	2
RA-MW-12A	S	2/10/2004	CHROMIUM, TOTAL	1.8E-01		1	1
RA-MW-12A	S	4/5/2004	CHROMIUM, TOTAL	1.4E-01		1	1
RA-MW-12A	S	8/15/2004	CHROMIUM, TOTAL	8.0E-02		1	1
RA-MW-12A	S	5/5/2005	CHROMIUM, TOTAL	1.1E-01		1	1
RA-MW-12A	S	12/12/2005	CHROMIUM, TOTAL	1.3E+00		1	1
RA-MW-12A	S	3/8/2006	CHROMIUM, TOTAL	8.5E-02		1	1
RA-MW-12A	S	6/15/2006	CHROMIUM, TOTAL	1.3E-01		1	1
RA-MW-12A	S	9/25/2006	CHROMIUM, TOTAL	5.3E+00		1	1
RA-MW-12A	S	12/15/2006	CHROMIUM, TOTAL	8.1E-02		1	1
RA-MW-12A	S	3/30/2007	CHROMIUM, TOTAL	7.9E-02		1	1
RA-MW-12A	S	6/5/2007	CHROMIUM, TOTAL	1.1E-01		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-13A
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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: -9

Confidence in Trend: 70.4%

Coefficient of Variation: 0.75

Mann Kendall Concentration Trend: (See Note) S

Data Table:

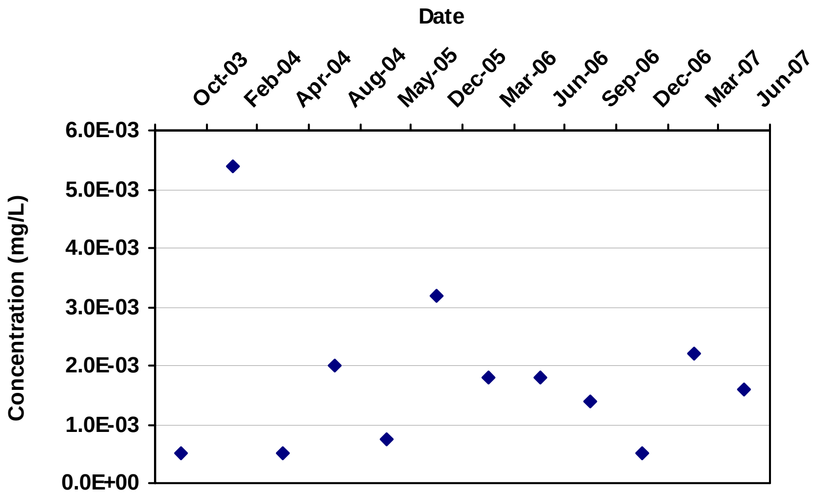
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-13A	T	10/15/2003	CHROMIUM, TOTAL	1.3E-03		2	1
RA-MW-13A	T	2/10/2004	CHROMIUM, TOTAL	4.4E-03		1	1
RA-MW-13A	T	4/5/2004	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-13A	T	8/15/2004	CHROMIUM, TOTAL	1.3E-03		1	1
RA-MW-13A	T	5/5/2005	CHROMIUM, TOTAL	5.6E-04		1	1
RA-MW-13A	T	12/12/2005	CHROMIUM, TOTAL	2.0E-03		1	1
RA-MW-13A	T	3/8/2006	CHROMIUM, TOTAL	1.9E-03		1	1
RA-MW-13A	T	6/15/2006	CHROMIUM, TOTAL	1.5E-03		1	1
RA-MW-13A	T	9/25/2006	CHROMIUM, TOTAL	6.3E-04		1	1
RA-MW-13A	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-13A	T	3/30/2007	CHROMIUM, TOTAL	1.4E-03		1	1
RA-MW-13A	T	6/5/2007	CHROMIUM, TOTAL	1.1E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-14A
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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: 0

Confidence in Trend: 47.3%

Coefficient of Variation: 0.78

Mann Kendall Concentration Trend: (See Note) S

Data Table:

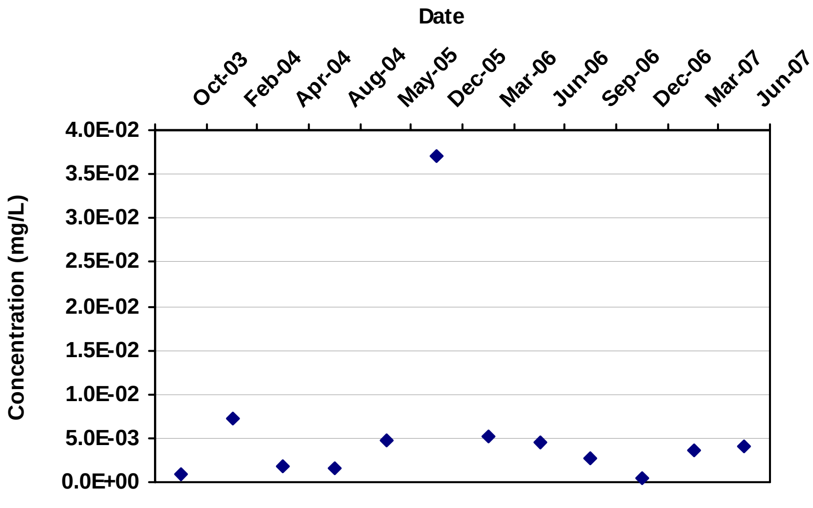
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-14A	T	10/15/2003	CHROMIUM, TOTAL	5.0E-04	ND	2	0
RA-MW-14A	T	2/10/2004	CHROMIUM, TOTAL	5.4E-03		1	1
RA-MW-14A	T	4/5/2004	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-14A	T	8/15/2004	CHROMIUM, TOTAL	2.0E-03		1	1
RA-MW-14A	T	5/5/2005	CHROMIUM, TOTAL	7.3E-04		1	1
RA-MW-14A	T	12/12/2005	CHROMIUM, TOTAL	3.2E-03		1	1
RA-MW-14A	T	3/8/2006	CHROMIUM, TOTAL	1.8E-03		1	1
RA-MW-14A	T	6/15/2006	CHROMIUM, TOTAL	1.8E-03		1	1
RA-MW-14A	T	9/25/2006	CHROMIUM, TOTAL	1.4E-03		1	1
RA-MW-14A	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-14A	T	3/30/2007	CHROMIUM, TOTAL	2.2E-03		1	1
RA-MW-14A	T	6/5/2007	CHROMIUM, TOTAL	1.6E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-15A
Well Type: S
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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: -2

Confidence in Trend: 52.7%

Coefficient of Variation: 1.61

Mann Kendall Concentration Trend: (See Note) NT

Data Table:

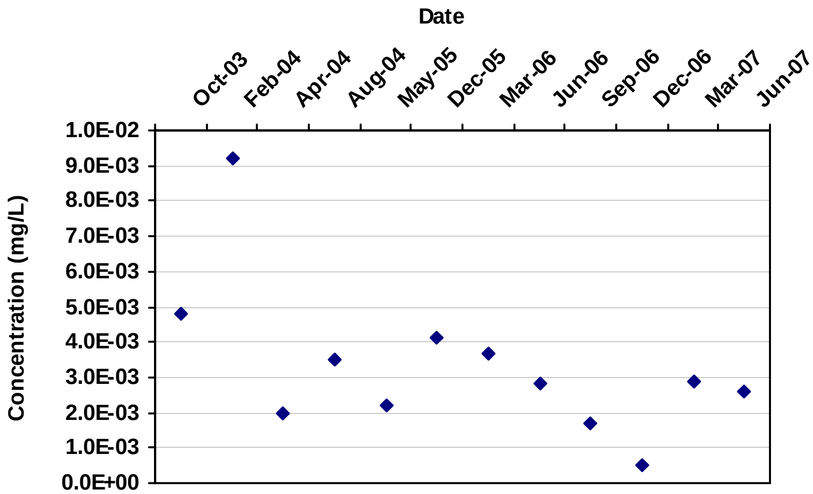
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-15A	S	10/15/2003	CHROMIUM, TOTAL	1.0E-03		2	1
RA-MW-15A	S	2/10/2004	CHROMIUM, TOTAL	7.2E-03		1	1
RA-MW-15A	S	4/5/2004	CHROMIUM, TOTAL	1.8E-03		1	1
RA-MW-15A	S	8/15/2004	CHROMIUM, TOTAL	1.5E-03		1	1
RA-MW-15A	S	5/5/2005	CHROMIUM, TOTAL	4.7E-03		1	1
RA-MW-15A	S	12/12/2005	CHROMIUM, TOTAL	3.7E-02		1	1
RA-MW-15A	S	3/8/2006	CHROMIUM, TOTAL	5.3E-03		1	1
RA-MW-15A	S	6/15/2006	CHROMIUM, TOTAL	4.6E-03		1	1
RA-MW-15A	S	9/25/2006	CHROMIUM, TOTAL	2.7E-03		1	1
RA-MW-15A	S	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-15A	S	3/30/2007	CHROMIUM, TOTAL	3.7E-03		1	1
RA-MW-15A	S	6/5/2007	CHROMIUM, TOTAL	4.0E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-16A
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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: -26

Confidence in Trend: 95.7%

Coefficient of Variation: 0.65

Mann Kendall Concentration Trend: (See Note) D

Data Table:

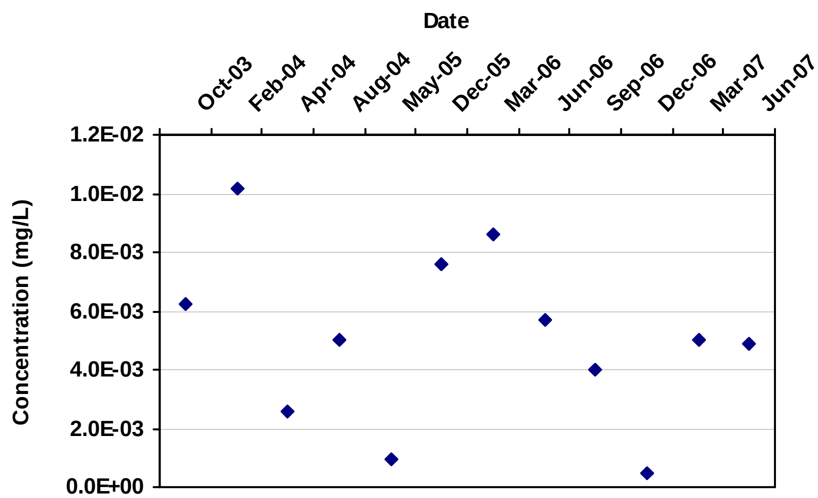
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-16A	T	10/15/2003	CHROMIUM, TOTAL	4.8E-03		2	2
RA-MW-16A	T	2/10/2004	CHROMIUM, TOTAL	9.2E-03		1	1
RA-MW-16A	T	4/5/2004	CHROMIUM, TOTAL	2.0E-03		1	1
RA-MW-16A	T	8/15/2004	CHROMIUM, TOTAL	3.5E-03		1	1
RA-MW-16A	T	5/5/2005	CHROMIUM, TOTAL	2.2E-03		1	1
RA-MW-16A	T	12/12/2005	CHROMIUM, TOTAL	4.1E-03		1	1
RA-MW-16A	T	3/8/2006	CHROMIUM, TOTAL	3.7E-03		1	1
RA-MW-16A	T	6/15/2006	CHROMIUM, TOTAL	2.8E-03		1	1
RA-MW-16A	T	9/25/2006	CHROMIUM, TOTAL	1.7E-03		1	1
RA-MW-16A	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-16A	T	3/30/2007	CHROMIUM, TOTAL	2.9E-03		1	1
RA-MW-16A	T	6/5/2007	CHROMIUM, TOTAL	2.6E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-17A
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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: -17

Confidence in Trend: 86.0%

Coefficient of Variation: 0.57

Mann Kendall Concentration Trend: (See Note) S

Data Table:

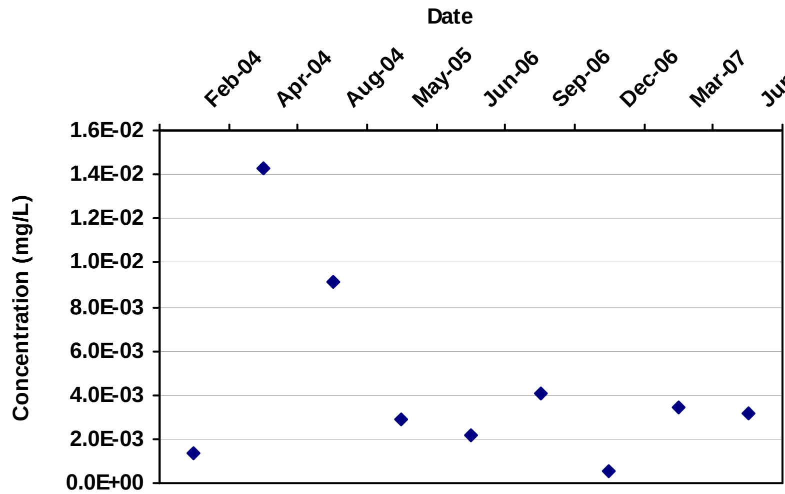
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-17A	T	10/15/2003	CHROMIUM, TOTAL	6.3E-03		2	2
RA-MW-17A	T	2/10/2004	CHROMIUM, TOTAL	1.0E-02		1	1
RA-MW-17A	T	4/5/2004	CHROMIUM, TOTAL	2.6E-03		1	1
RA-MW-17A	T	8/15/2004	CHROMIUM, TOTAL	5.0E-03		1	1
RA-MW-17A	T	5/5/2005	CHROMIUM, TOTAL	9.2E-04		1	1
RA-MW-17A	T	12/12/2005	CHROMIUM, TOTAL	7.6E-03		1	1
RA-MW-17A	T	3/8/2006	CHROMIUM, TOTAL	8.6E-03		1	1
RA-MW-17A	T	6/15/2006	CHROMIUM, TOTAL	5.7E-03		1	1
RA-MW-17A	T	9/25/2006	CHROMIUM, TOTAL	4.0E-03		1	1
RA-MW-17A	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-17A	T	3/30/2007	CHROMIUM, TOTAL	5.0E-03		1	1
RA-MW-17A	T	6/5/2007	CHROMIUM, TOTAL	4.9E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: W85-6A
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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:

-6

Confidence in Trend:

69.4%

Coefficient of Variation:

0.96

Mann Kendall Concentration Trend: (See Note)

S

Data Table:

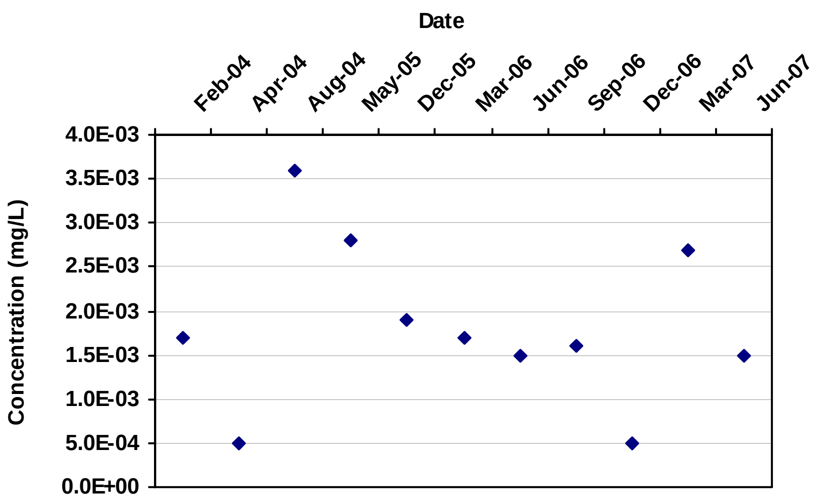
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W85-6A	T	2/10/2004	CHROMIUM, TOTAL	1.4E-03		1	1
W85-6A	T	4/5/2004	CHROMIUM, TOTAL	1.4E-02		1	1
W85-6A	T	8/15/2004	CHROMIUM, TOTAL	9.1E-03		1	1
W85-6A	T	5/5/2005	CHROMIUM, TOTAL	2.9E-03		1	1
W85-6A	T	6/15/2006	CHROMIUM, TOTAL	2.2E-03		1	1
W85-6A	T	9/25/2006	CHROMIUM, TOTAL	4.1E-03		1	1
W85-6A	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W85-6A	T	3/30/2007	CHROMIUM, TOTAL	3.4E-03		1	1
W85-6A	T	6/5/2007	CHROMIUM, TOTAL	3.2E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: W85-7A
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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: -14

Confidence in Trend: 84.0%

Coefficient of Variation: 0.51

Mann Kendall Concentration Trend: (See Note) S

Data Table:

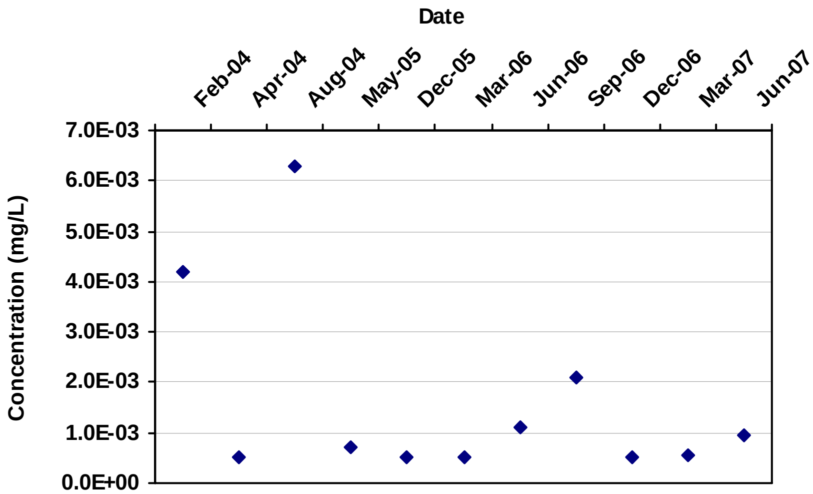
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W85-7A	T	2/10/2004	CHROMIUM, TOTAL	1.7E-03		1	1
W85-7A	T	4/5/2004	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W85-7A	T	8/15/2004	CHROMIUM, TOTAL	3.6E-03		1	1
W85-7A	T	5/5/2005	CHROMIUM, TOTAL	2.8E-03		1	1
W85-7A	T	12/12/2005	CHROMIUM, TOTAL	1.9E-03		1	1
W85-7A	T	3/8/2006	CHROMIUM, TOTAL	1.7E-03		1	1
W85-7A	T	6/15/2006	CHROMIUM, TOTAL	1.5E-03		1	1
W85-7A	T	9/25/2006	CHROMIUM, TOTAL	1.6E-03		1	1
W85-7A	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W85-7A	T	3/30/2007	CHROMIUM, TOTAL	2.7E-03		1	1
W85-7A	T	6/5/2007	CHROMIUM, TOTAL	1.5E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: W92-16A
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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: -5

Confidence in Trend: 61.9%

Coefficient of Variation: 1.17

Mann Kendall Concentration Trend: (See Note) NT

Data Table:

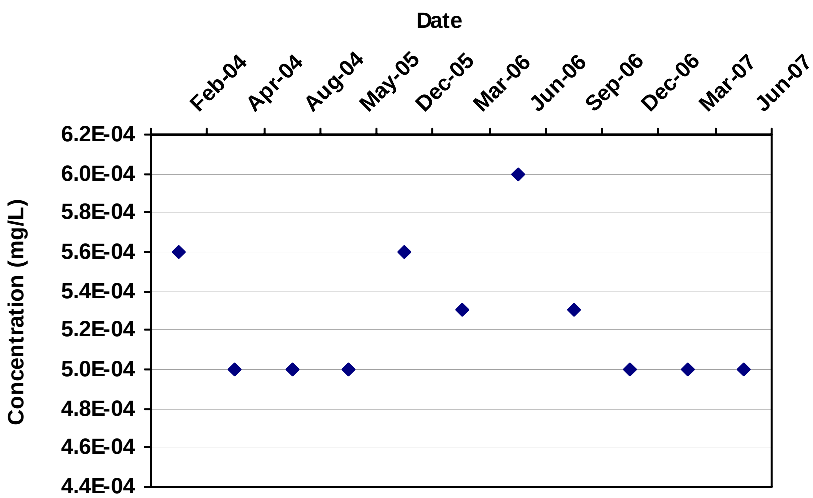
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W92-16A	T	2/10/2004	CHROMIUM, TOTAL	4.2E-03		1	1
W92-16A	T	4/5/2004	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W92-16A	T	8/15/2004	CHROMIUM, TOTAL	6.3E-03		1	1
W92-16A	T	5/5/2005	CHROMIUM, TOTAL	7.0E-04		1	1
W92-16A	T	12/12/2005	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W92-16A	T	3/8/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W92-16A	T	6/15/2006	CHROMIUM, TOTAL	1.1E-03		1	1
W92-16A	T	9/25/2006	CHROMIUM, TOTAL	2.1E-03		1	1
W92-16A	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W92-16A	T	3/30/2007	CHROMIUM, TOTAL	5.6E-04		1	1
W92-16A	T	6/5/2007	CHROMIUM, TOTAL	9.4E-04		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: W97-18A
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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: -9

Confidence in Trend: 72.9%

Coefficient of Variation: 0.07

Mann Kendall Concentration Trend: (See Note) S

Data Table:

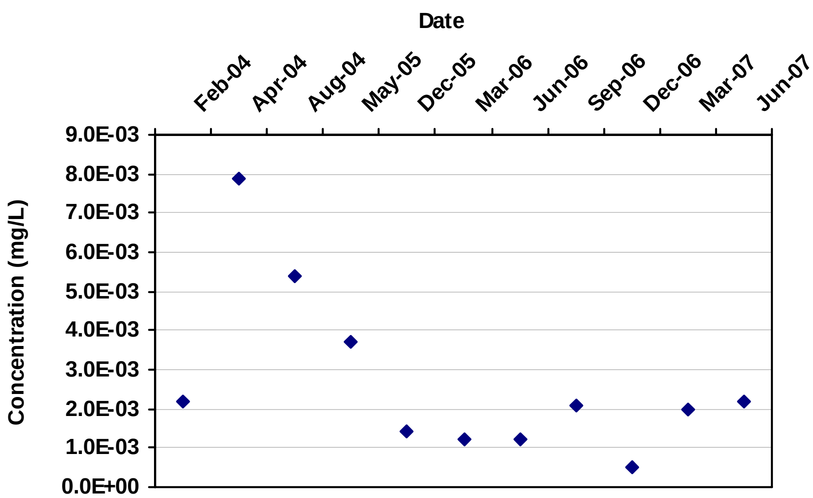
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W97-18A	T	2/10/2004	CHROMIUM, TOTAL	5.6E-04		1	1
W97-18A	T	4/5/2004	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W97-18A	T	8/15/2004	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W97-18A	T	5/5/2005	CHROMIUM, TOTAL	5.0E-04		1	1
W97-18A	T	12/12/2005	CHROMIUM, TOTAL	5.6E-04		1	1
W97-18A	T	3/8/2006	CHROMIUM, TOTAL	5.3E-04		1	1
W97-18A	T	6/15/2006	CHROMIUM, TOTAL	6.0E-04		1	1
W97-18A	T	9/25/2006	CHROMIUM, TOTAL	5.3E-04		1	1
W97-18A	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W97-18A	T	3/30/2007	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W97-18A	T	6/5/2007	CHROMIUM, TOTAL	5.0E-04	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

MAROS Mann-Kendall Statistics Summary

Well: W97-19A
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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:
-21

Confidence in Trend:
94.0%

Coefficient of Variation:
0.81

Mann Kendall Concentration Trend: (See Note)
PD

Data Table:

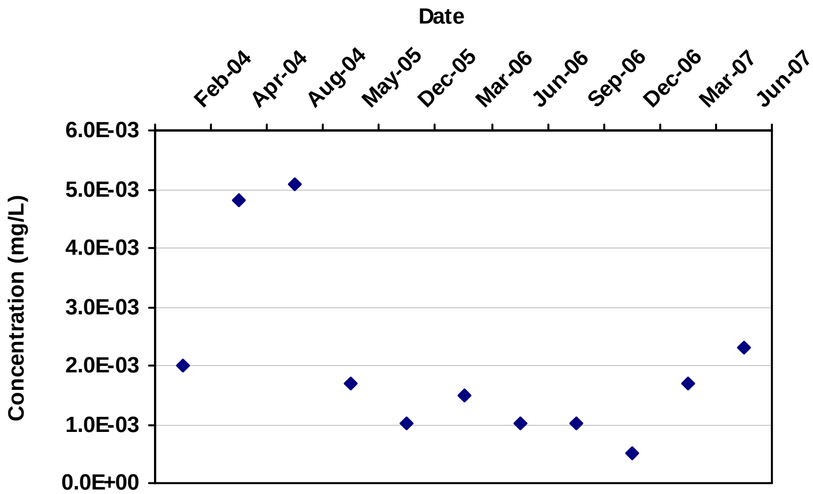
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W97-19A	T	2/10/2004	CHROMIUM, TOTAL	2.2E-03		1	1
W97-19A	T	4/5/2004	CHROMIUM, TOTAL	7.9E-03		1	1
W97-19A	T	8/15/2004	CHROMIUM, TOTAL	5.4E-03		1	1
W97-19A	T	5/5/2005	CHROMIUM, TOTAL	3.7E-03		1	1
W97-19A	T	12/12/2005	CHROMIUM, TOTAL	1.4E-03		1	1
W97-19A	T	3/8/2006	CHROMIUM, TOTAL	1.2E-03		1	1
W97-19A	T	6/15/2006	CHROMIUM, TOTAL	1.2E-03		1	1
W97-19A	T	9/25/2006	CHROMIUM, TOTAL	2.1E-03		1	1
W97-19A	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W97-19A	T	3/30/2007	CHROMIUM, TOTAL	2.0E-03		1	1
W97-19A	T	6/5/2007	CHROMIUM, TOTAL	2.2E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: W98-20A
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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:

-17

Confidence in Trend:

89.1%

Coefficient of Variation:

0.74

Mann Kendall Concentration Trend: (See Note)

S

Data Table:

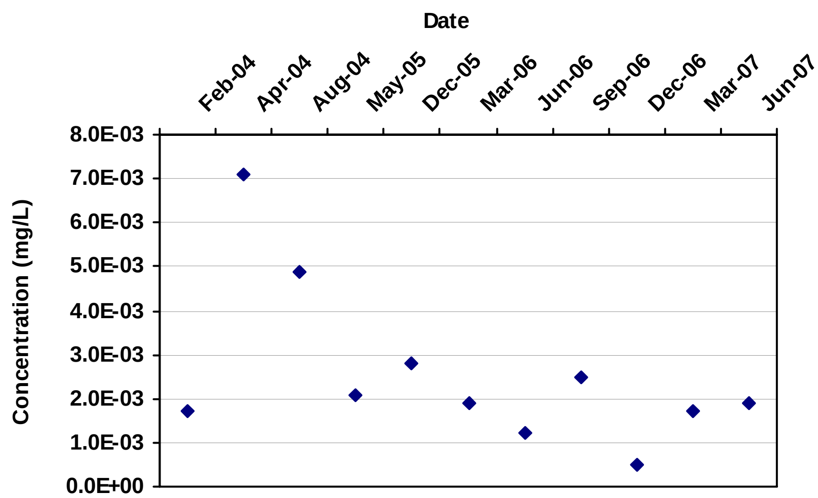
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W98-20A	T	2/10/2004	CHROMIUM, TOTAL	2.0E-03		1	1
W98-20A	T	4/5/2004	CHROMIUM, TOTAL	4.8E-03		1	1
W98-20A	T	8/15/2004	CHROMIUM, TOTAL	5.1E-03		1	1
W98-20A	T	5/5/2005	CHROMIUM, TOTAL	1.7E-03		1	1
W98-20A	T	12/12/2005	CHROMIUM, TOTAL	1.0E-03		1	1
W98-20A	T	3/8/2006	CHROMIUM, TOTAL	1.5E-03		1	1
W98-20A	T	6/15/2006	CHROMIUM, TOTAL	1.0E-03		1	1
W98-20A	T	9/25/2006	CHROMIUM, TOTAL	1.0E-03		1	1
W98-20A	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W98-20A	T	3/30/2007	CHROMIUM, TOTAL	1.7E-03		1	1
W98-20A	T	6/5/2007	CHROMIUM, TOTAL	2.3E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: W98-21A
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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: -21

Confidence in Trend: 94.0%

Coefficient of Variation: 0.73

Mann Kendall Concentration Trend: (See Note) PD

Data Table:

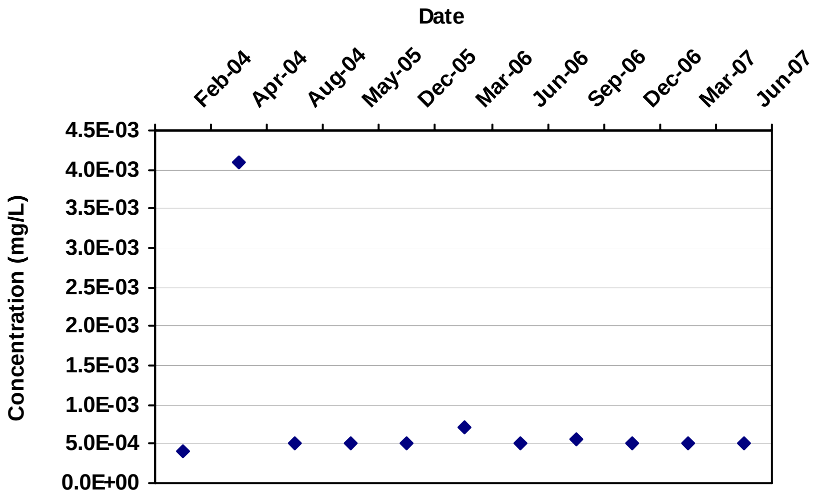
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W98-21A	T	2/10/2004	CHROMIUM, TOTAL	1.7E-03		1	1
W98-21A	T	4/5/2004	CHROMIUM, TOTAL	7.1E-03		1	1
W98-21A	T	8/15/2004	CHROMIUM, TOTAL	4.9E-03		1	1
W98-21A	T	5/5/2005	CHROMIUM, TOTAL	2.1E-03		1	1
W98-21A	T	12/12/2005	CHROMIUM, TOTAL	2.8E-03		1	1
W98-21A	T	3/8/2006	CHROMIUM, TOTAL	1.9E-03		1	1
W98-21A	T	6/15/2006	CHROMIUM, TOTAL	1.2E-03		1	1
W98-21A	T	9/25/2006	CHROMIUM, TOTAL	2.5E-03		1	1
W98-21A	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W98-21A	T	3/30/2007	CHROMIUM, TOTAL	1.7E-03		1	1
W98-21A	T	6/5/2007	CHROMIUM, TOTAL	1.9E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: W99-R5A
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
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:
0

Confidence in Trend:
46.9%

Coefficient of Variation:
1.29

Mann Kendall Concentration Trend: (See Note)
NT

Data Table:

Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W99-R5A	T	2/10/2004	CHROMIUM, TOTAL	4.1E-04		1	1
W99-R5A	T	4/5/2004	CHROMIUM, TOTAL	4.1E-03		1	1
W99-R5A	T	8/15/2004	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W99-R5A	T	5/5/2005	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W99-R5A	T	12/12/2005	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W99-R5A	T	3/8/2006	CHROMIUM, TOTAL	7.0E-04		1	1
W99-R5A	T	6/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W99-R5A	T	9/25/2006	CHROMIUM, TOTAL	5.5E-04		1	1
W99-R5A	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W99-R5A	T	3/30/2007	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W99-R5A	T	6/5/2007	CHROMIUM, TOTAL	5.0E-04	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

MAROS Mann-Kendall Statistics Summary

Project: Frontier Hard Chrome

User Name: MV

Location: Vancouver

State: Washington

Time Period: 10/15/2003 **to** 6/5/2007

Consolidation Period: No Time Consolidation

Consolidation Type: Geometric Mean

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
CHROMIUM, TOTAL								
RA-MW-15B	S	12	12	0.94	4	58.0%	No	NT
B87-8	S	11	11	1.10	2	53.0%	No	NT
RA-MW-11B	S	12	11	1.62	-48	100.0%	No	D
W92-16B	S	12	12	1.47	2	52.7%	No	NT
RA-MW-16B	S	12	12	1.45	8	68.1%	No	NT
RA-MW-12B	T	12	10	1.09	-28	96.9%	No	D
RA-MW-12C	T	12	12	0.70	-4	58.0%	No	S
RA-MW-13B	T	12	6	1.32	-13	79.0%	No	NT
B85-3	T	11	8	0.80	2	53.0%	No	NT
RA-MW-14B	T	12	9	1.21	-6	63.1%	No	NT
W99-R5B	T	11	10	0.74	-33	99.5%	No	D
W85-7B	T	11	4	1.58	-34	99.6%	No	D
W97-18B	T	11	8	0.39	12	79.9%	No	NT
W97-19B	T	11	9	0.99	-24	96.4%	No	D
W98-21B	T	11	10	0.62	-34	99.6%	No	D
RA-MW-13C	T	11	10	0.85	-6	64.8%	No	S

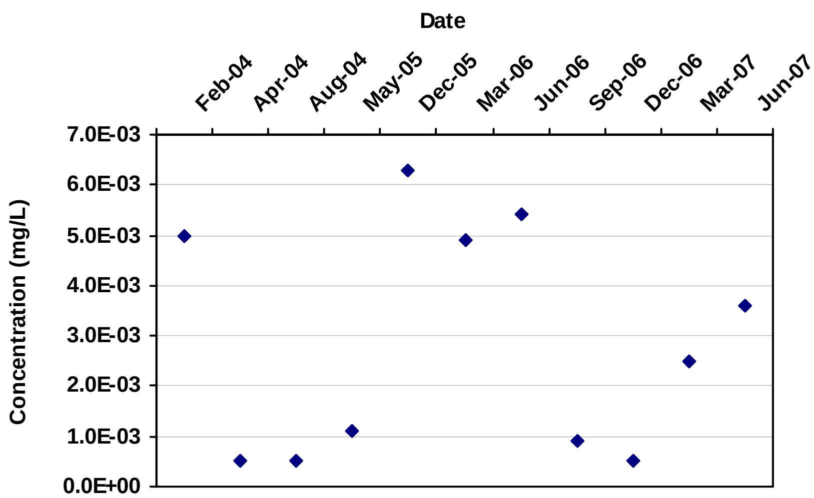
Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A)-Due to insufficient Data (< 4 sampling events); Source/Tail (S/T)

The Number of Samples and Number of Detects shown above are post-consolidation values.

MAROS Mann-Kendall Statistics Summary

Well: B85-3
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic: 2

Confidence in Trend: 53.0%

Coefficient of Variation: 0.80

Mann Kendall Concentration Trend: (See Note) NT

Data Table:

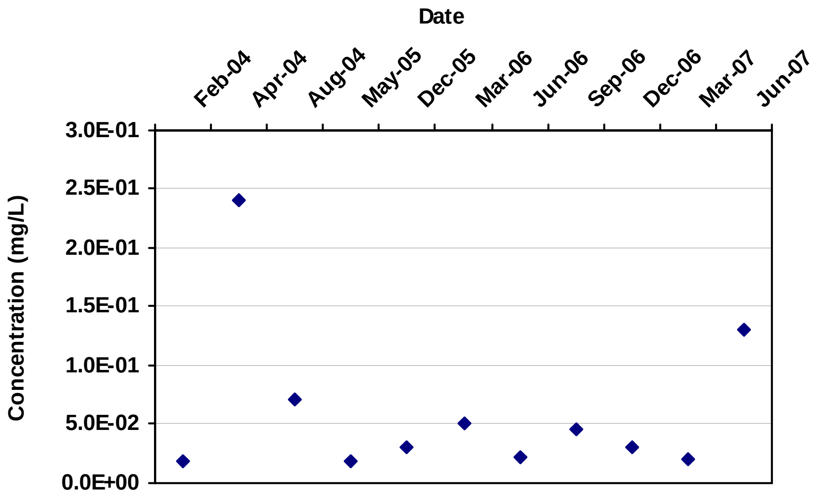
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
B85-3	T	2/10/2004	CHROMIUM, TOTAL	5.0E-03		1	1
B85-3	T	4/5/2004	CHROMIUM, TOTAL	5.0E-04	ND	1	0
B85-3	T	8/15/2004	CHROMIUM, TOTAL	5.0E-04	ND	1	0
B85-3	T	5/5/2005	CHROMIUM, TOTAL	1.1E-03		1	1
B85-3	T	12/12/2005	CHROMIUM, TOTAL	6.3E-03		1	1
B85-3	T	3/8/2006	CHROMIUM, TOTAL	4.9E-03		1	1
B85-3	T	6/15/2006	CHROMIUM, TOTAL	5.4E-03		1	1
B85-3	T	9/25/2006	CHROMIUM, TOTAL	9.0E-04		1	1
B85-3	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
B85-3	T	3/30/2007	CHROMIUM, TOTAL	2.5E-03		1	1
B85-3	T	6/5/2007	CHROMIUM, TOTAL	3.6E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: B87-8
Well Type: S
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic: 2

Confidence in Trend: 53.0%

Coefficient of Variation: 1.10

Mann Kendall Concentration Trend: (See Note) NT

Data Table:

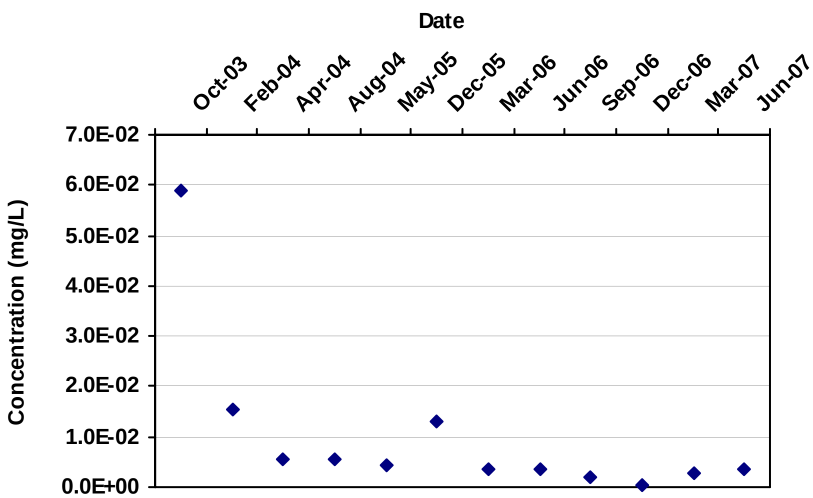
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
B87-8	S	2/10/2004	CHROMIUM, TOTAL	1.8E-02		1	1
B87-8	S	4/5/2004	CHROMIUM, TOTAL	2.4E-01		1	1
B87-8	S	8/15/2004	CHROMIUM, TOTAL	7.1E-02		1	1
B87-8	S	5/5/2005	CHROMIUM, TOTAL	1.9E-02		1	1
B87-8	S	12/12/2005	CHROMIUM, TOTAL	3.1E-02		1	1
B87-8	S	3/8/2006	CHROMIUM, TOTAL	5.0E-02		1	1
B87-8	S	6/15/2006	CHROMIUM, TOTAL	2.2E-02		1	1
B87-8	S	9/25/2006	CHROMIUM, TOTAL	4.6E-02		1	1
B87-8	S	12/15/2006	CHROMIUM, TOTAL	3.1E-02		1	1
B87-8	S	3/30/2007	CHROMIUM, TOTAL	2.0E-02		1	1
B87-8	S	6/5/2007	CHROMIUM, TOTAL	1.3E-01		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-11B
Well Type: S
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic: -48

Confidence in Trend: 100.0%

Coefficient of Variation: 1.62

Mann Kendall Concentration Trend: (See Note) D

Data Table:

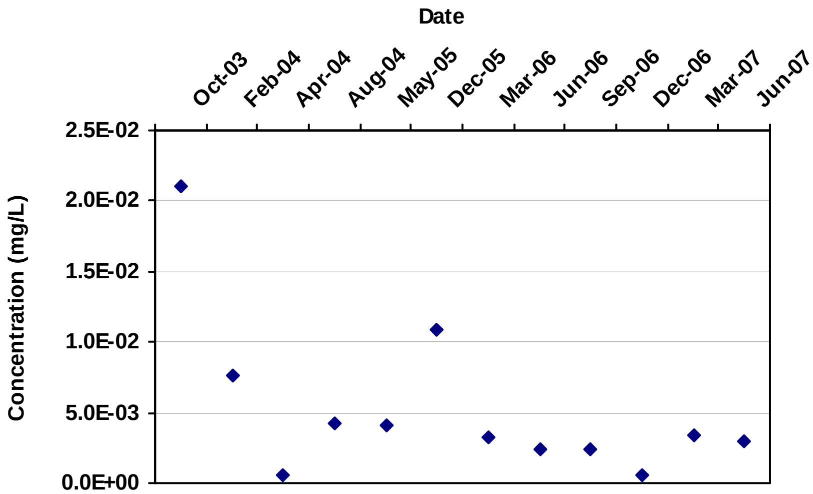
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-11B	S	10/15/2003	CHROMIUM, TOTAL	5.9E-02		2	2
RA-MW-11B	S	2/10/2004	CHROMIUM, TOTAL	1.6E-02		1	1
RA-MW-11B	S	4/5/2004	CHROMIUM, TOTAL	5.7E-03		1	1
RA-MW-11B	S	8/15/2004	CHROMIUM, TOTAL	5.6E-03		1	1
RA-MW-11B	S	5/5/2005	CHROMIUM, TOTAL	4.2E-03		1	1
RA-MW-11B	S	12/12/2005	CHROMIUM, TOTAL	1.3E-02		1	1
RA-MW-11B	S	3/8/2006	CHROMIUM, TOTAL	3.6E-03		1	1
RA-MW-11B	S	6/15/2006	CHROMIUM, TOTAL	3.7E-03		1	1
RA-MW-11B	S	9/25/2006	CHROMIUM, TOTAL	1.9E-03		1	1
RA-MW-11B	S	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-11B	S	3/30/2007	CHROMIUM, TOTAL	2.7E-03		1	1
RA-MW-11B	S	6/5/2007	CHROMIUM, TOTAL	3.4E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-12B
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic: -28

Confidence in Trend: 96.9%

Coefficient of Variation: 1.09

Mann Kendall Concentration Trend: (See Note) D

Data Table:

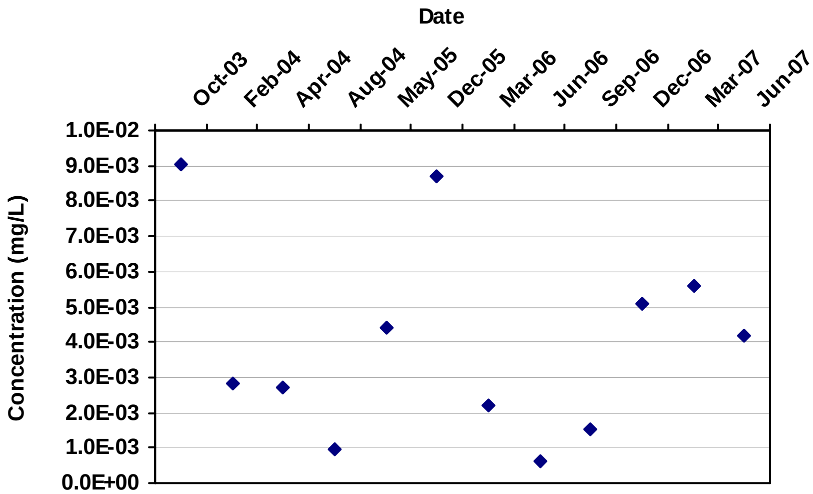
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-12B	T	10/15/2003	CHROMIUM, TOTAL	2.1E-02		2	2
RA-MW-12B	T	2/10/2004	CHROMIUM, TOTAL	7.6E-03		1	1
RA-MW-12B	T	4/5/2004	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-12B	T	8/15/2004	CHROMIUM, TOTAL	4.2E-03		1	1
RA-MW-12B	T	5/5/2005	CHROMIUM, TOTAL	4.1E-03		1	1
RA-MW-12B	T	12/12/2005	CHROMIUM, TOTAL	1.1E-02		1	1
RA-MW-12B	T	3/8/2006	CHROMIUM, TOTAL	3.3E-03		1	1
RA-MW-12B	T	6/15/2006	CHROMIUM, TOTAL	2.4E-03		1	1
RA-MW-12B	T	9/25/2006	CHROMIUM, TOTAL	2.4E-03		1	1
RA-MW-12B	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-12B	T	3/30/2007	CHROMIUM, TOTAL	3.4E-03		1	1
RA-MW-12B	T	6/5/2007	CHROMIUM, TOTAL	3.0E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-12C
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic: -4

Confidence in Trend: 58.0%

Coefficient of Variation: 0.70

Mann Kendall Concentration Trend: (See Note) S

Data Table:

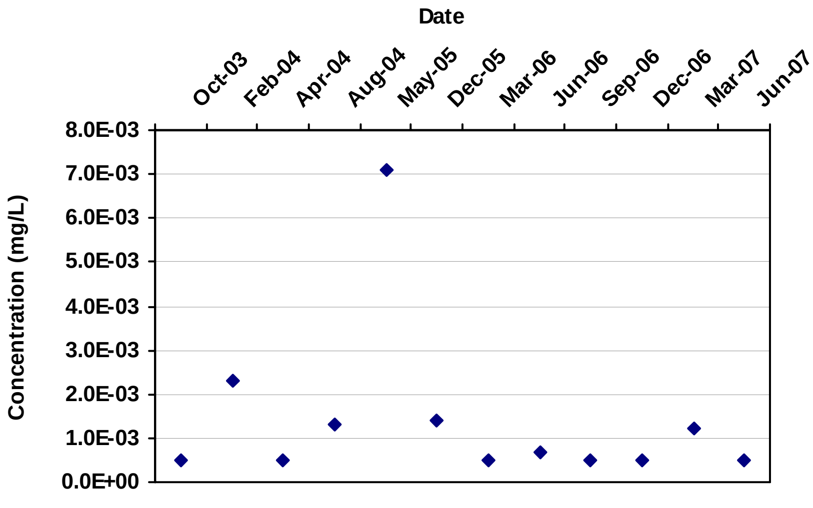
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-12C	T	10/15/2003	CHROMIUM, TOTAL	9.1E-03		2	2
RA-MW-12C	T	2/10/2004	CHROMIUM, TOTAL	2.8E-03		1	1
RA-MW-12C	T	4/5/2004	CHROMIUM, TOTAL	2.7E-03		1	1
RA-MW-12C	T	8/15/2004	CHROMIUM, TOTAL	9.8E-04		1	1
RA-MW-12C	T	5/5/2005	CHROMIUM, TOTAL	4.4E-03		1	1
RA-MW-12C	T	12/12/2005	CHROMIUM, TOTAL	8.7E-03		1	1
RA-MW-12C	T	3/8/2006	CHROMIUM, TOTAL	2.2E-03		1	1
RA-MW-12C	T	6/15/2006	CHROMIUM, TOTAL	6.0E-04		1	1
RA-MW-12C	T	9/25/2006	CHROMIUM, TOTAL	1.5E-03		1	1
RA-MW-12C	T	12/15/2006	CHROMIUM, TOTAL	5.1E-03		1	1
RA-MW-12C	T	3/30/2007	CHROMIUM, TOTAL	5.6E-03		1	1
RA-MW-12C	T	6/5/2007	CHROMIUM, TOTAL	4.2E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-13B
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic: -13

Confidence in Trend: 79.0%

Coefficient of Variation: 1.32

Mann Kendall Concentration Trend: (See Note) NT

Data Table:

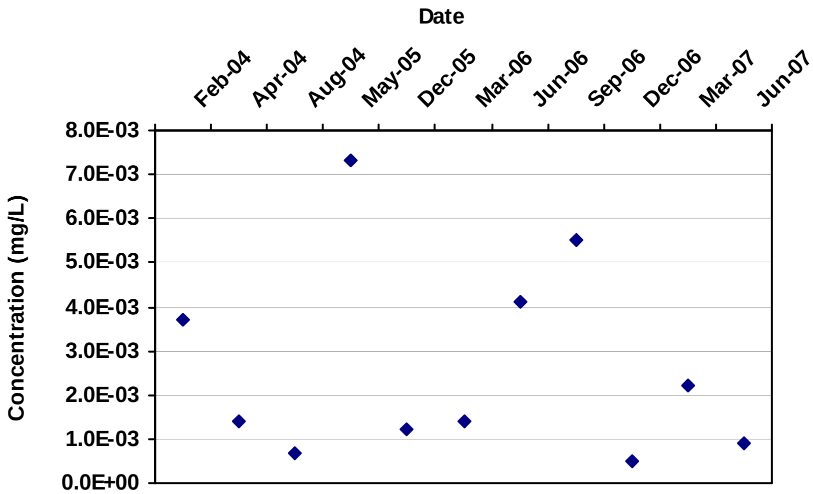
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-13B	T	10/15/2003	CHROMIUM, TOTAL	5.0E-04	ND	2	0
RA-MW-13B	T	2/10/2004	CHROMIUM, TOTAL	2.3E-03		1	1
RA-MW-13B	T	4/5/2004	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-13B	T	8/15/2004	CHROMIUM, TOTAL	1.3E-03		1	1
RA-MW-13B	T	5/5/2005	CHROMIUM, TOTAL	7.1E-03		1	1
RA-MW-13B	T	12/12/2005	CHROMIUM, TOTAL	1.4E-03		1	1
RA-MW-13B	T	3/8/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-13B	T	6/15/2006	CHROMIUM, TOTAL	7.0E-04		1	1
RA-MW-13B	T	9/25/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-13B	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-13B	T	3/30/2007	CHROMIUM, TOTAL	1.2E-03		1	1
RA-MW-13B	T	6/5/2007	CHROMIUM, TOTAL	5.0E-04	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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-13C
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic:
-6

Confidence in Trend:
64.8%

Coefficient of Variation:
0.85

Mann Kendall Concentration Trend: (See Note)
S

Data Table:

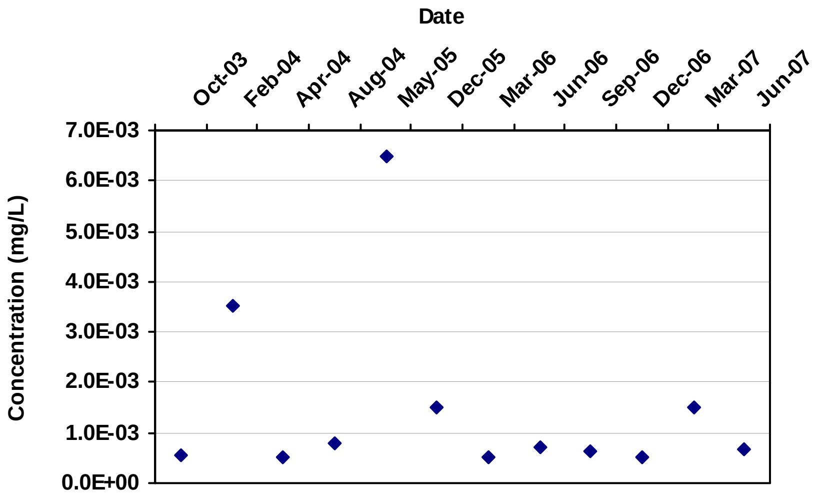
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-13C	T	2/10/2004	CHROMIUM, TOTAL	3.7E-03		1	1
RA-MW-13C	T	4/5/2004	CHROMIUM, TOTAL	1.4E-03		1	1
RA-MW-13C	T	8/15/2004	CHROMIUM, TOTAL	6.8E-04		1	1
RA-MW-13C	T	5/5/2005	CHROMIUM, TOTAL	7.3E-03		1	1
RA-MW-13C	T	12/12/2005	CHROMIUM, TOTAL	1.2E-03		1	1
RA-MW-13C	T	3/8/2006	CHROMIUM, TOTAL	1.4E-03		1	1
RA-MW-13C	T	6/15/2006	CHROMIUM, TOTAL	4.1E-03		1	1
RA-MW-13C	T	9/25/2006	CHROMIUM, TOTAL	5.5E-03		1	1
RA-MW-13C	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-13C	T	3/30/2007	CHROMIUM, TOTAL	2.2E-03		1	1
RA-MW-13C	T	6/5/2007	CHROMIUM, TOTAL	9.1E-04		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-14B
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic: -6

Confidence in Trend: 63.1%

Coefficient of Variation: 1.21

Mann Kendall Concentration Trend: (See Note) NT

Data Table:

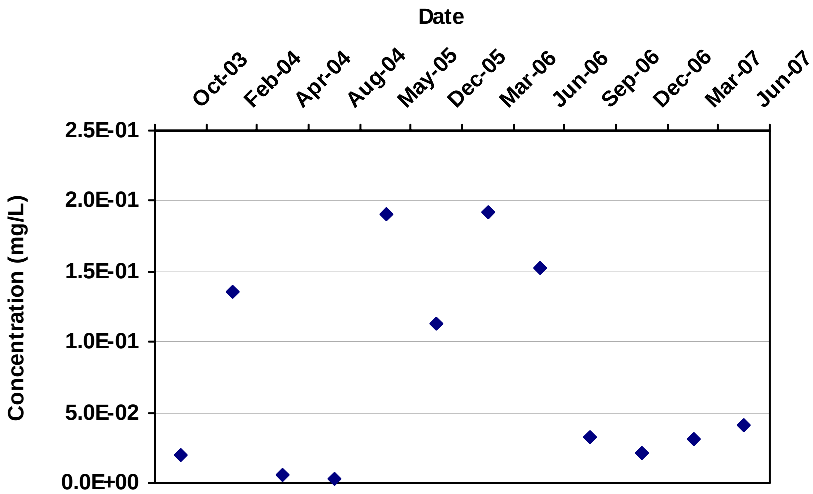
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-14B	T	10/15/2003	CHROMIUM, TOTAL	5.5E-04		2	1
RA-MW-14B	T	2/10/2004	CHROMIUM, TOTAL	3.5E-03		1	1
RA-MW-14B	T	4/5/2004	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-14B	T	8/15/2004	CHROMIUM, TOTAL	8.1E-04		1	1
RA-MW-14B	T	5/5/2005	CHROMIUM, TOTAL	6.5E-03		1	1
RA-MW-14B	T	12/12/2005	CHROMIUM, TOTAL	1.5E-03		1	1
RA-MW-14B	T	3/8/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-14B	T	6/15/2006	CHROMIUM, TOTAL	7.0E-04		1	1
RA-MW-14B	T	9/25/2006	CHROMIUM, TOTAL	6.4E-04		1	1
RA-MW-14B	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
RA-MW-14B	T	3/30/2007	CHROMIUM, TOTAL	1.5E-03		1	1
RA-MW-14B	T	6/5/2007	CHROMIUM, TOTAL	6.6E-04		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-15B
Well Type: S
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic: 4

Confidence in Trend: 58.0%

Coefficient of Variation: 0.94

Mann Kendall Concentration Trend: (See Note) NT

Data Table:

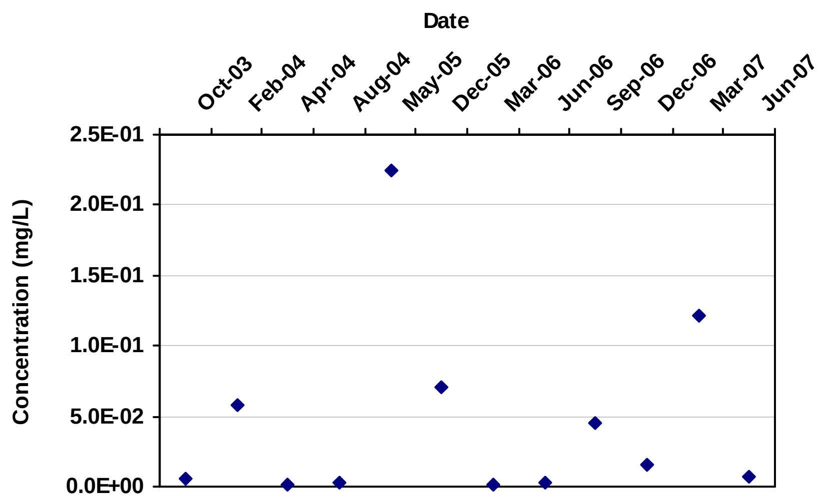
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-15B	S	10/15/2003	CHROMIUM, TOTAL	2.0E-02		2	2
RA-MW-15B	S	2/10/2004	CHROMIUM, TOTAL	1.4E-01		1	1
RA-MW-15B	S	4/5/2004	CHROMIUM, TOTAL	5.5E-03		1	1
RA-MW-15B	S	8/15/2004	CHROMIUM, TOTAL	2.2E-03		1	1
RA-MW-15B	S	5/5/2005	CHROMIUM, TOTAL	1.9E-01		1	1
RA-MW-15B	S	12/12/2005	CHROMIUM, TOTAL	1.1E-01		1	1
RA-MW-15B	S	3/8/2006	CHROMIUM, TOTAL	1.9E-01		1	1
RA-MW-15B	S	6/15/2006	CHROMIUM, TOTAL	1.5E-01		1	1
RA-MW-15B	S	9/25/2006	CHROMIUM, TOTAL	3.3E-02		1	1
RA-MW-15B	S	12/15/2006	CHROMIUM, TOTAL	2.1E-02		1	1
RA-MW-15B	S	3/30/2007	CHROMIUM, TOTAL	3.2E-02		1	1
RA-MW-15B	S	6/5/2007	CHROMIUM, TOTAL	4.1E-02		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: RA-MW-16B
Well Type: S
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic: 8

Confidence in Trend: 68.1%

Coefficient of Variation: 1.45

Mann Kendall Concentration Trend: (See Note) NT

Data Table:

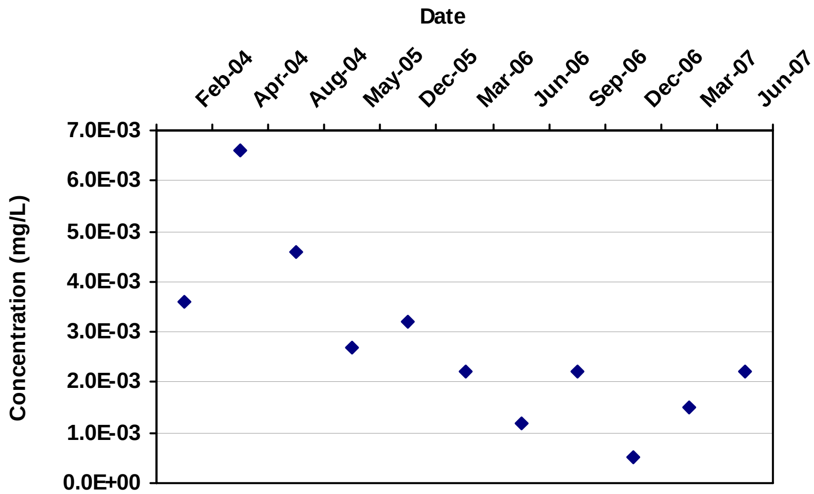
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
RA-MW-16B	S	10/15/2003	CHROMIUM, TOTAL	5.1E-03		2	2
RA-MW-16B	S	2/10/2004	CHROMIUM, TOTAL	5.7E-02		1	1
RA-MW-16B	S	4/5/2004	CHROMIUM, TOTAL	2.1E-03		1	1
RA-MW-16B	S	8/15/2004	CHROMIUM, TOTAL	2.8E-03		1	1
RA-MW-16B	S	5/5/2005	CHROMIUM, TOTAL	2.3E-01		1	1
RA-MW-16B	S	12/12/2005	CHROMIUM, TOTAL	7.1E-02		1	1
RA-MW-16B	S	3/8/2006	CHROMIUM, TOTAL	1.3E-03		1	1
RA-MW-16B	S	6/15/2006	CHROMIUM, TOTAL	3.2E-03		1	1
RA-MW-16B	S	9/25/2006	CHROMIUM, TOTAL	4.5E-02		1	1
RA-MW-16B	S	12/15/2006	CHROMIUM, TOTAL	1.6E-02		1	1
RA-MW-16B	S	3/30/2007	CHROMIUM, TOTAL	1.2E-01		1	1
RA-MW-16B	S	6/5/2007	CHROMIUM, TOTAL	7.0E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: W98-21B
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic: -34

Confidence in Trend: 99.6%

Coefficient of Variation: 0.62

Mann Kendall Concentration Trend: (See Note) D

Data Table:

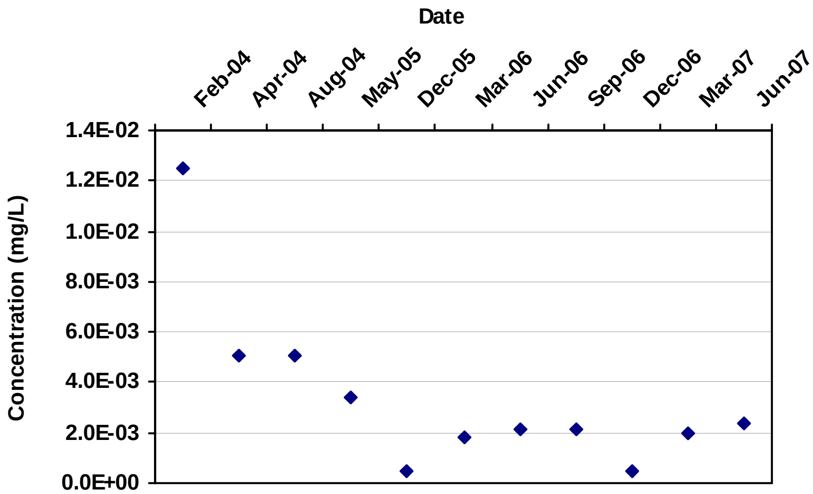
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W98-21B	T	2/10/2004	CHROMIUM, TOTAL	3.6E-03		1	1
W98-21B	T	4/5/2004	CHROMIUM, TOTAL	6.6E-03		1	1
W98-21B	T	8/15/2004	CHROMIUM, TOTAL	4.6E-03		1	1
W98-21B	T	5/5/2005	CHROMIUM, TOTAL	2.7E-03		1	1
W98-21B	T	12/12/2005	CHROMIUM, TOTAL	3.2E-03		1	1
W98-21B	T	3/8/2006	CHROMIUM, TOTAL	2.2E-03		1	1
W98-21B	T	6/15/2006	CHROMIUM, TOTAL	1.2E-03		1	1
W98-21B	T	9/25/2006	CHROMIUM, TOTAL	2.2E-03		1	1
W98-21B	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W98-21B	T	3/30/2007	CHROMIUM, TOTAL	1.5E-03		1	1
W98-21B	T	6/5/2007	CHROMIUM, TOTAL	2.2E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: W97-19B
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic:

-24

Confidence in Trend:

96.4%

Coefficient of Variation:

0.99

Mann Kendall Concentration Trend: (See Note)

D

Data Table:

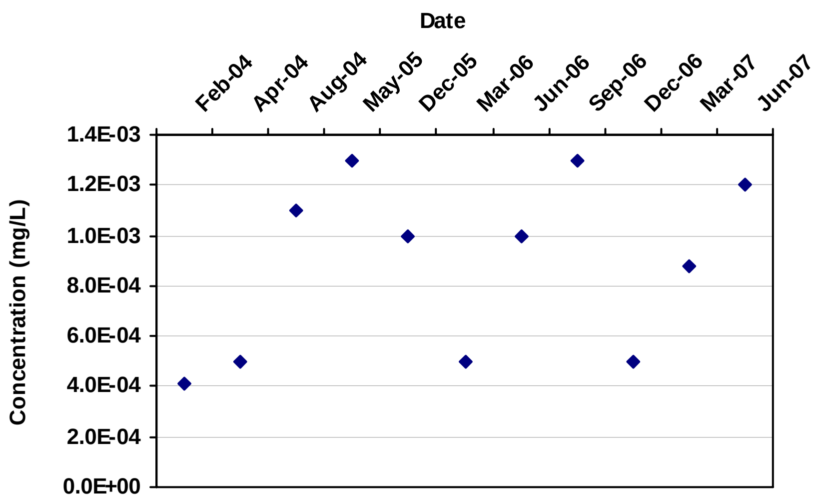
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W97-19B	T	2/10/2004	CHROMIUM, TOTAL	1.3E-02		1	1
W97-19B	T	4/5/2004	CHROMIUM, TOTAL	5.1E-03		1	1
W97-19B	T	8/15/2004	CHROMIUM, TOTAL	5.1E-03		1	1
W97-19B	T	5/5/2005	CHROMIUM, TOTAL	3.4E-03		1	1
W97-19B	T	12/12/2005	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W97-19B	T	3/8/2006	CHROMIUM, TOTAL	1.8E-03		1	1
W97-19B	T	6/15/2006	CHROMIUM, TOTAL	2.1E-03		1	1
W97-19B	T	9/25/2006	CHROMIUM, TOTAL	2.1E-03		1	1
W97-19B	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W97-19B	T	3/30/2007	CHROMIUM, TOTAL	2.0E-03		1	1
W97-19B	T	6/5/2007	CHROMIUM, TOTAL	2.4E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: W97-18B
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic:
12

Confidence in Trend:
79.9%

Coefficient of Variation:
0.39

Mann Kendall Concentration Trend: (See Note)
NT

Data Table:

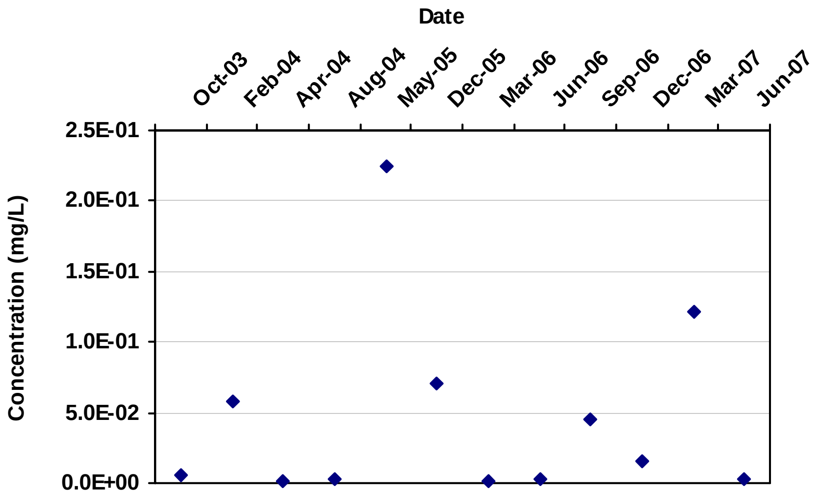
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W97-18B	T	2/10/2004	CHROMIUM, TOTAL	4.1E-04		1	1
W97-18B	T	4/5/2004	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W97-18B	T	8/15/2004	CHROMIUM, TOTAL	1.1E-03		1	1
W97-18B	T	5/5/2005	CHROMIUM, TOTAL	1.3E-03		1	1
W97-18B	T	12/12/2005	CHROMIUM, TOTAL	1.0E-03		1	1
W97-18B	T	3/8/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W97-18B	T	6/15/2006	CHROMIUM, TOTAL	1.0E-03		1	1
W97-18B	T	9/25/2006	CHROMIUM, TOTAL	1.3E-03		1	1
W97-18B	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W97-18B	T	3/30/2007	CHROMIUM, TOTAL	8.8E-04		1	1
W97-18B	T	6/5/2007	CHROMIUM, TOTAL	1.2E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: W92-16B
Well Type: S
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic: 2

Confidence in Trend: 52.7%

Coefficient of Variation: 1.47

Mann Kendall Concentration Trend: (See Note) NT

Data Table:

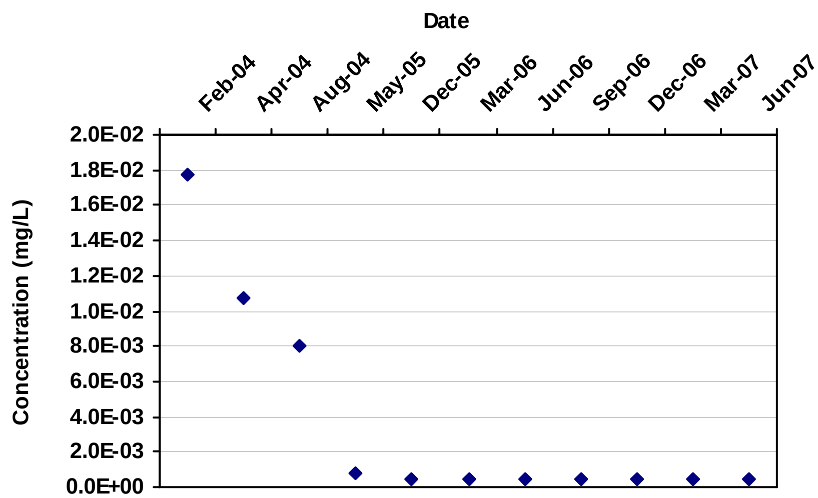
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W92-16B	S	10/15/2003	CHROMIUM, TOTAL	5.1E-03		2	2
W92-16B	S	2/10/2004	CHROMIUM, TOTAL	5.7E-02		1	1
W92-16B	S	4/5/2004	CHROMIUM, TOTAL	2.1E-03		1	1
W92-16B	S	8/15/2004	CHROMIUM, TOTAL	2.8E-03		1	1
W92-16B	S	5/5/2005	CHROMIUM, TOTAL	2.3E-01		1	1
W92-16B	S	12/12/2005	CHROMIUM, TOTAL	7.1E-02		1	1
W92-16B	S	3/8/2006	CHROMIUM, TOTAL	1.3E-03		1	1
W92-16B	S	6/15/2006	CHROMIUM, TOTAL	3.2E-03		1	1
W92-16B	S	9/25/2006	CHROMIUM, TOTAL	4.5E-02		1	1
W92-16B	S	12/15/2006	CHROMIUM, TOTAL	1.6E-02		1	1
W92-16B	S	3/30/2007	CHROMIUM, TOTAL	1.2E-01		1	1
W92-16B	S	6/5/2007	CHROMIUM, TOTAL	2.6E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: W85-7B
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic: -34

Confidence in Trend: 99.6%

Coefficient of Variation: 1.58

Mann Kendall Concentration Trend: (See Note) D

Data Table:

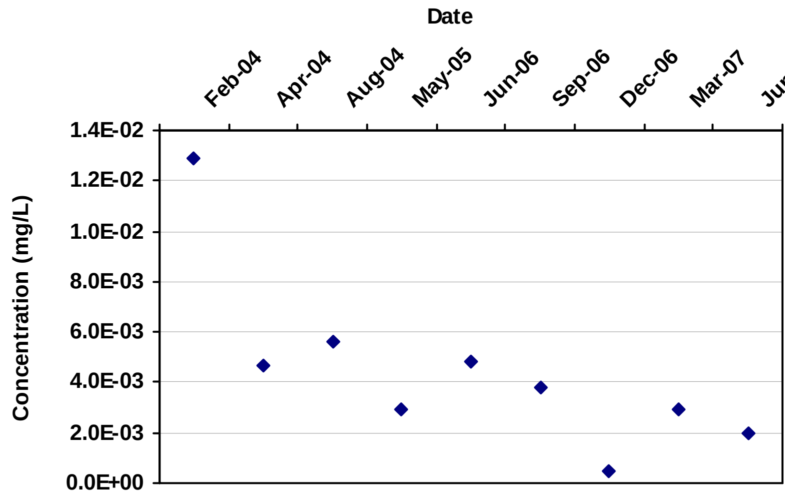
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W85-7B	T	2/10/2004	CHROMIUM, TOTAL	1.8E-02		1	1
W85-7B	T	4/5/2004	CHROMIUM, TOTAL	1.1E-02		1	1
W85-7B	T	8/15/2004	CHROMIUM, TOTAL	8.0E-03		1	1
W85-7B	T	5/5/2005	CHROMIUM, TOTAL	8.4E-04		1	1
W85-7B	T	12/12/2005	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W85-7B	T	3/8/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W85-7B	T	6/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W85-7B	T	9/25/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W85-7B	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W85-7B	T	3/30/2007	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W85-7B	T	6/5/2007	CHROMIUM, TOTAL	5.0E-04	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

MAROS Mann-Kendall Statistics Summary

Well: W85-6B
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic:

-23

Confidence in Trend:

99.1%

Coefficient of Variation:

0.79

Mann Kendall Concentration Trend: (See Note)

D

Data Table:

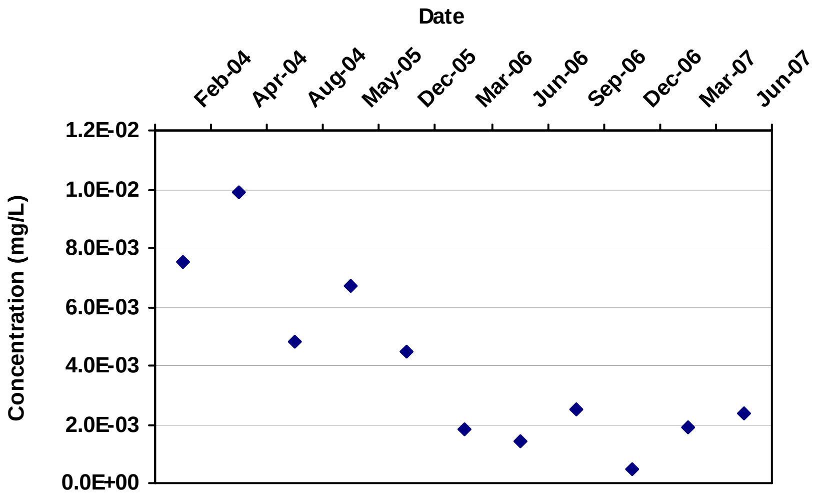
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
W85-6B	T	2/10/2004	CHROMIUM, TOTAL	1.3E-02		1	1
W85-6B	T	4/5/2004	CHROMIUM, TOTAL	4.7E-03		1	1
W85-6B	T	8/15/2004	CHROMIUM, TOTAL	5.6E-03		1	1
W85-6B	T	5/5/2005	CHROMIUM, TOTAL	2.9E-03		1	1
W85-6B	T	6/15/2006	CHROMIUM, TOTAL	4.8E-03		1	1
W85-6B	T	9/25/2006	CHROMIUM, TOTAL	3.8E-03		1	1
W85-6B	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W85-6B	T	3/30/2007	CHROMIUM, TOTAL	2.9E-03		1	1
W85-6B	T	6/5/2007	CHROMIUM, TOTAL	2.0E-03		1	1

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

MAROS Mann-Kendall Statistics Summary

Well: W99-R5B
Well Type: T
COC: CHROMIUM, TOTAL

Time Period: 10/15/2003 **to** 6/5/2007
Consolidation Period: No Time Consolidation
Consolidation Type: Geometric Mean
Duplicate Consolidation: Average
ND Values: Specified Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic: -33

Confidence in Trend: 99.5%

Coefficient of Variation: 0.74

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
W99-R5B	T	2/10/2004	CHROMIUM, TOTAL	7.5E-03		1	1
W99-R5B	T	4/5/2004	CHROMIUM, TOTAL	9.9E-03		1	1
W99-R5B	T	8/15/2004	CHROMIUM, TOTAL	4.8E-03		1	1
W99-R5B	T	5/5/2005	CHROMIUM, TOTAL	6.7E-03		1	1
W99-R5B	T	12/12/2005	CHROMIUM, TOTAL	4.5E-03		1	1
W99-R5B	T	3/8/2006	CHROMIUM, TOTAL	1.8E-03		1	1
W99-R5B	T	6/15/2006	CHROMIUM, TOTAL	1.4E-03		1	1
W99-R5B	T	9/25/2006	CHROMIUM, TOTAL	2.5E-03		1	1
W99-R5B	T	12/15/2006	CHROMIUM, TOTAL	5.0E-04	ND	1	0
W99-R5B	T	3/30/2007	CHROMIUM, TOTAL	1.9E-03		1	1
W99-R5B	T	6/5/2007	CHROMIUM, TOTAL	2.4E-03		1	1

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