OPTIMIZATION-BASED GROUNDWATER MODELING

OF AQUEOUS PHASE DNAPL TO ENHANCE

PLUME REMEDIATION MANAGEMENT

By

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Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirement for
the Degree of
DOCTOR OF PHILOSOPHY
December 2008

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PREFACE

This research was conducted to provide new information and an understanding of the new evolution of statistical software being developed to analyze the remediation effect of DNAPL plumes in groundwater. The mechanics of hydrogeology can no longer be the means of identifying the limits and degree of contamination spread and degradation. Due to the cost of earlier methods of deterministic models that relied on and required ever-increasing amounts of data, the new realm of non-deterministic or statistically-based models have been introduced. These rely on reducing available data by simulating a like duplication of the original data and when that no longer correlates; the model stops and uses the set of data that has been determined reasonable or statistically representative. The models introduced are those sponsored all or in part by the U.S. Air Force. The site used to test this software was Vance AFB since this site was selected for a voluntary incentive application of MAROS and was on the list for GTS but not funded. The analysis of MAROS proved to select sites for reduced testing or removal. At the same time, regulators were deleting and diminishing testing on their own forum. Some of the results overlapped. An important yet assumed premise is that the knowledge and fact that optimization studies were being performed helped in some part to motivate and result in decisions other than those suggested by the subject software, were implemented nonetheless and resulted in similar and justified cost savings to the taxpayers.

ACKNOWLEDGEMENTS

A doctoral degree was in my visions of accomplishments since first attending college. It demonstrated the height of effort and dedication to the institution of higher learning, which I have only come to know since beginning this endeavor. The road to completion included many people whom I can only begin to mention.

I am deeply grateful to my advisor, Dr. Avdesh Tyagi, who skillfully and knowingly led and directed me through the arduous process. His coaching was succinct and effective. Man times I felt hindered in direction and a simple discussion with him sparked and renewed my vision.

The contributions, reviews, comments, and discussion with the committee members, Dr. John Veenstra, Dr. Greg Wilber, and Dr. Jim Puckette, generated great significance in providing the same type of motivation and drive to complete the program.

It was Dr. William McTernan who provided groundwater modeling course that provided the spur that launched the final research topic.

Performing MAROS analyses for EA Engineering Company presented the opportunity for a real-time application that provided some positive side discussions that may in some way have lead to input to the project that was beneficial to al of us.

The support provided by Mr. Phil Hunter of AFCEE and Dr. Kirk Cameron of GTS were unusually helpful and appreciated.

My wife tolerated and supported this venture through the long times of study, research, and travel to classes and meetings up to 120 miles away. This was in addition to my full-time engineering consulting work. It is my hope that with success in this program, I will be able to return the benefit to her and many others in some way.

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CHAPTER 1

INTRODUCTION

Environmental pollution or subsurface contamination from petroleum products and solvents has been a major concern for the last three decades. Of particular concern are those with a carcinogenic nature or non-aqueous phase liquid chemical constituents. One group or variation of chemicals are categorized as Dense Non-aqueous Phase Liquids (DNAPLS) that are water immiscible organic liquids heavier than water and which tend to migrate to and dissolve to some degree in the groundwater aquifer. The most prevalent types are the halogenated organic solvents or which Trichoroethene, commonly known as TCE, is the subject contaminant of this paper (Kavanaugh, 1994). Initial efforts in evaluating plume degradation were based on tracking plume movement and change in contamination levels. Until the beginning of 2000, most applications for determining the fate of subsurface soil contamination have been based primarily on transport modeling. The movement was primarily based on hydraulic considerations, a physiochemical database, and design protocol to specify site-specific and generic soil cleanup guidelines. In other words, movement of a plume was typically directly related to groundwater movement (Lesage, 1992).

Many Air Force Installation Restoration Program (IRP) projects require compliance monitoring of groundwater remediation activities where groundwater contamination is still present. This long-term monitoring (LTM) involves active remediation systems as well as post closure sites. Such monitoring is dictated by the RCRA, CERCLA, and UST programs typically involving decades of extensive sampling. In addition, changes in the site conditions due to varying groundwater flow or attainment of compliance can lead to less effective or inefficient monitoring networks (AFCEE, 2006a). Computer tools for analyzing contaminated chemical plumes with regard to chemicals that combine with groundwater were initially those that modeled deterministically. Essentially the models began as stochastic methods in the 1980's and then transitioned to non-deterministic since the 1990's. Initially, groundwater modeling was performed with well test data to determine movement and characteristics of a generalized plume in meeting compliance requirements. Initially, this flow velocity or transport-time modeling is used to generate order-of-magnitude estimates of groundwater flow velocity. The groundwater gradient, media hydraulic conductivity, and media porosity are needed to obtain a flow velocity estimate. The velocity of the contaminated water changes due to physical absorption on the soil and other factors, such as chemical transformation and biological degradation causing the plume to move slower than the groundwater around it. "Plumes of different contaminants such as heavier-than water organic hydrocarbons, lighter-than water toluene, or lead, and toluene that exist at the same site may also move at different velocities, or a plume may separate over time into different constituents, as some contaminant compounds may absorb or degrade faster than others may." Furthermore, sites that demonstrate heterogeneous statrigraphy varying vertically and/or horizontally are not good candidates for the previous deterministic groundwater models. (Radian, 2000).

Past methods of remediation have included many various active methods such as pump-and-treat that have been balanced against the least active management tool of natural attenuation to arrive at a hybrid system of monitored natural attenuation (MNA) and an its enhancement termed long term monitoring with optimization (LTMO) (IT Corp, 1999 & 2000a). In a quest to reduce the high cost of continued monitoring and testing, new computerized methods have been developed to evaluate the effect of remediation and attenuation of plumes (AFCEE, 2006b: Ling, et al., 2004). As a result of those initiatives, Monitored Natural Attenuation (MNA) and risk-based goals were borne out of necessity in an attempt to utilize time in achieving required remediation levels without the cost of mechanical remediation methods (Aziz, 2003).

The major technique used for spatial analysis historically has been geostatistical methods using variograms and kriging. Other methods include exotic approaches such as variance reduction and a Baysian approach. Temporal sampling has utilized strategies based on autocorrelation and variogram analysis. The major hindrance to these approaches is mathematical complexity requiring considerable expertise and analytical time. A short record of data of only 4 to 5 years creates difficulty for autocorrelation and temporal variogram methods. Another aspect is that of shifting the goal from pristine restoration to that of determining the sufficiency of an LTM plan or Long-Term Monitoring Optimization Plan (LTMO) in meeting risk-based goals (Ling, 2004).

Radian points out that of several statistical tools available, the appropriate ones are those utilizing geostatistics and temporal trend analyses to optimize the number of monitoring wells necessary to allow defining a plume boundary and contaminant concentration characteristics to ultimately achieve program goals. Geostatistical methods are used to evaluate spatial orientation and correlation across a plume area to evaluate locations that have unacceptably high concentrations. On the other hand, linear regression analyses determine if the model is a good fit as well as demonstrating concentration correlation with time. (Radian, 2000).

Statistical tools that identify contaminant trends in a well or group of wells are Mann-Kendall or regression analysis. (Radian, 2000) Visual examination of plots of the results of these analyses for a well or group of wells of time or as a function of distance offers a highly sensitive means of detecting trends or potential trends in the data. From this, statistical tests are used to calculate the possibility that significant trends may be due to random variability. The Mann-Kendall test evaluates the trend of concentrations over time and does not require data at equally spaced times. It has few statistical assumptions such as normality and includes non-detects which are levels below reportable limits. However, since its function is to determine trends and as graphical data presentations, it does not account for actual concentrations. It also requires more than four samples to perform a trend analysis. (Radian, 2000).

Several new modeling and contamination analysis software programs became available that provided decision –support software to optimize LTM plans. Existing data are analyzed for spatial sampling, temporal analysis, data sufficiency, and evaluation strategy. One such model was the Monitoring and Remediation Optimization System (MAROS) program developed by the U.S. Air Force Center of Environmental Excellence (AFCEE – MAROS Users Guide) and available to the public.).

Specifically, this paper presents an application of MAROS to the optimization of the Long-Term Monitoring (LTM) Program at Vance AFB. That program had directed continued semiannual sampling for 15 years for two contaminated shallow aquifer plumes with 34 and 42 sampling wells. Test well data from previous years and new data would be evaluated to demonstrate the degree of attainment of risk-based goals and natural attenuation in meeting compliance goals (EA Project Management Plan, 2005). The contaminant-of-concern being evaluated is TCE which is toxic and can cause cancer making it a concern for living beings (IT, 2000a).

1.1 BACKGROUND

Much remediation study, data gathering, and remediation method application and monitoring have been performed over the past 20 years at the Vance location. For major areas of contamination that still exist, forms of monitored natural attenuation (MNA) have been implemented in varying degrees depending upon the degree of contamination. Site characterization and remediation activities have largely been completed at many military installations but more sites still require attention in the future such as the four remaining sites at Vance AFB. However, active contaminant monitoring systems have become increasingly costly to operate. This has led to the necessity of developing methods to optimize the system to both reduce costs and achieve the necessary contaminant levels required by law. It has become necessary that sites be evaluated with new methods to predict the need and level of continued monitoring.

Computer models are now available that are based on geostatistical methods that include spatial and temporal comparisons of data. These models are designed to determine if the number of wells and frequency of testing may be reduced, based on a tolerable uncertainty. Such software includes various and differing methods of analysis which are tailored to address the varied site conditions in order to appropriately predict the fate and monitoring efficiencies of a particular contaminated site (Lesage, 1992). In the past few years, new models have been developed for general application to such contaminated sites for the purpose of defining contaminant plume stability and expected future contaminant profiles. It was the intent of this paper and author's research to apply MAROS and GTS models to the identified contaminant plumes and provide recommendations for the approved long term monitoring plan for a contamination site.

Among the many computer software models being developed for managing LTMO, the U. S. Air Force has specifically adopted and supported the development of three models (IT Corp, 1999). One such model, MAROS (Monitoring and Remediation Optimization Software), is a tool that is particularly useful in obtaining a temporal evaluation. This shareware program is generally being used to analyze contaminant plumes at various Air Force installations. The model has some restrictive requirements for data and has required the additional requirement of creating data necessary for interpolation by other software programs that exercise kriging. .

The subject of this research includes evaluation of a particular site in northern Oklahoma that being Vance AFB in Enid (Figure 1.1). The presence of contamination sites

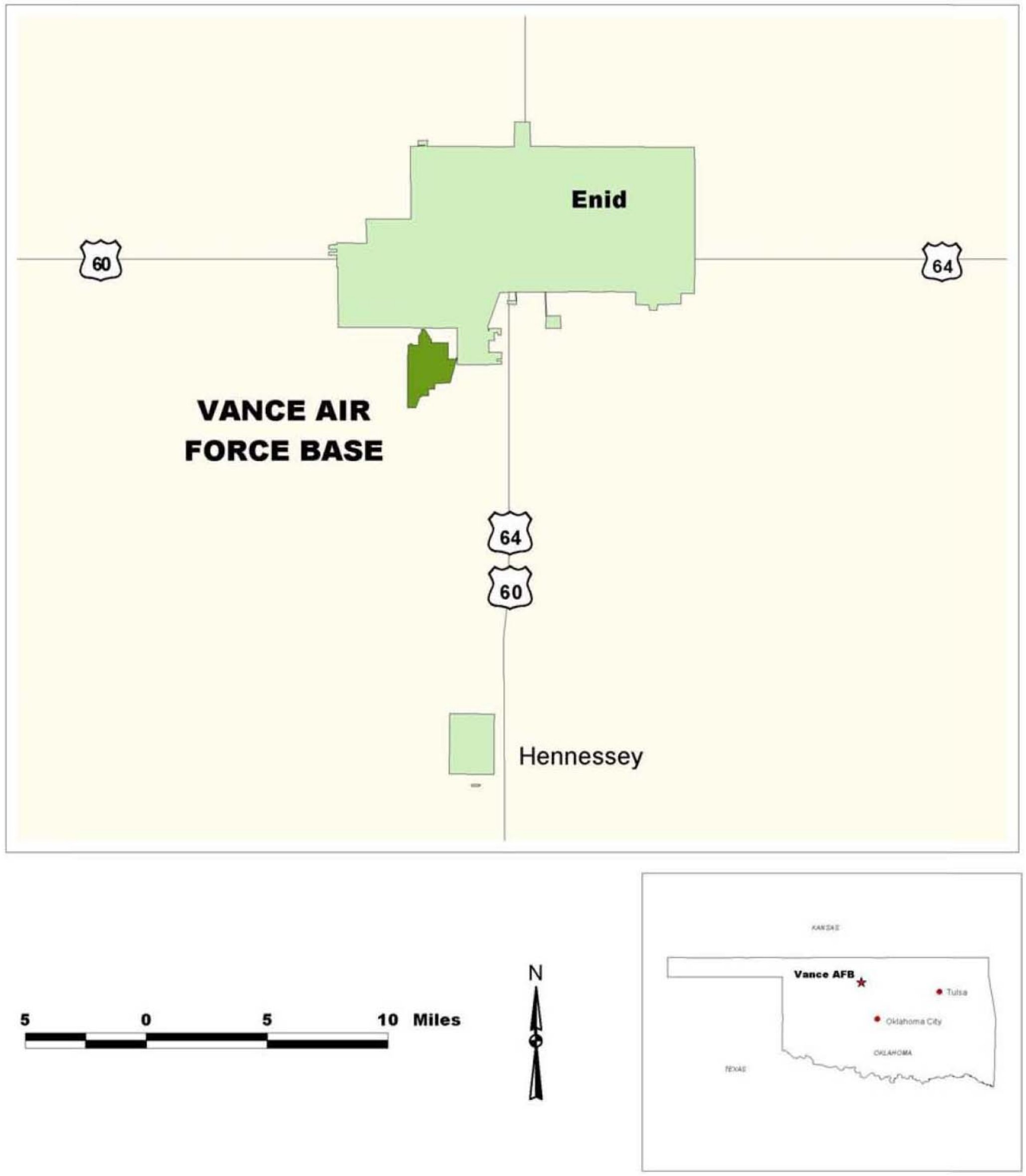

Figure 1.1. General Area Map – Vance AFB

resulting from disposal of chemical constituents used in industrial applications began receiving great emphasis in the last 40 years and has been one of the prime pursuits of the Environmental Protection Agency in clean up efforts. This base has been exercising remediation programs since approximately 1992 and is now utilizing a groundwater extraction system with a 25-year monitoring program. Plume and contamination areas which were originally identified as separate sites and areas are now concentrated into two collective sites termed CMI and IZ to be discussed later. The two specific plume areas are shown in Figure 1.2. The primary concern at this time involves a shallow transmissive zone with the primary contaminants-of-concern (COC) being TCE, its daughter products and BTEX.

However, the constituent of potential concern is essentially TCE (IT Corp, 2000). Semiannual monitoring is being conducted with the initiative to evaluate the possibility of optimizing the monitoring well program. This has specifically been offered as a MAROS application by the current remediation contractor on Vance AFB (EA, 2005).

Originally, Vance AFB occupied an area of about 110 acres in the time period of 1941 (and now over 2,000 acres) when construction began for a military airfield. Aircraft operations involved flying, fueling, maintenance, and repair of all components of reciprocating (later jet) engines. Waste of chemical cleaning compounds and other now known contaminants in and around the maintenance facilities was a normal practice. Interest stemming from the 1980's resulted in the identification of ultimately nine IRP

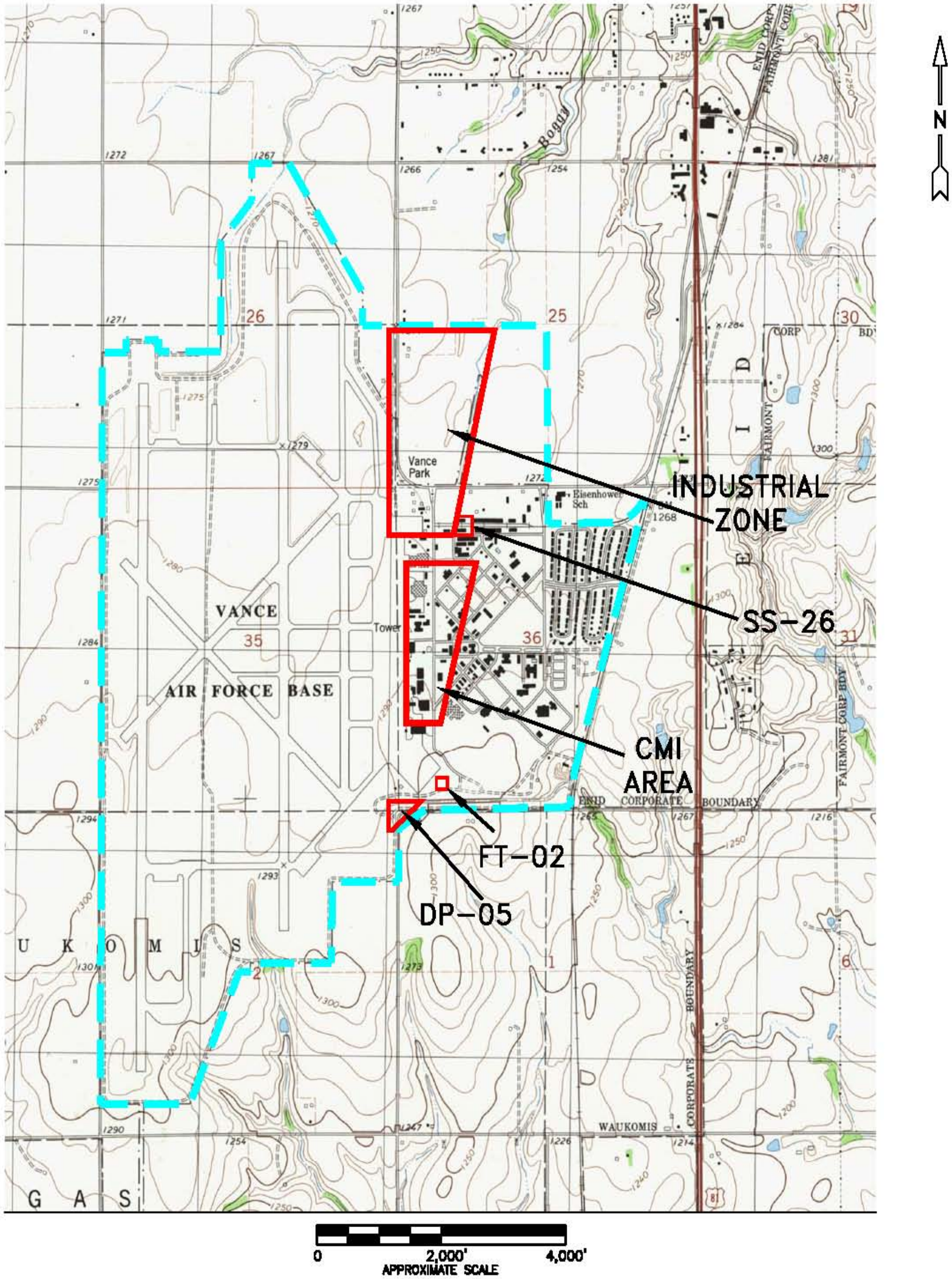

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Figure 1.2. Compliance Monitoring Sites – Vance Air Force Base

(Installation Restoration Program) sites that would eventually be involved in some type of remediation. Five corrective measure alternatives were proposed that included no action, MNA, bioremediation, and combinations thereof finally settling on groundwater extraction with MNA. Techniques have also included cutoff walls, phytoremediation, and natural attenuation. At this time, the nine IRP sites have been identified as four contamination areas; the Industrial Zone (sites LF-03, SS-07, and ST-08, Corrective Measures Implementation (CMI sites ST-12, WP-23, SS-24, and SS-25), plus a small follow-on monitoring of FT-02 and DP-05 which are all but insignificant in degree of concern. Again, the appendix includes figures that depict these sites and plume characteristics (Campbell, 1998: EA Engineering, 2006: IT Corp, 2000a).

The major interest of this research involves the DNAPL constituents of TCE, PCE, and daughter products in the shallow vadose zone. Many other constituents have been identified but are mainly under control. These include VOC's that are being remediated through phytoremediation at site LF-03. Other areas are being remediated with barrier walls and pump-and-treat technology through a groundwater treatment facility. It is the focus of this research to evaluate the fate and plume characteristics of the two principal areas of concern; the CMI for Corrective Measures Implementation and IZ for the Industrial Zone.

The resource data for studying and evaluating the monitoring wells has been performed by many separate engineering companies since the late 1980's. Unfortunately, the studies that were performed were not always in the same areas and in the same format. For instance, early investigation involved sites near the center of the flight line facilities which expanded to other various sites on the base. This evolved into several separate plume areas that did not overlay previous work which added to the difficulty in obtaining frequent and consistent data for major areas. As areas of contamination have been discovered over the years, they have been identified and numbered as specific locations that also correlated to specific plumes. Some of these sites were further combined into larger generalized plumes. The result is that today, there are two basic plumes labeled as "CMI" and "Industrial Zone".

The main intent of this research topic was to utilize existing computer modeling software and methods in evaluating the fate of DNAPL contaminant removal and optimization of the sampling system at a select industrial site (Vance AFB, Oklahoma). The principle models are MAROS and GTS which were developed by the U. S. Air Force Center of Environmental Excellence in San Antonio, Texas.

1.2 OBJECTIVES

The nature of industrial sites that have experienced some degree of chemical spillage leads to the realization the those sites are generally suspect and often found to contaminate the soil regime below. Some chemicals such as trichloroethene (TCE) are heavier than water and will attach to the soil and will also continue to partially dissolve in the water table below. The endeavor of this paper is to demonstrate the evaluation of a specific but heterogeneous aquifer scenario with regard to the degradation of a specific DNAPL or TCE and provide insight on the application at a similar site to that of Vance AFB.

1. Demonstrate variability in field water test well data and stratigraphic data and its effects on the results of the LTMO software programs and the impact on decision-making regarding achievement of regulatory goals of remediation.

2. Perform an analysis of the Vance sites with inferences as to organizing and positioning well data points with respect to the peculiarities of the site, i.e., the effect that an extraction well has on normally anticipated plume movement.

3. Show how the various modeling methods and results can be used to suggest and recommend degrees of achieved remediation as well as providing additional test sites.

4. Provide insight as to the application of LTMO methods to benefits of the evaluations and use of MAROS to provide recommendations mitigating sites similar to the LTMO plan as Vance AFB as it relates to TCE.

1.3 STATEMENT OF THE PROBLEM

The effect of measuring and evaluating remediation of DNAPL contaminants developed into an upward spiraling demand for resources that far exceeded available funds. The need to reduce the contaminant levels to a tolerable and acceptable regulatory limit remained but needed to be addressed through a method that balanced a reasonable amount of aquifer water test results with an acceptable level of risk to meet health and safety concerns. Early computer models were deterministic and required greater and greater amounts of data. It was in the advent of the 1990's that newer statistical and risk-based computer models were being developed in response to a governmental regulatory shift of emphasis toward achieving acceptable contaminant plume remediation with minimal active effort due to the introduction and promulgation of monitored natural attenuation where and when shown to be plausible.

Studies of aquifers contaminated with DNAPL constituents have historically required significant efforts and test data accumulation in terms of hydrologic movement, stratitographic data, consistency of data collection, evaluation of results with respect to regulatory standards, and suitable presentation of results. More data begets more data in the traditional determinate modeling methods of analyzing DNAPL degradation of contaminated aquifers. The newer method of analyzing degradation to achieve regulatory limits is faced with concerns over data consistency. It is also fraught with the issue of the adequacy provided by subjective evaluation of various statistical methods as they are weighed against the risk of declaring achievement in meeting regulatory goals.

New computer models have been developed to statistically evaluate either existing plume data or smaller amounts of data than earlier required. The basis of statistical analysis today is evaluation of a plumes characteristic degradation in separate terms of temporal and spatial modes and then to subjectively draw conclusions from the various alternate applications of statistics. This work will address the following problems:

1. Assimilation of data from various sources and irregularity in that data due to variability in water well testing due to regularity and availability of data.

2. Operation and application of recent computer statistical models as they apply to an individual military installation that involves customization for owners such as MAROS that was developed specifically by the U. S. Air Force for their needs.

3. Establishing a suitable representation of a contaminated plume requires general assumptions and modeling variations in order to arrive at a plume that best meets the intent of minimal data in meeting regulatory requirements.

4. In the case of TCE, a small portion of the original mass becomes dissolved in an aqueous phase in the aquifer and is used as the sole tool of predicting movement and degradation. This disregards the effect of post-remediation dissolution that may occur with contaminant attached to the soil. The preferred models do not account for this which increases the subjectivity of the results.

5. Not only should the cost of testing be reduced but the cost of evaluating the plumes should be minimized as well.

CHAPTER 2

LITERATURE REVIEW

The following is an actual case study or a well documented progression of actions to mitigate soil contamination at a military installation. Their program began in the 1980's and has evolved from the original deterministic approach and mechanical methods of remediation to that of statistical risk-assessment or a plan of Long Term Monitoring Optimization.

2.1 BACKGROUND OF VANCE AFB

One subject will be Vance AFB in Enid, Oklahoma that has generated almost 25 years of monitoring data and has been chosen to attempt to reduce the number and intensity of LTM. A brief history of the airfield and its awareness of contamination follow.

Construction of the airfield began in 1941 with operations beginning in the fall of that year. Aircraft operations involving flying, fueling, maintenance, and repair of all components of jet and propeller engines have been conducted continually since that time. During that period, some of the mentioned activities led to less than proper care of waste materials, primarily those of cleaning solvents, aircraft fuel waste, and various engine parts cleaning materials as well as paint wastes.

The paint-stripping site number 12 was constructed in 1967 and operated through 1988.

The area used to store paint stripping chemicals has since been removed and a collection sump was installed to remediate the spilled chemical by employing an extraction well pumping system in 1998. Although groundwater concentration of organic chemicals is still high, pumping yields are low, which is assumed to be due to the pump not being installed to the full depth of the shallow transmissive zone. It is assumed that the industrial waste pit that generated site 23 was removed around 1967. Previous investigations have taken place at these sites since 1988 and data from these studies was used in preparing feasibility studies, which examined alternatives for remediation. The Site 23 area was later identified as the Corrective Measures Implementation Plan (CMI) Area in 2002 and was comprised of Sites ST-12, WP-23, SS-24, and SS-25 (IT Corp., 2002a).

The north area of the original base was comprised of additional contaminated subsurface areas defined as Site 3, 5, 7 and 8. One was capped, another deemed not a hazard, another recently resolved with phytoremediation, leaving Site 7 to be remediated. In 1993, it was confirmed that shallow groundwater contamination extended into North Site 7. In 1997, an interceptor collector trench was constructed. Again, the extent of contaminant migration was discovered north beyond the base boundary. The result was the construction of additional 31 monitoring wells in 1997 and another interceptor wall in an area termed the Industrial Zone (IZ). See Figure 1.2 for the delineation of the CMI and IZ sites (IT Corp., 2000a & 2002a: EA, 2006).

Contaminated sites at Vance AFB in Enid, Oklahoma have generated almost 25 years of monitoring data and have been analyzed to attempt to reduce the number and intensity of

LTM. Early monitoring involved collecting large amounts of data that was based on transport modeling to indicate the spread of a contaminant plume due to hydrogeologic movement of groundwater. Typically, computer models such as MODFLO, BIOTRANS, and others predicated the travel of a plume and the degradation and change of characteristics of a contaminant. Several remediation techniques were used to collect and otherwise diminish the contaminant levels, including pump-and-treat and interceptor collector trenches. The models required immense amounts of data and costly monitoring. New computer modeling and analysis programs utilized statistical and risk-based goals in evaluating attainment of remediation levels with less data and cost. These included pseudo-and actual statistical platforms and provided a simpler method of analyzing available data and predict sampling required to achieve an acceptable level of remediation.

Several new modeling and contamination analysis software programs have become available that provided decision –support to optimize LTM plans. Existing data can be analyzed for spatial sampling, temporal analysis, data sufficiency, and evaluation strategy. One such model is MAROS sponsored by the U.S. Air Force and developed by others. While not purely statistical, this program utilizes Mann-Kendall statistics and a coefficient of variation. For optimization of monitoring wells, it uses the Delaunay triangulation method to analyze spatial importance of sampling locations and temporal analysis based on a modified CES Cost Effective Analysis method. The predominant contaminants of concern (COC) were a list of ten VOC’s with TCE being the most predominant in the shallow transmissive zone (EA, 2006).

The presence of contamination sites resulting from disposal of chemical constituents used in industrial applications began receiving great emphasis in the last 40 years. Vance Air Force Base (AFB) has been exercising remediation programs since approximately 1992 and is now utilizing a groundwater extraction system with a 25-year monitoring program. Plume and contamination areas which were originally identified as separate sites are now concentrated into two collective sites. The primary concern at this time involves a shallow transmissive zone with the primary contaminants-of-concern (COC) TCE and its daughter products and (IT Corp, Apr 2000). Semiannual monitoring is currently being conducted with the initiative to evaluate possibilities of optimizing or maximizing the efforts of the monitoring well program which could result in eliminating monitoring wells or reducing the frequency of testing (EA, 2006).

The MAROS software sponsored by the US Air Force was recommended for application in the current Vance AFB LTMO program in order to possibly reduce the number of monitoring wells on Vance as well as to reduce the number of monitoring events to achieve remediation. Currently it is comprised of four plume areas of which two labeled CMI and IZ (Industrial Zone) contain primarily TCE contamination. It is particularly challenging because the vast monitoring data accumulated for Vance AFB is not always consistent due to new sites that emerged and which were absorbed into larger collective plumes. MAROS will be used to evaluate data sufficiency, plume trend, size, shape, and movement to result in reducing and optimizing the LTM program over the next few years (EA, 2006).

2.2 EARLY MODELING OF PLUME ACTIVITY

Environmental pollution or subsurface contamination from petroleum products and solvents has been a major concern for the last three decades. Of particular concern due to their carcinogenic nature, are DNAPL and LNAPL constituents. Initial efforts in evaluating plume degradation were based on tracking plume movement and change in contamination levels. Until fairly recently, most applications for determining the fate of subsurface soil contamination have been based primarily on transport modeling. The movement was primarily based on hydraulic considerations, a physiochemical database, and design protocol to specify site-specific and generic soil cleanup guidelines (Lesage, 1992).

Determination of the movement of contaminants in the groundwater at Vance AFB utilized many computer modeling methods and software products. One of these was MODFLOW which is a modular three-dimensional groundwater flow model that assumes flow through a porous media. This software was coupled with MT3D and RT3D the first being a solute transport model for simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems, whereas RT3D shows this in 3 dimensions. Also applied was BIOTRANS which has been used for calibration to dissolved-phase plumes for modeled chemicals at a site. Initial field work began in 1992 with soil borings to a 30 foot depth. Chemical analyses were performed for VOC's, and RCRA metals. It was also discovered that the site was composed of discontinuous layers of clay strata which resulted in testing for contamination levels at a shallow, intermediate, and deep soil layers at Vance AFB. It should be mentioned that this software was used to evaluate many original contaminants of concern (COC) at Vance all of which have almost reached acceptable remediation levels excepting for the dissolved portion of TCE in two major plumes in the shallow soil zone (Radian, 1993).

A very small site number DP-05 (or LF-05 on the south edge of the base directly east of the inside runway taxiway) has experienced high levels of TCE. This area has a very short groundwater flow field that was not possible to evaluate with fate and transport modeling software so is being managed as a natural venting process of natural attenuation.

In the year 2000, an “Alternate Concentration Limits Report for Nine IRP Sites” was published to identify which constituents of potential concern (COPC) needed to be further evaluated and targeted TCE and bis (2-ethylhexl) phthalate as the major COPC’s. As a result of computer modeling of the site-wide flow model (MODFLOW) along with solute transport codes MT3D and RT3D, alternate concentration limits (ACL) were determined for 14 identified COPC’s that would migrate across a compliance boundary in 30 years. This identified the occurrence of biodegradation of organic constituents at Vance such as TCE to cis-1, 2-DCE to VC and finally ethane. The presence of TCE was essentially due to the initial waste products of TCE that were historically allowed to enter the soil at Vance (IT Corp, 2000b).

Since 2002, about 12 VOC’s demonstrating significant contaminant levels had been detected in the shallow zone while no such significant issues were reported for the chemicals that had entered the deeper soil zones. Today, the major concern is TCE in the shallow transmissive zone although as many as ten VOC's were detected that exceeded MCL's in that zone in the CMI and Industrial Zones in 2005 (Groundwater Services, 2004: IT Corp, Jan 2000). Plume maps have been published for the major areas CMI and Industrial Zone and significant monitoring well data have been published that can be utilized to develop an optimization plan (EA, 2006: IT Corp, 2002b).

2.3 ORIGIN OF LTMO - OPTIMIZATION

Methods of remediation have included many various active methods such as pump-and-treat that have been balanced against the least active management tool of natural attenuation to arrive at a hybrid system of monitored natural attenuation (MNA) and long term monitoring with optimization (LTMO) (IT Corp, 1999: IT Corp, 2000a).

Cronce (2003) summarized the basics of Remedial Process Optimization. This was spurred by several factors affecting cost and attainment of regulatory contaminant levels, increasingly affected by numerous remedial action systems already in place, long periods of time between record-of-decision and initiation of LTMO programs, and rapid technology development that needed to be implemented to update current remediation systems. Again, greater emphasis was needed to evaluate on capital costs and long-term cost of operations and monitoring. Obstacles to continuation of current remediation systems included reduced program funding, remediation designs that were inadequate for the future, inconsistencies in reliability and safety compliance, sites imposing the probability of perpetual remediation and monitoring costs, and constantly changing site conditions. The goals of LTMO included lowering costs, reducing risk, simplification, and accelerating closure and compliance by optimizing. In order to achieve these goals would require reevaluating factors that used to establish current exit strategy such as reviewing current regulatory and environmental conditions, updating risk assessment, seeking ways to increase efficiency, developing contingency options, and accelerating the closure period. This idea termed Remedial Action Optimization suggested reevaluation of existing plans to include reviewing record-of-decision (ROD) strategy, exercising Risk-Based Corrective Action plans, predicting effects of changes by combining CAD files and the plume model to predict system effectiveness, implementing active and passive remediation tools, developing ideas for reducing site closure, and offering alternate remedies such as reaction walls or natural attenuation for groundwater (Cronce, 2003).

From this evolved Long Term Monitoring Optimization (LTMO). Its components adopted many of the aspects from RPO. Objectives included minimizing costs and maximizing effectiveness and quality, and eliminating unnecessary data. Cost reduction utilized phased closure, performing risk/exposure and indicator analyses, and revising compliance objectives. Innovative steps included automated monitoring, on-site analyses, waste minimization with on-site treatment, better well construction, and non-intrusive sampling. The procedure to optimize long-term monitoring involved a pragmatic justification of sampling location and frequency, optimal field procedures and analytical protocol, and streamlining data management (Cronce, 2003).

Cameron (2004) stated that the buzz word “optimal” with regards to environmental monitoring is more about the price tag that has evolved. Early efforts of optimization concentrated on the best design layout of wells and locations to capture additional data from previously unsampled areas of a plume and to minimize classification error. Early geostatistical models were aimed at attaining the most probable pathways of the plume to place wells or picking new sampling points that would reduce kriging variations (by providing more data to satisfy the based of regularity of data for kriging). Basically, those efforts attempted to add information to the system to better identify a plume to better reach a target remedial response. He pointed out that today's shift in definition is to seek redundancy in existing monitoring wells with siting of new monitoring wells a second priority. It is significant that the 'main focus now is to subtract information from the system, that which adds little but at a great cost.' This new approach opposes the classic view of optimization and offers a "one-way" biased attitude involving trade-offs between loss of information and the expense for obtaining data.

Cameron (2004) pointed out that a key assumption spawned from LTM networks is twofold, either a groundwater plume is so effectively characterized that additional wells are not needed, or that so many different investigations and sampling efforts exist that it would be a politically incorrect to do more than remove data (utilize existing data to the best advantage). The data obtained for analysis of plumes is both spatial and temporal and creates the test data alluded to above. Optimization of monitoring plans has pursued both temporal and spatial regimes but typically do not optimize both at the same time (Cameron, 2004).

It was suggested by Cameron that statistical redundancy is supported by the idea that removal of some data results in a reduced data set that can be used to reconstruct characteristics of the original full data set. Further, a trend can always be found to intersect the known or reduced set in this case, and does not actually show other points were redundant. In the spatial sense, kriging can also reproduce the known or reduced set. There is no way to qualify how well other unsampled areas of a plume are represented by the reduced data. A better method is suggested that would test the accuracy of how well the reduced data would re-estimate the data that was eliminated. This is considered cross-validation in which true or already removed measurements are considered known in order to establish an explicit computation of error. Usually removed points are proximate to clustered sets resulting from attempts to characterize the plume and are fairly similar to the points retained in the reduced data set. Re-estimating unsampled areas of the site then pose more difficulty thus necessitating a more general approach for tackling redundancy (Cameron, 2004).

Determination of redundancy requires that a reduced-set accurately characterizes the full-data set. Further defining redundancy of temporal data eliminates some sampling events defined as “thinning out” by the use of specific criteria to characterize redundancy in individual wells. This is done by reconstructing the direction or slope of the trend in a linear trend in response to actual observation or in response to a local regulatory limit. Secondly, multiple well trends have been used to indicate the relative position of the plume in terms of the gradient and stability of groundwater mass. Regarding modeling software, the GTS (Geostatistical Temporal-Spatial) algorithm (discussed later) uses a full data set to estimate the trend (linear or nonlinear; seasonal, complex, or simple) and a confidence band around the length of the sampling period. The reduced data set reconstructs the original trend and non-redundancy occurs when the original trend cannot be duplicated within the baseline confidence limits. The spatially reduced data-set refers to eliminated well locations. This could simply involve elimination of wells from obvious clusters by maximizing space between wells. The current version of GTS emphasizes the ability of the reduced-data set to gauge plume extent or reconstruct surface maps. In the quest for optimality, it must be understood that while all data has significance, removal of data creates information loss. Optimality is the fine balance of loss of information versus the cost savings of not collecting and processing additional data, i.e. the trade-off of a minor loss of data versus cost savings (Cameron, 2004).

Costs of optimization are comprised of several categories. Initially it is understood that costs are not a linear function of the LTM network. Sites differ logistically as well as in the analytical costs due to varying sampling due to regulatory needs. Secondly, cost savings due to temporal reasons are affected by more complex variables when compared to simply eliminating wells. Reasons range from changed in contractors and regulatory plans, differing schedules impacted by the proximity of wells, and modifying the plan due deletion or addition of wells or modification from eliminating wells (Cameron, 2004).

CHAPTER 3

SOFTWARE

3.1 THREE MODELS OF CHOICE

Hunter (2005) provided an overview of LTMO that identified three predominantly accepted methods used by the U. S. Air Force. Apparently, LTMO methods demonstrated redundancy in well networks and recommended up to 40% reduction in testing. Tolerable uncertainty is accepted and focuses on essential data while improving and simplifying LTM programs. LTMO tools identify essential sampling locations, determine optimal sampling frequency, assess importance of individual wells but offer no purely objective result, but several related solutions. Requirements are relatively simple to operate these programs: electronic data, a conceptual site model, data sufficiency with sample size and number of events, a description of the current monitoring program, well construction data, and cleanup goals and regulatory limits (Hunter, 2005).

The U. S. Air Force utilizes three LTMO methods: GTS (Geostatistical Temporal-Spatial), MAROS, and Parsons 3-Tiered Approach. The AFCEE optimization tools of choice are GTS and MAROS. GTS provides an algorithm along with a software package. Its geostatistical and trend optimization methods are semi-objective by incorporating a variogram to analyze spatial correlation, kriging for spatial interpolation and regression, and a Locally Weighted Quadratic Regression (LWQR). GTS Temporal analysis optimizes sampling frequencies through individual wells analysis or "iterative thinning." Well groups and broad areas are analyzed through use of a temporal variogram. This method randomly weeds out data points and re-estimates a trend. It requires at least eight sampling events per well and the LWQR fits non-linear trends associated with seasonal patterns or complex trends (Cameron, 2004).

Optimization of data using a reduced data-set relies highly on the quality of the baseline. It requires both full data-measurement representing entire site conditions and secondly, the estimating data manipulation method maintains fidelity with the basic underlying statistical patterns in the baseline data. Historically, spatial optimization strategies have employed "kriging" and/or fate-and-transport modeling. Kriging creates a distance-weighted mapping system. Disadvantages include the fact that standard kriging requires one and only one data point per location. Inconsistent sampling schedules do not provide this. A wider time frame to include more wells creates multiple points at the same location. Averaging reduces variability of the data-set and negates the premise of identically distributed points. Another problem of point kriging is that of being an "interpolator" that basically assumes all observed measurements are correct and ignores error normally known to occur in reported values. Apparently, the "nugget" does not resolve this. Block kriging is used as workaround to average the individual kriged point estimates to create more smoothing. A second approach has been the use of fate-and-transport or geophysical modeling. It uses information about a hydrogeological model to include groundwater conductivity and transmissivity for example, to initially derive a geophysical finite element or difference model of an aquifer and create snapshots of the spatial contamination. However, it is not well suited to small sites with limited geophysical data. It also requires much up-front modeling and expertise but often predictions do not match empirical data. Cameron states that this model can be trained by fusing the model with empirical data (Cameron, 2004).

Plume characterization requires generating a grid or contaminant concentrations in three dimensions. Commonly used interpolation schemes included kriging, inverse distance weighting (IDW), and natural neighbor interpolation techniques. Accuracy of each method was determined with cross-validation by removing one sample at a time and interpolating to the location of the missing sample. An advantage of kriging is its ability to detect anisotropy in directional data and it gives more weight to samples in a vertical plane. Figure 3.1 demonstrates two curves that depict two directions or extremes of two isotropic conditions. It also deals with redundant information in clustered data.

The IDW method is simple and represents a weighted averaging whose near samples have a greater influence than distant samples. Natural neighbor interpolation is the same as IDW but bases weighting on distances and topological relationships and is more accurate when applied to clustered data. Results for all three methods indicate that kriging appears to be most accurate of the three.

It will be further discussed that kriging has been displaced by an alternative smoothing statistical method using a quadratic regression technique (Jones, 2003).

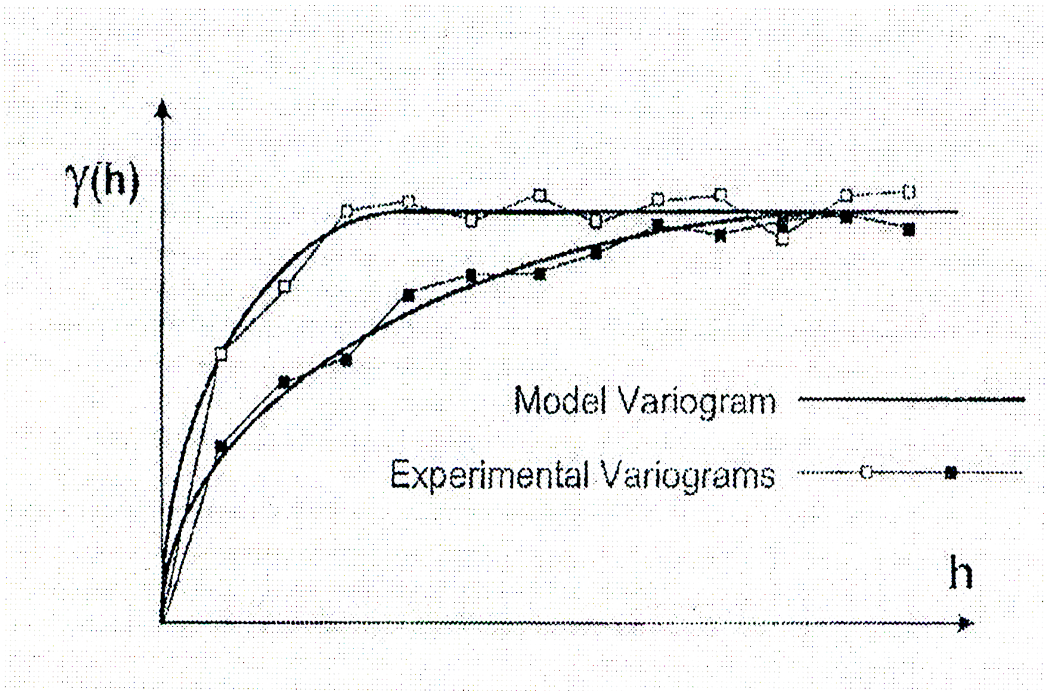


Figure 3.1. Modeling Anisotropy with Kriging (Jones, 2003)

3.2 GTS SOFTWARE

Of many methods, Cameron and Hunter offered a software algorithm known as the Geostatistical Temporal/Spatial (GTS) Optimization Algorithm. The initial startup requires access to existing data available in an electronic database, ERPIMS (Environmental Resource Program Information Management System), and GIS format. Basic parameters include hydrostratigraphy, locations of receptors, and the direction and rate of plume movement which are normally obtained from an effective groundwater monitoring program.

The GTS software package offers a similar approach to other models in that it first performs a qualitative analysis of the characterized site in the Data Exploration block along with a COC Analysis and Groundwater Horizon Analysis. It further pursues separate Temporal and Spatial Optimization. A copy of the overall GTS algorithm is provided in Figure 3.2. Data exploration and retrieval is similar to MAROS in that it is available from ERPIMS. There are more fields of data since depth of wells is required. This data must be imported as ASCII format and other import/export activities are dependent upon temporary data files and third party software applications (AFCEE, 2005).

GTS produces a concentration distribution map using color-coded circles of 10% increments of measurement values and mapped on the site. It also produces well time series plots of each well to allow view of apparent trends.

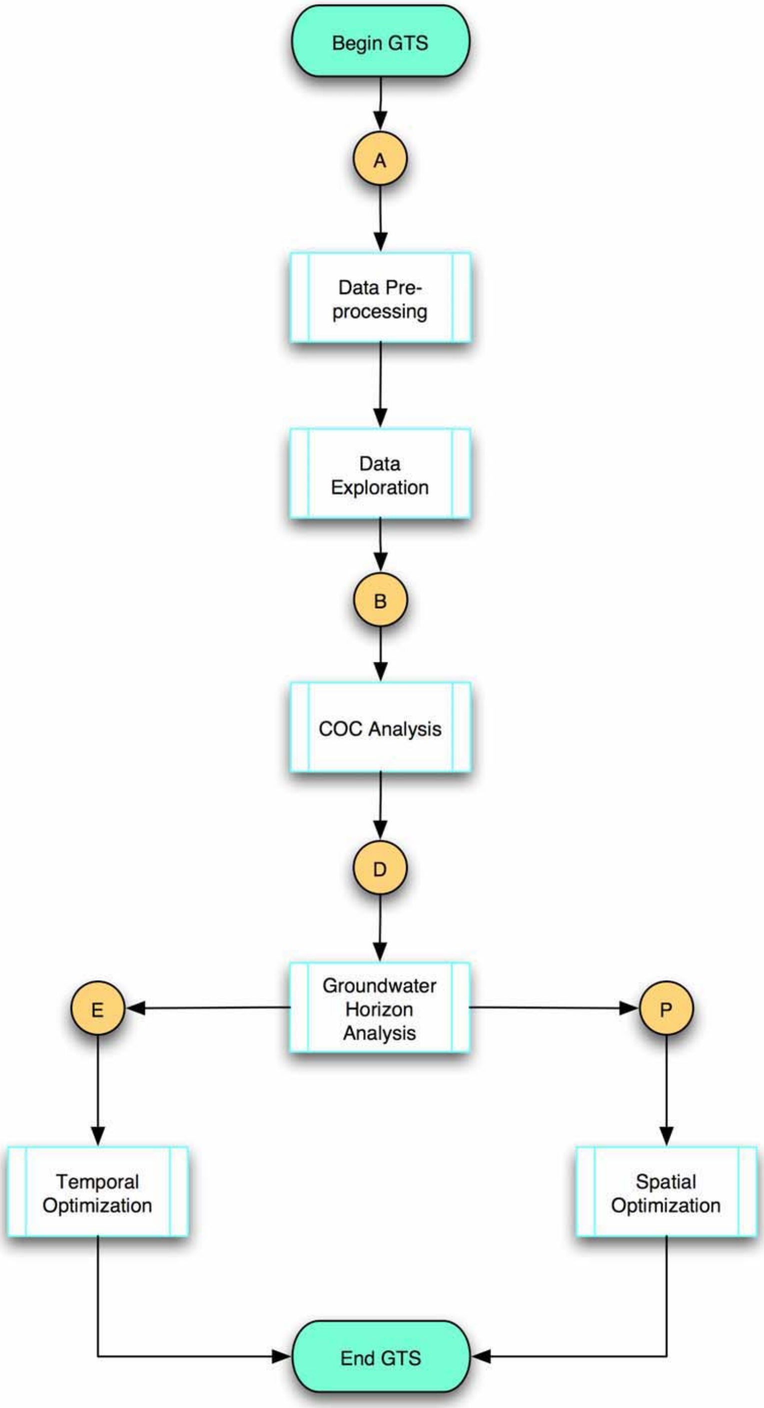


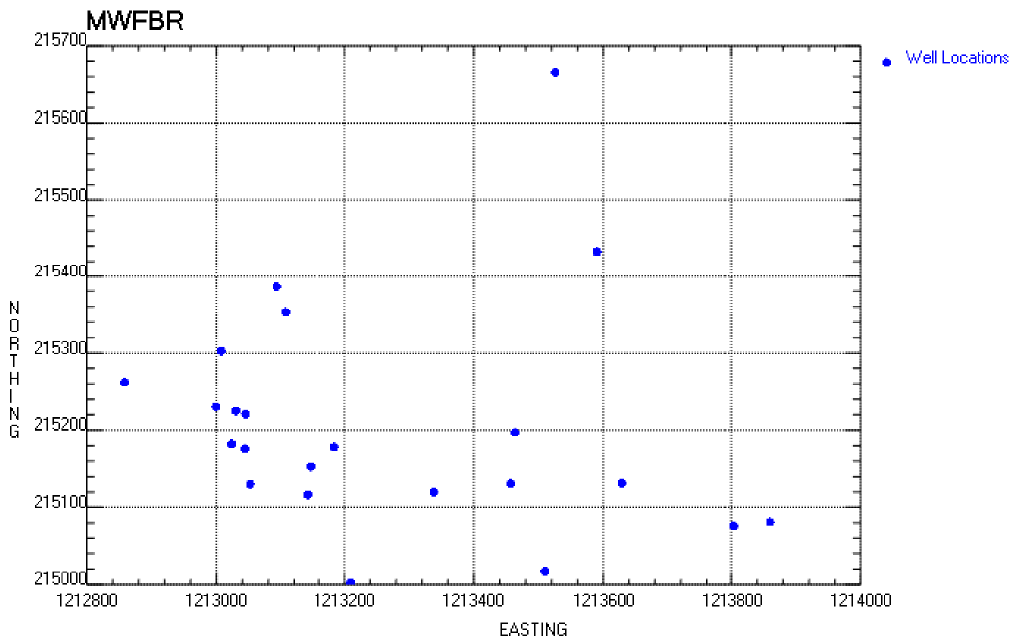
Figure 3.2. GTS Basic Algorithm (AFCEE, 2005)

The Ground Water Analysis tool provides well locations by horizon (depth of plume) and posts plots on a map per horizon (Figure 3.3). Temporal Optimization is generated as two components the first being a temporal diagram for a group of wells (Figure 3.4). It is comprised of nested pairs of concentration measurements for each well and estimated with locally weighted quadratic regression (LWQR). The variogram graphs these pairs against the lag time between sampling events (AFCEE, 2005).

Past temporal optimization tools or strategies have utilized linear trends or slopes in time series data. A confidence interval was estimated around the full-data slope and points were removed until the slope was outside the confidence interval. This did not work for nonlinear seasonal type trend data. This limited the use of a new tool called Iterative Thinning which was modified in a later version of GTS that incorporated LWQR to estimate the trend and the slope.

The module in GTS used to optimize the temporal interval is termed “Iterative Thinning”. It attempts to recreate the original trend with a reduced data-set after randomly “dropping” sampling events. An average interval between remaining events is iterated to arrive at a grand average interval which is compared to the weighted full data-set interval to generate the per cent reduction of sampling frequency (Cameron, 2004).

A confidence band can be estimated around the entire trend for a sampling period and for a full-data set. A fraction of data points are randomly removed and the trend re-estimated with LQWR with an identical bandwidth parameter.



Note: Northing and easting indicates north and east compass directions and also y and x coordinates respectively.

Figure 3.3. Post Plots by Horizon (AFCEE, 2005)

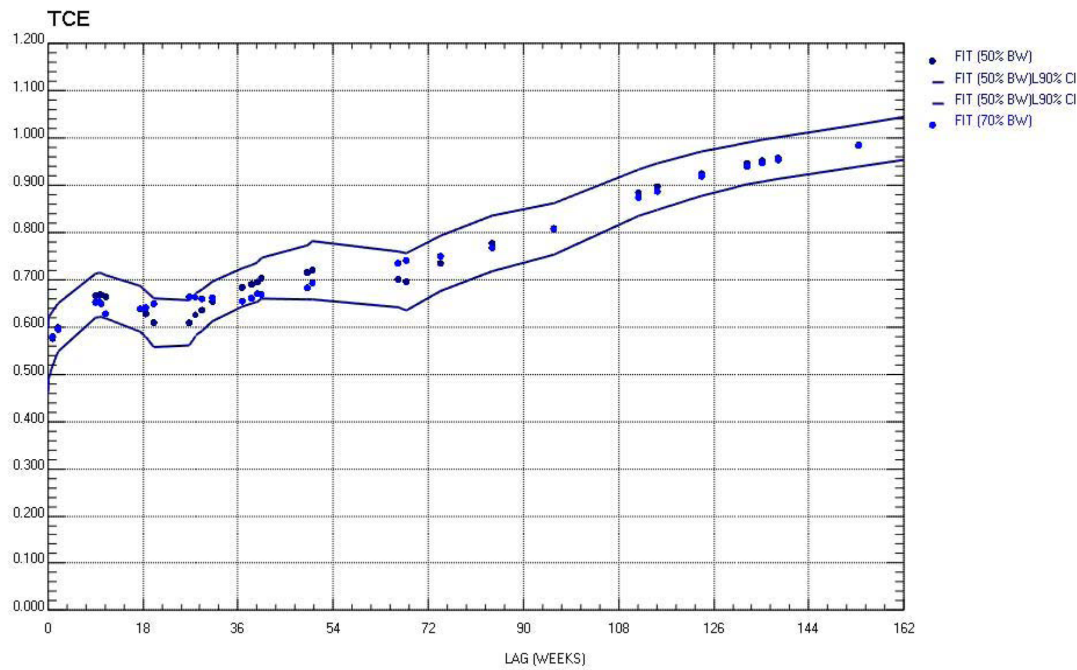


Figure 3.4. Temporal Variogram (AFCEE, 2005)

The entire trend is a baseline so a numerical cutoff of 25-30% is used to determine how many points are outside the baseline limits. Figure 3.5 shows the results of the process at which the maximal number of removable data points has been attained thus determining an optimal sampling interval for each well.

Iterative thinning determines the average sampling frequency and interval for a given well and constituent, fits a trend with statistical confidence bounds around this trend, and proceeds to iteratively and randomly remove fractions of the original data and then reestimate the trend. Concentrations outliers are screened to allow only significant outliers remain as shown in Figure 3.6. A parameter bandwidth must be selected using the Bandwidth Alternatives feature to allow selecting the necessary bandwidth between 40 and 80% as demonstrated in Figure 3.7 (AFCEE, 2005).

Spatial optimization techniques have turned from kriging to the newer method termed LWQR in the model known as GTS. It is driven by empirical data for a characterized site and allows reduction in sampling without the high cost of geophysical modeling. An improvement in establishing the baseline map and performing spatial estimating is through the implementation of a locally-weighted quadratic regression.

It is a smoother and not an interpolator and applies a best-fitting least-squares line similar to standard linear regression that does not coincide with any point but captures the overall trend. It allows multiple data points at any given location and does not require a priori spatial variance model. This avoids significant effort in kriging to properly gauge spatial correlation structure.

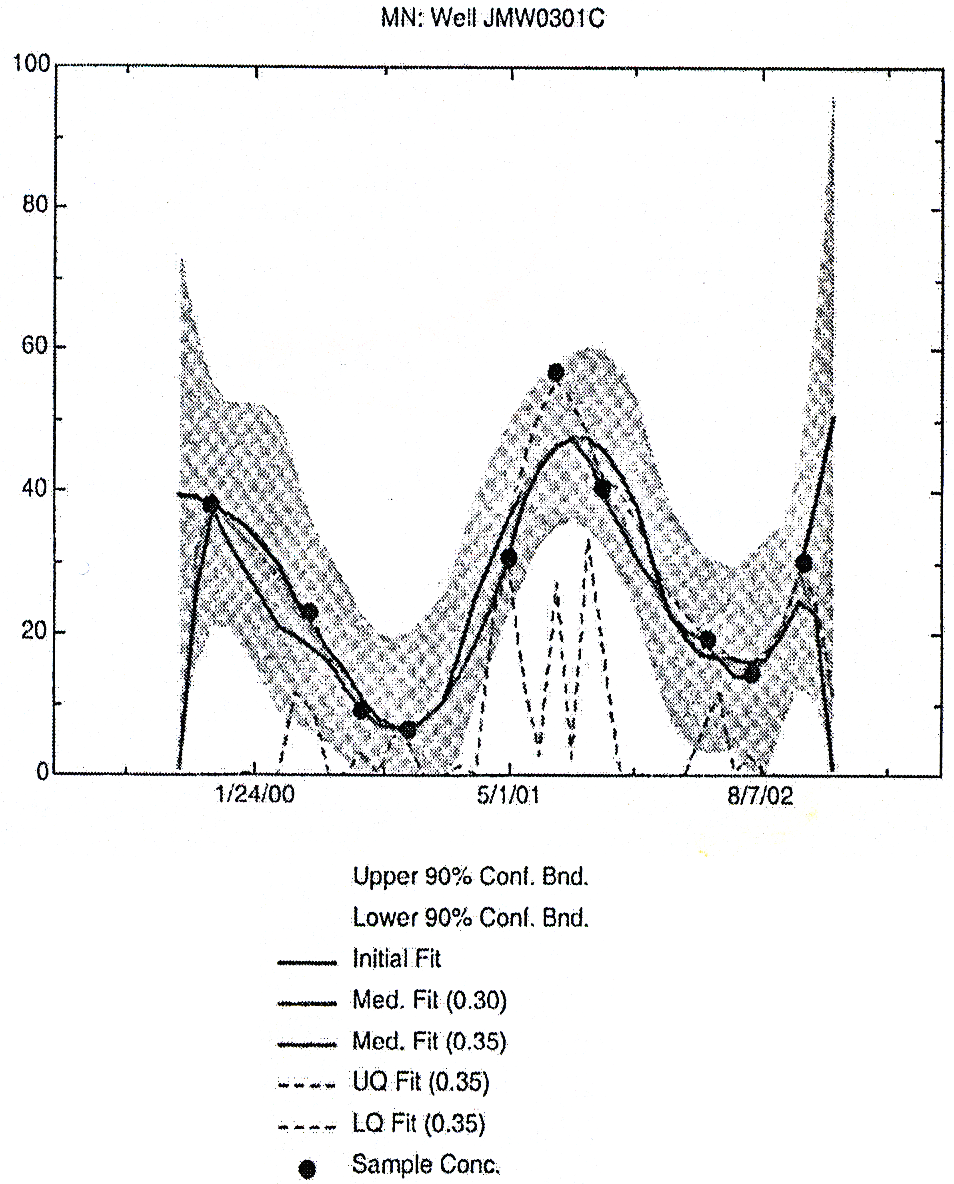


Figure 3.5. Iterative Thinning Results Example (Cameron, 2004)

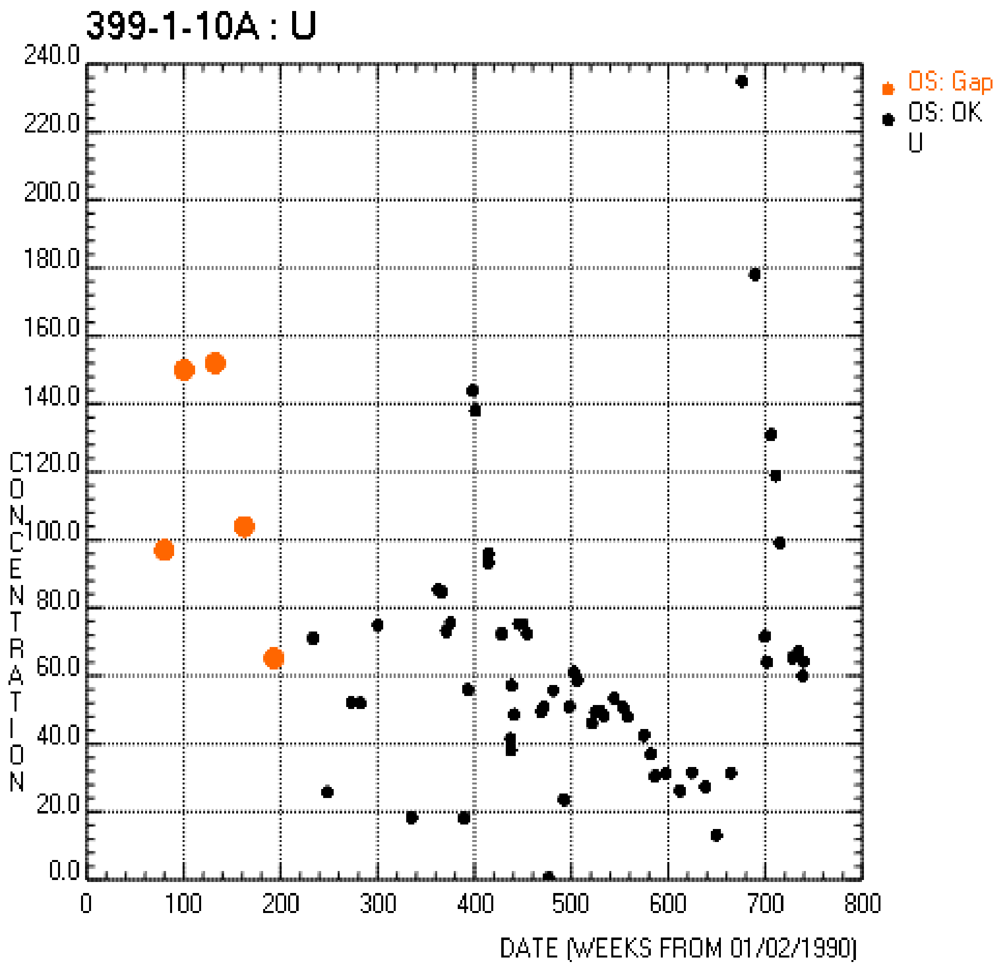


Figure 3.6. Outlier Time Series Plot (AFCEE, 2005)

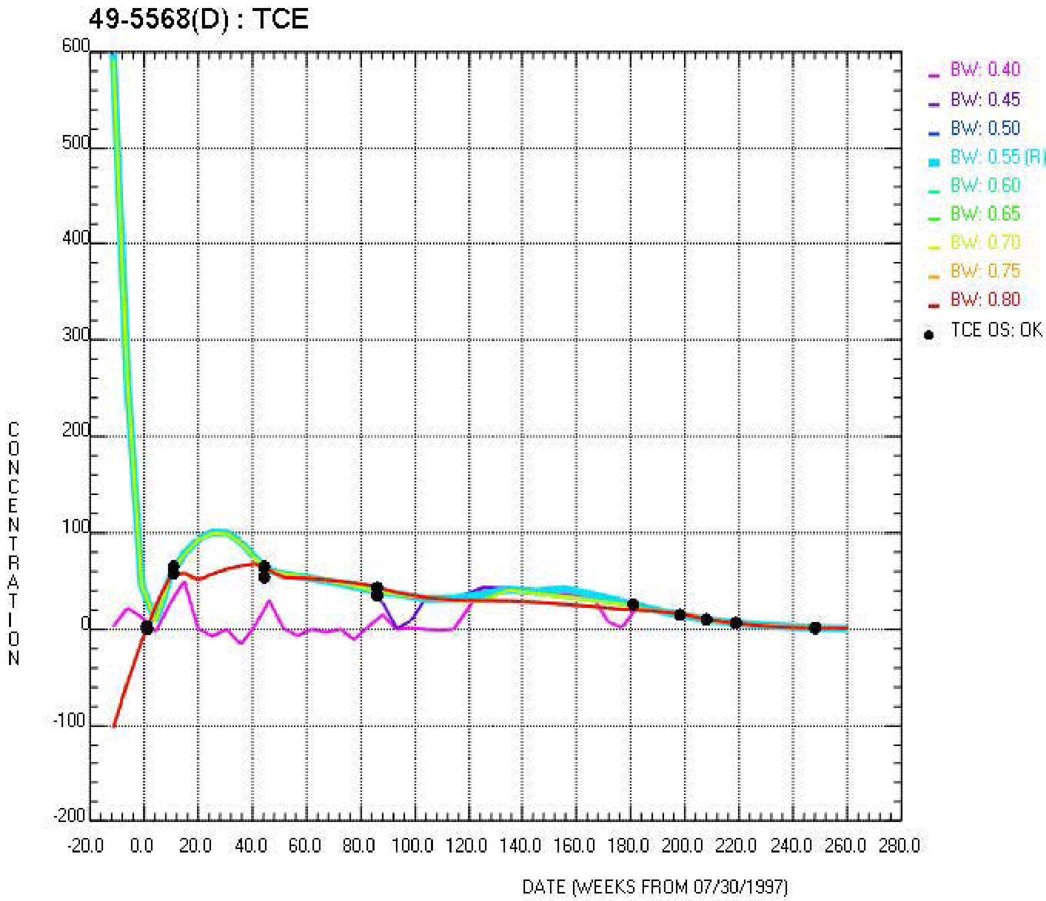


Figure 3.7. Recommended Well Bandwidth-R (AFCEE, 2005)

It avoids the process of properly fitting one or more variograms which is as much art as science. However, LWQR requires quasi-objective analyses of the residual of the fit and subjective estimations of how well the site features are represented. It was stated that the fitting process of LQWR is simpler than covariance model-building of kriging (Cameron, 2004).

The building of spatial maps is a significant function of the algorithm. Every LTM network contains two data features: (1) significant non-detects and (2) and univariate concentration skewness that are not handled by kriging. This resulted in ignoring large amounts of statistical information. GTS employs a multiple indicator local regression (MILR) to build maps. The overall data is declustered and cutoff levels are selected and rated with a zero or one (whether it exceeds the MCL). Then LQWR is applied to each level to generate a conditional cumulative distribution function.

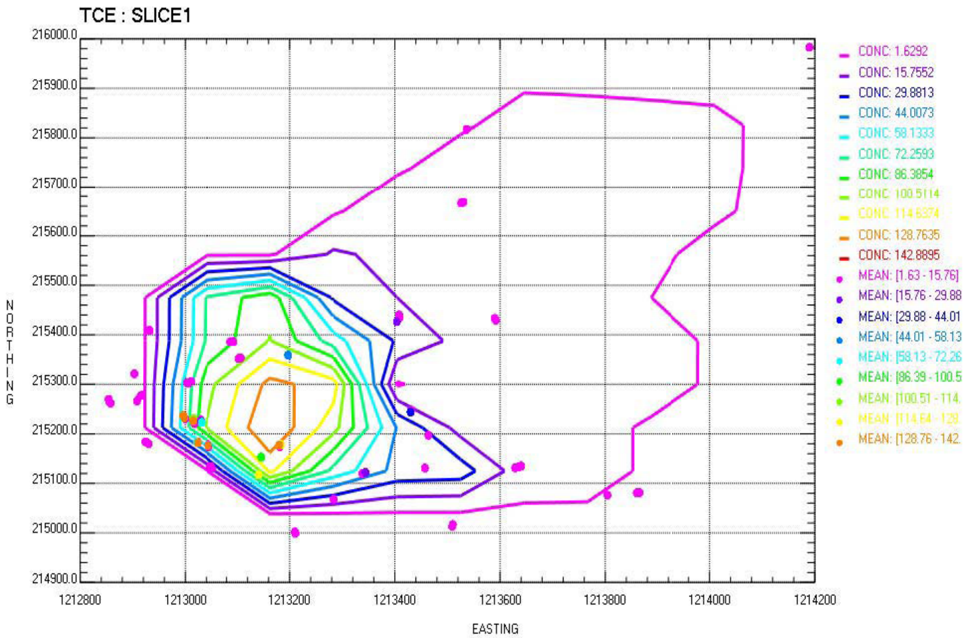
The optimization program must compare reduced data-set results to the baseline to determine accuracy and build the cost-accuracy trade-off curve. GTS now relegates a data point redundant only if without it, the baseline map can be properly reconstructed. Another step away from kriging involves both global and tracking measures of relative bias and mean squared error (MSE).

The method for selecting the well locations to keep or remove wells by GTS is a similar approach to local kriging except it substitutes global regression weights. These local weights computed as a weighted linear combination of known data values in a local neighborhood are a weight diagram or vector. Similar to global kriging weights, the weight diagram is accumulated and averaged to determine and retain the highest contributing wells in the reduced data set and removing the others (Cameron, 2004).

In the GTS User's Guide, a Time Slice Analysis is provided to time periods which are initially set at four weeks. GTS also requires determination of an array of coordinate pairs where spatial estimates will be estimated. The next step requires choosing a bandwidth as mentioned above, to estimate the site map. Base maps are created that allow the primary means for determining spatial redundancy. This is mapped with the multiple indicator local regression (MILR) whose local regression component is LWQR (Figure 3.8). The Optimal Sampling Network mode identifies wells that may be redundant and generates Spatial Diagnostic Graphs such as that in Figure 3.9. The user assigns removal cut levels to create the optimal sampling network. The outcome of the process is generation of a Redundant/Essential Well Location Plot that is color coded (Figure 3.10) (AFCEE, 2005).

3.3 THREE-TIERED APPROACH

A three-tiered approach for LTMO was developed to combine a qualitative evaluation with that of temporal trend and spatial statistical analyses. This is a system that has been apparently adapted from Parsons who was credited with developing an approach that evaluated and optimized long-term monitoring programs at characterized sites with an executed active LTMO program. A decision algorithm is typically applied to arrive at the optimal frequency of monitoring and proper spatial distribution.



Note: Northing and easting indicates north and east compass directions respectively.

Figure 3.8.Base Map (AFCEE, 2005)

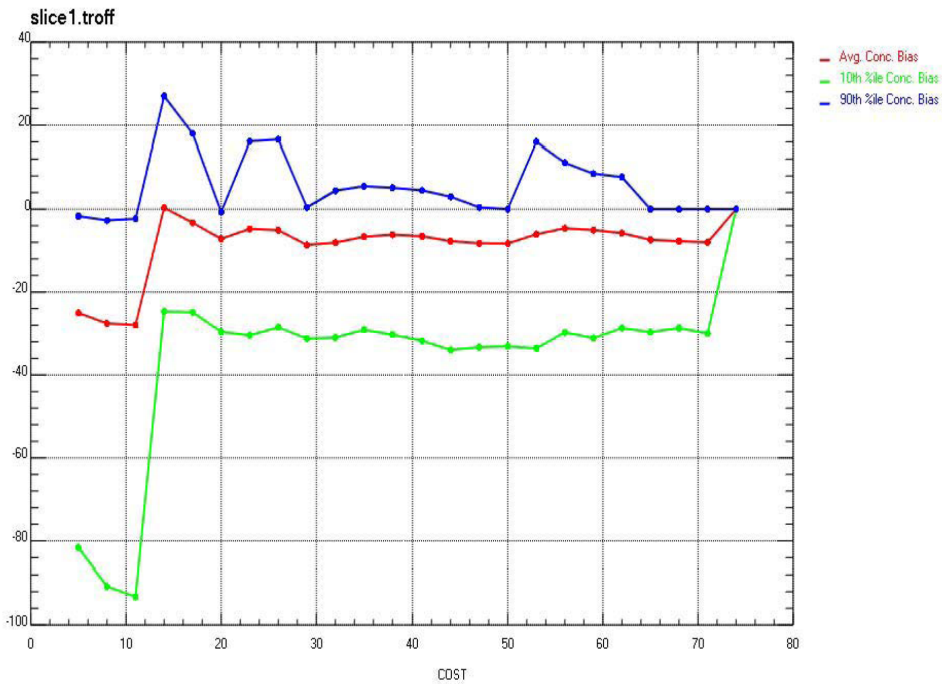
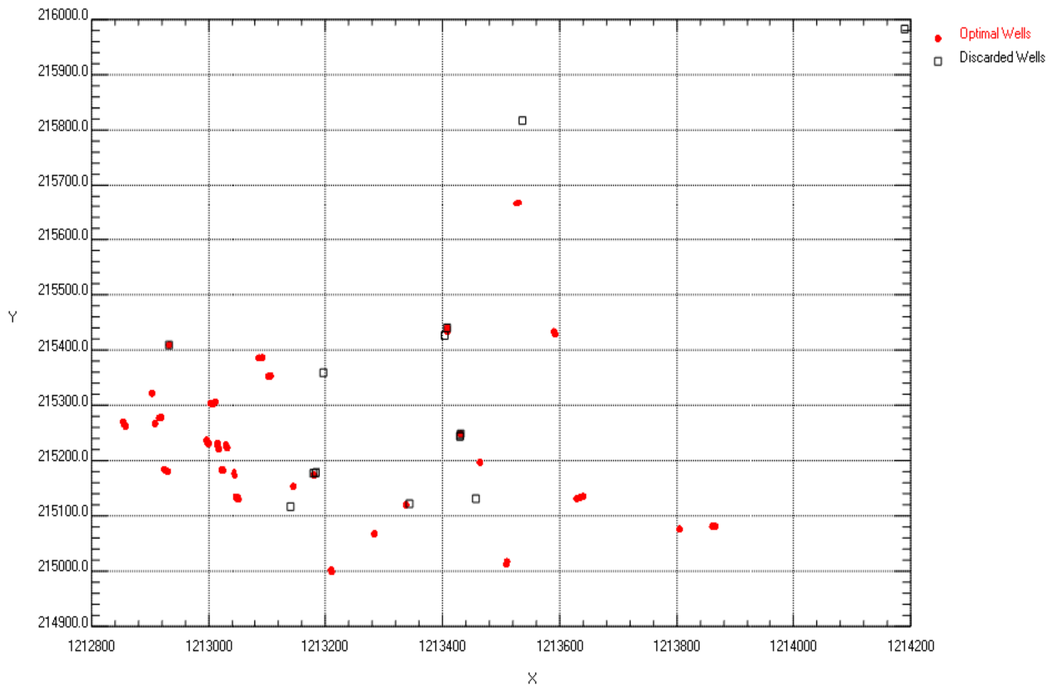


Figure 3.9. Spatial Diagnostic Graph (AFCEE, 2005)



Note: y and x indicates north and east compass directions respectively.

Figure 3.10. Redundant/Essential Well Location Plot (AFCEE, 2005)

Monitoring network design has revolved around applications of the following for either of two problems with monitoring plans and networks:

1. numerical simulation and optimization for detection monitoring at landfills.
2. ranking methods such as geostatistics in the design if monitoring networks for site characterization.

The three-tiered evaluation first identifies potential opportunities for LTMO. Factors include plume migration information, chemical concentrations, hydrostratigraphy, locations of potential receptors, and the rate and direction of the plume movement.

The second tier is temporal trend analysis which can be examined graphically (Figure 3.11) or statistically with Mann-Kendall statistics. Trends are plotted as contaminant concentrations over time or contaminant concentrations versus down-gradient distance. Incorrect conclusions about plume stability can be overcome with statistical procedures. Note that Mann-Kendall is well suited and requires as few as four test points are needed and test data can be adapted for seasonal variations. A trend statistic S can be calculated for each well with the following equation. A positive trend indicates increasing and a negative indicates a decreasing trend. The results may be misleading if the temporal data from individual monitoring wells is serially correlated only when data is collected more than quarterly (which is not the case for Vance data). It is interesting to note that the three-tiered method incorporates a flow chart or “algorithm” to utilize the results (Figure 3.12) (Nobel, 2004).

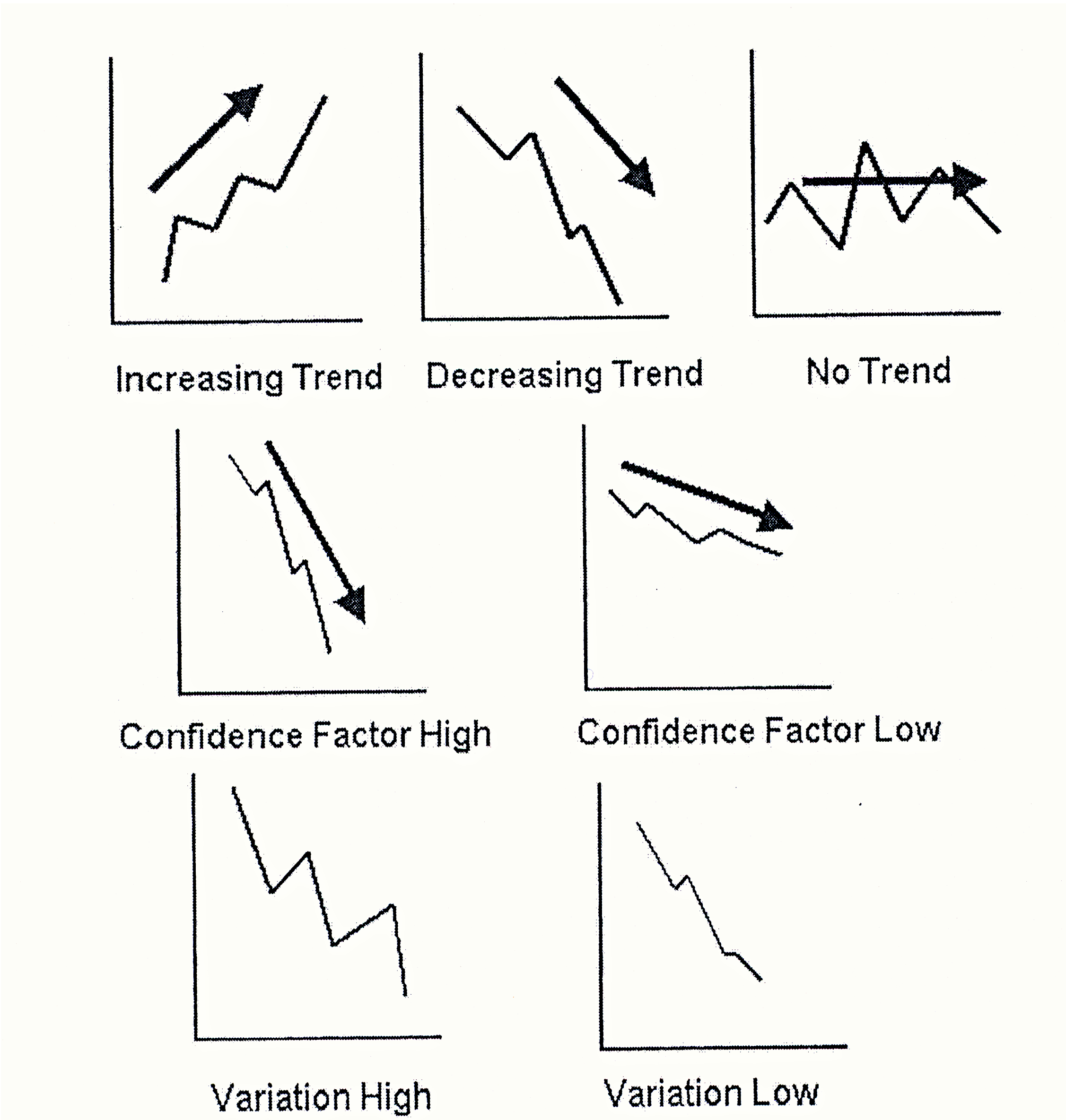


Figure 3.11. Conceptual Representation of Trends, Confidence Factors, and Levels of Variation to Illustrate Potential Concentrations Over Time (Nobel, 2004)

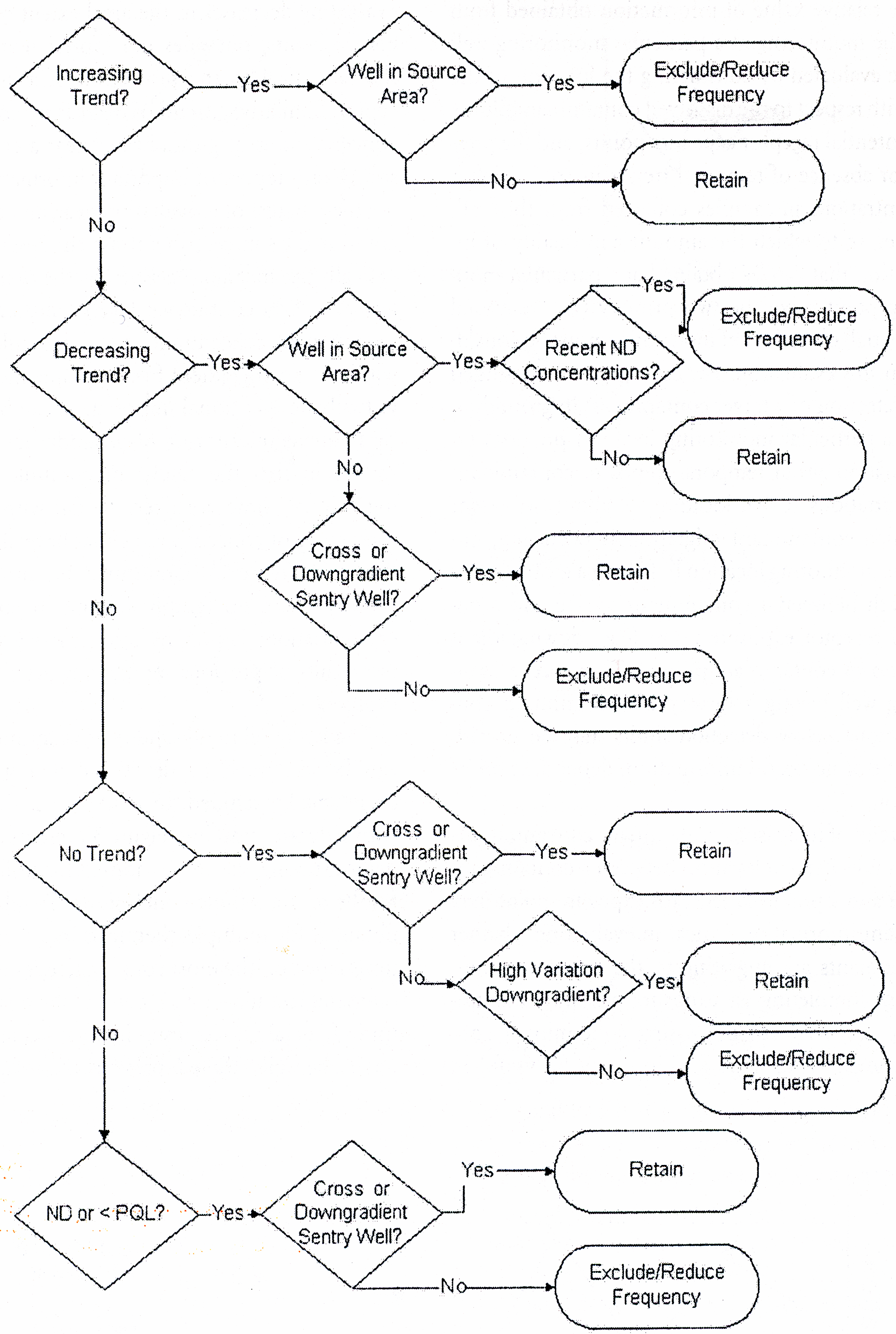


Figure 3.12. Temporal Evaluation Flow Chart (Nobel, 2004)

The third tier utilizes kriging for spatial statistical analysis. Nobel comments that geostatistics is based on the idea that values of a variable at locations close together are more similar than those farther apart. Fundamental to this is the idea of semivariance or the spatial dependence between samples defined by the following equation and as demonstrated in Figure 3.13.

$$\gamma(b) = 1/2n \ {*}\mathrm{sum}\,[g(x)-g(x+b)]^2$$

Where:

$\gamma(b)$ = semivariance calculated for all samples at a distance b from each other

$g(x)$ = value of the variable in sample at location x;

$g(x + b)$ = value of the variable in sample at a distance b from sample at location x;

n = number of samples in which the variable has been determined.

The semivariance is defined as half the average squared difference between two control values. Least squares methods are used to fit a theoretical model to calculated semivariance points since an irregular spread of points normally results for concentrations for every point on an LTMO site.

A total weighted COC must first be calculated and represents the sum of each point and its concentration divided by the COC cleanup level. A commercial software package is used to develop a semivariogram model, ultimately arriving at “rank statistics” of highest to lowest indicator concentrations.

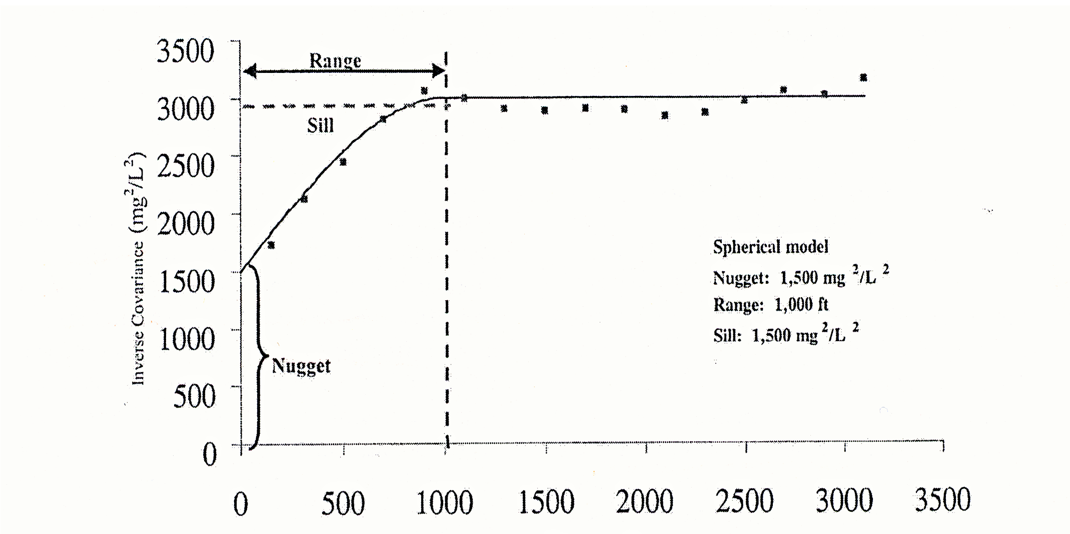


Figure 3.13. Idealized Variogram Model (Nobel, 2004)

The semivariogram models were used in a kriging system where one well at a time is removed to determine the degree of spatial uncertainty for each “missing well.” Wells are then ranked according to both changes in the median kriging standard deviation or amount of information that the well contributed toward describing spatial distribution of concentrations of the total weighted COC indicator. Candidates for removal are those providing the least information (Nobel, 2004).

3.4 MAROS BACKGROUND

The MAROS 2.2 software evaluates plume and well information in three basic phases as presented by Ling et al., 2004. While not purely statistical, it utilizes Mann-Kendall (nonparametric) and linear regression (parametric) trend analyses with a coefficient of variation. (Aziz, 2003). The first phase is that of evaluating site information and historical test data to determine local concentration trends and provide a plume status overview. The second phase is that of developing optimal sampling plans or minimizing wells while the third phase will assess data sufficiency of the performance of the future monitoring plan in meeting remediation goals. (Ling, et al., 2004). The idea is reduce the number of wells and test information based on a tolerable uncertainty (Lesage, 1992).

The first phase prepares consolidated information and data that become required inputs to the successive two phases. It provides the Mann-Kendall and linear regression results and moment analyses that indicate overall characteristics. The results will be shown later in Findings and Conclusions. The second phase of MAROS analysis utilizes conceptually simple and computationally inexpensive optimization methods to remove redundant monitoring wells, as well as recommend new sampling locations plus determine a future monitoring frequency. The detailed optimization analysis uses the Delaunay method and Modified Cost Effective Sampling (CES) method to determine the optimal sampling locations and frequency. The third and final phase utilizes power analysis to obtain additional information on the statistical sufficiency of sampling plans for individual as well as for a group of wells. (Ling, et al., 2004).

The Delaunay triangulation method is used to determine the number of sampling locations required based on spatial analysis of the relative importance of each sampling location. This 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 and indicates the value of this well. The process looks at the significance of a single well and removes it from the system. It then reevaluates the system and may find the well should not be removed based on the impact from the information loss.

In “Well Sufficiency Analysis,” the Delaunay Method is also used similarly to determine the need for new sampling locations. A high level of uncertainty from the MAROS algorithm may be arrived at from the concentration estimation error for each triangle area. The resultant slope factor will be classified as Small, Moderate, large, or Extremely Large. The latter two values will generate the need for an additional well but are not coupled to parameters such as hydrogeologic conditions. Therefore, additional professional judgment and regulatory considerations must supplement the results of this analysis.

“Sampling Frequency Determination**”** is performed by the “Modified CES Method.” This method is intended to provide the lowest frequency sampling regimen that meets regulatory requirements based on the magnitude, direction, and uncertainty or its concentration trend from available records. It begins by determining a preliminary location sampling frequency based on linear regression and Mann-Kendall analyses. The frequency may be change if the long term history of change is shown to be greater than the recent trend. The last step reduces frequency by one level if recent test results are less than ½ the Maximum Concentration Limit (MCL).

“Data Sufficiency Analysis or Power Analysis” provides a technique for further interpreting statistical tests by providing the probability of finding a difference in the variable of interest and the expected sample size of a plan based on the minimum detectable difference to be detected. This would provide how many more samples would be required in a longer period or an increased sample frequency to prove what is needed in the event a statistical test cannot prove the mean concentration is lower than a cleanup goal.

Typically a hypothetical statistical compliance boundary (HSCB, Figure 3.14) is established perpendicular to the plume movement. A plume concentration is projected on the HSCB using a decay coefficient to determine if the target concentration is achieved at the boundary. Such an evaluation for an entire site requires the following strategy; estimate the concentration versus distance with the decay coefficient from plume centerline wells, extrapolate the concentration over distance for each well, and compare the extrapolations with the compliance concentration (Erdman, 2007b).

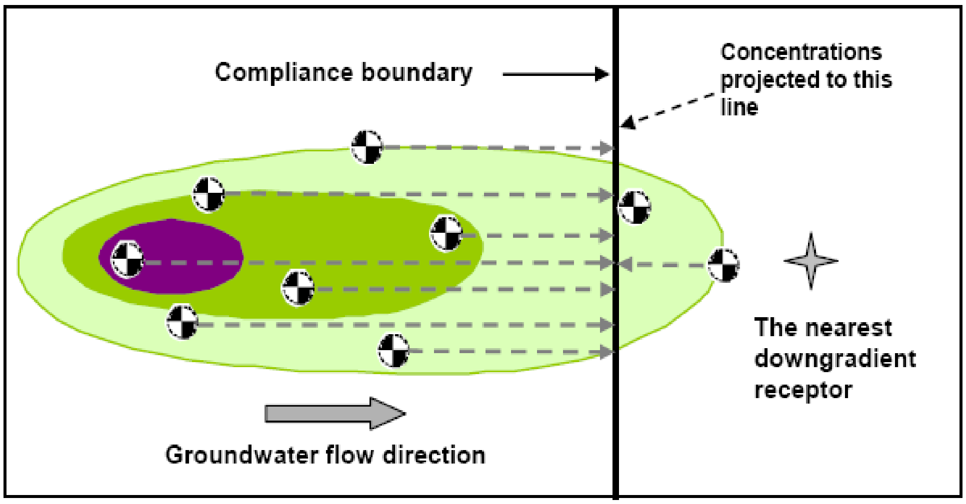


Figure 3.14. Hypothetical Statistical Analysis Boundary (HSCB)

Results will be Attained or Not Attained can be further analyzed over the period of sampling events to determine which, if any, sampling results will provide a powerful enough result to provide compliance relative to the location of the receptor or compliance boundary. In other words, compliance may be met at the boundary but a shorter length of time or distance from the plume may result in achieving compliance sooner (EPA, 2007).

CHAPTER 4

DATA DEVELOPMENT

The process of developing a data-base begins by collecting the necessary site data that includes hydrogeologic, hydraulic, and stratigraphic information to perform the computer analysis of LTMO models. As mentioned, the initial data collected was that needed for deterministic models with a never-ending appetite for data. Today's mode of statistical analysis requires less data and relies instead on probability methods. What follows is a case study of a data collection effort, the steps that comprise the software method and an evaluation of the variances that occurred.

4.1 CASE STUDY - VANCE AFB, OKLAHOMA

This research began with a report prepared for the purpose of optimizing the Long-Term Monitoring (LTM) Program at a specific military facility (Erdman, 2007). That report was based on results from MAROS to show that the monitoring program was being achieved and that fewer wells would be needed in the future (EA, 2005). The contaminant-of-concern is TCE, which is toxic and carcinogenic, and is therefore heavily regulated (IT, 2000).

Collection of data for LTM occurred over two decades of data collection. The groundwater monitoring plan now being implemented at Vance AFB is comprised of several data inputs from various environmental entities over the 1990's through 2006.

The data has been collected to provide the format of data needed to satisfy hydrogeologic transport models and continues to be of value for analyzing long-term monitoring plans with newer tools such as the MAROS 2.2 public domain software program.

Analysis by MAROS is performed in three phases. The first evaluates site information and historical monitoring data to obtain local concentration trends at different parts of the plume as well as the stability of the plume. The last two phases develop optimal sampling plans for future monitoring at the site and lastly assesses the statistical sufficiency of the sampling plans to reach the intended remediation goals. The most frequently reported methods used for optimizing LTM plans concentrate on temporal sampling based on frequency and spatial sampling based on (Ling, 2004). Temporal trend analysis is one of the most important objectives of water quality programs to aid in decision making with evaluation of treatment regulations and actions to be taken when adverse human health situations arise. Spatial analysis is necessary for determining proper water quality so that the effective number of monitoring points can be determined (Blinkiewicz, 1993).

4.2 DATA COLLECTION AND ERRORS

The processing of data will be discussed with regard to its effect on the quality of output data from the MAROS model. In order to aid the understanding of the computer software, a brief description of the MAROS tools will be provided at this time.

Data had been collected for the CMI and IZ area TCE shallow aquifer plumes for only a few years prior to the implementation plan begun in 2005 by EA Engineering, Science, and Technology, Inc. (EA, 2005). Early attempts to apply the earlier data often resulted in warnings from the MAROS software that insufficient data existed for MAROS to continue or that the results could be in error. It has been documented that sources of error begin in the sampling procedure. One of these is random error due to imprecision or variability in analytical instruments, sampling, or operator inconsistencies. A second is determinate or systematic error that includes calibration error, temperature changes, sample extraction oddities, instrument error drift, and even operator bias (Blinkiewicz, 1993). This is certainly relevant with the samples obtained over many years with as many different contractors and testing labs. Furthermore, some of the test data results used in the Vance EA Vance – MAROS Report (Erdman, 2007a) were obtained from final published site evaluation reports that included summarized results. Some other data was obtained from individual lab test data reports while some also originated from documented Excel format files obtained from the AFCEE office that sponsors MAROS. It is with the above nature of varied inputs that results from the MAROS study for Vance need to be scrutinized carefully. That is, the format is different in that compliance reports contain a single and final representative sample result whereas the lab reports will contain all data that includes redundant and often repetitive and similar results. If data is going to be utilized from reports that has reduced the data to its simplest form, then data from lab reports must also be screened to discard the non-detects and repetitive tests to create similarity of input data.

Uncertainty also exists in the hydrogeologic components in and around a plume area. It has been demonstrated that the Vance geology is stratified with intermingled clay lenses comprising three separate aquifer levels. The hydraulic characteristics have been shown to vary over time which has been reported by various different data collection companies such as General Engineering (2003, 2004), Kemron (IT Corp., 2003: Shaw, 2003) over time (Mugunthan, 2004).

4.3 DATA MANAGEMENT

As stated earlier, this paper seeks to demonstrate the effect of varying field test data results on the MAROS 2.2 output and products. This will address incomplete periods of test data, selection of a data evaluation period, and organizing the frequency of data. This will also reflect upon the actual MAROS results of the Vance AFB case study involving two TCE shallow aquifer plumes identified as the CMI and IZ areas. The effect of data setup in the beginning of the MAROS program is critical since the remaining two phases and methods rely on it. Data is continually being condensed and eliminated as the program steps proceed to the last analysis, “power analysis”, which addresses statistical sufficiency of monitoring plans (Ling, 2004).

This area of the MAROS software involves temporal and spatial analysis utilizing the Mann-Kendall, linear regression, and moment analysis functions which will be briefly described later. Even though MAROS goes on further to evaluate sufficiency of the monitoring plan, adequacy of wells or need for additional wells, and decay of the plume within the allowed site boundary, this author observed that it is from the beginning analysis of temporal, spatial, and moment analysis where the plume characteristics and individual site data is formulated for the advanced analyses.

It is significant to review the nature in which the program sees the input test data. It is stated in the AFCEE MAROS User Guide that it is preferable and necessary to have a minimum of data such as four test wells with the contaminant-of-concern (COC) or TCE being reported 4 of the last 6 sampling events. It is more or less suggested that data for wells be systematic and timely. However, in the case of multiple or scattered test results, it suggests that interpretation be left to MAROS by selecting a program setting of quarterly, semi-annual, annual and so forth. This did not necessarily provide a result that is presented in the following brief explanation of the first phase MAROS functions.

Groundwater monitoring data can be imported in various sources, primarily database-format Microsoft Excel spreadsheets, Microsoft Access tables, prior database archive files, or manually entered. Experience with the Vance data from various sources led to the conclusion that the Excel spreadsheet was the simplest method. Minimum data input is four wells with COC's reported and individual sampling locations with data from at least six most-recent sampling events. One author of a MAROS site evaluation suggested the user consolidate or "smooth" irregular data. This author's interpretation of this technique was applied to the Vance data as explained later.

Site Details include seepage velocity and current plume dimensions. It requires the analyst to split the wells into two zones; source and tail (the latter being down gradient from the source wells). The type of contaminant condition, such as liquid NAPL must be entered. The type and effect of the well must be considered, such as use of a remediation well or monitoring well in the final analysis.

Data consolidation is the result of all the raw data that may not be regular, or have duplicates, trace amounts, and so forth. It allows use of annual or smaller, but regular, segments of time and can be based on one of the following statistical parameters: median, geometric mean, mean, and maximum. "Non-detects" can be converted to the reporting limit or a fraction or one-half of it. Trace results can be actual values or a fraction thereof, or all or one-half of the detection limit. Duplicates are assigned an average, maximum, or first value. The resultant reduced data is graphically displayed as a time series in linear or semi-log plot (as required to emphasize the curve for particularly low levels and changed in data).

4.4 OVERVIEW OF STATISTICS OR PLUME TREND ANALYSIS

Trend analyses can be performed on contaminant concentrations in individual wells and in plumes. These concentrations are determined to be as follows for either of the two following analyses to be discussed:

- Increasing - I
- Probably Increasing - PI
- No Trend - NT
- Stable - S
- Probably Decreasing - PD
- Decreasing - D

The three statistical tools used to analyze plume stability are Mann-Kendall Trend analysis, linear regression trend analysis, and moment analysis. The Mann-Kendall test can be used with sets of missing or irregular data and a single groundwater constituent.

The S statistic measures an increase in concentration trend with a positive value and decrease with a negative value. The concentration trend is measured with the S statistic, confidence in the trend, and a Coefficient of Variation (COV). It can be seen in Table 2 for Mann-Kendall statistics that three trend conclusions can be achieved for a positive S value; I, PI, and NT. A confidence interval greater than 95% with a positive S value will predict an increasing contaminant concentration.

A similar scenario exists for linear regression, which analyzes trends in data over time but for only a single groundwater constituent. This analysis is based on the log-transformed concentration data versus time. The slope from this curve, the confidence level for the slope, and the COV of the untransformed data are used to determine the concentration trend. An example of a concentration trend would be a positive log slope with a confidence of less than 90% being categorized with No Trend. The coefficient of variation is a statistical measure of how individual data points vary about the mean and is otherwise defined as the standard deviation divided by the average. A negative log-slope is considered Stable with a COV < 1.0 and No Trend with a COV > 1.0. See Table 4.1 for the linear regression analysis (AFCEE, 2006b).

An Overall Plume Analysis is produced based on the results of the source and tail trend results. Those results are weighted and consolidated so that the direction and contaminant concentration in the source and tail zones are determined for each COC. This, along with the hydrogeologic factors, consolidated trend analysis, and location of potential receptors will allow MAROS to provide a general optimization plan to monitor the plume in the future.

MAROS 2.2 APPLICATION

Contaminant Trend Determinations

Mann-Kendall		
Mann-Kendall Statistic S	Confidence in Trend	Concentration Trend
>0	>95%	Increasing
>0	90-95%	Probably Increasing
>0	<90%	No Trend
≤0	<90% and COV ≥1	No Trend
≤0	<90% and COV <1	Stable
<0	90-95%	Probably Decreasing
<0	≥95%	Degreasing

Linear Regression		
	LN SLOPE	
Trend Confidence	Positive	Negative
<90%	No Trend	COV<1 Stable COV>1 No Trend
90-95%	Probably Increasing	Probably Decreasing
>95%	Increasing	Decreasing

Table 4.1. Contaminant Trend Concentrations Mann-Kendall and Linear Regression

Spatial Moment Analysis provides a relative estimate of plume stability as well as the mass and center of the plume and its spread using the Mann-Kendall methodology. This is applied to the zeroth and second moment analyses to determine the trend in plume mass and plume size. Spatial moments are calculated using the triangular areas of the Delaunay triangulation method. It represents a two-dimensional aquifer where the concentration is vertically averaged. Slope factors are also generated to indicate the importance of a sampling location in further analyses. As mentioned earlier, Delaunay triangulation is used to generate an importance factor of for each sampling location. The slope factor represents the relative concentration estimation errors at sampling locations. (Ling, 2004).

The zeroth moment is the sum of concentrations for all monitoring wells and is an estimate of the change in dissolved mass over time. This analysis can exhibit fluctuating temporal and spatial values and be sensitive to the frequency of site monitoring. Factors that effect the moment include spatial distribution of the sampled wells over time, different wells sampled in the network, and inconsistent delineation of the plume (AFCEE, 2006b).

The first moment estimates the center of mass in horizontal plane directions of xx (transverse) and yy (forward) directions relative to the movement derived from the distance from the original source to the new center of mass locations. This movement must be considered with respect to the original location of the source of contamination as well as groundwater flow direction and source removal or remediation. It should be noted that seasonal variation in rainfall or other hydraulic considerations can effect spreading or shrinking or transient movement as reflected in resultant spatial and temporal trends in the center of mass. Plume stability may be indicated by no appreciable movement or a “neutral trend” as termed by MAROS. The first moment trend should be compared to the zeroth moment trend to fully characterize the plume.

The second moment demonstrates the spread of the contaminant about the center of mass in the x and y directions. That is to say, it is measure of the spread of the concentration about the plume’s center of mass. The second moment reaction should be compared to the Zeroth moment to fully characterize the plume.

4.5 DATA AND ANALYSIS

The MAROS program needed to see the data in an organized systematic format. Several steps were implemented in the quest to obtain and create data files that would operate in MAROS and that could finally be applied to an actual site. The site selected was Vance AFB to determine if an acceptable level of remediation had been achieved for its shallow zone TCE contamination. The following demonstrates the process taken and observations that led to a successful application of MAROS to a real site while preparing the “MAROS 2.2 Application for the Shallow Zone Monitoring Optimization of DNAPL TCE” at the CMI and IZ Vance, AFB sites. The situation with the Vance project was sporadic test data collection over years for the two significant TCE shallow aquifer plumes. The data skipped years, was not periodic (not quarterly, annual, etc.) and was otherwise separated by such long periods that it was not reliable for analysis of plume activity. The following cases demonstrate efforts in pursuing satisfactory analysis and the effect on the results. Actual MAROS results from the above draft report are included to support the text.

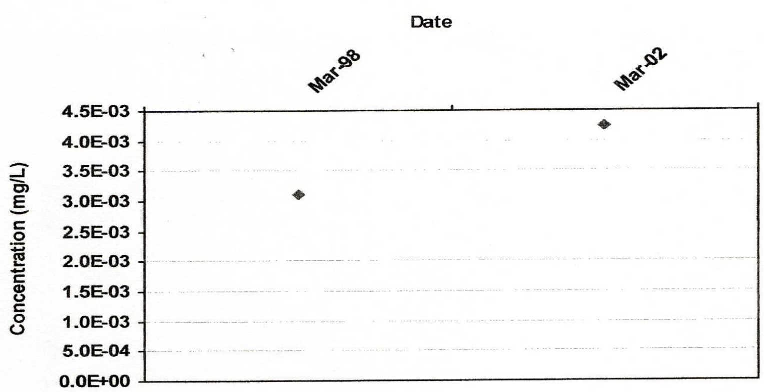
Step 1: Selection of initial data was attempted using the ERPIMS (Environmental Resource Program Information Management System) database which is a central repository of environmental site information provided by the Air Force Center of Environmental Excellence at Brooks AFB, San Antonio Texas. This data base has four separate intermingled subsets of data that are intricately cross-referenced with test well and monitoring data, well site locations and significant amounts of information and data fields of data. In fact, the author of the MAROS software recommended utilizing a simpler data acquisition method and then using the Excel format that is easier to manage than the Access format. Incidentally, it was discovered that the ERPIMS database was not updated so it did not include the latest Vance site data being generated by the firm EA that would be needed to exercise MAROS for the Vance CMI and IZ TCE plumes. The available data spanned from 1996 to 2002. The ERPIMS database was eventually updated but not until the EA Report had been drafted in the fall of 2007 (EA, 2007c).

Step 2: Data for the CMI and IZ sites had been sporadically collected and were found inadequate for MAROS in early trials performed in Step 1. Applications of available data were then performed by this writer to construct computer test files (which were not available in the MAROS tutorial software). These were successfully utilized to discover some of the limitations of MAROS which led to the creation and discovery of the actual minimum size of data entries necessary to create results that would generate meaningful results other than N/A or not applicable as shown in Step 3 to follow. This led to constructing an Excel file that MAROS would accept in the first stage of loading available Vance data.

Step 3: Several attempts with the AFCEE help desk to obtain Vance data from the ERPIMS data base led to receipt of monitoring well test data for the entire Vance area and included over 15,000 entries of all COC's. This was provided in four subset files in Excel format. These were carefully analyzed and filtered to provide the appropriate Excel format for MAROS with shallow aquifer wells exhibiting TCE and in respective CMI and IZ sites. That data set was supplemented by adding the test well sample results to the Excel file that were collected in the last round of monitoring well data sampling performed by EA in 2005. The following was discovered upon applying the data to MAROS. Several occurrences were identified where MAROS produced reports that insignificant data was provided to complete processing of spatial and temporal analyses or the advanced stage analyses of moment analysis or plume behavior.

Only four or five data points to as few as two were appearing in the reduced data for each well and were inadequate to generate overall meaningful results. Fewer than four sampling events would and failed to generate a Mann-Kendall analysis (Figure 4.1). This represents that inadequate data existed in the historical database to evaluate some wells. It will also be shown that the small number of test results would be inadequate to perform moment analyses. Moment analyses were based on the availability minimal data of only four testing events with six wells. However, well testing was performed at so many different times that MAROS could not identify at least 6 wells tested in one specific time period.

Well: MW25-05
Well Type: T
COC: TRICHLOROETHYLENE (TCE)



Mann Kendall S Statistic:

0

Confidence in Trend:

0.0%

Coefficient of Variation:

0.00

Mann Kendall Concentration Trend: (See Note)

N/A

Figure 4.1. MAROS Mann-Kendall Statistics Summary

Individual dates represented single groups and even though several were performed close in days for instance, they represented groups smaller than 6 and were not processed. Most sample events thus reflected less than the six wells needed to generate a moment calculation and very little of the test data could be processed. Data represented only five years at that time; 1996, 1998, 2002, 2005, and 2006 for all wells and did always provide the minimum tests for a group or wells thus being insufficient to generate meaningful results. Data could be more thoroughly recognized by grouping it into representative time periods by adjusting the test dates to correspond to a specific period along with selecting a time consolidation period as shown in Step 6.

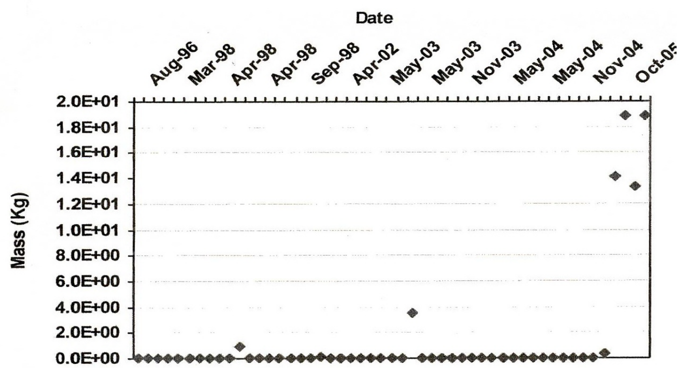
Step 4: It had originally been perceived that the data available from the past data recorded in the ERPIMS format plus the new test results by EA would provide adequate data sets. It became evident that additional data would be required so the extra effort was expended to review and extract 2003 and 2004 test data from actual lab test reports. This was added directly to the Excel database. When errors resulted in the MAROS operation, the data format was investigated more deeply. It was inadvertently discovered that the date field of Excel also contained a time of day that was not in previous data sets. This was overcome by saving the Excel file to a new Excel file, deleting the time of day, and returning the data set to an original data screen. The time of day was eliminated and the file operated okay in MAROS. The additional lab test data was obtained from actual lab test reports from source papers such as General Engineering Laboratories, Shaw and IT Kemron Data Evaluation Reports (Shaw Groundwater Monitoring Report, 2003). Another observation was that the increased data when analyzed by MAROS resulted in fewer recommended redundant wells and less dramatic reductions in frequency.

Step 5: Lastly, newly available test well data produced by EA from the fall of 2006 was added to the Excel input database. That was applied to MAROS and resulted in the most meaningful output results yet. Prior to this, an initial MAROS analysis was performed on the Vance CMI and IZ plumes using all accumulated test data that had been produced by EA through only the spring of 2006 (EA Engineering, 2005 and 2006). This had already added three structured semiannual test periods to the existing database through 2002 and more-or less fulfilled basic data needs of MAROS that was lacking in the past. However, the results were still limited for the plume analysis or Spatial Moment Analysis. Note that by allowing use of all test data points and their separate and respective reported times of occurrence, however scattered, resulted in an event or test date with the number of wells less than the minimum of six required. Time and again MAROS computed moment analysis and reported a mass of zero because it could not correlate the separated test dates into one representative period or event. This is demonstrated by the Zeroth Moment Analysis Figure 4.2. Note the separated and individual effective dates that are responsible for generating a number of wells less than six per event (effective date) and which generate zero estimated mass. MAROS is unable to evaluate most data points since most are not seen as a group of four or more wells.

Step 6: Selection of data by selecting a semiannual time periods resulted in grouping all well tests from 1998 to 2006 into their nearest semiannual period which required manually changing the test date to March 1 and September 1. That resulted in reorganizing actual test data into the nearest representative period that could be recognized by MAROS thus creating six or more tests that generated an estimated mass for the plume. This is further demonstrated in Figure 4.3 where the summation of wells.

COC: TRICHLOROETHYLENE (TCE)

Change in Dissolved Mass Over Time



Data Table:

Effective Date	Constituent	Estimated Mass (Kg)	Number of Wells
8/15/1996	TRICHLOROETHYLENE (TCE)	0.0E+00	1
3/12/1998	TRICHLOROETHYLENE (TCE)	0.0E+00	2
3/13/1998	TRICHLOROETHYLENE (TCE)	0.0E+00	3
3/18/1998	TRICHLOROETHYLENE (TCE)	0.0E+00	1
3/20/1998	TRICHLOROETHYLENE (TCE)	0.0E+00	1
3/21/1998	TRICHLOROETHYLENE (TCE)	0.0E+00	1
3/30/1998	TRICHLOROETHYLENE (TCE)	0.0E+00	3
3/31/1998	TRICH	0E+00	2
4/1/1998	TRICH	0E+00	1

Porosity: 0.20

Saturated Thickness:

Uniform: 20 ft

"Note less than 6 wells has zero mass"

Mann Kendall S Statistic:

218

Confidence in Trend:

100.0%

Coefficient of Variation:

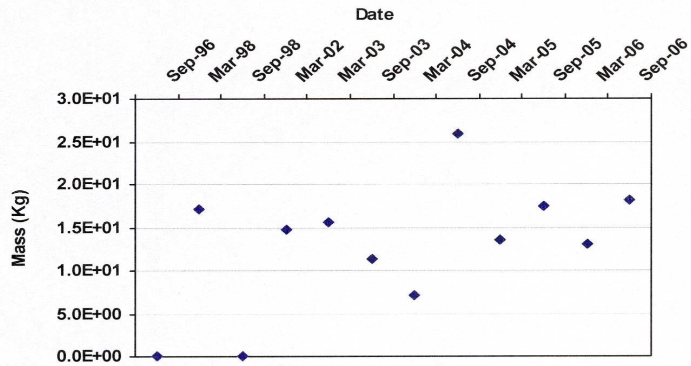
3.26

Zeroth Moment Trend:

Figure 4.2. MAROS Zeroth Moment Analysis, Lack of Mass

COC: TRICHLOROETHYLENE (TCE)

Change in Dissolved Mass Over Time



Data Table:

Effective Date	Constituent	Estimated Mass (Kg)	Number of Wells
9/1/1996	TRICHLOROETHYLENE (TCE)	0.0E+00	1
3/1/1998	TRICHLOROETHYLENE (TCE)	1.7E+01	17
9/1/1998	TRICHLOROETHYLENE (TCE)	0.0E+00	2
3/1/2002	TRICHLOROETHYLENE (TCE)	1.5E+01	19
3/1/2003	TRICHLOROETHYLENE (TCE)	1.6E+01	19
9/1/2003	TRICHLOROETHYLENE (TCE)	1.1E+01	19
3/1/2004	TRICHLOROETHYLENE (TCE)	7.1E+00	19
9/1/2004	TRICHLOROETHYLENE (TCE)	2.6E+01	19
3/1/2005	TRICHLOROETHYLENE (TCE)	1.4E+01	16
9/1/2005	TRICHLOROETHYLENE (TCE)	1.7E+01	16
3/1/2006	TRICHLOROETHYLENE (TCE)	1.3E+01	17
9/1/2006	TRICHLOROETHYLENE (TCE)	1.8E+01	17

Porosity: 0.20

Saturated Thickness:

Uniform: 20 ft

Mann Kendall S Statistic:

21

Confidence in Trend:

91.3%

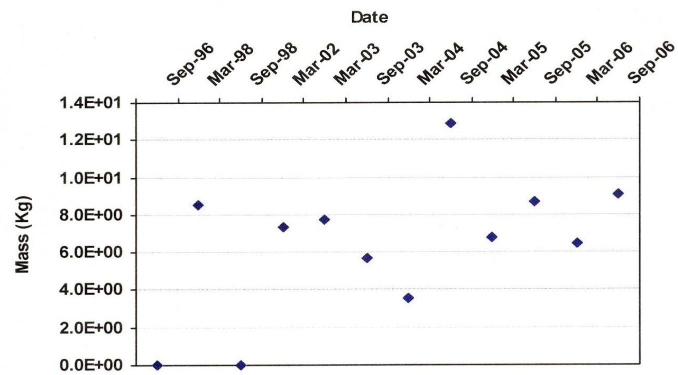
Figure 4.3. MAROS Zeroth Moment Analysis, Estimated Mass

exceeding six in the “Number of Wells” column calculates a total estimated mass of those wells.

Step 7: Another source of error is due to differences in hydrogeolgical parameters. For instance, the thickness of the shallow zone is generally understood to be roughly 20 feet thick while the saturated layer varies from 7 to 12 feet near the Site 12, 24, and 25 wells. Figure 4.3 demonstrates a significant decrease in the zeroth moment estimated masses (kg) of the CMI at 10 feet versus the greater masses reported at a 20 foot saturated aquifer thickness as shown in Figure 4.4. The assignment of depth is obviously simplistic since it has been recorded that the depth of aquifers at Vance varies significantly as does the hydraulic conductivity. Interestingly, the computed values of the first and second moments remained unchanged as might be expected since they utilized temporal and spatial data not connected to concentration parameters. However, further MAROS analyses of sufficiency and degree of natural degradation were affected where degradation and mass parameters are involved.

The variability of processing and assimilating input data as discussed have a significant effect on the outcome of recommendations by MAROS. However, the same data is used in creating Delaunay triangulation for plume concentration characteristics is used in the advanced methods of MAROS in developing optimal sampling plans and assessing statistical efficiency of those plans. The figures as presented here indicate that the management and interpretation of the input test data is highly dependent upon the person who is evaluating it. Only a slight change in the dates of testing can turn data from

Change in Dissolved Mass Over Time



Data Table:

Effective Date	Constituent	Estimated Mass (Kg)	Number of Wells
9/1/1996	TRICHLOROETHYLENE (TCE)	0.0E+00	1
3/1/1998	TRICHLOROETHYLENE (TCE)	8.5E+00	17
9/1/1998	TRICHLOROETHYLENE (TCE)	0.0E+00	2
3/1/2002	TRICHLOROETHYLENE (TCE)	7.4E+00	19
3/1/2003	TRICHLOROETHYLENE (TCE)	7.8E+00	19
9/1/2003	TRICHLOROETHYLENE (TCE)	5.7E+00	19
3/1/2004	TRICHLOROETHYLENE (TCE)	3.6E+00	19
9/1/2004	TRICHLOROETHYLENE (TCE)	1.3E+01	19
3/1/2005	TRICHLOROETHYLENE (TCE)	6.8E+00	16
9/1/2005	TRICHLOROETHYLENE (TCE)	8.7E+00	16
3/1/2006	TRICHLOROETHYLENE (TCE)	6.5E+00	17
9/1/2006	TRICHLOROETHYLENE (TCE)	9.1E+00	17

Porosity: 0.20

Saturated Thickness:

Uniform: 10 ft

Mann Kendall S Statistic:

21

Confidence in Trend:

91.3%

Figure 4.4. MAROS Zeroth Moment Analysis, Reduced Mass

generating “no” trends and lack of concentration of mass, into representative statistics with values that can be judged by regulators and others as meeting regulatory remediation goals.

CHAPTER 5

METHODOLOGY AND PROCEDURES

The goal of this research topic is to utilize existing computer modeling software and methods in evaluating the fate of DNAPL contaminant removal and optimization of the sampling system at a select industrial site (Vance AFB, Oklahoma). The principle models are MAROS and GTS which were developed by the U. S. Air Force Center of Environmental Excellence in San Antonio, Texas.

5.1 METHODOLOGY

Most methodology in the past has been aimed at tracking the movement of contaminated groundwater aquifer plumes and has been extended to determine the extent of contamination and concentration with time. Due to the high cost of active engineering methods of remediation and the associated management of maintaining test well data collection, it has become increasingly necessary to optimize the resources available in an attempt to reduce the costs of extended monitoring.

First of all it has become a practice to utilize natural processes to achieve the required remediation followed by extended monitoring. It is this new approach that has spurned new computer models and analysis programs that utilize newer geostatistical forecasting which lead to often reduced frequencies of monitoring solely to confirm the predicted results of reaching attenuated lower levels of contamination. This approach of Monitored

Natural Attenuation or MNA offers more complete site remediation with lower cost and exposure to humans and the ecology (AFCEE TT, 2003).

At Vance AFB (as well as other sites most likely in the 1980's and 1990's), MODFLOW and MT3D had been used to predict solute and transport of contaminants. However, two newer programs contain more powerful features and are being proposed to analyze the Vance sites. MAROS or Monitoring and Remediation Optimization System was developed by the Air Force Center for Environmental Excellence (2003) and Geostatistical Temporal/Spatial Algorithm Software (GTS) was jointly developed by the United States Air Force Center for Environmental Excellence Geological Survey and MacStat Consulting Ltd. (Aziz, 2003b: Prommer, 2003: Aziz, 2003).

5.2 GEOLOGY AND HYDROGEOLOGY OF THE VANCE AREA

Prior to proceeding with the analysis of Vance AFB, it is important to review the site characteristics and the unusual features. The geology of the area is underlain by bedrock of the Permian age Bison Formation that consists of brown shale and siltstone inter-bedded with minor sandstone. Groundwater sources are limited and water quality is poor from Permian bedrock aquifers. The underlying geology is comprised of layers, one with a maximum thickness of 120 feet with shale and siltstone "inter-fingered" grading laterally from one to another (Figure 5.1). The formation dips to the west-southwest at about 40 feet per mile. The area is not tectonically active and no significant surficial faults or folds are known to exist.

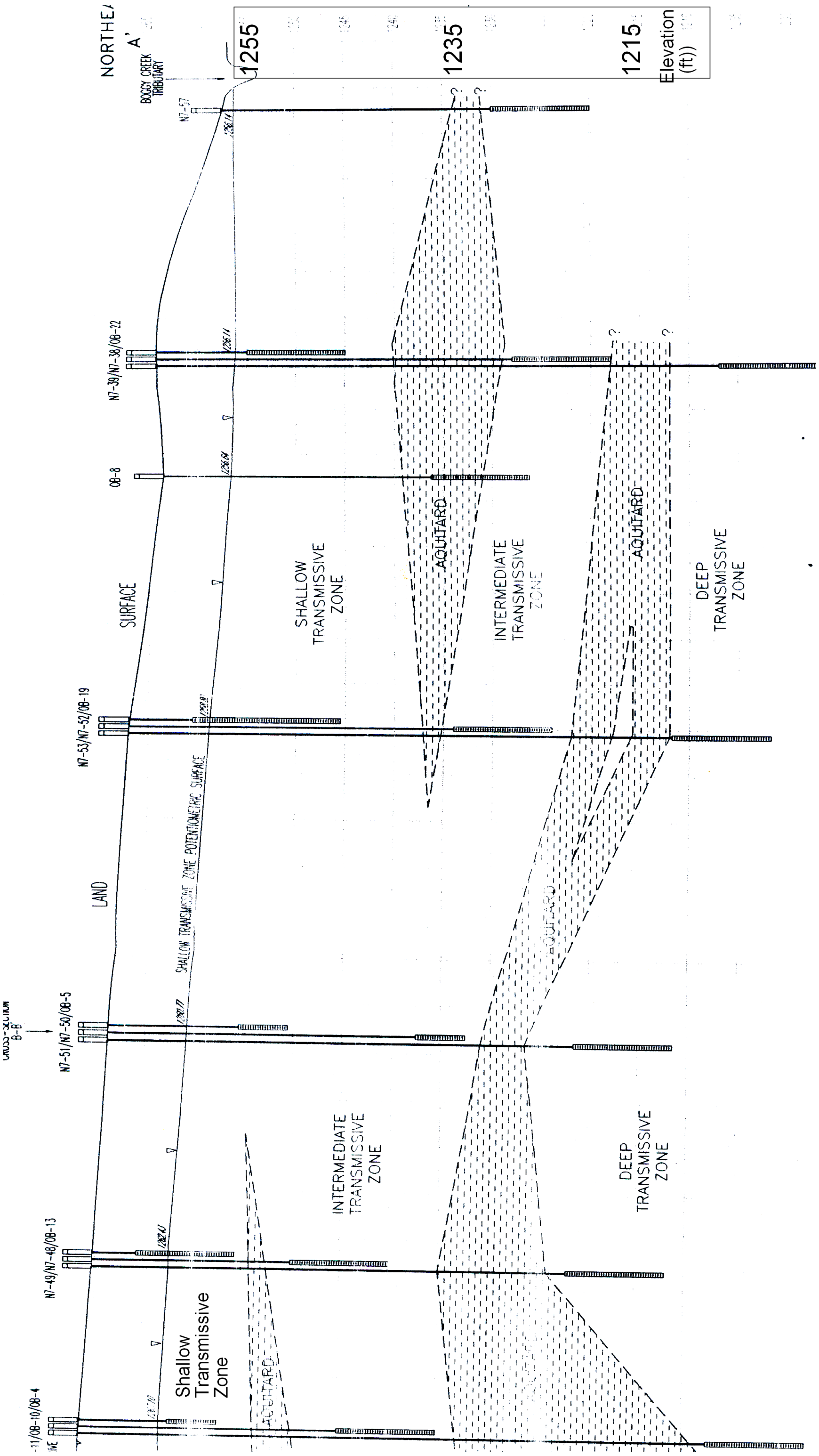


Figure 5.1. Vance AFB Geologic Cross Section

Weathering of the underlying bedrock has resulted in the uppermost soil layer being comprised of brown, silty loam material up to 2.0 feet thick. Unsaturated soils are mostly red to brown lean clays overlying red shale. The lower boundary of the shallow aquifer is usually encountered at 15 to 20 feet below land surface (BLS).

Two generalized water-bearing zones have been identified in this area. The deepest aquifer is confined at a depth of 60 to 80 feet and is overlain by a thick shale unit that prevents any hydraulic connection to the upper water-bearing zone. Above this are two intermingled transmissive zones termed intermediate and shallow, that vary in thickness and depth between 5 and 40 feet. Generally, the Shallow Zone or Aquifer layer starts at a 5 to 10 feet depth and may reach as far as 20 to 30 feet (Vance, 2004). Aquifer testing in 1991 revealed this to be unconfined and recharged by precipitation and therefore the focus of investigation since it was expected to be the first groundwater unit to be affected by migration of any contaminants released in the area. Testing from 14 initial monitoring wells was conducted in the shallow zone and at depths of 18.5 to 31.5 feet and represented silty and sandy clays underlain by silty by fine-grained silty sandstone units as well as lateral thickness variations of individual units, indicative of overall permeability of the shallow aquifer.

Across the entire plume area of study, the elevation of ground water transmissive zones varied from a range of depths from 7.5 to 29 feet, to that of 9 to 12 feet. This variance is due to two factors. The first is due to the low permeability of subsurface formations at this location and a second is due to drilling methods, which introduced smearing along the boreholes. Both of these factors were suggested as contributing to extremely slow groundwater inflows into the monitoring wells. A more permeable sandy clay material was discovered near the bottom of the wells. While depth off the aquifer was estimated between 20 to 22 feet, correlation to gamma ray logs suggested the base of the shallow aquifer occurred at 30 to 45 feet (Vance AFB, 1994).

Over time, groundwater level measurements and well depths were also collected for various wells throughout the project area and were categorized as shallow, intermediate, and deep. Groundwater contour surface maps changed little after 2002 but were generated based on the semiannual sampling events that were required by the Permit as modified in June 2001.

The aquifer thickness was originally derived from AQTESOLV (aquifer test analysis software) for twelve extraction wells in the area of sites 12, 24, and 25 of the CMI area. This provided an average saturated upper level or shallow aquifer thickness of 10 ft. The Theis solution was also used to calculate the transmissivity and storativity for each extraction well (IT, 2000a). The seepage velocity for the model was calculated using the Darcy velocity and an example is shown for the CMI area in Table 5.1.

5.3 REMEDIATION STRATEGY

The historical perspective of remediating chlorinated solvents at U.S. government contamination sites has implemented not only Monitoring Natural Attenuation or MNA but another approach termed Enhance Passive Remediation by the Department of Energy or DOE.

CMI Site

Groundwater Flow Movement Shallow Aquifer

Date	Flow Velocity per Zone V = feet/year	Hydraulic Gradient I = ft/ft
May 2005	21.20	0.0061
October 2005	18.11	0.0052
Average	19.66	
April 2006	18.11	0.0052
Oct 2006	17.07	0.0049
Average	17.59	
Average 2005-2006	**18.63** ft/yr.	

Table 5.1. Shallow or Upper Saturated Zone Site Specific Parameters

These strategies are based on natural and sustainable processes that will degrade and attenuate contamination. It first requires verifying and estimating the existing attenuation capacity at a site. Second, it needs to be determined if the attenuation capacity is adequate to attain regulatory limits within a certain physical distance.

Environmental remediation technologies take several forms spanning from highly active physical removal of contaminants to that of simply waiting for natural processes to perform. This is demonstrated in Figure 5.2. From left to right the methods speak of invasive techniques such as aggressive in situ chemical destruction to passive baseline pump-and-treat in the middle and non-invasive or simple MNA (Chapelle, 2004). Vance AFB has utilized many examples of non-natural attenuation technologies in a highly active pursuit of contamination cleanup efforts over almost 20 years.

Natural attenuation is a concept involving a balanced conveyance to and removal process of contaminants from groundwater systems. This is demonstrated in Figure 5.3 and identifies those input and consumption properties. Advection may be responsible for expansion of a plume over time if contaminant loading exceeds removal mechanisms. This would be the case in which enhanced plume remediation techniques would be applied. Conversely, if removal mechanisms exceed the contaminant loading, the plume will contract. A plume is considered stable when the loading and removal mechanisms are equal These three states of a contaminant plume (stable, expanding, or reducing) form the regulatory basis for utilizing MNA remedial strategy (Chapelle, 2004).

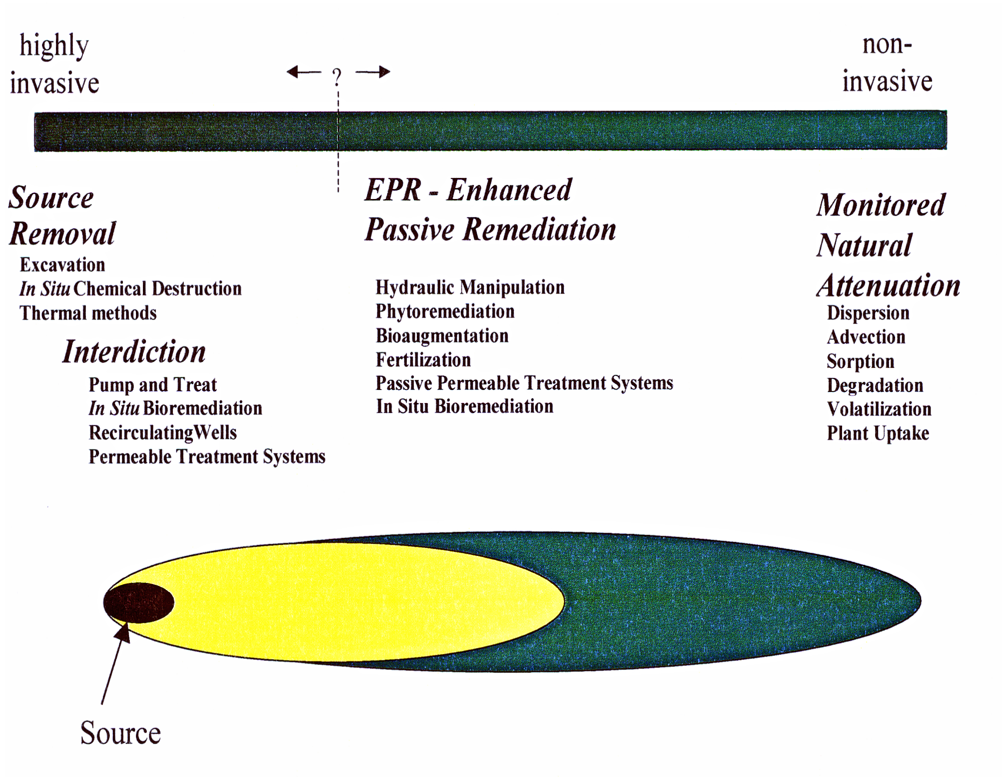


Figure 5.2. Contaminant Remediation Technologies

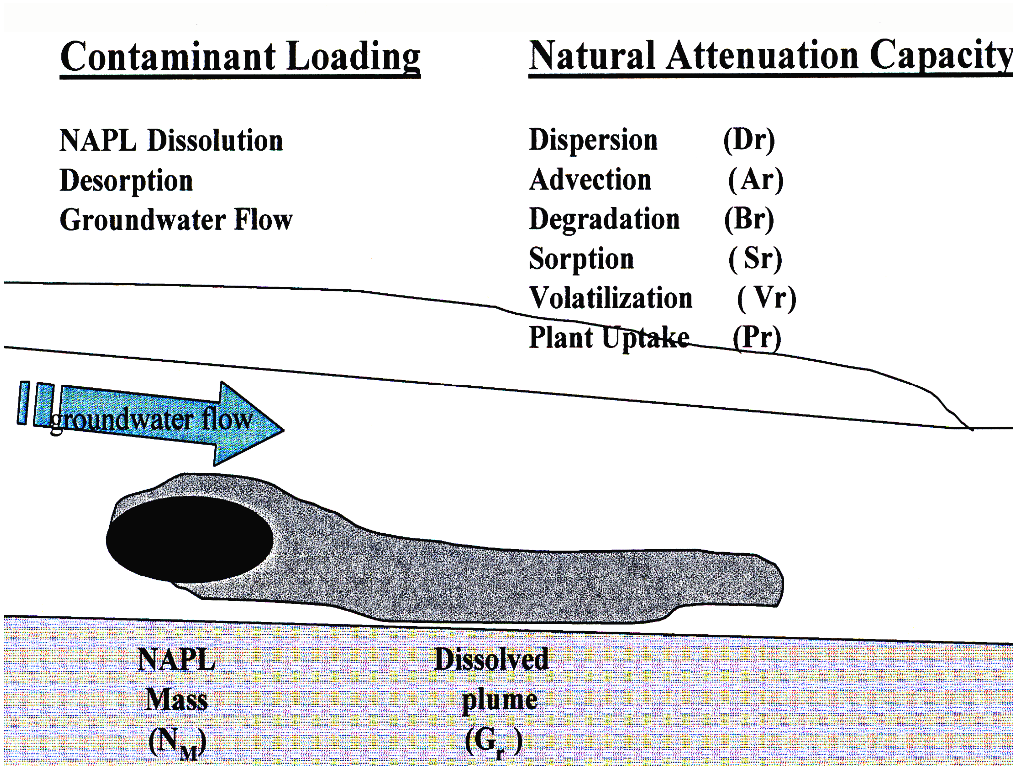


Figure 5.3. Schematic Diagram of Contaminant Loading and Natural Attenuation Capacity in Groundwater Systems

5.4 MOBILIZATION OF DNAPL

Before describing the mechanics of MNA processes, it is necessary to present the nature of a nonaqueous phase liquid (NAPL) or the chemical and physical differences between a hydrocarbon liquid and water. NAPL's are hydrocarbons that do not dissolve in water but rather appear as a separate oily phase whose movement in the subsurface is controlled by gravity, buoyancy, and capillary forces. Free-phase or mobile NAPL released at the surface forces itself into the soil-aquifer matrix due to hydrostatic pressure. Upper levels in the unsaturated zone may release vapors into the air or volatilize. Small blobs or ganglia may snap off the previous NAPL body and become trapped in pores by capillary forces (Bedient, 1994). While a physical interface exists between these, compounds in the NAPL may solubilize into groundwater. This, in effect, produces a situation where the non-aqueous liquid has effectively become an aqueous phase in so many words. To further define the nature of NAPL's, it is known that the specific gravity of the compound determines if it is dense (s.g. > water or 1.0) or light (s.g. < water or 1.0) (Huling, 1991).

These are further defined as DNAPL (dense non-aqueous liquids) or LNAPL (light non-aqueous liquids). The dense liquids can move downward past the water table and penetrate hundreds of feet into the saturated zone (Chapelle, 2004). A simple scenario is a DNAPL release that and travels vertically in the vadose zone and eventually is found in isolated residual globules held by capillary forces. This residual saturation will be leached or solubilized when water percolates through the vadose zone. Leaching can also be created by rising and falling water table levels.

Important DNAPL fate and transport parameters follow.

- Fluid density or mass per unit volume. This delineates immiscible hydrocarbon from LNAPL and DNAPL

- Viscosity is the resistance to flow due mainly to molecular cohesion which is inversely proportional to temperature. Hydraulic conductivity of porous media is function of both density and viscosity.

  $K = k\rho g / \mu$ where, K = hydraulic conductivity, k = intrinsic permeability, ρ = fluid mass density, g = gravity, μ = dynamic absolute viscosity

- Solubility where organic chemical partitions into the aqueous phase.

- Vapor pressure is how readily organic chemicals vaporize.

- Volatility is a measure of the transfer of the compound from aqueous to gaseous phase.

- Interfacial tension constitutes distinct interfaces between DNAPL and water, and between DNAPL and air. The force of attraction of the interior molecules and those on the surface of contact can increase to a point where two immiscible liquids are less likely to emulsify.

- Wetability is the affinity of soil for fluids and the organic phase. The wetting angle of 90 degrees determines wetting fluid; > 90 degrees is DNAPL, < 90 degrees is the fluid, and at 90 degrees neither fluid is attracted to the solid surfaces.

- Capillary force determines magnitude of residual saturation.

- Pore size distribution/initial moisture content directly affects the capillary forces.

- Stratigraphic gradient induces a lateral flow of the DNAPL that may be a different direction than groundwater flow.

- Ground water flow velocity affects dynamic pressure and viscous forces of the groundwater acting on the DNAPL.

- Residual Saturation is the volume of hydrocarbon trapped in the pores relative to the total volume of pores or the saturation in which NAPL is immobilized by capillary forces.

- Relative permeability is the ratio of the permeability of a fluid at a given saturation to its permeability at 100% saturation. (Huling, 1991).

Basically, DNAPL is defined in two different phase distributions. The unsaturated soil zone is comprised of four physical states: air, solid soil, water, and immiscible carbon or DNAPL (Figure 5.4, a & b). Contaminants exist as vapors, and may absorb or partition onto soil, dissolve into the water according to solubility, and be present as dense nonaqueous phase liquids. Six pathways of phase distribution can result by TCE can partitioning onto or between the soil, water, and air. In the four-phase system (Figure 5.5, a & b), TCE is immobile and migrates only in water in the residual zone or in the gas phase or volitilization in the unsaturated zone. Any of the gaseous, aqueous, or immiscible phases occupy the pore resulting in a maximum of three simultaneous flows of the three phases (Huling, 1991). The mobility of this system is poorly understood and is often deferred to the two-phase flow associated with the three-phase system to be explained shortly.

The physical, chemical, and biotic degradation properties of DNAPLs are the basis of their threat to the quality or water since they migrate easily into the saturated zone and penetrate deeply and along substantial horizontal paths.

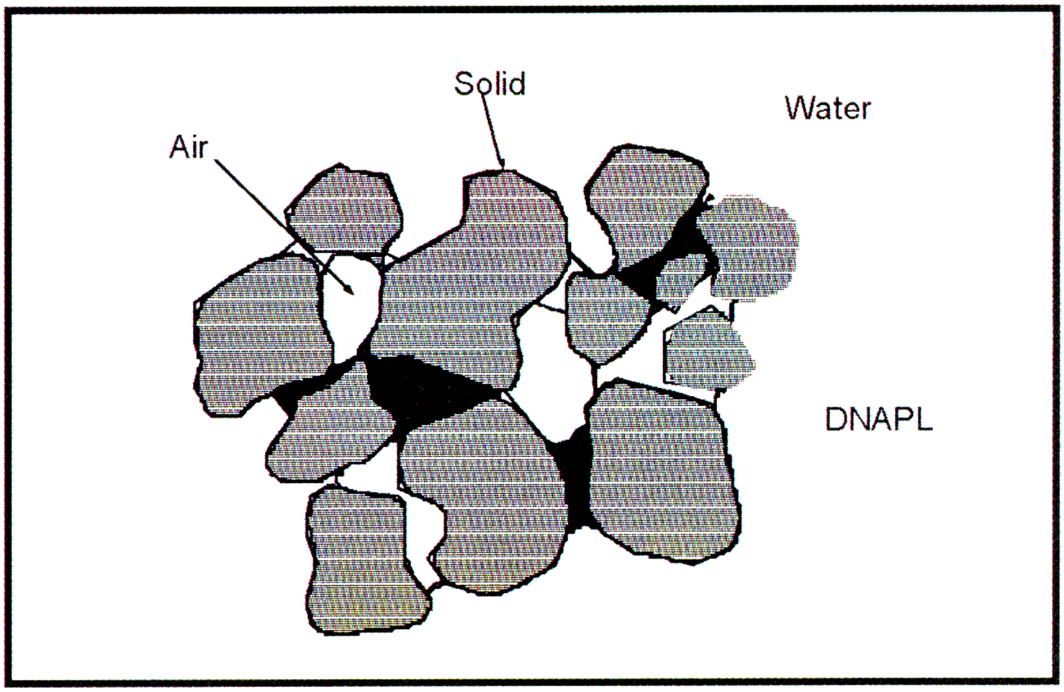


Figure 5.4.a. Four Physical States of DNAPL

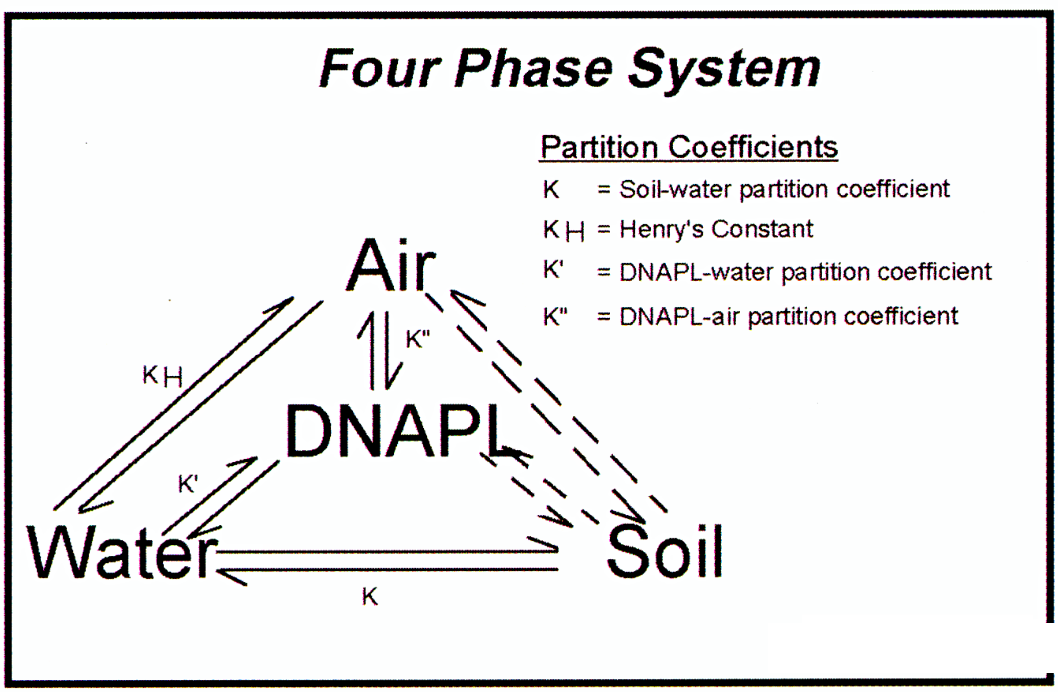


Figure 5.4.b. Distribution of DNAPL Among Four Phases in Vadose Zone

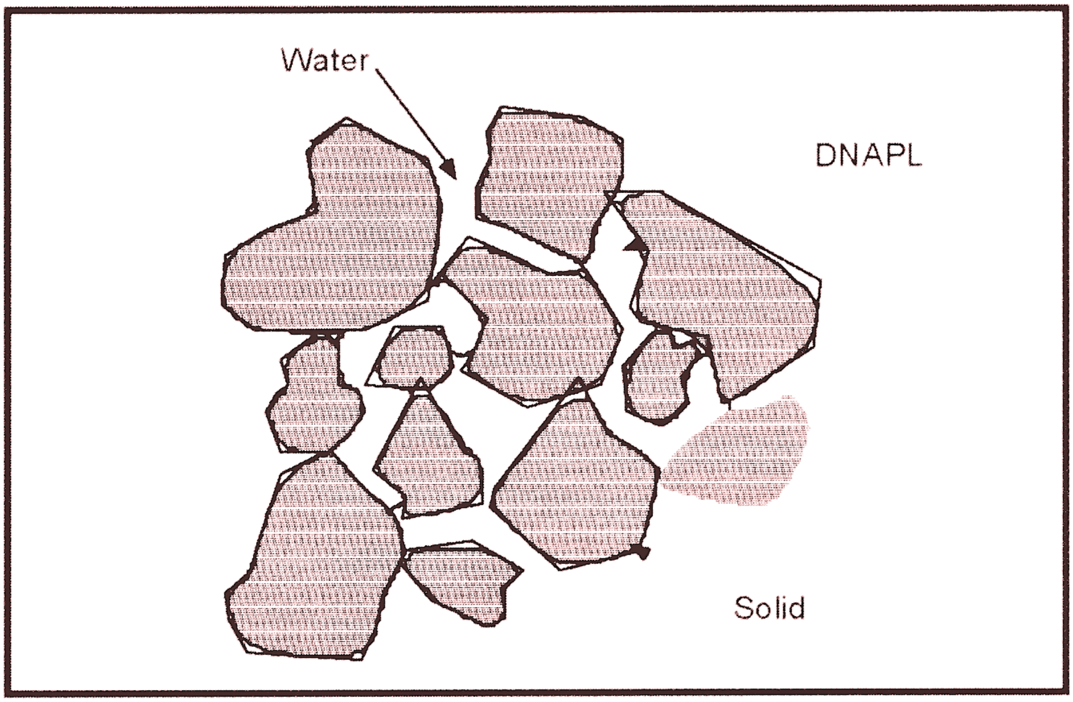


Figure 5.5.a. Three Physical States of DNAPL

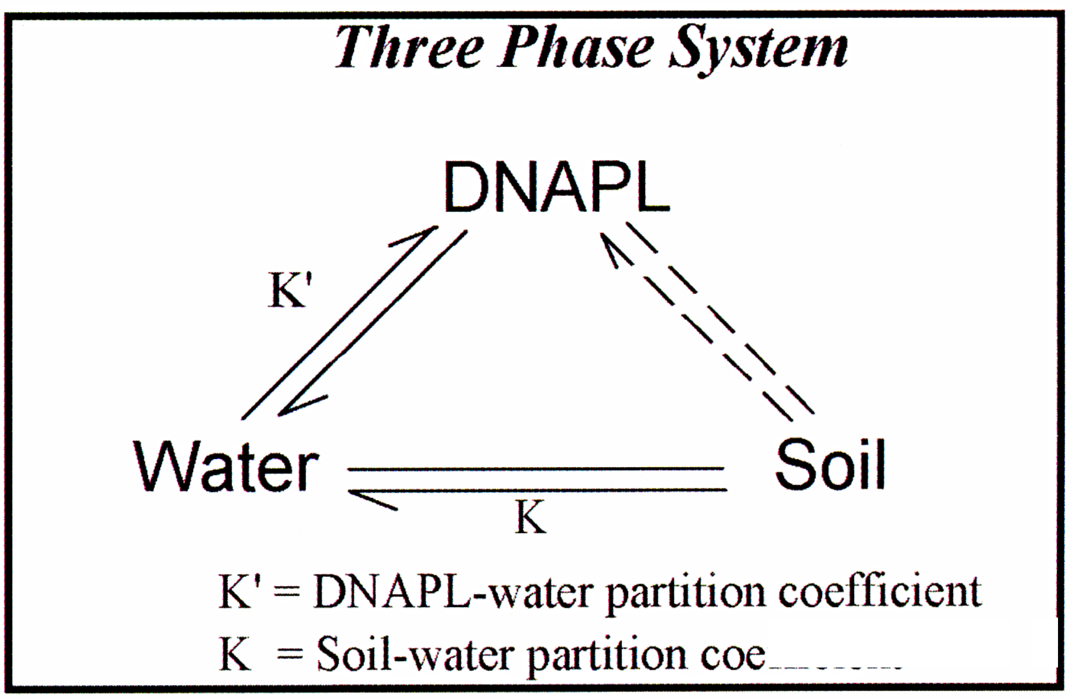


Figure 5.5.b. Distribution of DNAPL Among Three Phases in Vadose Zone

Rates of movement are dependent upon viscosity, density, and interfacial tension which contribute to the hydraulic conductivity of the chemical. Even though the DNAPL's exhibit low solubility (in microgram per liter range or PPB), they typically exceed drinking water standards.

DNAPL constituents slowly partition into the liquid phase creating a dissolved contaminant plume and the solvents do not easily or rapidly degrade biotically or abiotically. Large mobile plumes form and migrate significant distances from the source of the release. Partial degradation of chlorinated solvents can transform the products into "daughter" products such as vinyl chloride or DCE that pose a greater environmental concern (Kavanaugh, 2003)

DNAPL distribution and migration are controlled by two primary geologic conditions one being an unconsolidated porous media and the second being a consolidated (fractured) porous media. The latter media undergoes advective transport in the fracture network while the unconsolidated type demonstrates mean hydraulic conductivity, the degree of hydrologic heterogeneity (varied distribution of values for hydraulic conductivity, and extent of anisotropy and spatial correlation. That is, permeability values in the x and y direction differ from the z direction. The Vance hydrogeology more closely resembles the unconsolidated type in that the specific aquifers have been identified as shallow, intermediate, and deep. Fractured media is also defined as large or small matrix porosity with the Vance being the second type.

The typical aquifer encountered at Vance AFB is that of interspersed and interlocking clay lenses that comprised several layers or aquifers (Figure 5.1). These were originally thought to be a typical isotropic vadose zone of clay and shale rock composition. It is estimated that the performance of these aquifers is similar to rock aquifers. Those aquifers contain fractures of various lengths and apertures and DNAPL's are subject to complex pathways and follow a non-Darcian flow in open pathways or Darcian flow in the porous media filled cracks. Flow is affected by low permeable clay with pathways of varying permeability that allow preferential migration of DNAPL into low permeable formations. Over time at the Vance installation, it has been discovered that the greatest activity was in the upper or shallow zone as opposed to the intermediate and deeper zones that demonstrated lower and fewer concentrations of contaminants.

Again, the second scenario of DNAPL distribution is that of a three phase system of soil, water, and air occurs when a DNAPL reaches the groundwater table and contaminates the water directly. This is considered the case at Vance since the gaseous phase no longer exists. It will continue to migrate vertically downward until it exhausts the residual saturation or reaches a lower permeable formation where it will begin moving laterally (Figure 5.6). Contaminant distribution is termed "residual saturation." There are only three pathways of phase distribution. The presence of a perched impermeable shale and clay layer will intercept the vertical migration of DNAPL and may present multiple discontinuous layers or an intermediate and deep layer (Huling, 1991) such as the case at Vance. Lateral migration will continue although the directional gradient of the impermeable stratigraphic unit may differ from the normal groundwater flow.

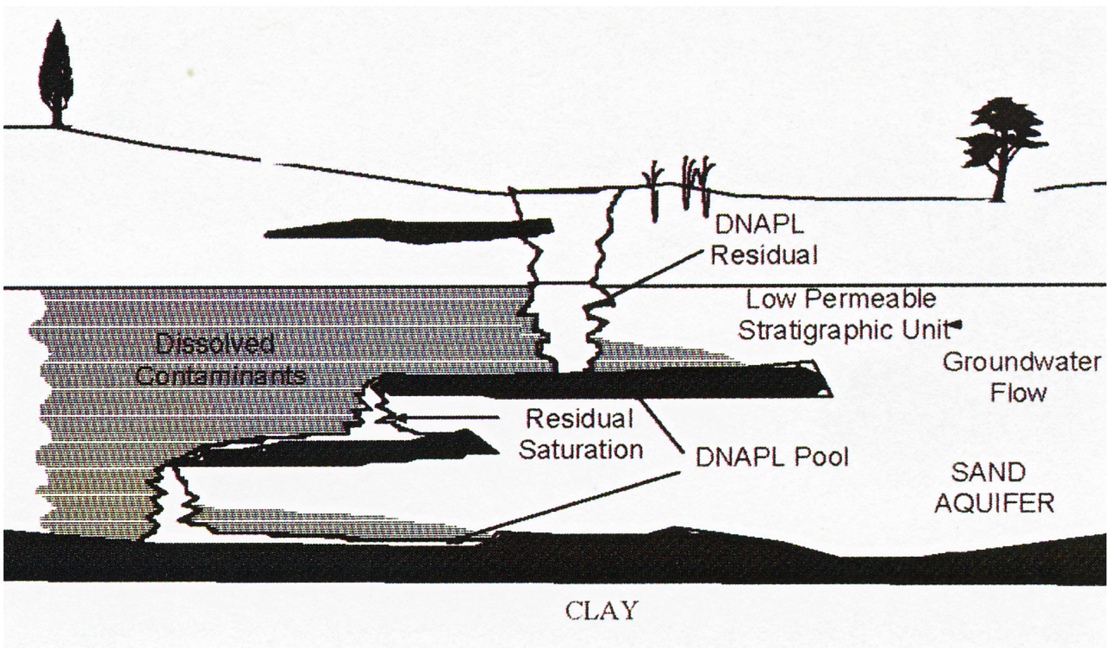


Figure 5.6. Perched and DNAPL Reservoirs

5.5 AQUEOUS or DISSOLVED PHASE

The contaminant or DNAPL takes on its aqueous attribute when considering both its intermingling with the subsurface soil and its dissolution characteristics as discussed above. The mass of dissolved hydrocarbons is demonstrated by the concentration observed from well tests over time. These represent the mass of contaminant that is held in the soil irrespective of the non-aqueous phase. That contamination is representative of the amount of pore volume occupied by the residual NAPL blobs trapped in individual pores. The concentration of In essence, this comprises what would otherwise be considered as the “dissolved phase” of a plume. This constitutes the remaining portion of the original mass of contamination that has not yet dissipated to regulatory limits. It is “locked up” in the soil-aquifer matrix and must overcome those forces holding it there which could also include the methods of degradation and plant uptake (Bediant, 1994).

5.6 FATE AND CONTAMINANT TRANSPORT MECHANISMS

Distribution of organic contaminants in groundwater and the soil system would result from functions of MNA. The transport concepts follow that relate to migration and fate of contaminants in a hazardous waste site plume (Bediant, 1994). These include dilution and dispersion, retardation from sorption onto aquifer sediments, advection, volitilization, and plant uptake. They also can occur with some degree of biological degradation and transformation. The latter could be considered dependent upon the types of other toxic chemicals and possible interaction with microbes in the soil. Therefore, this report will also seek to consider aerobic and anaerobic decomposition for the organic chemicals (Huling, 1991).

Advection demonstrates movement of the contaminant along with moving groundwater related to the seepage velocity. Advection is defined as the average linear velocity, or seepage velocity, is the Darcy velocity divided by the effective porosity or the pore space through which water flows. Tortuosity or the path through water around solids tends to create a seepage velocity that is less than the flow of microscopic velocities of water molecules moving along individual paths (Bedient, 1994).

Diffusion is related to this in that a solute in water moves away from an area of higher concentration to a lower concentration and in the absence of velocity. It is peculiar to clays with very low velocities. Dispersion is an effect of a greater degree. Advective-dispersive transport is created when a fluid is moving at an average linear velocity creating an advective front in which some mass advances and some lags. This is defined as producing a dispersed breakthrough curve caused by heterogeneities due to friction in a pore channel, velocity changes in channels of flow, and variable path lengths. Dispersion can occur in the longitudinal (y) and transverse x) directions and in front of the advective front. The normal shape of a representative two-dimensional plume is shown in Figure 5.7a. as compared to advection only in Figure 5.7b (Bediant, 1994).

In the later discussions of newer MNA software evaluation analytical tools, it will be seen that the mechanisms above are simulated in the prediction of contaminant plume movement and concentrations of contaminant.

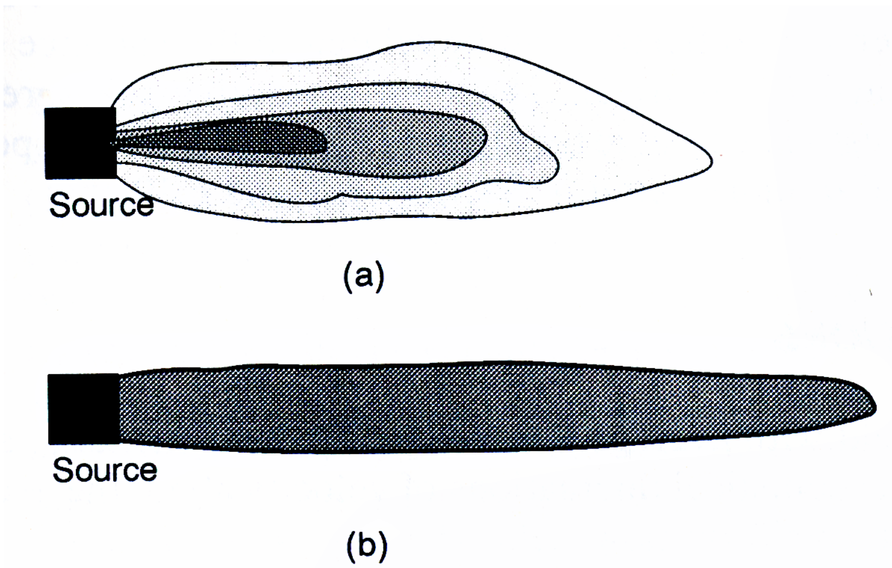


Figure 5.7. (a) Advection and dispersion. (b) Advection only.

It will be noted here that a mathematical model being applied to this site to describe the fate of chemicals is discussed primarily as that of the first-order rate. Generally, a mathematical model of solute transport would consider advection, dispersion, fluid sinks/sources, equilibrium-controlled sorption, and first-order rate reactions (Ruiz, 2001).

$$-\frac{R\,\partial C}{\partial t} = \frac{\partial}{\partial x_i}\left(D_{ij}\,\frac{\partial C}{\partial x_j}\right) - \frac{\partial}{\partial x_i}\left(v_i\,C\right) + \frac{q_s}{\theta}Cs - \lambda\left(C + \frac{\rho_b}{\theta}\,C\right)$$

This would include the retardation factor defined as:

$$R = 1 + \frac{\rho b\ C}{\theta\ C}$$

where: $\bar{C}$ is sorbed concentration MM^{-1}

C is dissolved concentration, ML^{-3}

v_t is seepage velocity LT^{-1}

D_{ij} is dispersion coefficient L^2T^{-1}

q_s is flow rate of fluid source or sink

Cs is concentration of the fluid source of sink flux ML-3

λ is reaction rate constant T^{-1}

θ is porosity

ρ_b is bulk density of porous media

In general, these would be the terms that would need to be applied for a chemical to determine the fate and transport. Types of reactions and other information specific to the constituent are discussed further below (Zheng, 1995). A compound will degrade over time at a particular rate in which biodegradation will be dependent upon environmental conditions and substrate concentration.

The Monod equation defines this as,

$$\mu = \mu_{max} S \ / \ K_s + S \tag{5.2}$$

Where μ = growth rate of microbe, S = substrate concentration, μ_{max} maximum growth rate of microbe, and K_s = a constant defined as the value of S at $\mu = 0.5\ \mu_{max}$ (Appendix 7, 2006).

While a zero-order rate constant exists that does not affect the rate of biodegradation as the substrate is biodegraded, the first-order rate constant is commonly used due to the lack of points and ease in which these values are calculated (Aoronson, 1997).

The above is represented by the first order decay model which takes into account natural attenuation processes to include biodegradation, hydrolysis, and sorption (Appendix 7, 2006).

$$C = C_o e^{-ktc} \qquad (5.3)$$

where: C = final concentration of stressors

Co = initial concentration of stressors

K = decay coefficient

tc = travel time

Retardation is a coefficient that takes into account the natural attenuation process of sorption which increases the travel time of stressors. Calculation of the retardation coefficient for dissolved organic constituents follows:

$$R = 1 + \frac{\rho b \; K_d}{n}$$

where: ρb = final concentration of stressors

ρs = initial concentration of stressors

n = porosity

K_d = decay coefficient

K_{oc} = sorption coefficient

f_{oc} = fraction of total organic carbon

$$R = 1 + \frac{\rho_s \,(1 - n)\, K_{oc}\, f_{oc}}{N}$$

Upon reviewing the mechanisms for DNAPL activity, Data collection, and methods of analysis, the next step will be to review an actual case study of aquifer contamination by TCE in two plumes.

5.7 MAROS CASE STUDY AT VANCE AFB

As mentioned earlier, the following will demonstrate the MAROS analysis features for the specific case study of Vance AFB, for plumes shown in Figure 1.2. Collection of data for LTM spanned nearly two decades. The groundwater monitoring plan now being implemented at Vance AFB is based on several data inputs from various entities over the 1990's through 2006. The data has been arranged in the format needed to satisfy hydrogeologic transport models and continues to be of value for analyzing long-term monitoring plans with newer tools such as the MAROS 2.2 public domain software program.

Over several years, various interim remediation measures were installed at Vance AFB to prevent the migration of contaminated water. One of these was the construction of a central groundwater treatment facility on the north boundary of the CMI zone. The facility was designed to treat and process contaminated water to reach an acceptable level virtually free of contaminants prior to disposal into the City of Enid sanitary sewer system. Interceptor collector trenches with extraction wells were constructed essentially at the head and tail ends of the current Site 07 plume. The head end was constructed in 1998 to prevent migration northward from Sites 03 and 08 and the second wall was constructed to prevent migration into the Boggy Creek tributary near the northern boundary of the base. That location was also designated as the northern extent of the project boundaries to be included for analyzing plume characteristics and achieving remedial goals. More recently, in 2002, an Oklahoma DEQ-approved corrective measure was implemented that included extraction wells and a cut-off wall. A series of extraction wells was installed in an attempt to achieve the remediation goals described in the approved Corrective Measures Study (CMS). This effectively separated the existing contaminated area within the boundary of the north end of the base, from the portion of the plume that had extended outside the base. Those wells within the base were generally identified as part of the Corrective Measures Implementation Plan (CMI) Area. As required by the 2001 Permit, that specified 34 wells to receive sampling and testing on a semiannual basis for 10 years followed by sampling at an annual basis for the following 15 years (Figure 5.8). The area north and outside the base boundary was identified as the Industrial Zone (IZ) and was comprised of 42 previous wells that included wells from the Installation Restoration Program Sites LF-03, SS-07, and LF-08 (Figure 5.9). The Permit modification in March 2003 allowed that wells be considered as having attained remediation at regulatory limits when a well had demonstrated it had achieving six consecutive sampling events with the COC detection below the MCL.

A regular frequency of semiannual sampling events began in 2005 for the CMI and IZ areas by EA Engineering, Science, and Technology, Inc., in accordance with the ODEQ Resource and Conservation Recovery Act (RCRA) Post Closure Permit. (EA, 2006 & 2007)

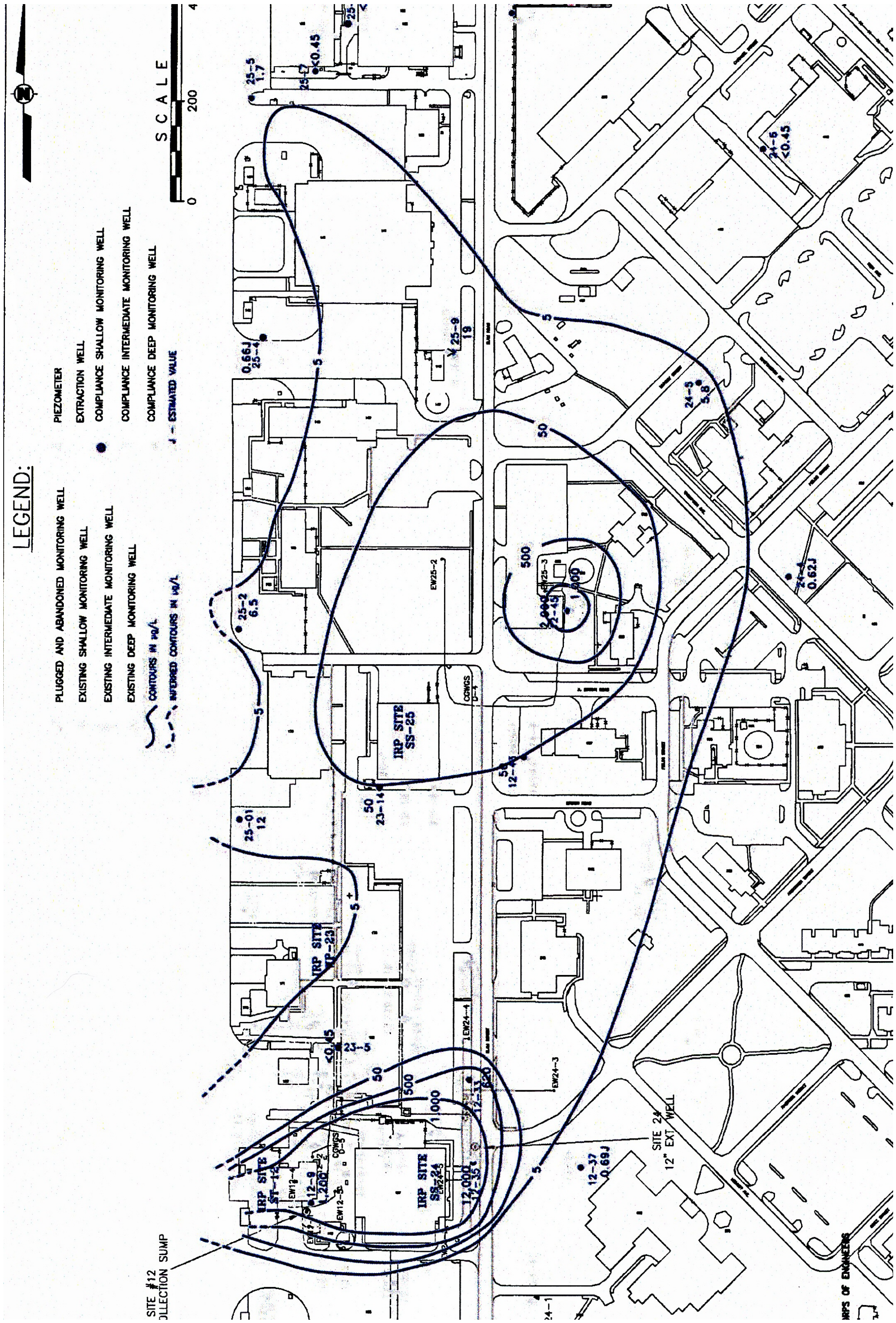


Figure 5.8. CMI Site Shallow Transmission Zone TCE Contours Oct 2006

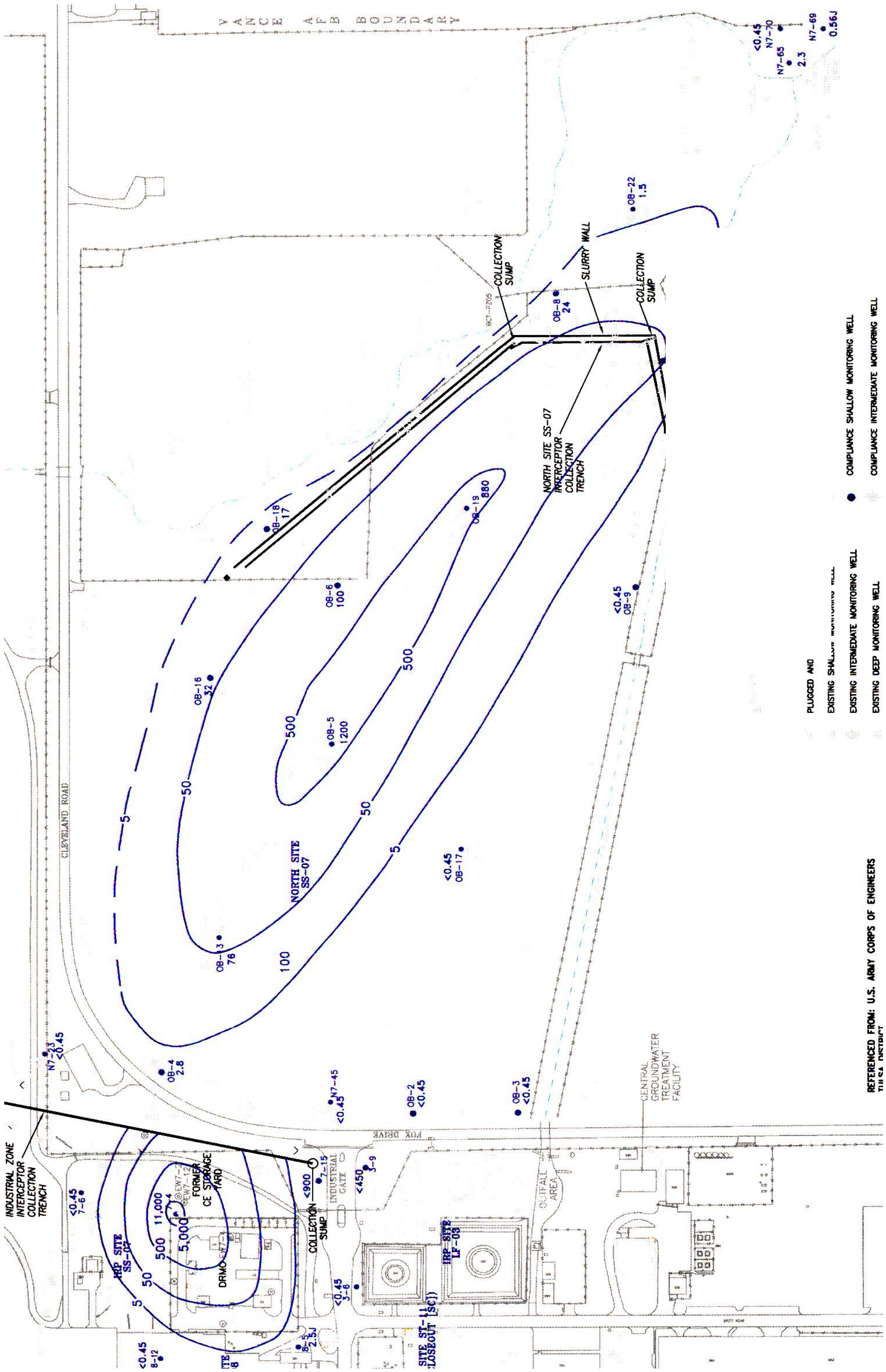


Figure 5.9. Industrial Zone Shallow Transmission Zone TCE Contours Oct 2006

For several contaminants in the CMI and IZ, performance monitoring and compliance monitoring are principally directed at the shallow hydraulic zone for TCE to control the hydraulic plume, monitor plume reduction, and reduce the number of monitoring wells. Only TCE was recommended for this analysis since it was the only persistent contaminant remaining that exhibited more than scant data as was evidenced by all other contaminants in 2005.

To apply MAROS methodology at the Vance CMI and IZ sites, the following site parameters were considered. Only TCE was determined to be above acceptable regulatory levels and only consistent in the shallow zone. Since it is a degraded product of TCE, cis-1,2-DCE was excluded from consideration due to very little detection exceeding the MCL. Some high levels of metals were detected but data was severely limited in number of wells sampled and data sets such that it would be improbable to analyze with MAROS. Some high levels of VOC's such as benzene, toluene, ethylbenzene, and xylene were detected in the deep, intermediate, and shallow zones. It should be mentioned that the geology is comprised of intermingled and sloped units of clay-shale resulting in three zones of water. The deepest is isolated from the upper two zones that vary in thickness from 5 to 40 feet with the shallow zone ranging from 5 to 30 feet. The VOC readings were few and sporadic indicating positive achievement of attenuation. There was not enough data to support or warrant MAROS evaluation, i.e., less than the required four sample events with at least six wells.

Flow velocity measurements of the shallow aquifer in the area of the two major plume areas of the CMI and IZ appeared to decrease from about 52 ft/yr in 2002 to less than 18 ft/yr in 2006. This is partly due to the varied site areas and distance of flow due to assigning larger plume areas and extending the permit boundaries through the acquisition of additional property on the north side of Vance AFB. The 2005-2006 flow velocities were determined over the length of the entire plume (about one-half mile) whereas the earlier evaluation tested just the current “source” of the plume (length of about 1,000 ft.). Although it appears the rate decreased from 2005 to 2006, the average of that rate or 18.63 ft/yr. was used in the MAROS analysis. Similarly, a rate of 14.67 ft/yr was applied to the IZ area (EA, 2006). The saturated thickness of 20 feet was used, based on the general knowledge that the shallow transmissive zone monitoring well screens placed at between 10 and 30 feet in depth.

5.8 OVERVIEW STATISTICS - PLUME TREND ANALYSIS

The Mann-Kendall Linear Regression Analysis requires a minimum amount of data to determine a trend with confidence. That data is considered to be two years of quarterly data but as few as four wells with four or more sampling events with measured concentrations over six most-recent sampling events) may suffice. The overall result of information weighing the results of both Mann-Kendall and Linear Regression temporal trend analyses are shown in Figures 5.10 and 5.11, respectively. Figure 5.10 represents the wells in the CMI area while Figure 5.11 represents the IZ wells. The “S/T” column indicates those wells that were located in the source (S) or tail (T) of the plume. It should be noted that the Information

WELL NAME	S/T	TREND RESULT
MW23-34	S	D
MW12-33	S	S
MW12-35	S	S
MW12-37	S	S
MW23-05	S	NT
MW23-14	S	S
MW12-09	S	NT
MW12-43	T	D
MW12-45	T	I
MW24-05	T	NT
MW25-15	T	S
MW25-01	T	I
MW25-02	T	D
MW25-04	T	S
MW25-05	T	S
MW25-07	T	D
MW25-08	T	NT
MW25-09	T	D
MW24-04	T	D

Figure 5.10. Results of Information Weighting –CMI Site

WELL NAME	S/T	TREND RESULT
OB-04	S	NT
N7-45	S	S
OB-02	S	PI
N7-23	S	S
OB-03	S	NT
OB-13	S	S
OB-16	T	D
OB-08	T	I
OB-06	T	S
OB-22	T	PD
OB-17	T	D
OB-18	T	NT
OB-19	T	S
N7-70	T	S
N7-69	T	D
N7-65	T	D
OB-21	T	PI
N7-41	T	S
N7-40	T	NT
OB-05	T	NT

Figure 5.11. Results of Information Weighting – IZ Site

Weighting step not only provides an opportunity for weighting lines of evidence previously explained, but it can also summarize the results of the Mann-Kendall and linear analysis results without weighting as shown in the above figures.

Those results show that wells with fewer than four sampling events could not be evaluated as indicated by “NT” (no trend) which amounted to four wells in the CMI and five in the IZ. The remaining 15 of a total of 19 CMI wells with sufficient data demonstrate that 13 wells have Probably Decreasing, Decreasing, or Stable trends and two wells show an Increasing trend. The remaining 14 of a total of 19 IZ wells with sufficient data demonstrate that 12 wells have Probably Decreasing, Decreasing, or Stable trends and three other wells show an Increasing or Probably Increasing trend.

5.9 RESULTS OF INFORMATION WEIGHTING – IZ SITE

The center of the CMI plume is increasing in concentration in the area of well 12-45. It is presumed that this is due to the presence of an extraction well about 50 feet away. Another extraction well is located about 200 feet west. Together, these extraction wells draw the groundwater or plume flow towards well 12-45 and create a false observation that the plume is increasing in concentration when it is actually sensing the contaminant being collected and sent to the groundwater treatment facility. Well 25-01 also shows a slight increase over time from 5.9 ug/l in 1998 to 12 ug/l in 2006, which may also be due to a similar effect from the extraction wells. This may correlate with the discovery of movement of the apparent center of the plume towards the west, as discussed in the following section.

Moment analysis is not as straightforward as it could be due to the varying evolution of contaminated sites in both the CMI and IZ areas and methods to control them. The contaminant concentration that was the basic core of the now-defined CMI area site originated at the area of well 12-01 which measured 9,600 ug/l in 1998 (well number 12-09 very nearby to the east registered 1,640 ug/l). The area at well 12-35 registered over 10,000 ug/l at the same time. This may be due in a large part to its location next to an extraction well. As a result, these two wells were included as source wells in the moment analysis.

The contaminant plume defined as the IZ area originally stemmed from contamination activity in the areas of sites LF-08, LF-03, and the early sites of LF-07 which were on the north end of the Vance AFB flight line or otherwise at the north boundary of the original air force base. The installation of an interceptor collection trench at the corner of Cleveland Road and Fox Drive essentially separated the original Site 3 and Site 8 wells from the area north of Site 07. Therefore, an evaluation of TCE was performed only on the wells north of the collection trench identified as N7 and OB wells as shown on Figure 4. Plume activity determined by test well data analysis in 2001 clearly indicated that the original plume on the north end of the base had split into two separate and distinct plumes. The larger segment of the plume identified with wells N7 and OB had reduced in concentration in a south-southwest direction.

The CMI site evaluation indicated reasonable stability of the TCE plume. The zeroth moment analysis showed a probably increasing (PI) trend or increase in dissolved mass for TCE. This may be due to the extraction well activity around well 12-45 which is collecting and thus creating a false reading of an increased concentration of contaminated groundwater as explained earlier. The grouping of test wells in the CMI area resulted in a range of 16 to 19 wells over time so indicated the increase was not due to varying the number of wells tested. It therefore seems to reflect the increase of concentration at well 12-45 and is supported by a high confidence in the trend. The zeroth moment of the IZ plume indicated no trend (NT) with a low confidence trend indicating a need for more monitoring.

The first moment, or center of mass of the TCE plume in the CMI, was indicated by MAROS to be probably decreasing (PD) which suggests that its center of mass was somehow closer to the source contrary to the groundwater movement in the opposite direction. This is likely in some degree to the current concentration around well 12-45 for TCE that had increased over time while the overall plume decreased in size. The mass initially indicated a movement away and then began to consistently retreat toward the source especially in late 2006 when the concentration decreased dramatically at well 12-45. It is noted that those movements were somewhat cyclical and were directly related to groundwater flow. (AFCEE, 2006a) They could relate to other hydraulic events such as rainfall. It too is supported by a high confidence in the trend. The first IZ moment indicates increasing distance from the source to the center of mass and is supported with a very high confidence trend.

The second moment, or spread of the contaminant about the center of mass over time in both x and y directions, demonstrates a Stable condition for the CMI in the y direction and Decreasing in the x direction. This moment provides a measure of the spread about the plume's center of mass or a narrowing in the width east-west while maintaining about the same length north-to-south. The Mann-Kendall statistic was slightly negative indicating slight movement towards the source which is consistent with the first moment. The high confidence trend is also consistent with the Mann-Kendall and Linear Regression spatial trend analyses which showed many tail wells (opposite and downstream of source wells) with Stable, Decreasing, or Probably Decreasing TCE concentration trends. The second IZ moment indicates the shift in the x and y direction of plume spread is relatively stable although the confidence trend of 75.8% is somewhat low. The Mann-Kendall S statistic of -9 is slightly negative and indicates a contracting plume.

Plume Analysis or overall plume stability was evaluated with weighting of wells by manually selecting the setting of "Medium" which assigned equal importance to each well and each trend result. This means that weighting will not be applied. The weighting method or lack of it will be equally applied to all wells in this scenario. The Monitoring System Category Screen produced during the MAROS processing, produced the following results. An overview of the CMI area indicated the source region trend was Stable; the tail region trend was Stable; and the moment analysis indicated the plume was most likely decreasing. Thus, the overall monitoring intensity needed was Moderate. An overview of the IZ area indicated the source region trend demonstrated no trend (NT) while the tail region trend indicated it was stable (S) while the moment analysis indicated the plume was most likely decreasing. Therefore, the overall monitoring intensity needed was Moderate.

These results are compatible with the discussion and results of the Moment Analysis. The TCE plumes shown in the 1998 and 2006 TCE contours maps indicated the plume was relatively stable but diminishing within the same basic contours as the original plume. The area north of center exhibited an abnormal increasing concentration near CMI well 12-45 while the periphery was definitely decreasing. Because of this increased concentration, the analysis suggested monitoring might be needed along the east side of the plume, as discussed later in this paper. Since the second moment indicated the plume center of mass was retreating slightly toward the source well, it seemed likely that monitoring that edge would be appropriate in case the direction shifted. The actual movement was an anomaly since the groundwater flow was in the opposite direction. Again, it may be conjectured that the movement was not actual but merely a reflection of the increased concentration at 12-45 which could have been creating a false simulation of increased concentration toward the south-southwest.

The results so far are based on knowledge from the MAROS application to general site trends but do not provide any recommendations concerning changes to the established sampling frequency. These overview statistics will be used next to supplement the detailed statistical analysis in the following section for well redundancy and sampling frequency with resulting MAROS well-by-well recommendations.

5.10 DETAILED STATISTICS - OPTIMIZATION ANALYSIS

During the history of the CMI and IZ sites, many well locations were sampled including monitoring wells, peizometers, extraction wells, and two interceptor trenches. Many are no longer in use due to various reasons. Of those remaining monitoring wells, there are 19 CMI well locations and 20 IZ well locations included in the analysis for this report. These were used in the following MAROS sampling optimization analysis for well redundancy and well sufficiency, sampling frequency, and data sufficiency analysis.

The object of the well redundancy analysis that incorporates the Delaunay Method is to identify wells that may be removed from the sampling system that have little impact on further well characterization. Such analysis was conducted on 19 and 20 wells, respectively, in both the CMI and IZ for the period 1996 through 2006. All wells were considered candidates for removal.

The Access module results indicated that the following CMI wells could be eliminated: 12-09, 12-33, 12-43, and 23-14. This is due to a relatively low slope factor that indicates the relative importance of the well is low. Note that the optimization analysis Delaunay diagram shows only 17 of the original 20 wells in the test analysis. A peripheral well 23-34 is not recommended for elimination possibly because it may be needed to monitor the apparent movement of the plume center of mass towards the southwest. It is consistent with the need to monitor such activity that well 25-01 remains on the periphery for the same reason. The Optimization Result Delaunay diagram for the last testing event (51st event in the total number of monitoring well test events) does not include wells 25-05 or 25-08, which were on the periphery and reported very low contamination levels well below the MCL (Figure 5.12).

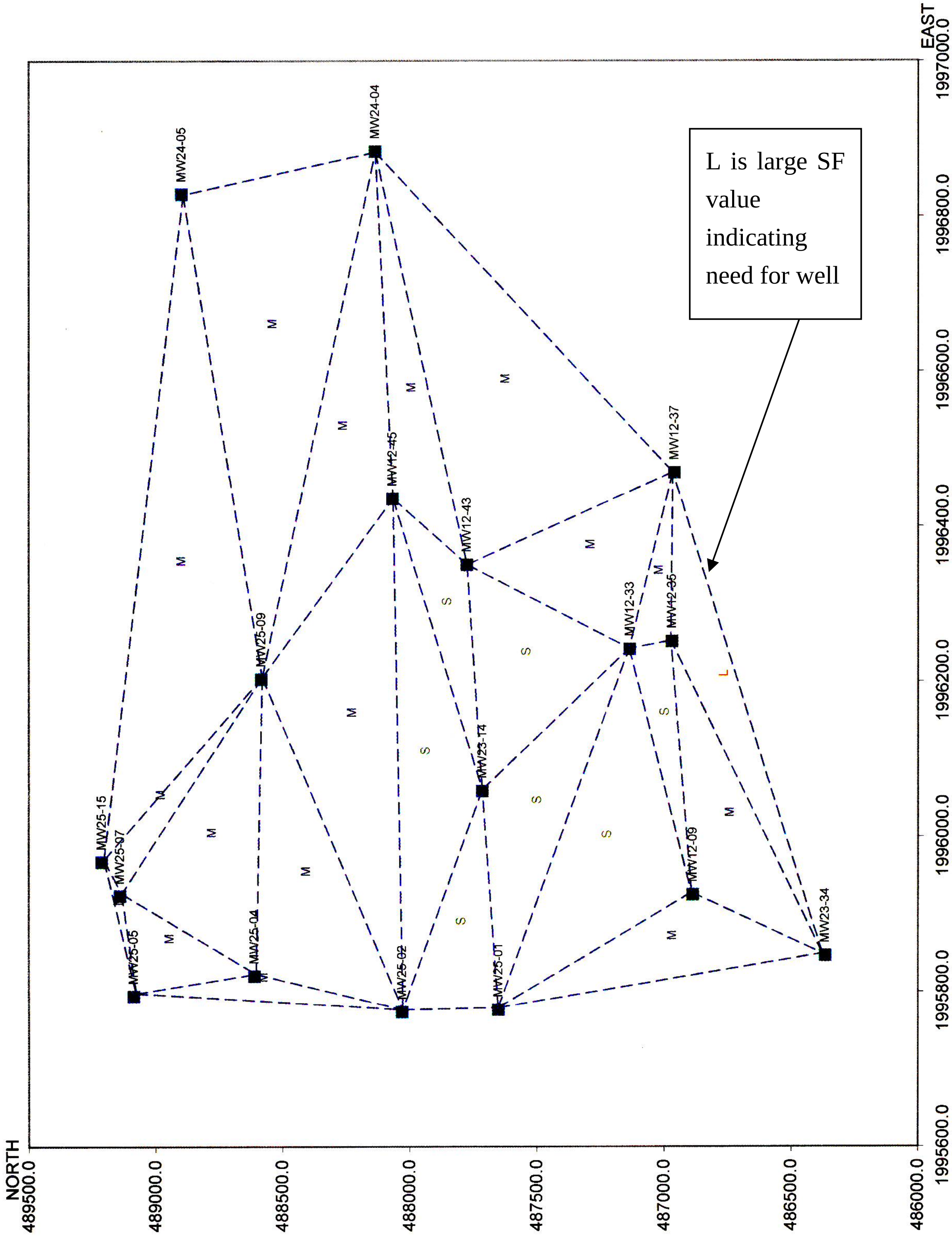


Figure 5.12. Delaunay Optimization of CMI Area

The Access module results indicated that the following IZ wells could be eliminated: OB-06 and 0B-08. The optimization analysis Delaunay diagram does not show eight of the 20 IZ shallow TCE zone wells; N7-23, N7-41, N7-45, N7-70, OB-02, OB-03, 0B-04, and OB-05 (Figure 5.13). This suggests they failed to generate slope factors due most likely to the low number of detected low concentration values. Upon selecting the optimization feature of MAROS, a separate graphic is generated that shows the remaining wells less the deleted wells

A comparison of protocols follows regarding recommendations for discontinued testing of monitoring wells in the CMI and IZ zones. In their February 2007 letter, the Oklahoma Department of Environmental Quality approved 25 wells at Vance AFB for discontinued testing since their MCL levels were lower than the MCL for six consecutive testing periods. Note that the only shallow well included in that letter that compared with MAROS was MW OB-08. The letter listed many additional shallow wells (23-34, 24-04, 25-5, OB-17, OB-22, N7-23, N7-41, N7-45, N7-65, N7-69, and N7-70) for discontinued testing. That criterion was based on test results for the previous six testing events that had resulted in contaminant levels below the MCL.

Comparison of the ODEQ recommendations and the wells omitted during MAROS optimization for the IZ area indicate general correlation with the southern band of wells OB-03 to N7-23. Those wells basically reported as having attained remediation below 5ppm for TCE. The MAROS Delaunay Optimization figure was created with wells that

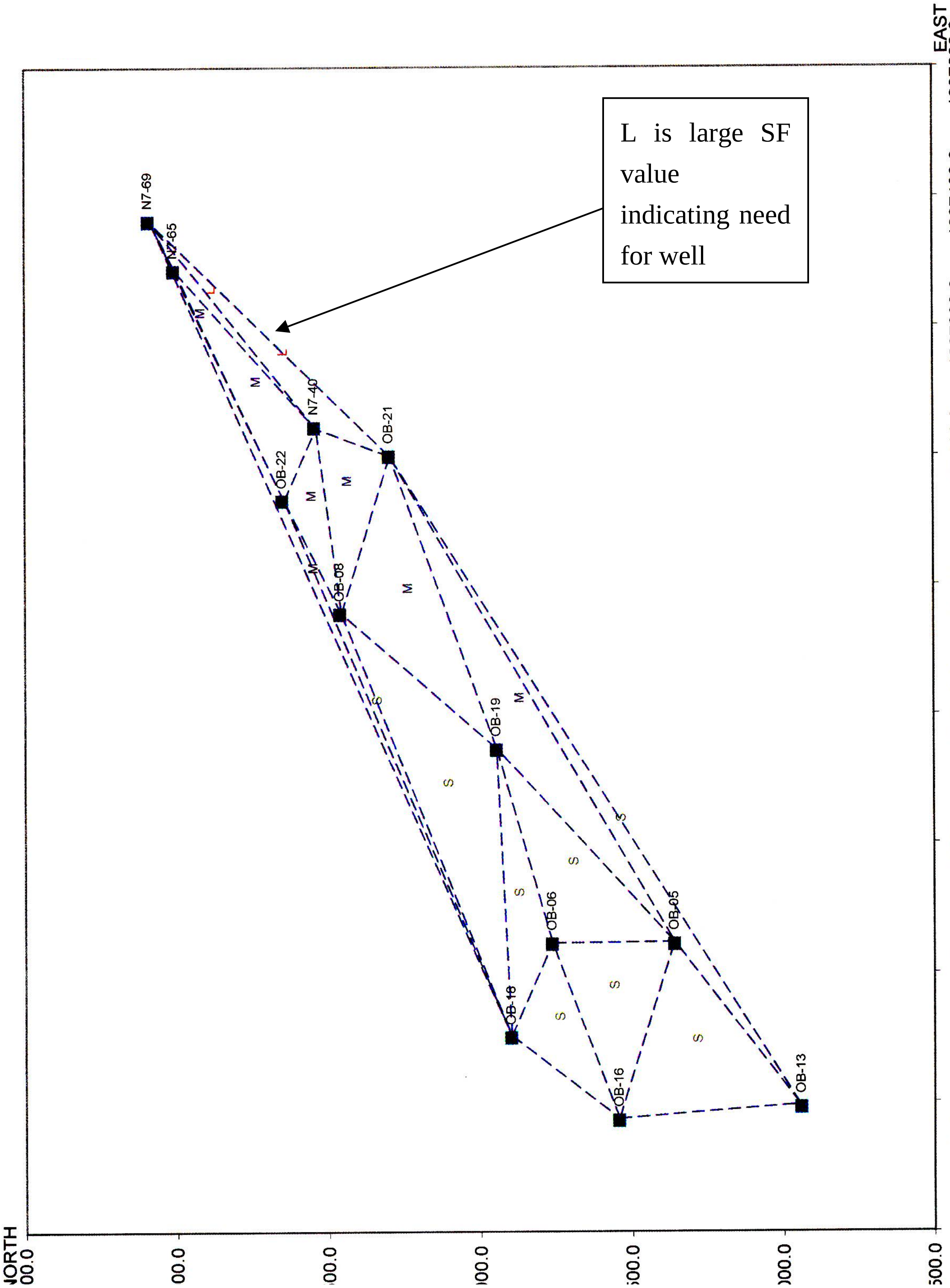


Figure 5.13. Delaunay Optimization of IZ Site

demonstrated detectable levels of TCE even though they were below the MCL. Other wells that had recorded lower numbers of detects became candidates for deletion. The wells on the north side of the North Site Interceptor Collector Trench continue to report enough detects to warrant MAROS to maintain them in the optimization analysis.

Well sufficiency analysis also incorporates the Delaunay method to determine the need for additional or new sampling locations was performed for the same sets of monitoring wells used above in the CMI and IZ. Areas within the monitoring well network that are determined to contain large uncertainty for predicting contaminant concentrations are identified with a recommendation for additional sample locations. New locations are sometimes required to complement and offer greater predictability when applying the triangular network calculations and enhance the spatial plume characterization. It cannot recommend new locations on the periphery since it would lack the triangulation needed. However, note that the Delaunay triangulation map for the CMI indicates a “Large" estimated slope factor (SF) level in the southeast corner of the monitoring area between wells 23-34 and 12-37 (Figure 5.12).

The MAROS sufficiency analysis tool utilizes Delaunay triangulation in creating relative concentration estimation errors at sampling locations. First, a slope factor value is obtained by comparing an estimated concentration of a well at the center of triangular vertices, to measured concentrations. Each Delaunay triangle is considered a potential area for new sampling locations. For this, an average slope factor value is estimated by dividing the each triangle into three parts and then calculating the average of the product of each slope factor and area divided by the sum of the areas. Triangular areas between wells that register high are candidates for new sampling points. The Large estimation above indicates the need for an additional monitoring well location. This may be due to uncertainty of adequate testing results when considering the first and second moment predictions. The Delaunay triangulation map for the IZ indicates a "Large" estimated SF level in the northeast corner of the monitoring area between well OB-21 and N7-69 (Figure 5.13). Again, these are considered irrelevant with respect to low contaminant levels and the proximity to the wells that are effectively not reporting TCE contamination.

Sampling Frequency Analysis by the Modified CES Method is performed to evaluate low MCL's of TCE in this case and provide recommendations for continuing or modified the current testing frequency. From the historical analysis and evaluation of all constituents of contamination at Vance AFB, it was concluded in 2002 that the primary COC would be TCE. This was entirely due to the number of concentrations that continued to exceed the MCL and the overall toxicity of the volatile organic compound. Some sampling frequency recommendations were default recommendations resulting from data that was otherwise insufficient and not recent. It was also due to having less than the six data records for a well even with the availability of the most recent 2005 and 2006 data which could have provided a minimal requirement of 4 of the 6 records needed to function. Without the needed data, conservative results are generated by MAROS such as quarterly rather that annual or annual rather than not at all, which should be the case for wells recommended for deletion.

The sampling frequency analysis for 19 sites in the CMI is based on semiannual data. All but two wells are recommended for annual sampling, with two wells quarterly. The sampling frequency analysis for 20 sites in the IZ is based on semiannual data. All but two wells are recommended for annual sampling with two wells quarterly and one semiannual. Note that, of those, 0B-05 is recommended for elimination.

Data Sufficiency by MAROS is performed with the statistical power analysis tool in order to assess the sufficiency of the current monitoring plans with respect to the difference between the mean or observed concentration and the regulatory cleanup goal of less than 5 mg/l. The result indicates the progress attained in meeting the desired remediation at a hypothetical statistical compliance boundary (HSCB). This is defined as the boundary where remediation of a COC groundwater contamination must reach attainment. Furthermore, it provides an analysis and recommendation in terms of increased monitoring to attain regulatory levels of contamination for individual well cleanup. The normal distribution assumption was the recommended mode and suggested that CMI wells 23-05, 23-34, 25-08, and 25-15 had reached attainment. The analysis concluded the following IZ wells had reached attainment: N7-45, OB-02, and OB-22. Status visualization is provided in Figures 5.14 and 5.15. Note that well 24-06 had been summarily discounted since no data was collected in 2003 and 2004.

Possible attainment was evaluated from a hypothetical statistical compliance boundary (HSCB) which was estimated to be Fox Drive for the CMI and the Boggy Creek Tributary for the IZ. The distance along the centerline of the CMI plume from the most

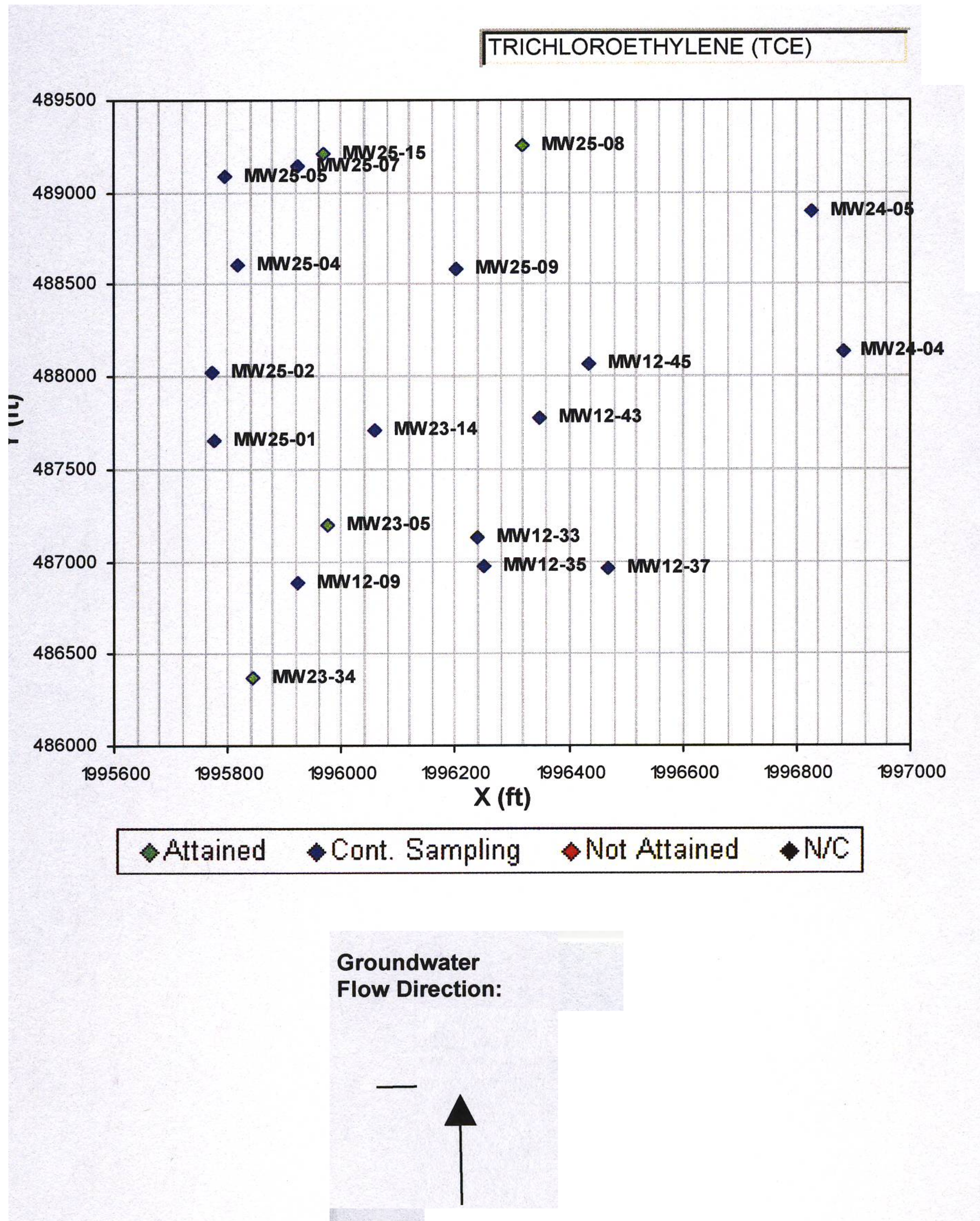


Figure 5.14. Individual Well Cleanup Status Visualization – CMI Site

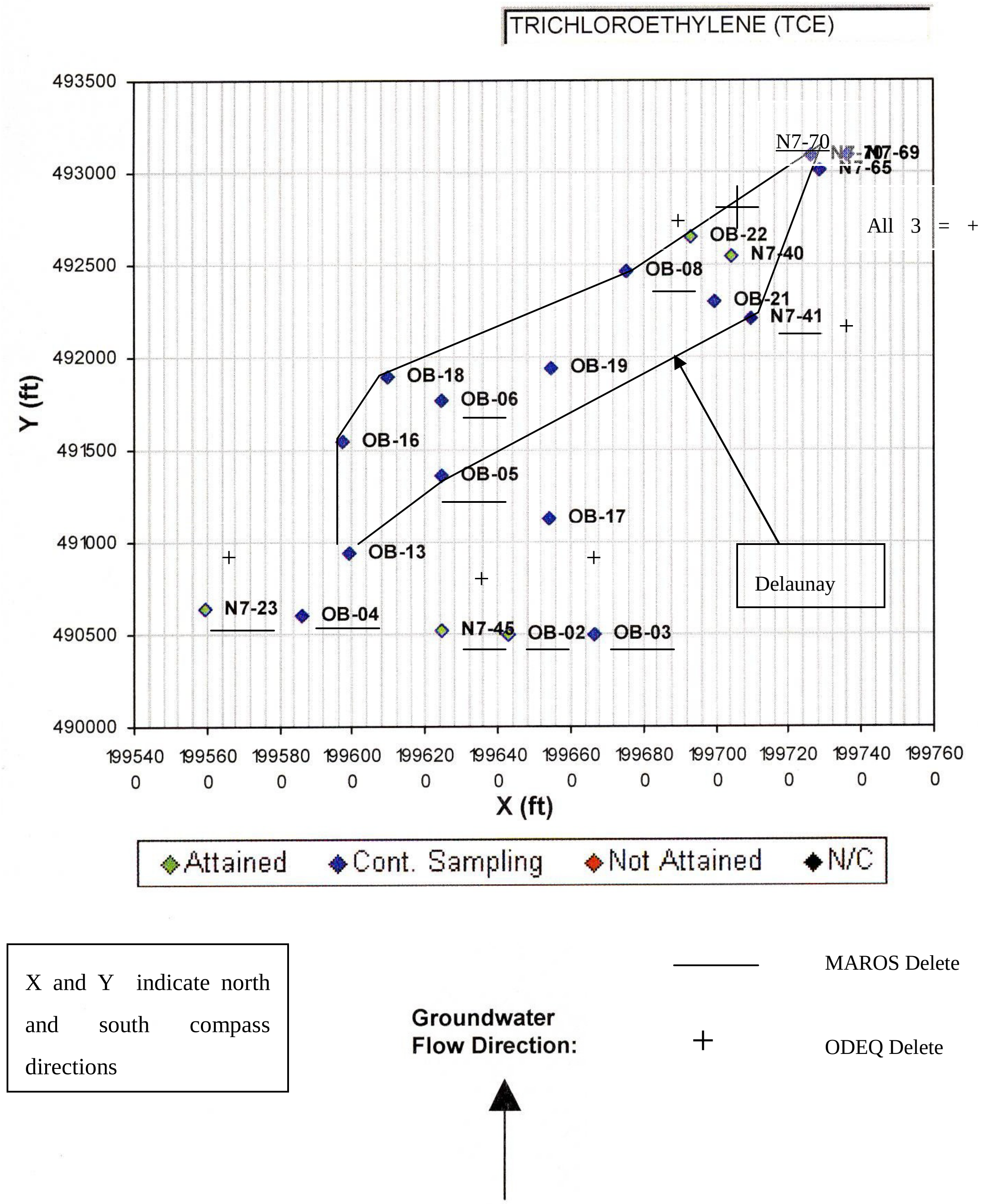


Figure 5.15. Individual Well Cleanup Status Visualization – IZ Site

down-gradient well to the most down gradient receptor (HSCB) in the direction of flow was estimated to be 1040.0 feet. Flow was estimated at NNE or 67.5 degrees counterclockwise from the beginning well. The distance along the centerline of the IZ plume from the most down gradient well to the most down gradient receptor (HSCB) was estimated to be 1-ft. Flow was also estimated at NNE or 67.5 degrees counterclockwise from the beginning well. Attainment appears to have been achieved at the latest sample events for both the CMI and IZ sites as shown in Tables 5.2 and 5.3 based on normal distribution. However, non-attainment is indicated previously for several sampling events. Due to the erratic history of cleanup status varying between attained and not attained, one should err on the side of caution and continue sampling as recommended by other portions of the MAROS analysis.

Regression coefficients at the HCSB for the CMI ranged from -1.25E-03 to -3.88E-03 and with confidence percentages greater than 95% (Table 5.4). Only four sampling events in 2005 and 2006 offered enough data to estimate plume centerline regressions. Considering the distance from the most down gradient well to a receptor (Fox Drive for CMI) of 1,040 feet, projected concentrations at that point were estimated at 1.1E-5 mg/l or well below the detection limit of 5 mg/l.

Regression coefficients at the HCSB for the IZ ranged from -3.28E-3 (last sample event) to -7.47E-4 but with confidence percentages as low as 78.5 % (Table 5.5). This utilized the five wells above for the IZ analysis. Use of many centerline points offered a greater number of regression coefficients but they are limited in value because of the confidence coefficient values. Considering the distance from the most down gradient well to a

Groundwater Flow Direction: 67 degrees **Distance to Receptor:** 1 feet

From Period: Sample Event 1 9/30/1997 **to** Sample Event 37 10/1/2006

Selected Plume Centerline Wells:

Well	Distance to Receptor (feet)
N7-69	1.0
N7-70	39.1
OB-22	575.5
N7-40	628.5
OB-08	818.3
OB-19	1373.9
OB-05	2030.6
OB-13	2513.6
OB-04	2878.7

The distance is measured in the Groundwater Flow Angle from the well to the compliance boundary.

Sample Event	Sample Size	Sample Mean	Sample Stdev.	Normal Distribution Assumption Cleanup Status	Power	Expected Sample Size
TRICHLOROETHYLENE (TCE)				Cleanup Goal = 0.005		
Sample Event 27	8	2.40E-03	2.73E-03	Attained	0.820	8
Sample Event 28	13	1.16E-03	2.37E-03	Attained	1.000	4
Sample Event 29	12	6.99E-03	2.08E-02	Not Attained	S/E	S/E
Sample Event 31	6	1.44E-03	1.10E-03	Attained	1.000	<=3
Sample Event 32	12	1.35E+01	2.25E+01	Not Attained	S/E	S/E
Sample Event 34	15	2.10E-02	4.45E-02	Not Attained	S/E	S/E
Sample Event 35	15	2.47E-02	5.25E-02	Not Attained	S/E	S/E
Sample Event 36	13	2.33E-02	5.13E-02	Not Attained	S/E	S/E
Sample Event 37	12	1.47E-03	2.55E-03	Attained	0.999	5

Inconsistent
Over Time

Table 5.2. MAROS Risk-Based Power Analysis for Site Cleanup – IZ Site

Groundwater Flow Direction: 67 degrees **Distance to Receptor:** 1040 feet

From Period: Sample Event 1 **to** Sample Event 51

8/15/1996 10/1/2006

Selected Plume Centerline Wells:

Well	Distance to Receptor (feet)
MW24-05	1171.3
MW12-45	2089.2
MW12-43	2391.1
MW12-33	3023.7
MW12-35	3172.2
MW12-09	3374.6

The distance is measured in the Groundwater Flow Angle from the well to the compliance boundary.

Sample Event	Sample Size	Sample Mean	Sample Stdev.	Normal Distribution Assumption: Cleanup Status	Power	Expected Sample Size
TRICHLOROETHYLENE (TCE)				Cleanup Goal = 0.005		
Sample Event 3	3	9.19E-05	6.96E-05	N/C	N/C	N/C
Sample Event 23	5	3.92E-01	6.38E-01	Not Attained	S/E	S/E
Sample Event 28	6	4.61E-05	8.13E-05	Attained	1.000	<=3
Sample Event 32	3	2.14E-02	1.28E-02	N/C	S/E	S/E
Sample Event 39	4	2.22E-05	1.75E-05	Attained	1.000	<=3
Sample Event 43	3	3.90E+00	2.51E+00	N/C	S/E	S/E
Sample Event 48	16	3.44E-03	9.79E-03	Not Attained	0.153	>100
Sample Event 49	16	1.87E-02	5.07E-02	Not Attained	S/E	S/E
Sample Event 50	17	3.83E-03	1.07E-02	Not Attained	0.114	>100
Sample Event 51	17	1.33E-03	4.04E-03	Attained	0.978	9

Inconsistent Over Time

Table 5.3. MAROS Risk-Based Power Analysis for Site Cleanup – CMI Site

Sampling Event	Number of centerline wells	Regression coefficient (1/ft)	Confidence in coefficient (%)
Feb 2002	6	-3.48E-03	98.9
Jul 2002	7	-3.44E-03	99.8
Dec 2002	4	-7.47E-04	93.7
Sep 2003	4	1.97E-03	90.9
May 2005	7	-1.36E-03	87.8
Oct 2005	7	-1.15E-03	81.3
Apr 2006	7	-1.44E-03	85.2
Oct 2006	6	-3.28E-03	97.3

Note: Negative coefficient is decay of concentration

Table 5.4. Vance AFB IZ Site Plume Centerline Concentration Regression Results

receptor at 1 foot, projected concentrations at that point were estimated at 6.9E-5 mg/l or well below the detection limit. A risk-based power analysis indicated the IZ had attained compliance one foot away from the north compliance boundary being the creek (Table 5.5).

The length of the HSCB can be adjusted to allow iterative analyses to estimate the hypothetical cleanup boundary. It could also provide a longer period of time to allow natural attenuation onto the newly acquired northern property on Vance AFB. This was pursued with success that allowed new construction in the IZ area.

5.11 MAROS RESULTS AT VANCE

The focus of the results of the MAROS report was concentrated on the shallow aquifer and the predominant persistent contaminant TCE. The data used was collected from samples through the years from 1997 to 2006 and was often not consistent in terms of frequency. Such periodic updating did not provide a consistent format for evaluating the long-term monitoring goals imposed on Vance AFB. Continuation of such sampling has been recognized accordingly and the high cost needed to be addressed.

The MAROS decision-support software utilized in this report was intended to assimilate the existing historical data to revise the existing long-term monitoring plans currently in place.

Sampling Event	Number of centerline wells	Regression coefficient (1/ft)	Confidence in coefficient (%)
Mar 1998	3	-3.41E-03	81.2
Apr 2002	3	7.44E-04	59.5
May 2003	3	-3.88E-03	85.9
Oct 2003	3	1.25E-03	77.4
May 2004	3	-3.63E-03	95.4
Oct 2004	3	8.74E-04	64.3
May 2005	6	1.86E-03	94.5
Oct 2005	6	1.34E-03	84.9
Apr 2006	6	1.81E-03	90.9
Oct 2006	6	2.48E-03	95.2

Note: Negative coefficient is decay of concentration

Table 5.5. Vance AFB CMI Site Plume Centerline Concentration Regression Results

The MAROS 2.2 software optimization program has been applied to two remaining collective sites at Vance AFB, the IZ and CMI, to evaluate the single most prevalent remaining COC (contaminant of concern), TCE (trichloroethylene). Those optimization results can be supplemented by the following recommendations to optimize the temporal and spatial monitoring network. The results of the MAROS temporal analysis for this report are summarized in Tables 5.6 and 5.7. Note that additional correlation as to the number of wells recommended for reduction is provided by a recommendation in the 2001 modification of the final closure plan to reduce a similar number of wells. That was based on criteria that facilitated closure of a well when it demonstrated lower than minimal MCL contaminant levels for six consecutive sampling periods.

Overview of Statistical Analyses demonstrates that the MAROS model incorporates two levels of analysis as mentioned earlier for optimizing long-term monitoring plans. The first is an overview statistical evaluation which follows with an interpretation of a trend analysis based on temporal trends and plume stability information. The role of the Mann-Kendall and Linear Regression methods is to evaluate the temporal trends for the CMI and IZ well systems. It is interesting that these two systems are comprised of nearly the same number of wells (19 and 20) and that sufficient data existed for 13 and 12 wells, respectively, showing a trend of Probably Decreasing, Decreasing, or Stable TCE Concentration trends.

The Overall Number of Sampling Events: 51

"Recent Period" defined by events: **From** Sample Event 18 **To** Sample Event 51

4/17/2002 10/1/2006

"Rate of Change" parameters used:

Constituent	Cleanup Goal	Low Rate	Medium Rate	High Rate
TRICHLOROETHYLENE (TCE)	0.005	0.0025	0.005	0.01

Units: Cleanup Goal is in mg/L; all rate parameters are in mg/L/year.

Well	Recommended Sampling Frequency	Frequency Based on Recent Data	Frequency Based on Overall Data
'RICHLOROETHYLENE (TCE)			
MW12-09	Quarterly	Quarterly	Annual
MW12-33	Quarterly	Quarterly	Annual
MW12-35	Annual	Annual	Annual
MW12-37	SemiAnnual	Annual	Quarterly
MW12-43	Annual	Annual	Annual
MW12-45	Quarterly	Quarterly	Quarterly
MW23-05	Biennial	Annual	Annual
MW23-14	Annual	Annual	Annual
MW23-34	Annual	Annual	Annual
MW24-04	Annual	Annual	Annual
MW24-05	Annual	Annual	Annual
MW25-01	Annual	Annual	Annual
MW25-02	Annual	Annual	Annual
MW25-04	Annual	Annual	Annual
MW25-05	Annual	Annual	Annual
MW25-07	Annual	Annual	Annual
MW25-08	Biennial	Annual	Annual
MW25-09	Annual	Annual	Annual
MW25-15	Biennial	Annual	Annual

Notes:

N/C not conducted due to small sample size ≤ 4.

S/E sample mean exceeds

Final Result

Table 5.6. MAROS Sampling Frequency Optimization Results – CMI Site

The Overall Number of Sampling Events: 37

"Recent Period" defined by events: **From** Sample Event 18 **To** Sample Event 37

7/27/1999 10/1/2006

"Rate of Change" parameters used:

Constituent	Cleanup Goal	Low Rate	Medium Rate	High Rate
TRICHLOROETHYLENE (TCE)	0.005	0.0025	0.005	0.01

Units: Cleanup Goal is in mg/L; all rate parameters are in mg/L/year.

Well	Recommended Sampling Frequency	Frequency Based on Recent Data	Frequency Based on Overall Data
TRICHLOROETHYLENE (TCE)			
N7-23	Annual	Annual	Annual
N7-40	Annual	Annual	Annual
N7-41	Biennial	Annual	Annual
N7-45	Annual	Annual	Annual
N7-65	Annual	Annual	Annual
N7-69	Annual	Annual	Annual
N7-70	Annual	Annual	Annual
OB-02	Biennial	Annual	Annual
OB-03	Annual	Annual	Annual
OB-04	Annual	Annual	Annual
OB-05	Quarterly	Quarterly	Quarterly
OB-06	Annual	Annual	Annual
OB-08	Annual	Annual	Annual
OB-13	Annual	Annual	Annual
OB-16	Annual	Annual	Annual
OB-17	Annual	Annual	Annual
OB-18	Annual	Annual	Annual
OB-19	Annual	Annual	SemiAnnual
OB-21	Quarterly	SemiAnnual	Quarterly
OB-22	Annual	Annual	Annual

Notes:

N/C not conducted due to small sample size ≤ 4.

S/E sample mean exceeds

Final Result

Table 5.7. MAROS Sampling Frequency Optimization Results – IZ Site

The CMI area demonstrates a stable source and tail region. However, the dissolved mass was increasing and moving toward the source (probably decreasing) while the spread was stable. Additional well-by-well analysis was then exercised. One of two wells that indicate an increase is MW12-45 which is most likely due to the proximity of an extraction well to the east thus monitoring the increased flow to that well. A second well MW25-01 is likely a response to the southwesterly movement of the plume or the first moment movement closer to the source. A moderate monitoring strategy was thus recommended for the CMI area.

The IZ area demonstrated a lack of a stable source probably contributed by the reestablishment of a source region as a result of the intercept wall constructed in 1999. The moment trend analysis for the IZ plume indicates a stable tail. There is NT (no trend) for the plume concentration although its center moving farther from the source (increasing), while the spread of the plume is stable. It was recommended to pursue a moderate monitoring strategy for the IZ due to the noted inconsistencies. This included the evaluation of the possible need for additional monitoring wells.

Detailed Statistics Modules were provided in the second level of MAROS analysis which evaluated well redundancy, well sufficiency, sampling frequency, and adequacy of data collection plans in characterizing a plume. The results of the CMI analysis suggested elimination of four wells (12-09, 12-33, 12-43, & 23-14) and two wells for the IZ site (OB-06 & OB-08). Be reminded that these only involve the shallow aquifer.

A comparison of protocols was provided regarding recommendations for discontinued testing of monitoring wells in the CMI and IZ zones. The Oklahoma Department of Environmental Quality approved 25 wells at Vance AFB for discontinued testing since their MCL levels were lower than the MCL for six consecutive testing periods. There was a general correlation in the recommendations from MAROS and ODEQ except that there was no indication that the MAROS results ever entered into their decision process.

Again, well 24-06 had been summarily discounted since no data was collected in 2003 and 2004. The result from the MAROS sufficiency analysis identified the possible need for one additional well on the southern edge of the plume. This may be due to the interpreted movement of the plume to the southwest. A similar result occurred in the IZ which indicated the possible need for additional wells beyond the interceptor trench. This is likely attributed to a false reading of relative differences in very low levels of contamination. In fact, the results of the February 26, 2007 Vance AFB letter eliminated these wells due to continued low- to nonexistent TCE contaminant levels. Therefore, the recommendations could be questioned.

Earlier MAROS analyses suggested that MW23-34 should be retained to monitor plume movement to the southwest direction. During Delaunay optimization, monitoring wells 25-5 and 25-8 were disregarded. The same occurred with wells N7-23, N7-41, and N7-45 in the IZ area. This indicates that an additional MAROS evaluation should be considered without the wells recommended for closure and to exclude those beyond the north interceptor wall.

The results of the sampling frequency analysis suggested a significant decrease from the semiannual testing now required. The recommended testing frequency was mostly annual. Regarding the CMI area, the quarterly recommendation for MW12-45 was consistent with the increase of concentration observed at that well. However, quarterly testing of two other wells recommended for elimination only made sense if the purpose is to insure that low levels persist prior to actual removal.

The recommended sample frequency for the CMI area was consistent with recommendations for the few wells where appreciable measurable contaminant continues to be recorded.

The data sufficiency – power analysis provided a positive evaluation that monitoring well data provides affirmation that attainment has been and can be reached at the compliance boundary as a minimum. This is consistent with the information provided for closure of the wells recommended in the February 26, 2007 Vance AFB letter as well as the wells discounted and eliminated by the MAROS analysis.

The final correlation of shallow monitoring well test results suggests that many more wells could be eliminated beyond the 13 identified in the February 2007 ODEQ letter. These could include the six wells identified by this MAROS report (or MW12-09, 12-33, 12-43, 23-14, OB-6, and OB-8) and possibly MW25-08, OB-02, OB-03, OB-04, and OB-05 that were discarded in the optimization analyses possibly due to lower MCL levels of concentration.

5.12 GTS MODEL AT VANCE AFB

Earlier in this paper, a case study was discussed for Vance AFB utilizing MAROS. What follows is an attempt to evaluate the same base data using GTS. The same plumes IZ and CMI are used as shown in Figure 1.2. The same data comprising the shallow aquifer is included in the format of input data for GTS. In addition, GTS requires well type, low and high water levels, well depth, and some other factors not required by MAROS.

In the case of Vance, only the shallow aquifer was being evaluated which did not require the intermediate and deep well information. Other information essentially involved identifying the type of well as monitoring, the aquifer (Vance's are separate as IZ and CMI), laboratory validation codes, logging company, and sample preparation codes. These were not directly related to the statistical analysis of the test data.

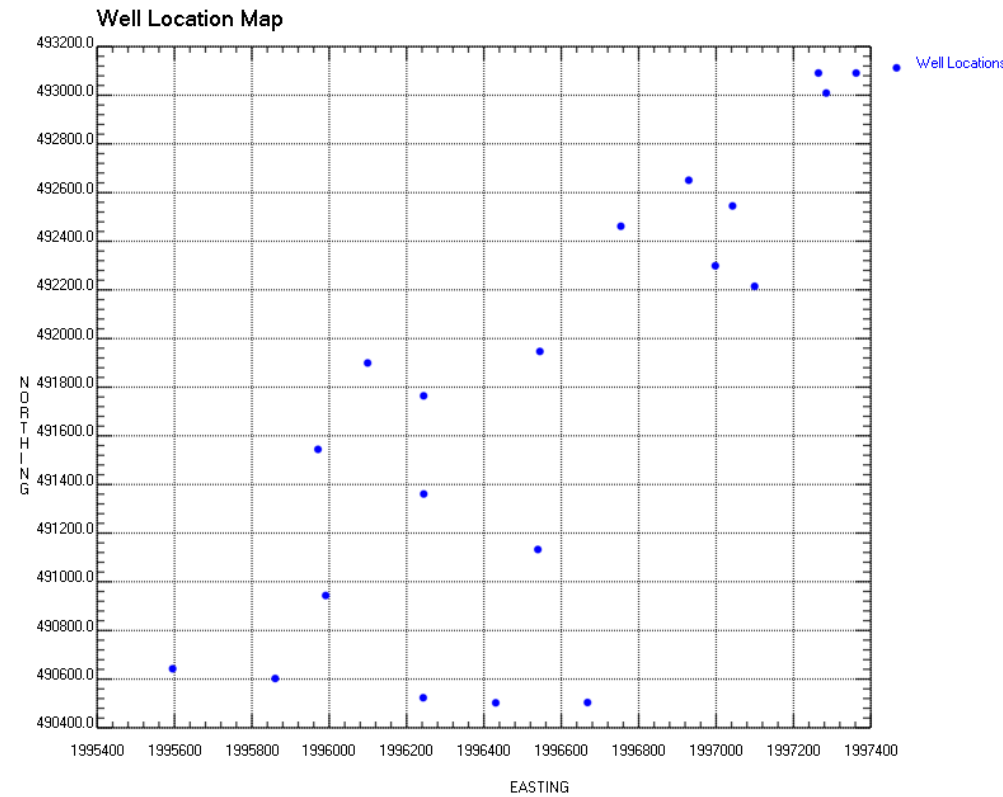
Sample data provided by the company marketing GTS included various data from a site. In my conversation with them, I learned that the Pease AFB data was comprised of the conglomeration of wells and data afforded by the installation. This included several levels of aquifers from a heterogeneous statrigraphy.

The process of evaluating Vance began by exercising the sample data provided by GTS. This included almost 9,000 entries for many COC's. The data was screened to include only TCE information which reduced the number of data entries to 555 for the years 1997 through 2002. This operated successfully and produced a final product recommending a reduction of wells for Pease, as it should have.

The next step involved operation of GTS within the parameters of the Vance subject plumes IZ and CMI. The number of Vance wells at the IZ area was 20 with a total of 184 data test entries. Data was substituted into the Pease model one step at a time which eventually duplicated the type of data except for differing site and well names as well as the actual data result values. The process of providing a "clean" dataset worthy of applying the statistical methods for this analysis was again revealed based on the disparate sources of data earlier discussed with Cameron. This was ultimately performed by substituting the Vance data a portion at a time and testing the operation of GTS. The following is a discussion of that process.

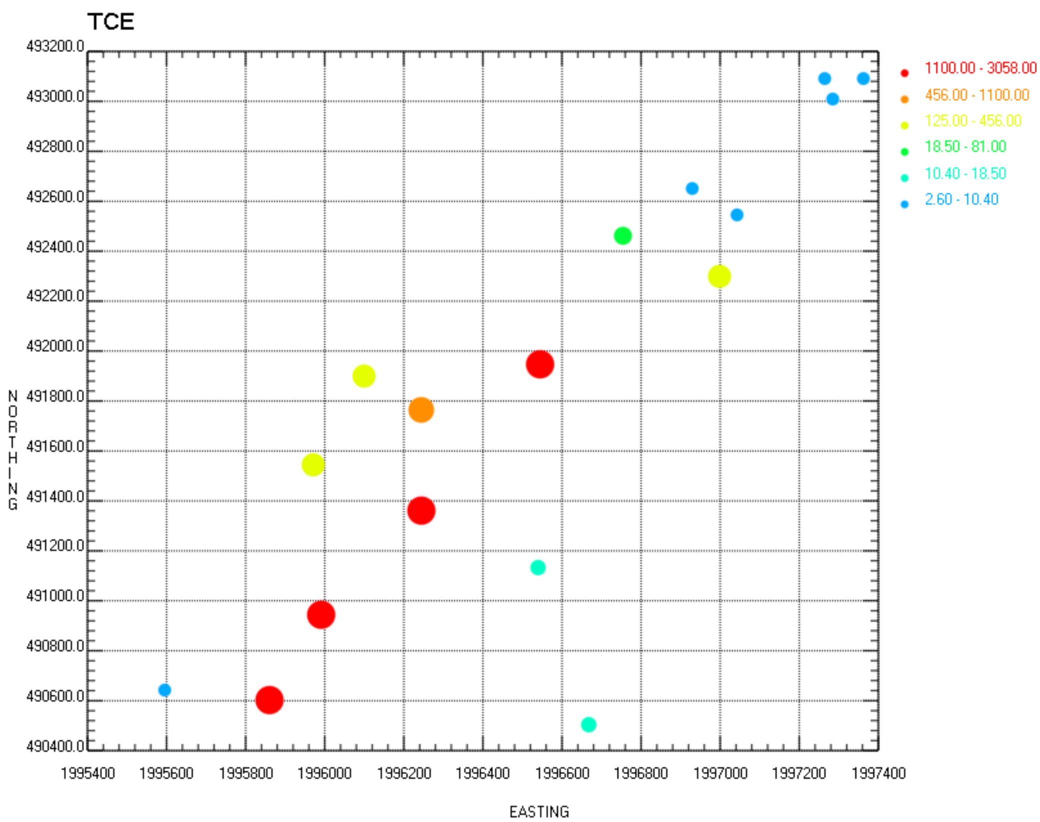
The data set was entered into the Data Browsing and Data Exploration steps of the GTS algorithm. The Well Location Map and Concentration Maps were generated for the site on Vance (Figures 5.16 and 5.17) which is similar to those from MAROS except that concentrations are shown as circles varying in size relative to concentration.

The model proceeded to produce a smoothed variogram (Figure 5.18). Outlier Time Series Plots were created for seven wells for example Figure 5.19 for N7-40. Bandwidth alternatives were produced for the remaining six wells. (Figure 5.20 for N7-69). Sampling intervals and frequencies were generated. Four time slice analyses were then performed followed by computing the estimation mesh. The Vance IZ boundary file was created with the corners of the state-plane coordinate system points that bounded the plume. The estimation mesh performed 9 cuts on 20 wells with 1296 nodes. A total time to run of zero hours searched zero nodes but increasing the time to 0.05 hours searched 1764 nodes (remained in processor).



Note: Northing and easting indicates north and east compass directions and also y and x coordinates respectively.

Figure 5.16 Well Location Map



Note: Northing and easting indicates north and east compass directions and also y and x coordinates respectively.

Figure 5.17 Concentration Map

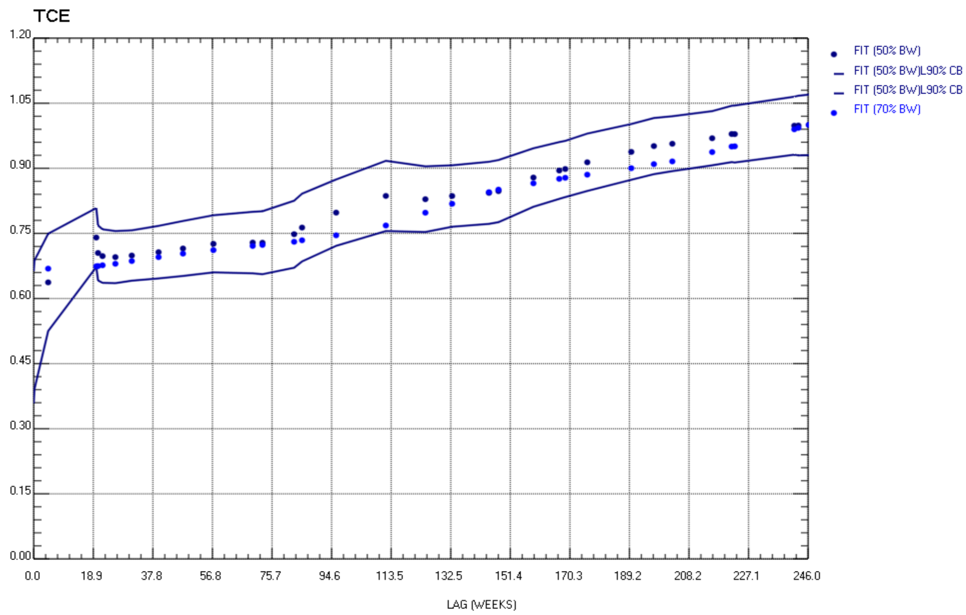


Figure 5.18 Smoothed Variogram

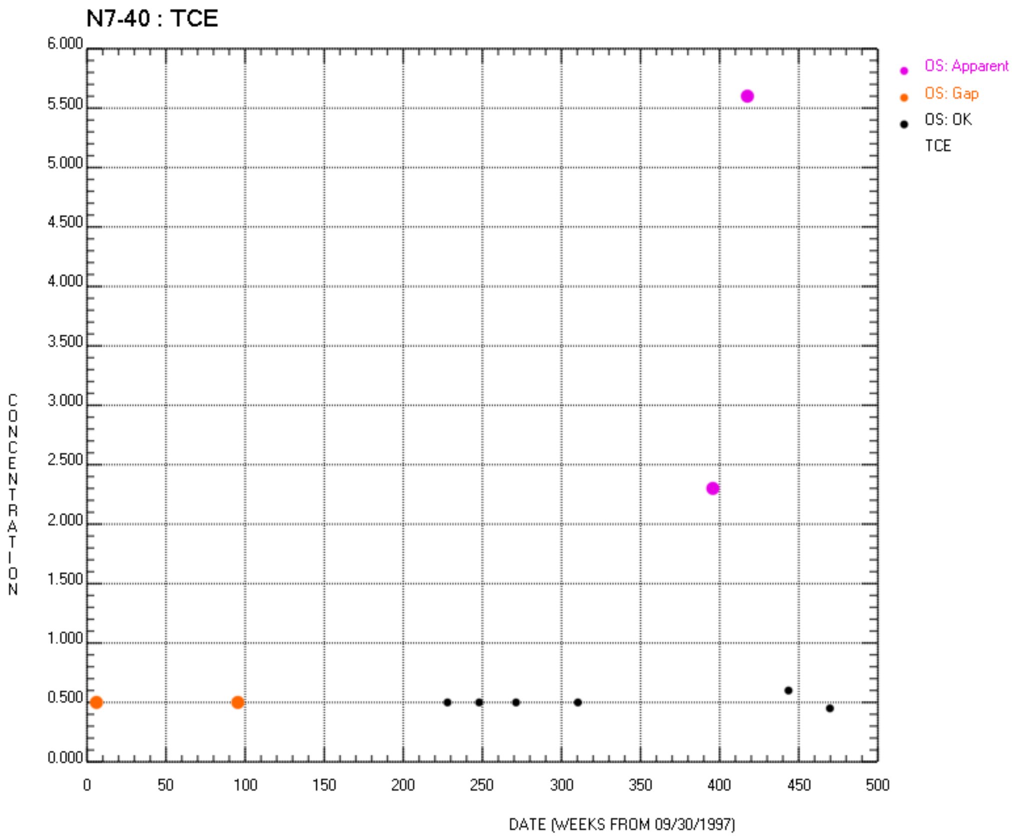


Figure 5.19 Outlier Plot

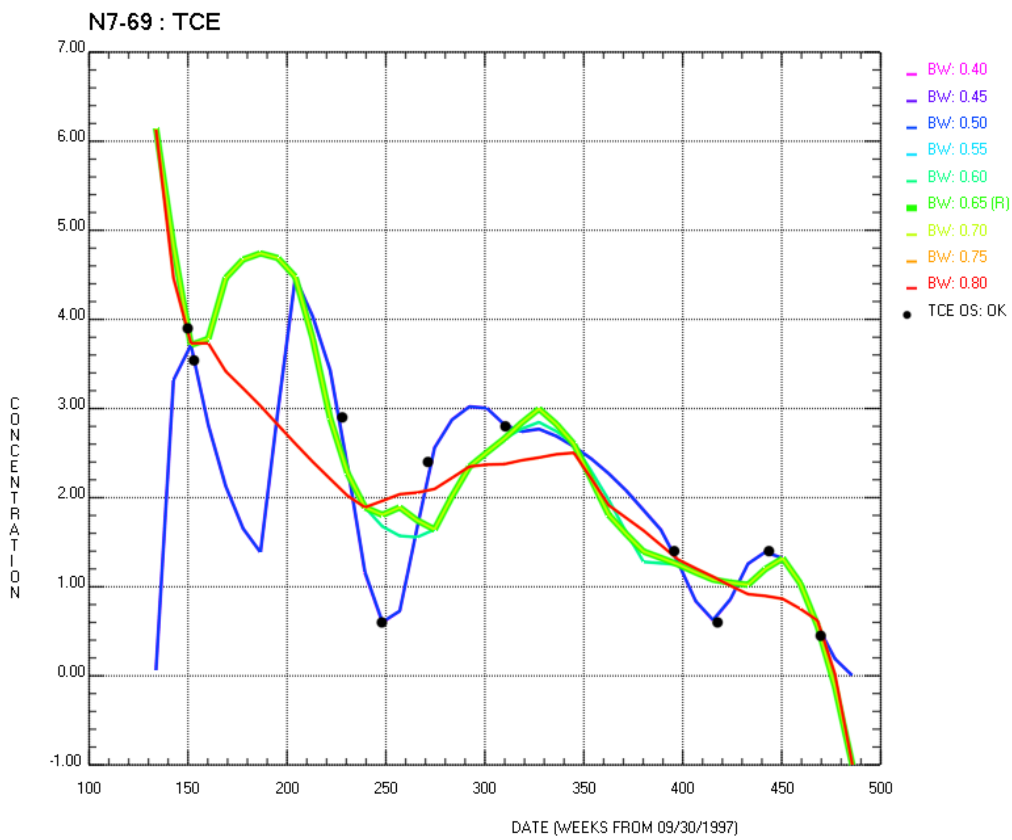


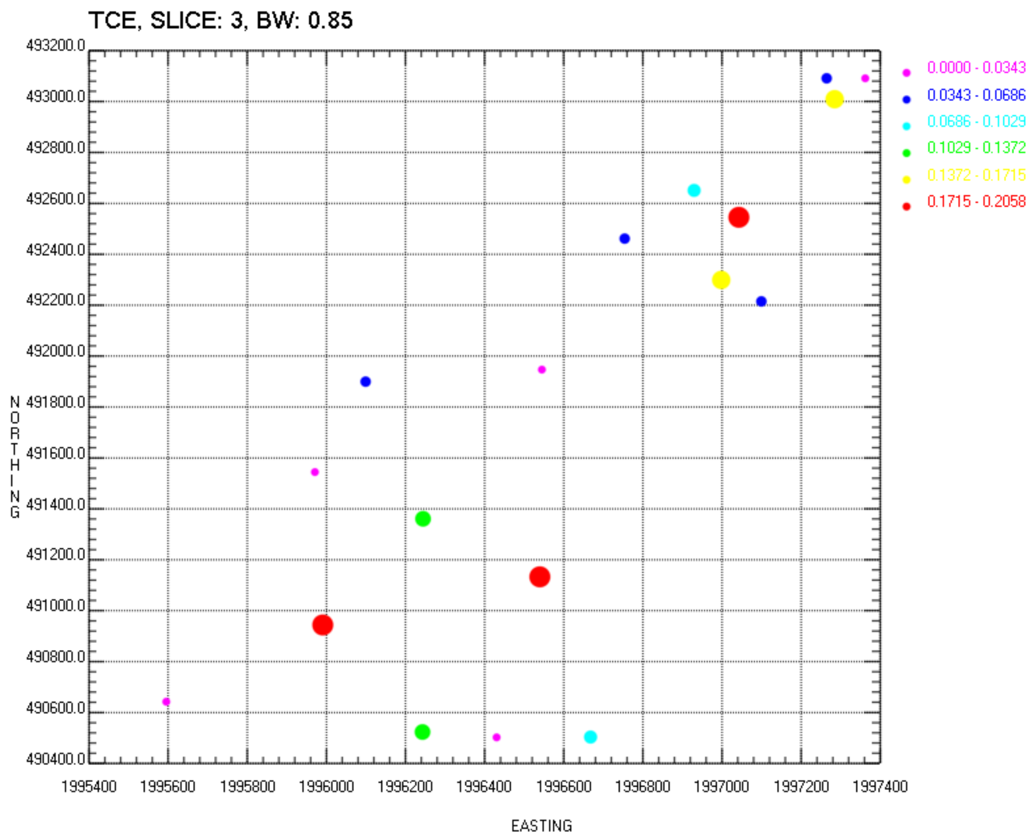
Figure 5.20 Bandwidth Alternative

COC Indicators were operated at 11 levels with a cutoff from 0.5 to 5700 and a percent of 0.1 to 0.992. Spatial Bandwidth Diagnostics created four (4) outputs, TS 1 to 4. A total of 60 Residual Maps were created for the 4 slices and 15 bandwidth variations (Figure 5.21). The Spatial Bandwidth produced 4 bandwidths of 0.30, 0.35, 0.40, and 0.25. There is an opportunity to change any of the four bandwidths at this juncture. Complete Base maps were created that depict the size if the plume and concentration (Figure 5.22).

Spatial Diagnostic Graph Data was created for the first time since running these tests. These are comprised of the Concentration Bias and MSE as well as the Probability Bias and MSE Plots Figure 5.23) that are necessary to obtain cutoff values for the final step to Compute Sampling Network.

Unfortunately, that is where the software crashed. Once the problem is solved, Redundant/Essential Well Locations can be determined.

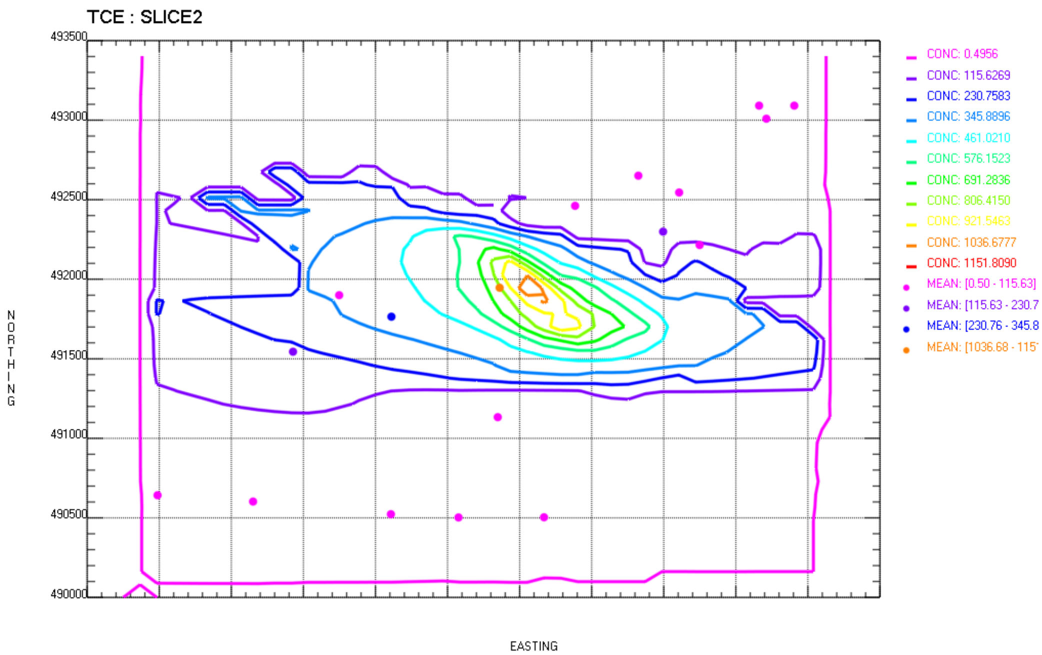
Further evaluation of the problem mentioned above began by comparing the test file with the Vance file of IZ data. This revealed that the Vance file contained 19 wells while the test "Pease" file contained 43 wells comprised of 332 entries. An earlier reduction of data to 300 entries failed to complete the modeling run. Also, removal of 32 entries at the beginning and end of the Pease file only reduced the total number of wells by three in either case, thus indicating 40 wells were utilized in that model run.



This map demonstrates residual concentration of contaminant by color-coding.

Note: NORTHING and EASTING indicates north and east compass directions and also y and x coordinates respectively.

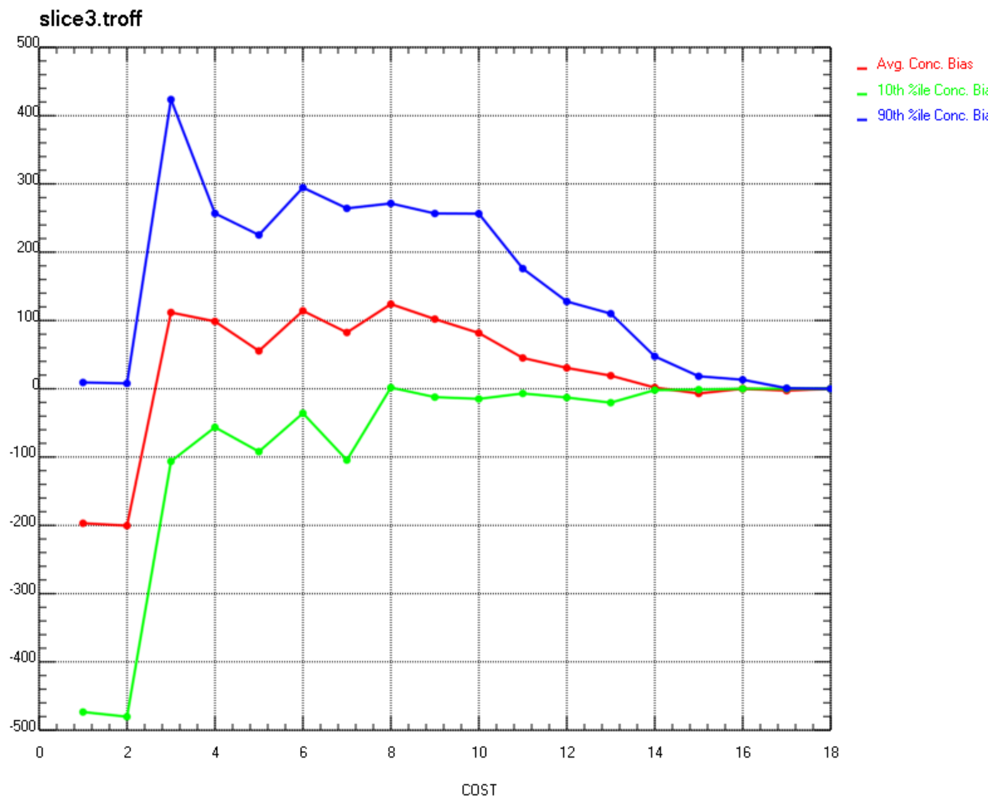
Figure 5.21 Residual Map



1995400 199740

Note: Northing and easting indicates north and east compass directions and also y and x coordinates respectively.

Figure 5.22 Base Map



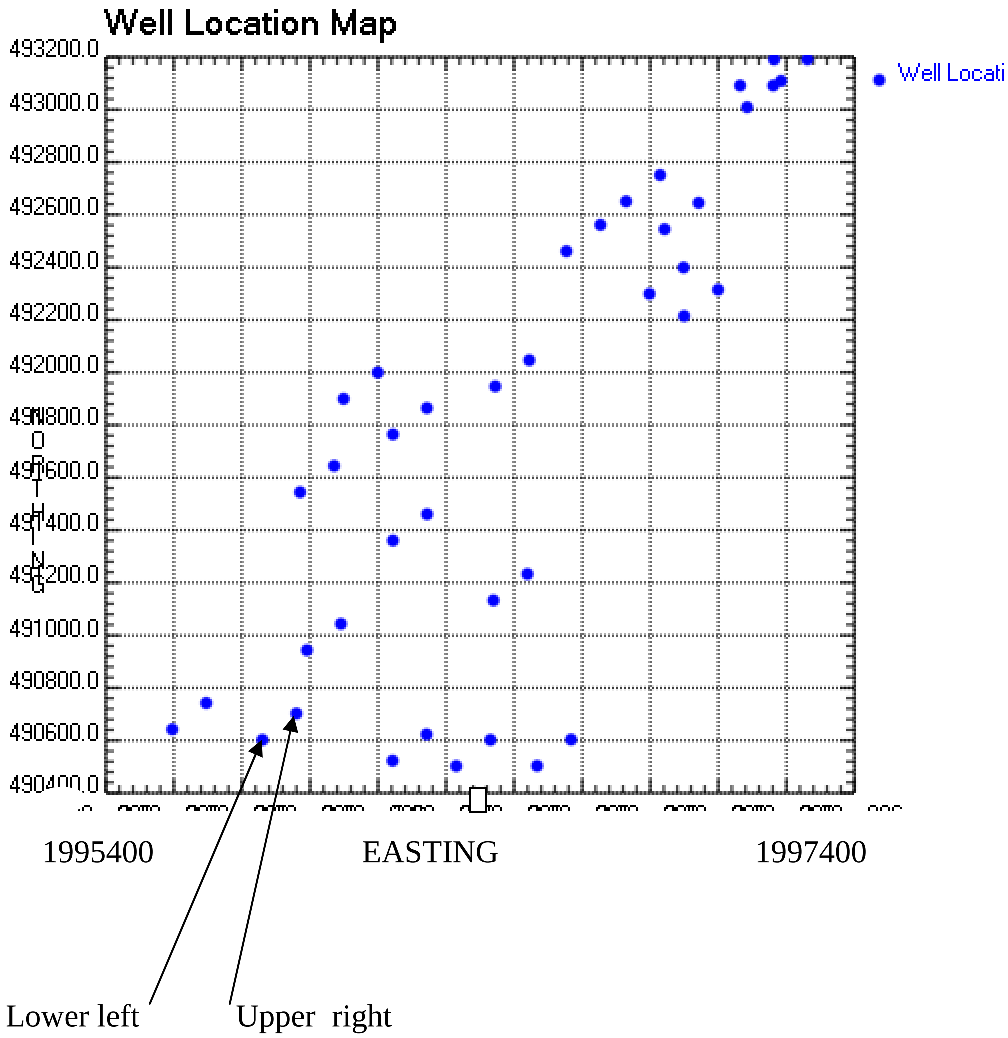
Note: Northing and easting indicates north and east compass directions and also y and x coordinates respectively.

Figure 5.23 Concentration Bias Map

As a trial, the Vance IZ data set was doubled to 366 entries. This was simulated by duplicating each well group with a suffix "a" and increasing the x and y coordinates of each duplicate well by 100. This resulted in presenting a duplicate "dummy" well directly northeast of the actual test wells. This is depicted in the new Well Location Map (Figure 5.24). The GTS run was successful created all model outputs which included the Base Map for Slice 1 (Figure 5.25) and Slice 2 (Figure 5.26). It seems that the concentration of the increased data set mimics the original data base map as a comparison appears to reveal. The slice 1 MSE Concentration is shown from which was extracted a cutoff level that was used to create the Redundant/Essential Location Map (Figure 5.27).

While it is not suggested that any other correlation of the two sets exists, the figure shows that the additional data sets did indeed result in completion of the GTS analysis. It is concluded that the nominal data sets of 183 entries for the IZ area is inadequate to provide the data necessary for GTS to perform its functions.

It appears that the UZ data set of 366 entries resulted in 20 sets of pairs of which 23 were shown as redundant wells leaving 17 as essential. This suggests that upon disregarding the "dummy" wells, that the difference of three (3) wells would be those not needed in the original set. This explanation is solely observation only and has no scientific bearing that can be explained. However, it mimics some of the wells that were recommended for removal by MAROS. At this time, GTS cannot be used to predict the actual number of wells to be reduced spatially or temporally. Further data gathering to provide the additional data sets is apparently one course of action to allow GTS to predict redundant and essential wells.



Diagonal pairs of well locations;
real well lower left and pseudo well upper right.

Note: Northing and easting indicates north and east compass directions and also y and x coordinates respectively.

Figure 5.24 Well Location Map

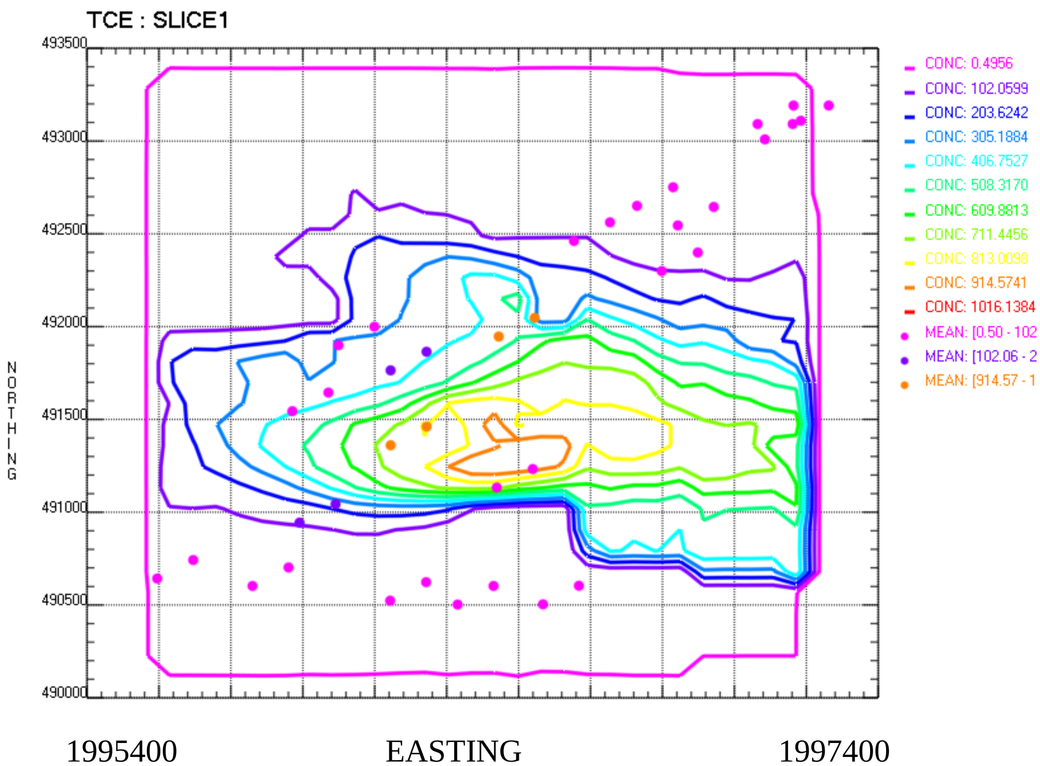


Figure 5.25 Base Map Slice 1

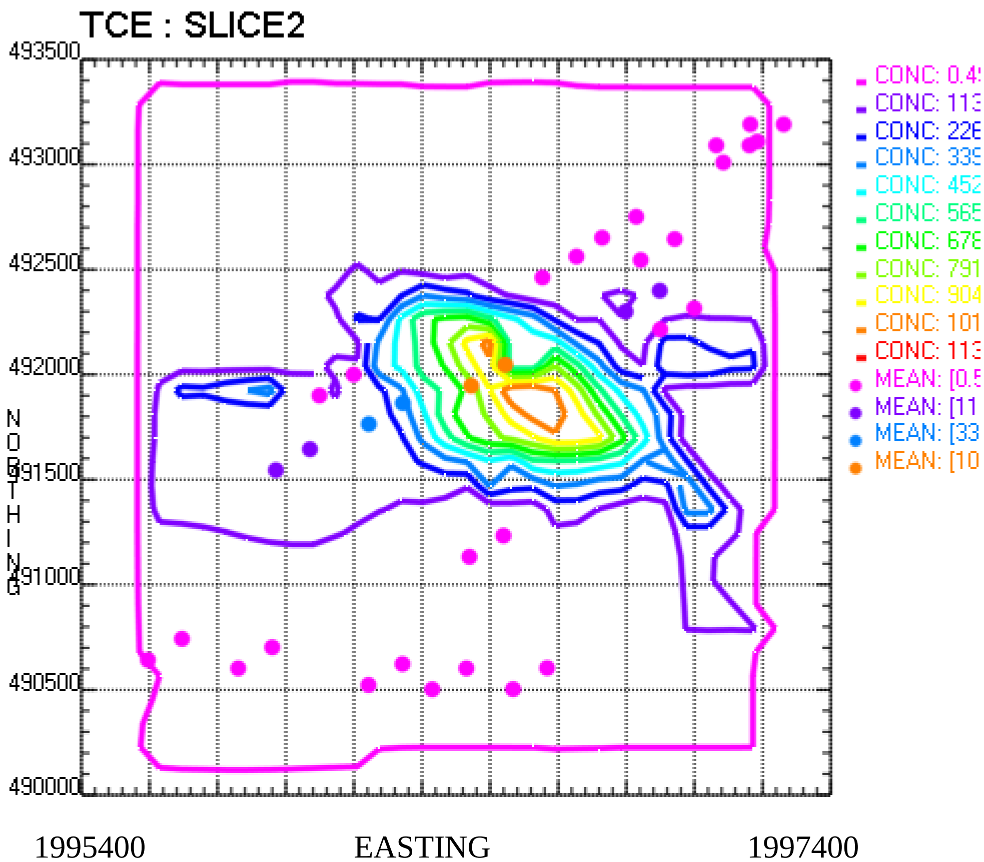
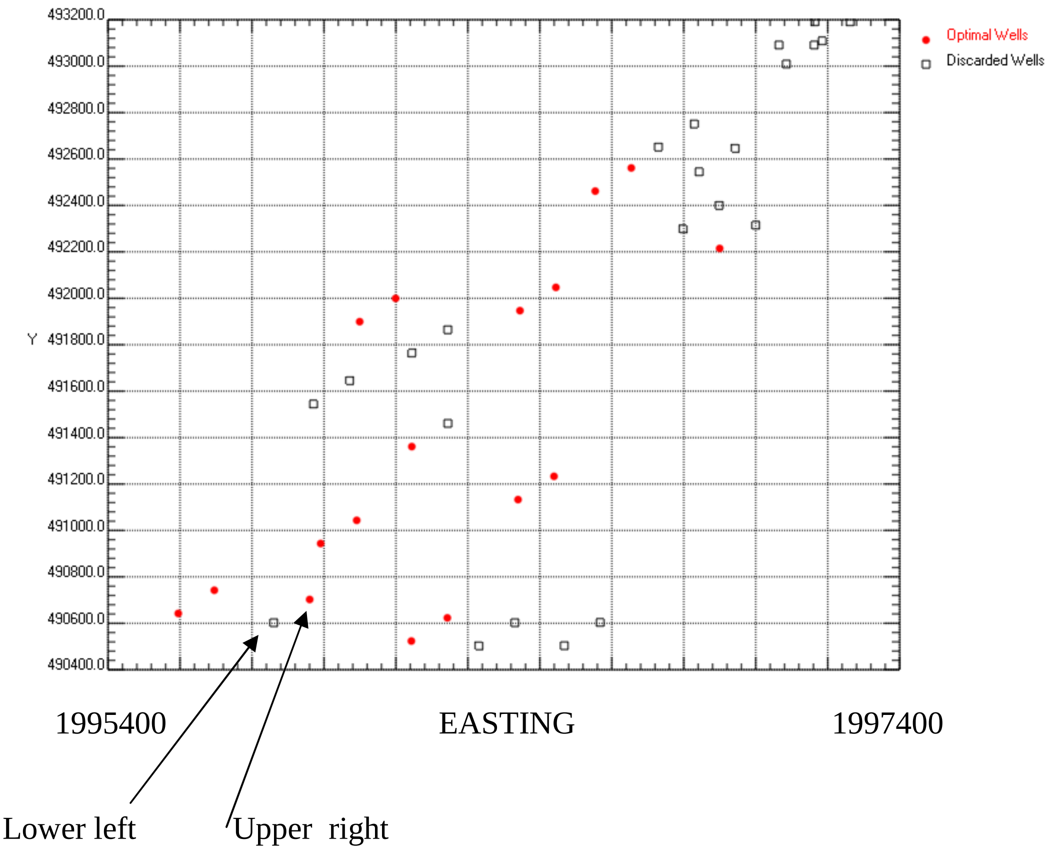


Figure 5.26 Base Map Slice 2



Note: Diagonal pairs of well locations;
real well lower left and pseudo well upper right.

Figure 5.27 Redundant/Essential Well Locations

5.12 COMPARE RESULTS of GEOSTATISTICAL MODELS

Of several complete software packages available for analyzing LTMO requirements, three specific models were selected for analysis and discussion as they pertain to small military bases. The results have offered reduction to LTMO systems as follows (Minsker, 2004). Nobel reported that the GTS was confirmed to eliminate 109 of 536 monitoring wells at the Massachusetts Military Reservation and also reduce the sampling frequency 40 to 70% generating cost savings of 30 to 63% at three other sites (Nobel, 2004). The intent of this paper was to discuss various optimization methods to support the intent to further undertake an analysis of the Vance data with the GTS algorithm. The Three-Tiered LTMO approach had been applied to 18 sites (10 to 300 wells) by 2004 producing reductions in well-sampling events ranging from 13 to 83% per year. Average reduction was 33% sampling events per year. It is indicated that optimization opportunities are fewer for sites with smaller numbers of wells. The three-tiered approach is included in the Roadmap for LTMO prepared by the U.S. Army Corps of Engineers and utilizes proprietary software (Nobel, 2004). The MAROS model was applied to 39 "compliance" monitoring well sites on Vance AFB and resulted in recommending elimination of five wells or a 13% decrease. Frequency was reduced almost entirely to annual from semiannual for all but five sites or a representative 81% reduction in frequency of sampling. Ironically, it also recommended adding a few wells which however was attributed to a false reading or relative differences in very low levels of contamination. (Erdman, 2007a)

5.13 VANCE OPTIMIZATION DISCUSSION AND COST SAVINGS

The ultimate goal of performing various analyses of contaminated waste sites and following up with test data is of course to eventually determine that the original contaminant affecting groundwater in this case has depleted to a level that is no longer dangerous to man or living organisms. However, such planned testing in the field, laboratory testing, and management review and decision-making have and continue to generate significant costs.

A comparison of the two software programs applied to the Vance LTMO concept and the method applied by the Vance regulators follows. As shown earlier, MAROS provided recommendations that collectively led to removing several monitoring wells along with associated reduction in the frequency of testing. The Figure 5.28 shows the GTS duplicate presentation of wells, those removed or not included by MAROS, and those eliminated by the Vance regulators. The IZ site was chosen since it contains the largest number of affected wells.

The MAROS process of evaluation includes many disconnected statistical analysis tools. One of those is sampling optimization performed by both Delaunay and Access methods to predict deletion of and need for more wells. It was noted that it represented only 12 of the 20 compliance wells for the IZ area and suggested eliminating two other wells. Although not determined from software documentation, the reason for eliminating eight wells was presumed due to a very low level or lack of detectable TCE needed to generate or very low level of the COC or TCE. The total number of wells recommended for

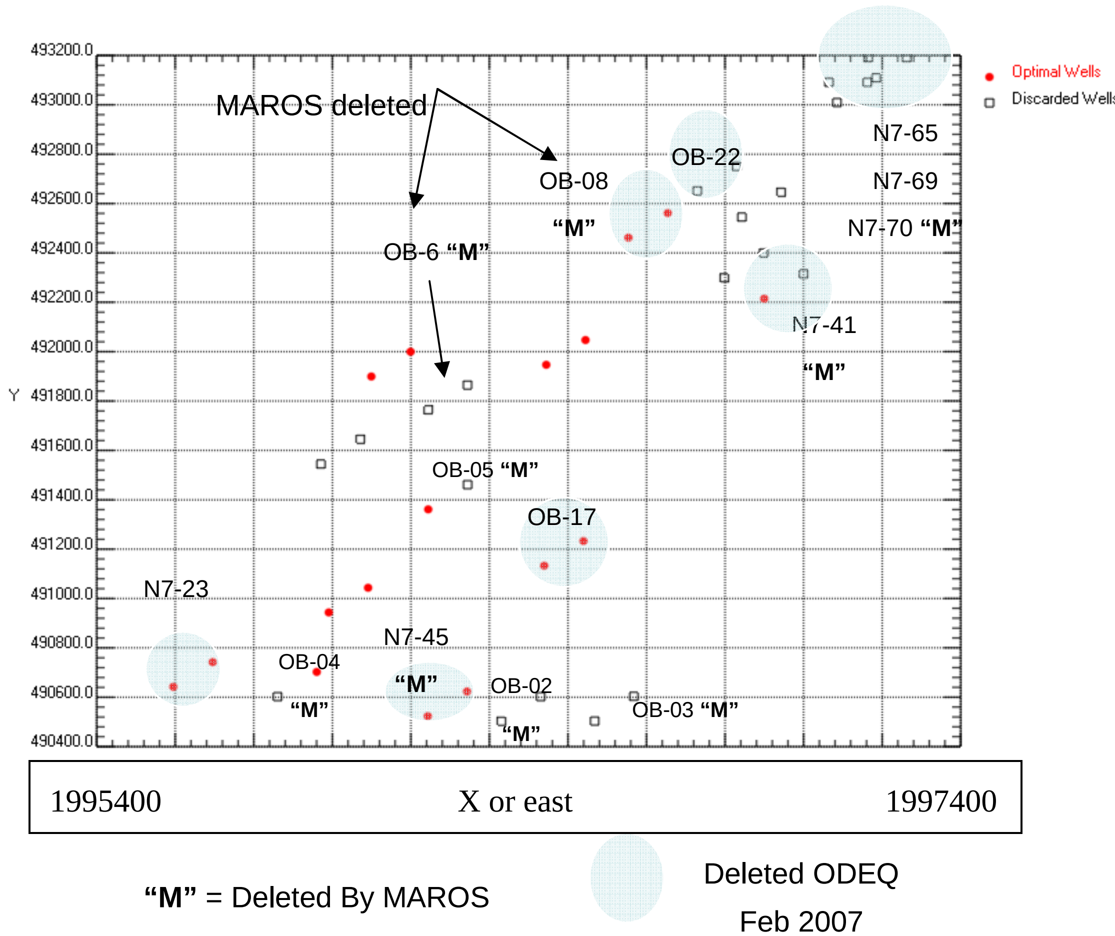


Figure 5.28. Comparison of Well Reduction Methods

deletion or discarded by MAROS in the IZ area was ten wells. In February 2007, regulators directed deletion of 25 monitoring wells at Vance that included nine wells in the IZ area.

Although speculative, it is nonetheless interesting to include the results of the GTS analysis in the IZ area. The well on the lower left of the pairs is the real well whereas that on the upper right is the pseudo well. One should notice the similarity of discarded wells common to MAROS results. In the IZ are, a general corollary demonstrated redundancy of some wells on the south and north ends of the plume. The plume area as defined by EA in 2007 for concentrations less than 5 mg/l, also correlates with the MAROS defined plume shown in Figure 5.13. The wells north of the cutoff or slurry wall have apparently reached a safe remediation level.

Some of the tools in the software programs are labeled with terms of cost but are actually related to cost in the recommendations that suggest reduced frequency of testing and removal of wells. Information from EA Engineering for example suggests that reduction on one testing round for one well could approximate $2,000. It is normal to test several wells at one point in time which provides an economy of scale. Still, the cost to enter the site (considering costs imposed by government security processes on military installations), the time to bail and properly prepare the sample along with shipment to the lab, testing and peroration of the report, and final analysis add up the cost. Removal of a well from the system represents a similar one-time cost which translates to lowering future costs of well testing.

In the case of Vance AFB, the temporal recommendation by MAROS included reducing the frequency of monitoring well testing from semiannual to annual. That would practically cut the cost of the sampling program cost in half. For the Vance model, this approximates about 27 wells or about $54,000 savings per year. .Further consideration of the spatial recommendation to eliminated six monitoring wells suggests another reduction of testing costs for twelve annual tests or another $24,000 per year. Since the MAROS recommendations are separate and not produced as a qualitative representation for a plume, it would be reasonable to avoid taking full credit for this aspect and simply base possible savings on the $54,000 figure.

While the suggested recommendations of the three methods presented in this research appear to be very different, the final results arrive very close to the same goal. For instance, the Vance decision to eliminate 14 monitoring wells represents $58,000 per year cost savings in no longer performing regular semiannual monitoring well testing. These results are not purely coincidental when one realizes the decisions are based on statistical information balanced in the overall equation of variables with the intent to reduce cost and achieve adequate remediation of the COC, TCE.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 SUMMARY

The advent of spilled industrial wastes entering the soil and groundwater has prompted intense application of remediation efforts over the past 30 years. Some of the most damaging chemicals are those labeled NAPL (non-aqueous phase liquids) that do not easily dissolve. However, a small portion of some such heavier-than water or DNAPL (dense non-aqueous) liquids such trichloroethylene enter and dissolve in groundwater aquifers. Many methods of analysis and remediation to include pump-and-treat have been implemented. The cost, time, effort had become increasingly higher and reached a prohibitive level. Early modeling software programs in the 1980’s were deterministic and stochastic and required immense amounts of data and resources to operate and analyze the results.

Efforts to both simplify analysis of plume characterization and remediation activity thus generated the advent of Long-Term Monitoring Optimization (LTMO). The basic idea was to rely on less data and with recommendations based on attaining acceptable levels of risk. The computer models utilize various statistical methods stemming from kriging that was developed for mining ore to that of artificial intelligence using Bayes theorem. Typically, statistical methods required a high level of statistical knowledge and effort to manage the computer programs and analyze the results.

LTMO was developed to allow natural attenuation to the fullest extent but to also provide reasonable monitoring in an effort to determine when contamination levels below an acceptable regulatory MCL had been attained. It further would provide intermediate information on the possible reduction (and new wells in certain cases) of monitoring wells or frequency of testing. The optimization software internal statistical methods and tools are all basically controlled by the spatial orientation of wells and temporal testing frequency. The U.S. Air Force Center of Engineering Excellence sponsored development of statistical long term monitoring optimization software. Three programs were selected for use but two were public-domain and intended to be useful to environmental staffing at military installations. Those two were MAROS and GTS the first being acclaimed to be fairly simple in nature. However, it contains many statistical methods which must be finally evaluated and judged by environmental and regulatory as to the validity of recommendations on continuation of an established LTMO plan.

A test site was selected as Vance AFB which had not yet been analyzed with MAROS or GTS. The research conducted discovered shortfalls in the data collection that was compensated by new testing under a current LTMO plan. Vance offered a relatively small data set for two general plume areas that exhibited only one problematic COC, that being TCE. It also attempted to utilize GTS with the same data set that resulted in producing MAROS recommendations. Difficulty in obtaining the data set for Vance was overcome through several trials or steps in assimilating and organizing the data for MAROS. Results and recommendations by MAROS for Vance were not always consistent with actual management of the contaminated plumes on Vance.

6.2 CONCLUSIONS

For groundwater remediation modeling, spatial and temporal software modeling of contaminated plumes has been determined the standard approach by all branches of the military. The application of MAROS at Vance AFB was selected due to its relatively small size and with the idea that most remediation of other contaminants at the deeper aquifer levels was practically attained. The shallow aquifer in the upper 20 feet of a major portion of the base was being monitored under a current LTMO plan. The MAROS program offered simpler statistical analysis with Mann-Kendall, linear regression, Delaunay triangulation, and regression power analysis for remediation. This paper has presented:

1. That MAROS can operate with minimal data sets with less information than required by other Long Term Monitoring Optimization Software as shown by the operation of the GTS software. This supports analysis of small facilities and geology similar to Vance.

2. The effect of limited well test data from contaminated plumes demonstrates that analysis is primarily dependent upon temporal data and frequency. The data must first be sorted into specific calendar dates of annual, semiannual, or quarterly periods.

3. In comparison to the higher level GTS statistical optimization program, MAROS is rated the simplest software to operate. Input data is simple requiring only general site identification, geostratigraphy, and hydrogeology. Input of data is simplified using the techniques offered in this paper.

4. As demonstrated by the Vance case, detailed recommendations of both optimization software programs did not necessarily correlate directly with the decision of the Vance regulators in reducing wells based on a low MCL six times in succession. However, a generalized comparison of those methods suggested they offered a similar overall effect of eliminating monitoring wells and inherently a degree of testing.

5. While the detailed recommendations of MAROS varied significantly from the actions implemented by the regulators, the value of estimated cost savings was similar. The value represented by MAROS was $54,000 per year which compared favorably to $56,000 per year represented by the actions taken by the Vance regulators.

The basis of the statistical LTMO optimization plans and their analyses is not designed or intended to create exact deterministic conclusions but offer reasonable ideas for managing the spatial organization and frequency of testing at existing locations with contaminated aquifers. It has been shown that even though the subject optimization programs utilize lesser amounts of data, uncertainty borne by data acquisition and management is still an issue. It is subject to statistical confidence and must be kept in mind when considering the value of the results. Often, regulators maintain an opinion that is well-founded in practical experience that offers another dimension of uncertainty when applied to decisions about attainment of remediation goals. Finally, it must be understood that the methods of statistical analysis ultimately combine professional judgment and in an ad-hoc approach (Minsker, 2004).

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APPENDIX

(See Supplementary File No. 1)

The following excerpts and information are provided to supplement the text and provide background for the reader.

- Feb 28, 2007 Vance AFB letter to eliminate 25 monitoring wells
- BIOTRANS input parameters from earlier testing at Vance
- Excerpts from Erdman 2007 draft MAROS 2.2 Application “Shallow Zone Aquifer Monitoring Network Optimization of (Aqueous) DNAPL TCE”
    - CMI site with 20-ft thick aquifer
    - IZ site with 20 foot thick aquifer
    - IZ site with 10 foot thick aquifer

VITA

RONALD R. ERDMAN

Candidate for the Degree of

Doctor of Philosophy

Thesis: Optimization-Based Groundwater Modeling of Aqueous Phase DNAPL to Enhance Plume Remediation Management

Major Field: Civil and Environmental Engineering

Biographical:

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Education: Graduated from West Allis Central High School, West Allis, Wisconsin June 1965; received a Bachelor of Science degree in Civil Engineering from Oklahoma State University, Stillwater, Oklahoma in May 1984. Completed the requirements for the Master of Science degree with a major in Civil Engineering from Oklahoma State University, Stillwater, Oklahoma in December 1984, completed the requirements for the Doctor of Philosophy degree with a major in Civil Engineering from Oklahoma State University, Stillwater, Oklahoma in December 2008.

Experience: Digital data processing/computer electronics technician/instructor U.S. Air Force for eight years; 14 years civil engineer in the U.S. Air Force; 10 years with Northrop Corporation as Chief Engineer for Vance AFB, Oklahoma; civil engineering consultant with Envirotech Engineering 2000 to present.

Professional Memberships: Registered professional engineer in Oklahoma, Kansas, and California; HAZMAT certified; past president of OSPE branch in Enid, Oklahoma

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    - CMI site with 20-ft thick aquifer

      (See Supplementary File No. 2)
    - IZ site with 20 foot thick aquifer
    - IZ site with 10 foot thick aquifer

DEPARTMENT OF THE AIR FORCE
AIR EDUCATION AND TRAINING COMMAND

FEB 28 2007

Colonel Christopher J. Thelen
Commander, 71st Mission Support Group
246 Brown Parkway, Suite 230
Vance AFB OK 73705-5036

Mr. Ron Erdman
2500 North 11th
Enid OK 73701

Dear Mr. Erdman

Vance AFB has requested a temporary authorization to eliminate sampling and analysis of 25 specific groundwater monitoring wells located on base from the Oklahoma Department of Environmental Quality (DEQ). This temporary authorization will provide Vance with sufficient time to request a permit modification for permanent elimination of these wells from the RCRA Part B Post-Closure Permit. These wells have shown little or no contaminants of concern for six consecutive sampling events.

This information is being provided to you because you or your organization is included on the Vance AFB facility mailing list.

A copy of the request to Oklahoma DEQ is attached for your information. If you have any questions or comments, please contact Ms. Marilyn Wells at 580-213-6303 or at marilyn.wells@vance.af.mil

Sincerely

CHRISTOPHER J. THELEN, Colonel, USAF

Attachment:
Letter to Oklahoma DEQ

cc:
HQ AETC/CEVR
EPA, Region VI

DEPARTMENT OF THE AIR FORCE
AIR EDUCATION AND TRAINING COMMAND

2 6 FEB 2007

Colonel Christopher J. Thelen
Commander, 71st Mission Support Group
246 Brown Parkway, Suite 230
Vance AFB OK 73705-5036

Dr. Saba Tahmassebi, Chief Engineer
Oklahoma Department of Environmental Quality
Land Protection Division
P. O. Box 1677
Oklahoma City OK 73101-1677

Dear Dr. Tahmassebi

Vance AFB requests a temporary authorization of a Class 2 permit modification, in accordance with 40 CFR 270.42(e). This temporary authorization is for the elimination of sampling specific groundwater wells during the next scheduled event in April. These wells are required by the Vance RCRA Post-Closure Permit. The list of wells is attached.

We are requesting this temporary authorization in accordance with your letter dated January 22, 2007. The requirements for a permit modification can not be met in time to eliminate the April sampling event. We understand that this temporary authorization is for 180 days and in order to permanently eliminate and abandon any of these wells will require the completion of a Class 2 permit modification. We anticipate the request for the permit modification will be made and a public meeting will be held in conjunction with our scheduled Restoration Advisory Board Meeting on June 7, 2007.

A notice about this temporary authorization request is being sent to all persons on the facility mailing list as specified in 40 CFR 124.10(c)(ix).

If you have any questions or comments about the information provided, please contact Ms. Marilyn Wells at (580) 213-6303.

Sincerely

CHRISTOPHER J. THELEN, Colonel, USAF

Attachment:
Selected Data Summary Tables

cc:
HQ AETC/CEVR
EPA, Region VI

Corrective Measures Implementation Sites
Selected Data Summary Tables
Vance AFB, Oklahoma

Water Bearing Zone	Monitor Well ID	Parameter	VOC & SVOC Concentrations (µg/L)						
			MCL[a]	May 2004	October 2004	May 2005	October 2005	April 2006*	October 2006*
IRP Site ST-12									
Deep	MW 12-19	cis-1,2-dichloroethene	70	< 1.00	< 1.00	0.38 J	<180	<0.37	<0.37
		bis (2-ethylhexyl) phthalate	6	**<9.62**	**< 9.8**	2.4 J	<0.53	<0.53	**9.1 J**
		diethyl phthalate	29,000[b]	<9.62	< 9.8	0.60 J	<0.71	<0.72	<0.71
Deep	MW 12-22	trichloroethene	5	< 1.00	< 1.00	<0.45	0.73 J	<0.45	<0.45
		bis (2-ethylhexyl) phthalate	6	**<9.62**	**<9.71**	1.2 J	<0.56	<0.53	0.66 J
		diethyl phthalate	29,000[b]	<9.62	< 9.71	0.45 J	<0.75	<0.72	<0.71
IRP Site WP-23									
Intermediate	MW 23-22	Bromomethane	8.7[b]	<1.00	<1.00	<0.72	<0.72	<0.72	2.5
		Chloromethane	210,000[b]	<1.00	<1.00	<0.48	<0.48	<0.48	0.53 J
		cis-1,2-dichloroethene	70	< 1.00	0.790 J	<0.37	0.42 J	0.45J	<0.37
		trichloroethene	5	< 1.00	3.53	3.1	2.6	0.59J	<0.45
		bis (2-ethylhexyl) phthalate	6	**<9.43**	**< 9.9**	<1.2	<0.53	<0.53	0.69 J, B
Intermediate	MW 23-28	All VOCs below MDLs							
		butyl benzyl phthalate	7,300[b]	<9.71	<9.9	0.41 J	<1.4	<1.4	<1.4
Deep	MW 23-32	bis (2-ethylhexyl) phthalate	6	**<9.71**	**<9.9**	<1.2	<0.53	<0.56	0.64 J, B
Shallow	MW 23-34	acetone	5,500b	<5.00	< 5.00	2.0 J	<0.82	<0.82	<0.82
		trichloroethene	5	<1.00	< 1.00	0.49 J	<0.45	<0.45	0.49 J
		bis (2-ethylhexyl) phthalate	6	**<9.62**	**< 9.9**	<1.3	1.2 J, B	**16 B**	2.9 J, B
IRP Site SS-24									
Shallow	MW 24-4	chloroform	80[b]	<1.00	<1.00	<0.35	<0.35	0.63 J	<0.35
		trichloroethene	5	1.59	1.47	0.86 J	0.58 J	1.2	0.62 J
Shallow	MW 24-6	bis (2-ethylhexyl) phthalate	6	**<9.62**	**<9.62**	<1.3	<0.53	<0.53	0.60 J
Intermediate	MW 24-12	All VOCs & SVOCs below MDLs							
IRP Site SS-25									
Shallow	MW 25-5	cis-1,2-dichloroethene	70	7.48	4.81	11	23	9.3	22
		1,1-dichlorothene	7	<1.00	<1.00	<0.43	0.51 J	<0.37	<0.37
		trans-1,2-dichloroethene	100	<1.00	<1.00	0.39 J	<0.37	<0.37	0.46 J
		trichloroethene	5	0.56 J	0.367 J	0.89 J	2.2	<0.45	1.7
		bis (2-ethylhexyl) phthalate	6	**<9.62**	**<9.80**	1.3 J, B	<0.53	3.0 J,B	**6.4 J, B**
Intermediate	MW 25-10	All VOCs & SVOCs below MDLs							

Notes and Abbreviations :

a Groundwater screening criterion is based on USEPA, National Primary Drinking Water Standards, Maximum Contaminant Levels (MCLs), EPA 2006.

b No MCL screening criterion available. Screening level provided by Oklahoma DEQ for Vance AFB (Referenced from EPA Region 6 Human Health Medium-Specific Screening Levels

Shaded and bold type exceed the constituent MCL/Screening Level

J – Estimated Result. Result is less than reporting limit.

B – Method Blank Contamination. The associated method blank contains the target analyte at a reportable level.

MCL - Maximum Contaminant Levels

MDL - Method Detection Limit

VOCs - Volatile Organic Compounds

SVOCs - Semivolatoile Organic Compounds

< - less than laboratory method detection level

µg/L - Micrograms per Liter

** April & October 2006 Analytical Data Validation Deemed All Data to be Useable for Comparison to MCLs & Screening Levels.*

ATCH (1)

Industrial Zone Sites
Selected Data Summary Tables
Vance AFB, Oklahoma

Water Bearing Zone	Monitor Well ID	Parameter	VOC (µg/L) & Metals (mg/L) Concentrations						
			MCL[a]	February 2004	August 2004	May 2005	October 2005	April 2006*	October 2006*
IRP Site SS-07									
Shallow	7-6	acetone	5,500[b]	<0.388	5.8	0.75 J	<0.82	<0.82	<0.82
		1,1-dichloroethane	1,200[b]	8.8	4.77	3.9	3.9	6.0	<0.39
		cis-1,2-dichloroethene	70	10.6	9.01	6	6.9	7.1	<0.37
		benzene	5	<0.010	2.55B	<0.39	<0.39	<0.39	<0.39
		Ethylbenzene	700	<0.007	0.699BJ	<0.42	<0.39	<0.42	<0.42
		Toluene	1,000	<0.006	10.2B	<0.35	<0.39	<0.39	<0.39
		Xylene (Total)	10,000	<0.010	11.9B	<0.03	<0.83	<0.83	<0.83
		Mercury	0.002	<0.000003	<.0000000472	<0.0000002	<0.0000002	0.000041 B,J	0.000000039 B
		Arsenic	0.010	<0.0038	**<0.0224**	0.0082	0.0037 B	<0.0023	0.0058
		Barium	2	0.13	0.0908	0.669	0.266	0.116	0.822
		Chromium	0.1	<0.0070	0.000928 J	0.0322	0.0047 B	0.0034 B	0.0638
		Lead	0.015	<0.0010	<0.00172	0.0097	0.0022 B, J	0.0029 B	0.00294
		Selenium	0.05	<0.0036	0.00795	<0.0026	**2.3 B**	0.0021 B	<0.005
Shallow	OB-8	cis-1,2-dichloroethene	70	2.2	2.88	3.2	0.0028	1.8	1.8
		trichloroethene	5	**18.7**	**25.7**	**17**	**24**	**18**	**19**
		Mercury	0.002	<0.000003	<.0000000472	<0.00000020	0.000049 B	<0.000027	0.00011 B
		Arsenic	0.010	<0.0038	<0.0224	<0.005	0.0026 B	<0.0023	0.0025 B
		Barium	2	0.055	0.0586	0.106	0.0798 B	0.112	0.069 B
		Chromium	0.1	<0.0070	0.00121J	0.0091 B	0.0038 B	0.0108	0.002 B
		Silver	180[b]	<0.00060	0.000874 J	<0.010	<0.010	<0.010	0.0018 B, J
		Selenium	0.05	<0.0036	0.0391	0.0106	0.0082	0.0082	0.0122 J
Shallow	OB-17	acetone	5,500[b]	<0.388	8.91	<0.71	<0.82	0.0499 J	<0.05
		Mercury	0.002	<0.000003	<.0000000472	<0.000026	0.000045 B	0.000068 B, J	0.000000041 B
		Arsenic	0.010	<0.0038	**<0.0224**	0.0038 B	**0.0148**	**0.0197**	0.0064
		Barium	2	0.077	0.0283	0.0707 B	0.355	0.622	0.157
		Chromium	0.1	<0.0070	0.000874 J	0.0067 B	0.0516	**0.123**	0.0236
		Lead	0.015	<0.0010	<0.00172	<0.0022	**0.0181 J**	0.0499 J	0.0143
		Selenium	0.05	<0.0036	0.0391	0.0368	0.0167	0.0262	0.017
Shallow	OB-22	acetone	5,500[b]	<0.388	4.75 J	<0.71	1.6 J	<0.82	<0.82
		trichloroethene	5	1.43	1.25	1.2	1.5	1.0	0.91 J
		Mercury	0.002	<0.000003	<.0000000472	<0.00000020	<0.00000020	0.000035 B, J	<0.0000002
		Barium	2	0.089	0.083	0.119	0.0642 B	0.0698 B	.069 B
		Chromium	0.1	<0.0070	0.00139 J	0.0113	<0.00082	<0.0025	0.0024 B
		Lead	0.015	<0.0010	<0.00172	<0.005	<0.005	0.0026 B	<0.005
		Selenium	0.05	<0.0036	0.00795	**0.0109**	0.0075	0.0079	0.0062
Shallow	N7-23	acetone	5,500[b]	<0.388	<2.29	1.1 J	<0.82	<0.82	<0.82
		trichloroethene	5	4.46	<0.360	<0.45	<0.45	<0.45	<0.45
		Arsenic	0.010	<0.0038	<0.00224	0.0076	0.0048 B	0.0029 B	0.0045 B
		Barium	2	<0.00050	0.0731	0.278	0.102	0.093.2 B	0.126
		Chromium	0.1	<0.0070	0.0025 J	0.0299	0.006 B	<0.0025	0.0076
		Lead	0.015	<0.0010	<0.00172	0.0111	0.0024 B, J	0.0025 B	0.0031
Deep	N7-39	trichloroethene	5	4.21	3.13	1.1	1.3	<0.45	<0.45
		Arsenic	0.010	<0.0038	**<0.0447**	.004 B	0.0025 B	<0.005	0.0044 B
		Barium	2	0.02	0.0184	0.0568 B	0.015 B	0.0289 B	0.0312 B
		Cadmium	0.005	<0.00020	<0.000313	<0.005	<0.005	0.0011 B	<0.005
		Chromium	0.1	<0.0070	0.0219	0.0456	0.0102	0.0085 B	0.0142
		Lead	0.015	<0.0010	<0.00172	<0.005	<0.005	0.0037 B	<0.005
		Selenium	0.05	<0.0036	0.0152	0.0104	0.0092	0.013	0.0055
Shallow	N7-41	acetone	5,500[b]	<0.388	<2.29	1.2 J	1.8 J	<0.82	<0.82
		Mercury	0.002	<0.000003	<.0000000472	0.000029 B	<0.000026	<0.000027	<0.0000002
		Arsenic	0.010	<0.0038	<0.00224	**0.0184**	<0.0037	<0.0023	<0.005
		Barium	2	0.12	0.147	0.505	0.0925 B	0.117	0.124
		Cadmium	0.005	<0.00020	<0.000313	0.0021	<0.00023	<0.00047	<0.005
		Chromium	0.1	<0.0070	0.000595 J	0.0606	<0.00082	<0.0025	<0.010
		Lead	0.015	<0.0010	<0.00172	**0.0325**	<0.0022	0.0018 B	<0.005
		Selenium	0.05	<0.0036	0.0152	<0.0026	0.0018 B	<0.0016	<0.005
Shallow	N7-45	acetone	5,500[b]	<0.388	3.39	<0.71	3.39 J	NS	NS
		Mercury	0.002	<0.000003	<0.0000000472	<0.000026	0.000043 B	NS	NS
		Barium	2	0.089	0.0929	0.103	0.108	NS	NS
		Cadmium	0.005	<0.00020	0.000669 J	<0.00023	0.0036 B	NS	NS
		Chromium	0.1	<0.0070	0.00251 J	0.0058 B	0.0028 B	NS	NS
		Lead	0.015	<0.0010	<0.00172	<0.0022	0.0025 B, J	NS	NS
		Selenium	0.05	<0.0036	0.0091	<0.0026	0.0038 B	NS	NS

ATCH (2)

Industrial Zone Sites
Selected Data Summary Tables
Vance AFB, Oklahoma

Water Bearing Zone	Monitor Well ID	Parameter	VOC (µg/L) & Metals (mg/L) Concentrations						
			MCL[a]	February 2004	August 2004	May 2005	October 2005	April 2006*	October 2006*
Deep	N7-51	acetone	5,500[b]	<0.388	<2.29	1.2 J	<0.82	<0.82	<0.82
		trichloroethene	5	1.62	2.53	1.9	1.4	1.0	0.57 J
		Mercury	0.002	<0.000003	<.0000000472	<0.0000002	<0.0000002	0.000037	0.000000044 B
		Arsenic	0.010	<0.0038	<0.00224	0.0082	0.0095	0.0058	0.0252
		Barium	2	0.021	0.0701	0.0526 B	0.0199 B	0.0337 B	0.503
		Chromium	0.1	<0.0070	0.00615	0.0584	0.0069 B	0.0065 B	0.0948
		Lead	0.015	<0.0010	0.0146	<0.005	<0.005	0.0023 B,J	**0.04**
		Selenium	0.05	<0.0036	0.0392	0.0309	0.0277	0.0304	0.0235
Shallow	N7-65	trichloroethene	5	1.29	0.00177	2	1.7	1.4	1.2
		Mercury	0.002	<0.000003	<0.0000000472	<0.0000002	<0.0000002	0.000086 B,J	<0.0000002
		Barium	2	0.1	<0.0738	0.128	0.0593 B	0.062 B	0.0637 B
		Cadmium	0.005	<0.00020	<0.000313	<0.005	<0.00023	<0.005	1.1 B
		Chromium	0.1	<0.0070	<0.000696	0.0028 B	<0.00082	<0.0025	<0.010
		Selenium	0.05	<0.0036	<0.0281	0.0092	0.0059	0.0054	0.0033 B
Shallow	N7-69	trichloroethene	5	1.68	0.781	1.4	0.59 J	1.4	<0.45
		Mercury	0.002	<0.000003	<0.0000000472	0.000039 B	<0.0000002	0.000042 B,J	0.000000028 B
		Arsenic	0.010	<0.0038	**<0.0447**	0.0067	0.0031 B	<0.0023	0.005
		Barium	2	0.7	0.823	1.18	0.779	0.509	0.305
		Chromium	0.1	<0.0070	0.00306	0.0207	0.011	<0.0025	<0.01
		Lead	0.015	<0.0010	<0.00172	0.0147	0.012	<0.0017	<0.005
		Selenium	0.05	<0.0036	<0.141	0.004 B	0.0027 B	0.0049 B	<0.005
Shallow	N7-70	All VOCs below MDLs							
		Mercury	0.002	<0.000003	<0.0000000472	<0.0000002	<0.0000002	0.000035 B,J	<0.0000002
		Arsenic	0.010	<0.0038	**<0.024**	<0.005	<0.005	<0.005	0.0026 B
		Barium	2	0.26	0.136	0.213 J	0.158	0.133	0.324
		Chromium	0.1	<0.0070	0.000819	0.0091 B	<0.00082	0.0025	0.0179
		Lead	0.015	<0.0010	<0.00172	<0.005	<0.005	<0.005	0.008
		Selenium	0.05	<0.0036	<0.00281	0.0038 B	0.0024 B	0.0046 B	0.0057
IRP Site ST-08									
Shallow	8-2	benzene	5	<0.020	0.729 J	0.77 J	0.45 J	0.53 J	0.42 J
		2-butanone (MEK)	1,900[b]	<0.204	<2.31	<0.19	9.7 J	<0.84	<0.84
		ethylbenzene	700	<0.014	0.689 J	0.52 J	0.51 J	0.45 J	0.45 J
		vinyl chloride	2	<0.116	<0.550	0.61 J	<0.40	0.44 J	<0.40
		Mercury	0.002	<0.000003	<0.0000000472	<0.000026	0.000052 B, J	<0.000054	0.000000088
		Arsenic	0.010	<0.0038	**0.030**	**0.02**	**0.0313**	**0.0204**	**0.0575**
		Barium	2	0.47	0.35	0.296	0.419	0.333	0.849
		Chromium	0.1	<0.0070	<0.000503	<0.00082	0.0079 B	<0.0025	0.092
		Lead	0.015	<0.0010	<0.00172	<0.0022	0.0092	<0.0017	**0.0591**
Deep	8-13	cis-1,2-dichloroethene	70	<0.042	<0.300	<0.37	0.89 J	<0.37	<0.37
		trichloroethene	5	<0.037	<0.360	<0.45	0.52 J	<0.45	<0.45
		Mercury	0.002	<0.000003	<0.0000000472	<0.000026	0.000049 B, J	<0.000027	<0.0000002
		Arsenic	0.01	<0.0038	0.00624	<0.005	<0.005	0.0059	0.0091
		Barium	2	0.026	0.0467	0.0214 B	0.0218 B	0.0468 B	0.148
		Chromium	0.1	0.011	0.0243	0.0068 B	0.0176	0.0076 B	0.0294
		Lead	0.015	<0.0010	0.00463	<0.005	<0.005	0.0029 B	0.0131
		Selenium	0.05	<0.0036	0.0229	0.0393	0.0144	0.0357	0.0301

Notes and Abbreviations :

a *Groundwater screening criterion is based on USEPA, National Primary Drinking Water Standards, Maximum Contaminant Levels (MCLs), EPA 2006.*

b *No MCL screening criterion available. Screening level provided by Oklahoma DEQ for Vance AFB (Referenced from EPA Region 6 Human Health Medium-Specific Screening Levels 2006).*

Shaded and bold type exceed the constituent MCL/Screening Level
NR - No result reported for COC
NS - Not Sampled. Results not available due to dry well.
NA - Indicates value not available
J – Estimated Result. Result is less than reporting limit.
B – Method Blank Contamination. The associated method blank contains the target analyte at a reportable level.
MCL - Maximum Contaminant Levels
MDL - Method Detection Limit
VOCs - Volatile Organic Compounds
SVOCs - Semivolatoile Organic Compounds
< - less than laboratory method detection level
µg/L - Micrograms per Liter
mg/L - Milligrams per Liter
** April & October 2006 Analytical Data Validation Deemed All Data to be Useable for Comparison to MCLs & Screening Levels.*

ATch(3)

Table 5-7
BIOTRANS - Site 12 Trichloroethene Input Parameters
Vance Air Force Base, Oklahoma

Parameter Type	Parameter	Value	Units	Reference
Spatial Data	Model Grid Spacing	106 by 153	ft^2	---
	Flow Conditions	Uniform Flow	---	---
	Groundwater Flow Direction	15	degrees from North	Figure 3-1
	Hydraulic Gradient	0.006	unitless	Figure 3-1
	Hydraulic Conductivity	2.8	ft / day	USACE, 1991*
	Aquifer Thickness (T)	20	ft	OHM, 1995
Transport	Porosity	0.4	unitless	Domenico, 1990
	Bulk Density	1.58	g / cm^3	USACE, 1991
	Longitudinal Dispersivity (L)	50	ft	See Note[1]
	Transverse Dispersivity	0.1(L)	ft	ES&T, 1994
	Oil-Water Mass Transfer Coefficient	0.0	unitless	See Note[2]
	Molecular Weight of NAPL	0.0	g / mole	See Note[2]
	Density of NAPL	0.0	g / cm^3	See Note[2]
	Immobile Zone Pore Fraction	0.0	unitless	See Note[3]
	Mobile-Immob. Mass Transfer Coeff.	0.0	1 / day	See Note[3]
Chemical Data	Initial Mass Fraction in NAPL	0.140	unitless	See Note[11]
	Molecular Weight	131.39	g / mole	---
	Solubility	1,100	mg / L	HRI, 1993
	Organic Carbon Partitioning Coeff.	126	mL / g	USEPA, 1986
	Adsorption Coefficient**	7.56E-02	mL / g	---
	First-Order Decay Constant***	4.19E-05	1 / day	Howard, 1991
	Volatilization Loss Coefficient	0.0	1 / day	---
	Initial Background Concentration	0.0	mg / L	---
Point Source Data	See Appendix B			

Notes:

* - The hydraulic conductivity was calculated based on an analysis of weathered zones which is discussed in Appendix A of the August 1995 Modeling Work Plan.

** - In calculating the adsorption coefficient, the fraction of organic carbon, assumed to be 0.0006, was multiplied by the organic carbon partitioning coefficient.

*** - The first-order decay constants (k) were calculated using the equation, k=.693/h.
The variable h is 10X the groundwater half life given by Howard (1991).
These half lives were chosen since BIOTRANS modelling was in the saturated zone.

1 - The longitudinal dispersivity was modified during model calibration from its original, calculated value. Since a conservatively high hydraulic conductivity was used, a lower longitudinal dispersivity was required to produce model calibration.

2 - These transport input parameters were not employed since a NAPL was not used as a contaminant source.

3 - These transport input parameters were not employed because the entire pore fraction was assumed to be mobile.

11 - The initial mass fraction was based on past site analytical data.

DRAFT REPORT

MAROS 2.2 APPLICATION

of

Shallow Zone Aquifer Monitoring Network Optimization of DNAPL TCE

of

Industrial Zone (IZ) and CMI Area

Vance AFB, Oklahoma

for

U.S Army Corps of Engineers, Tulsa District
Contract Number W912BV-04-D-2020

Submitted to EA Engineering, Science, and Technology

By

Ron Erdman

TABLE 1

CMI Area
Compliance Monitoring Wells

Well Identification	Water Bearing Zone
Site ST-12	
12-9	Shallow
12-33	Shallow
12-35	Shallow
12-37	Shallow
12-43	Shallow
12-45	Shallow
12-30	Intermediate
12-34	Intermediate
12-38	Intermediate
12-13	Deep
12-19	Deep
12-20	Deep
12-21	Deep
12-22	Deep
Site WP-23	
23-5	Shallow
23-14	Shallow
23-34	Shallow
23-21	Intermediate
23-22	Intermediate
23-28	Intermediate
23-32	Deep
Site SS-24	
24-4	Shallow
24-5	Shallow
24-6	Shallow
24-12	Intermediate
Site SS-25	
25-1	Shallow
25-2	Shallow
25-4	Shallow
25-5	Shallow
25-7	Shallow
25-8	Shallow
25-9	Shallow
25-15	Shallow
25-10	Intermediate

TABLE 2

Industrial Zone
Compliance Wells

Well Identification	Water Bearing Zone
Site LF-03	
3-6	Shallow
3-9	Shallow
3-7	Deep
Site SS-07	
7-4	Shallow
7-6	Shallow
7-15	Shallow
7-7	Deep
OB-2	Shallow
OB-3	Shallow
OB-4	Shallow
OB-5	Shallow
OB-6	Shallow
OB-8	Shallow
OB-9	Shallow
OB-13	Shallow
OB-16	Shallow
OB-17	Shallow
OB-18	Shallow
OB-19	Shallow
OB-21	Shallow
OB-22	Shallow
N7-40	Shallow
N7-41	Shallow
N7-45	Shallow
N7-23	Shallow
N7-65	Shallow
N7-69	Shallow
N7-70	Shallow
N7-38	Intermediate
N7-48	Intermediate
N7-50	Intermediate
N7-52	Intermediate
N7-39	Deep
N7-51	Deep
N7-53	Deep
Site ST-08	
8-2	Shallow
8-5	Shallow
8-9	Shallow
8-12	Shallow
8-16	Shallow
8-18	Intermediate
8-13	Deep

Table 4

Shallow or Upper Saturated Zone Site Specific Parameters

Note: Existing potentiometric surface maps were developed for compliance wells over time were used to determine groundwater flow direction. The following is a review of available data from the various testing companies involved in the Vance project from its inception and deals with *only the shallow* transmissive zone.

The direction of groundwater flow has been documented as NNE which relates to an angle of 67.5 degrees CCW from due east that conforms to MAROS methodology. Since the Site Information in MAROS only allows N or NE, it was decided to use due north for the initial evaluation. The angle of 67 degrees was used in the risk-based analysis.

CMI Site

Groundwater Flow Movement Shallow Aquifer

Date	Flow Velocity per Zone V = feet/year	Hydraulic Gradient I = ft/ft
May 2005	21.20	0.0061
October 2005	18.11	0.0052
Average	19.66	
April 2006	18.11	0.0052
Oct 2006	17.07	0.0049
Average	17.59	
Average 2005-2006	**18.63** ft/yr.	

Previous flow velocities for specific areas varied and were higher in the past, such as an average of 37.83 ft/yr. for sites 12 and 23 in 2003 (ref.9), which could indicate an average seepage flow of about 25.0 ft/yr. However, the 2005-2006 average seepage velocity of 18.63 ft/yr. was used in this report and is slightly conservative for with regard to groundwater flow which may fluctuate over time.

Average Hydraulic Conductivity value of 6.75E-4 cm/sec per aquifer pump testing in 1990 by USACE, Tulsa District (USACE, November 1991).

The groundwater flow velocities were calculated and averaged for the year based on the above average K and an assumed effective porosity of 20 percent.

Groundwater flow velocity is based on the standard formula: V = Ki/n; where:

V = groundwater flow velocity
K = hydraulic conductivity
I = hydraulic gradient
n = effective porosity

Flow Direction - North-northeast

Gradient – Flattened out on the southern portion

Groundwater flow velocities for 2006 were averaged from calculations using the average hydraulic conductivity value, average gradients from groundwater surface maps, and an assumed effective porosity of 20 percent.

(26,1)

The shallow zone has been documented as a depth 10 t0 30 feet below the ground surface, or 20 feet as a result of compiling data from various sources over the years. For instance, a 20-foot depth was applied to Site 12 BIOTRANS modeling in 1996.

Data for Site 12 monitoring also included the following information (6):

Well No.	Screen interval (ft.)
12-9	8.0 to 17.5
12-33	9.36-19.36
12-37	13.42-23.42
12-43	10.0-20.0
12.45	11.54-21.54
23-5	8.0-28.9
23-14	10.0-18.0
23-34	11.0-16.0
24-4	13.0-18.0
24-5	14.5-24.5
24-6	10.5-20.5

Table 5

Shallow or Upper Saturated Zone Site Specific Parameters

Note: Existing potentiometric surface maps were developed for compliance wells over time were used to determine groundwater flow direction. The following is a review of available data from the various testing companies involved in the Vance project from its inception and deals with *only the shallow* transmissive zone.

The direction of groundwater flow has been documented as NNE which relates to an angle of 67.5 degrees CCW from due east that conforms to MAROS methodology. Since the Site Information in MAROS only allows N or NE, it was decided to use due north for the initial evaluation. The angle of 67 degrees was used in the risk-based analysis.

IZ Site

Groundwater Flow Movement

Date	Flow Velocity per Zone V = feet/year	Hydraulic Gradient I = ft/ft
	Shallow	Shallow
May 2005	15.0	0.0044
October 2005	15.0	0.0044
Average	15.0	
April 2006	13.45	0.0039
Oct 2006	16.03	0.0047
Average	14.74	
Average 2005-2006	**14.87** ft/yr.	

Average Hydraulic Conductivity value of 6.75E-4 cm/sec per aquifer pump testing in 1990 by USACE. Tulsa District (USACE, November 1991).

The groundwater flow velocities were calculated and averaged for the year based on the above average K and an assumed effective porosity of 20 percent.

Groundwater flow velocity is based on the standard formula: V = Ki/n: where:

V = groundwater flow velocity
K = hydraulic conductivity
I = hydraulic gradient

n = effective porosity

Flow Direction - North-northeast

Gradient – Flattened out on the southern portion

Groundwater flow velocities for 2006 were averaged from calculations using the average hydraulic conductivity value, average gradients from groundwater surface maps, and an assumed effective porosity of 20 percent.

CMI Area

20 ft deep

Site Information

Provide information regarding the current site, 2-D plume information.

SITE DETAILS

General

Project: Vance EA CMI

Location: Enid

State: Oklahoma

Hydrogeology and Plume Information

Seepage Velocity: 18.63 ft/yr

Main Constituents: Chlorinated Solvent

Current Plume Width: 1120 ft

Current Plume Length: 2240 ft

Maximum Plume Length: 3200 ft

GW Fluctuations: ☑ Yes ☐ No

Source Information

Free-Phase NAPL Present: ☐ Yes ☑ No

Current Source Treatment: Pump and Treat; In-situ Biodegradation

Down-gradient Information

Distance from Source to Nearest:

Downgradient receptor: 400 ft

Downgradient property line: 3200 ft

Distance from Edge of Tail to Nearest

Downgradient receptor: 225 ft

Downgradient property line: 1680 ft

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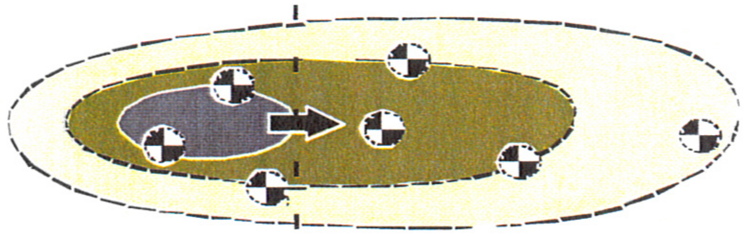
SITE DETAILS

Source/Tail Zone Selection



Source Zone | Tail Zone

Select representative wells in the "Source" - S and "Tail" - T zones or "Not Used". Choose either Tail or Source or Not Used by clicking on the box to the right of the well in the table below. A maximum number of 200 wells in each category can be chosen.

Well Name	Source	Tail	Not Use
MW12-09	✓		
MW12-33	✓		
MW12-35	✓		
MW12-37	✓		
MW12-43		✓	
MW12-45		✓	
MW23-05	✓		
MW23-14	✓		
MW23-34	✓		
MW24-04		✓	
MW24-05		✓	
MW25-01		✓	
MW25-02		✓	
MW25-04		✓	
MW25-05		✓	
MW25-07		✓	
MW25-08		✓	
MW25-09		✓	
MW25-15		✓	

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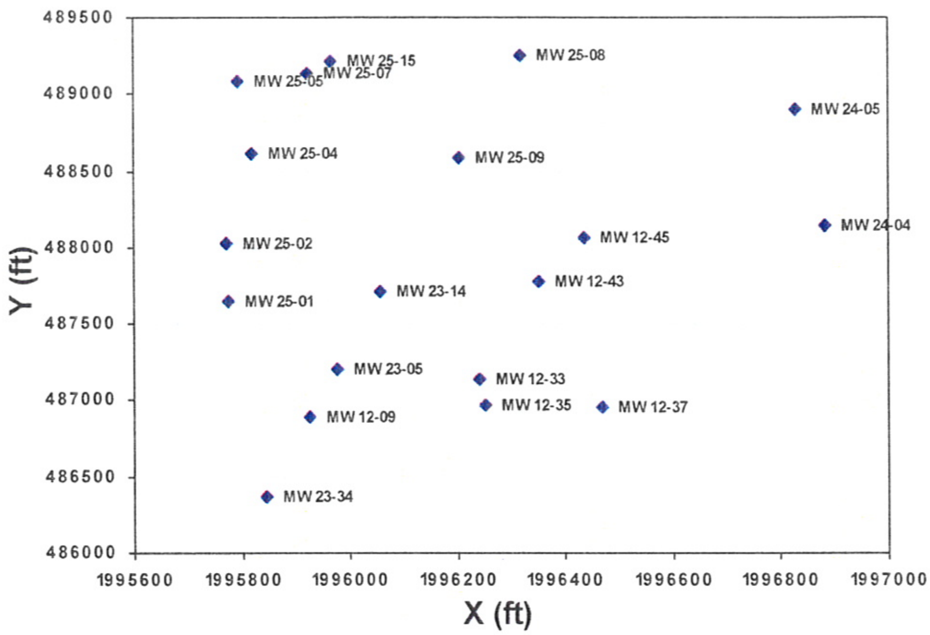
Well Locations

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



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SITE DETAILS

Reduced Data Table

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

Well Name	Source/ Tail	Date	COC	Result Number (mg/L)	Flag
MW23-34	S	9/1/1998	TRICHLOROETHYLENE (TCE)	1.2E-03	
MW23-34	S	3/1/2006	TRICHLOROETHYLENE (TCE)	2.3E-04	
MW23-34	S	9/1/2005	TRICHLOROETHYLENE (TCE)	2.3E-04	
MW23-34	S	3/1/2005	TRICHLOROETHYLENE (TCE)	2.5E-04	
MW23-34	S	3/1/2004	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW23-34	S	3/1/2003	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW12-37	S	9/1/2004	TRICHLOROETHYLENE (TCE)	2.6E+00	
MW23-34	S	3/1/2002	TRICHLOROETHYLENE (TCE)	2.7E-04	
MW23-14	S	3/1/2003	TRICHLOROETHYLENE (TCE)	5.9E-02	
MW23-34	S	9/1/2004	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW12-37	S	3/1/2005	TRICHLOROETHYLENE (TCE)	4.4E-03	
MW12-37	S	3/1/1998	TRICHLOROETHYLENE (TCE)	1.8E-02	
MW12-37	S	3/1/2002	TRICHLOROETHYLENE (TCE)	4.1E-02	
MW12-37	S	3/1/2003	TRICHLOROETHYLENE (TCE)	2.7E-02	
MW23-14	S	3/1/2006	TRICHLOROETHYLENE (TCE)	4.3E-02	
MW12-09	S	3/1/2005	TRICHLOROETHYLENE (TCE)	6.1E-01	
MW23-14	S	9/1/2006	TRICHLOROETHYLENE (TCE)	5.0E-02	
MW23-14	S	3/1/1998	TRICHLOROETHYLENE (TCE)	1.2E-01	
MW23-14	S	3/1/2005	TRICHLOROETHYLENE (TCE)	3.3E-02	
MW23-05	S	9/1/2003	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW23-05	S	3/1/1998	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW23-05	S	3/1/2003	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW23-05	S	3/1/2004	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW23-34	S	9/1/2006	TRICHLOROETHYLENE (TCE)	2.5E-04	
MW23-05	S	3/1/2002	TRICHLOROETHYLENE (TCE)	3.2E-04	
MW23-34	S	9/1/2003	TRICHLOROETHYLENE (TCE)	3.2E-04	
MW23-14	S	9/1/2005	TRICHLOROETHYLENE (TCE)	7.9E-02	
MW23-14	S	3/1/2004	TRICHLOROETHYLENE (TCE)	1.3E-02	
MW23-14	S	9/1/2003	TRICHLOROETHYLENE (TCE)	2.3E-02	
MW23-14	S	3/1/2002	TRICHLOROETHYLENE (TCE)	7.4E-02	
MW23-14	S	9/1/2004	TRICHLOROETHYLENE (TCE)	6.9E-02	
MW12-37	S	9/1/2005	TRICHLOROETHYLENE (TCE)	1.0E-02	
MW23-05	S	9/1/2004	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW12-09	S	3/1/2002	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW12-33	S	9/1/2004	TRICHLOROETHYLENE (TCE)	3.1E-01	
MW12-33	S	9/1/2005	TRICHLOROETHYLENE (TCE)	4.8E-01	
MW12-33	S	3/1/2006	TRICHLOROETHYLENE (TCE)	6.1E-01	
MW12-33	S	9/1/2006	TRICHLOROETHYLENE (TCE)	6.2E-01	
MW12-33	S	3/1/2005	TRICHLOROETHYLENE (TCE)	3.6E-01	
MW12-33	S	3/1/2002	TRICHLOROETHYLENE (TCE)	5.3E-01	

MW12-37	S	9/1/2003	TRICHLOROETHYLENE (TCE)	1.2E-02
MW12-09	S	3/1/1998	TRICHLOROETHYLENE (TCE)	1.4E+00
MW12-33	S	3/1/1998	TRICHLOROETHYLENE (TCE)	7.6E-01
MW12-09	S	3/1/2003	TRICHLOROETHYLENE (TCE)	4.8E-01
MW12-09	S	9/1/2003	TRICHLOROETHYLENE (TCE)	1.5E+00
MW12-09	S	3/1/2004	TRICHLOROETHYLENE (TCE)	1.0E-01
MW12-09	S	9/1/2004	TRICHLOROETHYLENE (TCE)	1.2E+00
MW12-09	S	9/1/2005	TRICHLOROETHYLENE (TCE)	1.5E-01
MW12-09	S	9/1/2006	TRICHLOROETHYLENE (TCE)	1.2E+00
MW12-09	S	9/1/1996	TRICHLOROETHYLENE (TCE)	4.6E+00
MW12-09	S	3/1/2006	TRICHLOROETHYLENE (TCE)	1.4E-01
MW12-35	S	9/1/2005	TRICHLOROETHYLENE (TCE)	5.0E+00
MW12-37	S	3/1/2004	TRICHLOROETHYLENE (TCE)	1.6E-02
MW12-35	S	9/1/2004	TRICHLOROETHYLENE (TCE)	1.6E+01
MW12-35	S	9/1/2003	TRICHLOROETHYLENE (TCE)	1.8E+01
MW12-35	S	3/1/1998	TRICHLOROETHYLENE (TCE)	8.1E+00
MW12-35	S	3/1/2003	TRICHLOROETHYLENE (TCE)	1.1E+01
MW12-33	S	3/1/2004	TRICHLOROETHYLENE (TCE)	2.4E-01
MW12-37	S	9/1/2006	TRICHLOROETHYLENE (TCE)	3.5E-04
MW12-33	S	3/1/2003	TRICHLOROETHYLENE (TCE)	4.1E-01
MW12-35	S	3/1/2004	TRICHLOROETHYLENE (TCE)	3.9E+00
MW12-35	S	3/1/2006	TRICHLOROETHYLENE (TCE)	4.3E+00
MW12-35	S	9/1/2006	TRICHLOROETHYLENE (TCE)	1.2E+01
MW12-35	S	3/1/2002	TRICHLOROETHYLENE (TCE)	3.1E+00
MW12-35	S	3/1/2005	TRICHLOROETHYLENE (TCE)	3.4E+00
MW12-33	S	9/1/2003	TRICHLOROETHYLENE (TCE)	2.5E-01
MW12-37	S	3/1/2006	TRICHLOROETHYLENE (TCE)	3.2E-04
MW12-43	T	9/1/2005	TRICHLOROETHYLENE (TCE)	1.4E-01
MW24-04	T	3/1/2004	TRICHLOROETHYLENE (TCE)	1.6E-03
MW24-04	T	3/1/1998	TRICHLOROETHYLENE (TCE)	1.6E-03
MW12-45	T	9/1/2005	TRICHLOROETHYLENE (TCE)	3.2E+00
MW12-43	T	9/1/2003	TRICHLOROETHYLENE (TCE)	1.7E-01
MW12-43	T	9/1/2006	TRICHLOROETHYLENE (TCE)	5.0E-02
MW12-43	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.6E-01
MW24-04	T	9/1/2004	TRICHLOROETHYLENE (TCE)	1.5E-03
MW12-43	T	3/1/2005	TRICHLOROETHYLENE (TCE)	1.3E-01
MW12-43	T	3/1/2003	TRICHLOROETHYLENE (TCE)	2.3E-01
MW12-43	T	3/1/2002	TRICHLOROETHYLENE (TCE)	2.5E-01
MW12-43	T	9/1/2004	TRICHLOROETHYLENE (TCE)	1.5E-01
MW12-43	T	3/1/2004	TRICHLOROETHYLENE (TCE)	8.5E-02
MW12-45	T	9/1/2006	TRICHLOROETHYLENE (TCE)	2.9E+00
MW12-45	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.9E+00
MW12-45	T	3/1/2005	TRICHLOROETHYLENE (TCE)	1.9E+00
MW12-45	T	9/1/2004	TRICHLOROETHYLENE (TCE)	9.9E-01
MW12-45	T	9/1/2003	TRICHLOROETHYLENE (TCE)	4.6E-01
MW12-45	T	3/1/2003	TRICHLOROETHYLENE (TCE)	6.9E-01
MW12-45	T	3/1/1998	TRICHLOROETHYLENE (TCE)	5.5E-01
MW12-45	T	3/1/2002	TRICHLOROETHYLENE (TCE)	5.9E-01

MW12-45	T	3/1/2004	TRICHLOROETHYLENE (TCE)	7.5E-01	
MW12-43	T	3/1/1998	TRICHLOROETHYLENE (TCE)	3.0E-01	
MW25-05	T	9/1/2004	TRICHLOROETHYLENE (TCE)	1.8E-04	
MW25-07	T	3/1/2004	TRICHLOROETHYLENE (TCE)	2.2E-03	
MW25-07	T	3/1/1998	TRICHLOROETHYLENE (TCE)	5.2E-03	
MW25-07	T	3/1/2002	TRICHLOROETHYLENE (TCE)	5.8E-03	
MW25-07	T	3/1/2003	TRICHLOROETHYLENE (TCE)	4.2E-03	
MW25-07	T	9/1/2003	TRICHLOROETHYLENE (TCE)	1.3E-03	
MW25-07	T	3/1/2005	TRICHLOROETHYLENE (TCE)	2.3E-03	
MW25-07	T	9/1/2005	TRICHLOROETHYLENE (TCE)	1.9E-03	
MW25-07	T	9/1/2006	TRICHLOROETHYLENE (TCE)	2.3E-04	
MW24-04	T	3/1/2002	TRICHLOROETHYLENE (TCE)	7.5E-03	
MW25-07	T	9/1/2004	TRICHLOROETHYLENE (TCE)	2.8E-03	
MW25-08	T	3/1/1998	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW25-05	T	3/1/1998	TRICHLOROETHYLENE (TCE)	3.1E-03	
MW25-05	T	3/1/2002	TRICHLOROETHYLENE (TCE)	4.3E-03	
MW25-05	T	3/1/2003	TRICHLOROETHYLENE (TCE)	1.7E-03	
MW25-05	T	3/1/2004	TRICHLOROETHYLENE (TCE)	2.8E-04	
MW25-05	T	3/1/2005	TRICHLOROETHYLENE (TCE)	4.5E-04	
MW25-05	T	9/1/2005	TRICHLOROETHYLENE (TCE)	2.2E-03	
MW25-05	T	3/1/2006	TRICHLOROETHYLENE (TCE)	2.3E-04	
MW25-05	T	9/1/2006	TRICHLOROETHYLENE (TCE)	1.7E-03	
MW25-05	T	9/1/2003	TRICHLOROETHYLENE (TCE)	1.9E-04	
MW25-07	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.6E-03	
MW25-09	T	9/1/2004	TRICHLOROETHYLENE (TCE)	2.6E-02	
MW25-15	T	9/1/2004	TRICHLOROETHYLENE (TCE)	1.9E-04	
MW25-15	T	3/1/2004	TRICHLOROETHYLENE (TCE)	2.2E-04	
MW25-15	T	9/1/2003	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW25-15	T	3/1/2003	TRICHLOROETHYLENE (TCE)	2.8E-04	
MW25-15	T	3/1/2002	TRICHLOROETHYLENE (TCE)	2.0E-03	
MW25-15	T	9/1/1998	TRICHLOROETHYLENE (TCE)	1.8E-03	
MW25-15	T	9/1/2006	TRICHLOROETHYLENE (TCE)	2.3E-04	
MW25-09	T	3/1/2004	TRICHLOROETHYLENE (TCE)	8.3E-03	
MW25-09	T	3/1/1998	TRICHLOROETHYLENE (TCE)	8.4E-02	
MW25-08	T	3/1/2003	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW25-09	T	9/1/2003	TRICHLOROETHYLENE (TCE)	3.8E-02	
MW25-08	T	9/1/2004	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
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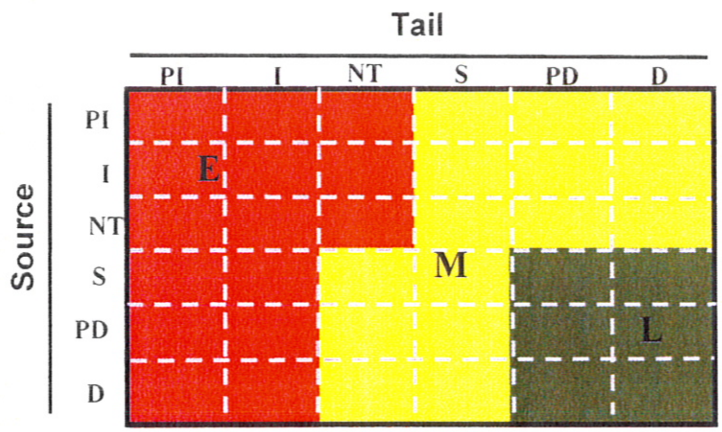
MW25-09	T	3/1/2006	TRICHLOROETHYLENE (TCE)	2.1E-02	
MW25-09	T	3/1/2003	TRICHLOROETHYLENE (TCE)	6.6E-02	
MW25-08	T	3/1/2004	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW25-08	T	3/1/2002	TRICHLOROETHYLENE (TCE)	2.5E-04	
MW25-08	T	9/1/2003	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
MW25-04	T	3/1/1998	TRICHLOROETHYLENE (TCE)	7.9E-03	
MW25-09	T	3/1/2002	TRICHLOROETHYLENE (TCE)	9.8E-02	
MW24-05	T	9/1/2005	TRICHLOROETHYLENE (TCE)	1.5E-02	

MW25-04	T	3/1/2004	TRICHLOROETHYLENE (TCE)	1.6E-03
MW25-01	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.3E-02
MW25-01	T	9/1/2006	TRICHLOROETHYLENE (TCE)	1.2E-02
MW25-01	T	3/1/2003	TRICHLOROETHYLENE (TCE)	8.8E-03
MW25-01	T	3/1/2005	TRICHLOROETHYLENE (TCE)	8.6E-03
MW24-05	T	9/1/2004	TRICHLOROETHYLENE (TCE)	5.0E-03
MW24-05	T	3/1/1998	TRICHLOROETHYLENE (TCE)	6.3E-03
MW24-05	T	3/1/2002	TRICHLOROETHYLENE (TCE)	7.2E-03
MW24-05	T	3/1/2003	TRICHLOROETHYLENE (TCE)	3.9E-03
MW25-01	T	3/1/1998	TRICHLOROETHYLENE (TCE)	5.9E-03
MW24-05	T	3/1/2005	TRICHLOROETHYLENE (TCE)	8.6E-03
MW25-01	T	9/1/2003	TRICHLOROETHYLENE (TCE)	5.3E-03
MW24-05	T	3/1/2006	TRICHLOROETHYLENE (TCE)	5.2E-03
MW24-05	T	9/1/2006	TRICHLOROETHYLENE (TCE)	5.8E-03
MW24-05	T	9/1/2003	TRICHLOROETHYLENE (TCE)	5.8E-03
MW24-04	T	9/1/2003	TRICHLOROETHYLENE (TCE)	3.4E-03
MW24-04	T	9/1/2006	TRICHLOROETHYLENE (TCE)	3.1E-04
MW24-04	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.2E-03
MW24-04	T	9/1/2005	TRICHLOROETHYLENE (TCE)	2.9E-04
MW24-04	T	3/1/2005	TRICHLOROETHYLENE (TCE)	4.3E-04
MW25-15	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.5E-03
MW24-05	T	3/1/2004	TRICHLOROETHYLENE (TCE)	2.4E-03
MW25-02	T	3/1/2003	TRICHLOROETHYLENE (TCE)	3.2E-02
MW24-04	T	3/1/2003	TRICHLOROETHYLENE (TCE)	2.6E-03
MW25-04	T	3/1/2002	TRICHLOROETHYLENE (TCE)	4.3E-03
MW25-04	T	3/1/2003	TRICHLOROETHYLENE (TCE)	2.8E-03
MW25-04	T	9/1/2003	TRICHLOROETHYLENE (TCE)	2.8E-04
MW25-04	T	3/1/2005	TRICHLOROETHYLENE (TCE)	1.8E-03
MW25-04	T	9/1/2004	TRICHLOROETHYLENE (TCE)	2.0E-03
MW25-04	T	3/1/2006	TRICHLOROETHYLENE (TCE)	6.2E-03
MW25-04	T	9/1/2005	TRICHLOROETHYLENE (TCE)	1.7E-03
MW25-02	T	9/1/2004	TRICHLOROETHYLENE (TCE)	1.9E-02
MW25-01	T	9/1/2005	TRICHLOROETHYLENE (TCE)	1.5E-02
MW25-02	T	3/1/2002	TRICHLOROETHYLENE (TCE)	3.7E-02
MW25-04	T	9/1/2006	TRICHLOROETHYLENE (TCE)	3.3E-04
MW25-02	T	3/1/2004	TRICHLOROETHYLENE (TCE)	1.8E-02
MW25-02	T	3/1/2005	TRICHLOROETHYLENE (TCE)	2.1E-02
MW25-02	T	9/1/2005	TRICHLOROETHYLENE (TCE)	2.1E-02
MW25-02	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.4E-02
MW25-02	T	9/1/2006	TRICHLOROETHYLENE (TCE)	6.5E-03
MW25-02	T	9/1/2003	TRICHLOROETHYLENE (TCE)	9.0E-03
MW25-01	T	3/1/2004	TRICHLOROETHYLENE (TCE)	6.7E-03
MW25-01	T	9/1/2004	TRICHLOROETHYLENE (TCE)	7.0E-03
MW25-01	T	3/1/2002	TRICHLOROETHYLENE (TCE)	8.0E-03
MW25-02	T	3/1/1998	TRICHLOROETHYLENE (TCE)	4.6E-02

TREND ANALYSIS

Monitoring System Category



Graph Key:

Monitoring System Categories

E: Extensive

M: Moderate

L: Limited

Plume Status

(I) Increasing (PI) Probably Increasing
(S) Stable (PD) Probably Decreasing (D) Decreasing

(NT) NoTrend

COC	Tail Stability	Source Stability	Category Result
TRICHLOROETHYLENE (TC	S	S	M

Worst Case: M

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MAROS Site Results

Project: Vance EA -CMI

User Name: Erd

Location: Enid

State: Oklahoma

User Defined Site and Data Assumptions:

Hydrogeology and Plume Information:

Groundwater Seepage Velocity: 18.63 ft/yr

Current Plume Length: 2240 ft

Current Plume Width 1120 ft

Number of Tail Wells: 12

Number of Source Wells: 7

Source Information:

Source Treatment: Pump and Treat

NAPL is not observed at this site.

Down-gradient Information:

Distance from Edge of Tail to Nearest:

Down-gradient receptor: 225 ft

Down-gradient property: 1680 ft

Distance from Source to Nearest:

Down-gradient receptor: 400 ft

Down-gradient property: 3200 ft

Data Consolidation Assumptions:

Time Period: 8/15/1996 **to** 10/1/2006

Consolidation Period: Other

Consolidation Type: Median

Duplicate Consolidation: Average

ND Values: Specified Detection Limit

J Flag Values : Actual Value

Plume Information Weighting Assumptions:

Consolidation Step 1. Weight Plume Information by Chemical

Summary Weighting: Weighting Applied to All Chemicals Equally

Consolidation Step 2. Weight Well Information by Chemical

Well Weighting: No Weighting of Wells was Applied.

Chemical Weighting: No Weighting of Chemicals was Applied.

Note: These assumptions were made when consolidating the historical montoring data and lumping the Wells and COCs.

1. Compliance Monitoring/Remediation Optimization Results:

Preliminary Monitoring System Optimization Results: Based on site classification, source treatment and Monitoring System Category the following suggestions are made for site Sampling Frequency, Duration of Sampling before reassessment, and Well Density. These criteria take into consideration: Plume Stability, Type of Plume, and Groundwater Velocity.

COC	Tail Stability	Source Stability	Level of Effort	Sampling Duration	Sampling Frequency	Sampling Density
TRICHLOROETHYLENE (TCE)	S	S	M	Remove treatment system if previously reducing concentation	No Recommendation	35

Note:

Plume Status: (I) Increasing; (PI)Probably Increasing; (S) Stable; (NT) No Trend; (PD) Probably Decreasing; (D) Decreasing

Design Categories: (E) Extensive; (M) Moderate; (L) Limited (N/A) Not Applicable, Insufficient Data Available

Level of Monitoring Effort Indicated by Analysi Moderate

2. Spatial Moment Analysis Results:

Moment Type	Constituent	Coefficient of Variation	Mann-Kendall S Statistic	Confidence in Trend	Moment Trend
Zeroth Moment: Mass					
	TRICHLOROETHYLENE (TCE)	0.58	21	91.3%	PI
1st Moment: Distance to Source					
	TRICHLOROETHYLENE (TCE)	0.20	-19	94.6%	PD
2nd Moment: Sigma XX					
	TRICHLOROETHYLENE (TCE)	0.23	-23	97.7%	D
2nd Moment: Sigma YY					
	TRICHLOROETHYLENE (TCE)	0.16	-9	75.8%	S

Note: The following assumptions were applied for the calculation of the Zeroth Moment:

Porosity: 0.20 **Saturated Thickness:** Uniform: 20 ft

Mann-Kendall Trend test performed on all sample events for each constituent. Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A)-Due to insufficient Data (< 4 sampling events).

MAROS Sampling Location Optimization Result

Project: **User Name:**

Location: **State:**

Sampling Events Analyzed: **From** Sample Event 1 8/15/1996 **to** Sample Event 51 10/1/2006

Parameters used:

Constituent	Inside SF	Hull SF	Area Ratio	Conc. Ratio
TRICHLOROETHYLENE (TCE)	0.2	0.01	0.95	0.95

Well	X (feet)	Y (feet)	Removable?	Average Slope Factor*	Minimum Slope Factor*	Maximum Slope Factor*	Eliminated?
TRICHLOROETHYLENE (TCE)							
MW12-09	1995924.88	486887.34	☑	0.120	0.023	0.220	☑
MW12-33	1996241.38	487134.19	☑	0.131	0.083	0.208	☑
MW12-35	1996251.50	486968.56	☑	0.454	0.399	0.501	☐
MW12-37	1996468.88	486958.78	☑	0.648	0.098	0.870	☐
MW12-43	1996350.13	487775.25	☑	0.083	0.032	0.206	☑
MW12-45	1996435.38	488067.06	☑	0.484	0.447	0.541	☐
MW23-05	1995977.25	487197.28	☑	0.752	0.752	0.752	☐
MW23-14	1996058.50	487713.44	☑	0.088	0.028	0.242	☑
MW23-34	1995846.50	486367.09	☑	0.854	0.495	0.895	☐
MW24-04	1996883.13	488135.41	☑	0.780	0.652	0.862	☐
MW24-05	1996828.25	488897.41	☑	0.182	0.011	0.756	☐
MW25-01	1995776.50	487650.50	☑	0.320	0.006	0.736	☐
MW25-02	1995773.75	488029.13	☑	0.195	0.015	0.559	☐
MW25-04	1995820.00	488610.50	☑	0.317	0.034	0.697	☐
MW25-05	1995794.13	489085.50	☑	0.511	0.102	0.818	☐
MW25-07	1995923.25	489139.63	☑	0.324	0.131	0.614	☐
MW25-08	1996319.25	489256.13	☑	0.589	0.177	1.000	☐
MW25-09	1996202.75	488583.00	☑	0.254	0.092	0.476	☐
MW25-15	1995967.00	489212.16	☑	0.331	0.086	0.747	☐

Note: The Slope Factor indicates the relative importance of a well in the monitoring network at a given sampling event; the larger the SF value of a well, the more important the well is and vice versa; the Average Slope Factor measures the overall well importance in the selected time period; the state coordinates system (i.e., X and Y refer to Easting and Northing respectively) or local coordinates systems may be used; wells that are NOT selected for analysis are not shown above.
* When the report is generated after running the Excel module, SF values will NOT be shown above.

SAMPLING OPTIMIZATION

Access Module - All-in-one Results

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

LocID	E S Coord	N S Coord	Eliminated?
MW12-09	1995924.9	486887.3	☑
MW12-33	1996241.4	487134.2	☑
MW12-35	1996251.5	486968.6	☐
MW12-37	1996468.9	486958.8	☐
MW12-43	1996350.1	487775.3	☑
MW12-45	1996435.4	488067.1	☐
MW23-05	1995977.3	487197.3	☐
MW23-14	1996058.5	487713.4	☑
MW23-34	1995846.5	486367.1	☐
MW24-04	1996883.1	488135.4	☐
MW24-05	1996828.3	488897.4	☐
MW25-01	1995776.5	487650.5	☐
MW25-02	1995773.8	488029.1	☐
MW25-04	1995820.0	488610.5	☐
MW25-05	1995794.1	489085.5	☐
MW25-07	1995923.3	489139.6	☐
MW25-08	1996319.3	489256.1	☐
MW25-09	1996202.8	488583.0	☐
MW25-15	1995967.0	489212.2	☐

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

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Supplementary File No. 2

- IZ site with 20 foot thick aquifer
- IZ site with 10 foot thick aquifer

IZ Area

20 ft deep

SITE DETAILS

Site Information

Provide information regarding the current site, 2-D plume information.

General

Project: Vance EA IZ (OB-N7)

Location: Enid State Oklahoma

Hydrogeology and Plume Information

Seepage Velocity: 14.87 ft/yr Main Constituents: Chlorinated Solvent

Current Plume Width 666 ft Current Plume Length 2266 ft

Maximum Plume Length 2933 ft GW Fluctuations: ☑ Yes ☐ No

Source Information

Free-Phase NAPL Present: ☐ Yes ☑ No

Current Source Treatment: **Pump and Treat**
In-situ Biodegradation

Down-gradient Information

Distance from Source to Nearest:			Distance from Edge of Tail to Nearest		
Downgradient receptor:	3600	ft	Downgradient receptor:	770	ft
Downgradient property line:	2900	ft	Downgradient property line:	570	ft

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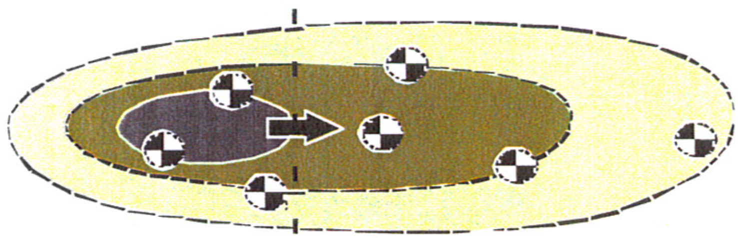
SITE DETAILS

Source/Tail Zone Selection



Select representative wells in the "Source" - S and "Tail" - T zones or "Not Used". Choose either Tail or Source or Not Used by clicking on the box to the right of the well in the table below. A maximum number of 200 wells in each category can be chosen.

Well Name	Source	Tail	Not Use
N7-23	✓		
N7-40		✓	
N7-41		✓	
N7-45	✓		
N7-65		✓	
N7-69		✓	
N7-70		✓	
OB-02	✓		
OB-03	✓		
OB-04	✓		
OB-05		✓	
OB-06		✓	
OB-08		✓	
OB-13	✓		
OB-16		✓	
OB-17		✓	
OB-18		✓	
OB-19		✓	
OB-21		✓	
OB-22		✓	

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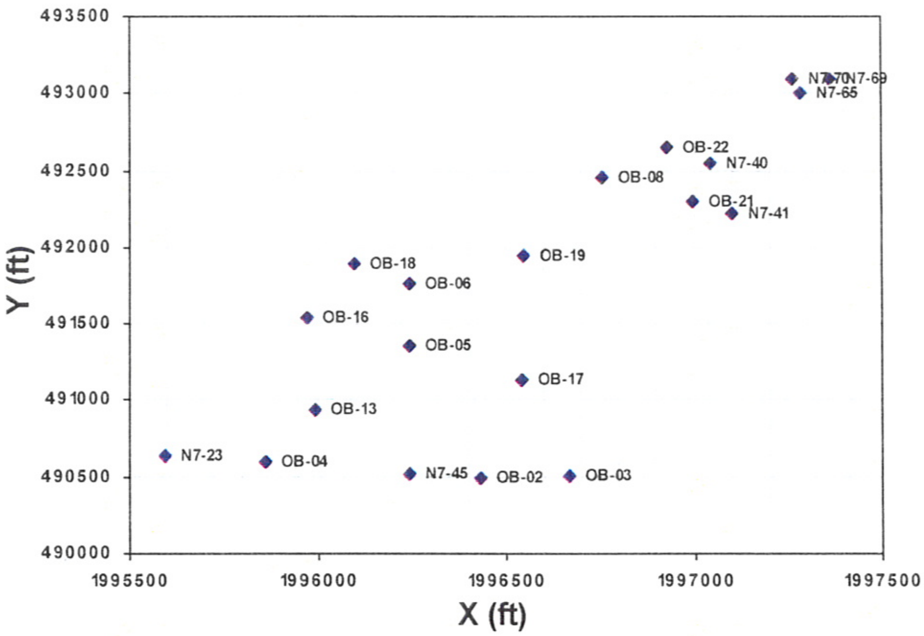
SITE DETAILS

Well Locations

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



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Reduced Data Table

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

Well Name	Source/ Tail	Date	COC	Result Number (mg/L)	Flag
OB-13	S	3/1/1998	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-04	S	9/1/2002	TRICHLOROETHYLENE (TCE)	1.4E-02	
OB-04	S	3/1/1998	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-03	S	9/1/1999	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-03	S	9/1/1997	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-03	S	3/1/1998	TRICHLOROETHYLENE (TCE)	1.1E-02	
OB-13	S	9/1/2002	TRICHLOROETHYLENE (TCE)	8.2E-01	
OB-13	S	9/1/2005	TRICHLOROETHYLENE (TCE)	7.6E-02	
OB-13	S	9/1/2006	TRICHLOROETHYLENE (TCE)	1.2E-01	
OB-13	S	3/1/2006	TRICHLOROETHYLENE (TCE)	1.3E-01	
OB-02	S	9/1/2002	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-13	S	3/1/2002	TRICHLOROETHYLENE (TCE)	8.6E-01	
N7-45	S	9/1/1999	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-13	S	9/1/2003	TRICHLOROETHYLENE (TCE)	4.3E-01	
OB-13	S	3/1/2005	TRICHLOROETHYLENE (TCE)	1.5E-01	
OB-03	S	9/1/2003	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-03	S	9/1/2002	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-02	S	3/1/1998	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-02	S	9/1/1997	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-02	S	9/1/1999	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-02	S	9/1/2005	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-02	S	3/1/2005	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-02	S	9/1/2003	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-13	S	9/1/1997	TRICHLOROETHYLENE (TCE)	2.3E+00	
OB-04	S	9/1/1997	TRICHLOROETHYLENE (TCE)	3.7E+00	
N7-23	S	9/1/2005	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-23	S	3/1/2005	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-23	S	3/1/1998	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-45	S	9/1/2003	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-23	S	9/1/2003	TRICHLOROETHYLENE (TCE)	4.2E-03	
N7-45	S	9/1/2002	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-23	S	9/1/1997	TRICHLOROETHYLENE (TCE)	4.0E-03	
N7-23	S	9/1/2000	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-04	S	3/1/2006	TRICHLOROETHYLENE (TCE)	5.5E-03	
OB-04	S	9/1/2005	TRICHLOROETHYLENE (TCE)	2.8E-03	
OB-04	S	3/1/2005	TRICHLOROETHYLENE (TCE)	1.0E-02	
OB-04	S	9/1/2003	TRICHLOROETHYLENE (TCE)	3.8E-02	
N7-45	S	9/1/1997	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-45	S	3/1/1998	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-23	S	9/1/1999	TRICHLOROETHYLENE (TCE)	2.3E-03	

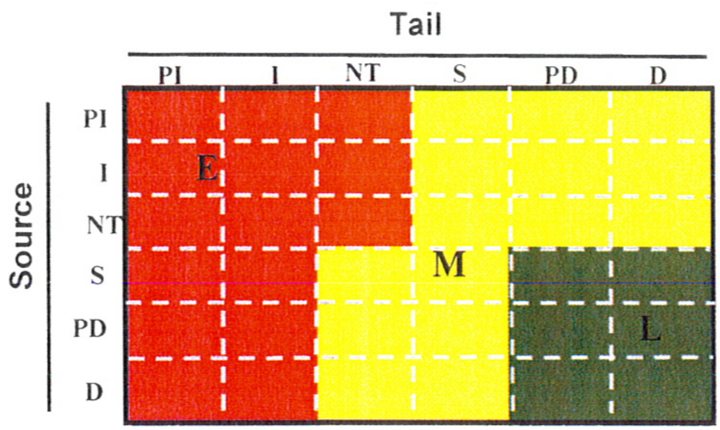
N7-23	S	3/1/2003	TRICHLOROETHYLENE (TCE)	1.8E-04	
OB-05	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.4E+00	
OB-05	T	9/1/2002	TRICHLOROETHYLENE (TCE)	1.3E+00	
OB-05	T	9/1/2003	TRICHLOROETHYLENE (TCE)	1.1E+00	
OB-05	T	9/1/2005	TRICHLOROETHYLENE (TCE)	1.2E+00	
OB-05	T	9/1/2006	TRICHLOROETHYLENE (TCE)	1.1E+00	
OB-05	T	9/1/1997	TRICHLOROETHYLENE (TCE)	1.8E+00	
N7-69	T	9/1/2003	TRICHLOROETHYLENE (TCE)	2.8E-03	
OB-05	T	3/1/2005	TRICHLOROETHYLENE (TCE)	1.7E+00	
N7-40	T	9/1/2002	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-65	T	3/1/2002	TRICHLOROETHYLENE (TCE)	4.6E-03	
N7-41	T	3/1/2002	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-41	T	9/1/1999	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-41	T	9/1/1997	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-41	T	9/1/2002	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-70	T	9/1/2000	TRICHLOROETHYLENE (TCE)	1.3E-03	
N7-40	T	9/1/1999	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-65	T	9/1/2005	TRICHLOROETHYLENE (TCE)	1.8E-03	
N7-40	T	9/1/2003	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-40	T	3/1/2005	TRICHLOROETHYLENE (TCE)	2.3E-03	
N7-40	T	9/1/2005	TRICHLOROETHYLENE (TCE)	5.6E-03	
N7-40	T	3/1/2006	TRICHLOROETHYLENE (TCE)	3.0E-04	
N7-40	T	9/1/2006	TRICHLOROETHYLENE (TCE)	2.3E-04	
N7-40	T	9/1/1997	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-40	T	3/1/2002	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
N7-69	T	9/1/2006	TRICHLOROETHYLENE (TCE)	2.3E-04	
N7-70	T	3/1/2002	TRICHLOROETHYLENE (TCE)	3.1E-03	
OB-05	T	3/1/1998	TRICHLOROETHYLENE (TCE)	1.0E-03	
N7-70	T	9/1/2003	TRICHLOROETHYLENE (TCE)	4.1E-04	
OB-06	T	9/1/2005	TRICHLOROETHYLENE (TCE)	1.0E-01	
N7-69	T	3/1/2002	TRICHLOROETHYLENE (TCE)	2.9E-03	
N7-69	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.4E-03	
N7-65	T	9/1/2006	TRICHLOROETHYLENE (TCE)	1.2E-03	
N7-69	T	9/1/2000	TRICHLOROETHYLENE (TCE)	3.7E-03	
N7-65	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.4E-03	
N7-69	T	3/1/2005	TRICHLOROETHYLENE (TCE)	1.4E-03	
N7-69	T	9/1/2005	TRICHLOROETHYLENE (TCE)	3.0E-04	
N7-65	T	9/1/2003	TRICHLOROETHYLENE (TCE)	2.6E-03	
N7-65	T	9/1/2002	TRICHLOROETHYLENE (TCE)	2.6E-03	
N7-65	T	3/1/2005	TRICHLOROETHYLENE (TCE)	2.0E-03	
N7-70	T	9/1/2002	TRICHLOROETHYLENE (TCE)	1.7E-03	
N7-69	T	9/1/2002	TRICHLOROETHYLENE (TCE)	1.4E-03	
OB-18	T	9/1/1997	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-18	T	9/1/2006	TRICHLOROETHYLENE (TCE)	1.7E-02	
OB-19	T	3/1/2002	TRICHLOROETHYLENE (TCE)	1.0E+00	
OB-19	T	9/1/2002	TRICHLOROETHYLENE (TCE)	9.8E-01	
OB-19	T	3/1/2005	TRICHLOROETHYLENE (TCE)	9.6E-01	
OB-19	T	9/1/2006	TRICHLOROETHYLENE (TCE)	7.2E-01	

OB-19	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.3E+00	
OB-19	T	9/1/2005	TRICHLOROETHYLENE (TCE)	8.8E-01	
OB-18	T	9/1/2003	TRICHLOROETHYLENE (TCE)	5.8E-02	
OB-19	T	3/1/2003	TRICHLOROETHYLENE (TCE)	1.3E+00	
OB-18	T	3/1/1998	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-18	T	9/1/1999	TRICHLOROETHYLENE (TCE)	1.7E-01	
OB-18	T	3/1/2002	TRICHLOROETHYLENE (TCE)	1.7E-01	
OB-18	T	3/1/2003	TRICHLOROETHYLENE (TCE)	3.2E-02	
OB-18	T	3/1/2005	TRICHLOROETHYLENE (TCE)	1.4E-02	
OB-18	T	9/1/2005	TRICHLOROETHYLENE (TCE)	1.7E-02	
OB-06	T	3/1/1998	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-19	T	9/1/2003	TRICHLOROETHYLENE (TCE)	1.0E+00	
OB-21	T	9/1/2006	TRICHLOROETHYLENE (TCE)	9.4E-02	
OB-22	T	9/1/2005	TRICHLOROETHYLENE (TCE)	1.5E-03	
OB-22	T	3/1/2005	TRICHLOROETHYLENE (TCE)	1.2E-03	
OB-22	T	9/1/2003	TRICHLOROETHYLENE (TCE)	2.4E-03	
OB-22	T	9/1/2002	TRICHLOROETHYLENE (TCE)	2.1E-03	
OB-22	T	3/1/2002	TRICHLOROETHYLENE (TCE)	2.1E-03	
OB-22	T	9/1/1999	TRICHLOROETHYLENE (TCE)	2.5E-03	
OB-19	T	9/1/1997	TRICHLOROETHYLENE (TCE)	8.3E-01	
OB-22	T	9/1/2006	TRICHLOROETHYLENE (TCE)	4.6E-04	
OB-18	T	9/1/2002	TRICHLOROETHYLENE (TCE)	2.6E-02	
OB-21	T	9/1/1997	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-21	T	9/1/1999	TRICHLOROETHYLENE (TCE)	5.6E-03	
OB-21	T	9/1/2002	TRICHLOROETHYLENE (TCE)	1.4E-01	
OB-21	T	9/1/2003	TRICHLOROETHYLENE (TCE)	1.3E-01	
OB-21	T	3/1/2005	TRICHLOROETHYLENE (TCE)	9.8E-02	
OB-21	T	3/1/2006	TRICHLOROETHYLENE (TCE)	8.6E-02	
OB-21	T	9/1/2005	TRICHLOROETHYLENE (TCE)	9.0E-02	
OB-22	T	9/1/1997	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-08	T	3/1/2003	TRICHLOROETHYLENE (TCE)	5.9E-03	
OB-18	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.3E-02	
OB-08	T	9/1/1999	TRICHLOROETHYLENE (TCE)	1.0E-02	
OB-08	T	3/1/2002	TRICHLOROETHYLENE (TCE)	1.0E-02	
OB-08	T	9/1/2002	TRICHLOROETHYLENE (TCE)	7.4E-03	
OB-08	T	9/1/2003	TRICHLOROETHYLENE (TCE)	1.2E-02	
OB-08	T	9/1/2005	TRICHLOROETHYLENE (TCE)	2.4E-02	
OB-08	T	3/1/2005	TRICHLOROETHYLENE (TCE)	1.7E-02	
OB-08	T	9/1/2006	TRICHLOROETHYLENE (TCE)	1.9E-02	
OB-16	T	3/1/2002	TRICHLOROETHYLENE (TCE)	1.2E-01	
OB-06	T	3/1/2003	TRICHLOROETHYLENE (TCE)	3.4E-01	
OB-06	T	9/1/2006	TRICHLOROETHYLENE (TCE)	4.7E-02	
OB-06	T	3/1/2006	TRICHLOROETHYLENE (TCE)	9.3E-02	
OB-22	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.0E-03	
OB-06	T	3/1/2005	TRICHLOROETHYLENE (TCE)	1.1E-01	
OB-06	T	9/1/1997	TRICHLOROETHYLENE (TCE)	4.6E-01	
OB-06	T	9/1/2003	TRICHLOROETHYLENE (TCE)	2.9E-01	
OB-08	T	3/1/2006	TRICHLOROETHYLENE (TCE)	1.8E-02	

OB-16	T	3/1/1998	TRICHLOROETHYLENE (TCE)	2.1E-01	
OB-17	T	9/1/1999	TRICHLOROETHYLENE (TCE)	1.2E-02	
OB-17	T	9/1/1997	TRICHLOROETHYLENE (TCE)	1.2E-02	
OB-17	T	3/1/1998	TRICHLOROETHYLENE (TCE)	1.7E-02	
OB-17	T	9/1/2003	TRICHLOROETHYLENE (TCE)	2.9E-04	
OB-17	T	9/1/2002	TRICHLOROETHYLENE (TCE)	4.0E-04	
OB-17	T	3/1/2002	TRICHLOROETHYLENE (TCE)	1.2E-03	
OB-08	T	9/1/1997	TRICHLOROETHYLENE (TCE)	1.0E-03	ND
OB-16	T	9/1/1997	TRICHLOROETHYLENE (TCE)	1.5E-01	
OB-05	T	3/1/2002	TRICHLOROETHYLENE (TCE)	1.2E+00	
OB-16	T	9/1/1999	TRICHLOROETHYLENE (TCE)	1.2E-01	
OB-16	T	9/1/2002	TRICHLOROETHYLENE (TCE)	1.1E-01	
OB-16	T	9/1/2003	TRICHLOROETHYLENE (TCE)	9.1E-02	
OB-16	T	3/1/2005	TRICHLOROETHYLENE (TCE)	3.8E-02	
OB-16	T	9/1/2005	TRICHLOROETHYLENE (TCE)	3.2E-02	
OB-16	T	3/1/2006	TRICHLOROETHYLENE (TCE)	2.5E-02	
OB-16	T	9/1/2006	TRICHLOROETHYLENE (TCE)	2.2E-02	
OB-16	T	3/1/2003	TRICHLOROETHYLENE (TCE)	1.2E-01	

TREND ANALYSIS

Monitoring System Category



Graph Key:

Monitoring System Categories

E Extensive

M Moderate

L Limited

Plume Status

(I) Increasing (PI) Probably Increasing
(S) Stable (PD) Probably Decreasing (D) Decreasing

(NT) NoTrend

COC	Tail Stability	Source Stability	Category Result
TRICHLOROETHYLENE (TC	S	NT	M

Worst Case: M

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MAROS Site Results

Project: Vance EA IZ (OB-N7)

User Name: Erd

Location: Enid

State: Oklahoma

User Defined Site and Data Assumptions:

Hydrogeology and Plume Information:

Groundwater Seepage Velocity: 14.87 ft/yr

Current Plume Length: 2266 ft

Current Plume Width 666 ft

Number of Tail Wells: 14

Number of Source Wells: 6

Source Information:

Source Treatment: Pump and Treat

NAPL is not observed at this site.

Down-gradient Information:

Distance from Edge of Tail to Nearest:

Down-gradient receptor: 770 ft

Down-gradient property: 570 ft

Distance from Source to Nearest:

Down-gradient receptor: 3600 ft

Down-gradient property: 2900 ft

Data Consolidation Assumptions:

Time Period: 9/30/1997 **to** 10/1/2006

Consolidation Period: Other

Consolidation Type: Median

Duplicate Consolidation: Average

ND Values: Specified Detection Limit

J Flag Values : Actual Value

Plume Information Weighting Assumptions:

Consolidation Step 1. Weight Plume Information by Chemical

Summary Weighting: Weighting Applied to All Chemicals Equally

Consolidation Step 2. Weight Well Information by Chemical

Well Weighting: No Weighting of Wells was Applied.

Chemical Weighting: No Weighting of Chemicals was Applied.

Note: These assumptions were made when consolidating the historical montoring data and lumping the Wells and COCs.

1. Compliance Monitoring/Remediation Optimization Results:

Preliminary Monitoring System Optimization Results: Based on site classification, source treatment and Monitoring System Category the following suggestions are made for site Sampling Frequency, Duration of Sampling before reassessment, and Well Density. These criteria take into consideration: Plume Stability, Type of Plume, and Groundwater Velocity.

COC	Tail Stability	Source Stability	Level of Effort	Sampling Duration	Sampling Frequency	Sampling Density
TRICHLOROETHYLENE (TCE)	S	NT	M	Remove treatment system if previously reducing concentation	No Recommendation	36

Note:

Plume Status: (I) Increasing; (PI)Probably Increasing; (S) Stable; (NT) No Trend; (PD) Probably Decreasing; (D) Decreasing

Design Categories: (E) Extensive; (M) Moderate; (L) Limited (N/A) Not Applicable, Insufficient Data Available

Level of Monitoring Effort Indicated by Analysi Moderate

2. Spatial Moment Analysis Results:

Moment Type	Constituent	Coefficient of Variation	Mann-Kendall S Statistic	Confidence in Trend	Moment Trend
Zeroth Moment: Mass					
	TRICHLOROETHYLENE (TCE)	0.77	2	52.7%	NT
1st Moment: Distance to Source					
	TRICHLOROETHYLENE (TCE)	0.20	35	99.7%	I
2nd Moment: Sigma XX					
	TRICHLOROETHYLENE (TCE)	0.24	-9	72.9%	S
2nd Moment: Sigma YY					
	TRICHLOROETHYLENE (TCE)	0.29	-7	67.6%	S

Note: The following assumptions were applied for the calculation of the Zeroth Moment:

Porosity: 0.20 **Saturated Thickness:** Uniform: 20 ft

Mann-Kendall Trend test performed on all sample events for each constituent. Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A)-Due to insufficient Data (< 4 sampling events).

MAROS Sampling Location Optimization Result

Project: Vance EA IZ (OB-7N) **User Name:** Erd

Location: Enid **State:** Oklahoma

Sampling Events Analyzed: From Sample Event 1 9/30/1997 to Sample Event 37 10/1/2006

Parameters used:

Constituent	Inside SF	Hull SF	Area Ratio	Conc. Ratio
TRICHLOROETHYLENE (TCE)	0.2	0.01	0.95	0.95

Well	X (feet)	Y (feet)	Removable?	Average Slope Factor*	Minimum Slope Factor*	Maximum Slope Factor*	Eliminated?
TRICHLOROETHYLENE (TCE)							
N7-23	1995595.38	490642.34	☑	0.766	0.468	1.000	☐
N7-40	1997042.75	492545.16	☑	0.511	0.009	1.000	☐
N7-41	1997099.75	492214.78	☑	0.480	0.426	0.539	☐
N7-45	1996243.00	490523.31	☑	0.229	0.115	0.342	☐
N7-65	1997284.88	493009.16	☑	0.334	0.087	0.630	☐
N7-69	1997362.25	493091.28	☑	0.444	0.051	0.681	☐
N7-70	1997264.63	493091.28	☑	0.238	0.141	0.586	☐
OB-02	1996430.50	490502.53	☑	0.465	0.000	1.000	☐
OB-03	1996667.88	490503.63	☑	0.362	0.132	1.000	☐
OB-04	1995860.38	490602.53	☑	0.305	0.085	0.611	☐
OB-05	1996244.38	491360.91	☑	0.340	0.292	0.429	☐
OB-06	1996244.25	491764.38	☑	0.040	0.002	0.181	☑
OB-08	1996754.13	492461.53	☑	0.188	0.065	0.535	☑
OB-13	1995991.13	490943.69	☑	0.307	0.141	0.453	☐
OB-16	1995971.13	491544.59	☑	0.214	0.139	0.293	☐
OB-17	1996539.50	491132.91	☑	0.766	0.667	0.825	☐
OB-18	1996099.38	491899.56	☑	0.280	0.157	0.794	☐
OB-19	1996544.75	491946.78	☑	0.360	0.264	0.531	☐
OB-21	1996998.25	492299.16	☑	0.378	0.084	0.667	☐
OB-22	1996929.50	492650.84	☑	0.334	0.055	0.869	☐

Note: The Slope Factor indicates the relative importance of a well in the monitoring network at a given sampling event; the larger the SF value of a well, the more important the well is and vice versa; the Average Slope Factor measures the overall well importance in the selected time period; the state coordinates system (i.e., X and Y refer to Easting and Northing respectively) or local coordinates systems may be used; wells that are NOT selected for analysis are not shown above.

* When the report is generated after running the Excel module, SF values will NOT be shown above.

SAMPLING OPTIMIZATION

Access Module - All-in-one Results

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

LocID	E S Coord	N S Coord	Eliminated?
N7-23	1995595.4	490642.3	☐
N7-40	1997042.8	492545.2	☐
N7-41	1997099.8	492214.8	☐
N7-45	1996243.0	490523.3	☐
N7-65	1997284.9	493009.2	☐
N7-69	1997362.3	493091.3	☐
N7-70	1997264.6	493091.3	☐
OB-02	1996430.5	490502.5	☐
OB-03	1996667.9	490503.6	☐
OB-04	1995860.4	490602.5	☐
OB-05	1996244.4	491360.9	☐
OB-06	1996244.3	491764.4	☑
OB-08	1996754.1	492461.5	☑
OB-13	1995991.1	490943.7	☐
OB-16	1995971.1	491544.6	☐
OB-17	1996539.5	491132.9	☐
OB-18	1996099.4	491899.6	☐
OB-19	1996544.8	491946.8	☐
OB-21	1996998.3	492299.2	☐
OB-22	1996929.5	492650.8	☐

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

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MAROS Sampling Frequency Optimization Results

Project: Vance EA IZ (OB-N7) **User Name:** Erd

Location: Enid **State:** Oklahoma

The Overall Number of Sampling Events: 37

"Recent Period" defined by events: **From** Sample Event 18 7/27/1999 **To** Sample Event 37 10/1/2006

"Rate of Change" parameters used:

Constituent	Cleanup Goal	Low Rate	Medium Rate	High Rate
TRICHLOROETHYLENE (TCE)	0.005	0.0025	0.005	0.01

Units: Cleanup Goal is in mg/L; all rate parameters are in mg/L/year.

Well	Recommended Sampling Frequency	Frequency Based on Recent Data	Frequency Based on Overall Data
TRICHLOROETHYLENE (TCE)			
N7-23	Annual	Annual	Annual
N7-40	Annual	Annual	Annual
N7-41	Biennial	Annual	Annual
N7-45	Annual	Annual	Annual
N7-65	Annual	Annual	Annual
N7-69	Annual	Annual	Annual
N7-70	Annual	Annual	Annual
OB-02	Biennial	Annual	Annual
OB-03	Annual	Annual	Annual
OB-04	Annual	Annual	Annual
OB-05	Quarterly	Quarterly	Quarterly
OB-06	Annual	Annual	Annual
OB-08	Annual	Annual	Annual
OB-13	Annual	Annual	Annual
OB-16	Annual	Annual	Annual
OB-17	Annual	Annual	Annual
OB-18	Annual	Annual	Annual
OB-19	Annual	Annual	SemiAnnual
OB-21	Quarterly	SemiAnnual	Quarterly
OB-22	Annual	Annual	Annual

Note: Sampling frequency is determined considering both recent and overall concentration trends. Sampling Frequency is the final recommendation; Frequency Based on Recent Data is the frequency determined using recent (short) period of monitoring data; Frequency Based on Overall Data is the frequency determined using overall (long) period of monitoring data. If the "recent period" is defined using a different series of sampling events, the results could be different.

CMI Area

10 ft deep

10-31-07

SITE DETAILS

Site Information

Provide information regarding the current site, 2-D plume information.

General

Project: EA Vance CMI

Location: Enid   State: Oklahoma

Hydrogeology and Plume Information

Seepage Velocity: 18.63 ft/yr   Main Constituents: Chlorinated Solvent

Current Plume Width: 1120 ft   Current Plume Length: 2240 ft

Maximum Plume Length: 3200 ft   GW Fluctuations: ☑ Yes ☐ No

Source Information

Free-Phase NAPL Present: ☐ Yes ☑ No

Current Source Treatment: Pump and Treat / In-situ Biodegradation

Down-gradient Information

Distance from Source to Nearest:			Distance from Edge of Tail to Nearest		
Downgradient receptor:	400	ft	Downgradient receptor:	225	ft
Downgradient property line:	3200	ft	Downgradient property line:	1680	ft

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MAROS Site Results

Project: EA Vance CMI

User Name: Ron

Location: Enid

State: Oklahoma

User Defined Site and Data Assumptions:

Hydrogeology and Plume Information:

Groundwater Seepage Velocity: 18.63 ft/yr

Current Plume Length: 2240 ft

Current Plume Width 1120 ft

Number of Tail Wells: 12

Number of Source Wells: 7

Source Information:

Source Treatment: Pump and Treat

NAPL is not observed at this site.

Down-gradient Information:

Distance from Edge of Tail to Nearest:

Down-gradient receptor: 225 ft

Down-gradient property: 1680 ft

Distance from Source to Nearest:

Down-gradient receptor: 400 ft

Down-gradient property: 3200 ft

Data Consolidation Assumptions:

Time Period: 8/15/1996 **to** 10/1/2006

Consolidation Period: Other

Consolidation Type: Median

Duplicate Consolidation: Average

ND Values: Specified Detection Limit

J Flag Values : Actual Value

Plume Information Weighting Assumptions:

Consolidation Step 1. Weight Plume Information by Chemical

Summary Weighting: Weighting Applied to All Chemicals Equally

Consolidation Step 2. Weight Well Information by Chemical

Well Weighting: No Weighting of Wells was Applied.

Chemical Weighting: No Weighting of Chemicals was Applied.

Note: These assumptions were made when consolidating the historical montoring data and lumping the Wells and COCs.

1. Compliance Monitoring/Remediation Optimization Results:

Preliminary Monitoring System Optimization Results: Based on site classification, source treatment and Monitoring System Category the following suggestions are made for site Sampling Frequency, Duration of Sampling before reassessment, and Well Density. These criteria take into consideration: Plume Stability, Type of Plume, and Groundwater Velocity.

COC	Tail Stability	Source Stability	Level of Effort	Sampling Duration	Sampling Frequency	Sampling Density
TRICHLOROETHYLENE (TCE)	S	S	M	Remove treatment system if previously reducing concentation	No Recommendation	35

Note:

Plume Status: (I) Increasing; (PI)Probably Increasing; (S) Stable; (NT) No Trend; (PD) Probably Decreasing; (D) Decreasing

Design Categories: (E) Extensive; (M) Moderate; (L) Limited (N/A) Not Applicable, Insufficient Data Available

Level of Monitoring Effort Indicated by Analysi: Moderate

2. Spatial Moment Analysis Results:

Moment Type	Constituent	Coefficient of Variation	Mann-Kendall S Statistic	Confidence in Trend	Moment Trend
Zeroth Moment: Mass					
	TRICHLOROETHYLENE (TCE)	0.58	21	91.3%	PI
1st Moment: Distance to Source					
	TRICHLOROETHYLENE (TCE)	0.20	-19	94.6%	PD
2nd Moment: Sigma XX					
	TRICHLOROETHYLENE (TCE)	0.23	-23	97.7%	D
2nd Moment: Sigma YY					
	TRICHLOROETHYLENE (TCE)	0.16	-9	75.8%	S

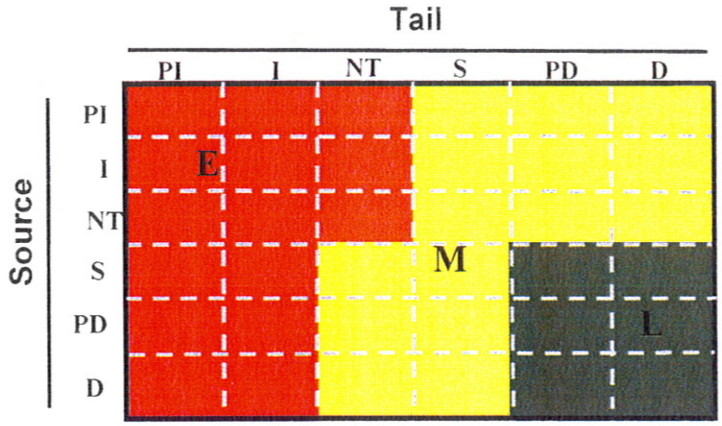
Note: The following assumptions were applied for the calculation of the Zeroth Moment:

Porosity: 0.20 **Saturated Thickness:** Uniform: 10 ft

Mann-Kendall Trend test performed on all sample events for each constituent. Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A)-Due to insufficient Data (< 4 sampling events).

TREND ANALYSIS

Monitoring System Category



Graph Key:

Monitoring System Categories

E: Extensive

M: Moderate

L: Limited

Plume Status

(I) Increasing (PI) Probably Increasing
(S) Stable (PD) Probably Decreasing (D) Decreasing

(NT) NoTrend

COC	Tail Stability	Source Stability	Category Result
TRICHLOROETHYLENE (TC	S	S	M

Worst Case: M

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MAROS Sampling Location Optimization Result

Project: EA Vance CMI **User Name:** Ron

Location: Enid **State:** Oklahoma

Sampling Events Analyzed: **From** Sample Event 1 8/15/1996 **to** Sample Event 51 10/1/2006

Parameters used:

Constituent	Inside SF	Hull SF	Area Ratio	Conc. Ratio
TRICHLOROETHYLENE (TCE)	0.2	0.01	0.95	0.95

Well	X (feet)	Y (feet)	Removable?	Average Slope Factor*	Minimum Slope Factor*	Maximum Slope Factor*	Eliminated?
TRICHLOROETHYLENE (TCE)							
MW12-09	1995924.88	486887.34	☑	0.120	0.023	0.220	☑
MW12-33	1996241.38	487134.19	☑	0.131	0.083	0.208	☑
MW12-35	1996251.50	486968.56	☑	0.454	0.399	0.501	☐
MW12-37	1996468.88	486958.78	☑	0.648	0.098	0.870	☐
MW12-43	1996350.13	487775.25	☑	0.083	0.032	0.206	☑
MW12-45	1996435.38	488067.06	☑	0.484	0.447	0.541	☐
MW23-05	1995977.25	487197.28	☑	0.752	0.752	0.752	☐
MW23-14	1996058.50	487713.44	☑	0.088	0.028	0.242	☑
MW23-34	1995846.50	486367.09	☑	0.854	0.495	0.895	☐
MW24-04	1996883.13	488135.41	☑	0.780	0.652	0.862	☐
MW24-05	1996828.25	488897.41	☑	0.182	0.011	0.756	☐
MW25-01	1995776.50	487650.50	☑	0.320	0.006	0.736	☐
MW25-02	1995773.75	488029.13	☑	0.195	0.015	0.559	☐
MW25-04	1995820.00	488610.50	☑	0.317	0.034	0.697	☐
MW25-05	1995794.13	489085.50	☑	0.511	0.102	0.818	☐
MW25-07	1995923.25	489139.63	☑	0.324	0.131	0.614	☐
MW25-08	1996319.25	489256.13	☑	0.589	0.177	1.000	☐
MW25-09	1996202.75	488583.00	☑	0.254	0.092	0.476	☐
MW25-15	1995967.00	489212.16	☑	0.331	0.086	0.747	☐

Note: The Slope Factor indicates the relative importance of a well in the monitoring network at a given sampling event; the larger the SF value of a well, the more important the well is and vice versa; the Average Slope Factor measures the overall well importance in the selected time period; the state coordinates system (i.e., X and Y refer to Easting and Northing respectively) or local coordinates systems may be used; wells that are NOT selected for analysis are not shown above.
* When the report is generated after running the Excel module, SF values will NOT be shown above.

MAROS Sampling Frequency Optimization Results

Project: EA Vance CMI **User Name:** Ron

Location: Enid **State:** Oklahoma

The Overall Number of Sampling Events: 51

"Recent Period" defined by events: **From** Sample Event 18 4/17/2002 **To** Sample Event 51 10/1/2006

"Rate of Change" parameters used:

Constituent	Cleanup Goal	Low Rate	Medium Rate	High Rate
TRICHLOROETHYLENE (TCE)	0.005	0.0025	0.005	0.01

Units: Cleanup Goal is in mg/L; all rate parameters are in mg/L/year.

Well	Recommended Sampling Frequency	Frequency Based on Recent Data	Frequency Based on Overall Data
TRICHLOROETHYLENE (TCE)			
MW12-09	Quarterly	Quarterly	Annual
MW12-33	Quarterly	Quarterly	Annual
MW12-35	Annual	Annual	Annual
MW12-37	SemiAnnual	Annual	Quarterly
MW12-43	Annual	Annual	Annual
MW12-45	Quarterly	Quarterly	Quarterly
MW23-05	Biennial	Annual	Annual
MW23-14	Annual	Annual	Annual
MW23-34	Annual	Annual	Annual
MW24-04	Annual	Annual	Annual
MW24-05	Annual	Annual	Annual
MW25-01	Annual	Annual	Annual
MW25-02	Annual	Annual	Annual
MW25-04	Annual	Annual	Annual
MW25-05	Annual	Annual	Annual
MW25-07	Annual	Annual	Annual
MW25-08	Biennial	Annual	Annual
MW25-09	Annual	Annual	Annual
MW25-15	Biennial	Annual	Annual

Note: Sampling frequency is determined considering both recent and overall concentration trends. Sampling Frequency is the final recommendation; Frequency Based on Recent Data is the frequency determined using recent (short) period of monitoring data; Frequency Based on Overall Data is the frequency determined using overall (long) period of monitoring data. If the "recent period" is defined using a different series of sampling events, the results could be different.