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LETTER REPORT REGARDING GEOSTATISTICAL ANALYSIS OF GROUNDWATER DATA
OPERABLE UNIT 3 (OU3) NAS JACKSONVILLE FL
12/7/1994

NOTE: This document contains
the corrected table
4.1 per 12/9/94
transmittal by Dr. R.

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ABB Environmental Services, Inc.
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RE: Letter Report on "*Geostatistical Analysis of Groundwater Data, Operable Unit 3 (OU3), NAS Jacksonville, Jacksonville, Florida.*"

Dear Mr. Redfern:

In response to the RFP NVEY94-077, Geostatistics Technical Expert Services, a geostatistical review of available groundwater data at OU3 was conducted. These data are described in the Remedial Investigation and Feasibility Study (RI/FS) Workplan, Final Draft, April 1994 (hereinafter referred to as the "workplan"). The following provides a concise report on the findings of the review and the recommendation for additional investigations in support of the RI/FS at OU3.

The site under investigation is Operable Unit 3 (OU3) at the NAS Jacksonville, Jacksonville Florida. For a detailed description of the environmental history and conditions at OU3 readers are referred to the workplan.

This study focuses on a comprehensive geostatistical analysis of groundwater data at OU3. The site-specific information represent an extensive set of groundwater chemical data sampled and analyzed from various layers of the underlying surficial aquifer at OU3. The availability of this large data set provides an opportunity for a detailed study to reassess the proposed investigative strategy in the workplan. Such an approach is consistent with a phased and focused environmental investigation.

Various applicable U.S. EPA documents, including "*Data Quality Objectives for Superfund*," September, 1993, recommend periodic analyses of field data in order to reassess the need for additional information. Such flexible and iterative process can lead to a more focused design that can save resources in later field activities. A phased approach is performed through various steps that methodically increase the detail of understanding with increasingly focused investigative activities. Such an approach yields a plan which concentrates work where it is needed and minimizes redundant efforts.

To achieve the above stated objective at OU3, the complex spatial structure of groundwater contaminants must be recognized. These complexities are due to various factors including historical release patterns, as well as complicated biological, chemical, and hydrogeological processes that influence the fate and transport of contaminants in subsurface

environments. As recommended by the above cited EPA document, these complexities justify the use of appropriate spatial statistical techniques, such as geostatistics, to characterize and delineate the extent of groundwater contamination.

1.0 DEFINITION OF GEOSTATISTICAL ANALYSIS

A general introduction to geostatistics is presented herein as background to the development of the rationale for the groundwater data analysis. Geostatistics (Journel and Huijbregts, 1978) are a collection of techniques for the analysis of spatially correlated data. Geostatistical techniques incorporate the spatial characteristics of actual data into statistical estimation processes. Geostatistics permit the performance of critical tasks, such as: optimization of spatial mapping for chemical and physical variables, estimating average block values, and the design of sampling and monitoring schemes. In statistical terms, geostatistics provides tools for extraction of the maximum amount of information from spatially-correlated data.

Samples collected at different locations within the same site usually display a wide range of variability. As a result, the concentration of a constituent under investigation at an unsampled location cannot be predicted with certainty, even if this constituent was sampled at other nearby locations. Geostatistics recognize these difficulties and, according to well-defined criteria, provide the statistical tools for: (1) calculating the most accurate predictions based on sample results and other relevant information, (2) quantifying the accuracy of these predictions, and (3) selecting the analytes and additional locations to be sampled, if necessary.

The United States Environmental Protection Agency (U.S. EPA) has taken the lead in promotion of geostatistics by producing the first public-domain software package, known as *GEO-EAS (Geostatistical Environmental Assessment Software)* developed by Englund and Sparks (EPA/600/4-88/033a, 1988). This package was followed by another EPA package, known as *GEOPACK*, developed by Yates and Yates (EPA/600/8-90/004, 1990). The successful results of application of GEO-EAS prompted the U.S. EPA to recommend its use in the analysis of environmental data, as stated in various documents, including "*Guidance for Data Usability in Risk Assessment*" (EPA/540/G-90/008, 1990) and "*Basics of Pump-and-Treat Ground-Water Remediation Technology*" (EPA/600/8-90/003, 1990). This current study is based on the use of GEO-EAS.

The main features of linear geostatistics to be applied are:

1. Geostatistics provide a model of the spatial continuity of data in a statistical framework. For example, if site-specific data indicate the presence of a high level of spatial correlation in a given direction, then points which are closer in that direction are assigned a higher correlation value.
2. Geostatistical estimates are calculated as weighted sums of the adjacent sampled concentrations. These weights depend on the exhibited correlation structure. For

example, if data appear to be highly correlated in space, the points which are closer to the estimated points will receive higher weights than those further away. The criterion for selection of these weights is the minimization of estimation variance. In this framework, geostatistical estimates may be regarded as the most accurate estimates among linear estimators (i.e., Best Linear Unbiased Estimator), implying that the geostatistical estimation processes are based on well-defined criteria, and thus, are superior to subjective estimation techniques.

3. Geostatistical techniques can process sample results averaged over different volumes and sizes. In other words, depending on whether the estimation is a point or a block value, geostatistics will yield different results, consistent with the geometry of the estimation domain.

The first task in any geostatistical investigation is to identify the spatial structure of the investigated variable in a given area. This task is done by developing the estimated variogram of the collected data. The user's manual of GEO-EAS defines the variogram as the plot of the variance (one-half the mean squared difference) of paired sample results as a function of the distance between samples. Variograms provide a means of quantifying the commonly observed relationship that samples close together will tend to have more similar values than samples far apart.

Three main features of a typical variogram are: (1) range, (2) sill, and (3) nugget effect (Figure 1-1). Range is the distance at which the variogram reaches its maximum value. Paired samples whose in-between distance is greater than the range are uncorrelated. Therefore, the range is regarded as a measure of spatial continuity of the investigated variable. Sill is the upper limit of any variogram which tends to level off at large distances. Sill is a measure of the population variability of the investigated variable; the higher the sill, the greater the variability in the population. Nugget effect is exhibited by the apparent jump of the variogram at the origin, which may be attributed to small-scale variability of the investigated process and/or to measurement errors.

The most accurate estimation can be accomplished if the investigated variable is well structured. Such variable will have a variogram with a long range (i.e., high continuity), low sill values (i.e., small population variance), and small nugget effect (i.e., no significant small-scale variabilities, or measurement errors). In such an instance, a coarse grid can provide sufficient information to construct a reasonable map of the spatial distribution of the investigated variable. This map will allow the users to identify the potential areas of concern with a high degree of accuracy.

1.1 BASIC CONCEPTS OF A PHASED/GEOSTATISTICAL INVESTIGATION

In order to achieve a comprehensive groundwater characterization in an efficient manner, an investigation should proceed in a phased manner, as referenced in the Office of Solid Waste and Emergency Response (OSWER) directive 9502.00-6C RFI Guidance (and EPA 530/SW-87-

001).. In the phased approach, the sampling is performed through various steps that methodically increase the detail of understanding with increasingly focused sampling activities.

The above approach yields a plan which concentrates work where it is needed and minimizes statistically redundant efforts. In this approach, the sampling results are analyzed to define the activities of the subsequent steps by identifying the information needs. Therefore, subsequent steps can concentrate on critical zones and crucial constituents of concern. In order to maintain objectivity, sampling in subsequent steps should be based on the geostatistical analysis of data collected from previous phases. Geostatistics provides a rigorous criteria against which results may be compared for selecting subsequent sampling activities.

Geostatistical analyses include estimation of values at unsampled locations. The linear geostatistical point estimation technique is known as *point kriging*, which yields the estimated value at an unsampled location through calculation of a linear combination of measurements (Figure 1.2):

$$Z_0^* = \sum_{i=1}^n \lambda_i Z_i \quad (1)$$

where Z_0^* = estimated value of parameter Z at location x_0 ; z_i = constituent concentration at location x_i ; λ_i = kriging weight of the constituent concentration Z_i ; and n = number of nearby sample points. The kriging weights are calculated such that Z_0^* will have the minimum estimation variance (i.e., to be most accurate). The estimation variance is derived as:

$$V_o = -\sum_{i=0}^n \sum_{j=0}^n \lambda_i \lambda_j \gamma_{ij} \quad (2)$$

where V_o = estimation (or kriging) variance of estimation of Z_0^* ; γ_{ij} = variogram between Z_i and Z_j ; and $\lambda_o = -1$. Variogram, γ_{ij} , is defined as 1/2 the variance of $[Z_i - Z_j]$, which represents the statistical structure of the parameter under investigation. This important function must be determined based on available data. The incorporation of site-specific spatial structures of investigated parameters is the main feature of geostatistics, distinguishing it from classical statistical techniques that usually ignore this structure.

1.2 GEOSTATISTICAL SAMPLING PLAN ASSESSMENT

Geostatistical estimates have been used in the optimization of sampling designs because of two factors: (1) each estimate comes with an estimation variance, and (2) the estimation

variance does not depend on the individual observations. Therefore, at a given point, a determination can be made of the accuracy gained by additional observations. In effect, the impact of any new sampling location can be evaluated before any new samples are actually collected. This is due to the uncertainty-reducing effectiveness of any sampling scheme which depends only on the number and location of sample sites, and not on the magnitude of concentrations at those sites.

In a sampling activity, critical areas can be defined based on quantile values, such as the upper 95 percentile values, generated as follows:

$$Z_{95}(x_o) = Z_o^* + 1.64(V_o)^{1/2} \quad (3)$$

where $Z_{95}(x_o)$ = the upper 95 percentile value at location x_o . The estimated 95 percentile value for a given point implies that if a sample would be collected from that point, there would be a 95 percent chance that its concentration would be lower than the estimated 95 percentile value.

In the above calculations, it is implicitly assumed that the investigated variable, Z , is normally distributed. In certain instances, where histograms of collected data do not support such hypothesis, it is appropriate to use non-linear estimation procedures, such as log-kriging. GEO-EAS provides options for log-kriging. In this approach the above geostatistical computations are applied to log-transformed values of the original data. The use of such a technique provides more flexibility in the analysis process. For a more detailed review of geostatistical techniques and their applications in groundwater investigations, see ASCE (1991 a, 1991 b).

2.0 SUMMARY OF OU3 GROUNDWATER DATA

The workplan provides a detailed description of available groundwater data at the site. The chronology of current data set includes the results of the following sampling activities:

1985/86	NARF Data
1988	Wright Street Investigation
1990	Building 780 Investigation
1992	Milcon P615 Data
1993	Building 101 and P159 Data
1993	Scoping Study Field Program (SSFP)

The data are collected from three levels in the underlying surficial aquifer at OU3. These levels are:

- | | |
|-----------------|--|
| Aquifer Level 1 | The uppermost layer above the upper clay unit
(Sampling depths ranging from 8' to 22' below land surface) |
| Aquifer Level 2 | Sand layer below the upper clay unit
(Sampling depths ranging from 17' to 83' below land surface) |
| Aquifer Level 3 | Above the lower clay unit
(Sampling depths ranging from 44' to 91.5' below land surface) |

The above stratigraphy is supported by geologic logs of two 150-foot soil borings, fifteen deep piezometer, and sixty-three CPT (Cone Penetrometer Testing) soundings. Besides the above noted upper and lower clay units, the other main physical and stratigraphic features that influence the groundwater flow at OU3 include: an approximately 17-foot deep sea wall along the eastern boundary of OU3 along the St. Johns River, and a deep clay formation along the former tidal lagoon.

2.1 MEASURED PARAMETERS

Available data contain 99 measured parameters, including selected volatile organic compounds (VOCs), halogenated hydrocarbons, pesticide and PCBs, metals, and total petroleum hydrocarbon (TPH), as listed in Table 2.1.

The current data set includes 13,389 chemical results of which 9,226 are classified as water matrix. The analysis of this large data set necessitated the use of a relational data base software. For this purpose Microsoft's ACCESS™ was utilized. This relational data base tool offered an efficient means for retrieving and grouping various components of the above data set.

3.0 CONTAMINANTS OF CONCERN

As noted in the workplan and supported by Table 2.1, chlorinated aliphatic hydrocarbons (CAH) appear to be the most wide-spread groundwater contaminants at OU3. The only other group of parameters that exhibit wide-spread elevated concentrations are metals. These latter results, however, are considered as invalid due to the reported turbidity of the collected groundwater samples. Therefore, the focus of this investigation is on the geostatistical analysis of CAH data in groundwater.

CAH compounds include the chlorinated solvents and their natural transformation products that represent the most prevalent organic groundwater contaminants in the country (McCarty, 1994). The major chlorinated solvents are carbon tetrachloride (CT), tetrachloroethene (PCE), trichloroethene (TCE), and 1,1,1-trichloroethane (TCA). These compounds can be transformed by chemical and biological processes in soils to form a variety of other CAHs, including chloroform (CF), methylene chloride (MC), cis- and trans-1,2-

dichloroethene (c-DCE, t-DCE), 1,1-dichloroethene (1,1-DCE), vinyl chloride (VC), 1,1-dichloroethane (DCA), and chloroethane (CA). These latter products are usually referred to as solvents' daughter products. Figure 3.1 displays the anaerobic chemical and biological transformation pathways for various chlorinated solvents.

3.1 TCA AND TCE TRANSFORMATIONS AT OU3

Of the chlorinated solvents data at OU3, TCA and TCE display the most wide-spread presence (Table 2.1). Site-specific data on TCA and TCE transformations are summarized in Tables 3.1 and 3.2, respectively.

In addition, Figures 3.2.a and 3.2.b provide chemical and biological transformation data at locations in the vicinity of the highest measured concentrations of TCA and TCE, respectively. Highest TCA concentration was reported at Building 780 in 1990. Highest TCE measurement was made at NARFB1 in 1986. In 1993 a set of DPT (direct push technology) samples were taken from a point very close to NARFB1. This location is denoted as CW22 which is situated approximately up-gradient of NARFB1.

The above tables and figures lead to the following conclusions:

1. The site-specific data provide a strong evidence on the on-going intrinsic biological and chemical transformations of the main chlorinated solvent contaminants at OU3, i.e., TCE and TCA.
2. TCA has displayed a stronger affinity to chemical and biological transformations than TCE. This was confirmed by McCarty (1994). Such a condition has resulted into a more limited presence of TCA in the surficial aquifer at OU3 when compared to TCE data.

3.2 TCE AS SIGNATURE CONTAMINANT

In order to provide an efficient means for the analysis of groundwater contaminants at OU3, a signature contaminant is identified. Signature contaminants are defined as contaminants of concern (COCs) that display wide-spread above-MCL presence whose spatial extent includes areas contaminated by other COCs. The selection of signature contaminants would allow a conservative groundwater characterization at the site.

At OU3, TCE appears to be the signature contaminant of choice. This conclusion is supported by the following:

1. TCE and TCA are among the main CAH solvents that have already been identified by the workplan as principal groundwater contaminants at OU3. This conclusion is supported by both on-site and off-site laboratory results.

2. Other detected CAHs at OU3 appear to be mainly daughter products of TCA and TCE. Therefore, a comprehensive investigation of the two main CAH solvents, i.e., TCA and TCE, should provide a conservative characterization of groundwater contamination at OU3.
3. TCA appears to be more amenable to chemical and biological transformation than TCE. Therefore, TCA appears to be less persistent than TCE in long-run.
4. Site specific data clearly indicate that TCE has the most wide-spread above-MCL spatial presence at OU3.

Therefore, all subsequent analyses will be conducted by considering TCE as the signature contaminant.

4.0 GEOSTATISTICAL ANALYSIS OF TCE DATA

Table 4.1 provides available TCE data at various aquifer levels. GEO-EAS allows the presentation of TCE data in a graphical format known as postplot. Figures 4.1 through 4.3 display the TCE data in the aquifer level 1 in a chronological order of 1985-86, 1988-90, and 1992-1993, respectively.

Figures 4.4 and 4.5 display postplots of TCE data in the aquifer levels 2 and 3, respectively. Actual values are shown in Table 4.1. These latter measurements were made primarily during 1993 SSFP at OU3.

The above postplots reveal the following findings:

1. The aquifer level 1 is the most impacted layer of the surficial aquifer illustrating the most wide-spread presence of detected TCE measurements.
2. Visual inspections of Figures 4.1 through 4.3 reveal that impacted zones (i.e., zones with detected TCE) in the aquifer level 1 display directional tendencies consistent with the surficial stratigraphy and groundwater flow in the aquifer level 1. At this level the presence of the sea wall and the deep clay layer along the former tidal lagoon diverts the east-ward groundwater flow to the northeast in the northern OU3, and to the southeast in the southern OU3. These patterns are consistent with the depicted surficial groundwater flow in the workplan.
3. Visual inspection of Figure 4.4, however, reveals a different distribution pattern in the aquifer level 2. At this level the impacted zones do not display anisotropic tendencies and appear to be influenced by an east-ward flow toward the St. Johns River.
4. Figure 4.5 indicates that the impacted zones in the aquifer level 3 are rather limited in

extent. The spatial distribution of these impacted zones appear to be consistent with those in the aquifer level 2. The detected concentrations in this deeper level, however, are much lower than those measured in the aquifer level 2. This implies that the migration of contaminants in the deeper depths of the surficial aquifer is dominated by dispersive processes.

4.1 DATA FILE PREPARATIONS

Based on the above results, TCE data in the aquifer levels 1 and 2 were subjected to geostatistical analyses through the use of GEO-EAS. For this purpose, GEO-EAS files were generated based on the following conservative rules:

1. The undetected values of TCE were replaced by the detection limit of .001 mg/l.
2. Estimated laboratory concentrations are used as actually-measured values.
3. The entire available TCE data are used in the multi-level analyses. This rule provides a conservative base for mapping of TCE-impacted zones. Such mapping results ignore the fact that previously measured TCE concentrations may have been attenuated due to either construction-related activities, and/or chemical and biological transformations.
4. In cases of multiple sampling from the same location only the highest measured or estimated value is used.

4.2 EXPLORATORY DATA ANALYSES

Upon the generation of GEO-EAS files of TCE concentration data in the aquifer levels 1 and 2, exploratory analyses were conducted. GEO-EAS's STAT1 program was used to generate the histogram of TCE data in the aquifer levels 1 and 2, as shown in Figures 4.6 and 4.7, respectively.

Due to the skewed shape of these histograms, their log-transformed values were also computed and plotted on normal probability plots, as shown in Figures 4.6 and 4.7. These latter plots clearly indicate that the above-detection TCE data are log-normally distributed. Therefore, all subsequent geostatistical analyses are conducted using log-transformed TCE data.

4.3 VARIOGRAPHY RESULTS

Multi-level variography results of TCE data were conducted using GEO-EAS's VARIO program. These results are shown in the following figures, as listed below:

- Figure 4.8 Aquifer Level 1 (North), Omni-directional Variogram
- Figure 4.9 Aquifer Level 1 (North), Directional Variograms
- Figure 4.10 Aquifer Level 1 (South), Omni-directional Variogram

Figure 4.11 Aquifer Level 1 (South), Directional Variograms

Figure 4.12 Aquifer Level 2, Omni-directional Variogram

The above experimental variograms and their fitted models revealed the following spatial tendencies. In GEO-EAS 0° is defined as east and angles are measured counter-clockwise.

1. In the northern part of the aquifer level 1, TCE data exhibit a strong directional tendency along the 25° northeast (Figure 4.9). The fitted anisotropic variogram model is a nested spherical model with a nugget = 1.5, a sill = 4.2, a maximum range = 1,100' along 25°, and a minimum range = 275' along 115°. This anisotropic model is consistent with the general surficial groundwater flow in the northern part of OU3.
2. In the southern part of the aquifer level 1, TCE data exhibit a directional tendency along the 120° southwest (Figure 4.11). The fitted anisotropic variogram model is a nested spherical model with a nugget = 1.2, a sill = 1.3, a maximum range = 350' along 120°, and a minimum range = 275' along 30°. This anisotropic model is consistent with the general surficial groundwater flow in the southern part of OU3.
3. The aquifer level 2 TCE data do not show any directional tendencies (Figure 4.12). The fitted isotropic omni-directional variogram model is a nested spherical model with a nugget = 2, a sill = 3.5, and a range = 550'. Such results imply that the impact of the sea wall on groundwater flow in the aquifer level 2 is not significant.

4.3 TCE MAPPING RESULTS

Upon determination of the level-specific variograms, kriging program of GEO-EAS, KRIGE, was used in order to generate appropriate grid files. The generated files were then contoured through the use of SURFER™ and then superimposed on the CADD map of OU3. Iso-concentration maps of TCE in the aquifer levels 1 and 2 are shown in Figures 4.13 and 4.14, respectively.

For contouring purposes the following contour intervals were used:

.003 mg/l	Florida MCL
.005 mg/l	Federal MCL
.010 mg/l	
.100 mg/l	

The above maps (Figures 4.13 and 4.14) were accompanied by their accuracy maps in the form of geometric standard deviation contour maps, as illustrated in Figures 4.15 and 4.16, respectively. These latter maps provide spatial measures for the assessment of accuracy of the geostatistical interpolation results.

5.0 ANALYSIS OF GEOSTATISTICAL RESULTS

A summary discussion of the above geostatistical results are presented in this section. For the clarity of presentation, this discussion is divided into a number of subsections.

5.1 EXTENT OF TCE-IMPACTED ZONES

Kriged maps of TCE (Figures 4.13 and 4.14) reveal the extent of TCE-impacted zones in the aquifer levels 1 and 2. These conservative iso-concentrations maps reveal spatial patterns composed of a few hotspots, surrounded by slightly-above-MCL peripheries. Such spatial patterns are due to the following factors:

1. The hotspots appear to be concentrated around their original sources. This pattern can be attributed to: (1) the low permeability of the surficial aquifer at OU3, (2) sorption to soil and retardation effects, and (3) the continuous pavements at OU3 which have significantly reduced the natural infiltration into the surficial aquifer.
2. The peripheries of TCE-impacted zones in the aquifer level 1 are primarily influenced by groundwater flow at OU3. In this aquifer level, the flow regime is skewed away from the St. Johns River. This skewed flow regime is due to the presence of the sea wall and the deep clay layer around former tidal lagoon.
3. In the aquifer level 2 TCE-impacted zones appear to be devoid of any strong anisotropic tendencies. Such a pattern implies that the impact of the sea wall on the flow regime in the aquifer level 2 is not significant.
4. Low permeability of the surficial aquifer, sorption/retardation effects, absence of infiltration, and chemical/biological transformations of TCE have further hindered the migration of the peripheries of the TCE-impacted zones in the surficial aquifer.

The above hotspots have already been identified either as Potential Source of Contamination (PSC) or other locations in the workplan that include:

PSC 11, Building 101
PSC 12, Old Test Cell Building
PSC 14, Battery Shop
PSC 15, Former Solvent and Paint Sludge Disposal Area, NADEP
Construction Site P615
Building 780, Current Location of Closed-loop Solvent Recycling Center
Building 106, Dry Cleaning Facility

5.2 RELIABILITY OF INTERPOLATED TCE-IMPACTED ZONES

Depicted TCE-impacted zones in Figures 4.13 and 4.14 provide a conservative basis for

delineating the extent of groundwater contamination at OU3. This is due to the following factors:

1. While pre-SSFP measurements focused mostly on specific hotspots, more recent SSFP provided an unbiased site-wide chemical data set. This permitted identification of TCE as the signature contaminant based on a comprehensive data set.
2. The selection of TCE as the signature contaminant is further confirmed by the comparison of the TCE maps to the postplots of other major COCs. For example, TCA postplots clearly indicate that the above-MCL TCA zones are well inside the TCE-impacted zones in all levels of the surficial aquifer. Few daughter products were present in zones immediately outside of the TCE-impacted zones at generally low concentrations. Their occurrences are further discussed in Section 5.4.
3. TCE data are prepared in a manner to generate conservative GEO-EAS files, as discussed in Section 4.1.
4. The entire TCE measurements, dating from 1985 to present, are included in these analyses. This is despite the fact that previously reported TCE concentrations in many hotspots may have been significantly attenuated due to either construction-related removals and activities, chemical/biological transformations, and/or to sorption/retardation effects.
5. The workplan does not contain any information about any recent releases into the surficial aquifer since the completion of SSFP. Therefore, the computed kriged maps can be considered as a conservative depiction of current groundwater contamination at OU3.

The reliability of the kriged maps are further verified through the use of the accuracy maps generated by GEO-EAS's KRIGE program. Figures 4.15 and 4.16 provide such spatial measures in the form of kriging standard deviation of log-TCE values. To convert this measure back to a mg/l scale, the following equation (Ang and Tang, 1975) can be used as a conservative back-transformation procedure:

$$\sigma = \sqrt{\mu^2(e^{\sigma_{\ln}^2} - 1)} \quad (4)$$

where σ = estimation standard deviation of TCE in mg/l, μ = mean estimated TCE concentration in mg/l, and σ_{\ln} = estimation standard deviation of log-TCE.

To assess the accuracy of the interpolated boundaries of above-MCL TCE impacted zones, Florida MCL of .003 mg/l is used as μ in Equation 4. Visual inspection of Figures 4.15 and 4.16 indicate that in the vicinity of the interpolated boundaries σ_{\ln} is between 1.6 to 2 in the aquifer level 1, and is between 2 and 2.4 in the aquifer level 2. The use of these values in

Equation 4 results into the following estimation standard deviations as:

Aquifer Level 1	.010 to .020 mg/l (10 to 20 ppb)
Aquifer Level 2	.020 to .050 mg/l (20 to 50 ppb)

The above values are conservatively-biased estimates of standard deviations of mean TCE concentration along the .003 mg/l contour line. These values indicate that the current interpolated boundaries of the TCE-impacted zones are adequately depicted in Figures 4.13 and 4.14.

5.3 DNAPL PRESENCE

Figures 4.13 and 4.14 display dots that denote the sampling spots with potential DNAPL presence of either TCE or TCA. For this purpose, all measurement above 1% solubility of TCE or TCA at 11 mg/l and 15 mg/l, respectively, have been identified. These locations are listed in Table 5.1.

Furthermore, using Equation 3, the upper 95-percentile point values of estimated TCE was computed over the entire estimation grids in the aquifer levels 1 and 2. The highest upper 95-percentile values are 15 mg/l and 7 mg/l in the aquifer levels 1 and 2, respectively.

The above site-specific data and the highest upper 95-percentile values indicate that the potential DNAPL presence appears to be limited to few hotspots. The low permeability of the surficial aquifer, sorption/retardation effects, and the absence of naturally occurring infiltration seem to have inhibited the migration of DNAPLs.

The few TCE and TCA measurements above the 1% solubility levels appear to be isolated instances. Such results make the possibility of free-phase DNAPL plumes unlikely. Therefore, any further DNAPL-driven investigation beyond the boundaries of the original sources seem to be unwarranted.

5.4 DAUGHTER PRODUCT PRESENCE

As noted earlier, the widespread presence of TCE and TCA daughter products indicate significant levels of intrinsic chemical/biological transformations at OU3. Figures 5.1 and 5.2 display the TCE-impacted zones in the aquifer levels 1 and 2, respectively, where two types of zones are identified. These zones are: (1) locations where only daughter products were detected, and (2) locations where above-MCL TCE or TCA values have been detected in the absence of any daughter products.

The locations where only daughter products were detected are situated along the boundaries of the TCE-Impacted zones. This confirms the complete transformation of marginal TCE concentrations.

The locations where above-MCL TCE values have been detected in the absence of any daughter products may indicate either adverse conditions for biochemical transformations, or relatively fresh releases into the groundwater.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The above geostatistical analyses of groundwater data at OU3 lead to following conclusions and recommendations.

6.1 TCE-IMPACTED ZONE CLASSIFICATION

The kriged TCE contour maps clearly indicate that the TCE-impacted zones at OU3 can be grouped into two classes:

1. **Hotspots:** Relatively highly contaminated groundwater mainly concentrated around a limited number of sources of contamination; and
2. **Peripheral Areas:** Zones surrounding the above hotspots with concentrations slightly above MCL.

Hotspots appear to be mostly confined to the proximity of their original sources due to: (1) the low permeability of the surficial aquifer, (2) sorption/retardation effects, and (3) the absence of infiltration-driven flows.

Peripheral areas, on the other hand, are more wide spread and appear to be impacted by relatively slow-moving directional groundwater flow in both aquifer levels 1 and 2. These peripheral areas are impacted by chemical and biological transformation of CAH solvents. This is supported by the presence of daughter products outside of the delineated TCE-impacted zones.

Given the above classification and hydrogeological limitations of the site, the range of feasible remedies at OU3 appear to include:

1. Surgical time-limited treatment of selected hotspots, and
2. Intrinsic bioremediation/natural attenuation of peripheral areas along with institutional controls, including groundwater monitoring at critical boundaries.

The above classes of remedies are consistent with EPA guidance documents, such as "*Guidance for Evaluating the Technical Impracticability of Groundwater Restoration*," September 1993, OSWER Directive 9234.2-25, and "*Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA*," August 1993, OSWER Publication 9360.0-32.

6.2 RECOMMENDED ADDITIONAL DATA ANALYSES

At present, a large site-wide data set exists. Therefore, more emphasis must be placed upon the analysis of currently available data, rather than collecting more samples. Therefore the following additional activities are recommended:

1. **Geostatistical Analysis of Soil Data at OU3:** Currently large number of soil data exists. To complete the present geostatistical analysis of groundwater data at OU3, available soil data must also be subjected to similar analyses. Such investigation provides information on the extent of soil contamination at OU3 that can be used in risk assessment, as well as further refinement of potential sources of contamination.
2. **Groundwater Modeling:** Current efforts by USGS on groundwater flow modeling must be pursued and completed. Results of groundwater modeling can aid decision-makers to delineate critical boundaries along the impacted bank of the St. Johns River.
3. **3-D Visualization of Lithological Information:** Currently available geologic logs of two 150-foot soil borings, fifteen deep piezometer, and sixty-three CPT (Cone Penetrometer Testing) soundings should be incorporated into a three-dimensional visualization package, such as Dynamics-Graphics™. Such a tool will yield an efficient means for the analysis of hydrogeological conditions at OU3. By performing this graphic analysis any need for additional CPT/geological data will be eliminated.
4. **Incorporation of Soil/Groundwater/Facility Information into a GIS System:** This option provides a highly efficient means for incorporation and analysis of different types of environmental data in a spatial format. GIS systems have proved to be highly effective when dealing with large environmental data sets. GIS can also incorporate facility information, waste unit data, as well as areal photographs. This provides a comprehensive tool for holistic analyses of site data by all those involved in the decision-making process.

6.3 ADDITIONAL RI/FS SAMPLING

As noted above, the current data set provides a large informational base for the RI. This data set has not been fully explored, yet. Therefore, in my opinion, no further sitewide sampling is needed until the data set is fully evaluated and the results warrant additional sampling. This study has only focused on groundwater data at OU3. Analyses of soil data may further clarify the remaining questions about the extent of hotspots at OU3.

In general, any additional sampling at this phase must be justified in support of the FS and the selected remedies. In other words, as stated in the EPA's 1993 DQO document, a sampling should be performed, if and only if, our decisions are dependent on its results. Such a rule eliminates unnecessary measurements.

Additional measurements, if any, will be limited and focused in nature. The following provides a number of such measurements which may be needed in the FS phase of the investigation:

1. **Hotspot detailed delineations:** Upon the completion of a comprehensive soil/groundwater data analysis, few hotspot among the current list of potential sources of contamination, may be selected as candidates for surgical time-limited treatments.

The selection of any remedy must be commensurate with the hydrogeological limitations of the site. Therefore, procedures that provide only hydraulic containment, such as most pump-and-treat operations, do not seem to be suitable for the treatment of hotspots at OU3. On the other hand, enhanced bioremediation alternatives appear to be promising.

Upon the selection of a hotspot and the appropriate remedies for its surgical time-limited remediation the following site-specific rule should be applied:

IF a potential remedy of a selected hotspots necessitates a detail delineation of that hotspot,
AND the current kriged map does not provide a sufficiently accurate map around the targeted hotspot,
THEN up to four locations along the main directions must be located along the existing kriged contour line delineating the targeted hotspot. At each location two DPT samples from the aquifer levels 1 and 2 shall be collected and analyzed for COCs. These new measurements are then incorporated into the existing data set, followed by the re-kriging of contour lines around the targeted hotspot. This process can be performed concurrently at the site.

The above approach eliminates the need for an extensive sampling campaign by focusing on the needed information. This type of information may be needed in the FS.

2. **Remedy-Specific Sampling:** Specific remedies may require additional special data. For example, if air sparging is considered at a hotspot, during its pilot study more detailed information on permeability of underlying formations may be needed. Such data should be collected in support of the FS, and only as part of the pilot investigations.
3. **Sampling in Support of Natural Remediation:** There are already extensive data on CAH solvents and their daughter products that can be used in support of the intrinsic bioremediation/natural attenuation. However, limited additional data from the peripheral areas may be needed to further assess the long-term potential of intrinsic bioremediation at the peripheral zones at OU3. McCarty (1994) identifies information on nitrate, nitrite, sulfate, Fe(II), methane, and total organic carbon as indicators necessary for evaluating the potential intrinsic transformation of CAH solvents. This limited additional sampling, if any, should be planned after consulting with intrinsic bioremediation experts.

4. **Long-term Monitoring along Critical Boundaries:** The current multi-level TCE kriged maps indicate that there are potentially impacted areas along the bank of the St. Johns River at OU3. These critical locations are situated along the southern boundary of OU3 (in both aquifer levels 1 and 2), as well as its eastern boundary (in the aquifer level 2). Upon the confirmation of these critical boundaries by USGS groundwater modeling efforts, the current piezometers at OU3 and additional required monitoring wells can be utilized as a monitoring network along the critical boundaries of OU3. This program can be incorporated in the FS as a part of institutional controls. If in future, the proposed monitoring network indicates an environmental threat to the St. John's River, then remedial options including containment along the impacted boundary may be considered.

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8. ACKNOWLEDGEMENTS

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If I can be of any further assistance, please do not hesitate to contact me.

Sincerely,

A handwritten signature in black ink, appearing to read "Shahrokh Rouhani". The signature is fluid and cursive, with a long horizontal stroke at the beginning and a small flourish at the end.

Shahrokh Rouhani, Ph.D., P.E.

Attachment 1: Tables
Attachment 2: Figures

cc: M. Maughon
W. Britton
C. Bernier
D. Gaskins
S. Allison

ATTACHMENT 1

TABLES

Table 2.1
List of Parameters Detected in Groundwater Samples at OU3

Parameter	Number of Samples	Number of Detects	Percentage of Detects	Number of Non-Detects or Estimated	Maximum Concentration	Unit
1,1,1-Trichloroethane	255	20	8	235	106	MG/L
1,1,2-Trichloroethane	205	4	2	201	2	MG/L
1,1-Dichloroethane	232	15	6	217	42	MG/L
1,1-Dichloroethene	235	13	6	222	53.5	MG/L
1,2-Dichlorobenzene	200	1	1	199	0.01	MG/L
1,2-Dichloroethane	218	4	2	214	2	MG/L
1,2-Dichloroethene (total)	32	4	13	28	7	MG/L
1,3-Dichlorobenzene	196	0	0	196	0.01	MG/L
1,4-Dichlorobenzene	200	0	0	200	0.01	MG/L
2,4-Dimethylphenol	26	1	4	25	0.01	MG/L
2-Butanone	28	1	4	27	6	MG/L
2-Methylnaphthalene	29	0	0	29	0.02	MG/L
2-Methylphenol	20	1	5	19	0.027	MG/L
4,4'-DDD	200	0	0	200	0.001	MG/L
4,4'-DDE	202	0	0	202	0.001	MG/L
4,4'-DDT	200	0	0	200	0.001	MG/L
4-Methyl-2-Pentanone	28	1	4	27	14	MG/L
4-Methylphenol	23	0	0	23	0.1	MG/L
Acenaphthene	26	0	0	26	0.01	MG/L
Acetone	36	12	33	24	2	MG/L
alpha-BHC	196	0	0	196	0.001	MG/L
alpha-Chlordane	22	0	0	22	0	MG/L
Aluminum	29	20	69	9	222000	MG/L
Anthracene	16	0	0	16	0.01	MG/L
Antimony	23	0	0	23	0.06	MG/L
Aroclor-1254	196	0	0	196	0.001	MG/L
Arsenic	215	48	22	167	13	MG/L
Barium	41	12	29	29	438	MG/L
Benzene	224	3	1	221	2	MG/L
Benzo(a)Anthracene	16	0	0	16	0.01	MG/L

Table 2.1
(continued)

Parameter	Number of Samples	Number of Detects	Percentage of Detects	Number of Non-Detects or Estimated	Maximum Concentration	Unit
Benzo(a)Pyrene	16	0	0	16	0.01	MG/L
Benzo(b)Fluoranthene	16	0	0	16	0.01	MG/L
Benzo(g,h,i)Perylene	16	0	0	16	0.01	MG/L
Benzo(k)Fluoranthene	16	0	0	16	0.01	MG/L
Beryllium	29	4	14	25	5	MG/L
beta-BHC	202	0	0	202	0.001	MG/L
bis(2-Chloroethyl)Ether	20	1	5	19	0.017	MG/L
bis(2-Ethylhexyl)Phthalate	29	0	0	29	0.1	MG/L
Bromodichloromethane	217	7	3	210	2	MG/L
Cadmium	205	3	1	202	1	MG/L
Calcium	29	29	100	0	37200	MG/L
Carbazole	22	0	0	22	0.01	MG/L
Carbon Disulfide	19	6	32	13	2	MG/L
Carbon Tetrachloride	211	6	3	205	2	MG/L
Chlorobenzene	23	1	4	22	2	MG/L
Chloroethane	46	4	9	42	4	MG/L
Chloroform	212	5	2	207	2	MG/L
Chloromethane	19	6	32	13	2	MG/L
Chromium	209	23	11	186	255	MG/L
Chrysene	22	0	0	22	0.01	MG/L
cis-1,2-Dichloroethene	180	21	12	159	4.9	MG/L
cis-1,3-Dichloropropane	6	1	17	5	0.006	MG/L
Cobalt	23	4	17	19	0.05	MG/L
Copper	29	14	48	15	37	MG/L
Cyanide	22	1	5	21	0.012	MG/L
delta-BHC	202	0	0	202	0.001	MG/L
Di-n-Butylphthalate	22	0	0	22	0.01	MG/L
Dibenzofuran	22	0	0	22	0.01	MG/L
Dibromochloromethane	19	0	0	19	2	MG/L
Dieldrin	202	0	0	202	0.001	MG/L
Diethylphthalate	16	0	0	16	0.01	MG/L

Table 2.1
(continued)

Parameter	Number of Samples	Number of Detects	Percentage of Detects	Number of Non-Detects or Estimated	Maximum Concentration	Unit
Endrin ketone	16	0	0	16	0	MG/L
Ethylbenzene	216	1	0	215	2	MG/L
Fluoranthene	16	0	0	16	0.01	MG/L
Fluorene	22	0	0	22	0.01	MG/L
gamma-BHC (Lindane)	202	0	0	202	0.001	MG/L
gamma-Chlordane	22	0	0	22	0	MG/L
Heptachlor	196	0	0	196	0.001	MG/L
Heptachlor epoxide	202	0	0	202	0.001	MG/L
Indeno(1,2,3-cd)Pyrene	16	0	0	16	0.01	MG/L
Iron	29	28	97	1	66900	MG/L
Lead	215	27	13	188	22	MG/L
m/p-Xylene	180	0	0	180	0.001	MG/L
Magnesium	29	24	83	5	16600	MG/L
Manganese	29	28	97	1	165	MG/L
Mercury	29	7	24	22	0.001	MG/L
Methoxychlor	16	0	0	16	0	MG/L
Methylene Chloride	35	4	11	31	94	MG/L
Naphthalene	29	2	7	27	0.31	MG/L
Nickel	218	20	9	198	65	MG/L
o-Xylene	180	0	0	180	0.001	MG/L
Phenanthrene	22	0	0	22	0.01	MG/L
Phenol	16	1	6	15	0.035	MG/L
Potassium	29	18	62	11	14300	MG/L
Pyrene	16	0	0	16	0.01	MG/L
Selenium	29	3	10	26	0.05	MG/L
Silver	23	1	4	22	0.01	MG/L
Sodium	29	27	93	2	11900	MG/L
Tetrachloroethene	217	15	7	202	9.6	MG/L
Thallium	16	0	0	16	0.01	MG/L
Toluene	240	18	8	222	3	MG/L
Total Petroleum Hydrocarbons	180	7	4	173	1218	MG/L

Table 2.1
(continued)

Parameter	Number of Samples	Number of Detects	Percentage of Detects	Number of Non-Detects or Estimated	Maximum Concentration	Unit
trans-1,2-Dichloroethene	207	21	10	186	8	MG/L
Trichloroethene	245	52	21	193	155.3	MG/L
Trichlorofluoromethane	14	1	7	13	0.013	MG/L
Vanadium	29	19	66	10	298	MG/L
Vinyl Chloride	53	8	15	45	2	MG/L
Xylene (total)	30	1	3	29	2	MG/L
Zinc	44	29	66	15	193	MG/L

Table 3.1 TCE Transformation Data at OU3

Aquifer Levels	Detected Sample Locations	Detected above .003 mg/l without Daughter Products	Sample Locations with Daughter Products Only
Level 1	34	3	10
Level 2	21	4	2
Level 3	9	2	3

Table 3.2 TCA Transformation Data at OU3

Aquifer Levels	Detected Sample Locations	Detected above .003 mg/l without Daughter Products	Sample Locations with Daughter Products Only
Level 1	9	0	17
Level 2	2	0	1
Level 3	1	0	0

Measured TCE Concentrations (mg/l) in Groundwater Samples
(Aquifer Level 1)

Eastng	Northing	Result	Qualifier	Sample ID	Depth
444321.004	2142444.509	0.001	U	U3B101MW01	13
444546.891	2143070.899	0.001	U	U3B101MW02	13
444552.652	2143029.63	0.001	U	U3B101MW03	13
444722.21	2142749.073	0.004	J	U3B101MW04	13
445583.383	2143149.745	0.001	U	U3CW01A01	11
445586.561	2142749.045	0.001	U	U3CW02A01	12.5
445585.352	2142350.047	0.001	U	U3CW03A01	10
445587.518	2141946.994	0.001	U	U3CW04A01	14
445584.745	2141549.707	0.001	U	U3CW05A01	10.5
445585.134	2141150.023	0.001	U	U3CW06A01	10
445587.07	2140750.565	0.001	U	U3CW07A01	13
445382.956	2140552.405	0.001	U	U3CW08A01	12
445385.782	2140950.249	0.001	U	U3CW09A01	14
445395.821	2141349.8	0.001	U	U3CW10A01	10
445382.851	2141740.541	0.004	J	U3CW11A01	22
445384.146	2142149.957	0.001	U	U3CW12A01	12
445386.553	2142544.49	0.001	U	U3CW13A01	13
445383.204	2142948.995	0.001	U	U3CW14A01	12
445181.704	2143152.044	0.001	U	U3CW15A01	11.5
445158.52	2142741.155	0.001	U	U3CW16A01	9
445189.683	2142300.073	0.001	U	U3CW17A01	9
445181.605	2141979.752	0.001	U	U3CW18A01	8
445169.657	2141547.299	0.001	U	U3CW19A01	17.5
445184.025	2141112.829	0.001	U	U3CW20A01	15
445187.18	2140748.934	0.001	U	U3CW21A01	10
444983.269	2140555.224	0.012	E	U3CW22A01	10
444986.119	2140950.471	0.12	E	U3CW23A01	11
444984.021	2141393.675	0.001	U	U3CW24A01	14
444979.949	2141755.209	0.001	U	U3CW25A01	13
444994.994	2142149.196	0.001	U	U3CW26A01	15
444982.796	2142935.382	0.001	U	U3CW28A01	10
444783.26	2143149.368	0.001	U	U3CW29A01	11.5
444789.162	2142746.365	0.001	U	U3CW30A01	15
444786.66	2142347.641	0.001	U	U3CW31A01	10
444759.427	2141949.683	0.003	E	U3CW32A01	14.5
444621.884	2142160.341	6.9	E	U3CW34A01	13
444621.884	2142160.341	4.5	E	U3CW34A01	13
444621.884	2142160.341	19	E	U3CW34A01	13
444716.525	2142628.326	0.2	E	U3CW35A01	13
444563.502	2142977.834	0.001	U	U3CW36A01	17
444425.609	2143130.765	0.001	U	U3CW37A01	9
444563.702	2142823.978	0.001	U	U3CW38A01	17
444285.46	2142393.544	0.072	E	U3CW39A01	10
444372.538	2141867.91	0.001	U	U3CW40A01	13
444209.033	2141692.262	0.22	E	U3CW41A01	12.5
444213.099	2142243.405	0.001	U	U3CW42A01	10
444130.605	2142940.759	0.001	U	U3CW43A01	16
445725.275	2143457.349	0.001	U	U3CW44A01	17
445256.421	2143450.479	0.001	U	U3CW45A01	13
444725.7	2143428.535	0.001	U	U3CW46A01	11
444174.859	2143415.143	0.001	U	U3CW47A01	11
443866.654	2143163.856	0.051	E	U3CW48A01	13
443863.554	2142781.089	0.58	E	U3CW49A01	12
443907.579	2142367.062	0.032	E	U3CW50A01	12.5
443871.118	2141959.415	0.001	U	U3CW51A01	13
443800.812	2141585.366	0.001	U	U3CW52A01	10
444247.932	2141492.388	0.001	U	U3CW53A01	11.5
444688.208	2141432.767	0.001	U	U3CW54A01	14
444681.719	2140909.171	0.001	U	U3CW55A01	12
444677.315	2140320.846	0.001	U	U3CW56A01	16

Measured TCE Concentrations (mg/l) in Groundwater Samples
(Aquifer Level 1)

Easting	Northing	Result	Qualifier	Sample ID	Depth
443723.473	2143142.739	0.001	U	U3CW57A01	9
443665.372	2142845.645		E	U3CW58A01	11
443666.067	2141594.312	0.001	U	U3CW59A01	10.5
443732.159	2142380.61	0.001		U3CW60A01	11.5
443360.88	2142761.459	0.001	U	U3CW61A01	15
443314.6	2142932.947	0.001	U	U3CW62A01	13
443357.954	2143113.841	0.001	U	U3CW63A01	14
444219.645	2143146.368		7	U3GW7801	6
444244.523	2143228.523	0.34		U3GW7805	6
444771.743	2142776.763		U	U3MW1	9
444721.16	2141954.041	0.025		U3MW10	12
444771.743	2141862.973	0.026		U3MW11	12.5
444725.248	2141776.842	0.001	U	U3MW12	12.5
444721.16	2141693.271	0.001	U	U3MW13	13
444721.16	2141642.799	0.001	U	U3MW14	13
444725.248	2142659.545	0.001	U	U3MW2	10
444771.743	2142562.442	0.013		U3MW3	10
444725.248	2142469.545	0.001	U	U3MW4	10
444771.743	2142380.489	0.169		U3MW5	10
444721.16	2142289.603	0.001	U	U3MW6	11
444771.743	2142212.799	0.001	U	U3MW7	11
444725.248	2142138.006	0.001	U	U3MW8	11
444771.743	2142046.938	0.135		U3MW9	11
445223.15	2140387.664	0.009		U3NARF10	16
444915.844	2139961.319	0.001	U	U3NARF12	15
445637.5	2140211.349	0.001	U	U3NARF13	16
444633.789	2141427.381	0.003		U3NARF2	16
444959.768	2141482.424	0.006		U3NARF3	14
445397.675	2140199.847	0.17		U3NARF4	14
445137.575	2140164.679	0.004		U3NARF5	10
444959.002	2142595.724	0.001	U	U3NARF6	11
444959.002	2142595.724	0.006		U3NARF6	11
445611.384	2143244.567	0.001	U	U3P159MW01	13
445315.107	2143261.429	0.001	U	U3P159MW02	13
445315.028	2143184.547	0.001	U	U3P159MW03	13
444905.273	2142808.594	0.01		U3P159MW04	13
444837.628	2142902.67	0.001	U	U3P159MW05	13
444837.718	2142790.91	0.001	U	U3P159MW06	13
444842.08	2142674.205	0.13		U3P159MW07	13
444888.552	2140977.048	0.001	U	U3W01	15
444887.255	2140935.822	0.007	J	U3W02	15
444600.233	2140979.577	0.001	U	U3W03	17
444824.625	2140935.822	11.3		U3W04	15
444641.554	2140999.586	0.001	U	U3W05	15
444997.505	2140935.822	0.008	J	U3W06	13

Measured TCE Concentrations (mg/l) in Groundwater Samples
(Aquifer Level 2)

Eastings	Northing	Result	Qualifier	Sample ID	Depth
445583.383	2143149.745	0.001	U	U3CW01A02	37.5
445583.383	2143149.745	0.001	U	U3CW01A02	37.5
445586.561	2142749.045	0.042		U3CW02A02	37
445585.352	2142350.047	0.001	U	U3CW03A02	24
445587.518	2141946.994	0.001	U	U3CW04A02	43
445587.518	2141946.994	0.001	U	U3CW04A02	43
445584.745	2141549.707	0.001	U	U3CW05A02	40
445585.134	2141150.023	0.001	U	U3CW06A02	24
445587.07	2140750.565	0.001	U	U3CW07A02	31
445382.956	2140552.405	0.001	U	U3CW08A02	36
445385.782	2140950.249	0.001	U	U3CW09A02	35
445395.821	2141349.8	0.001	U	U3CW10A02	35
445395.821	2141349.8	0.001	U	U3CW10A02	35
445382.851	2141740.541	0.001	U	U3CW11A02	45
445384.146	2142149.957	0.001	U	U3CW12A02	28
445386.553	2142544.49	0.001	U	U3CW13A02	20
445383.204	2142948.995	0.001	U	U3CW14A02	19
445383.204	2142948.995	0.001	U	U3CW14A02	19
445181.704	2143152.044	0.001	U	U3CW15A02	39
445158.52	2142741.155	0.172	E	U3CW16A02	35
445158.52	2142741.155	2.8		U3CW16A02	35
445189.683	2142300.073	0.001	U	U3CW17A02	48.5
445189.683	2142300.073	0.001	U	U3CW17A02	48.5
445181.605	2141979.752	0.001	U	U3CW18A02	20.5
445169.657	2141547.299	0.058	E	U3CW19A02	32
445184.025	2141112.829	0.001	U	U3CW20A02	33
445187.18	2140748.934	0.003		U3CW21A02	33
444983.269	2140555.224	0.12	E	U3CW22A02	33
444986.119	2140950.471	0.001	U	U3CW23A02	36
444984.021	2141393.675	0.001	U	U3CW24A02	33
444979.949	2141755.209	0.002		U3CW25A02	45
444979.949	2141755.209	0.004	J	U3CW25A02	45
444994.994	2142149.196	0.001	U	U3CW26A02	23
444981.868	2142543.76	0.001	U	U3CW27A02	17
444982.796	2142935.382	0.001	U	U3CW28A02	40
444783.26	2143149.368	0.001	U	U3CW29A02	37
444789.162	2142746.365	0.001	U	U3CW30A02	41
444786.66	2142347.641	6.1	E	U3CW31A02	38
444786.66	2142347.641	3.2	E	U3CW31A02	38
444786.66	2142347.641	9.8		U3CW31A02	38
444759.427	2141949.683	0.001	U	U3CW32A02	72
444653.209	2141687.399	0.001	U	U3CW33A02	60
444621.884	2142160.341	0.007		U3CW34A02	23
444716.525	2142628.326	0.001		U3CW35A02	39
444563.502	2142977.834	0.001	U	U3CW36A02	33
444425.609	2143130.765	0.062	E	U3CW37A02	27
444563.702	2142823.978	0.025		U3CW38A02	30
444285.46	2142393.544	0.001	U	U3CW39A02	27
444372.538	2141867.91	0.001	U	U3CW40A02	83
444209.033	2141692.262	0.001	U	U3CW41A02	47
444209.033	2141692.262	0.002	J	U3CW41A02	47
444213.099	2142243.405	0.001	U	U3CW42A02	30
444130.605	2142940.759	4.4	E	U3CW43A02	35
445725.275	2143457.349	0.001	U	U3CW44A02	39
445256.421	2143450.479	0.001	U	U3CW45A02	35
444725.7	2143428.535	0.001	U	U3CW46A02	40
444174.859	2143415.143	0.001	U	U3CW47A02	30
444174.859	2143415.143	0.001	J	U3CW47A02	30
443866.654	2143163.856	0.001	U	U3CW48A02	39
443863.554	2142781.089	0.001		U3CW49A02	30

Measured PCB Concentrations (ng/l) in Groundwater Samples
(Aquifer Level 2)

Easting	Northing	Result	Qualifier	Sample ID	Depth
443907.579	2142367.062	0.001	U	U3CW50A02	24
443907.579	2142367.062	0.001	U	U3CW50A02	24
443871.118	2141959.415	0.001	U	U3CW51A02	68
443800.812	2141585.366	0.001		U3CW52A02	32
444247.932	2141492.388	0.001	U	U3CW53A02	53
444247.932	2141492.388	0.001	U	U3CW53A02	53
444688.208	2141432.767	0.001	U	U3CW54A02	35
444681.719	2140909.171	0.001	U	U3CW55A02	40
444681.719	2140909.171	0.001	U	U3CW55A02	40
444681.719	2140909.171	0.001	U	U3CW55A02	40
444677.315	2140320.846	0.001	U	U3CW56A02	40
443723.473	2143142.739	0.05	E	U3CW57A02	31
443665.372	2142845.645	0.012		U3CW58A02	35
443666.067	2141594.312	0.001	U	U3CW59A02	55
443666.067	2141594.312	0.001	U	U3CW59A02	55
443732.159	2142380.61	0.001	U	U3CW60A02	38
443360.88	2142761.459	0.001	U	U3CW61A02	43
443314.6	2142932.947	0.07		U3CW62A02	40
443357.954	2143113.841	0.021		U3CW63A02	33.5
444965.14	2140260.219	0.001	U	U3NARF11	24
445015.461	2140433.129	0.001	U	U3NARF9	24
445026.715	2140513.281	155.3		U3NARFB1	32

Measured TCE Concentrations (mg/l) in Groundwater Samples
(Aquifer Level 3)

Easting	Northing	Result	Qualifier	Sample ID	Depth
445583.383	2143149.745	0.001	U	U3CW01A03	62
445586.561	2142749.045	0.023		U3CW02A03	60
445585.352	2142350.047	0.001	U	U3CW03A03	74
445587.518	2141946.994	0.001	U	U3CW04A03	70
445584.745	2141549.707	0.001	U	U3CW05A03	82
445585.134	2141150.023	0.001	U	U3CW06A03	40
445587.07	2140750.565	0.001	U	U3CW07A03	91.5
445382.956	2140552.405	0.001	U	U3CW08A03	60
445385.782	2140950.249	0.001	U	U3CW09A03	54
445395.821	2141349.8	0.002		U3CW10A03	60
445382.851	2141740.541	0.001	U	U3CW11A03	80
445384.146	2142149.957	0.001	U	U3CW12A03	60
445383.204	2142948.995	0.001	U	U3CW14A03	63
445181.704	2143152.044	0.001	U	U3CW15A03	64
445158.52	2142741.155	0.001	U	U3CW16A03	57
445189.683	2142300.073	0.001	U	U3CW17A03	75
445169.657	2141547.299	0.001	U	U3CW19A03	58.5
445184.025	2141112.829	0.001	U	U3CW20A03	57
445187.18	2140748.934	0.001	U	U3CW21A03	57
444983.269	2140555.224	0.001		U3CW22A03	64
444986.119	2140950.471	0.001		U3CW23A03	62
444984.021	2141393.675	0.001	U	U3CW24A03	52
444994.994	2142149.196	0.001	U	U3CW26A03	67
444981.868	2142543.76	0.001	U	U3CW27A03	44
444982.796	2142935.382	0.001	U	U3CW28A03	56
444783.26	2143149.368	0.001	U	U3CW29A03	65
444786.66	2142347.641	0.002		U3CW31A03	60
444653.209	2141687.399	0.001	U	U3CW33A03	84
444621.884	2142160.341	0.001	U	U3CW34A03	61
444716.525	2142628.326	0.001	U	U3CW35A03	69
444563.502	2142977.834	0.001	U	U3CW36A03	67
444425.609	2143130.765	0.001	U	U3CW37A03	48
444563.702	2142823.978	0.005		U3CW38A03	70
444285.46	2142393.544	0.001	U	U3CW39A03	49
444209.033	2141692.262	0.001	U	U3CW41A03	62.5
444213.099	2142243.405	0.001	U	U3CW42A03	80
444130.605	2142940.759	0.006		U3CW43A03	77
445725.275	2143457.349	0.001	U	U3CW44A03	85
445256.421	2143450.479	0.001	U	U3CW45A03	67
444725.7	2143428.535	0.001	U	U3CW46A03	65
444174.859	2143415.143	0.001	U	U3CW47A03	42
443866.654	2143163.856	0.001	U	U3CW48A03	77
443863.554	2142781.089	0.001	U	U3CW49A03	53
443907.579	2142367.062	0.001	U	U3CW50A03	85
443800.812	2141585.366	0.001	U	U3CW52A03	56.5
444247.932	2141492.388	0.001	U	U3CW53A03	73
444688.208	2141432.767	0.001	U	U3CW54A03	57
444681.719	2140909.171	0.001	U	U3CW55A03	64
444677.315	2140320.846	0.001	U	U3CW56A03	72
443723.473	2143142.739	0.005		U3CW57A03	58
443665.372	2142845.645	0.22		U3CW58A03	62
443666.067	2141594.312	0.001	U	U3CW59A03	75
443732.159	2142380.61	0.001	U	U3CW60A03	60
443732.159	2142380.61	0.001	U	U3CW60A03	60
443360.88	2142761.459	0.001	U	U3CW61A03	83
443314.6	2142932.947	0.001	U	U3CW62A03	82
443357.954	2143113.841	0.001	U	U3CW63A03	73

Table 5.1 TCE and TCA Measurements above 1% Solubility Level

Aquifer Level	Sampling Location	Measured TCE (mg/l)	Measured TCA (mg/l)
Level 1	CW34	19.0	U
	W04	11.3	-
	GW7801	7.0	106.0
Level 2	NARFB1	155.3	25.5
Level 3	-	-	-

ATTACHMENT 2

FIGURES

(Semi-)Variogram:

$$\gamma_{ij} = \frac{1}{2}E[Z_i - Z_j]^2$$

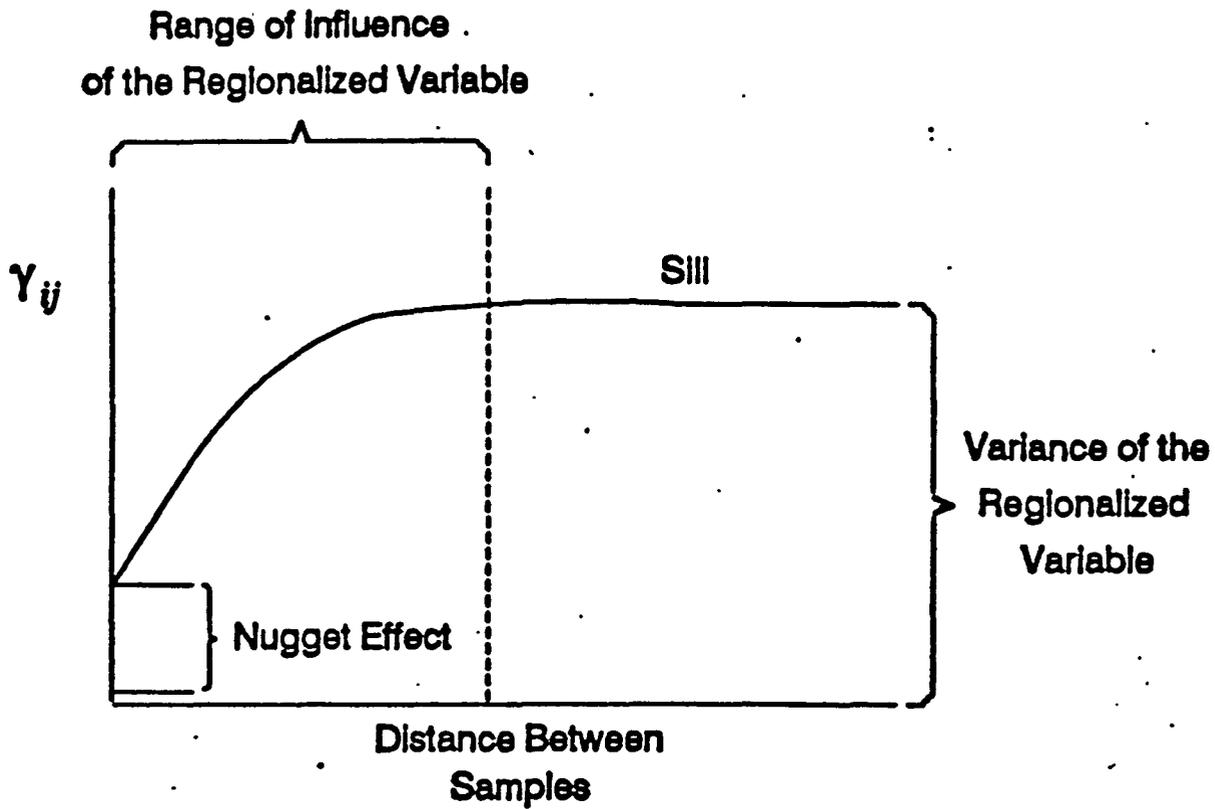
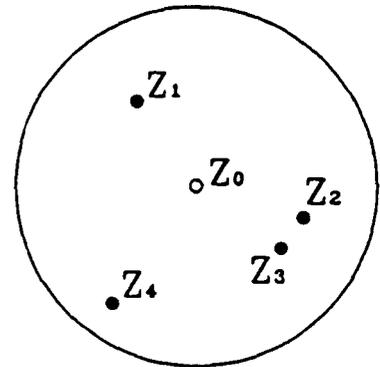


Figure 1.1
Features of a Typical Variogram

- **Mapping (Point Estimation)**

$$Z_o^* = \sum_{i=1}^n \lambda_i z_i$$



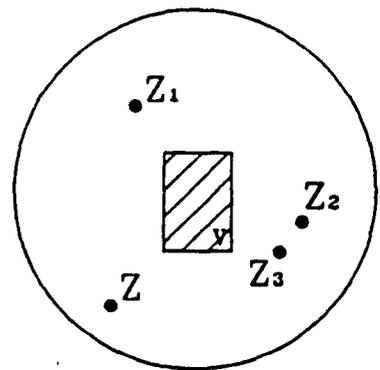
where,

- Z_o^* = Estimated point value at x_i ,
- z_i = Measured value at x_i ,
- λ_i = Estimation weight of z_i .

- ◆ Produces the Most Accurate Contour Map

- **Block or Areal Estimation**

$$Z_V^* = \sum_{i=1}^n \lambda_i z_i$$



where

- Z_V^* = Estimated block value.

- ◆ Ideal for Risk Assessment

Figure 1.2
Examples of Geostatistical Linear Estimations

- Chemical and Biological Transformations

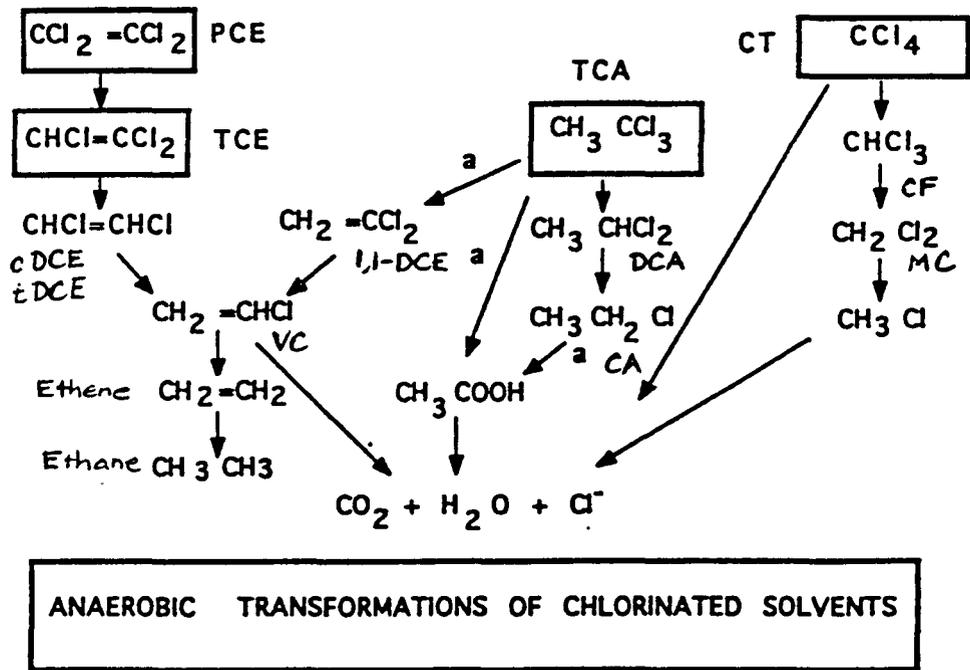
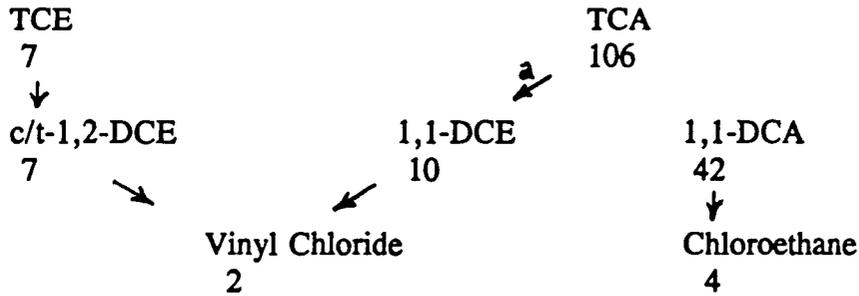


Figure 3.1
Anaerobic Transformation of Chlorinated Solvents

Highest Measured TCA (GW7801)

GW7801 (1990)



GW7805 (1990)

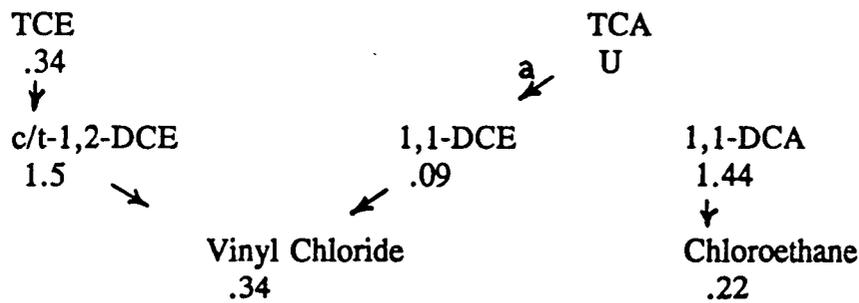


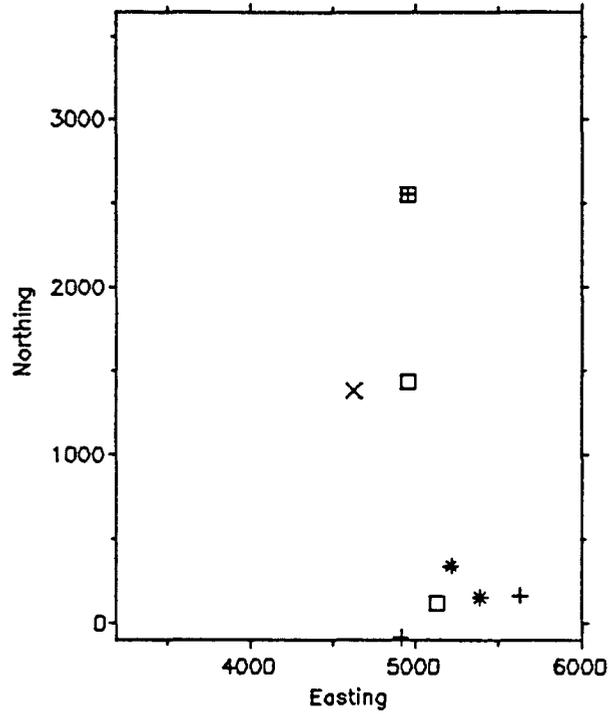
Figure 3.2.a
Highest Measured TCA and Daughter Products at OU3

Highest Measured TCE (NARFB1)

	<u>NARFB1 (1986)</u>	<u>CW22 (1993)</u>
Level 1		PCE U ↓ TCE .012 ↓ t-1,2-DCE U c-1,2-DCE .002
Level 2	PCE .48 ↓ TCE 155.3 ↓ t-1,2-DCE 8	<hr/> PCE U ↓ TCE .12 ↓ t-1,2-DCE .002 c-1,2-DCE .002
Level 3		<hr/> PCE U ↓ TCE U ↓ t-1,2-DCE U c-1,2-DCE U

Figure 3.2.b
Highest Measured TCE and Daughter Products at OU3

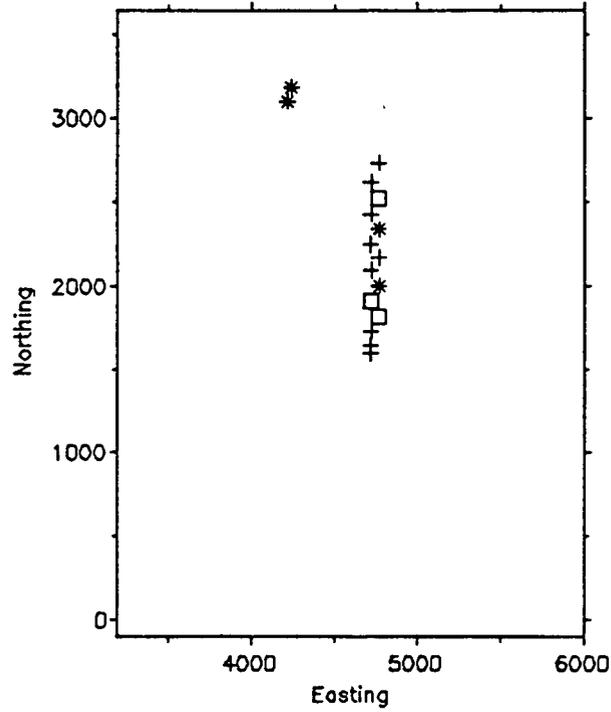
Postplot of Groundwater TCE
Level 1 (1985-86)



1st Quartile:	.001	≅	+	≅	.001
2nd Quartile:	.001	<	x	≅	.003
3rd Quartile:	.003	<	□	≅	.006
4th Quartile:	.006	<	*	≅	.170

Figure 4.1
TCE Postplot (1986-1988)

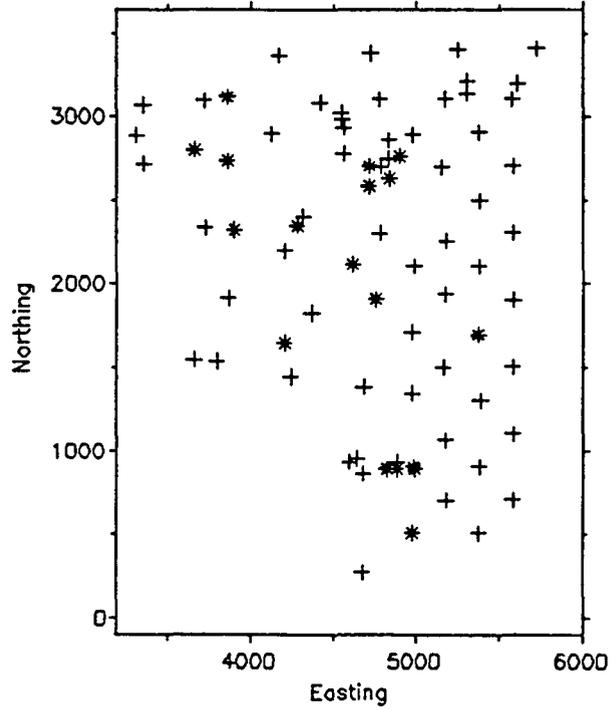
Postplot of Groundwater TCE
Level 1 (1988-90)



1st Quartile:	.001	≅	+	≅	.001
2nd Quartile:	.001	<	x	≅	.001
3rd Quartile:	.001	<	□	≅	.026
4th Quartile:	.026	<	*	≅	7.000

Figure 4.2
TCE Postplot (1988-1990)

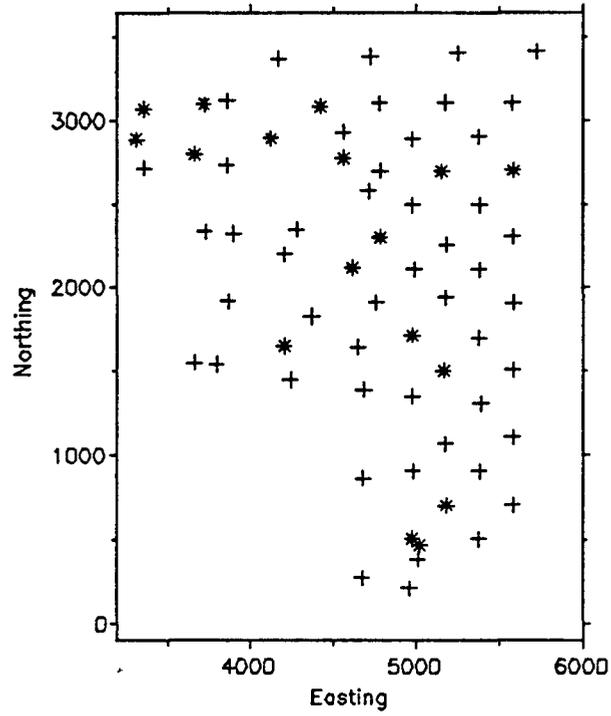
Postplot of Groundwater TCE
Level 1 (1992-93)



1st Quartile: .001 ≤ + ≤ .001
2nd Quartile: .001 < X ≤ .001
3rd Quartile: .001 < □ ≤ .001
4th Quartile: .001 < * ≤ 19.000

Figure 4.3
TCE Postplot (1992-1993)

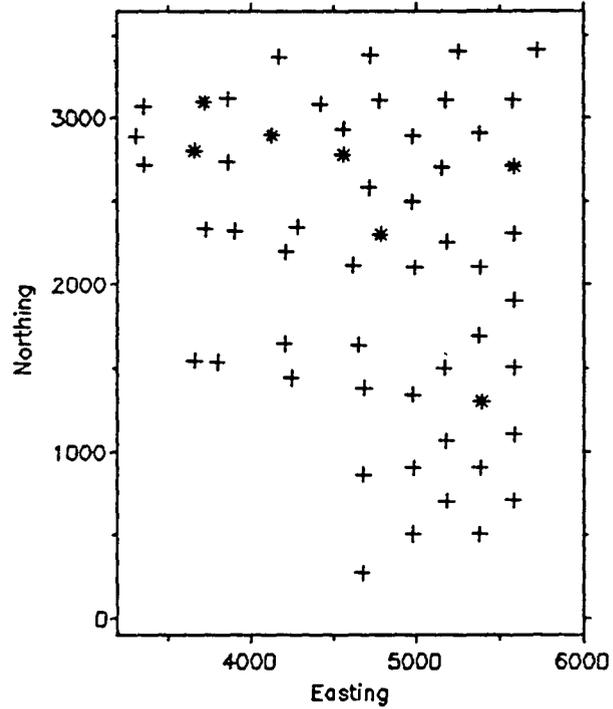
Postplot of Groundwater TCE
Level 2



1st Quartile:	.001 \cong + \cong .001
2nd Quartile:	.001 < x \cong .001
3rd Quartile:	.001 < □ \cong .001
4th Quartile:	.001 < * \cong 155.300

Figure 4.4
TCE Postplot (Aquifer Level 2)

Postplot of Groundwater TCE
Level 3 (1993)



1st Quartile: $.001 \leq + \leq .001$
 2nd Quartile: $.001 < X \leq .001$
 3rd Quartile: $.001 < \square \leq .001$
 4th Quartile: $.001 < * \leq .220$

Figure 4.5
TCE Postplot (Aquifer Level 3)

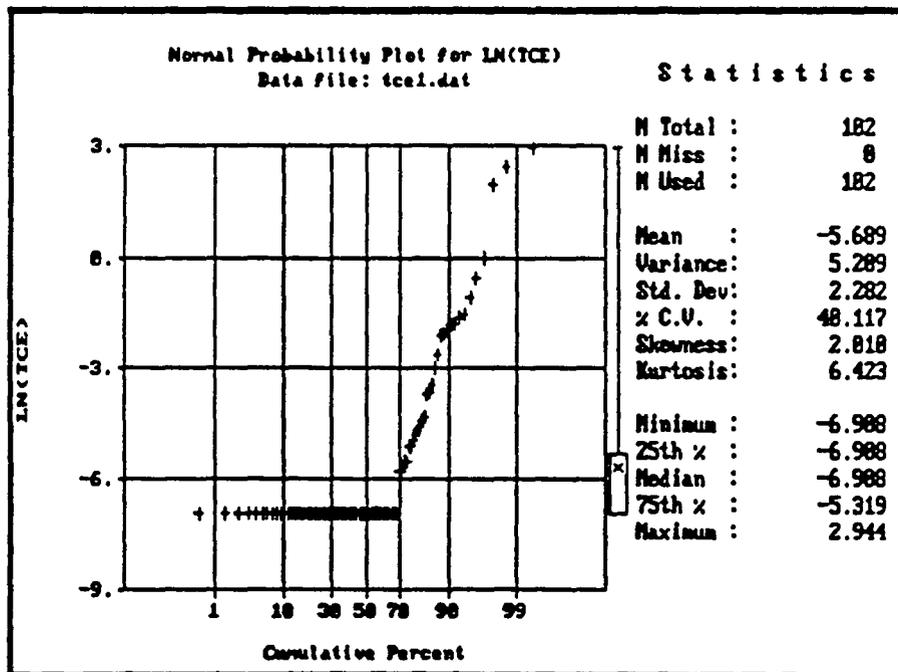
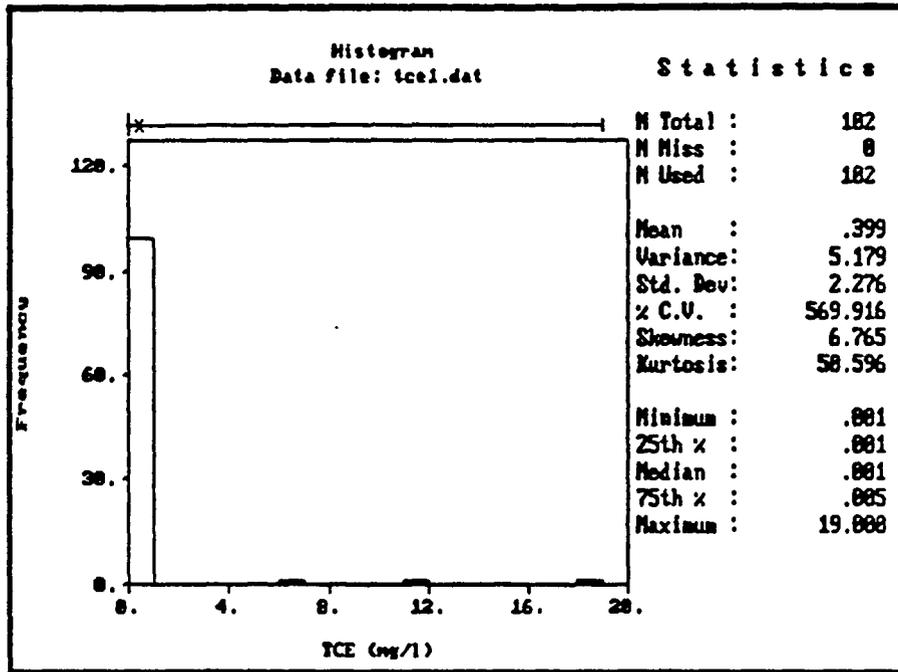


Figure 4.6
Statistical Analysis of TCE Data
(Aquifer Level 1)

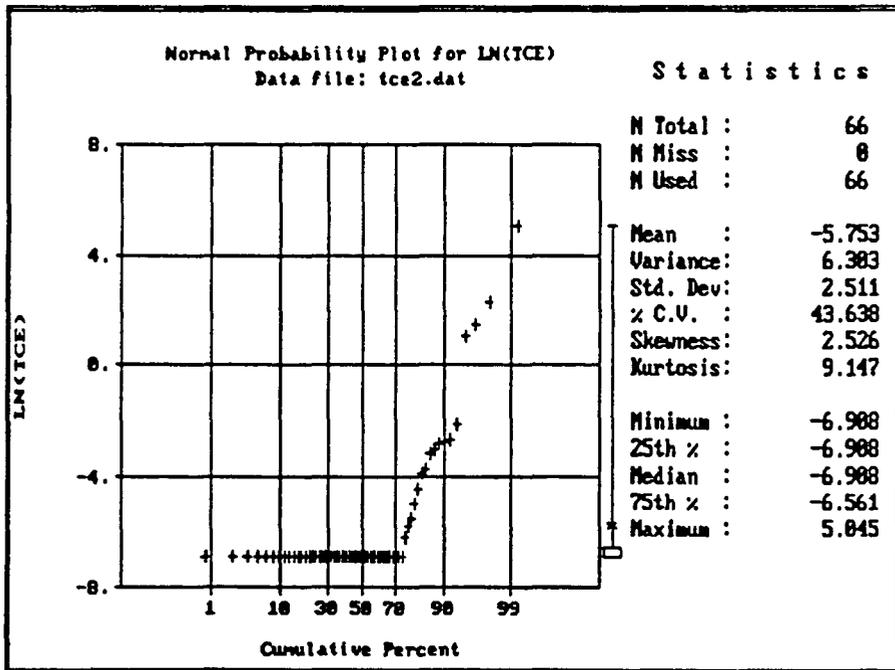
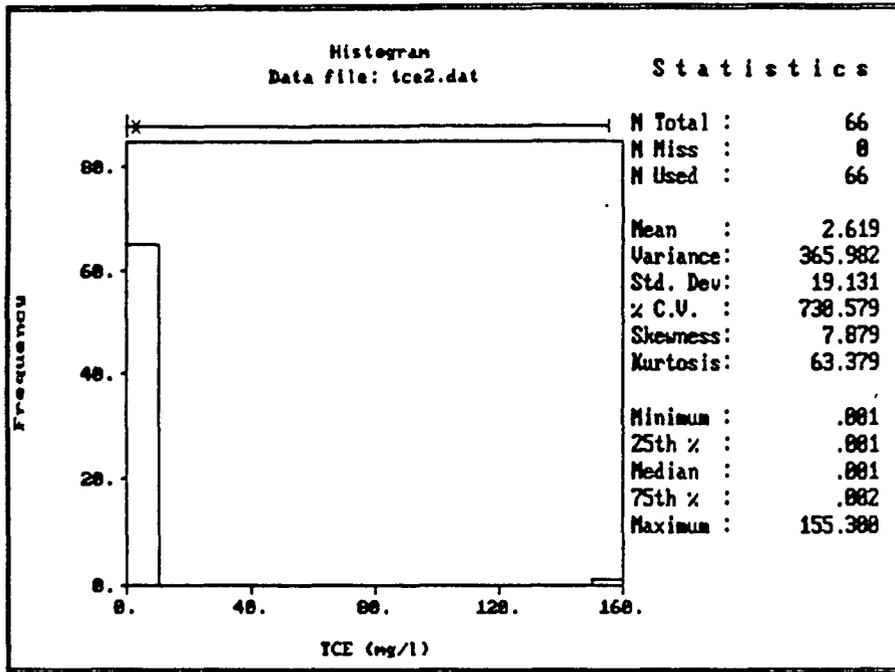
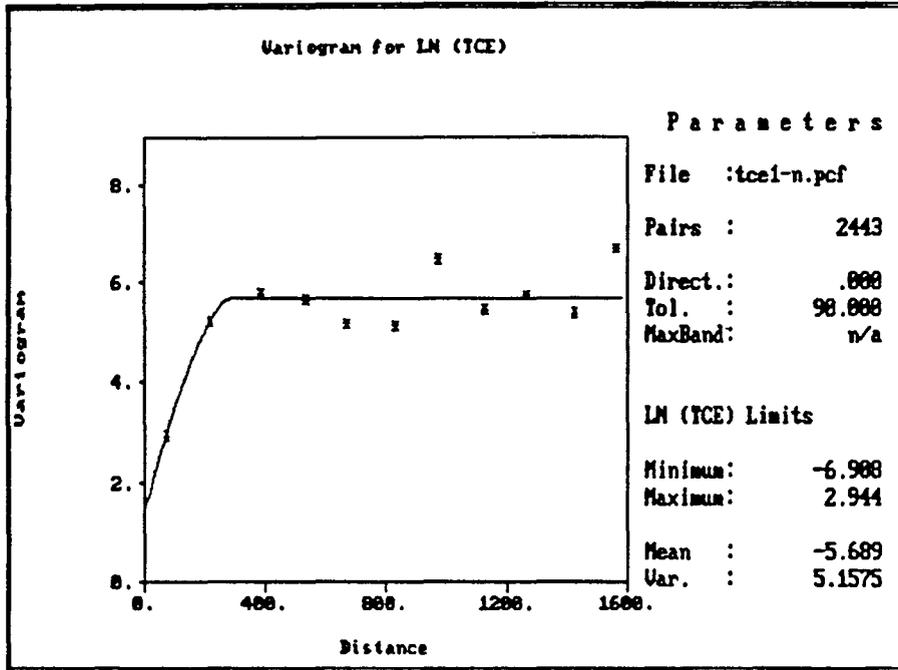


Figure 4.7
Statistical Analysis of TCE Data
(Aquifer Level 2)



MODEL					
Pairs	Avg Distance	Value	Pairs	Avg Distance	Value
1	27	71.578	2.932	18	
2	172	214.769	5.228	19	
3	216	383.438	5.801	20	
4	236	532.882	5.684	21	
5	275	668.798	5.184	22	
6	334	838.287	5.145	23	
7	298	973.913	6.581	24	
8	277	1126.772	5.488		
9	231	1268.722	5.776		
10	199	1426.957	5.483		
11	178	1563.914	6.718		
12					
13					
14					
15					
16					
17					

Model	Nugget :	1.500
Type	Sill	Range
Spherical	4.200	300.000

Figure 4.8
 Omni-directional Variogram
 Aquifer Level 1 (North)

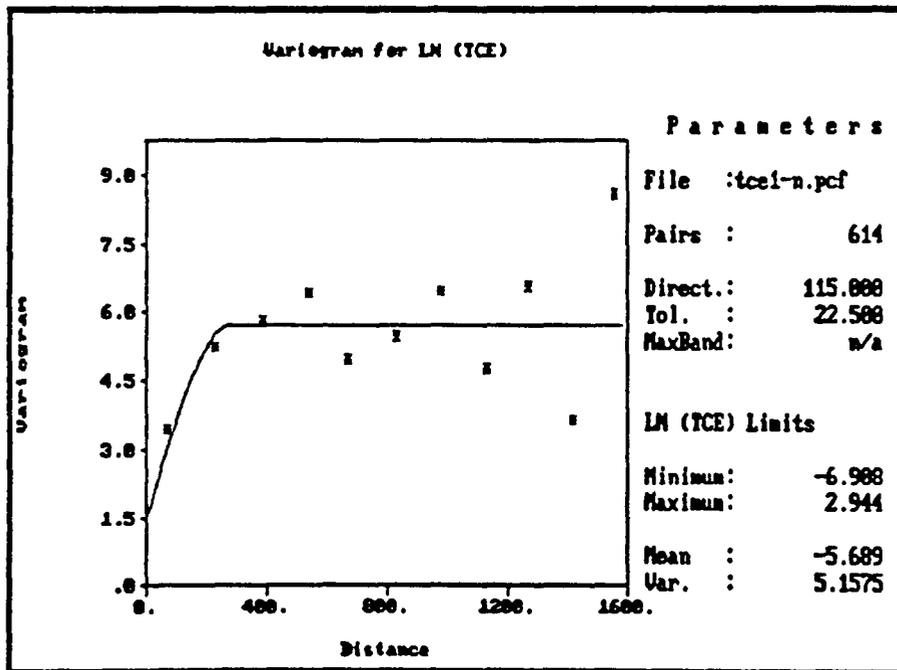
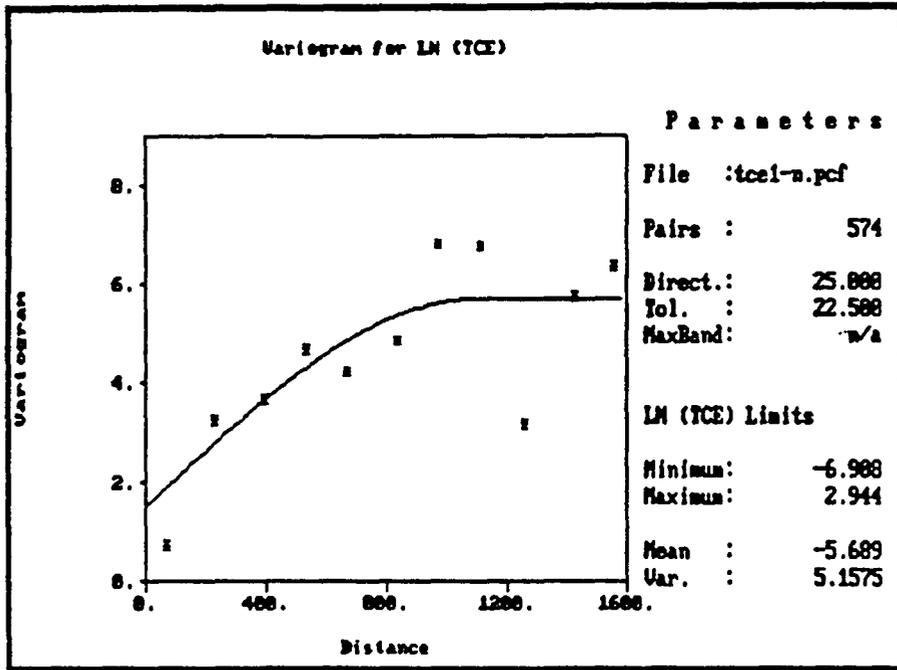
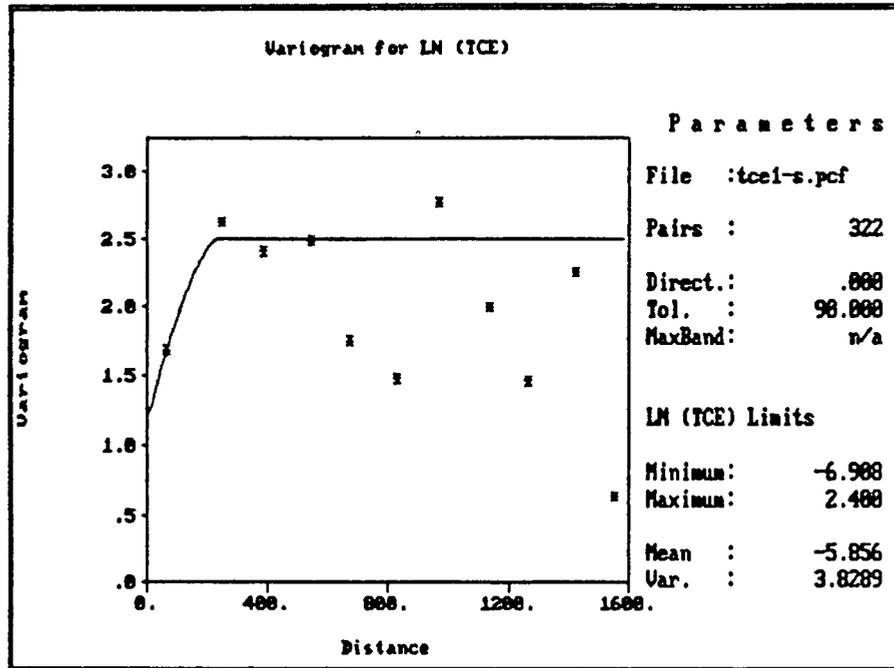


Figure 4.9
 Directional Variogram
 Aquifer Level 1 (North)



MODEL					
Pairs	Avg Distance	Value	Pairs	Avg Distance	Value
1	7	64.326	1.687	18	
2	38	244.217	2.619	19	
3	43	385.152	2.482	20	
4	58	542.538	2.482	21	
5	58	672.817	1.768	22	
6	38	829.258	1.482	23	
7	41	971.492	2.761	24	
8	25	1137.855	2.885		
9	11	1267.553	1.468		
10	14	1425.118	2.257		
11	5	1554.791	.634		
12					
13					
14					
15					
16					
17					

Model	Mugget :	1.200
Type	Sill	Range
Spherical	1.300	250.000

Figure 4.10
 Omni-directional Variogram
 Aquifer Level 1 (South)

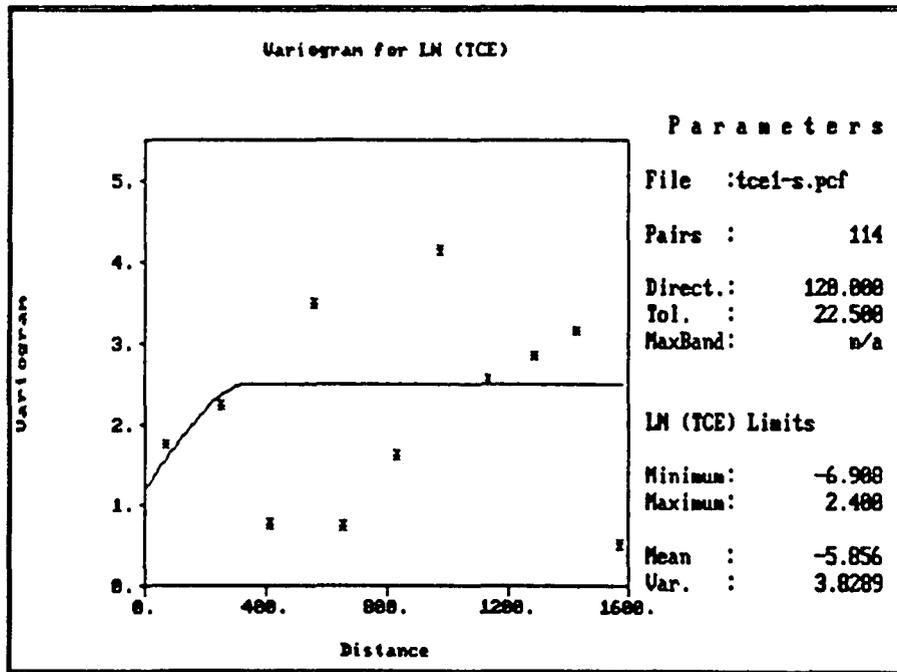
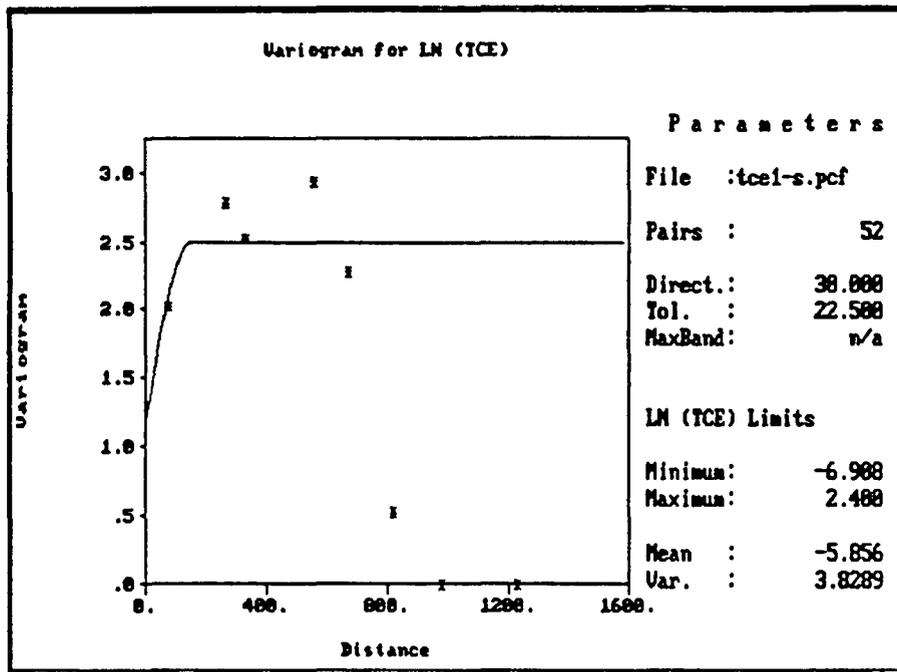
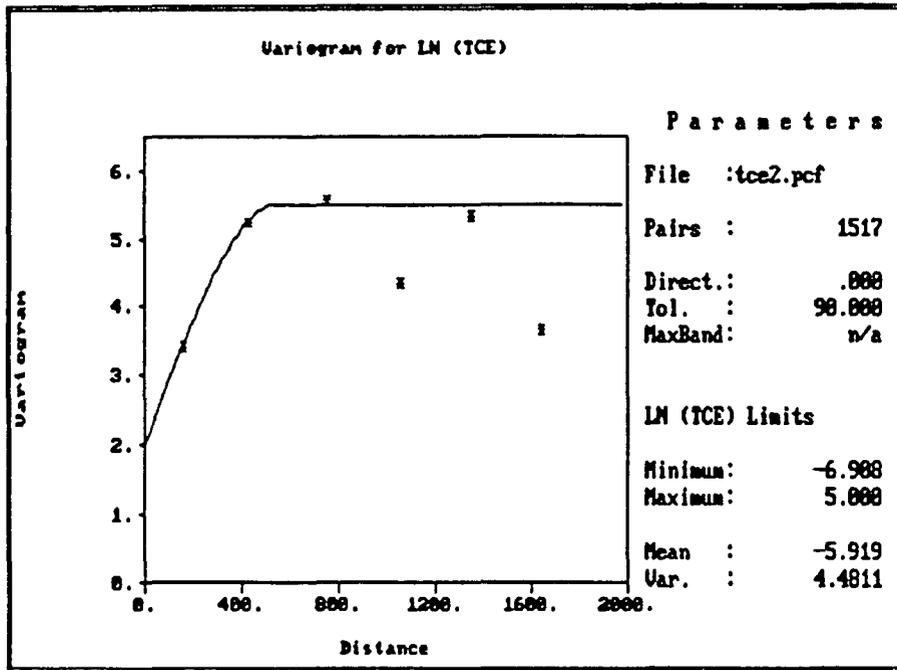
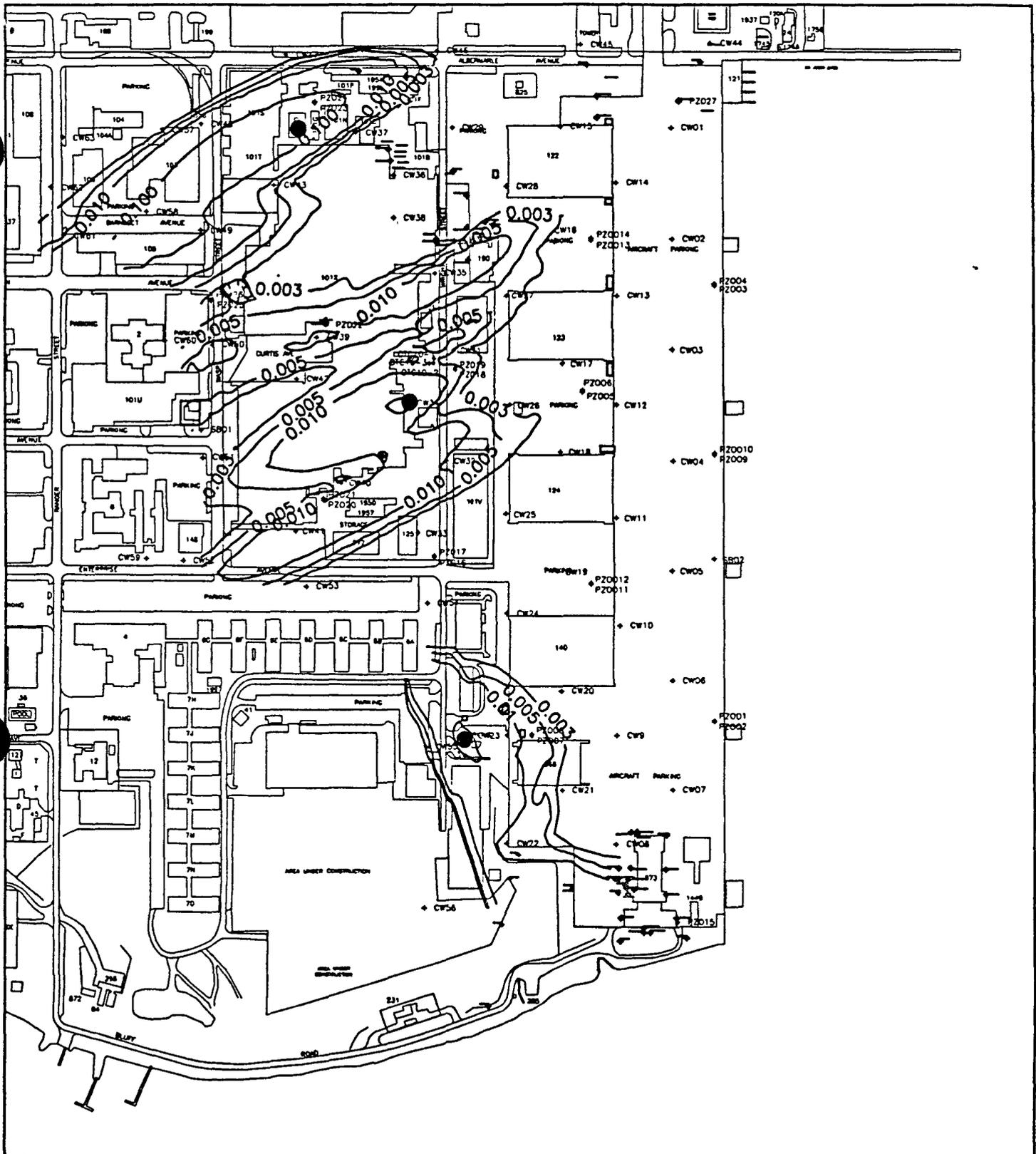


Figure 4.11
Directional Variograms
Aquifer Level 1 (South)



MODEL							
	Pairs	Avg Distance	Value		Pairs	Avg Distance	Value
	1	10	158.637	3.404	18		
	2	274	426.677	5.233	19		
	3	298	755.479	5.559	20		
	4	325	1054.184	4.357	21		
	5	316	1351.833	5.329	22		
	6	294	1644.766	3.668	23		
	7				24		
	8						
	9						
	10				Model		
	11					Nugget :	2.000
	12				Type	Sill	Range
	13				Spherical	3.500	550.000
	14						
	15						
	16						
	17						

Figure 4.12
 Omni-directional Variogram
 Aquifer Level 2



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FIGURE 4.13

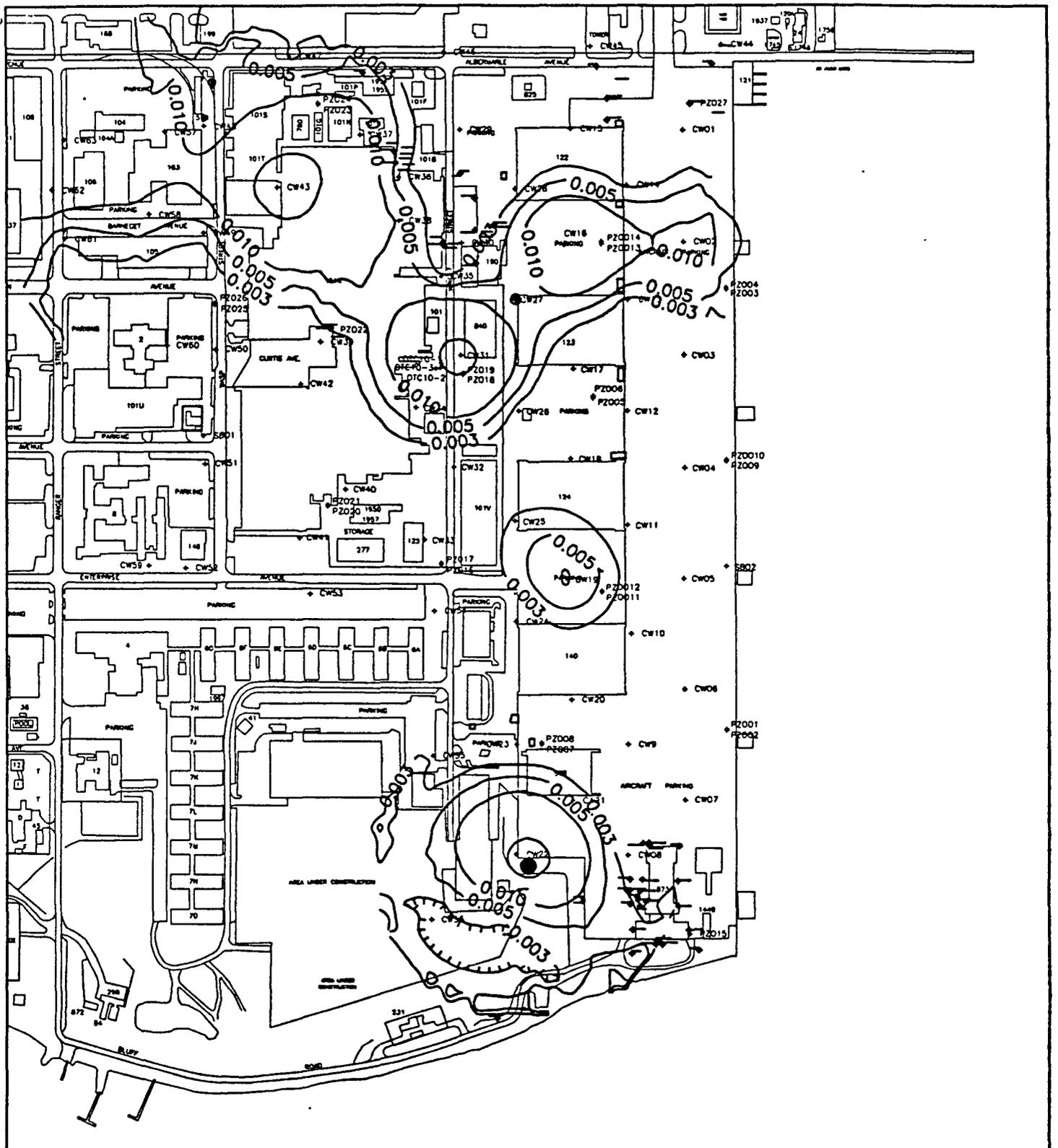
TCE Kriged Map

OU3 Aquifer Level 1

NAS Jacksonville
Jacksonville, Florida

LEGEND

- TCE Concentration (mg/l)
- TCE or TCA Above 1% Solubility

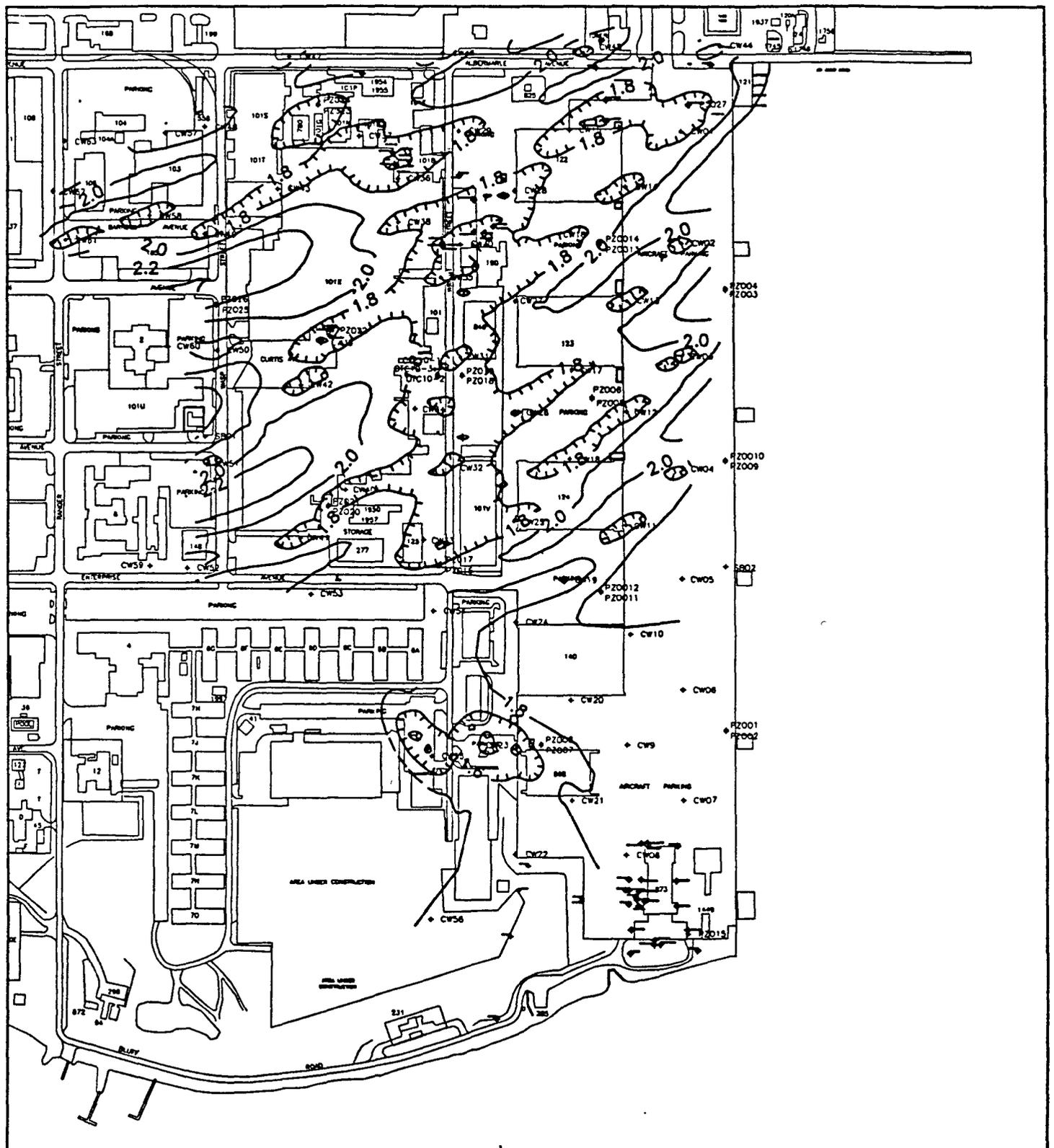


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FIGURE 4.14
 TCE Kriged Map
 OU3 Aquifer Level 2
 NAS Jacksonville
 Jacksonville, Florida

LEGEND

- TCE Concentration (mg/l)
- TCE or TCA Above 1% Solubility

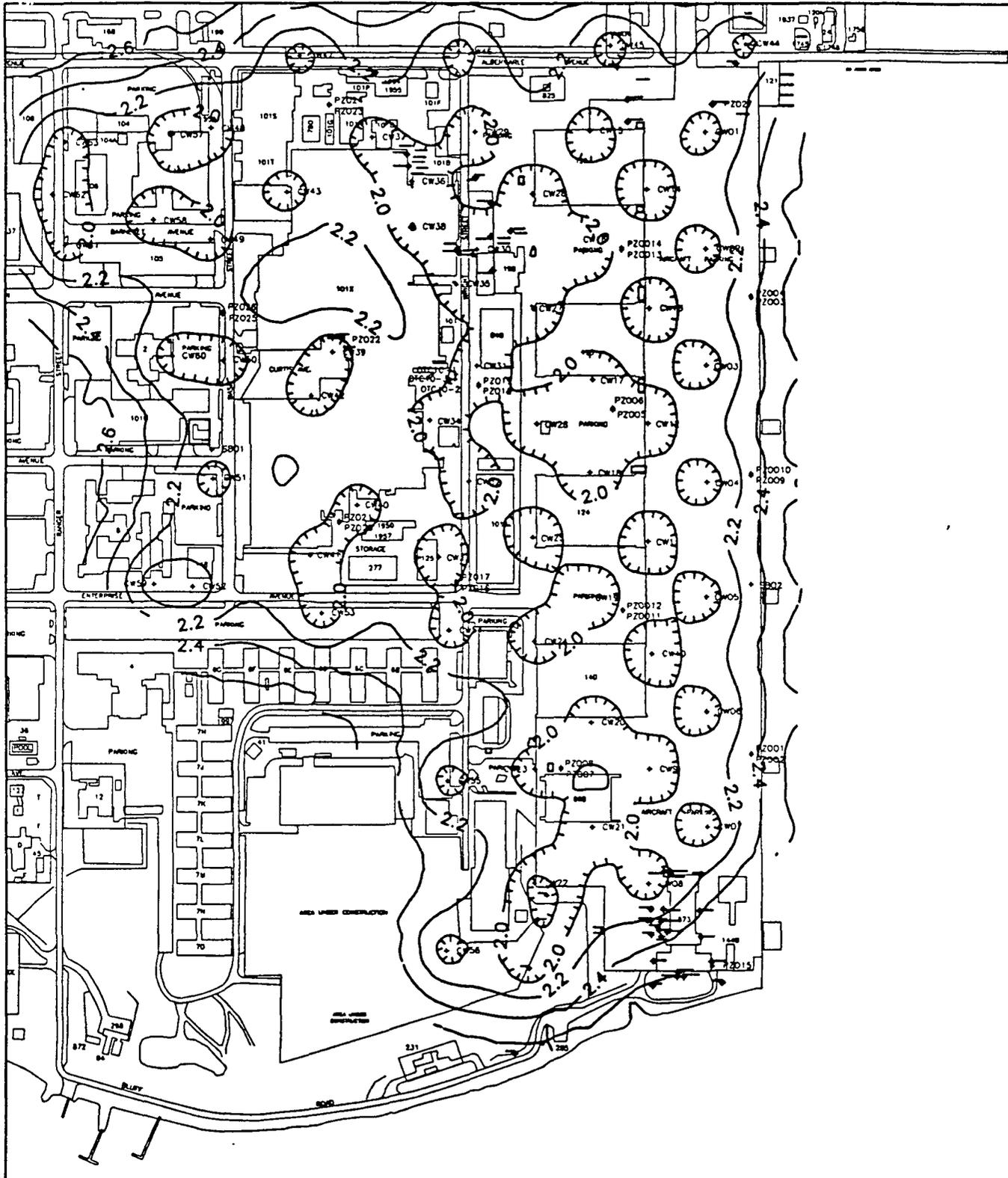


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LEGEND

— TCE Standard Deviation

FIGURE 4.15
 TCE Geometric
 Standard Deviation
 OU3 Aquifer Level 1
 NAS Jacksonville
 Jacksonville, Florida

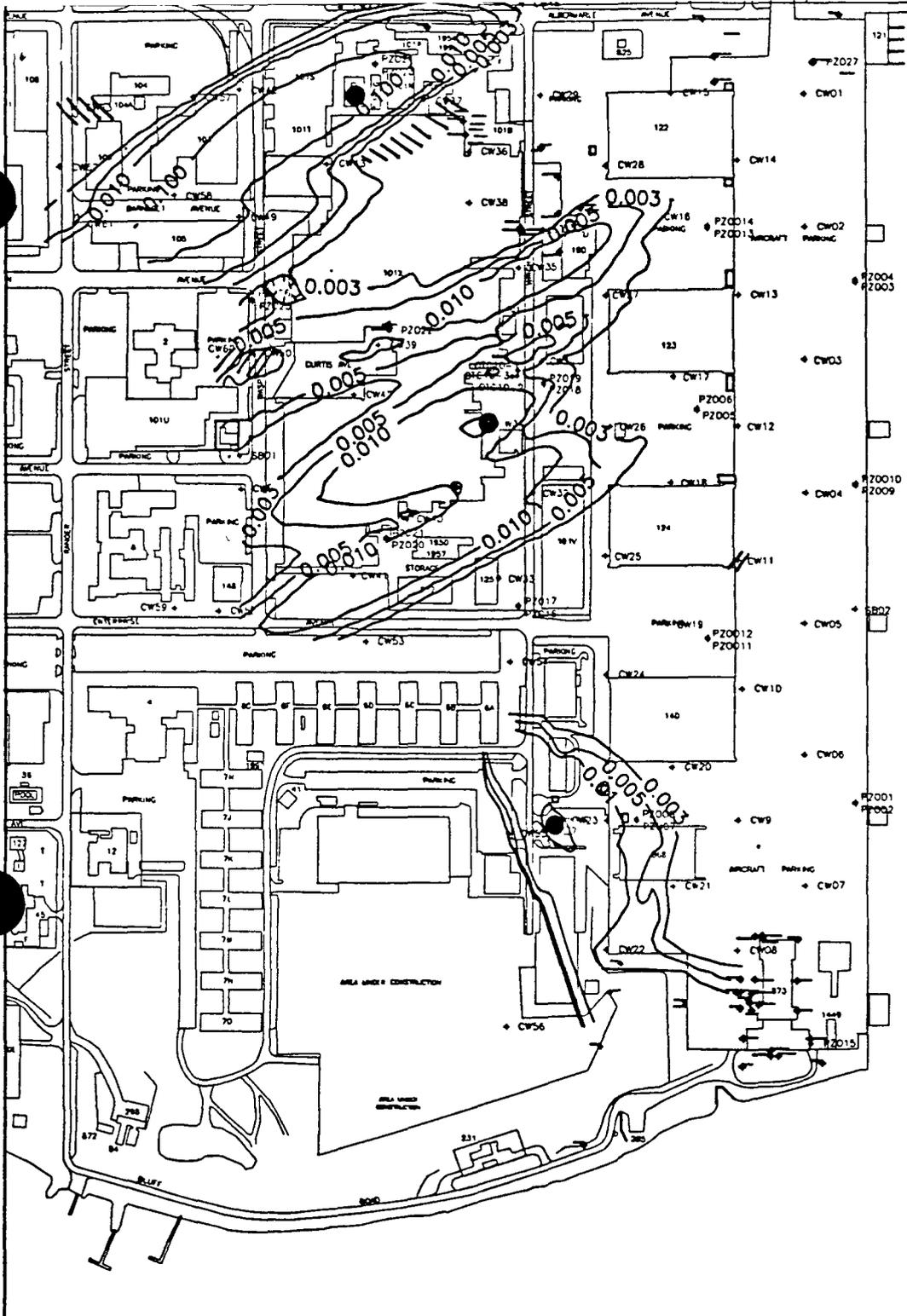


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FIGURE 4.16
 TCE Geometric
 Standard Deviation
 OU3 Aquifer Level 2
 NAS Jacksonville
 Jacksonville, Florida

LEGEND

— TCE Standard Deviation

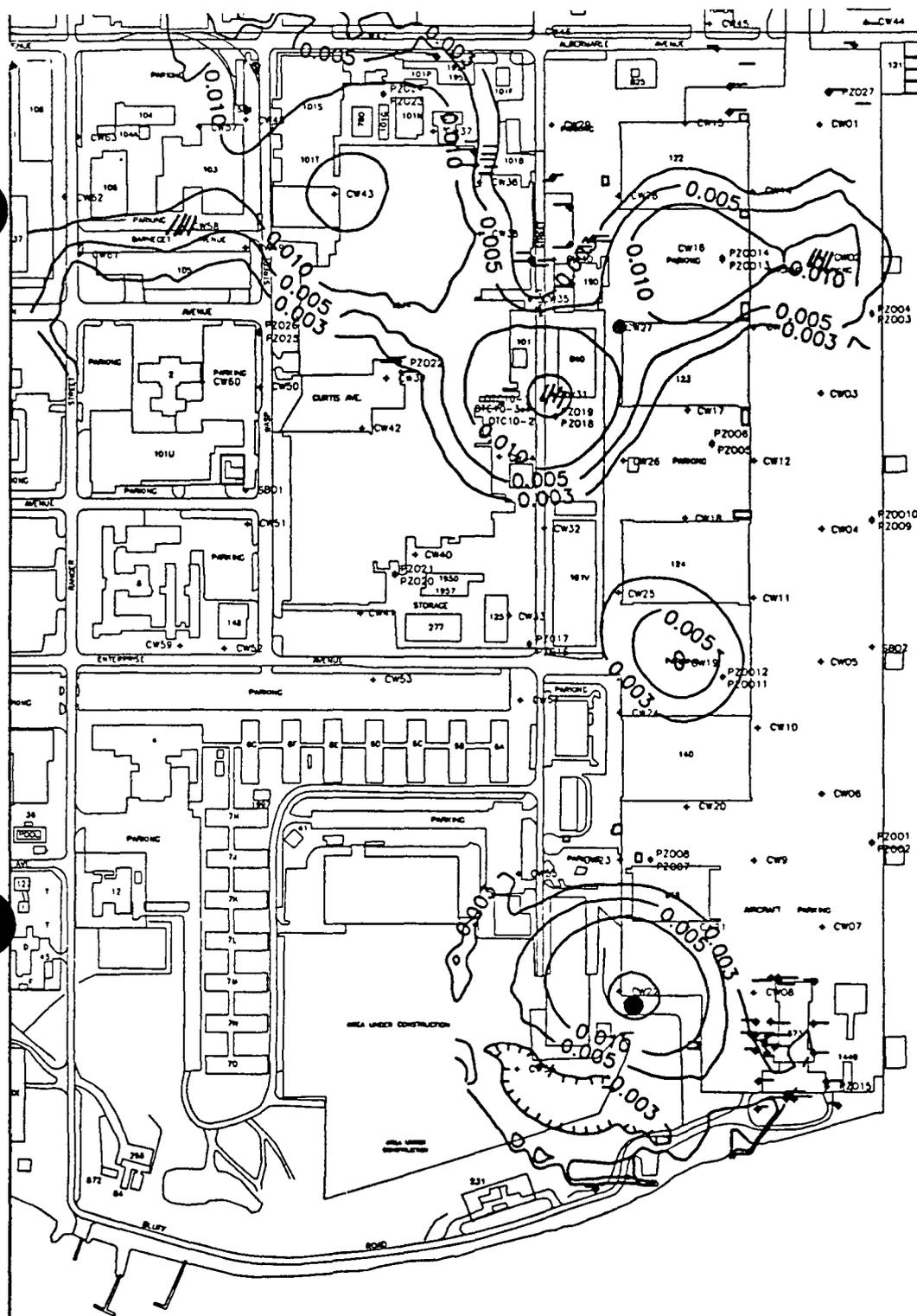


-  Only Daughter Products Detected
-  Only TCE or TCA Detected

FIGURE 5.1
TCE Kriged Map
OU3 Aquifer Level 1
NAS Jacksonville
Jacksonville, Florida

LEGEND

-  TCE Concentration (mg/l)
-  TCE or TCA Above 1% Solubility



- Only Daughter Products Detected
- Only TCE or TCA Detected

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FIGURE 5.2
TCE Kriged Map
OU3 Aquifer Level 2
NAS Jacksonville
Jacksonville, Florida

LEGEND

- TCE Concentration (mg/l)
- TCE or TCA Above 1% Solubility

SITENAME	PCR	DESCRIPTION	LOCATION	CWE	ACTUALS	SIQH	T	CT	TITLE	S	DATE	CONTRNO	EIC	REMARKS
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October 94

2,41,43,KT	C004D	PSC 2, IMP W/UST TEST CELL,OU2, KTC	NAS JACKSONVILLE	1,516,079	1,516,079	Ye	C	CL	IRA	O	10/30/94	93-0936	1853	NEGOTIATED
OU 3	C004D	PLATING SHOP TECH SUPPORT ABB	NAS JACKSONVILLE	46,334	46,334	No	C	CL	IRA	O	10/30/94	89-0317	1853	*NEGOTIATED
Total for Month:				1,562,413	1,562,413									

December 94

OU 3	C004D	PLATING SHOP DEMO - RAC	NAS JACKSONVILLE	0	0	Ye	C	CL	IRA	C	12/10/94	93-0936	1858	NEG NEXT WEEK
RCRA 01	S064U	HANGER 1000	NAS JACKSONVILLE	0	0	No	C	CL	RCRA-RA	P	12/15/94	93-0936	1824	RAC REMOVAL OF PIPING RCRA
UST 05	S064Q	MOP - MONITORING	NAS JACKSONVILLE	0	0	No	D	CD	UST-RD	P	12/24/94	2275	1842	UST
VARIOUS	C004A	DATA TRANSFER	NAS JACKSONVILLE	0	0	No	S	CS	RI/FS	P	12/30/94	2275	1883	
OU 1/3	C004D	GWE IRA SV/MTGS/WP-BECHTEL	NAS JACKSONVILLE	0	0	Ye	C	CL	IRA	P	12/30/94	93-0936	1855	IF NEEDED
OU 2	C004D	PSC 2, 41, 43, IRA TECH SUPPORT	NAS JACKSONVILLE	0	0	No	C	CL	IRA	P	12/30/94	89-0317	1853	*NEGOTIATED
VARIOUS	C004D	WASTE REMOVALS-SITES 2,3,11,26,41,42,43,48	NAS JACKSONVILLE	0	0	No	C	CL	IRA	P	12/30/94	2275	1857	
HANGR 1000	S064U	C/O TRENCH DRAIN	NAS JACKSONVILLE	1,030	1,030	Ye	C	CL	RCRA-RA	C	12/30/94	93-1111	1824/05	*
TANK 119	S064Q	TANK 119, CAR/RAP	NAS JACKSONVILLE	0	0	No	D	CD	UST-RD	P	12/31/94	93-0662	184	DESIGN
Total for Month:														

Total for 1st Quarter:

January 95

HANGER 115		CAR/RAP	NAS JACKSONVILLE	0	0	No	C	CL	UST-RI	P	1/10/95	89-0317	1842	
2-4,41-43	C004A	OU 2 COMPLETE RI/FS	NAS JACKSONVILLE	0	0	No	S	CS	RI/FS	P	1/30/95	89-0317	1857	

FY95 DERA EXECUTION - NAS JACKSONVILLE

22-Nov-94

SITENAME	PCR	DESCRIPTION	LOCATION	CWE	ACTUALS	SI	O	T	CT	TITLE	S	DATE	CONTRNO	EIC	REMARKS
2-4,41-43	C004D	RI/FS - RAC (SITES 2,3,4,41,42,43)	NAS JACKSONVILLE		0	Ye	S	C	S	RI/FS	P	1/30/95	93-0936	1857	
26, 27	C004D	LNAPL IRA- COST GROWTH	NAS JACKSONVILLE		0	Ye	C	C	CL	IRA	P	1/30/95	RAC-N	1855	PRECOP 12/12
11 - 15	C004D	TECH SUPPORT-PHASE II (SITES 11,12,13,14,15)	NAS JACKSONVILLE		0	No	C	C	CL	IRA	P	1/30/95	89-0317	1857	CONSTRUCTION
Total for Month:					0										

February 95

26,27	C004D	IRP WASTE DISPOSAL	NAS JACKSONVILLE		0	No	C	C	CL	RD/RA	P	2/1/95	DRMS	1857	
11-15	C004A	OU 3 COMPLETE RI/FS	NAS JACKSONVILLE		0	No	S	C	CS	RI/FS	P	2/10/95	89-0317	1857	
41,43	C004D	IRA CHANGES - RAC	NAS JACKSONVILLE		0	Ye	C	C	CL	RD/RA	P	2/10/95	93-0936	1858	
KTC,PSC2	C004D	IRA CHANGES - RAC	NAS JACKSONVILLE		0	Ye	C	C	CL	RD/RA	P	2/10/95	93-0936	1858	
UST 01	S359B	PCAS/RAM - REMEDIATION/RAC	NAS JACKSONVILLE		0	Ye	C	C	CL	UST-RA	P	2/10/95	93-0936	1842	
UST 01	S359B	REMEDATION/RAC	NAS JACKSONVILLE		0	Ye	C	C	CL	UST-RA	P	2/10/95	93-0936	1842	
UST 01	S359B	PHASE I - REMEDIATION/RAC	NAS JACKSONVILLE		0	Ye	C	C	CL	UST-RA	P	2/15/95	93-0936	1842	
OLD GAS ST		CAR/RAP	NAS JACKSONVILLE		0	No	C	C	CL	UST-RI	P	2/28/95		1842	
HANGER 115		UST	NAS JACKSONVILLE		0	No	C	C	CL	UST	P	2/28/95		1842	
Total for Month:					0										

March 95

PSC 3,42	C004D	PHASE I -OU#2	NAS JACKSONVILLE		0	Ye	C	C	CL	RD/RA	P	3/10/95	93-0936	1858	
OU 3	C004D	PLATING SHOP DEMO - RAC	NAS JACKSONVILLE		0	Ye	C	C	CL	IRA	C	3/10/95	93-0936	1858	
UST 01	S359B	PHASE II - REMEDIATION/RAC	NAS JACKSONVILLE		0	Ye	C	C	CL	UST-RA	P	3/15/95	93-0936	1842	