

APPENDIX F
STABLE ISOTOPE STUDY ANALYSIS

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APPENDIX F

STABLE ISOTOPE STUDY ANALYSIS

The technical approach for the analysis of stable isotope data collected in the Orion Park Housing Area (OPHA) is presented in the following sections. An interpretation of the stable isotope study results is presented in Section 6.2 of this Report.

OBJECTIVE

The primary objective of the stable isotope study is to evaluate and determine if the trichloroethene (TCE) and cis-1,2-dichloroethene (cis-1,2-DCE) beneath the OPHA originates from off-site and/or on-site source(s). It is believed that the objective can be achieved using multiple lines of evidence, including an understanding of site-specific hydrogeology and geochemistry (including isotopic composition).

ISOTOPE BASICS

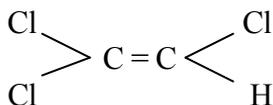
Isotopes are forms of an element whose nuclei have the same atomic number (the number of protons in the nucleus), but different mass numbers because they contain different numbers of neutrons. In scientific nomenclature, isotopes are specified by the name of the particular element and a superscripted prefix to the chemical symbol (e.g., ^{12}C). Different isotopes of a given element have the same number of electrons and the same electronic structure. Because the chemical behavior of an atom is largely determined by its electronic structure, isotopes exhibit nearly identical chemical behavior. The primary exception is that, due to their larger masses, heavier isotopes tend to react somewhat more slowly than lighter isotopes of the same element (this phenomenon is termed the kinetic isotope effect). Similarly, two molecules that differ only in the isotopic nature of their atoms (isotopologues) will have nearly identical electronic structure, and therefore, have similar physical and chemical properties.

Although isotopes exhibit nearly identical electronic and chemical behavior, their nuclear behavior varies dramatically. Atomic nuclei consist of protons and neutrons bound together by the strong nuclear force. Because protons are positively charged, they repel each other. Neutrons, which are electronically neutral, allow some separation between the positively charged protons, reducing the electrostatic repulsion and stabilizing the nucleus. For this reason, neutrons are necessary for two or more protons to be bound into a nucleus. As the number of protons increases, additional neutrons are needed to form a stable nucleus. If too many neutrons or too few neutrons are present, the nucleus becomes unstable and is subject to nuclear decay, resulting in a radioactive isotope. Stable isotopes are nuclides that do not decay to other isotopes on geologic time scales, but may themselves be produced by the decay of radioactive isotopes.

Several isotopes, either radioactive or both radioactive and stable, of each element can be found in nature.

ISOTOPIC COMPOSITION OF TCE

TCE is made up of three chlorine (Cl) atoms, two carbon (C) atoms and one hydrogen (H) atom in the following structural formula:



Each of these elements (Cl, C, and H) have several isotopes, with two stable isotopes occurring for each.

Chlorine Isotopes – Cl has two stable isotopes, ^{35}Cl and ^{37}Cl that occur naturally in a ratio of approximately 3:1. $^{37}\text{Cl}/^{35}\text{Cl}$ ratios are normally reported in terms of permil (‰) deviation relative to Standard Mean Ocean Chloride ($\delta^{37}\text{Cl}_{\text{SMOC}}$) using the conventional δ notation.

Carbon Isotopes – C has two stable isotopes, ^{12}C and ^{13}C , that occur naturally in a ratio of approximately 89:1. $^{13}\text{C}/^{12}\text{C}$ ratios are normally reported in terms of ‰ deviation relative to Pee Dee Belemnite ($\delta^{13}\text{C}_{\text{PDB}}$) using the conventional δ notation.

Hydrogen Isotopes – H has two stable isotopes, ^1H and ^2H (the latter often referred to as deuterium), that occur naturally in a ratio of approximately 6,421:1. $^2\text{H}/^1\text{H}$ ratios are normally reported in terms of ‰ deviation relative to Standard Mean Ocean Water ($\delta^2\text{H}_{\text{SMOW}}$) using the conventional δ notation.

To date, only the Cl and C isotopes have been analyzed and evaluated at the OPHA.

APPLICATION OF $\delta^{37}\text{Cl}$ AND $\delta^{13}\text{C}$ VALUES

It has been shown that $\delta^{37}\text{Cl}$ and $\delta^{13}\text{C}$ values for TCE from different sources vary (see table below), and can be used to differentiate and “fingerprint” specific sources of TCE (Alimi et al., 2001). Since all δ values are comparisons to an internationally recognized standard (such as SMOC or PDB described above), any compound with a greater value (heavier or more enriched in the heavier isotope) than the standard will have a positive value. Conversely, any compound with a lesser value (lighter or less enriched in the heavier isotope) than the standard will have a negative value.

Ratio	Range of Values (‰)	Manufacture & Date	Reference
$\delta^{37}\text{Cl}$	$+4.08 \pm 0.34$	DOW, 1992	(Shouakar-Stash et al., 2003)
	-3.19 ± 0.07	Stan Chem, 1993	(Shouakar-Stash et al., 2003)
	$+2.49 \pm 0.26$	ICI, 1993	(Shouakar-Stash et al., 2003)
	-2.54 ± 0.34	PPG, 1993	(Shouakar-Stash et al., 2003)
	$+3.90 \pm 0.09$	DOW, 1995	(Shouakar-Stash et al., 2003)
	-2.70 ± 0.34	PPG, 1995	(Shouakar-Stash et al., 2003)
$\delta^{13}\text{C}$	-31.90 ± 0.05	DOW, Not Specified	(Van Warmerdam et al., 1995)
	-31.32 ± 0.03	ICI, Not Specified	(Jendrzewski et al., 2001)
	-27.80 ± 0.01	PPG, Not Specified	(Shouakar-Stash et al., 2003)

Additionally, the $\delta^{37}\text{Cl}$ and $\delta^{13}\text{C}$ values from a specific TCE source are unaffected by dilution mechanisms and will remain constant (Slater, 2003). However, natural attenuation of TCE by microbial biodegradation will result in a shift of the $\delta^{37}\text{Cl}$ and $\delta^{13}\text{C}$ values due to enrichment of the heavier ^{37}Cl and ^{13}C isotopes. As described earlier, heavier isotopes tend to react somewhat more slowly than lighter isotopes of the same element, and as such, the ^{35}Cl and ^{12}C bonds are easier to break during microbial biodegradation, resulting in a skewing of the natural ratio of Cl and C isotopes to a greater concentration of the heavier ^{37}Cl and ^{13}C in the remaining TCE (the $\delta^{37}\text{Cl}$ and $\delta^{13}\text{C}$ values increase). During microbial biodegradation, the kinetic isotope effect for Cl and C follows a predicted kinetic isotope effect trendline equation. A linear shift is thus noted on a plot of $\delta^{37}\text{Cl}$ and $\delta^{13}\text{C}$ vs. the natural logarithm of TCE concentration, and all isotope values on this linear trendline are derived from a single TCE source when the biodegradation rate is uniform. Recent studies have used stable isotopes to differentiate between different zones in chlorinated ethane plumes and to link plume sources (Hunkeler et al., 2004).

APPLICATION OF $\delta^{37}\text{Cl}$ AND $\delta^{13}\text{C}$ VALUES FOR IDENTIFICATION OF POTENTIAL SOURCES

To assess whether TCE may have been derived from multiple sources, $\delta^{37}\text{Cl}$ vs. $\delta^{13}\text{C}$ values are plotted on arithmetic axes to see if any distinct “isotopic ratio signature” or “clustering” patterns are present, which include any linear groupings indicative of kinetic isotope effect (kinetic isotope effect trendline) that follows a Rayleigh distillation equation. Assuming conservative mixing behavior, such distinct groupings of isotopic ratio signatures (i.e., grouped $\delta^{37}\text{Cl}$ and $\delta^{13}\text{C}$ values) are unique to various manufacturers’ TCE compositions (as discussed above), and thus indicative of a separate source material. Knowledge of local hydrostratigraphy and groundwater flow directions is used as supporting lines of evidence to aid in interpretation of the clustering patterns. Patterns can be examined along groundwater flow lines and if the mixing behavior is conservative, then these wells should cluster together on the data plot since the unique composition pattern should not change. Recent studies have used stable isotopes to differentiate between different zones in chlorinated ethane plumes, dividing a PCE plume into three distinct domains representing a different episode (i.e., “slug”) and location of dense non-aqueous phase liquid release and to link plume sources (Hunkeler et al., 2004). A cluster analysis, a non-statistical algorithm used to discover structures in data, may prove useful in explaining clustering of data points in groups (Statsoft, 2006).

However, if the TCE has undergone microbial biodegradation (which is typical for TCE), there will be a shift of the $\delta^{37}\text{Cl}$ and $\delta^{13}\text{C}$ values due to enrichment of the heavier ^{37}Cl and ^{13}C isotopes (kinetic isotope effect). Similar kinetic isotope shifts would cluster values along a single regression line when $\delta^{37}\text{Cl}$ and $\delta^{13}\text{C}$ values are plotted on arithmetic axes against the log of the TCE concentration (Slater, 2003). This regression line indicates the exponential isotope enrichment expected from biodegradation processes, which follows a predictable kinetic isotope effect trendline equation from the initial TCE source material. The wells do not plot in the order of distance from the source due to slug flow and various hydrogeologic factors described in Section 6.3. Field investigations have shown that the kinetic isotope effect trendline equation is constant when steady state (or stable) conditions (i.e., uniform biodegradation) occur at a site (Chu et al., 2004). A similar TCE source would experience a similar biodegradation rate along the kinetic isotope effect trendline, whereas a separate TCE source would exhibit either a tightly grouped cluster or an additional linear regression line with a different slope and position on the plot. Again, knowledge of local hydrostratigraphy and groundwater flow directions is used as supporting lines of evidence to aid in interpretation of the

clustering patterns along the isotope enrichment (kinetic isotope effect trendline) regression trendline. Patterns are examined along groundwater flow lines and if the biodegradation rates are similar, then these wells will cluster together on the regression line indicating a similar source. An upper and lower confidence limit can be calculated for the regression line to test if there are wells that lie outside the confidence interval boundaries and thus might indicate different TCE sources. However, the spatial distribution of $\delta^{37}\text{Cl}$ and $\delta^{13}\text{C}$ values due to multiple distinct and commingled TCE sources, if present, can cause variations in the isotope ratio signatures, which can impart some degree of uncertainty in the analysis. Two or more unique isotopic signatures from different sources can become commingled together such that an expected linear shift is not present or in the $\delta^{37}\text{Cl}$ and $\delta^{13}\text{C}$ vs. the natural logarithm of TCE concentration plot. If, however, only one kinetic isotope effect is noted among all wells across an entire site, and there is adequate “uniqueness” (i.e., separation) among TCE from each distinct source, then determination of distinct sources is simplified and retains a greater degree of certainty. Such is the case with the isotopic data for the OPHA.

CLUSTER ANALYSIS

Cluster analysis (first used by Tryon, 1939) is an exploratory data analysis tool that uses algorithms and methods for grouping different observations in a way that the degree of association between two observations is maximal if they belong to the same group and minimal otherwise (Statsoft, 2006). The analysis begins with each observation being separate and forming its own cluster. In a series of successive steps, the two observations closest together are joined to form a cluster. This could be a single observation joining an existing cluster or two individual observations joining to form another cluster. As the observations are aggregated (or amalgamated), successively larger clusters of increasingly dissimilar elements are assembled until all observations are joined as one cluster. This is depicted as a hierarchical dendrogram.

Observations are clustered together using well-defined similarity rules. Similarities are a set of rules that serve as criteria for grouping or separating items (Statsoft, 2006). The joining or tree clustering method uses the dissimilarities (similarities) or matrix distances between observations when forming the clusters. The data are processed and an $n \times n$ distance matrix, D , is computed where n is the number of observations. The matrix entries, $d(i, j)$, in row i and column j , are the computed distances in matrix space between observations i and j . The distance is the actual geometric distance between the data points within the calculated two- or three-dimensional matrix space and do not represent a physical distance in the field. There are several methodologies to calculate the distance. Commonly, Euclidean distance [$\text{distance}(x,y) = \{\sum_i (x_i - y_i)^2\}^{-1/2}$] is used in this analysis (Minitab Inc., 2003a). Use of a squared Euclidean distance [$\text{distance}(x,y) = \sum_i (x_i - y_i)^2$] places progressively greater weight on objects that are farther apart (Statsoft, 2006).

Linkage is an amalgamation rule to determine when two clusters are sufficiently similar to be linked together (Statsoft, 2006). At each amalgamation stage, the two closest clusters are joined. At the start, when each observation constitutes a cluster, the distance between clusters is simply the inter-observation distance. Subsequently, after observations are joined together, the linkage rule is necessary for calculating inter-cluster distances when there are multiple observations in a cluster (Minitab Inc., 2003a). With complete linkage, or “furthest neighbor,” the distances between clusters are determined by the greatest distance between any two objects in the different clusters, i.e., by the “furthest neighbors” (Statsoft, 2006). This method ensures that all observations in a cluster are within a maximum distance and tends to produce clusters with similar diameters (Minitab Inc., 2003a). The results can be sensitive to outliers (Milligan, 1980).

The similarity level at any step is the percent of the minimum distance at that step relative to the maximum inter-observation distance in the data (Minitab Inc., 2003a). Because the similarity level collapses to zero as the clusters are joined together as one, the analyst must select a step where there is enough change in similarity (or an abrupt shift) to establish a final number of clusters. This is termed as cutting the dendrogram (Minitab Inc., 2003a). The analysis is rerun with the determined number of clusters and the dendrogram is recreated with tables summarizing each cluster by the number of observations, within the cluster sum of squares, the average distance from observation to the cluster centroid, and the maximum distance of observation to the cluster centroid. In general, a cluster with a small sum of squares is more compact than one with a large sum of squares. The centroid is the vector of variable means for the observations in that cluster and is used as a cluster midpoint (Minitab Inc., 2003a).

For the OPHA analysis, the data were analyzed using squared Euclidean distance and complete linkage, a method that usually performs quite well in cases when the objects actually form naturally distinct “clumps” (Statsoft, 2006). Each sampling event (August and December 2005) was analyzed individually and the average $\delta^{37}\text{Cl}$, $\delta^{13}\text{C}$, and TCE values were assembled into an 11 x 11 x 3 matrix. The August data showed a gradual reduction in similarity with a more noticeable break at 93.49 percent into five clusters (Figure F-1) as follows:

- MCH-1UA, MCH-11UA, MCH-7UA, and MCH-9UA
- MCH-5UA and 87B1
- MCH-3UA and MCH-2LA
- MCH-4LA and MCH6-LA
- MCH-10LA

There is a very distinct break into two clusters at 63.10 percent (MCH-4LA, MCH6-LA, and MCH-10LA versus the remaining wells).

December data also showed a similar trend with a noticeable break into five clusters at 93.80 percent (Figure F-2) as follows:

- MCH-1UA, MCH-7UA, MCH-3UA, and MCH-2LA
- MCH-5UA and 87B1
- MCH-9UA, MCH-11UA, and MCH-4LA
- MCH6-LA and MCH-10LA

There is also a very distinct break into two clusters at 63.91 percent (MCH6-LA and MCH-10LA versus the remaining wells).

These clusters were used to substantiate the groupings of the wells as shown on the $\delta^{13}\text{C}$ vs. $\delta^{37}\text{Cl}$ plots (Figures F-3 and F-4).

REGRESSION ANALYSIS

Regression analysis is used to investigate and model the relationship between a response variable and one or more predictors. The least squares procedure is generally used when the response variable is continuous (Minitab Inc., 2003b). Parameter estimates are obtained by minimizing the sum of squared errors and result in a slope (m) and Y-intercept (b) for a best fit regression line in the form of $y_{\text{predicted}} = mx + b$. The goodness of fit is computed as the R^2 value that represents the square of the correlation coefficient. Any data point that is far from the regression line (and would have a large residual value from the sum of squares calculation) may represent erroneous data or be indicative of a poorly fitting regression line. Observations where the absolute value of the standardized residual is greater than 2 are considered unusual and generally indicative of an outlier (Minitab Inc., 2003b).

When TCE undergoes microbial biodegradation (which is typical for TCE), there will be a shift of the $\delta^{37}\text{Cl}$ and $\delta^{13}\text{C}$ values due to enrichment of the heavier ^{37}Cl and ^{13}C isotopes (kinetic isotope effect). Similar kinetic isotope shifts would cluster values along a single regression line when $\delta^{37}\text{Cl}$ and $\delta^{13}\text{C}$ values are plotted on arithmetic axes against the log of the TCE concentration (Slater, 2003). This regression line indicates the exponential isotopic enrichment expected from biodegradation processes, which follows a well-defined kinetic isotope effect trendline equation. The wells do not plot in the order of distance from the source due to slug flow and various hydrogeologic factors described in Section 6.3. A similar TCE source would experience a similar biodegradation rate along the progression that biodegradation is proceeding from a common source material. Knowledge of local hydrostratigraphy and groundwater flow directions is used as a supporting line of evidence to aid in interpretation of any clustering patterns along the regression line. If the biodegradation rates are similar, then related wells should cluster together on the regression line indicating a similar source. If the regression line shows a good fit (high R^2 correlation), an upper and lower confidence interval for the regression line can be calculated using the coefficient of variation (CV) to normalize the data and test if there are wells that lie outside the confidence interval boundaries and thus, might indicate different TCE sources or different biodegradation mechanisms. The coefficient of variation is calculated as the standard deviation divided by the mean. This value is multiplied by the predicted $\delta^{37}\text{Cl}$ or $\delta^{13}\text{C}$ ($y_{\text{predicted}}$) and then added or subtracted from the predicted $\delta^{37}\text{Cl}$ or $\delta^{13}\text{C}$ to obtain the upper and lower confidence intervals, respectively ($y_{\text{predicted}} \pm y_{\text{predicted}} * \text{CV}$).

For the OPHA analysis, linear regressions for $\delta^{37}\text{Cl}$ and $\delta^{13}\text{C}$ were calculated using the isotopes as the response variables compared to the log concentration of TCE. The data are plotted on Figures F-5 through F-8 and the correlation results are tabulated below on Table F-1. As can be seen on Figures F-5 through F-8, many of the data line up in a linear fashion, exhibiting exponential enrichment following a kinetic isotope effect trendline equation, but there are several observations that consistently are off the kinetic isotope effect trendline. For the most part, correlation using all of the data points is only fair for August $\delta^{37}\text{Cl}$ and poor for the remaining analyses (December $\delta^{37}\text{Cl}$ and both rounds of $\delta^{13}\text{C}$) suggesting either mixing of multiple sources or differing biodegradation rates. The MCH-2LA datum had a large standardized residual greater than 2 for December $\delta^{37}\text{Cl}$ and both rounds of $\delta^{13}\text{C}$ (2.23, 2.14 and 2.11, respectively) indicating that this point is probably an outlier. Two other wells, MCH-5UA and 87B1, consistently plot away from the general group of wells (see Figures F-6 through F-8). The August $\delta^{37}\text{Cl}$ data (see Figure F-5) show a deviation from well MCH-9UA.

As a tool for evaluating the relative impact of these data that fall away from the general grouping of wells along the linear trend, these points were removed sequentially from the linear regression and the R^2 was recalculated as an indication of improvement with the correlation. The results in Table F-1 show little improvement for $\delta^{37}\text{Cl}$ in August, but much improved correlation in December. With the removal of the same wells from the regression analysis, the $\delta^{13}\text{C}$ correlation is also greatly improved compared to regressions using all data, although the resultant R^2 correlation is still only fair. This suggests that groundwater in the vicinity of the larger group of wells (those following the linear trend) probably represents the same source, and groundwater from these wells is undergoing similar kinetic isotopic enrichment. Wells MCH-2LA (a probable outlier based on the large standardized residual), MCH-5UA, and 87B1 may represent different sources, different groundwater flow regimes or different biodegradation environments or any combination thereof.

Table F-1. Linear Regression Correlation Summary

$\delta^{37}\text{Cl}$				$\delta^{13}\text{C}$			
August 2005		December 2005		August 2005		December 2005	
Wells Excluded	R^2	Wells Excluded	R^2	Wells Excluded	R^2	Wells Excluded	R^2
none	0.740	none	0.331	None	0.032	none	0.025
MCH-9UA	0.840	MCH-2LA	0.528	MCH-2LA	0.116	MCH-2LA	0.070
MCH-9UA MCH-5UA	0.823	MCH-2LA MCH-5UA	0.796	MCH-2LA MCH- 5UA	0.268	MCH-2LA MCH-5UA	0.629
MCH-9UA MCH-5UA 87B1	0.837	MCH-2LA MCH-5UA 87B1	0.968	MCH-2LA MCH- 5UA 87B1	0.775	MCH-2LA MCH-5UA 87B1	0.764

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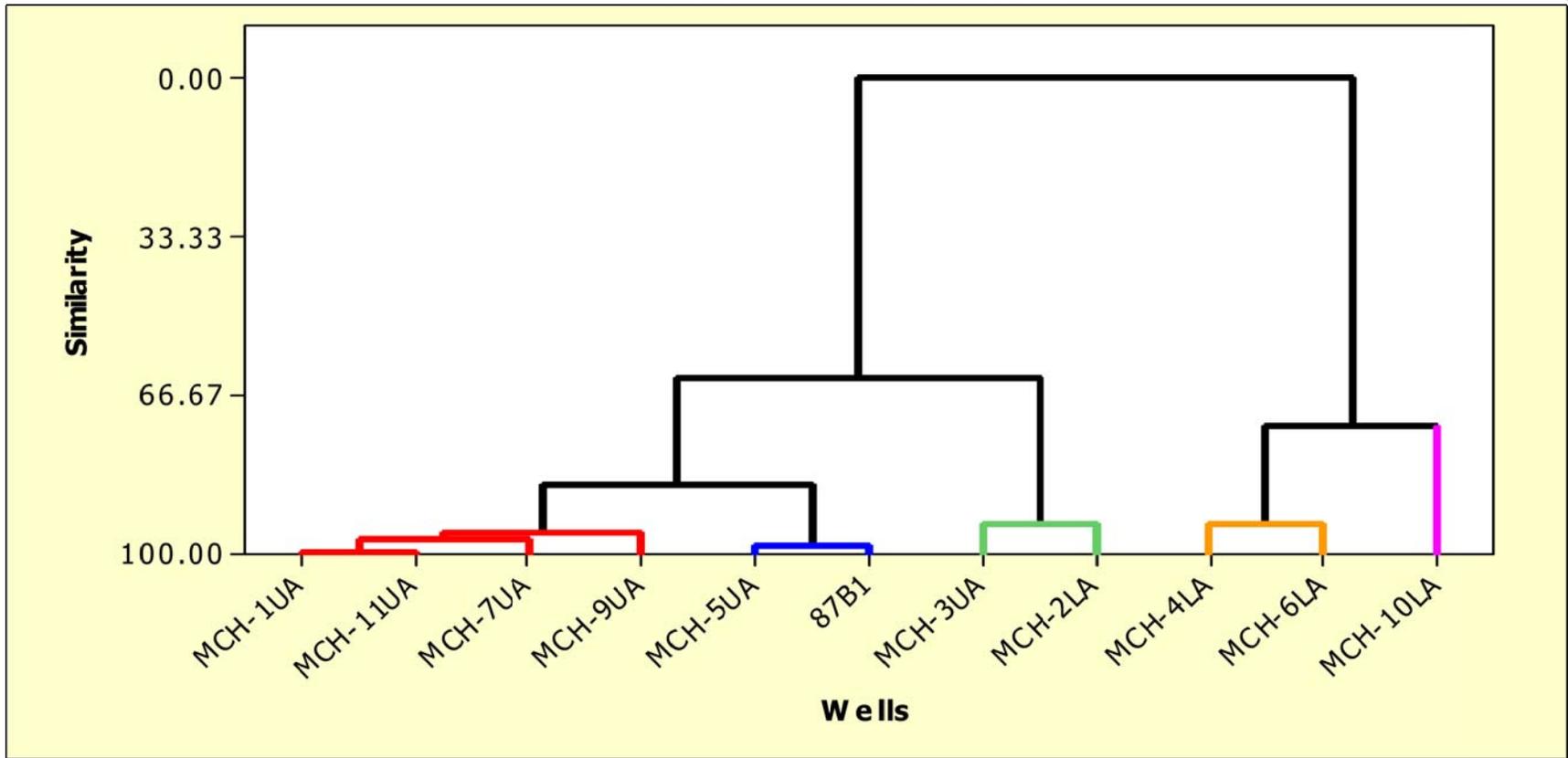
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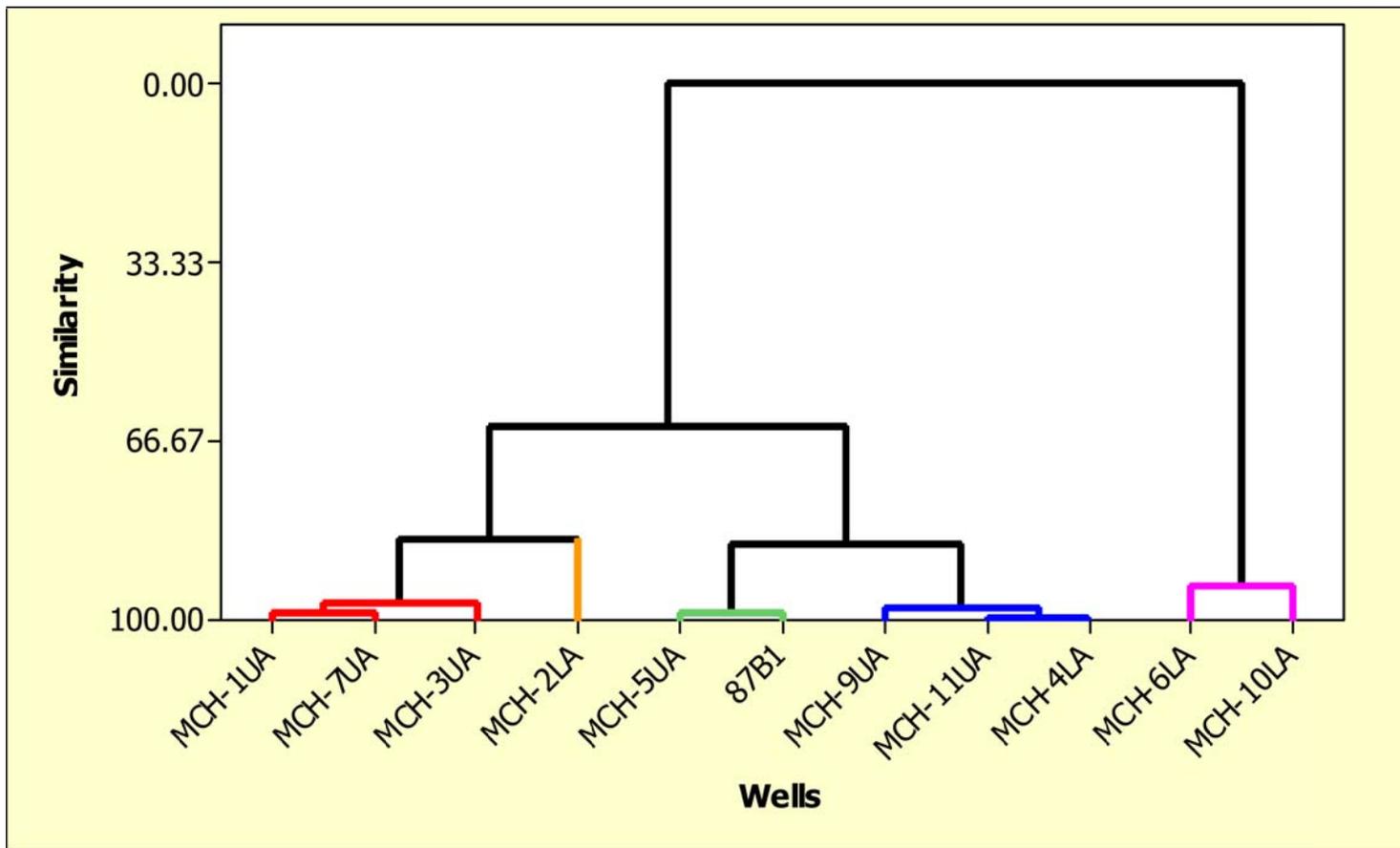


BASE REALIGNMENT AND CLOSURE
 PROGRAM MANAGEMENT OFFICE WEST
 SAN DIEGO, CA
 GROUNDWATER MONITORING WELL INSTALLATION AND
 SAMPLING REPORT FOR ORION PARK HOUSING AREA
 FIGURE F-1
 PARTITION INTO 5 CLUSTERS, AUGUST 2005
 MOFFETT COMMUNITY HOUSING
 MOFFETT FIELD, CA

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BASE REALIGNMENT AND CLOSURE
PROGRAM MANAGEMENT OFFICE WEST
SAN DIEGO, CA

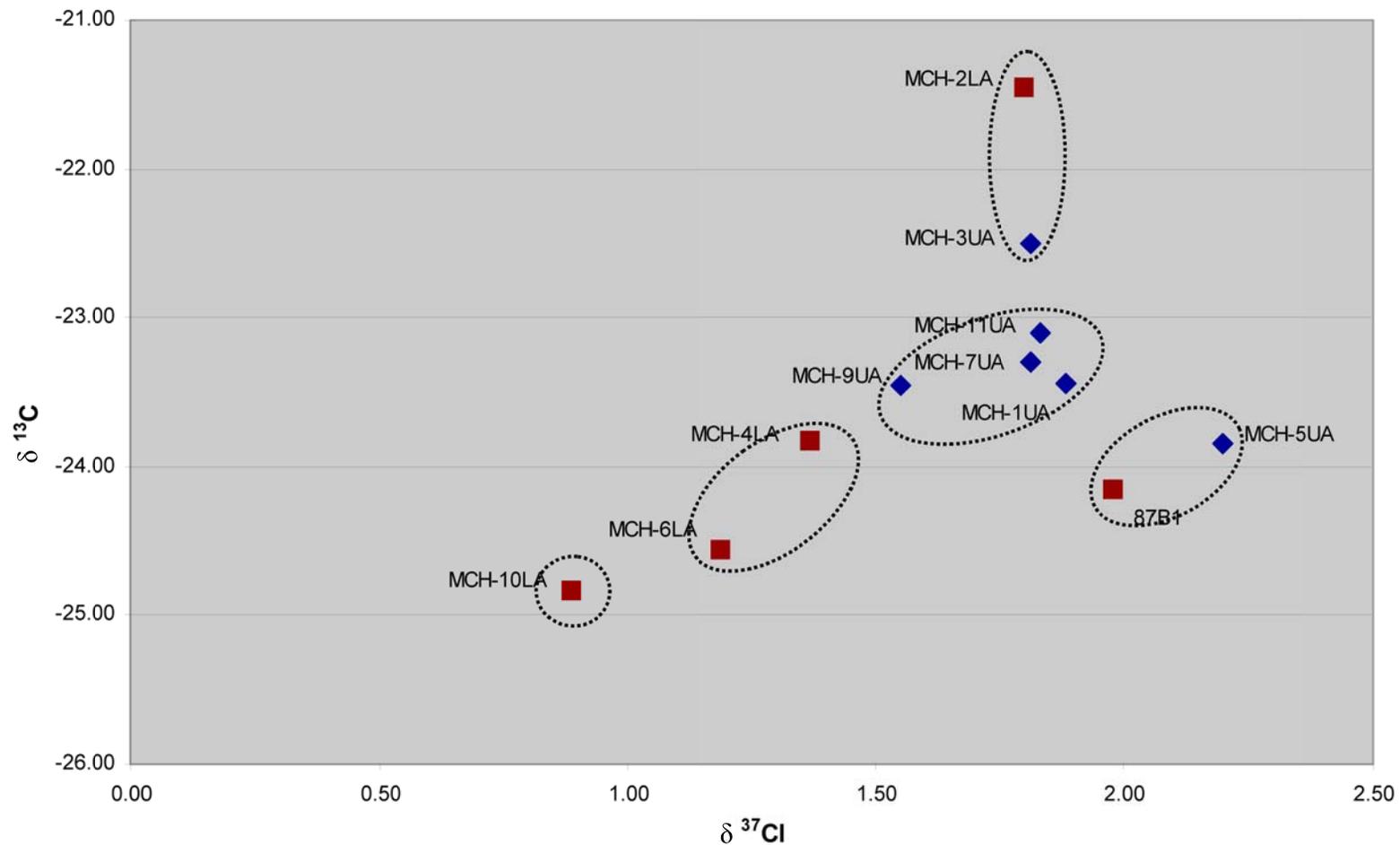
GROUNDWATER MONITORING WELL INSTALLATION AND
SAMPLING REPORT FOR ORION PARK HOUSING AREA
FIGURE F-2

PARTITION INTO 5 CLUSTERS, DECEMBER 2005
MOFFETT COMMUNITY HOUSING
MOFFETT FIELD, CA

REVISION: 0
AUTHOR: KLD
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TETRA TECH EC, INC.



LEGEND

◆ Upper A Aquifer Well

■ Lower A Aquifer Well

$$\delta^{37}\text{Cl} = (R_{\text{Cl-sample}}/R_{\text{Cl-standard}} - 1) \times 1,000$$

$$R_{\text{Cl}} = {}^{37}\text{Cl}/{}^{35}\text{Cl}$$

$$\delta^{13}\text{C} = (R_{\text{C-sample}}/R_{\text{C-standard}} - 1) \times 1,000$$

$$R_{\text{C}} = {}^{13}\text{C}/{}^{12}\text{C}$$

Cl-standard = Standard Mean Ocean Chloride

C-standard = Vienna Pee-Dee Belemnite

C - carbon

Cl - chlorine

BASE REALIGNMENT AND CLOSURE
PROGRAM MANAGEMENT OFFICE WEST
SAN DIEGO, CA

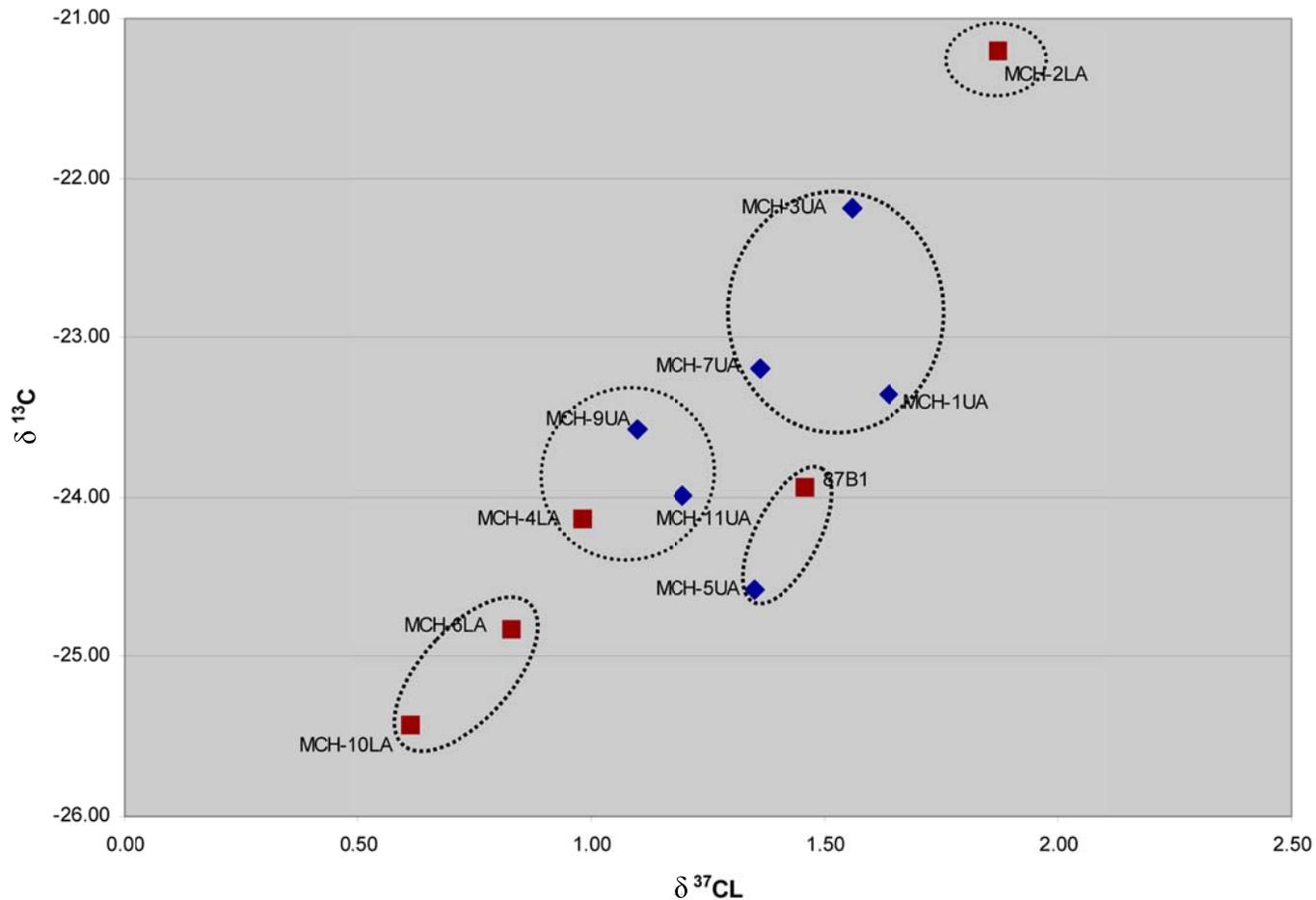
GROUNDWATER MONITORING WELL INSTALLATION AND
SAMPLING REPORT FOR ORION PARK HOUSING AREA
FIGURE F-3

δ¹³C vs δ³⁷Cl, AUGUST 2005

MOFFETT COMMUNITY HOUSING
MOFFETT FIELD, CA

REVISION: 0
AUTHOR: KLD
FILE : 061004f3.DWG





LEGEND

◆ Upper A Aquifer Well

■ Lower A Aquifer Well

$$\delta^{37}\text{Cl} = (R_{\text{Cl-sample}}/R_{\text{Cl-standard}} - 1) \times 1,000$$

$$R_{\text{Cl}} = {}^{37}\text{Cl}/{}^{35}\text{Cl}$$

$$\delta^{13}\text{C} = (R_{\text{C-sample}}/R_{\text{C-standard}} - 1) \times 1,000$$

$$R_{\text{C}} = {}^{13}\text{C}/{}^{12}\text{C}$$

Cl-standard = Standard Mean Ocean Chloride

C-standard = Vienna Pee-Dee Belemnite

C - carbon

Cl - chlorine

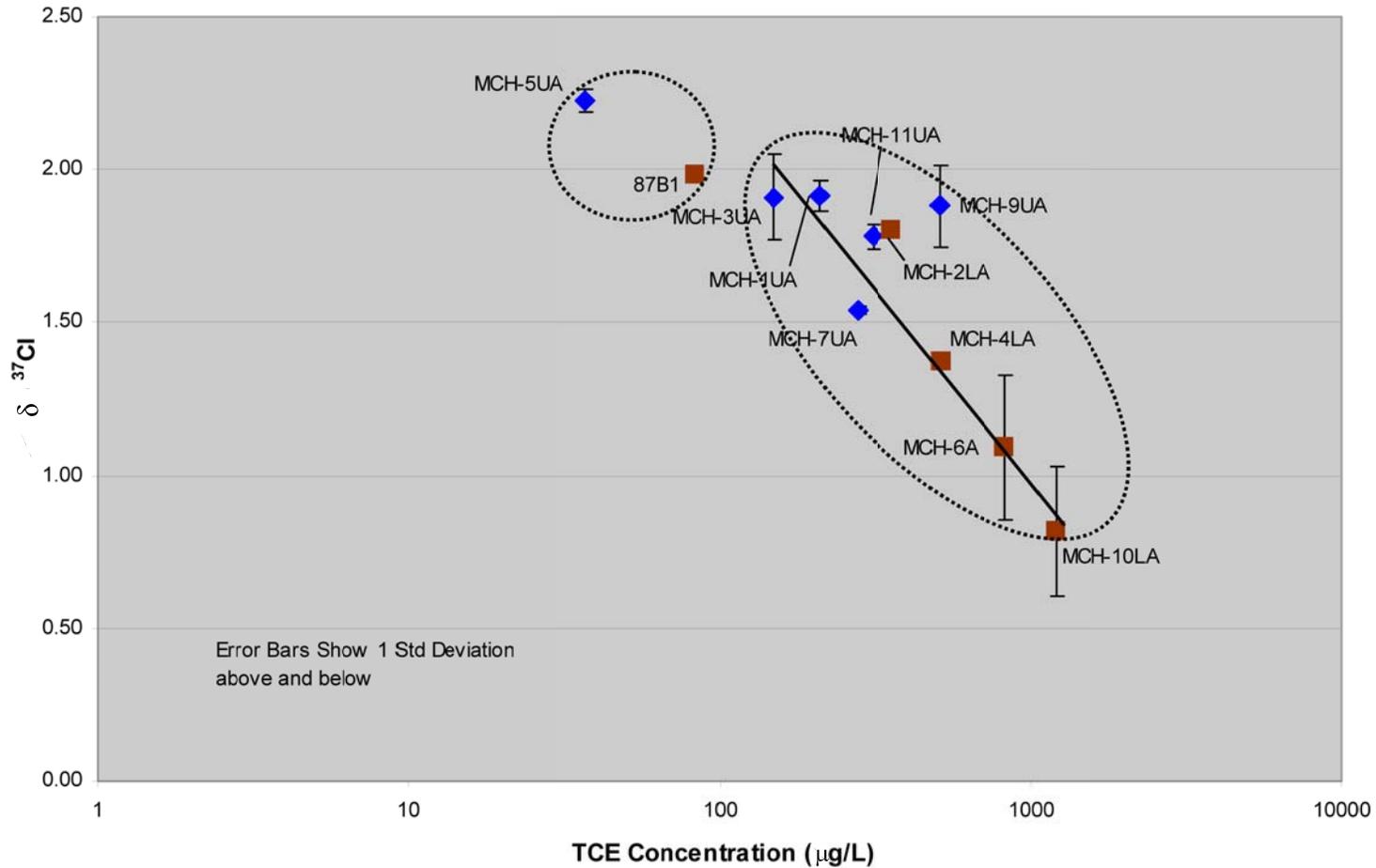
BASE REALIGNMENT AND CLOSURE
PROGRAM MANAGEMENT OFFICE WEST
SAN DIEGO, CA

GROUNDWATER MONITORING WELL INSTALLATION AND
SAMPLING REPORT FOR ORION PARK HOUSING AREA
FIGURE F-4

δ¹³C vs δ³⁷Cl, DECEMBER 2005
MOFFETT COMMUNITY HOUSING
MOFFETT FIELD, CA

REVISION: 0
AUTHOR: KLD
FILE : 061004f4.DWG





LEGEND

◆ Upper A Aquifer Well

■ Lower A Aquifer Well

$$\delta^{37}\text{Cl} = (R_{\text{Cl-sample}}/R_{\text{Cl-standard}} - 1) \times 1,000$$

$$R_{\text{Cl}} = {}^{37}\text{Cl}/{}^{35}\text{Cl}$$

Cl-standard = Standard Mean Ocean Chloride

$\mu\text{g/L}$ -micrograms per liter

Cl - chlorine

TCE - trichloroethene

Std- Standard

BASE REALIGNMENT AND CLOSURE
 PROGRAM MANAGEMENT OFFICE WEST
 SAN DIEGO, CA

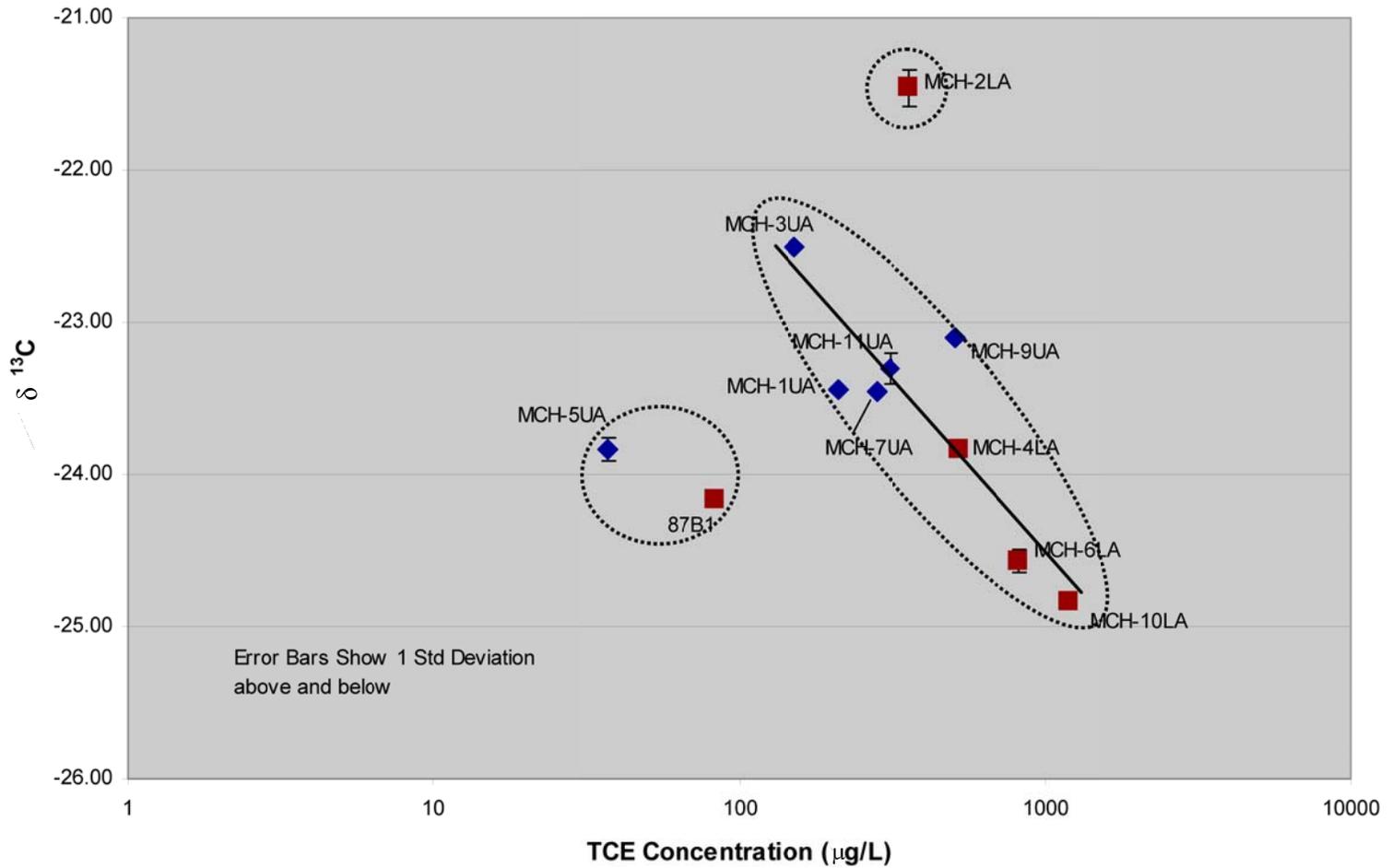
GROUNDWATER MONITORING WELL INSTALLATION AND
 SAMPLING REPORT FOR ORION PARK HOUSING AREA
 FIGURE F-5

$\delta^{37}\text{Cl}$ vs TCE, AUGUST 2005

MOFFETT COMMUNITY HOUSING
 MOFFETT FIELD, CA

REVISION: 0
 AUTHOR: KLD
 FILE : 061004f5.DWG





LEGEND

◆ Upper A Aquifer Well

■ Lower A Aquifer Well

$$\delta^{13}C = (R_{C\text{-sample}}/R_{C\text{-standard}} - 1) \times 1,000$$

$$R_C = {}^{13}C/{}^{12}C$$

C-standard = Vienna Pee-Dee Belemnite

µg/L-micrograms per liter

C - carbon

TCE - trichloroethene

Std- Standard

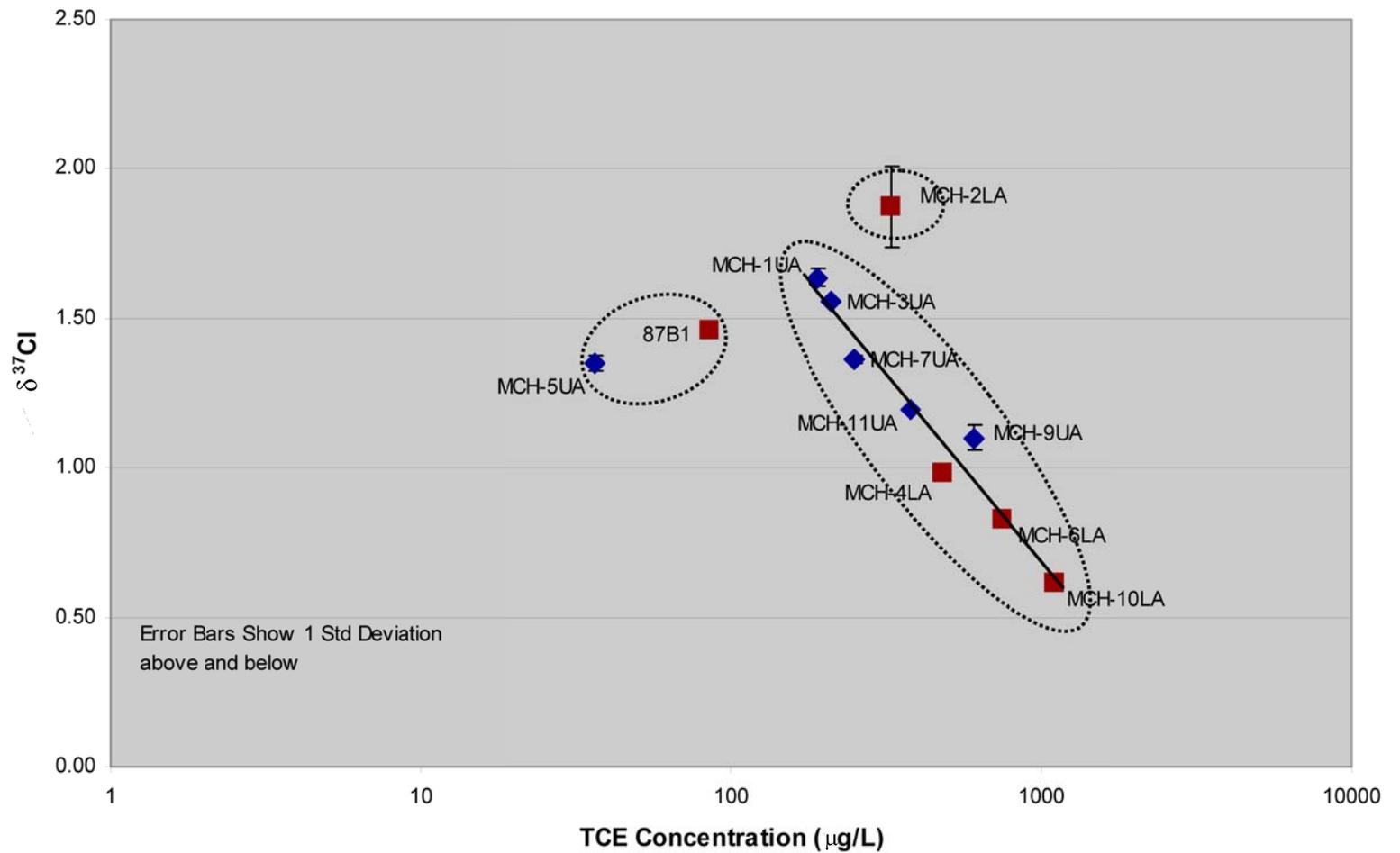
BASE REALIGNMENT AND CLOSURE
PROGRAM MANAGEMENT OFFICE WEST
SAN DIEGO, CA

GROUNDWATER MONITORING WELL INSTALLATION AND
SAMPLING REPORT FOR ORION PARK HOUSING AREA
FIGURE F-6

δ¹³C vs TCE, AUGUST 2005
MOFFETT COMMUNITY HOUSING
MOFFETT FIELD, CA

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LEGEND

◆ Upper A Aquifer Well

■ Lower A Aquifer Well

$$\delta^{37}\text{Cl} = (R_{\text{Cl-sample}}/R_{\text{Cl-standard}} - 1) \times 1,000$$

$$R_{\text{Cl}} = {}^{37}\text{Cl}/{}^{35}\text{Cl}$$

Cl-standard = Standard Mean Ocean Chloride

µg/L - micrograms per liter

Cl - chlorine

TCE - trichloroethene

Std - Standard

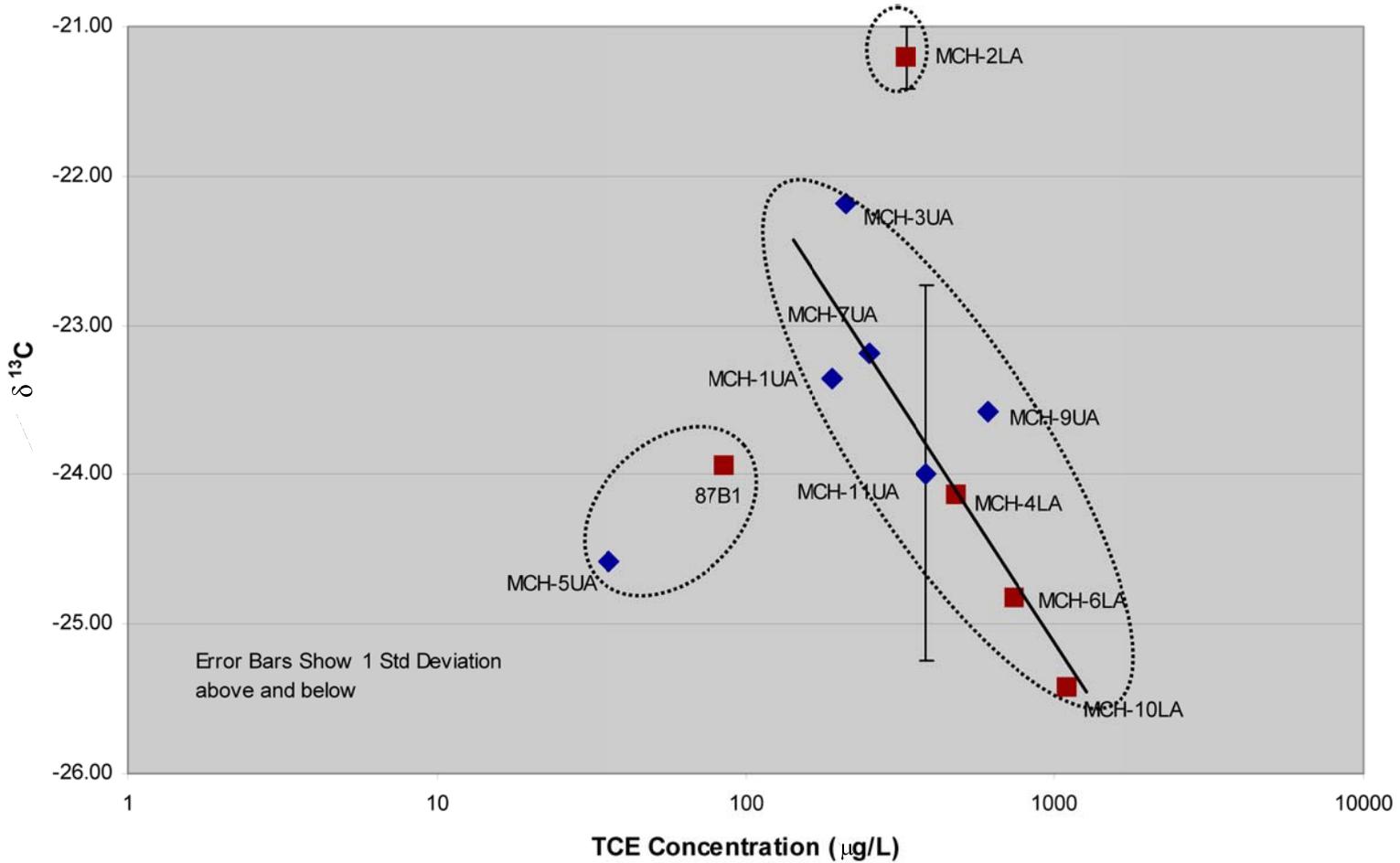
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GROUNDWATER MONITORING WELL INSTALLATION AND
SAMPLING REPORT FOR ORION PARK HOUSING AREA
FIGURE F-7

δ³⁷Cl vs TCE, DECEMBER 2005
MOFFETT COMMUNITY HOUSING
MOFFETT FIELD, CA

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Error Bars Show 1 Std Deviation above and below

LEGEND

◆ Upper A Aquifer Well

■ Lower A Aquifer Well

$$\delta^{13}C = (R_{C\text{-sample}}/R_{C\text{-standard}} - 1) \times 1,000$$

$$R_C = {}^{13}C/{}^{12}C$$

C-standard = Vienna Pee-Dee Belemnite

µg/L-micrograms per liter

C - carbon

TCE - trichloroethene

Std- Standard

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GROUNDWATER MONITORING WELL INSTALLATION AND
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FIGURE F-8

δ¹³C vs TCE, DECEMBER 2005
MOFFETT COMMUNITY HOUSING
MOFFETT FIELD, CA

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