APPENDIX H

STATISTICAL AND GEOCHEMICAL EVALUATION OF SITE METALS DATA

Technical Memorandum

From: Paul F. Goetchius, DVM
Senior Toxicologist
Risk Management Services

To: Fort McClellan (FTMC) Risk Assessment File

Date: 24 June 2003

Subject: ***Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC: Revision 2.***

Note: Early Shaw E & I experience with the previously agreed-upon 28 April 2003 memo describing the protocol for background screening revealed considerable inefficiency arising from characteristics of the background data sets and occasionally the site data sets. Primary among these is a high percentage of non-detects, which renders the statistical tests described in Tier 2 invalid. Conversations between Shaw E & I and EPA Region IV led to revision of the Tier 2 statistical procedure whereby comparison with the 95th upper tolerance limit could be substituted for the previously designated tests under certain conditions.

The purpose of this memo is to describe the protocol for background screening – comparing site data with background data – for the purpose of selecting site-related chemicals. This memo is intended to reflect agreement reached between the USACE (via Shaw E & I) and EPA Region IV during informal discussion on 24 to 26 March 2003, as amended by further conversations between Shaw E & I and EPA Region IV. Background screening is part of the chemical of potential concern (COPC) or chemical of potential ecological concern (COPEC) selection step of a risk assessment.

Background screening will be performed as a multi-tiered process as follows:

Tier 1: *(Tier 1 remains unchanged from the 28 April 2003 memo.)* The maximum detected concentration (MDC) of site data is compared with the background screening criterion (BSC). Chemicals for which the MDC of site data does not exceed the BSC are considered to be present at background concentrations, are not selected as site-related chemicals and are not considered further in the risk assessment. Chemicals for which the MDC of site data exceeds the BSC are carried forward to Tier 2.

Tier 2: Tier 2 is performed in two steps: (a) The Slippage test is performed as the preferred high value test. In those cases where the Slippage test is inappropriate, comparison of site data with the background 95 UTL (or 95th percentile for background data sets for which estimation of a UTL is inappropriate) is performed instead of the Slippage test. (b) The Wilcoxon Rank Sum test (WRST) is performed. In those cases where the WRST cannot be performed (generally due to a large number of non-detects in the background or site data set), comparison of site data with the

background UTL is performed as described above. Metals that "fail" any of the statistical tests that were performed are evaluated under Tier 3.

Tier 3: *(Tier 3 remains unchanged from the 28 April memo.)* Tier 3 consists of a geochemical evaluation to determine whether concentrations of site metals are naturally occurring or elevated due to contamination. Geochemical evaluations are based on the natural association between a trace element and one or more specific soil-forming minerals that concentrate that trace element. The correlation of the trace element of interest with a major element representing the abundance of the specific mineral that concentrates the trace element is evaluated. The selection of the major reference element is dependent on a number of general and site-specific factors as discussed below.

Some elements, under certain environmental conditions, display exclusive associations with specific reference elements. For instance, in oxic, neutral-pH soils, arsenic, selenium, and vanadium are almost exclusively associated with iron oxides, so iron is usually used as a reference element for these trace elements (Bowell, 1994; Schiff and Weisberg, 1997). The reason for this association is well understood, and is based on aqueous speciation and surface chemistry effects. These three elements are present in oxic soil pore fluid as negatively charged oxyanions ($HAsO_4^{-2}$, $HSeO_3^-$, $H_2VO_4^-$) (Pourbaix, 1974; EPRI, 1986; Brookins, 1988). Iron oxides maintain a positive surface charge that strongly attracts these oxyanions, resulting in the observed linear correlations (Bowell, 1994).

Cadmium, nickel, lead, and zinc exist in the pore fluid of most soils as positively charged divalent cations (Cd^{+2}, Ni^{+2}, Pb^{+2}, Zn^{+2}) (Brookins, 1988; Pourbaix, 1974). These trace elements have a strong affinity to adsorb on clay minerals which maintain a negative surface charge (EPRI, 1984). These elements are usually evaluated against aluminum, which is a major component of all clay minerals.

Chromium can be present in soil pore fluid as a mixture of aqueous species with different charges such as $Cr(OH)_2^+$, $Cr(OH)_3^o$, and $Cr(OH)_4^-$, depending on the pH of the pore fluid (EPRI, 1984). The positive, neutral, and negative charges on these species result in the distribution of chromium on several different types of sorptive surfaces, including clay and iron oxide minerals. Higher soil pH conditions will favor the anionic Cr species which adsorb on iron oxides, and lower soil pH conditions will favor the cationic Cr species which preferentially adsorb on clay minerals.

Manganese oxides have a specific affinity to adsorb barium, cobalt, and lead (Kabata-Pendias, 2001). In most soils, the manganese concentrations are too low for it to form discrete manganese oxide minerals. However, in oxic, manganese-rich soils, minerals such as pyrolusite (MnO_2) and nsutite ($MnO_{1.9}$) will form that strongly adsorb Ba, Co, and Pb. Under reducing, low CO_2 conditions, the minerals MnO•OH, Mn_2O_3 and Mn_3O_4 will form, which also concentrate these trace elements. Under reducing, high CO_2 conditions however, Mn will be present as rhodochrosite ($MnCO_3$) which does not have as strong adsorptive properties as the Mn-oxides (EPRI, 1984).

Soils that contain fragments of limestone often show linear correlations between barium, cadmium, cobalt, nickel, strontium, lead, and zinc versus calcium. This is because these divalent metals readily substitute for calcium in calcite ($CaCO_3$) and dolomite [$(Ca,Mg)CO_3$], which are the major minerals present in limestone. This association is also common in arid regions where the divalent metals co-precipitate with calcite and gypsum ($CaSO_4 \cdot 2H_2O$) in caliche horizons.

Arkosic soils that contain unweathered fragments of feldspar have very different trace/major element associations, reflecting the mineralogy of the primary igneous or metamorphic source material. For instance, beryllium is associated with alkali feldspars which all contain sodium, potassium and aluminum, so the correlations of beryllium versus those major elements would be evaluated.

Total organic carbon is a good reference element for mercury, which has a strong affinity for adsorption on natural organic material. Mercury often shows better correlations with total organic carbon than with inorganic reference elements.

In reducing environments such as swamps, bogs, and wetlands where organic content is high, anaerobic sulfate-reducing conditions can become established. Under these conditions, trace elements such as arsenic, cadmium, nickel, lead, and zinc will co-precipitate with iron as sulfide minerals. These trace metals in this environment would be expected to be correlated with iron and sulfide in soil samples.

Care must be taken in the selection of reference elements to ensure that those elements are themselves not directly or indirectly impacted by contamination. Aluminum is usually a good reference element because it is not sensitive to redox conditions, and direct aluminum contamination is rare. A further advantage of aluminum is its low solubility over the neutral pH range, but it does become soluble at pH conditions below 4 and above 9. The release of strong acids or bases will leach aluminum from soil and solubilize aluminum in groundwater, so evaluation of the pH conditions is important.

Examining the correlation between iron versus aluminum in soil is an important tool in geochemical evaluations. Both elements tend to concentrate in the finer grain size fractions as oxide and clay minerals, respectively. Concentrations of iron and aluminum may vary from sample to sample by orders of magnitude reflecting differences in grain size, but they are usually present at a fixed ratio. Site samples that plot off of the trend established by the background samples and exhibit anomalously high Fe/Al ratios, may have some excess component of iron, suggesting contamination from rust, machine shop sweepings, ferric chloride sludge, etc. If iron contamination is identified in some samples, then those samples should be identified as such and removed from the evaluation, or an alternate reference element should be selected.

Iron and manganese in groundwater are subject to reductive dissolution effects which should be evaluated before they are used as reference elements. The release of organic contaminants such as hydrocarbon fuels or chlorinated solvents can establish local reducing environments caused by anaerobic microbial degradation of the organic compounds. The establishment of local reducing conditions can drive the dissolution of iron and manganese oxides, which become soluble as the redox potential drops below a threshold value. Dissolution of these oxide minerals can mobilize the trace elements that were adsorbed on the oxide surfaces, which is a process termed "reductive dissolution." Several investigations have documented the mobilization of arsenic, selenium, and other trace elements under locally reducing redox conditions (Sullivan and Aller, 1996; Nickson, et al., 2000; Belzile, et al., 2000).

Evidence for reductive dissolution would be a correlation between elevated trace elements (arsenic, selenium, and vanadium in particular) versus lower redox conditions. Low redox conditions can be identified in groundwater by local depressions in oxidation-reduction potential or dissolved oxygen measurements, or the presence of reducing gases such as hydrogen, methane, ethane, or ethene. Anaerobic microbes can also reduce sulfate to sulfide and nitrate to ammonia, resulting in local depressions in sulfate and nitrate concentrations, and local detections of sulfide and ammonia. In areas impacted by chlorinated solvents, additional evidence for the establishment of anaerobic reducing conditions is the presence of dichloroethene and/or vinyl chloride, which are reductive dechlorination products resulting from the microbial degradation of trichloroethene or tetrachloroethene under anaerobic conditions.

An additional technique that is used to identify the presence of local reducing conditions in groundwater is a correlation plot of iron versus aluminum. These two elements are usually highly correlated in oxic groundwater because they are both insoluble and tend to be present as suspended particulates at a fairly constant ratio. If local reducing conditions are present, then samples from those areas will have a higher Fe/Al ratio than oxic areas because iron becomes soluble under reducing conditions but aluminum does not. Results can be independently confirmed by evaluating manganese versus aluminum because manganese and iron have similar redox behavior.

All available laboratory and field data are examined to determine if there is a local reducing environment that is driving the dissolution of iron and manganese oxides, as this effect may cause erroneous geochemical evaluation results if this process is not taken into account. Data are also evaluated for pH anomalies and the presence of organic contaminants that may alter the geochemical environment.

References

Belzile, N., Y. W. Chen, and R. Xu, 2000, "Early Diagenetic Behavior of Selenium in Freshwater Sediments," ***Applied Geochemistry***, Vol. 15, pp. 1439-1454.

Bowell, R. J., 1994, "Sorption of Arsenic by Iron Oxides and Oxyhydroxides in Soils," ***Applied Geochemistry***, Vol. 9, pp. 279-286.

Brookins, D. G., 1988, ***Eh-pH Diagrams for Geochemistry***, Springer-Verlag.

EPRI, 1984, ***Chemical Attenuation Rates, Coefficients, and Constants in Leachate Migration, Volume 1: A Critical Review***, Electric Power Research Institute, EPRI EA-3356, Palo Alto, California.

EPRI, 1986, ***Speciation of Selenium and Arsenic in Natural Waters and Sediments, Volume 2: Arsenic Speciation***, Electric Power Research Institute, EPRI EA-4641, Palo Alto, California.

Kabata-Pendias, A., 2001, ***Trace Elements in Soils and Plants***, Third Edition, CRC Press.

Nickson, R. T., J. M. McArthur, P. Ravenscroft, W. G. Burgess, and K. M. Ahmed, 2000, "Mechanism of Arsenic Release to Groundwater, Bangladesh and West Bengal," ***Applied Geochemistry***, Vol. 15, pp. 403-413.

Pourbaix, 1974, ***Atlas of Electrochemical Equilibria in Solutions***, National Association of Corrosion Engineers, Houston, Texas.

Science Applications International Corporation (SAIC), 1998, ***Final Background Metals Survey Report***, prepared for U.S. Army Corps of Engineers, Mobile District, July.

Schiff, K. and S. B. Weisberg, 1997, "Iron as a Reference Element for Determining Trace Metal Enrichment in California Coastal Shelf Sediments," *in*: S. Weisberg, C. Francisco, and D. Hallock, (eds.), ***Southern California Coastal Water Research Project Annual Report 1995-96***, pp. 68-78.

Sullivan, K. A. and R. C. Aller, 1996, "Diagenetic Cycling of Arsenic in Amazon Shelf Sediments," ***Geochimica et Cosmochimica Acta***, Vol. 60, No. 9, pp. 1465-1477.

STATISTICAL
(TIERS 1 AND 2)

Statistical Comparison of Site and Background Data
Training Area T-5 Sites
Fort McClellan, Alabama

1.0 Introduction

This report provides the Tier 1 and Tier 2 site-to-background comparison results for the Training Area T-5 Sites at Fort McClellan located in Calhoun County, Alabama. Tier 1 and Tier 2 evaluations have been performed for target analyte list (TAL) metals in the surface soil, subsurface soil, groundwater, sediment, and surface water data sets. In the first step of the comparison, the maximum detected concentration (MDC) of each element is compared to two times the arithmetic mean of the background data (SAIC, 1998). Any metal that has an MDC greater than the background screening value is carried forward for Tier 2 evaluation, which includes the Slippage Test and the Wilcoxon Rank Sum Test (WRS).

The methodology and results of the Tier 1 and Tier 2 comparisons are summarized in Tables 1 through 5, and described in more detail in the following sections. Site data used in the site-to-background comparison include 53 surface soil samples (0 to 1 foot below ground surface [bgs]), 37 subsurface soil samples (1 to 12 feet bgs), 74 groundwater samples, 5 sediment samples, and 5 surface water samples that were collected at the site. It is noted that the soil data set for this evaluation includes 5 surface soil samples and 5 subsurface soil samples from adjacent Parcel 232Q-X.

Background distributions and screening values have been established for TAL metals in surface soil, subsurface soil, groundwater, sediment, and surface water for Fort McClellan (SAIC, 1998).

2.0 Comparison Methodology

This section describes the statistical techniques that were employed in the Training Area T-5 Sites site-to-background comparisons.

2.1 Statistical Procedures

Contamination can be caused by a variety of processes that yield different spatial distributions of elevated contaminant concentrations. Slight but pervasive contamination can occur from non-point-source releases, and can result in slight increases in contaminant concentrations in a large

Table 1

Summary of Site to Background Comparison for Surface Soil
Training Area T-5 Sites
Fort McClellan, Alabama

Metal	Frequency of Detection	Tier 1 Evaluation[a]	Slippage Test[b]	Wilcoxon Rank Sum Test[b]	Hot Measurement Test[b,c]	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	53 / 53	Failed	Passed	Failed	NA	Yes
Antimony	0 / 53	NA	NA	NA	NA	
Arsenic	53 / 53	Failed	Passed	Failed	NA	Yes
Barium	53 / 53	Failed	Passed	Failed	NA	Yes
Beryllium	34 / 53	Failed	Failed	Failed	NA	Yes
Cadmium	5 / 53	Failed	NA[d]	NA[e]	Failed	Yes
Calcium	51 / 53	Failed	Passed	Failed	NA	Yes
Chromium	53 / 53	Failed	Passed	Failed	NA	Yes
Cobalt	51 / 53	Failed	Passed	Failed	NA	Yes
Copper	53 / 53	Failed	Failed	Failed	NA	Yes
Iron	53 / 53	Failed	Passed	Failed	NA	Yes
Lead	53 / 53	Failed	Passed	Passed	NA	
Magnesium	53 / 53	Failed	Passed	Failed	NA	Yes
Manganese	53 / 53	Failed	Passed	Passed	NA	
Mercury	20 / 52	Failed	Passed	NA[e]	Passed	
Nickel	49 / 53	Failed	Passed	Failed	NA	Yes
Potassium	52 / 53	Failed	Passed	Failed	NA	Yes
Selenium	15 / 53	Failed	Failed	NA[e]	Failed	Yes
Silver	1 / 53	Failed	Passed	NA[e]	Failed	Yes
Sodium	15 / 53	Passed	NA	NA	NA	
Thallium	2 / 53	Passed	NA	NA	NA	
Vanadium	53 / 53	Failed	Passed	Failed	NA	Yes
Zinc	53 / 53	Failed	Passed	Failed	NA	Yes

NA = not applicable; MDC = maximum detected concentration

[a] Tier 1 evaluation (site MDC compared to 2 x the background mean) per *Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2,* Technical Memorandum, 24 June 2003 by Paul Goetchius.

[b] Part of Tier 2 evaluation per the above referenced memo.

[c] Performed only when the Slippage test and/or WRS test cannot be performed.

[d] Slippage test is not performed on data sets for which the maximum background value is a nondetect.

[e] WRS test is not performed on data sets containing 50% or more nondetects.

Table 2

Summary of Site to Background Comparison for Subsurface Soil
Training Area T-5 Sites
Fort McClellan, Alabama

Metal	Frequency of Detection	Tier 1 Evaluation[a]	Slippage Test[b]	Wilcoxon Rank Sum Test[b]	Hot Measurement Test[b,c]	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	37 / 37	Failed	Failed	Failed	NA	Yes
Antimony	3 / 37	Failed	NA[d]	NA[e]	Passed	
Arsenic	37 / 37	Failed	Passed	Failed	NA	Yes
Barium	37 / 37	Failed	Passed	Failed	NA	Yes
Beryllium	24 / 37	Failed	Passed	Failed	NA	Yes
Cadmium	0 / 37	NA	NA	NA	NA	
Calcium	32 / 37	Failed	Passed	Failed	NA	Yes
Chromium	37 / 37	Failed	Passed	Failed	NA	Yes
Cobalt	35 / 37	Failed	Passed	Failed	NA	Yes
Copper	37 / 37	Failed	Passed	Failed	NA	Yes
Iron	37 / 37	Failed	Failed	Failed	NA	Yes
Lead	37 / 37	Failed	Passed	Failed	NA	Yes
Magnesium	37 / 37	Failed	Passed	Failed	NA	Yes
Manganese	37 / 37	Failed	Passed	Failed	NA	Yes
Mercury	16 / 37	Failed	Passed	NA[e]	Failed	Yes
Nickel	36 / 37	Failed	Passed	Failed	NA	Yes
Potassium	35 / 37	Failed	Passed	Failed	NA	Yes
Selenium	15 / 37	Failed	NA[d]	NA[e]	Failed	Yes
Silver	2 / 37	Failed	NA[d]	NA[e]	Failed	Yes
Sodium	13 / 37	Passed	NA	NA	NA	
Thallium	6 / 37	Failed	Passed	NA[e]	Passed	
Vanadium	37 / 37	Failed	Passed	Failed	NA	Yes
Zinc	37 / 37	Failed	Passed	Failed	NA	Yes

NA = not applicable; MDC = maximum detected concentration

[a] Tier 1 evaluation (site MDC compared to 2 x the background mean) per *Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2*, Technical Memorandum, 24 June 2003 by Paul Goetchius.

[b] Part of Tier 2 evaluation per the above referenced memo.

[c] Performed only when the Slippage test and/or WRS test cannot be performed.

[d] Slippage test is not performed on data sets for which the maximum background value is a nondetect.

[e] WRS test is not performed on data sets containing 50% or more nondetects.

Table 3

Summary of Site to Background Comparison for Groundwater
Training Area T-5 Sites
Fort McClellan, Alabama

Metal	Frequency of Detection	Tier 1 Evaluation[a]	Slippage Test[b]	Wilcoxon Rank Sum Test[b]	Hot Measurement Test[b,c]	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	42 / 74	Failed	Passed	Passed	NA	
Antimony	0 / 74	NA	NA	NA	NA	
Arsenic	8 / 74	Failed	Passed	NA[e]	Passed	
Barium	72 / 74	Failed	Passed	Failed	NA	Yes
Beryllium	1 / 74	Failed	NA[d]	NA[e]	Failed	Yes
Cadmium	1 / 74	Failed	NA[d]	NA[e]	Passed	
Calcium	67 / 74	Failed	Passed	Failed	NA	Yes
Chromium	5 / 74	Failed	NA[d]	NA[e]	Failed	Yes
Cobalt	10 / 74	Failed	Passed	NA[e]	Failed	Yes
Copper	5 / 74	Failed	Passed	NA[e]	Passed	
Iron	68 / 74	Failed	Passed	Passed	NA	
Lead	8 / 74	Failed	NA[d]	NA[e]	Failed	Yes
Magnesium	55 / 74	Passed	NA	NA	NA	
Manganese	70 / 74	Failed	Passed	Failed	NA	Yes
Mercury	1 / 74	Passed	NA	NA	NA	
Nickel	9 / 74	Passed	NA	NA	NA	
Potassium	20 / 74	Passed	NA	NA	NA	
Selenium	1 / 74	Passed	NA	NA	NA	
Silver	0 / 74	NA	NA	NA	NA	
Sodium	26 / 74	Failed	Passed	NA[e]	Passed	
Thallium	1 / 74	Failed	NA[d]	NA[e]	Passed	
Vanadium	6 / 74	Failed	NA[d]	NA[e]	Failed	Yes
Zinc	11 / 74	Failed	Passed	NA[e]	Passed	

NA = not applicable; MDC = maximum detected concentration

[a] Tier 1 evaluation (site MDC compared to 2 x the background mean) per *Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2,* Technical Memorandum, 24 June 2003 by Paul Goetchius.

[b] Part of Tier 2 evaluation per the above referenced memo.

[c] Performed only when the Slippage test and/or WRS test cannot be performed.

[d] Slippage test is not performed on data sets for which the maximum background value is a nondetect.

[e] WRS test is not performed on data sets containing 50% or more nondetects.

Table 4

Summary of Site to Background Comparison for Sediment
Training Area T-5 Sites
Fort McClellan, Alabama

Metal	Frequency of Detection	Tier 1 Evaluation[a]	Slippage Test[b]	Wilcoxon Rank Sum Test[b]	Hot Measurement Test[b,c]	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	5 / 5	Passed	NA	NA	NA	
Antimony	0 / 5	NA	NA	NA	NA	
Arsenic	5 / 5	Passed	NA	NA	NA	
Barium	5 / 5	Passed	NA	NA	NA	
Beryllium	1 / 5	Passed	NA	NA	NA	
Cadmium	3 / 5	Failed	Passed	Failed	NA	Yes
Calcium	5 / 5	Passed	NA	NA	NA	
Chromium	5 / 5	Failed	Passed	Failed	NA	Yes
Cobalt	4 / 5	Failed	Passed	Passed	NA	
Copper	5 / 5	Failed	Passed	Failed	NA	Yes
Iron	5 / 5	Passed	NA	NA	NA	
Lead	5 / 5	Passed	NA	NA	NA	
Magnesium	5 / 5	Passed	NA	NA	NA	
Manganese	5 / 5	Passed	NA	NA	NA	
Mercury	0 / 5	NA	NA	NA	NA	
Nickel	5 / 5	Passed	NA	NA	NA	
Potassium	4 / 5	Passed	NA	NA	NA	
Selenium	0 / 5	NA	NA	NA	NA	
Silver	0 / 5	NA	NA	NA	NA	
Sodium	2 / 5	Passed	NA	NA	NA	
Thallium	0 / 5	NA	NA	NA	NA	
Vanadium	5 / 5	Passed	NA	NA	NA	
Zinc	5 / 5	Failed	Passed	Failed	NA	Yes

NA = not applicable; MDC = maximum detected concentration

[a] Tier 1 evaluation (site MDC compared to 2 x the background mean) per *Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2,* Technical Memorandum, 24 June 2003 by Paul Goetchius.

[b] Part of Tier 2 evaluation per the above referenced memo.

[c] Performed only when the Slippage test and/or WRS test cannot be performed.

Table 5

Summary of Site to Background Comparison for Surface Water
Training Area T-5 Sites
Fort McClellan, Alabama

Metal	Frequency of Detection	Tier 1 Evaluation[a]	Slippage Test[b]	Wilcoxon Rank Sum Test[b]	Hot Measurement Test[b,c]	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	4 / 5	Passed	NA	NA	NA	
Antimony	0 / 5	NA	NA	NA	NA	
Arsenic	0 / 5	NA	NA	NA	NA	
Barium	5 / 5	Passed	NA	NA	NA	
Beryllium	0 / 5	NA	NA	NA	NA	
Cadmium	0 / 5	NA	NA	NA	NA	
Calcium	5 / 5	Passed	NA	NA	NA	
Chromium	1 / 5	Failed	NA[d]	NA[e]	Passed	
Cobalt	0 / 5	NA	NA	NA	NA	
Copper	0 / 5	NA	NA	NA	NA	
Iron	4 / 5	Passed	NA	NA	NA	
Lead	0 / 5	NA	NA	NA	NA	
Magnesium	5 / 5	Passed	NA	NA	NA	
Manganese	5 / 5	Passed	NA	NA	NA	
Mercury	1 / 5	Failed	NA[d]	NA[e]	Failed	Yes
Nickel	0 / 5	NA	NA	NA	NA	
Potassium	0 / 5	NA	NA	NA	NA	
Selenium	0 / 5	NA	NA	NA	NA	
Silver	0 / 5	NA	NA	NA	NA	
Sodium	4 / 5	Passed	NA	NA	NA	
Thallium	0 / 5	NA	NA	NA	NA	
Vanadium	0 / 5	NA	NA	NA	NA	
Zinc	0 / 5	NA	NA	NA	NA	

NA = not applicable; MDC = maximum detected concentration

[a] Tier 1 evaluation (site MDC compared to 2 x the background mean) per *Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2,* Technical Memorandum, 24 June 2003 by Paul Goetchius.

[b] Part of Tier 2 evaluation per the above referenced memo.

[c] Performed only when the Slippage test and/or WRS test cannot be performed.

[d] Slippage test is not performed on data sets for which the maximum background value is a nondetect.

[e] WRS test is not performed on data sets containing 50% or more nondetects.

percentage of samples. Localized, or "hot-spot," contamination can result in elevated concentrations in a small percentage of the total number of site samples. No single two-sample statistical comparison test is sensitive to both of these modes of contamination. For this reason, the use of several simultaneous tests is recommended for a valid and complete comparison of site versus background distributions (U.S. Environmental Protection Agency [EPA], 1989, 1992, and 1994; U.S. Navy, 2002).

Analytes that fail the Tier 1 and Tier 2 comparisons are subject to a geochemical evaluation to determine if the elevated concentrations are due to natural processes or if they represent potential contamination.

2.1.1 Tier 1

In this step of the background screening process, the maximum detected concentration (MDC) of the site data set is compared to the background screening value of two times the background mean (SAIC, 1998). Elements for which the site MDC does not exceed the background screening value are considered to be present at background concentrations, and are not considered site-related chemicals. Elements for which the site MDC exceeds the background screening value undergo further evaluation (Tier 2).

2.1.2 Tier 2

Slippage Test. The nonparametric Slippage test is designed to detect a difference between the upper tails of two distributions, and has been recommended for use in site-to-background comparisons to identify potential localized, or hot-spot, contamination (U.S. Navy, 2002). The test is performed by counting the number (K) of detected concentrations in the site data set that exceed the maximum background measurement, and then comparing this number to a critical value (K_c), which is a function of the number of background samples and the number of site samples. If $K > K_c$, then potential contamination is indicated and the analyte will be subjected to geochemical evaluation. If K K_c, then localized contamination is not suspected.

Critical values tables for site and background data sets up to size $n = 50$ are provided in U.S. Navy (2002). Critical values for larger data sets are calculated using the test statistic provided in Rosenbaum (1954). In this report, the Slippage test is performed at the 95 percent confidence level. The test cannot be performed if the maximum background value is a nondetect, because the actual concentration in that sample is unknown.

Wilcoxon Rank Sum Test. The nonparametric WRS test is designed to detect a difference between the medians of two data sets, and has been recommended for use in site-to-background comparisons to identify slight but pervasive contamination (EPA, 2000; U.S. Navy, 2002). In this report, the WRS test is performed when the site and background data sets each contain less than 50 percent nondetects (i.e., measurements reported as not detected below the laboratory reporting limit). The WRS test will not be performed on data sets containing 50 percent or more nondetects. The medians of such data sets are unknown, and hence the test results would lack sufficient power to yield reliable results.

The WRS test compares two data sets of size n and m ($n > m$), and tests the null hypothesis that the samples were drawn from populations with distributions having the same medians. To perform the test, the two sets of observations are pooled and arranged in order from smallest to largest. Each observation is assigned a rank; that is, the smallest is ranked 1, the next largest is ranked 2, and so on up to the largest observation, which is ranked $(n + m)$. If ties occur between or within samples, each one is assigned the mid-rank. Next, the sum of the ranks of smaller data set m is calculated. Then the test statistic Z is determined as follows:

$$Z = \frac{W - m(m+n+1)/2}{\sqrt{mn(m+n+1)/12}}$$

where:

W = Sum of the ranks of the smaller data set
m = Number of data points in smaller group
n = Number of data points in larger group.

This test statistic Z is used to find the two-sided significance. For instance, if the test statistic yields a probability of a Type I error (p-level) less than 0.2, then there is a statistically significant difference between the medians at the 80 percent confidence level. A Type I error involves rejecting the null hypothesis when it is true. If the p-level is greater than 0.2, then there is no reasonable justification to reject the null hypothesis at the 80 percent confidence level. It can therefore be concluded that the medians of the two data sets are similar, and it can be assumed to be drawn from the same population.

If the p-level is less than 0.2, then the medians of the two distributions are significantly different at the 80 percent confidence level. This can occur if the site data are shifted higher or lower than the background data. If the site data are shifted higher relative to background, then

contamination may be indicated, and the analyte in question will be carried on for geochemical evaluation; however, if the site data are shifted lower relative to background, then contamination is not indicated. If the p-level is greater than 0.2, then pervasive site contamination is not suspected.

Box Plots. A quick, robust graphical method recommended by the EPA to visualize and compare two or more groups of data is the box plot comparison (EPA, 1989 and 1992). These plots provide a summary view of the entire data set, including the overall location and degree of symmetry. The box encloses the central 50 percent of the data points so that the top of the box represents the 75th percentile and the bottom of the box represents the 25th percentile. The small box within the larger box represents the median of the data set. The upper whisker extends outward from the box to the maximum point and the lower whisker extends to the minimum point. Nondetect results are set equal to one-half of the reporting limit for plotting purposes.

For each analyte, box plots of site and background data are placed side by side to visually compare the distributions and qualitatively determine whether the data sets are similar or distinct. Accordingly, the box plots are a necessary adjunct to the WRS test. As described previously, the WRS test may indicate that the medians of the site and background data sets are significantly different. Examination of the box plots will confirm whether that difference is caused by site data that are shifted higher or lower relative to background.

Hot Measurement Test. The hot measurement test is performed only when the Slippage test or WRS test cannot be performed (due to a high percentage of nondetects, etc.). The hot measurement test consists of comparing each site measurement with a concentration value that is representative of the upper limit of the background distribution (EPA, 1994). Ideally, a site sample with a concentration above the background screening value would have a low probability of being a member of the background distribution, and may be an indicator of contamination. It is important to select such a background screening value carefully so that the probability of falsely identifying site samples as contaminated or uncontaminated is minimized.

The 95th upper tolerance limit (95th UTL) is recommended as a screening value for normally or lognormally distributed analytes and the 95th percentile is recommended as a screening value for nonparametrically distributed analytes (EPA, 1989, 1992, and 1994). Site samples with concentrations above these values are not necessarily contaminated, but should be considered suspect. To perform the test, each analyte's site MDC is compared to the background 95th UTL or 95th percentile, in accordance with the type of background distribution. If the site MDC

exceeds the background screening value, then that analyte will undergo a geochemical evaluation. If the MDC does not exceed the background threshold value, then hot-spot contamination is not indicated.

2.1.3 Geochemical Evaluation

If an analyte fails either of the statistical tests described above then a geochemical evaluation is performed to determine if the elevated concentrations are caused by natural processes. The methodology and results of the geochemical evaluation are provided in Appendix H.

3.0 Results of the Site-to-Background Comparisons

This section presents the results of the site-to-background comparisons for 23 TAL metals in the Area T-5 surface soil, subsurface soil, groundwater, sediment, and surface water samples. The WRS test results with corresponding box plots are provided in Attachment 1. Tables 1 through 5 summarize the Tier 1 and Tier 2 test results for each media as discussed in the following sections.

3.1 Surface Soil

Twenty-three TAL metals were evaluated in the Area T-5 surface soil. Antimony had no detected concentration in surface soil site samples and is not considered any further. Two metals (sodium and thallium) have no detected concentrations above their respective background screening values, and thus they pass the Tier 1 evaluation. These metals are not discussed further. The remaining twenty metals are carried forward for Tier 2 evaluation.

Table 1 summarizes the surface soil statistical site-to-background comparison results. Box plots are provided in Attachment 1.

Aluminum

Tier 1 Evaluation

Seventeen site samples exceed the background screening value of 16,306 milligrams per kilogram (mg/kg).

Slippage Test

K_c for aluminum is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, aluminum passes the Slippage Test.

WRS Test
The WRS test p-level of < 0.001 indicates significant difference between the site and background distributions.

Box Plot
Box plots for the site and background data sets are provided in Figure 1-1. The site minimum and median are higher than the corresponding background values. The site maximum is lower than the background maximum.

Conclusion
Because aluminum in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Arsenic

Tier 1 Evaluation
Four site samples exceed the background screening value of 13.73 mg/kg.

Slippage Test
K_c for arsenic is 4, and no arsenic samples exceed the maximum background measurement (K=0). Because $K < K_c$, arsenic passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-2).

Conclusion
Because arsenic in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Barium

Tier 1 Evaluation
Eight site samples exceed the background screening value of 123.94 mg/kg.

Slippage Test
K_c for barium is four, and one site sample exceeds the maximum background measurement (K=1). Because $K < K_c$, barium passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates significant difference between the site and background distributions.

Box Plot
The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-3).

Conclusion
Because barium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Beryllium

Tier 1 Evaluation
Thirteen of the 34 detected concentrations exceed the background screening value of 0.8 mg/kg.

Slippage Test
K_c for beryllium is five, and nine site samples exceed the maximum background measurement (K=9). Because $K > K_c$, beryllium fails the Slippage Test.

WRS Test
The p-level of < 0.001 indicates significant difference between the site and background distributions.

Box Plot
The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-4).

Conclusion
Because beryllium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Cadmium

Tier 1 Evaluation
All five detected concentrations exceed the background screening value of 0.29 mg/kg. The remaining forty-eight samples are nondetects with reporting limits that are above the background screening value.

Slippage Test
The maximum background value for cadmium is a nondetect, so the Slippage test could not be performed.

WRS Test
The WRS test was not performed because the site data set contains 91 percent nondetects.

Box Plot
The shape and location of the site box plot are defined by the high percentage of nondetects (91 percent) and the replacement values of one-half the reporting limits (Figure 1-5). The site minimum, median, and maximum are higher than the corresponding background values.

Conclusion
Because cadmium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Calcium

Tier 1 Evaluation
Nine site samples exceed the background screening value of 1,723 mg/kg.

Slippage Test
K_c for calcium is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, calcium passes the Slippage Test.

WRS Test
The p-level of 0.01 indicates weak agreement between the site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-6).

Conclusion
Because calcium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Chromium

Tier 1 Evaluation
Three site samples exceed the background screening value of 37.04 mg/kg.

Slippage Test
K_c for chromium is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, chromium passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-7).

Conclusion
Because chromium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Cobalt

Tier 1 Evaluation
Seven site samples exceed the background screening value of 15.15 mg/kg.

Slippage Test
K_c for cobalt is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, cobalt passes the Slippage Test.

WRS Test
The p-level of 0.002 indicates poor agreement between the site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-8).

Conclusion
Because cobalt in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Copper

Tier 1 Evaluation
Twenty-six site samples exceed the background screening value of 12.71 mg/kg.

Slippage Test
K_c of copper is four, and ten site samples exceed the maximum background measurement (K=10). Because $K > K_c$ copper fails the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-9).

Conclusion
Because copper in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Iron

Tier 1 Evaluation
Seven site samples exceed the background screening value of 34,154 mg/kg.

Slippage Test
K_c for iron is four, and one site sample exceeds the maximum background measurement (K=1). Because $K < K_c$, iron passes the Slippage Test.

WRS Test
The p-level of 0.002 indicates poor agreement between the site and background distributions.

Box Plot
The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-10).

Conclusion
Because iron in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Lead

Tier 1 Evaluation
Six site samples exceed the background screening value of 40.05 mg/kg.

Slippage Test
K_c for lead is 4, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, lead passes the Slippage Test.

WRS Test
The p-level of 0.436 indicates good agreement between the site and background distributions.

Box Plot
The site minimum is higher than the background minimum, and the site median and maximum are lower than the corresponding background values (Figure 1-11).

Conclusion
Because lead in surface soil is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

Magnesium

Tier 1 Evaluation
Ten site samples exceed the background screening value of 1,033 mg/kg.

Slippage Test
K_c for magnesium is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, magnesium passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than background maximum (Figure 1-12).

Conclusion
Because magnesium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Manganese

Tier 1 Evaluation
Four site samples exceed the background screening value of 1,579 mg/kg.

Slippage Test
K_c for manganese is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, manganese passes the Slippage Test.

WRS Test
The p-level of 0.612 indicates strong agreement between the site and background distributions.

Box Plot
The site minimum is higher than the background minimum, and the site median and maximum are lower than the corresponding background values (Figure 1-13).

Conclusion
Because manganese in surface soil is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

Mercury

Tier 1 Evaluation
Two of the twenty detected concentrations exceed the background screening value of 0.08 mg/kg. The remaining 32 samples are nondetects with reporting limits that are above the background screening value.

Slippage Test
K_c, for mercury is four, and no site samples exceed the maximum background measurement (K=0). Since $K < K_c$, mercury passes the Slippage test.

WRS Test
The WRS test was not performed because the site and background data sets contain 62 and 66 percent nondetects, respectively.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-14).

Hot Measurement Test
The site MDC of mercury does not exceed the background 95th percentile of 0.125 mg/kg.

Conclusion
Because mercury in surface soil is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

Nickel

Tier 1 Evaluation
Seventeen site samples exceed the background screening value of 10.33 mg/kg.

Slippage Test
K_c for nickel is four, and four site samples exceed the maximum background measurement (K=4). Because K K_c, nickel passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-15).

Conclusion
Because nickel in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Potassium

Tier 1 Evaluation
Eighteen site samples exceed the background screening value of 799.76 mg/kg.

Slippage Test
K_c for potassium is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, potassium passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-16).

Conclusion
Because potassium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Selenium

Tier 1 Evaluation

All fifteen detected concentrations in the site data set exceed the background screening value of 0.48 mg/kg. The remaining 38 samples are nondetects with reporting limits that are above the background screening value.

Slippage Test

K_c for selenium is four, and five site samples exceed the maximum background measurement (K=5). Because $K > K_c$, selenium fails the Slippage Test.

WRS Test

The WRS test was performed because the site and background data sets contain 72 and 99 percent nondetects, respectively.

Box Plot

The shapes and locations of the background and site box plots are defined by the high percentages of nondetects (99 and 72 percent, respectively) and the replacement values of one-half the reporting limits (Figure 1-17). The site minimum, median, and maximum are higher than the corresponding background values.

Hot Measurement Test

The site MDC of selenium exceeds the background 95th percentile of 0.563 mg/kg.

Conclusion

Because selenium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Silver

Tier 1 Evaluation

The single detected concentration exceeds the background screening value of 0.36 mg/kg. The remaining 52 samples are nondetects with reporting limits that are above the background screening value.

Slippage Test

K_c for silver is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, silver passes the Slippage Test.

WRS Test

The WRS test was not performed because the site data set contains 98 percent nondetects.

Box Plot

The shape and location of the site box plot are defined by the high percentage of nondetects (98 percent) and the replacement values of one-half the reporting limits (Figure 1-18). The site minimum, median, and maximum are higher than the corresponding background values.

Hot Measurement Test
The site MDC of silver exceeds the background 95th percentile of 0.774 mg/kg.

Conclusion
Because silver in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Vanadium

Tier 1 Evaluation
Two site samples exceed the background screening value of 58.84 mg/kg.

Slippage Test
K_c for vanadium is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, vanadium passes the Slippage Test.

WRS Test
The p-level of 0.022 indicates poor agreement between the site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-19).

Conclusion
Because vanadium in surface soil failed the statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Zinc

Tier 1 Evaluation
Twenty-two site samples exceed the background screening value of 40.64 mg/kg.

Slippage Test
K_c for zinc is four, and one site sample exceeds the maximum background measurement (K=1). Because $K < K_c$, zinc passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-20).

Conclusion
Because zinc in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

3.2 Subsurface Soil

Twenty-three TAL metals were evaluated in the Area T-5 subsurface soil data set. Cadmium had no detected concentrations in the subsurface soil site samples and is not considered any further. Sodium had no detected concentration above its respective background screening value, and thus it passes the Tier 1 evaluation. Cadmium is not discussed further. The remaining 21 metals are carried forward for Tier 2 evaluation.

Table 2 summarizes the subsurface soil statistical soil-to-background comparison results. Box plots are provided in Attachment 1.

Aluminum

Tier 1 Evaluation

Twenty-three site samples exceed the background screening value of 13,591 mg/kg.

Slippage Test

K_c for aluminum is four, and seven site samples exceed the maximum background measurement (K=7). Because $K > K_c$, aluminum fails the Slippage Test.

WRS Test

The WRS test p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-21).

Conclusion

Because aluminum in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Antimony

Tier 1 Evaluation

Three detected concentrations exceed the background screening value of 1.31 mg/kg. The remaining 34 samples are nondetects with reporting limits that are above the background screening value.

Slippage Test

The maximum background result for antimony is a nondetect, so the Slippage test could not be performed.

WRS Test

The WRS test was not performed because the site data set contains 92 percent nondetects.

Box Plot
The location and shape of the site box plot are largely defined by the high percentages of nondetects (92 percent) and the replacement values of one-half the reporting limits (Figure 1-22). The site minimum, median, and maximum are higher than the corresponding background values.

Hot Measurement Test
The site MDC of antimony does not exceed the background 95th percentile of 7.14 mg/kg.

Conclusion
Because antimony in subsurface soil is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

Arsenic

Tier 1 Evaluation
Five site samples exceed the background screening value of 18.3 mg/kg.

Slippage Test
K_c for arsenic is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, arsenic passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-23).

Conclusion
Because arsenic in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Barium

Tier 1 Evaluation
One site sample exceeds the background screening value of 233.62 mg/kg.

Slippage Test
K_c for barium is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, barium passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between site and background distributions.

Box Plot
The site minimum is slightly lower than the background minimum (Figure 1-24). The site median is higher than the background median, and the site maximum is lower than the background maximum.

Conclusion
Because barium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Beryllium

Tier 1 Evaluation
Eleven of the 24 detected concentrations exceed the background screening value of 0.86 mg/kg.

Slippage Test
K_c for beryllium is four, and three site samples exceed the maximum background measurement (K=3). Because $K < K_c$, beryllium passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-25).

Conclusion
Because beryllium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Calcium

Tier 1 Evaluation
Ten site samples exceed the background screening value of 637.17 mg/kg.

Slippage Test
K_c for calcium is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, calcium passes the Slippage Test.

WRS Test
The p-level of 0.121 indicates weak agreement between the site and background distributions.

Box Plot
The site minimum and maximum are lower than the corresponding background values, and the site median is higher than the background median (Figure 1-26).

Conclusion
Because calcium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Chromium

Tier 1 Evaluation
Two site samples exceed the background screening value of 38.25 mg/kg.

Slippage Test
K_c for chromium is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, chromium passes the Slippage Test.

WRS Test
The p-level of 0.006 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is slightly lower than the background maximum (Figure 1-27).

Conclusion
Because chromium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Cobalt

Tier 1 Evaluation
Ten site samples exceed the background screening value of 17.54 mg/kg.

Slippage Test
K_c for cobalt is four, and one site sample exceeds the maximum background measurement (K=1). Because $K < K_c$, cobalt passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-28).

Conclusion
Because cobalt in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Copper

Tier 1 Evaluation

Thirteen site samples exceed the background screening value of 19.43 mg/kg.

Slippage Test

K_c for copper is four, and two site samples exceed the maximum background measurement (K=2). Because $K < K_c$, copper passes the Slippage Test.

WRS Test

The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-29).

Conclusion

Because copper in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Iron

Tier 1 Evaluation

Seven site samples exceed the background screening value of 44,817 mg/kg.

Slippage Test

K_c for iron is four, and six site samples exceed the maximum background measurement (K=6). Because $K > K_c$, iron fails the Slippage Test.

WRS Test

The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-30).

Conclusion

Because iron in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Lead

Tier 1 Evaluation

Three site samples exceed the background screening value of 38.53 mg/kg.

Slippage Test
K_c for lead is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, lead passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-31).

Conclusion
Because lead in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Magnesium

Tier 1 Evaluation
Eleven site samples exceed the background screening value of 766.24 mg/kg.

Slippage Test
K_c for magnesium is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, magnesium passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum is slightly higher than the background minimum, and the site median is higher than the background median (Figure 1-32). The site maximum is lower than the background maximum.

Conclusion
Because magnesium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Manganese

Tier 1 Evaluation
Four site samples exceed the background screening value of 1,355 mg/kg.

Slippage Test
K_c for manganese is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, manganese passes the Slippage Test.

WRS Test
The p-level of 0.018 indicates poor agreement between the site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-33).

Conclusion
Because manganese in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Mercury

Tier 1 Evaluation
Four of the sixteen detected concentrations exceed the background screening value of 0.07 mg/kg. The remaining 21 samples are nondetects with reporting limits that are above the background screening value.

Slippage Test
K_c for mercury is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, mercury passes the Slippage Test.

WRS Test
The WRS test was not performed because the site and the background data sets contain 57 and 53 percent nondetects, respectively.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-34).

Hot Measurement Test
The site MDC of mercury exceeds the background 95th percentile of 0.094 mg/kg.

Conclusion
Because mercury in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Nickel

Tier 1 Evaluation
Seventeen site samples exceed the background screening value of 12.89 mg/kg.

Slippage Test
K_c for nickel is four, and one site samples exceed the maximum background measurement (K=1). Because $K < K_c$, nickel passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-35).

Conclusion
Because nickel in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Potassium

Tier 1 Evaluation
Seventeen site samples exceed the background screening value of 710.74 mg/kg.

Slippage Test
K_c for potassium is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, potassium passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-36).

Conclusion
Because potassium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Selenium

Tier 1 Evaluation
Fifteen detected concentrations exceed the background screening value of 0.47 mg/kg. The remaining 22 samples are nondetects with reporting limits that are above the background screening value.

Slippage Test
The maximum background value for selenium is a nondetect, so the Slippage test could not be performed.

WRS Test
The WRS test was not performed because the site and background data sets contain 59 and 98 percent nondetects, respectively.

Box Plot
The shape and location of background box plot are defined by the high percentage of nondetects (98 percent) and the replacement values of one-half the reporting limits (Figure 1-37). The site minimum, median, and maximum are higher than the corresponding background values.

Hot Measurement Test
The site MDC of selenium does exceed the 95th percentile of 0.574 mg/kg.

Conclusion
Because selenium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Silver

Tier 1 Evaluation
Two detected concentrations exceed the background screening value of 0.24 mg/kg. The remaining 35 samples are nondetects with reporting limits that are above the background screening value.

Slippage Test
The maximum background value for silver is a nondetect, so the Slippage test could not be performed.

WRS Test
The WRS test was not performed because the site data set contains 95 percent nondetects.

Box Plot
The shape and location of the site box plot are defined by the high percentage of nondetects (95 percent) and the replacement values of one-half the reporting limits (Figure 1-38). The site minimum, median, and maximum are higher than the corresponding background values.

Hot Measurement Test
The site MDC of silver exceeds the 95th percentile of 0.88 mg/kg.

Conclusion
Because silver in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Thallium

Tier 1 Evaluation
Three of the six detected concentrations exceed the background screening value of 1.4 mg/kg. The remaining 31 samples are nondetects with reporting limits that are above the background screening value.

Slippage Test
K_c for thallium is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, thallium passes the Slippage Test.

WRS Test
The WRS test was not performed because the site data set contains 84 percent nondetects.

Box Plot
The shape and location of the site box plot are defined by the high percentage of nondetects (84 percent) and the replacement values of one-half the reporting limits (Figure 1-39). The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum.

Hot Measurement Test
The site MDC of thallium does not exceed the 95th percentile of 6.62 mg/kg.

Conclusion
Because thallium in subsurface soil is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

Vanadium

Tier 1 Evaluation
One site sample exceeds the background screening value of 64.89 mg/kg.

Slippage Test
K_c for vanadium is four, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, vanadium passes the Slippage Test.

WRS Test
The p-level of 0.01 indicates weak agreement between the site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-40).

Conclusion
Because vanadium in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Zinc

Tier 1 Evaluation
Twenty-three site samples exceed the background screening value of 34.86 mg/kg.

Slippage Test
K_c for zinc is four, and four site samples exceed the maximum background measurement (K=4). Because K K_c, zinc passes the Slippage Test.

WRS Test
The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-41).

Conclusion
Because zinc in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

3.3 Groundwater

This section presents the results of the site-to-background comparisons for 23 metals unfiltered groundwater samples. Two metals (antimony and silver) have no detects in the groundwater site samples and are not considered any further. Five metals (magnesium, mercury, nickel, potassium, and selenium) have no detected concentrations that exceeded their respective background screening values. These metals are considered within the background range based on the Tier 1 evaluation, and are not discussed further. The remaining sixteen metals are carried forward for Tier 2 evaluation.

Table 3 summarizes the groundwater statistical site-to-background comparison results. The box plots are provided in Attachment 1.

Aluminum

Tier 1 Evaluation
Five of the 42 detected concentrations exceed the background screening value of 2.335 mg/L.

Slippage Test
K_c for aluminum is six, and one site sample exceeds the maximum background measurement (K=1). Because $K < K_c$, aluminum passes the Slippage Test.

WRS Test
The p-level of 0.694 indicates excellent agreement between the site and background distributions.

Box Plot
The site minimum and maximum are higher than the corresponding background values, and the site median is lower than the background median (Figure 1-42).

Conclusion
Because aluminum in groundwater is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

Arsenic

Tier 1 Evaluation

One of the eight detected concentrations exceeds the background screening value of 0.0178 mg/L.

Slippage Test

K_c for arsenic is six, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, arsenic passes the Slippage Test.

WRS Test

The WRS test was not performed because the site and background data sets contain 89 and 84 percent nondetects, respectively.

Box Plot

The shapes and locations of the site and background box plots are defined by the high percentage of nondetects (89 and 84 percent, respectively) and the replacement values of one-half the reporting limits (Figure 1-43). The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-43).

Hot Measurement Test

The site MDC of arsenic does not exceed the 95th percentile of 0.117 mg/L.

Conclusion

Because arsenic in groundwater is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

Barium

Tier 1 Evaluation

Twelve site samples exceed the background screening value of 0.127 mg/L.

Slippage Test

K_c for barium is 6, and two site samples exceed the maximum background measurement (K=2). Because $K < K_c$, barium passes the Slippage Test.

WRS Test

The p-level of 0.08 indicates poor agreement between the site and background distributions.

Box Plot

The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-44).

Conclusion

Because barium in groundwater failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Beryllium

Tier 1 Evaluation

The single detected concentration exceeds the background screening value of 0.0012 mg/L. The remaining 73 samples are nondetects with reporting limits that are above the background screening value.

Slippage Test

The maximum background value for beryllium is a nondetect, so the Slippage test could not be performed.

WRS Test

The WRS test was not performed because the site and background data sets contain 99 and 72 percent nondetects, respectively.

Box Plot

The shapes and locations of the site and background box plots are defined by the high percentages of nondetects (99 and 72 percent, respectively) and the replacement values of one-half the reporting limits (Figure 1-45). The site minimum, median, and maximum are higher than the corresponding background values.

Hot Measurement Test

The site MDC of beryllium exceeds the background 95th percentile of 0.005 mg/L.

Conclusion

Because beryllium in groundwater failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Cadmium

Tier 1 Evaluation

The single detected concentration exceeds the background screening value of 0.0025 mg/L. The remaining 73 samples are nondetects with reporting limits that are above the background screening value.

Slippage Test

The maximum background value for cadmium is a nondetect, so the Slippage test could not be performed.

WRS Test

The WRS test was not performed because the site and background data sets contain 99 and 64 percent nondetects, respectively.

Box Plot

The shape and location of the site box plot are defined largely by the high percentage of nondetects (99 percent) and the replacement values of one-half the reporting limits (Figure 1-46). The site minimum, median, and maximum are higher than the corresponding background values.

Hot Measurement Test
The site MDC of cadmium does not exceed the background 95th percentile of 0.00678 mg/L.

Conclusion
Because cadmium in groundwater is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

Calcium

Tier 1 Evaluation
Seventeen site samples exceed the background screening value of 56.493 mg/L.

Slippage Test
K_c for calcium is six, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, calcium passes the Slippage Test.

WRS Test
The p-level of 0.027 indicates weak agreement between the site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than background maximum (Figure 1-47).

Conclusion
Because calcium in groundwater failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Chromium

Tier 1 Evaluation
There is no background screening value for chromium. Five site samples have detected concentrations.

Slippage Test
The maximum background value for chromium is a nondetect, so the Slippage test could not be performed.

WRS Test
The WRS test was not performed because the site and background data sets contain 93 and 100 percent nondetects, respectively.

Box Plot
The shapes and locations of the site and background box plots are largely defined by the high percentages of nondetects (93 and 100 percent, respectively) and the replacement values of one-half the reporting limits (Figure 1-48). The site minimum, median, and maximum are higher than the corresponding background values.

Hot Measurement Test
The site MDC of chromium exceeds the background 95th percentile of 0.0168 mg/L.

Conclusion
Because chromium in groundwater failed statistical comparison to background, it will be carried forward for geochemical evaluation.

Cobalt

Tier 1 Evaluation
Two of the 10 detected concentrations exceed the background screening value of 0.0234 mg/L. The remaining 64 samples are nondetects with reporting limits that are below the background screening value.

Slippage Test
K_c for cobalt is six, and two site samples exceed the maximum background measurement (K=2). Because $K < K_c$, cobalt passes the Slippage Test.

WRS Test
The WRS test was not performed because the site and background data sets contain 86 and 94 percent nondetects, respectively.

Box Plot
The shapes and locations of the site and background box plots are largely defined by the high percentages of nondetects (86 and 94 percent, respectively) and the replacement values of one-half the reporting limits (Figure 1-49). The site minimum and median are lower than the corresponding background values, the site maximum is higher than the background maximum.

Conclusion
Because cobalt in groundwater failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Copper

Tier 1 Evaluation
Two of the five detected concentrations exceed the background screening value of 0.0255 mg/L. The remaining 69 samples are nondetects with reporting limits that are below the background screening value.

Slippage Test
K_c for copper is six, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, copper passes the Slippage Test.

WRS Test
The WRS test was not performed because the site and background data sets contain 93 and 82 percent nondetects, respectively.

Box Plot
The site minimum and median are slightly higher than the corresponding background values, and the site maximum is lower than background maximum (Figure 1-50).

Conclusion
Because copper in groundwater is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

Iron

Tier 1 Evaluation
Six site samples exceed the background screening value of 7.04 mg/L.

Slippage Test
K_c for iron is six, and one site sample exceeds the maximum background measurement (K=1). Because $K < K_c$, iron passes the Slippage Test.

WRS Test
The p-level of 0.281 indicates good agreement between the site and background distributions.

Box Plot
The site minimum and median are lower than the corresponding background values, and the site maximum is higher than the background maximum (Figure 1-51).

Conclusion
Because iron in groundwater is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

Lead

Tier 1 Evaluation
One of the eight detected concentrations exceeds the background screening value of 0.008 mg/L. The remaining 66 samples are nondetects with reporting limits that are above the background screening value.

Slippage Test
The maximum background value for lead is a nondetect, so the Slippage test could not be performed.

WRS Test
The WRS test was not performed because the site and background data sets contain 89 and 60 percent nondetects, respectively.

Box Plot
The shape and location of the site box plot are largely defined by the high percentage of nondetects (89 percent) and the replacement values of one-half the reporting limits (Figure 1-52). The site minimum, median, and maximum are higher than the corresponding background values.

Hot Measurement Test
The site MDC of lead exceeds the background 95th percentile of 0.0434 mg/L.

Conclusion
Because lead in groundwater failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Manganese

Tier 1 Evaluation
Twenty-five site samples exceed the background screening value of 0.5805 mg/L.

Slippage Test
K_c for manganese is six, and three site samples exceed the maximum background measurement (K=3). Because $K < K_c$, manganese passes the Slippage Test.

WRS Test
The p-level of 0.011 indicates weak agreement between the site and background distributions.

Box Plot
The site minimum, median, and maximum are higher than the corresponding background values (Figure 1-53).

Conclusion
Because manganese in groundwater failed the statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Sodium

Tier 1 Evaluation
One of the twenty-six detected concentrations exceeds the background screening value of 14.846 mg/L.

Slippage Test
K_c for sodium is six, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, sodium passes the Slippage Test.

WRS Test
The WRS test was not performed because the site data set contains 65 percent nondetects.

Box Plot
The site minimum is slightly higher than the background minimum, and the site median and maximum are lower than the corresponding background values (Figure 1-54).

Hot Measurement Test
The site MDC of sodium does not exceed the background 95th UTL of 49.028 mg/L.

Conclusion
Because sodium in groundwater is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

Thallium

Tier 1 Evaluation
The single detected concentration exceeds the background screening value of 0.001455 mg/L. The remaining 73 samples are nondetects with reporting limits that are above the background screening value.

Slippage Test
The maximum background value for thallium is a nondetect, so the Slippage test could not be performed.

WRS Test
The WRS test was not performed because the site and background data sets contain 99 and 88 percent nondetects, respectively.

Box Plot
The shapes and locations of the site and background box plots are largely defined by the high percentages of nondetects (99 and 88 percent, respectively) and the replacement values of one-half the reporting limits (Figure 1-55). The site minimum, median, and maximum are higher than the corresponding background values.

Hot Measurement Test
The site MDC of thallium does not exceed the background 95th percentile of 0.01 mg/L.

Conclusion
Because thallium in groundwater is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

Vanadium

Tier 1 Evaluation
One of the six detected concentrations exceeds the background screening value of 0.017 mg/L. The remaining 68 samples are nondetects with reporting limits above or below the background screening value.

Slippage Test
The maximum background value for vanadium is a nondetect, so the Slippage test could not be performed.

WRS Test
The WRS test was not performed because the site and background data sets contain 92 and 96 percent nondetects, respectively.

Box Plot
The shapes and locations of the site and background box plots are largely defined by the high percentages of nondetects (92 and 96 percent, nondetects) and the replacement values of one-half the reporting limits (Figure 1-56). The site minimum is lower than the background minimum, and the site median and maximum are higher than the corresponding background values.

Hot Measurement Test
The site MDC of vanadium exceeds the background 95th percentile of 0.0276 mg/L.

Conclusion
Because vanadium in groundwater failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Zinc

Tier 1 Evaluation
One of the eleven detected concentrations exceeds the background screening value of 0.21997 mg/L.

Slippage Test
K_c for zinc is six, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, zinc passes the Slippage Test.

WRS Test
The WRS test was not performed because the site and background data sets contain 85 and 56 percent nondetects, respectively.

Box Plot
The shape and location of the site box plot are largely defined by the high percentage of the nondetects (85 percent) and the replacement values of one-half the reporting limits (Figure 1-57). The site minimum is slightly higher than the background minimum, and the site median is higher than the background median. The site maximum is lower than the corresponding background maximum.

Hot Measurement Test
The site MDC of zinc does not exceed the background 95th percentile of 1.155 mg/L.

Conclusion
Because zinc in groundwater is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

3.3 Sediment

Twenty-three TAL metals in the Area T-5 sediment data set. Five metals (antimony, mercury, selenium, silver, and thallium) have no detected concentrations in the sediment site samples, and are not discussed further. Thirteen metals (aluminum, arsenic, barium, beryllium, calcium, iron, lead, magnesium, manganese, nickel, potassium, sodium, and vanadium) have no detected

concentrations above their respective background screening values, and thus they pass the Tier 1 evaluation. These metals are not discussed further. The remaining five metals are carried forward for Tier 2 evaluation.

Table 4 summarizes the sediment statistical site-to-background comparison results. Box plots are provided in Attachment 1.

Cadmium

Tier 1 Evaluation

The three detected concentrations exceed the background screening value of 0.43 mg/kg. The remaining two samples are nondetects with reporting limits that are above the background screening value.

Slippage Test

K_c for cadmium is two, and one site sample exceeds the maximum background measurement (K=1). Because $K < K_c$, cadmium passes the Slippage Test.

WRS Test

The p-level of < 0.001 indicates a significant difference between the site and background distributions.

Box Plot

The site minimum and median are higher than the corresponding background values, the site maximum is slightly higher than background maximum (Figure 1-58).

Conclusion

Because cadmium in sediment failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Chromium

Tier 1 Evaluation

One sample exceeds the background screening value of 31.15 mg/kg.

Slippage Test

K_c for chromium is two, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, chromium passes the Slippage Test.

WRS Test

The p-level of 0.137 indicates weak agreement between the site and background distributions.

Box Plot

The site minimum and median are higher than the corresponding background values, and the site maximum is slightly lower than the background maximum (Figure 1-59).

Conclusion
Because chromium in sediment failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Cobalt

Tier 1 Evaluation
One of the four detected concentrations in the site data set exceeds the background screening value of 11.01 mg/kg.

Slippage Test
K_c for cobalt is two, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, cobalt passes the Slippage Test.

WRS Test
The p-level of 0.28 indicates good agreement between the site and background distributions.

Box Plot
The site minimum is higher than the background minimum, and the site median and maximum are lower than the corresponding background values (Figure 1-60).

Conclusion
Because cobalt in sediment is within the range of background, it will not be carried forward for Tier 3 evaluation.

Copper

Tier 1 Evaluation
Two site samples exceed the background screening value of 17.12 mg/kg.

Slippage Test
K_c for copper is two, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, copper passes the Slippage Test.

WRS Test
The p-level of 0.004 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-61).

Conclusion
Because copper in sediment failed statistical comparison to background, it will be carried forward for Tier 3, geochemical evaluation.

Zinc

Tier 1 Evaluation

Two site samples exceed the background screening value of 52.74 mg/kg.

Slippage Test

K_c for zinc is two, and no site samples exceed the maximum background measurement (K=0). Because $K < K_c$, zinc passes the Slippage Test.

WRS Test

The p-level of 0.107 indicates weak agreement between the site and background distributions.

Box Plot

The site minimum and median are higher than the corresponding background values, and the site maximum is lower than the background maximum (Figure 1-62).

Conclusion

Because zinc in sediment failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

3.4 Surface Water

Twenty-three TAL metals were evaluated in the Area T-5 surface water data set. Fourteen metals (antimony, arsenic, beryllium, cadmium, cobalt, copper, lead, nickel, potassium, selenium, silver, thallium, vanadium, and zinc) have no detected concentration in the surface water site samples and are not considered any further. Eight metals (aluminum, barium, calcium, iron, magnesium, manganese, mercury, and sodium) have no detected concentrations above their respective background screening values, and thus they pass the Tier 1 evaluation. These metals are not discussed further. The remaining metal (chromium) is carried forward for Tier 2 evaluation.

Table 5 summarizes the surface water statistical site-to-background comparison results. Box plots are provided in Attachment 1.

Chromium

Tier 1 Evaluation

The single detected concentration exceeds the background screening value of 0.01113 mg/L. The remaining four samples are nondetects with reporting limits that are above the background screening value.

Slippage Test

The maximum background value for chromium is a nondetect, so the Slippage test could not be performed.

WRS Test
The WRS test was not performed because the site and background data sets contain 80 and 98 percent nondetects, respectively.

Box Plot
The shapes and locations of the site and background box plots are largely defined by the high percentages of nondetects (80 and 98 percent, respectively) and the replacement values of one-half the reporting limits (Figure 1-63). The site minimum and median are higher than the corresponding background values, and the site maximum is slightly lower than the background maximum.

Hot Measurement Test
The site MDC of chromium does not exceed the 95th percentile of 0.0168 mg/L.

Conclusion
Because chromium in surface water is within the range of background, it will not be carried forward for Tier 3 geochemical evaluation.

Mercury

Tier 1 Evaluation
There is no background screening value for mercury. One site sample has a detected concentration.

Slippage Test
The maximum background value for mercury is a nondetect, so the Slippage test could not be performed.

WRS Test
The WRS test was not performed because the site and background data sets contain 80 and 100 percent nondetects, respectively.

Box Plot
The shapes and locations of the site and background box plots are largely defined by the high percentages of nondetects (80 and 100 percent, respectively) and the replacement values of one-half the reporting limits (Figure 1-64). The site minimum, median, and maximum are higher than the corresponding background values.

Hot Measurement Test
The site MDC of mercury exceeds the 95th percentile of 0.0168 mg/L.

Conclusion
Because chromium in surface water failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

4.0 Summary and Conclusions

The statistical methodology used to compare the Area T-5 and background data sets for 23 elements in surface soil, subsurface soil, groundwater, sediment, and surface water includes a comparison of the site MDC to the background screening value (Tier 1 evaluation). Analytes that failed this comparison were subjected to the Slippage test and WRS test. Box-and-whisker plots were prepared to visually compare the two data sets and properly interpret the WRS test results. The hot measurement test was performed for elements with data sets that precluded either the Slippage test or WRS test. Analytes that failed any of the statistical tests in the Tier 2 evaluation are carried forward for geochemical evaluation to determine if the elevated concentrations can be explained as a result of natural processes. Tables 1 through 5 summarize the comparison test results and show the metals carried forward for geochemical evaluation.

5.0 References

Rosenbaum, S., 1954, "Tables for a Nonparametric Test of Location," ***Annals of Mathematical Statistics***, Vol. 24, pp. 146-150.

Science Application International Corporation (SAIC), 1998, ***Final Background Metals Survey Report, Fort McClellan, Anniston, Alabama***, prepared for U.S. Army Corps of Engineers, Mobile, Alabama, July.

U.S. Environmental Protection Agency (EPA), 1989, ***Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Interim Final Guidance***, Office of Solid Waste, Waste Management Division, EPA/530/SW-89/026, July.

U.S. Environmental Protection Agency (EPA), 1992, ***Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Addendum to Interim Final Guidance***, Environmental Statistics and Information Division, Office of Policy, Planning, and Evaluation, EPA/530/R-93/003, July.

U.S. Environmental Protection Agency (EPA), 1994, ***Statistical Methods For Evaluating The Attainment Of Cleanup Standards***, Environmental Statistics and Information Division, Office of Policy, Planning, and Evaluation, EPA/230/R-94/004, June.

U.S. Environmental Protection Agency (EPA), 2000, ***Guidance for Data Quality Assessment: Practical Methods for Data Analysis, EPA QA/G-9, QA00 Update***, Office of Environmental Information, EPA/600/R-96/084, July.

U.S. Navy, 2002, ***Guidance for Environmental Background Analysis, Volume 1: Soil***, NFESC User's Guide UG-2049-ENV, Naval Facilities Engineering Command, Washington, D.C., April.

ATTACHMENT 1

Figure 1-1. Box Plot Comparison for Aluminum in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

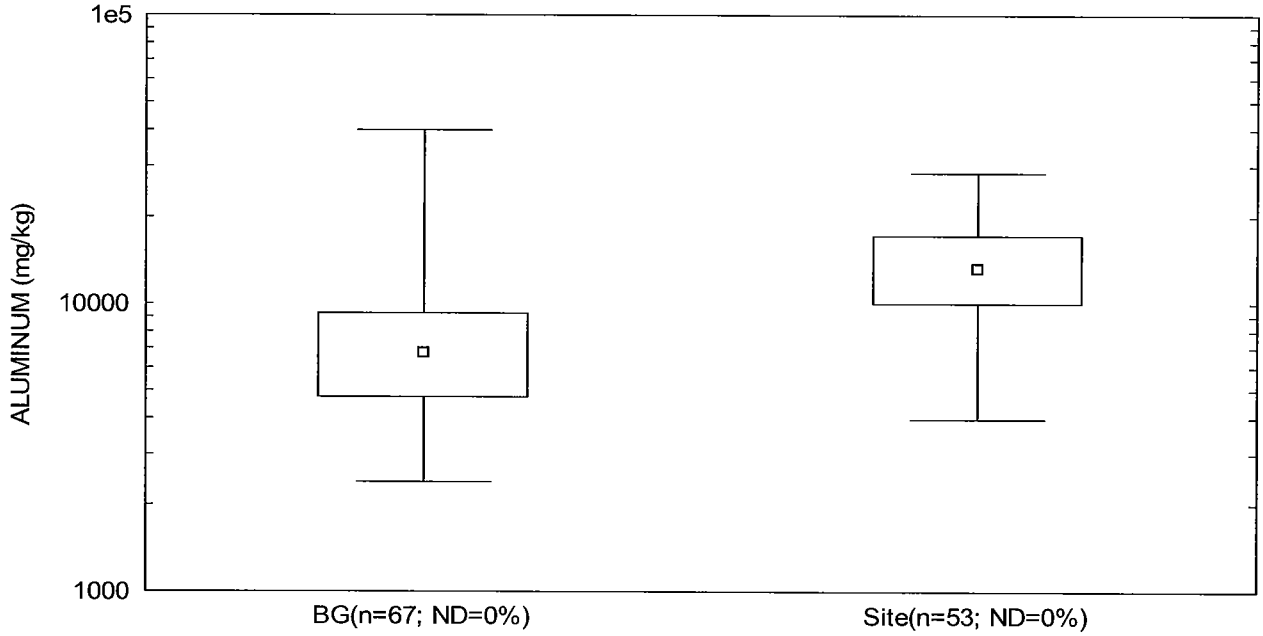


Figure 1-2. Box Plot Comparison for Arsenic in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

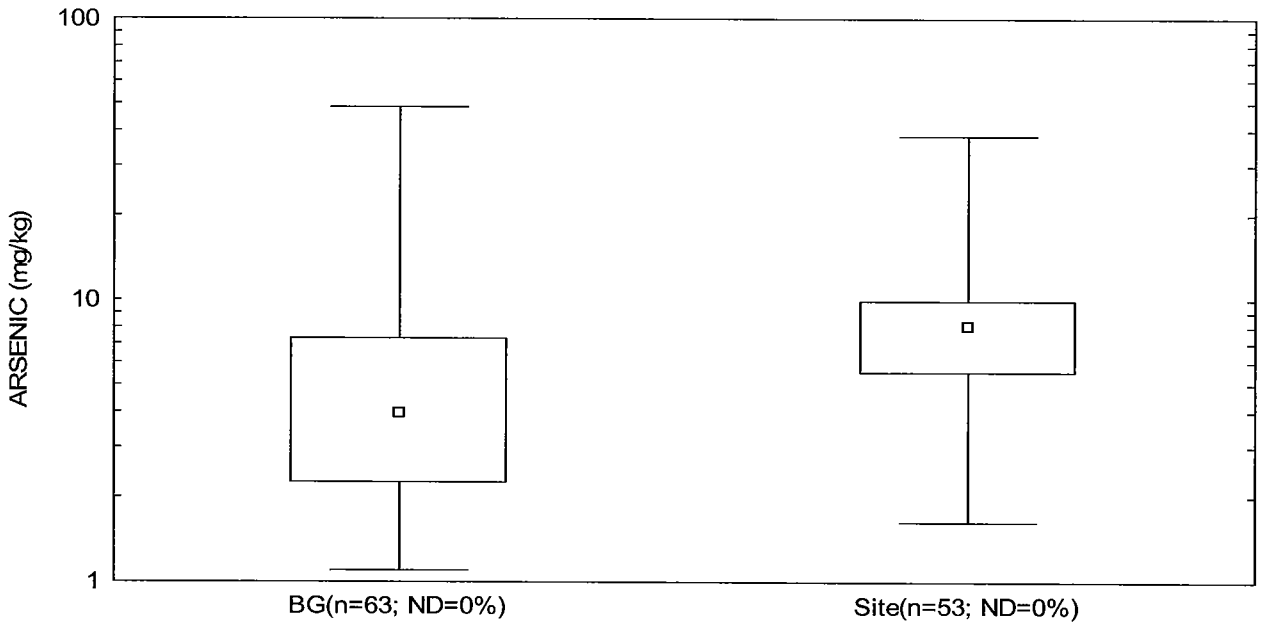


Figure 1-3. Box Plot Comparison for Barium in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

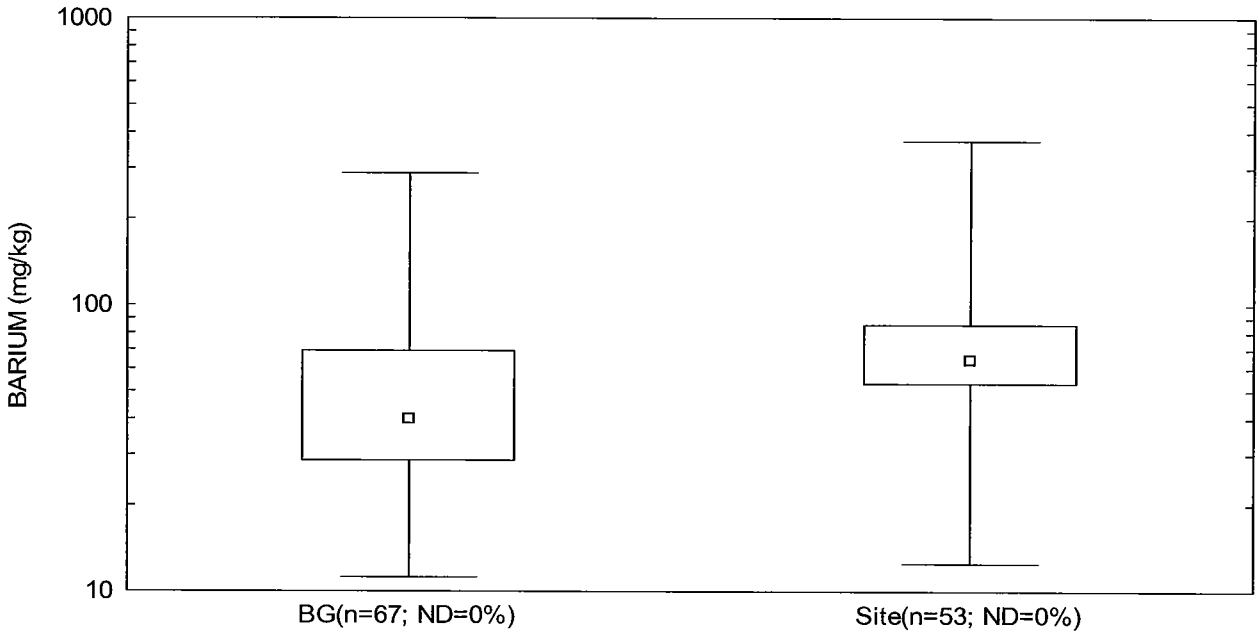


Figure 1-4. Box Plot Comparison for Beryllium in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

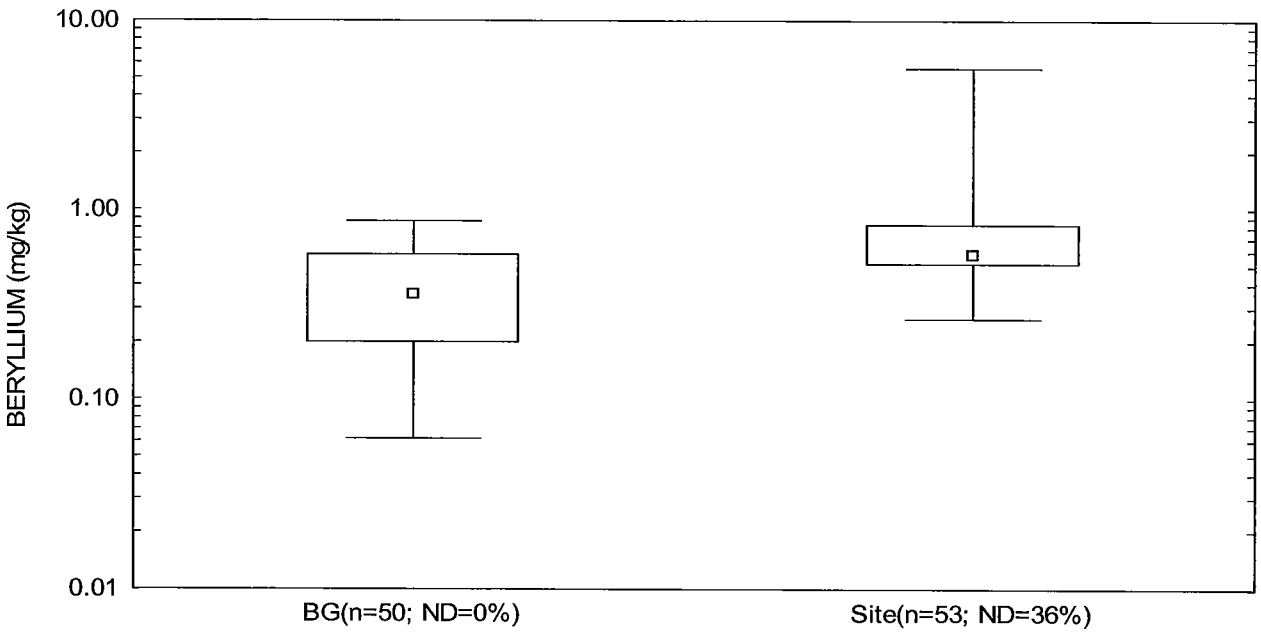


Figure 1-5. Box Plot Comparison for Cadmium in Surface Soil
Area T-5, Ft. McClellan

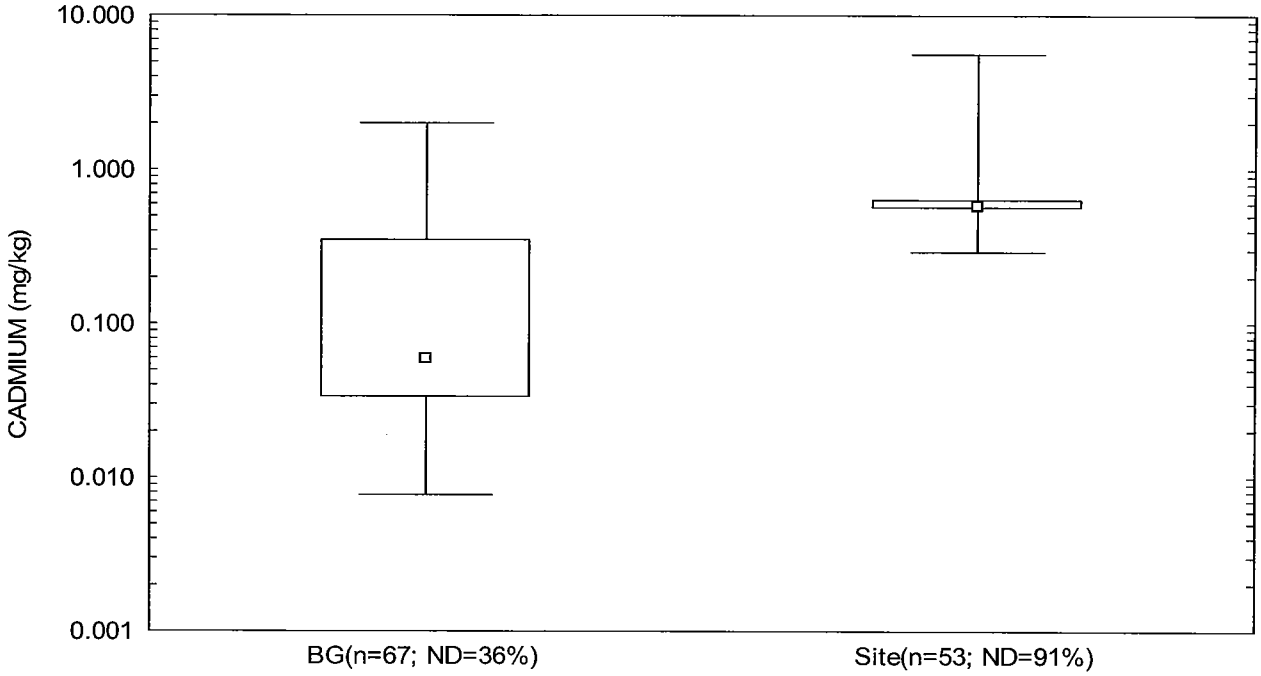


Figure 1-6. Box Plot Comparison for Calcium in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level = 0.01)

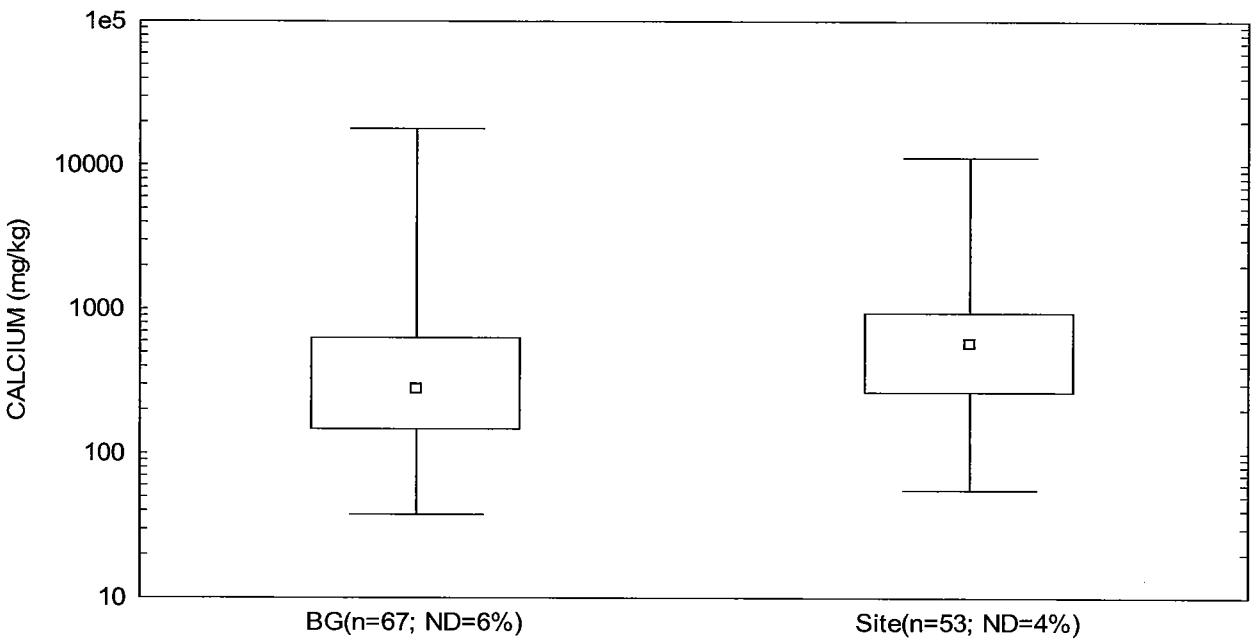


Figure 1-7. Box Plot Comparison for Chromium in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

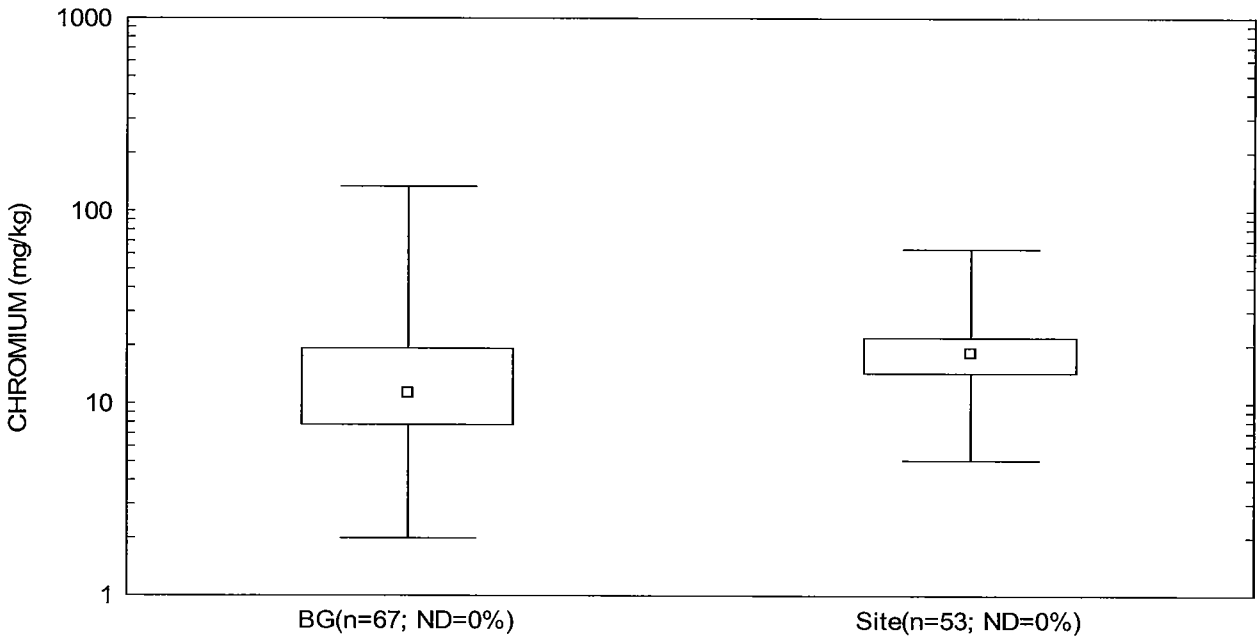


Figure 1-8. Box Plot Comparison for Cobalt in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level = 0.002)

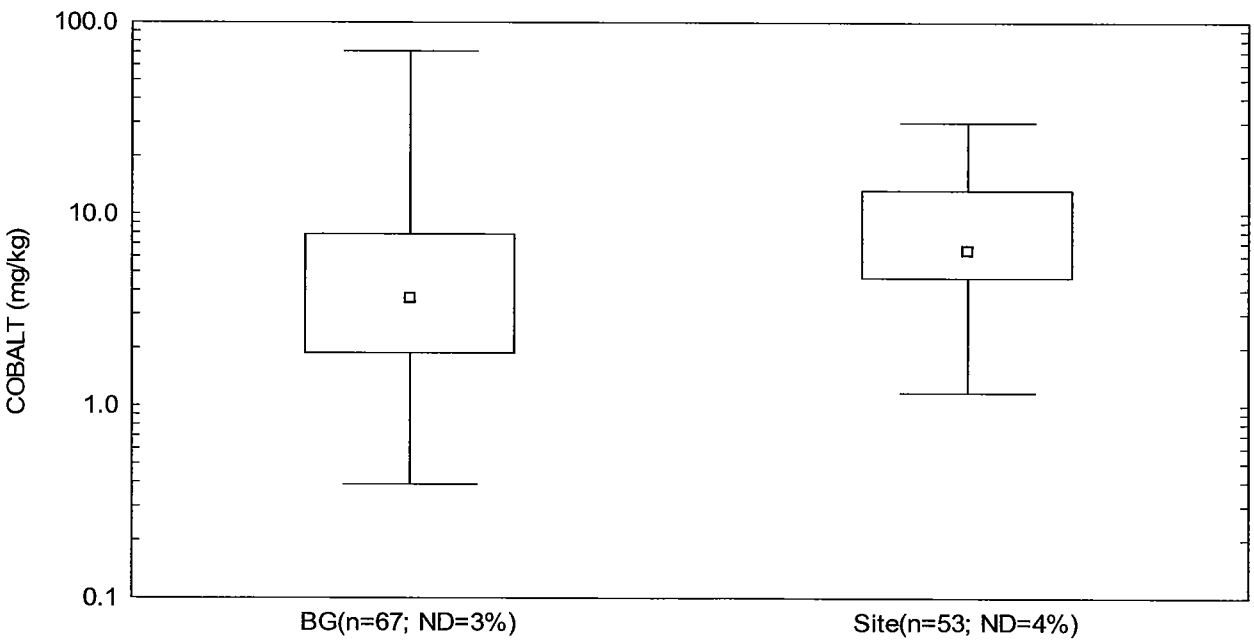


Figure 1-9. Box Plot Comparison for Copper in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

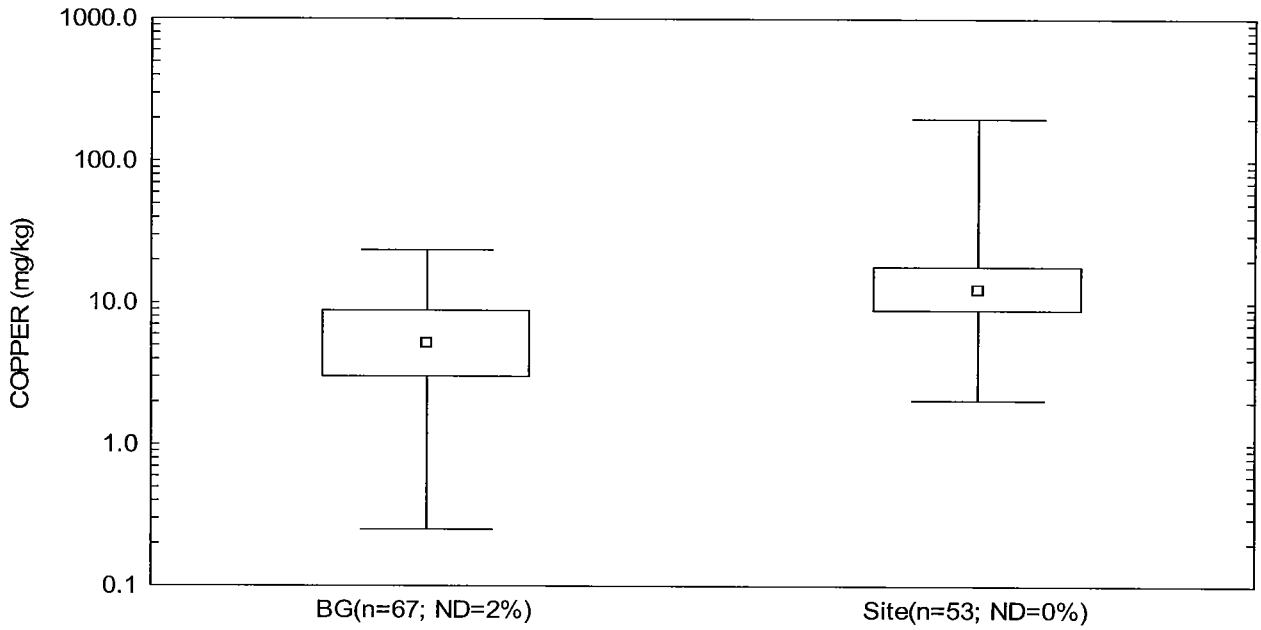


Figure 1-10. Box Plot Comparison for Iron in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level = 0.002)

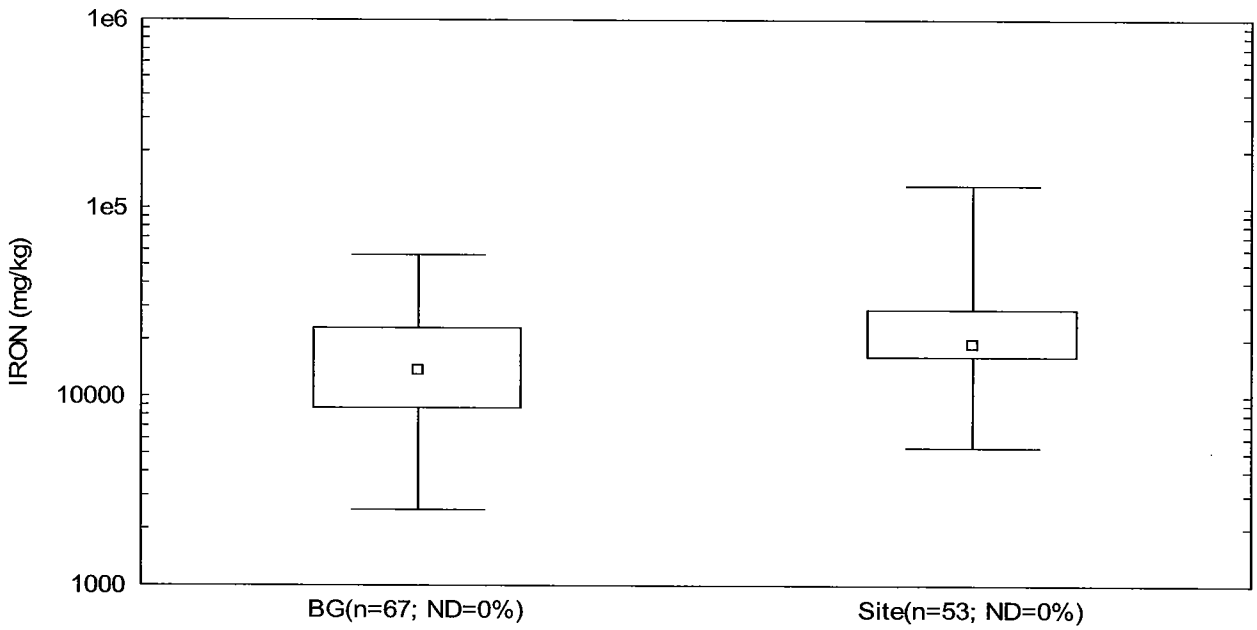


Figure 1-11. Box Plot Comparison for Lead in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level = 0.436)

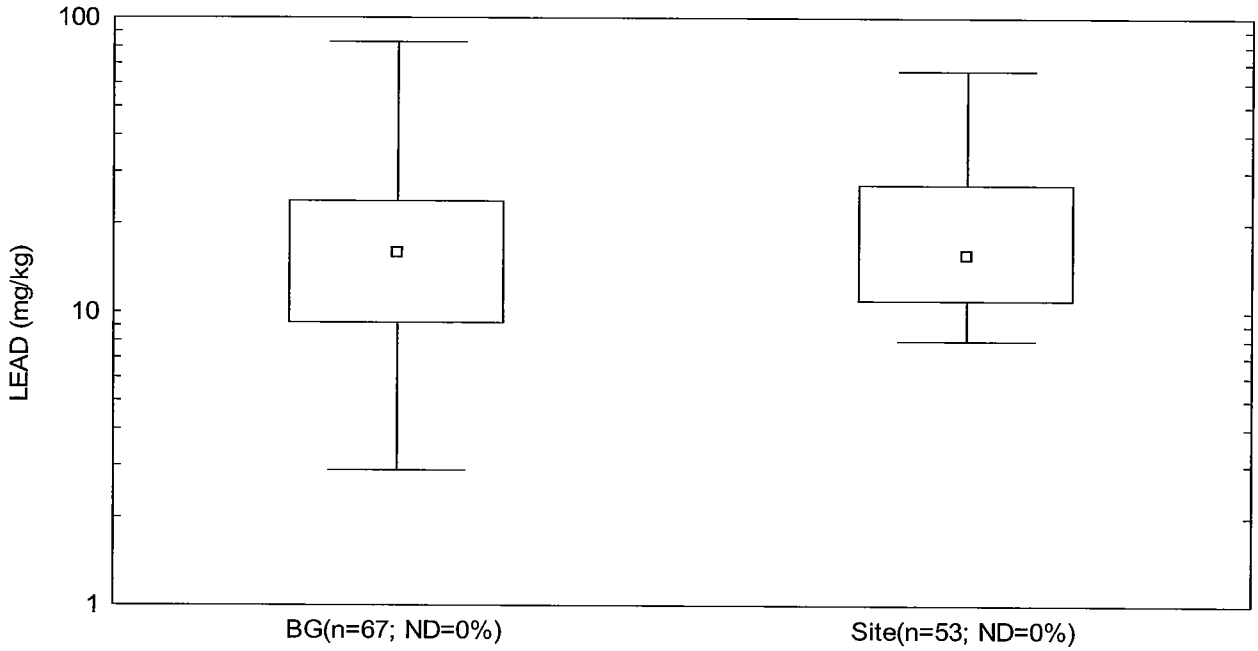


Figure 1-12. Box Plot Comparison for Magnesium in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

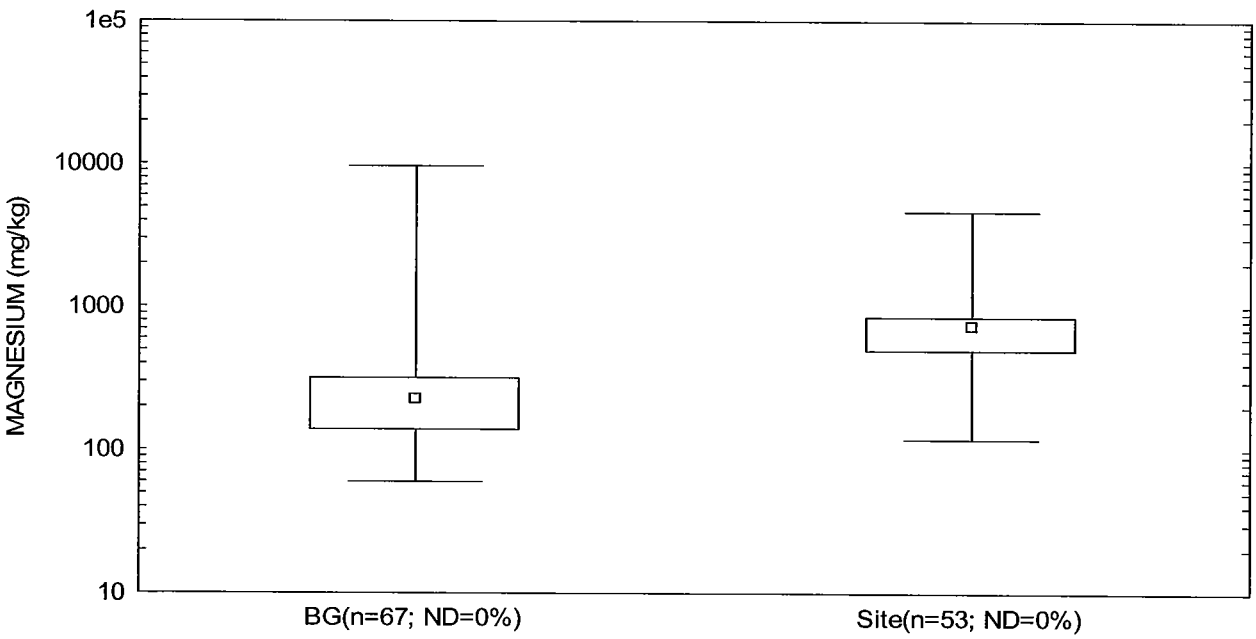


Figure 1-13. Box Plot Comparison for Manganese in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level = 0.612)

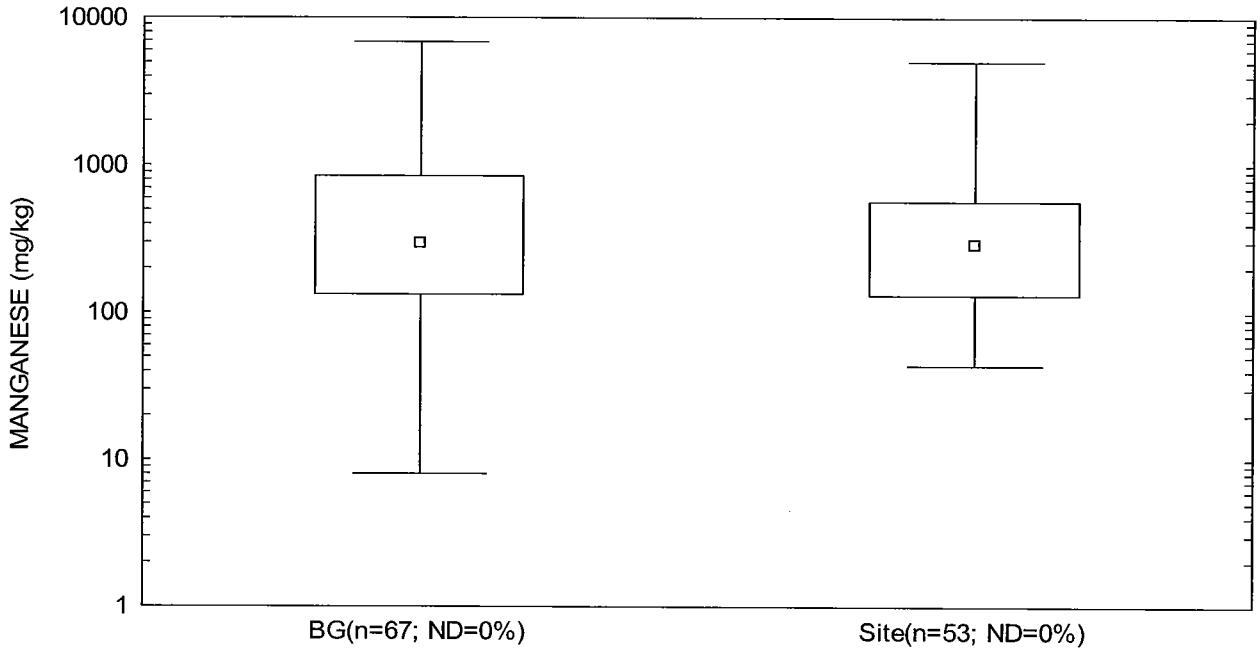


Figure 1-14. Box Plot Comparison for Mercury in Surface Soil
Area T-5, Ft. McClellan

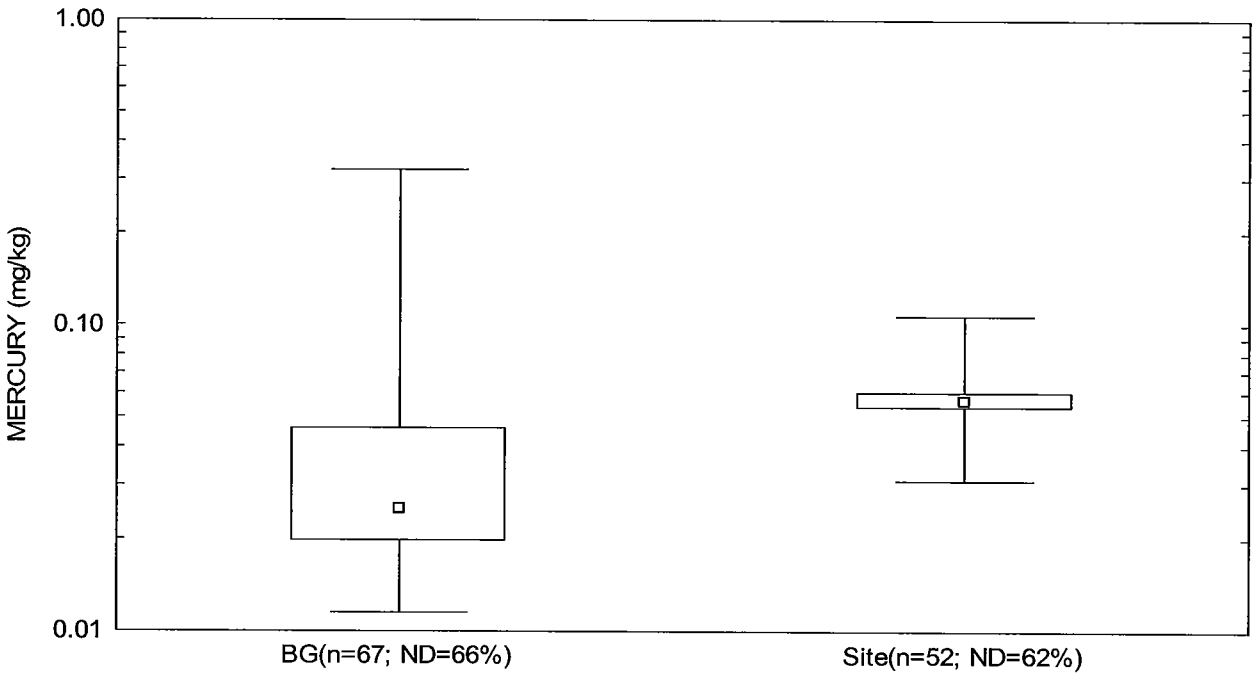


Figure 1-15. Box Plot Comparison for Nickel in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

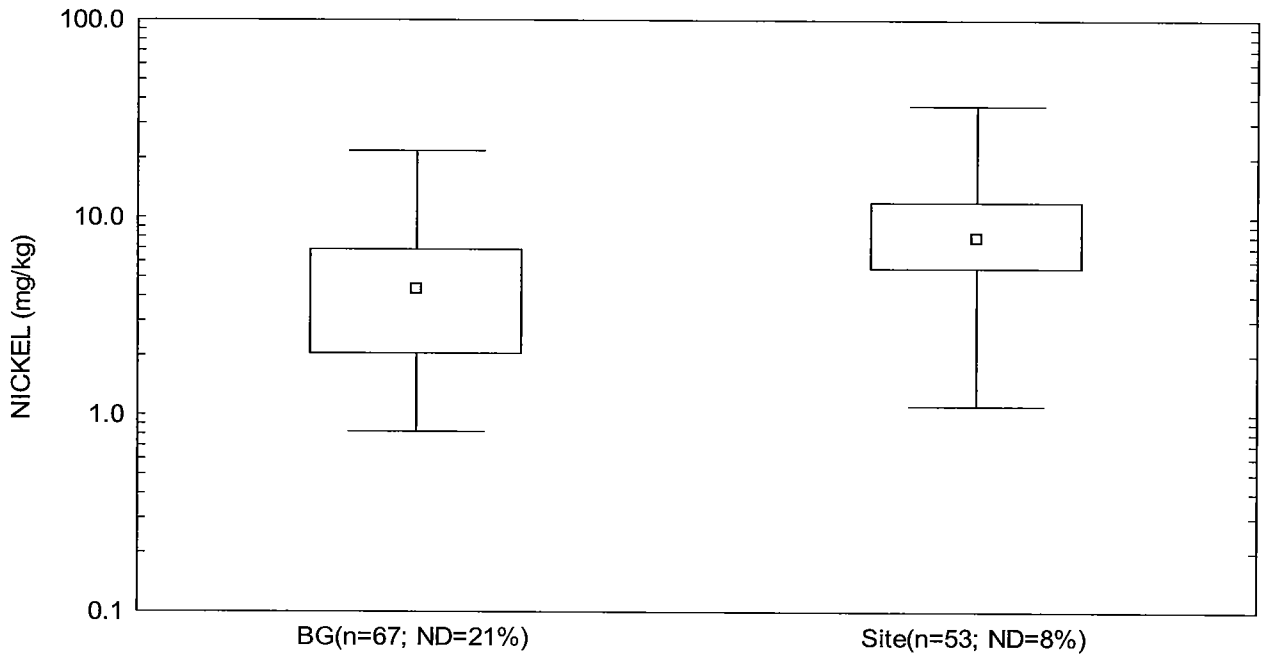


Figure 1-16. Box Plot Comparison for Potassium in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

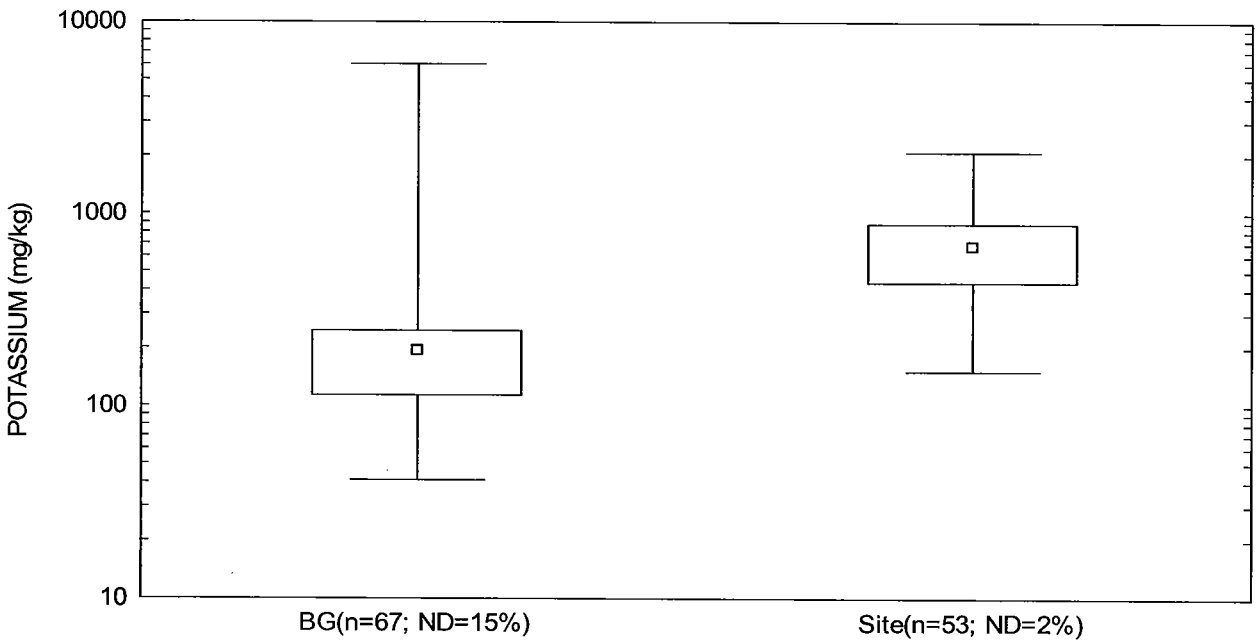


Figure 1-17. Box Plot Comparison for Selenium in Surface Soil
Area T-5, Ft. McClellan

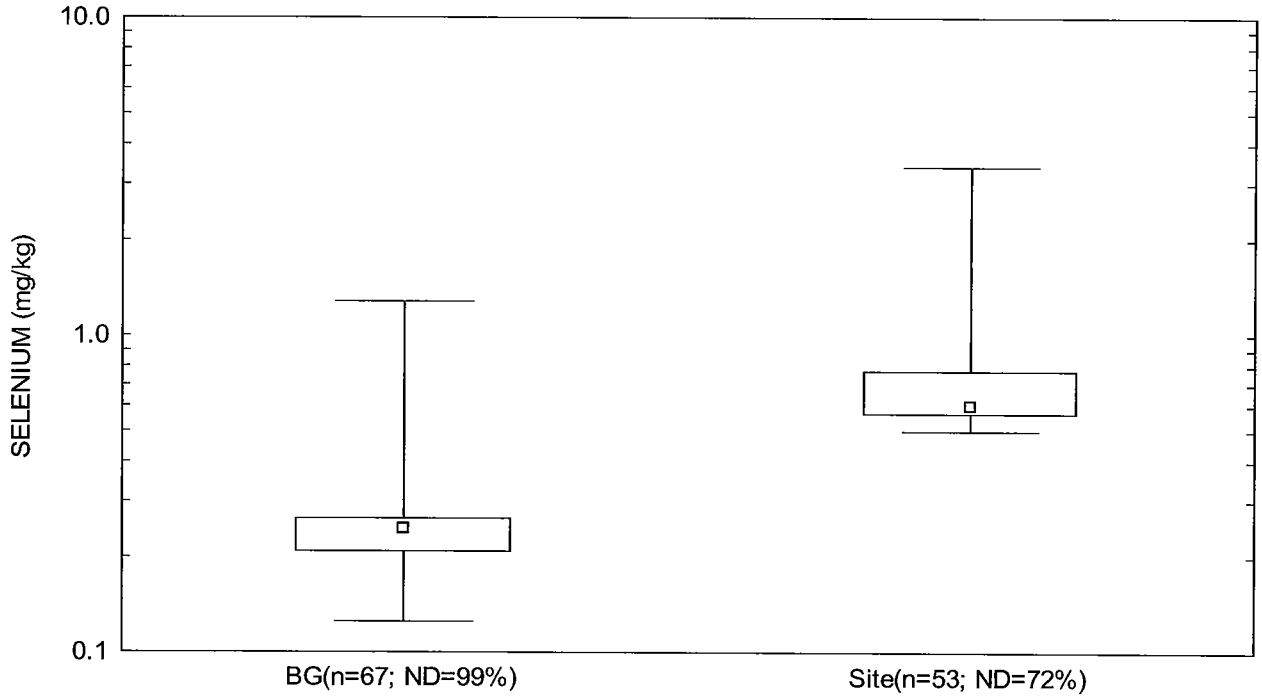


Figure 1-18. Box Plot Comparison for Vanadium in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level = 0.022)

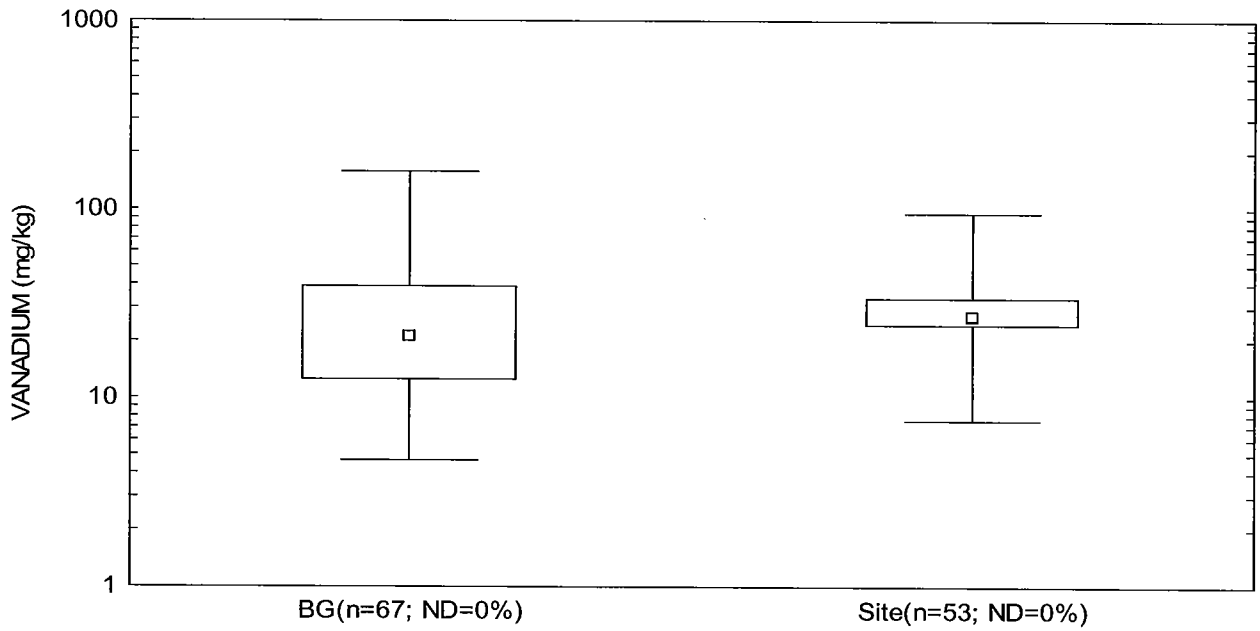


Figure 1-19. Box Plot Comparison for Zinc in Surface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

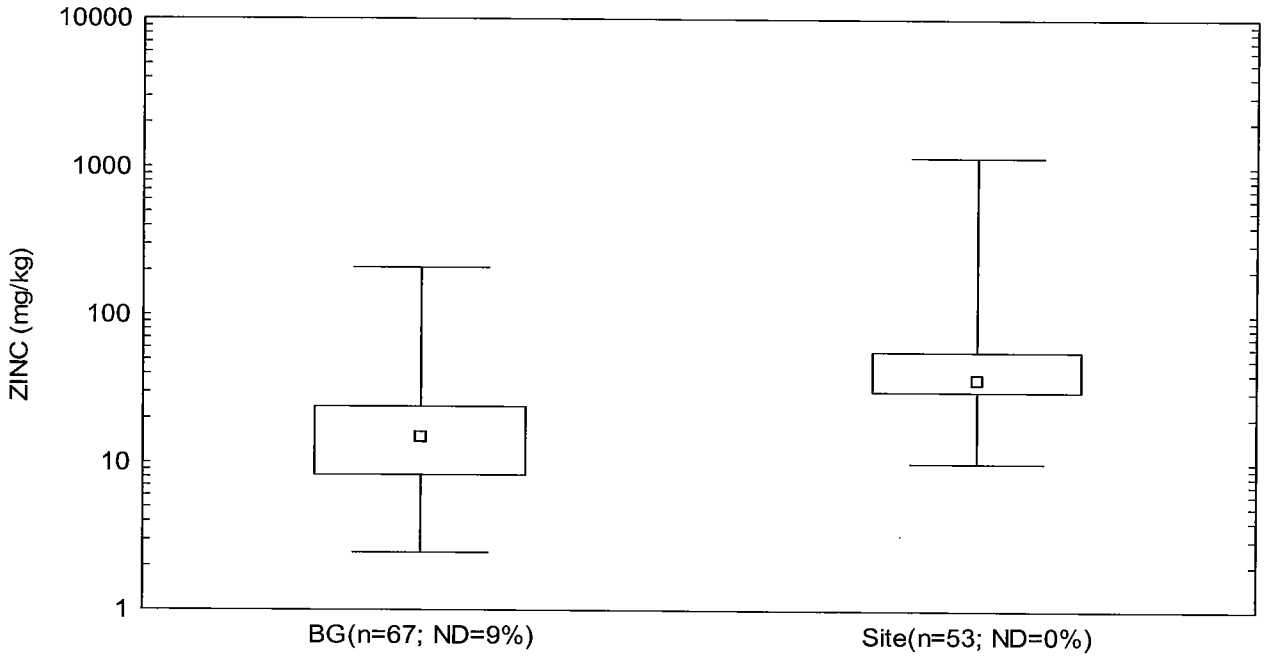


Figure 1-20. Box Plot Comparison for Aluminum in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

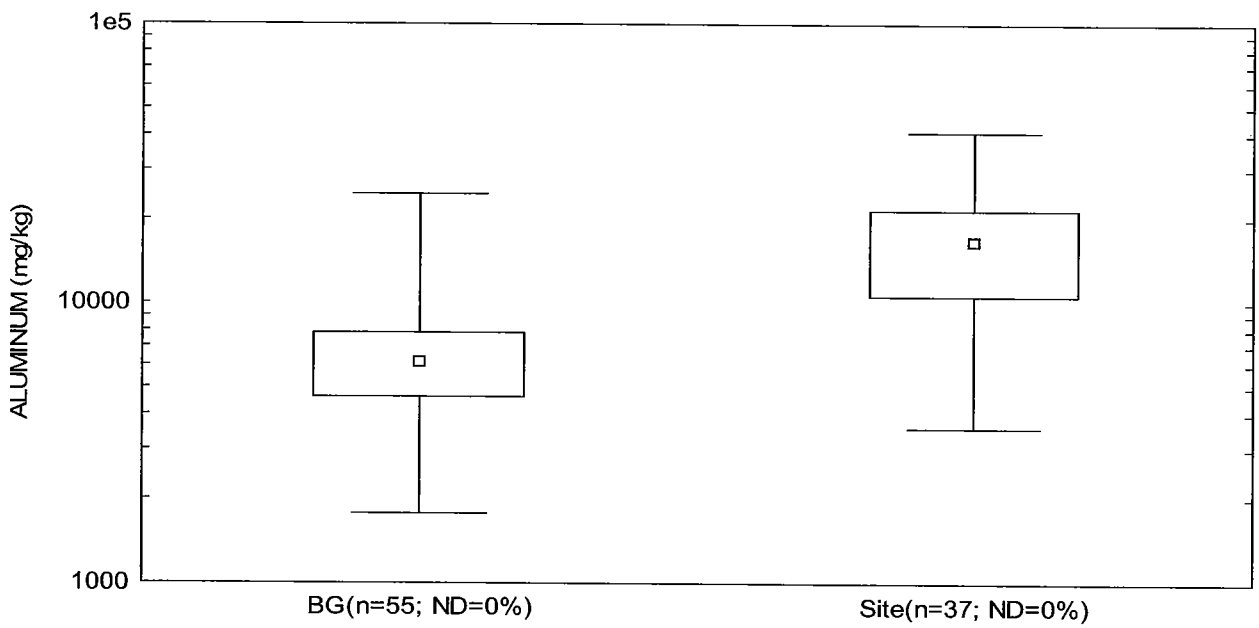


Figure 1-21. Box Plot Comparison for Antimony in Subsurface Soil
Area T-5, Ft. McClellan

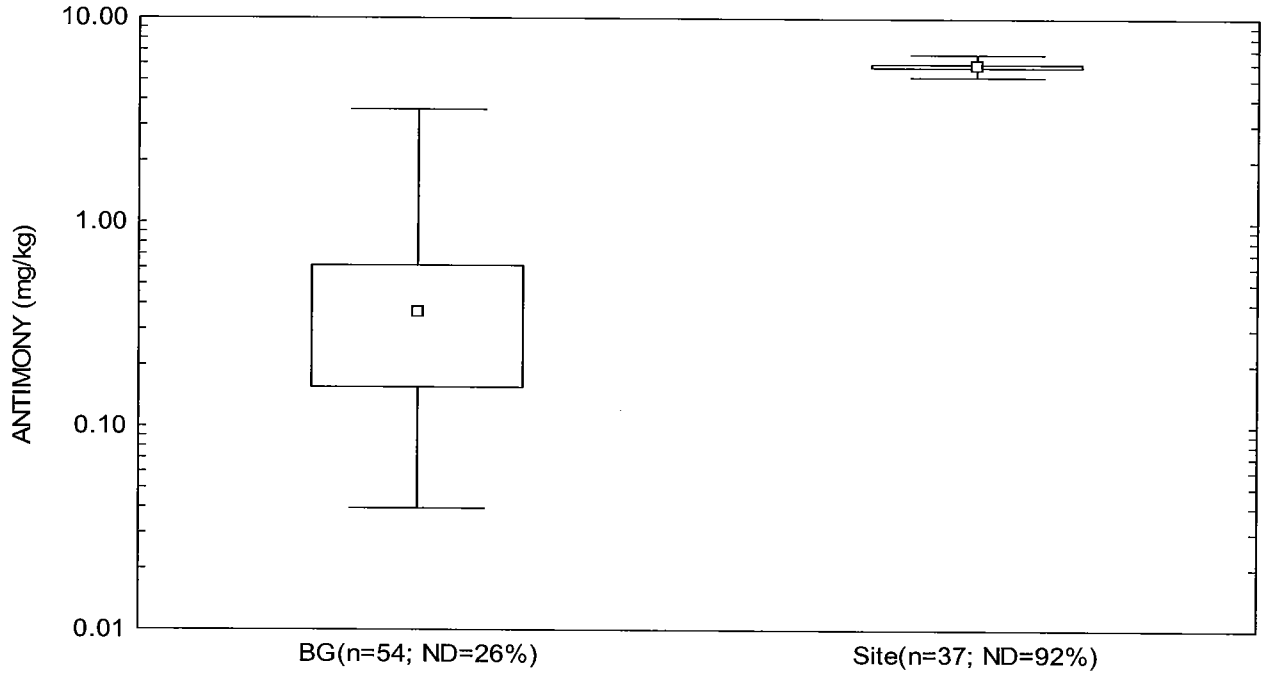


Figure 1-22. Box Plot Comparison for Arsenic in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

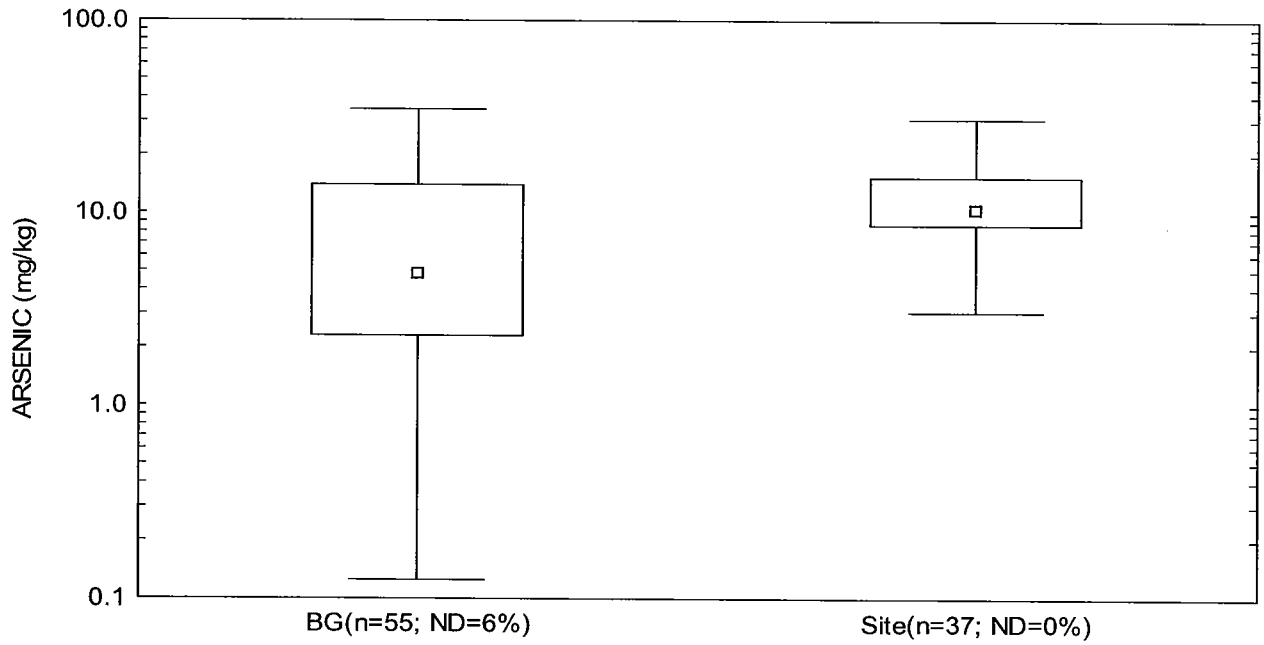


Figure 1-23. Box Plot Comparison for Barium in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

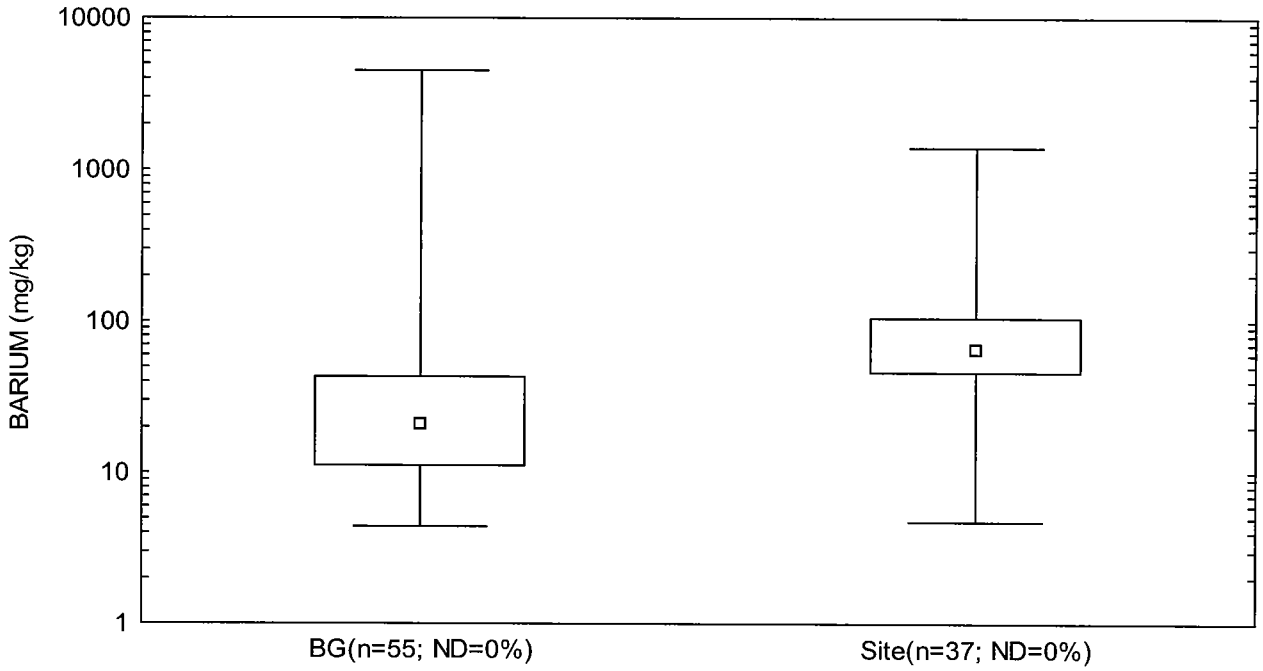


Figure 1-24. Box Plot Comparison for Beryllium in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

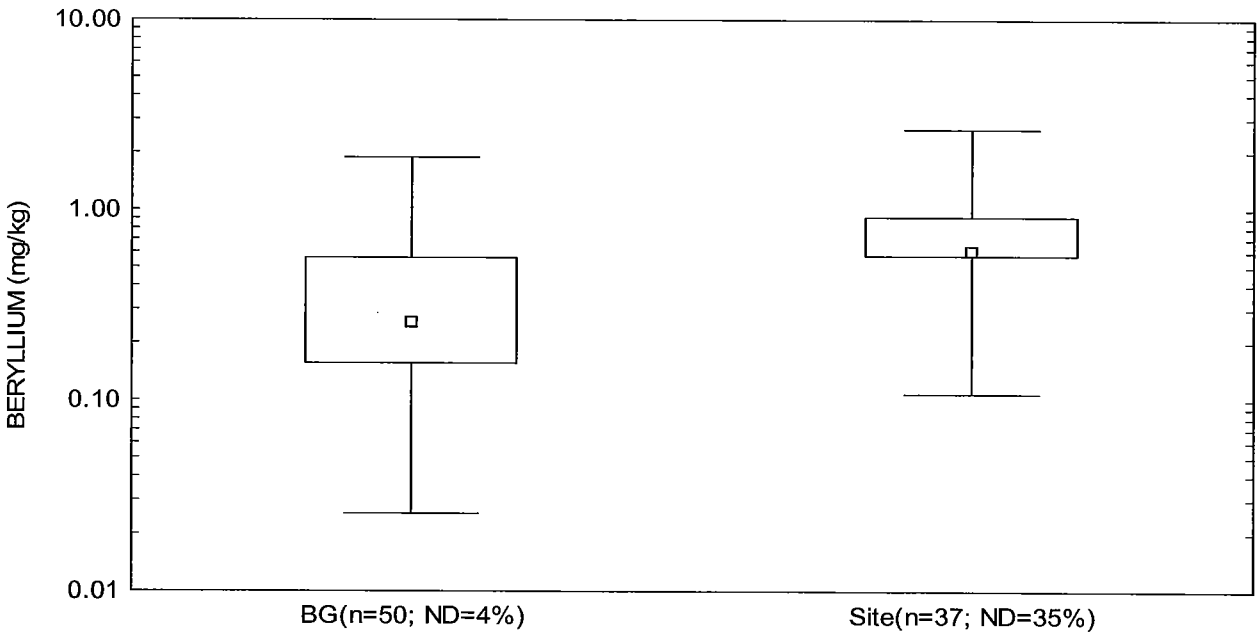


Figure 1-25. Box Plot Comparison for Calcium in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level = 0.121)

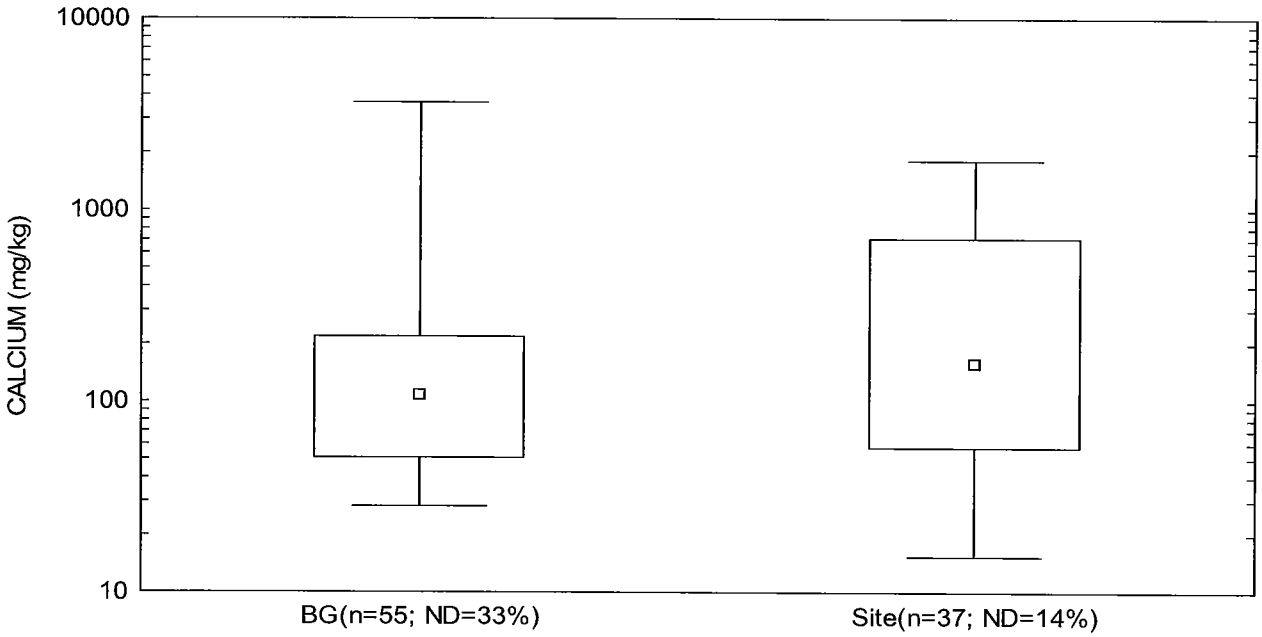


Figure 1-26. Box Plot Comparison for Chromium in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level = 0.006)

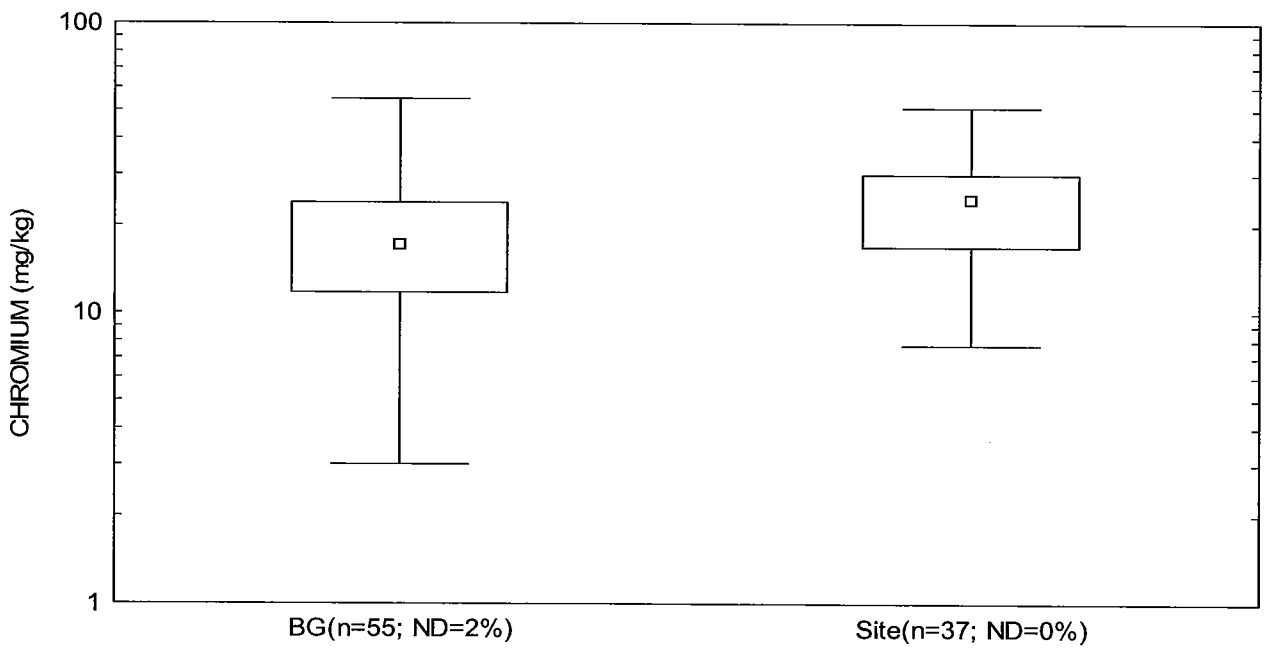


Figure 1-27. Box Plot Comparison for Cobalt in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

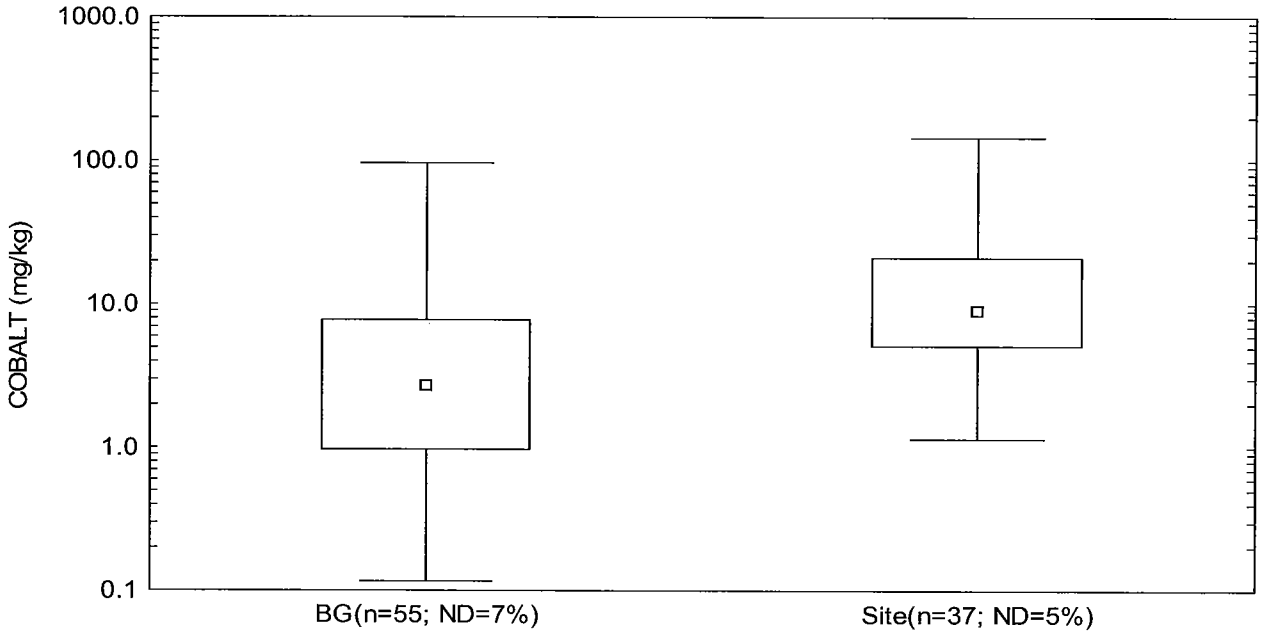


Figure 1-28. Box Plot Comparison for Copper in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

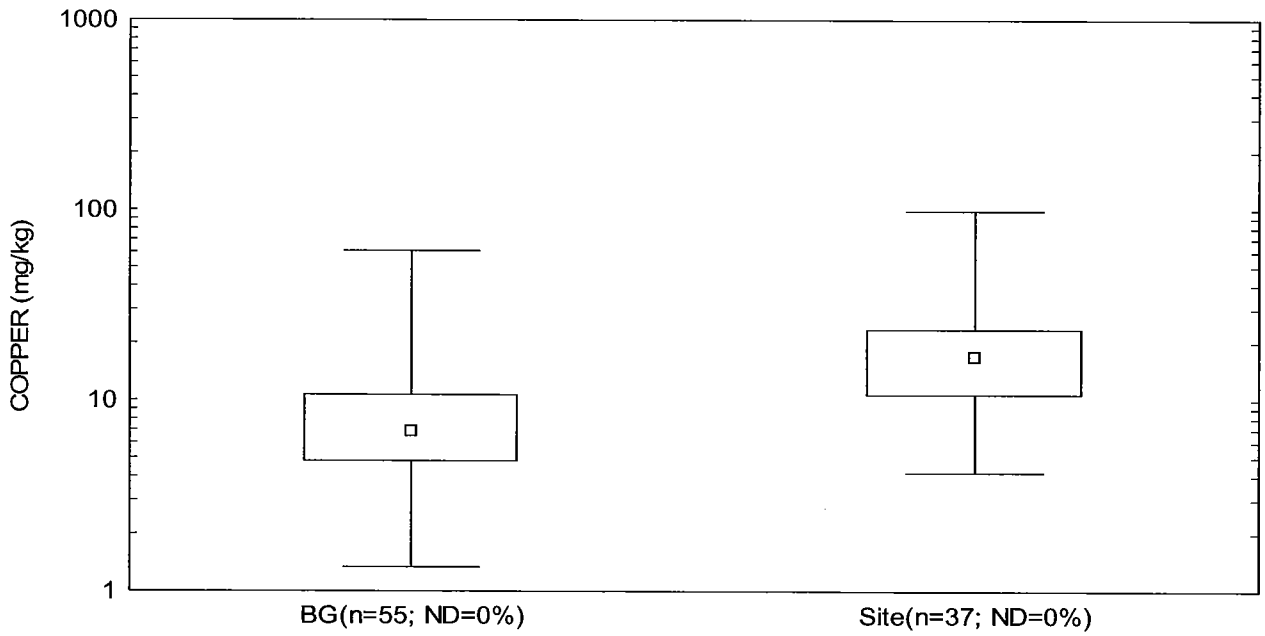


Figure 1-29. Box Plot Comparison for Iron in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

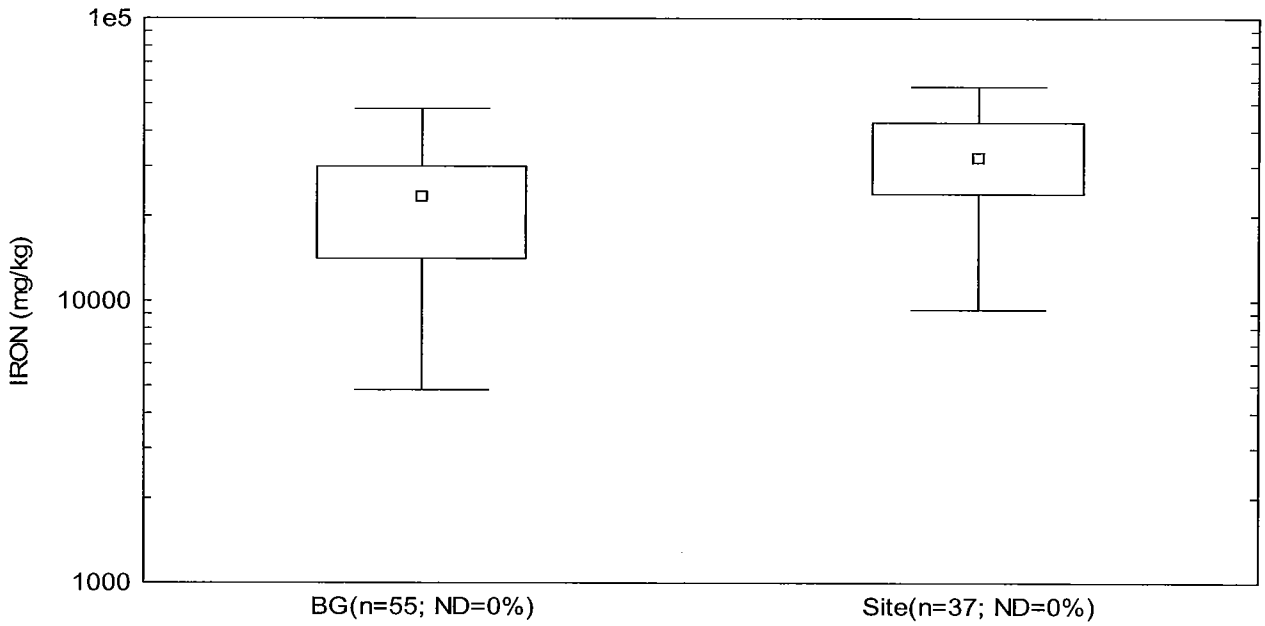


Figure 1-30. Box Plot Comparison for Lead in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

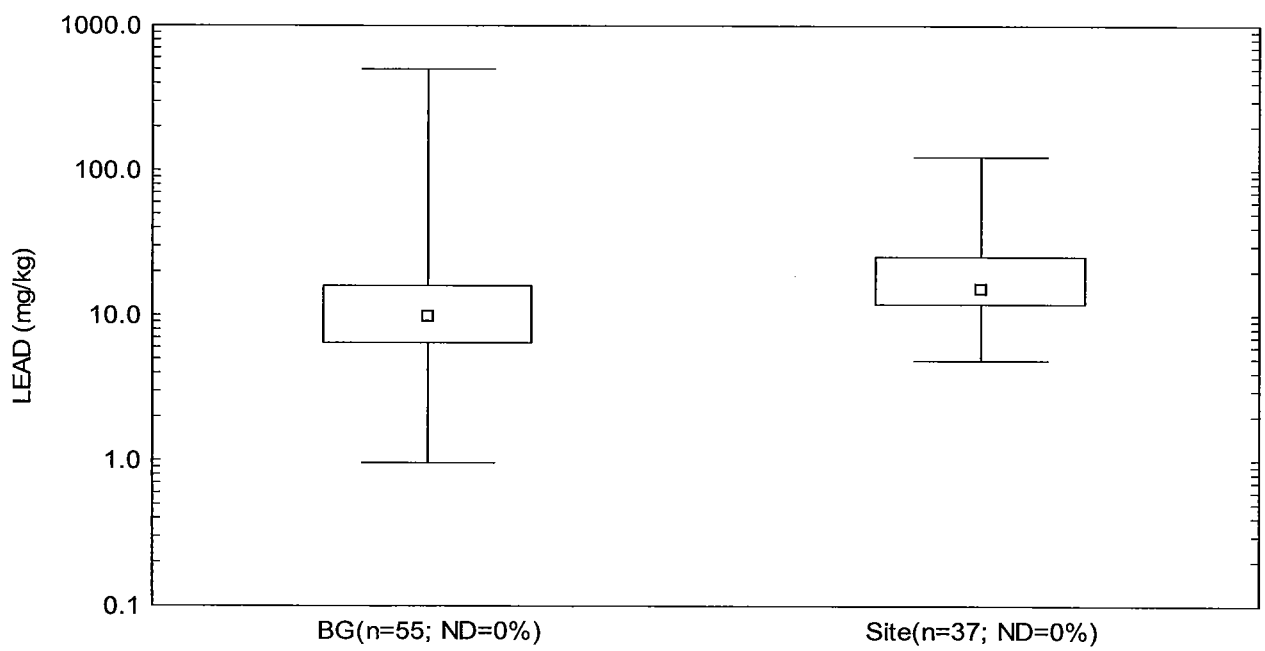


Figure 1-31. Box Plot Comparison for Magnesium in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

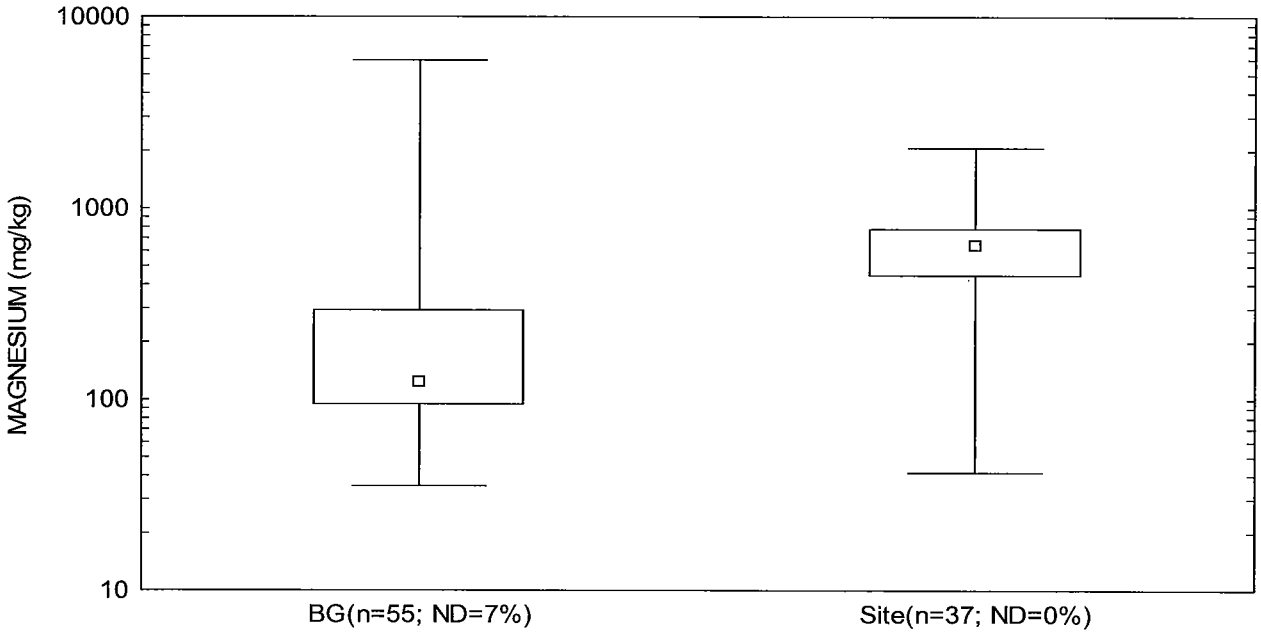


Figure 1-32. Box Plot Comparison for Manganese in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level = 0.018)

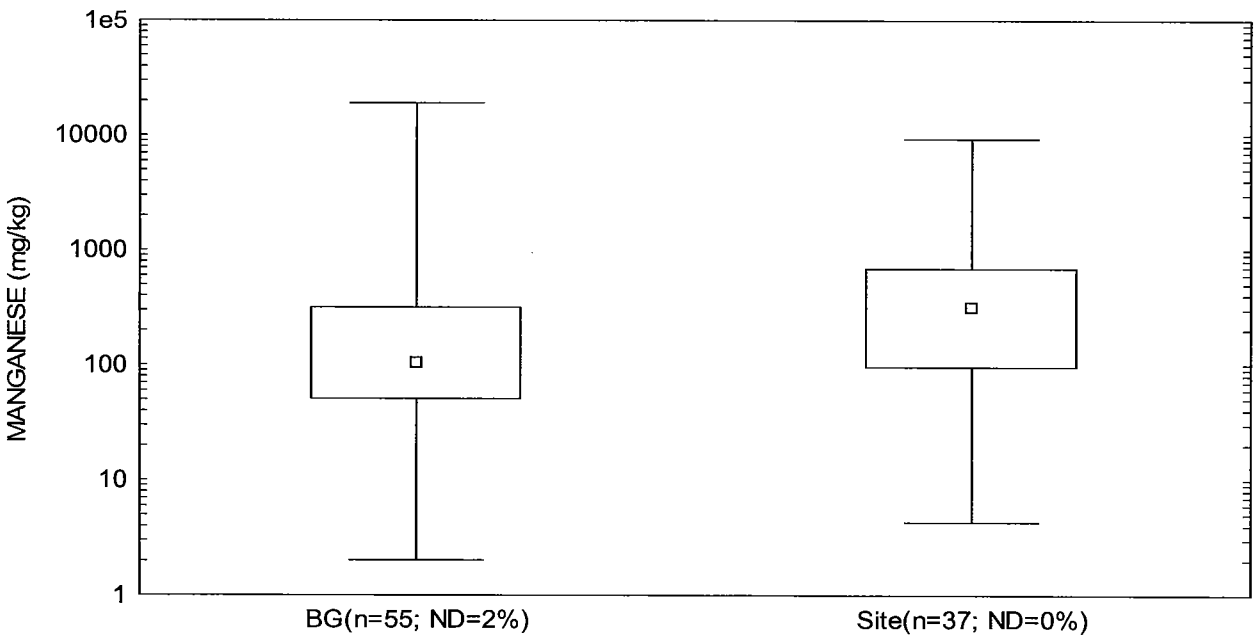


Figure 1-33. Box Plot Comparison for Mercury in Subsurface Soil
Area T-5, Ft. McClellan

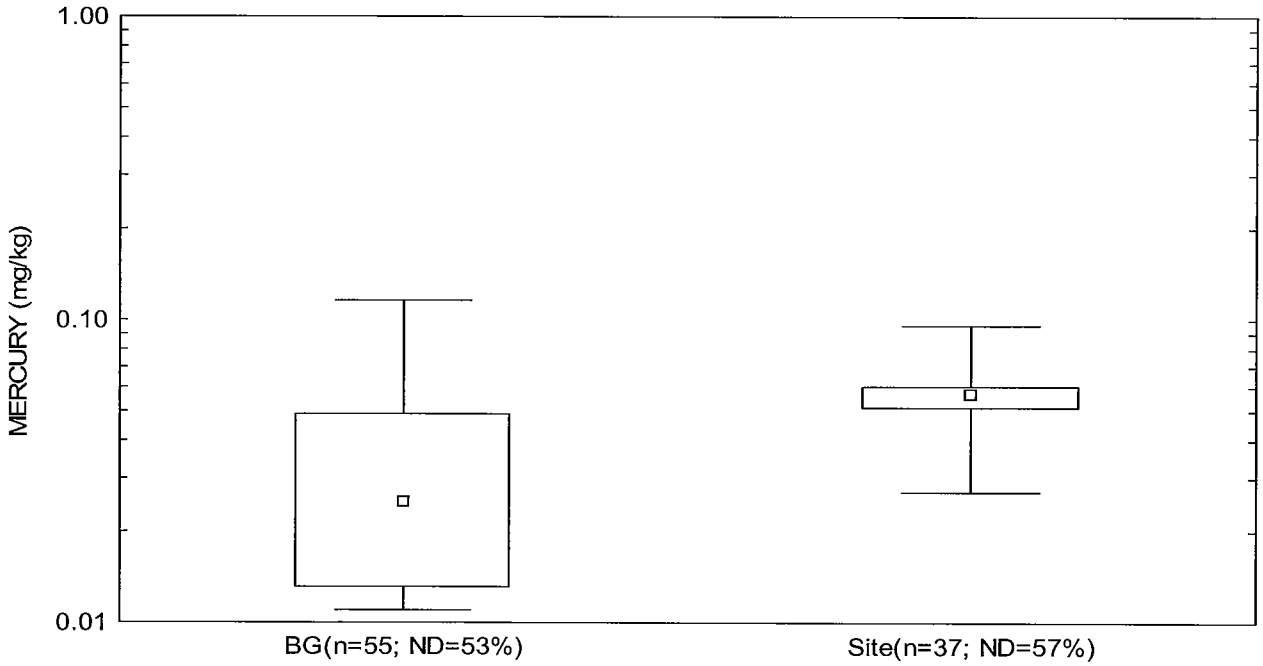


Figure 1-34. Box Plot Comparison for Nickel in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

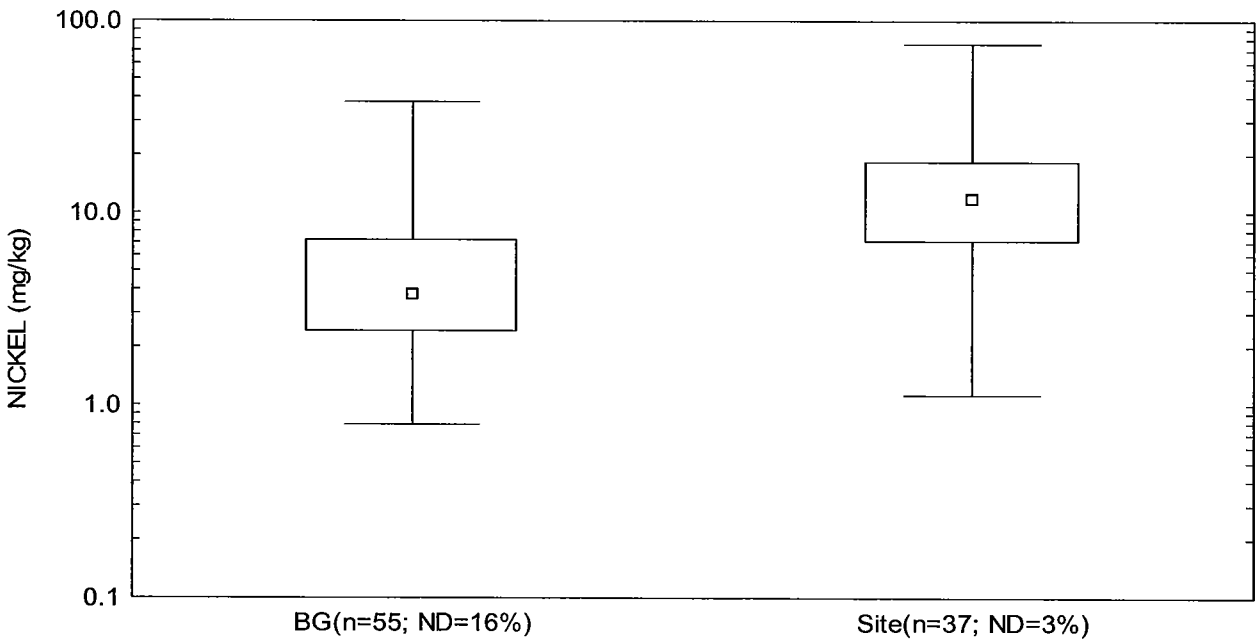


Figure 1-35. Box Plot Comparison for Potassium in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

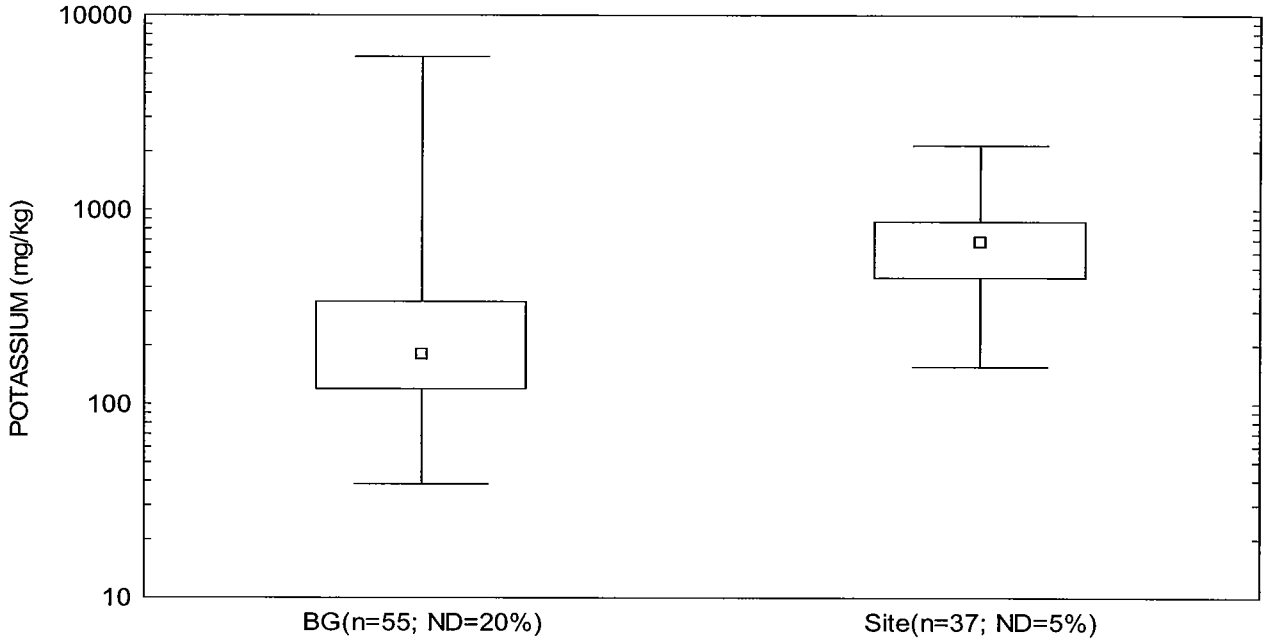


Figure 1-36. Box Plot Comparison for Selenium in Subsurface Soil
Area T-5, Ft. McClellan

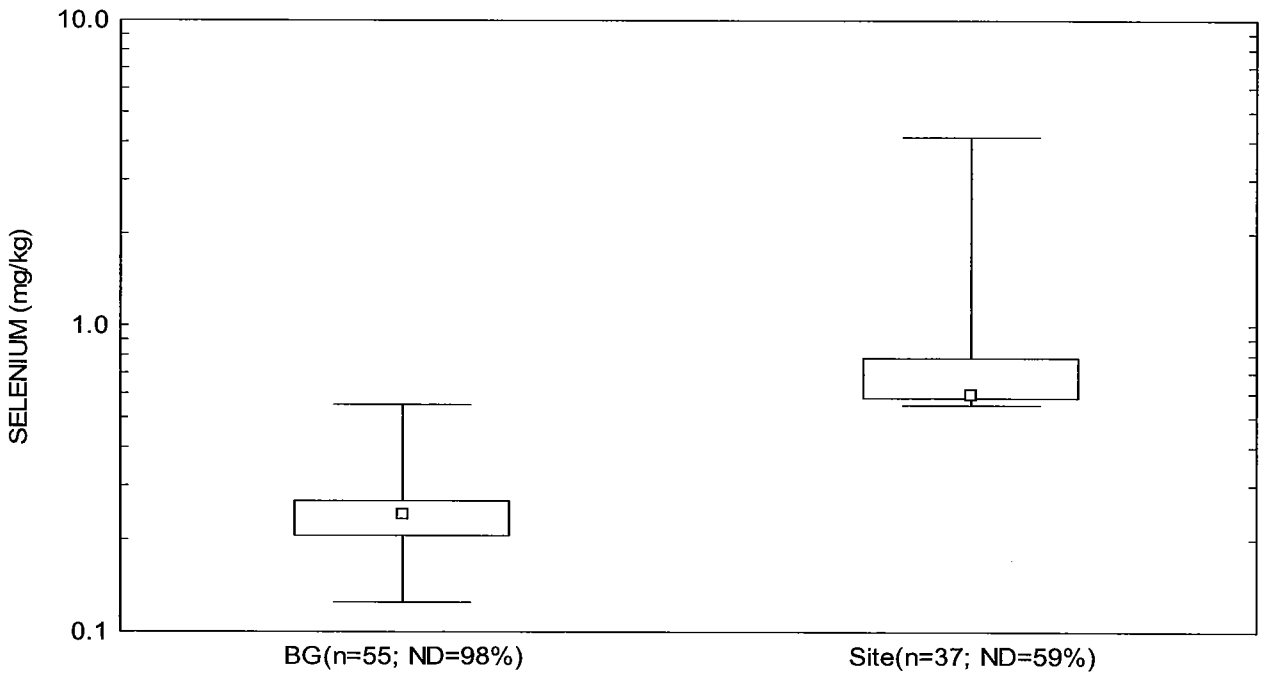


Figure 1-37. Box Plot Comparison for Silver in Subsurface Soil
Area T-5, Ft. McClellan

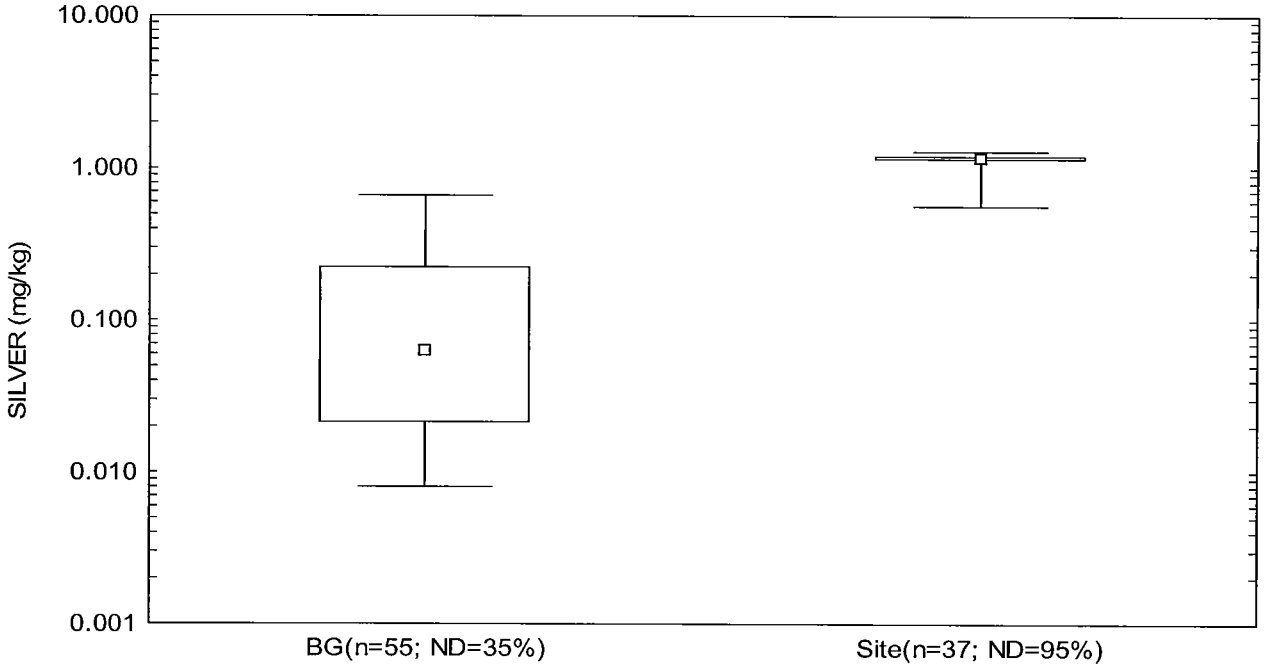


Figure 1-38. Box Plot Comparison for Thallium in Subsurface Soil
Area T-5, Ft. McClellan

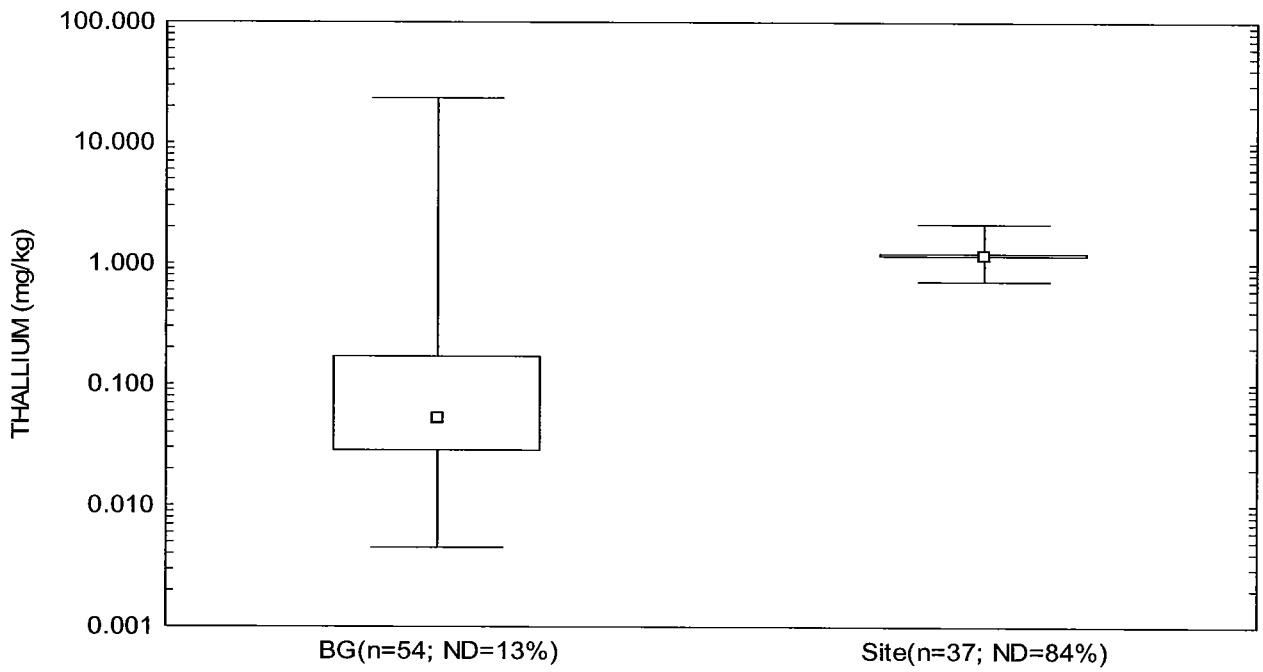


Figure 1-39. Box Plot Comparison for Vanadium in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level = 0.01)

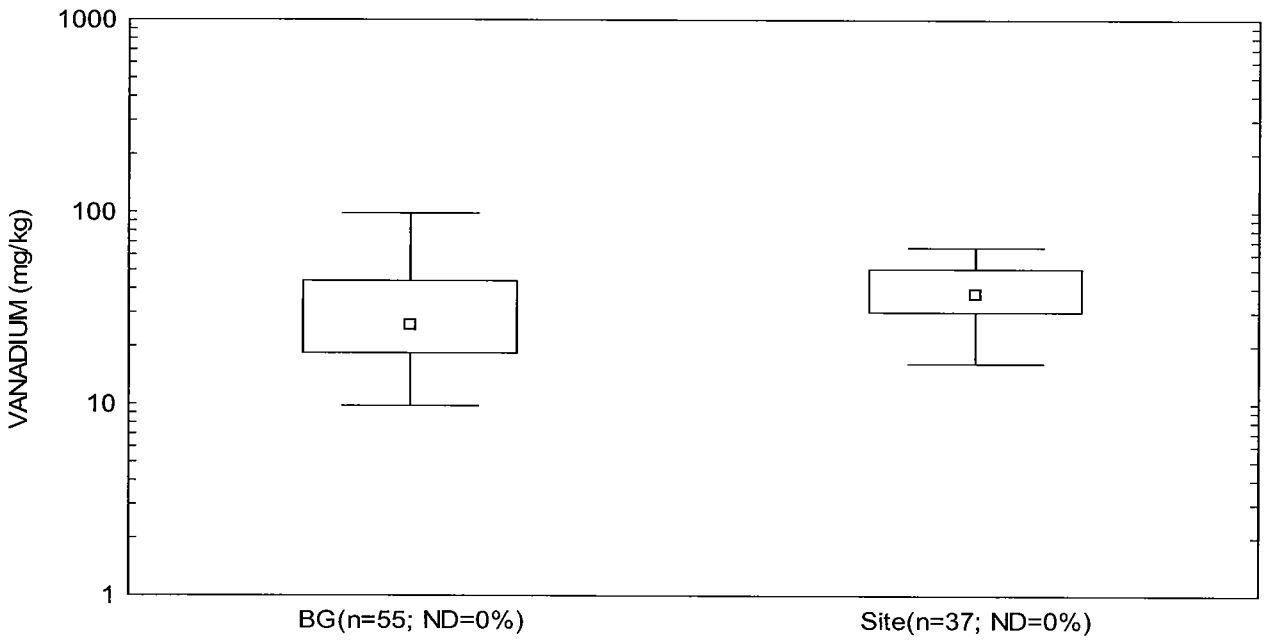


Figure 1-40. Box Plot Comparison for Zinc in Subsurface Soil
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

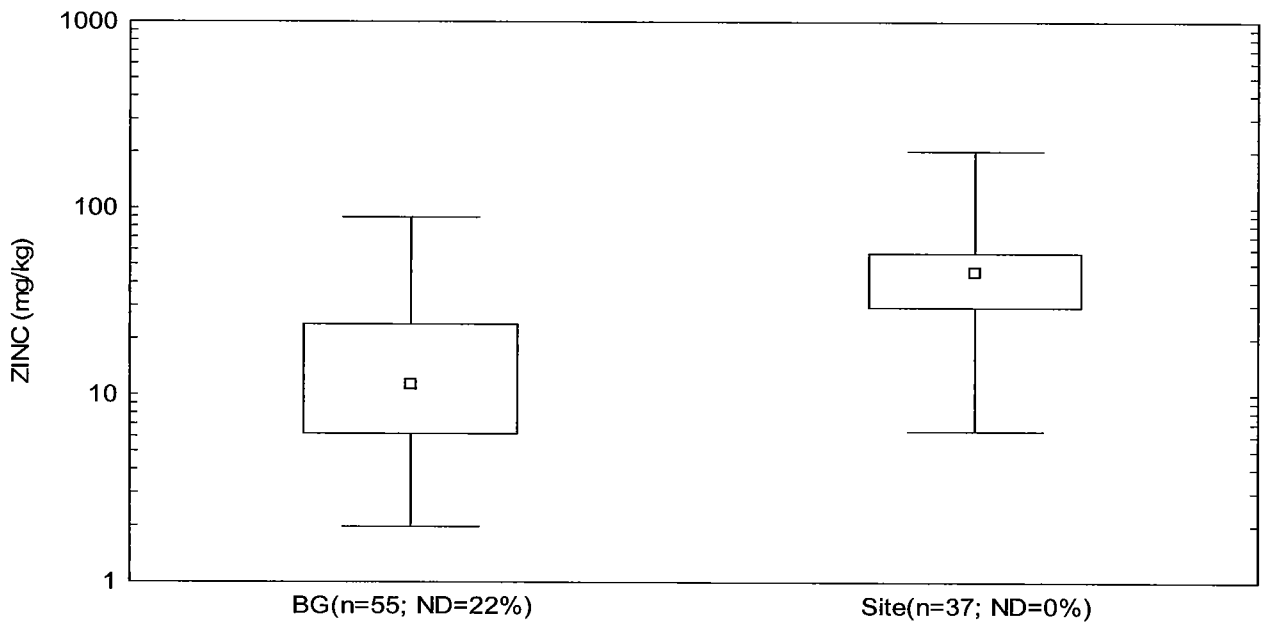


Figure 1-41. Box Plot Comparison for Aluminum in Groundwater
Area T-5, Ft. McClellan
(WRS Test p-level = 0.694)

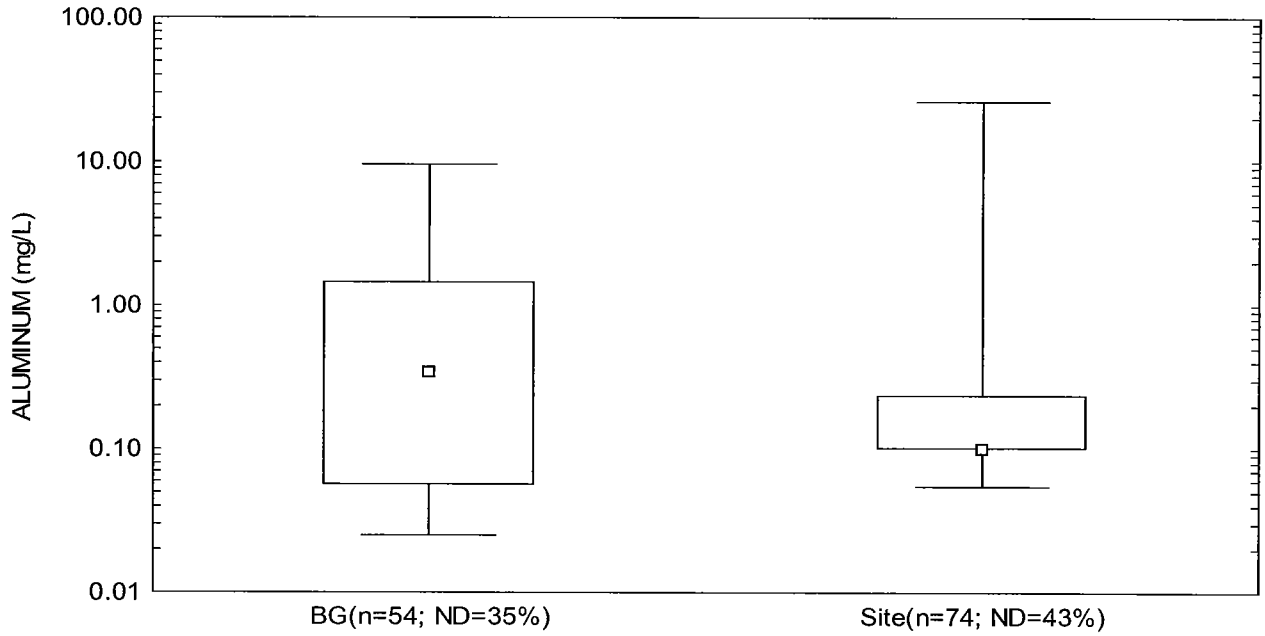


Figure 1-42. Box Plot Comparison for Arsenic in Groundwater
Area T-5, Ft. McClellan

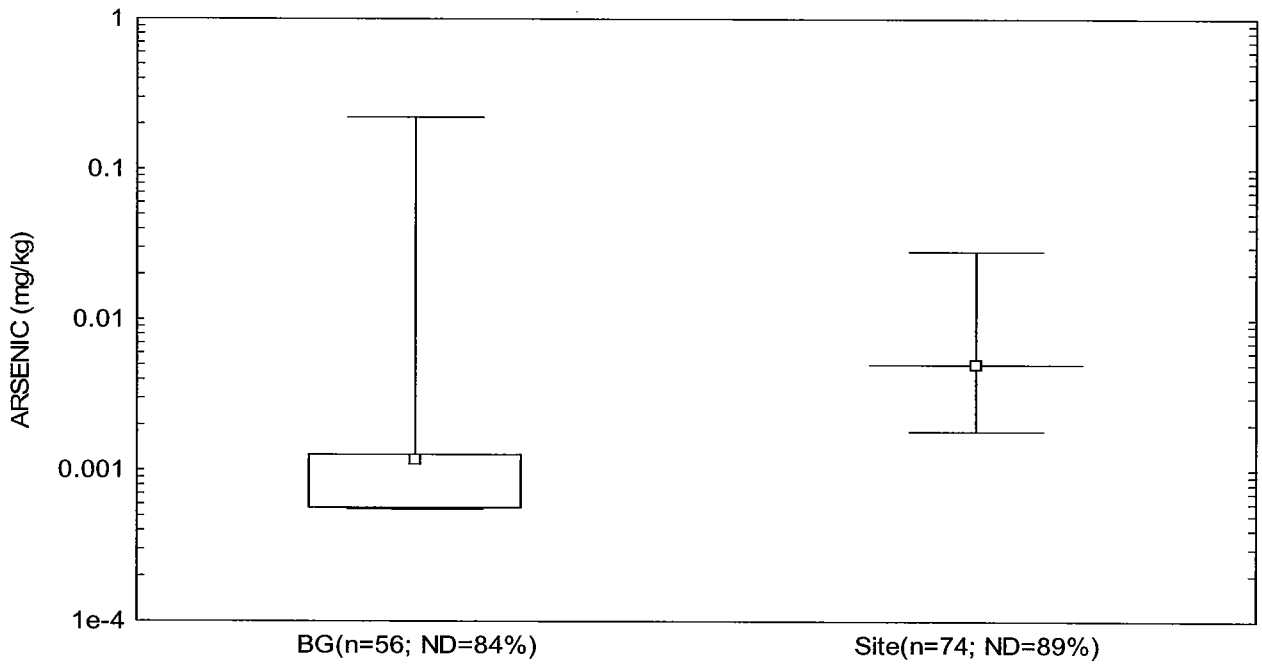


Figure 1-43. Box Plot Comparison for Barium in Groundwater
Area T-5, Ft. McClellan
(WRS Test p-level = 0.08)

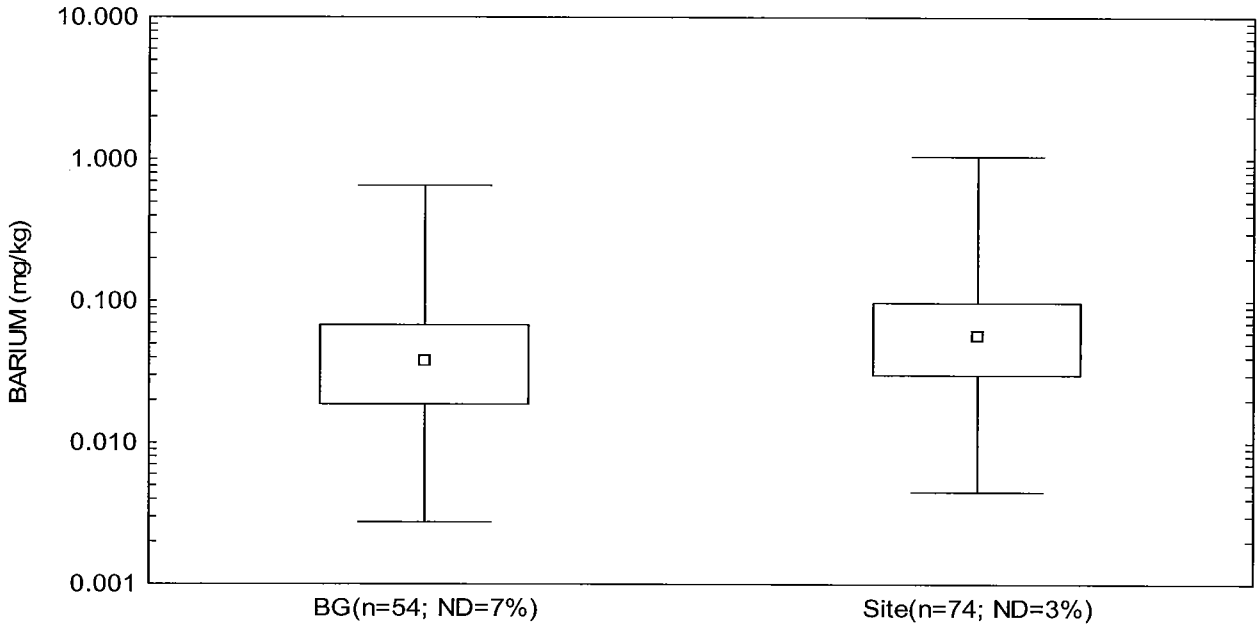


Figure 1-44. Box Plot Comparison for Beryllium in Groundwater
Area T-5, Ft. McClellan

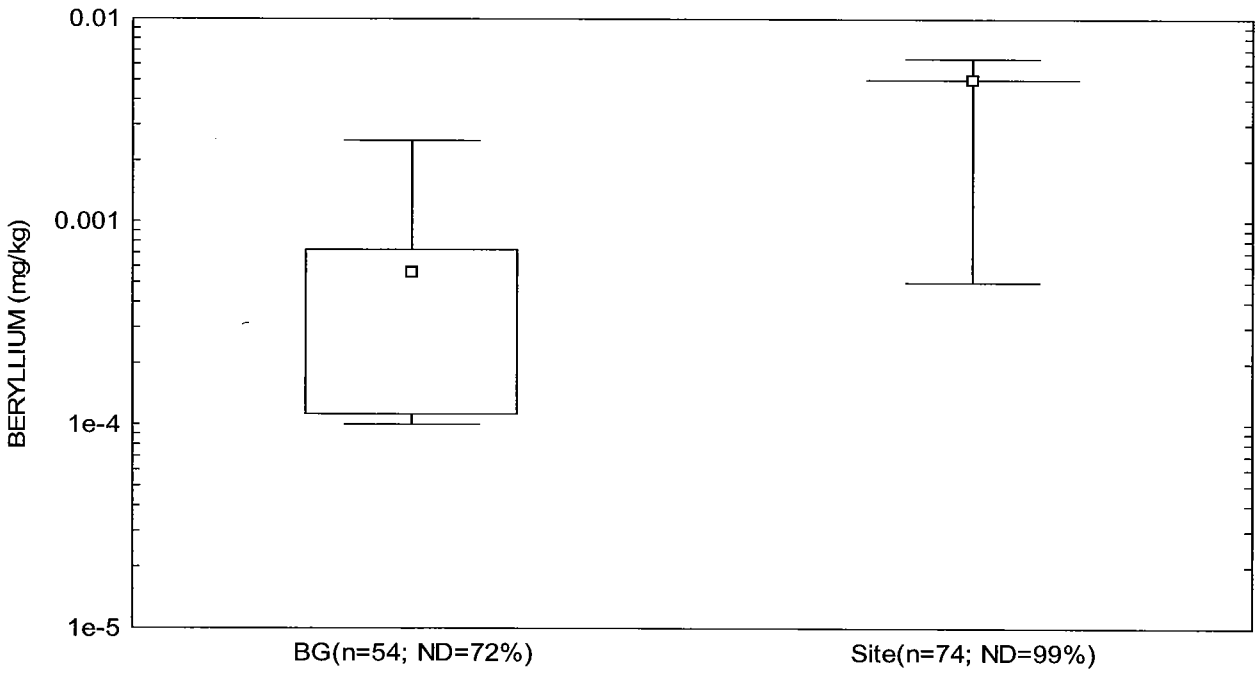


Figure 1-45. Box Plot Comparison for Cadmium in Subsurface Soil
Area T-5, Ft. McClellan

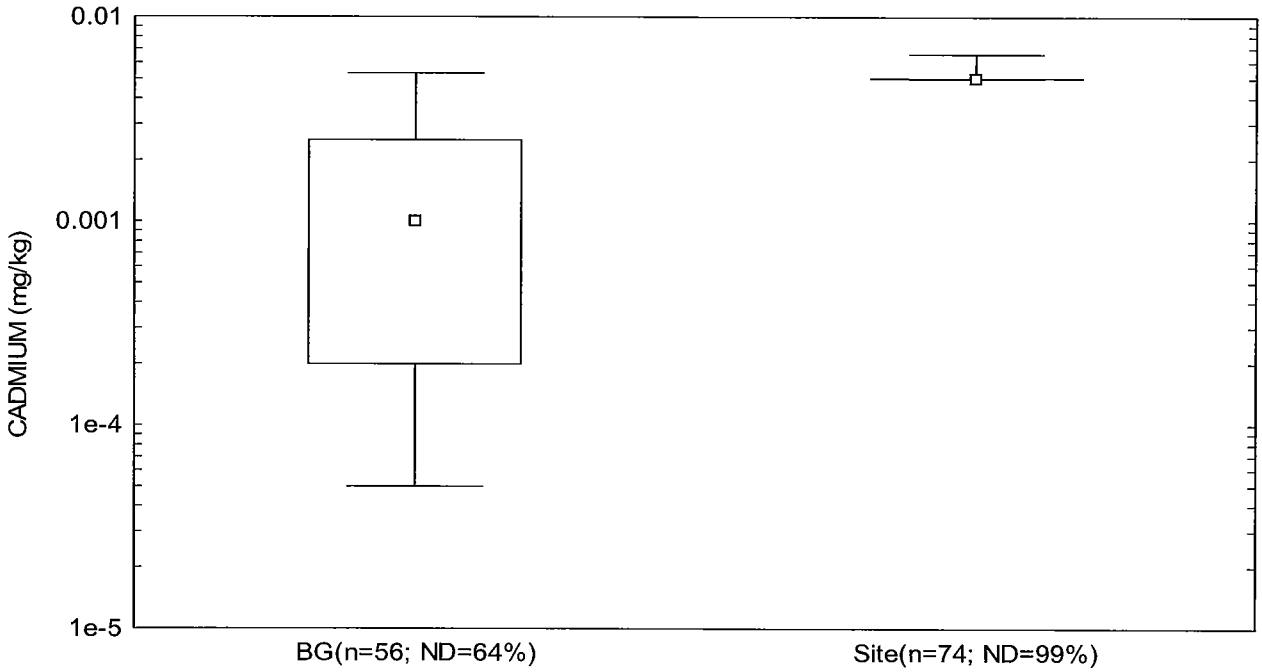


Figure 1-46. Box Plot Comparison for Calcium in Groundwater
Area T-5, Ft. McClellan
(WRS Test p-level = 0.027)

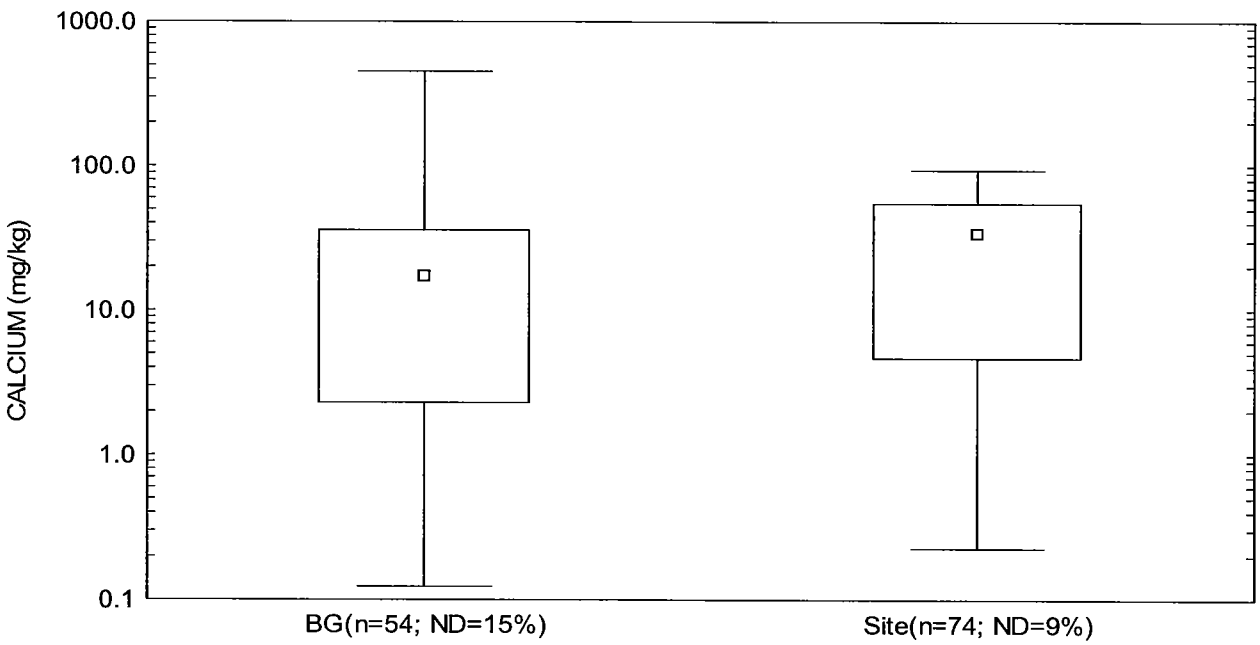


Figure 1-47. Box Plot Comparison for Chromium in Groundwater
Area T-5, Ft. McClellan

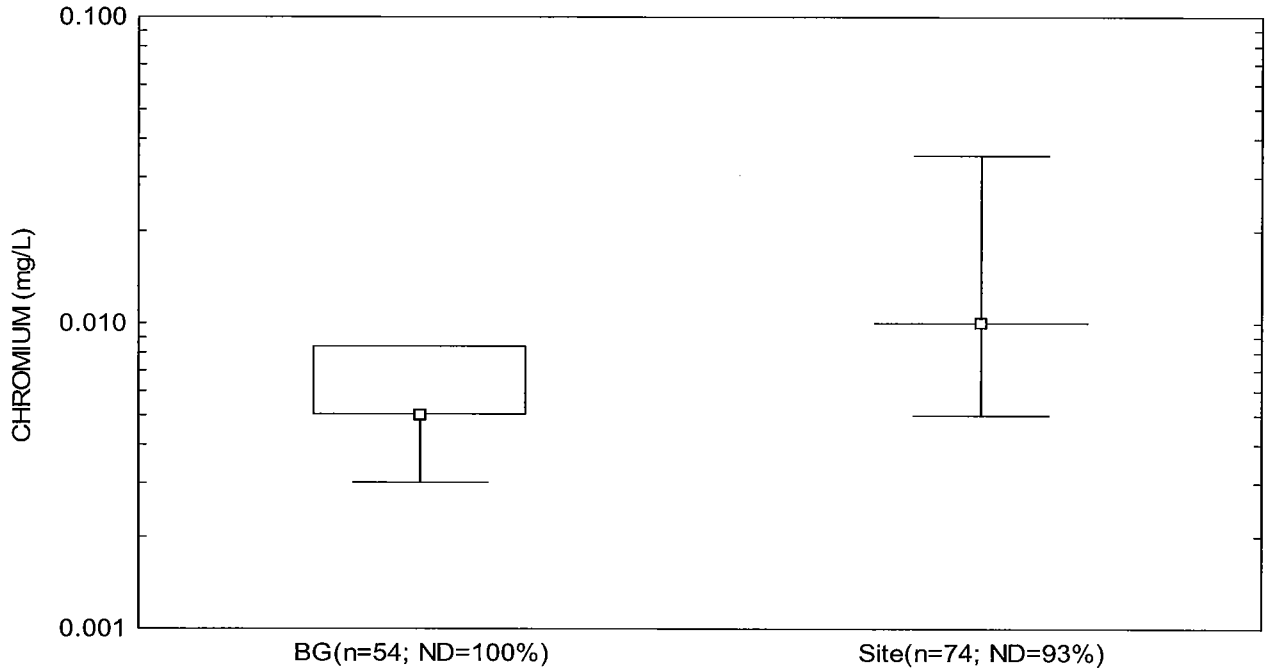


Figure 1-48. Box Plot Comparison for Cobalt in Groundwater
Area T-5, Ft. McClellan

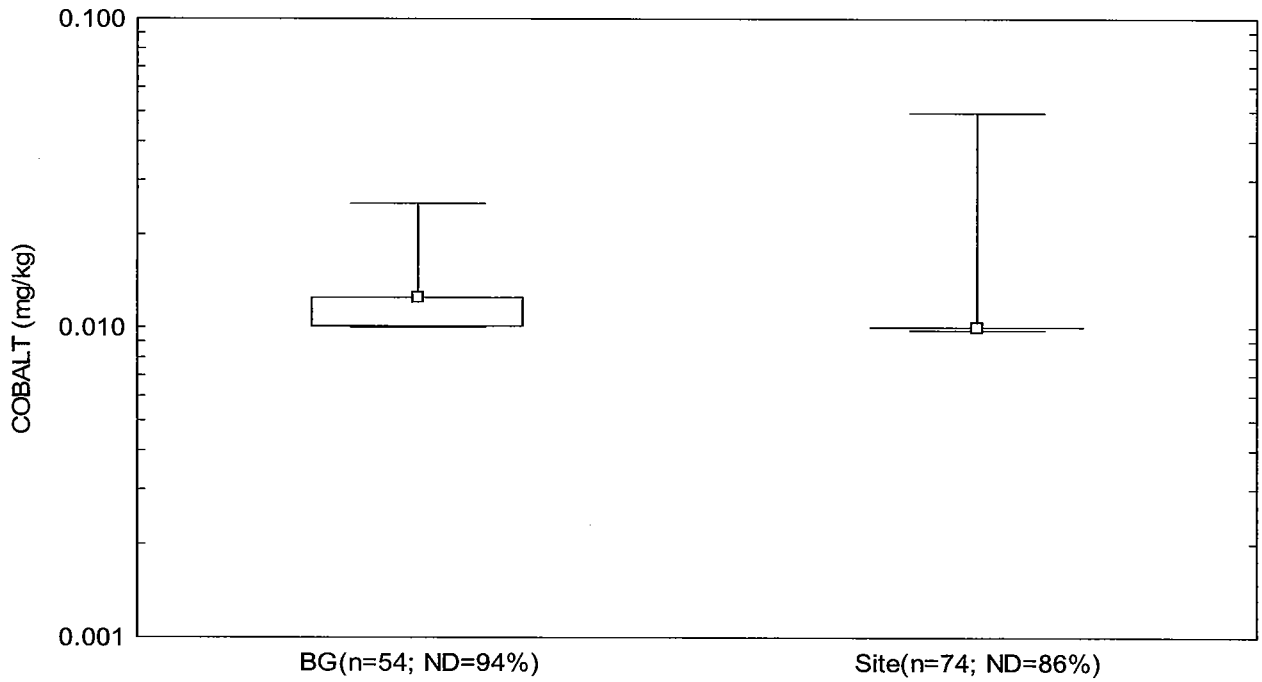


Figure 1-49. Box Plot Comparison for Copper in Groundwater
Area T-5, Ft. McClellan

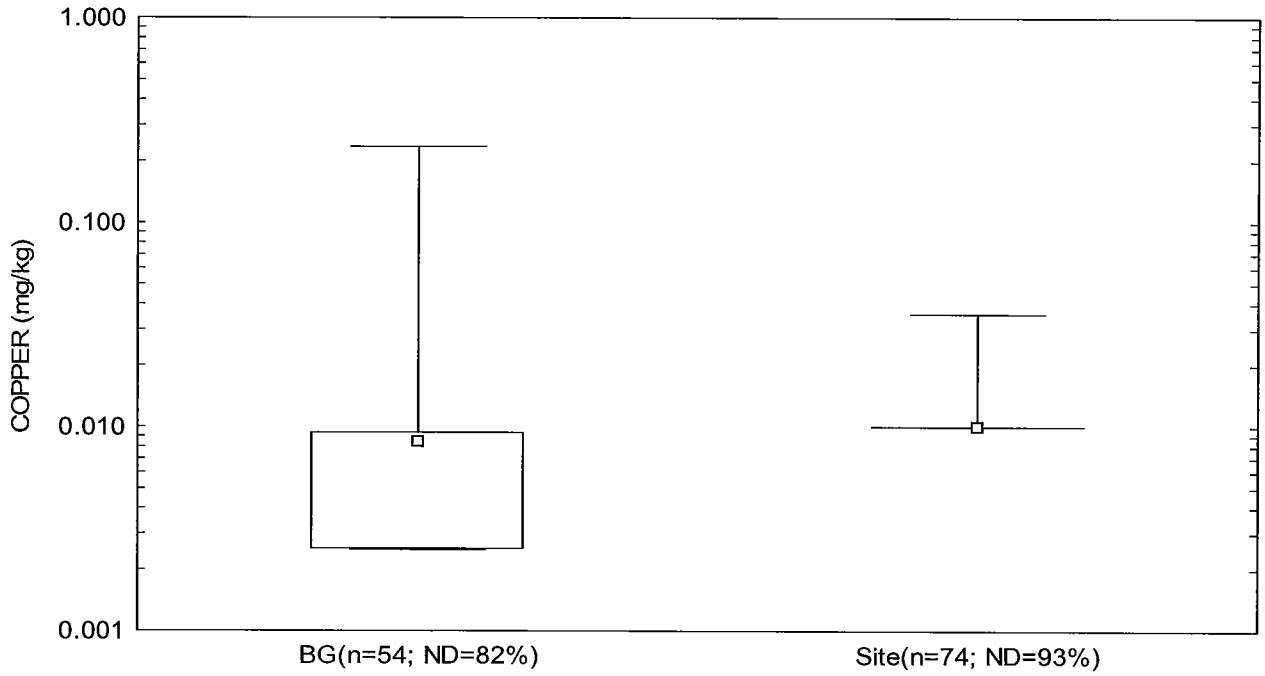


Figure 1-50. Box Plot Comparison for Iron in Groundwater
Area T-5, Ft. McClellan
(WRS Test p-level = 0.281)

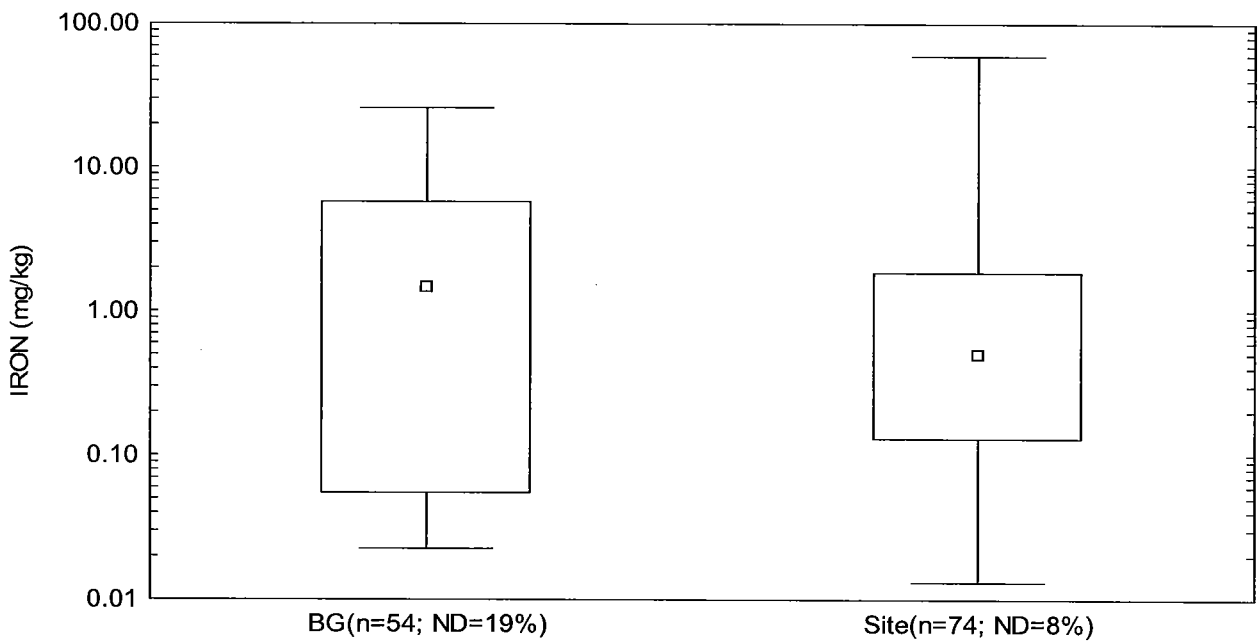


Figure 1-51. Box Plot Comparison for Lead in Groundwater
Area T-5, Ft. McClellan

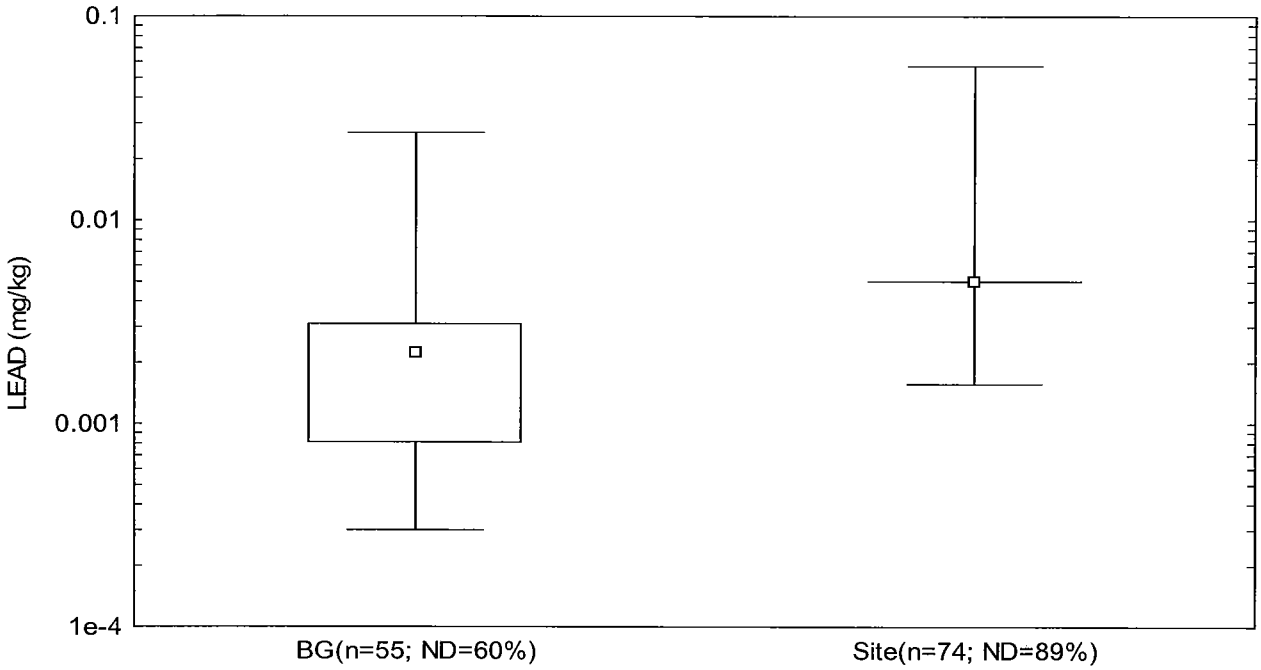


Figure 1-52. Box Plot Comparison for Manganese in Groundwater
Area T-5, Ft. McClellan
(WRS Test p-level = 0.011)

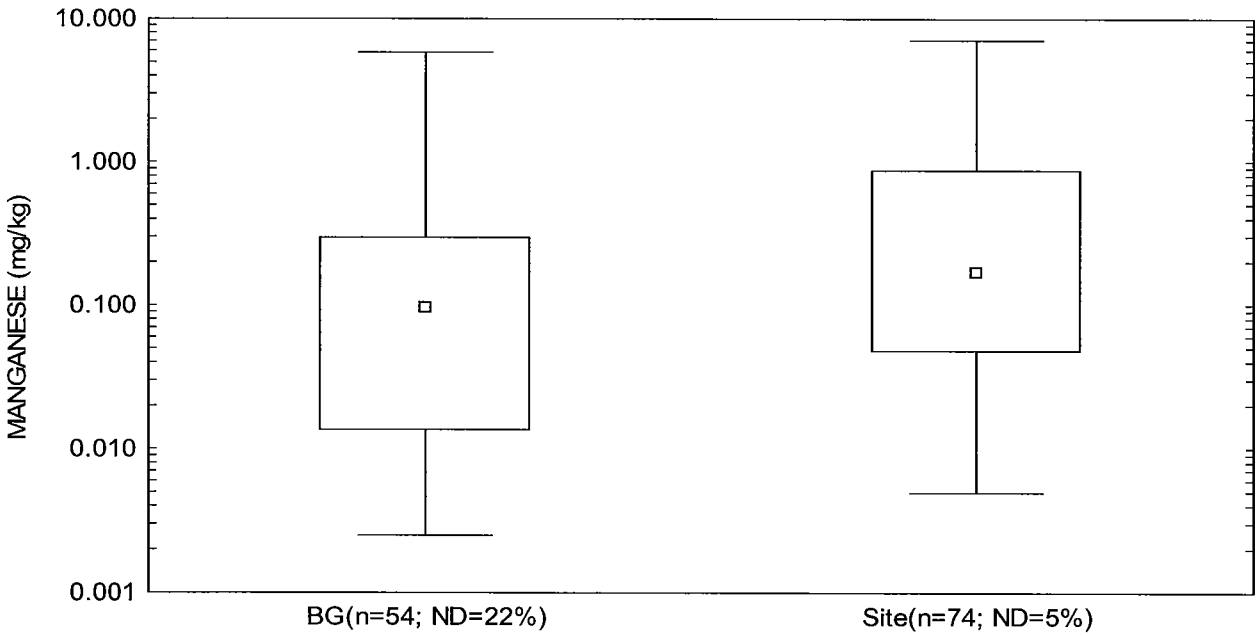


Figure 1-53. Box Plot Comparison for Potassium in Groundwater
Area T-5, Ft. McClellan

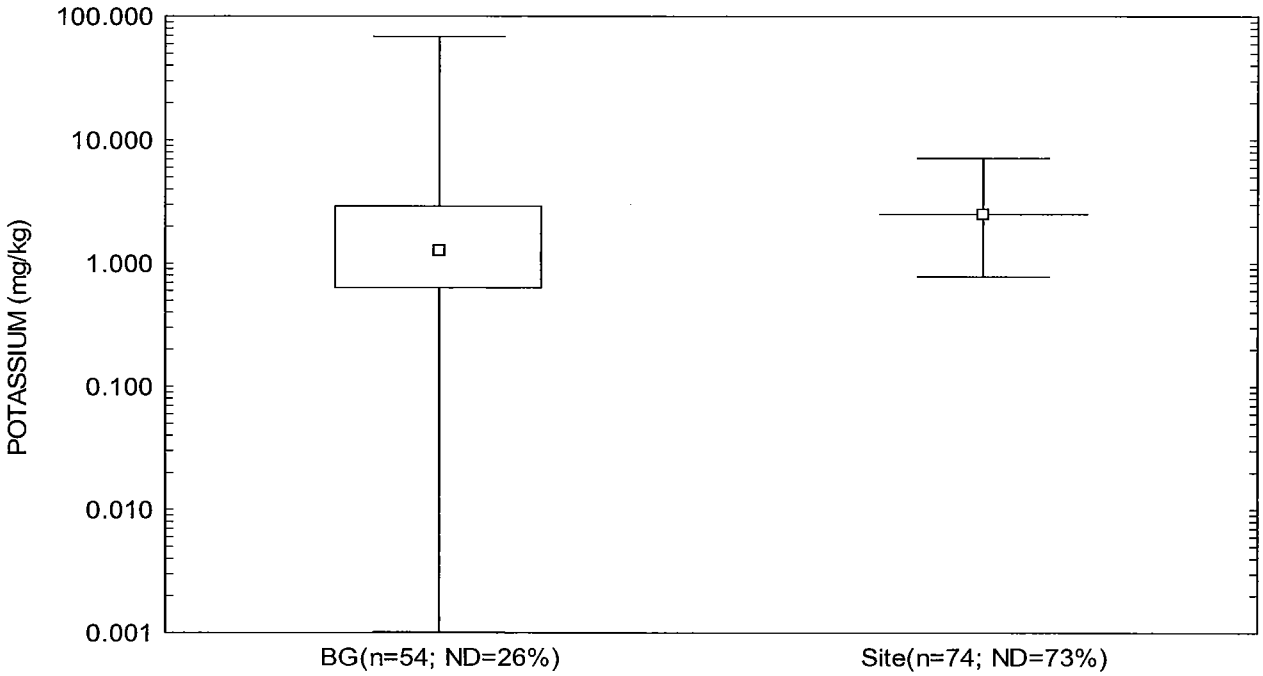


Figure 1-54. Box Plot Comparison for Sodium in Groundwater
Area T-5, Ft. McClellan

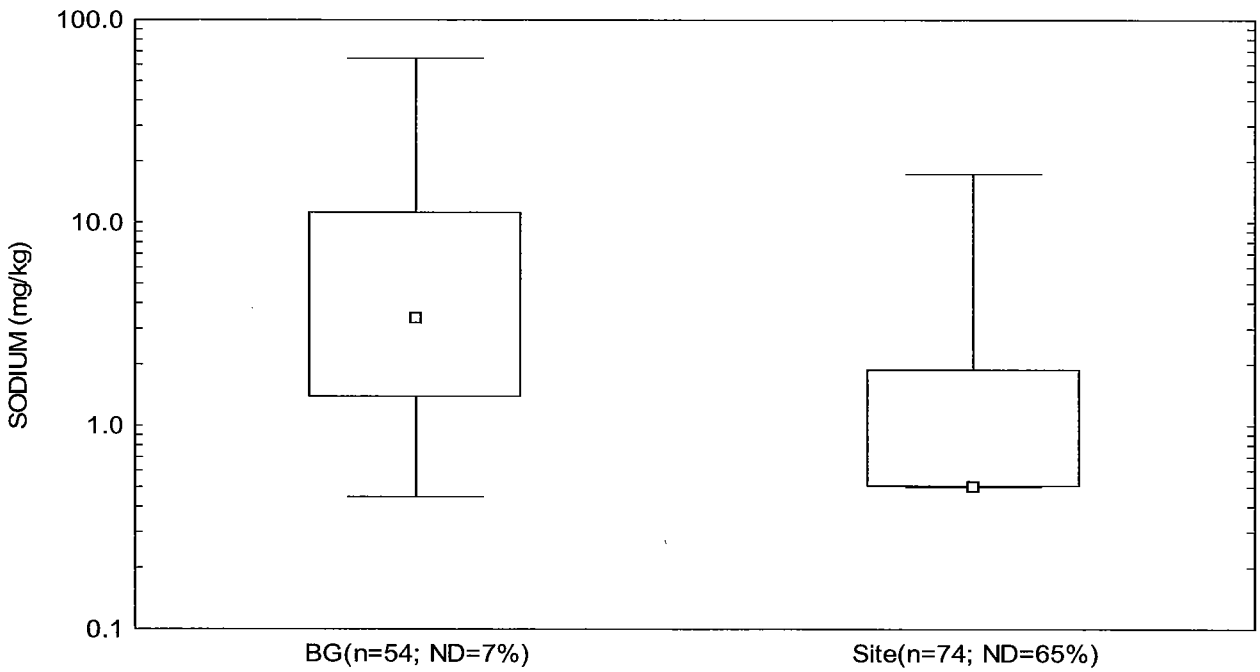


Figure 1-55. Box Plot Comparison for Thallium in Groundwater
Area T-5, Ft. McClellan

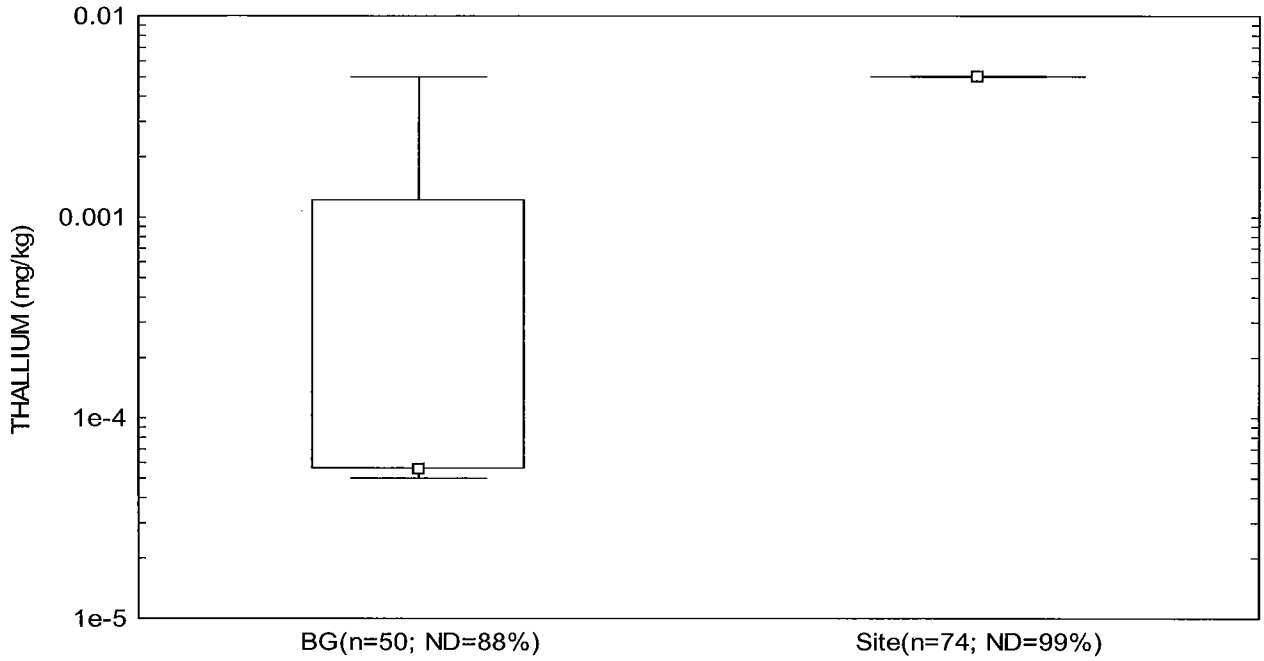


Figure 1-56. Box Plot Comparison for Vanadium in Groundwater
Area T-5, Ft. McClellan

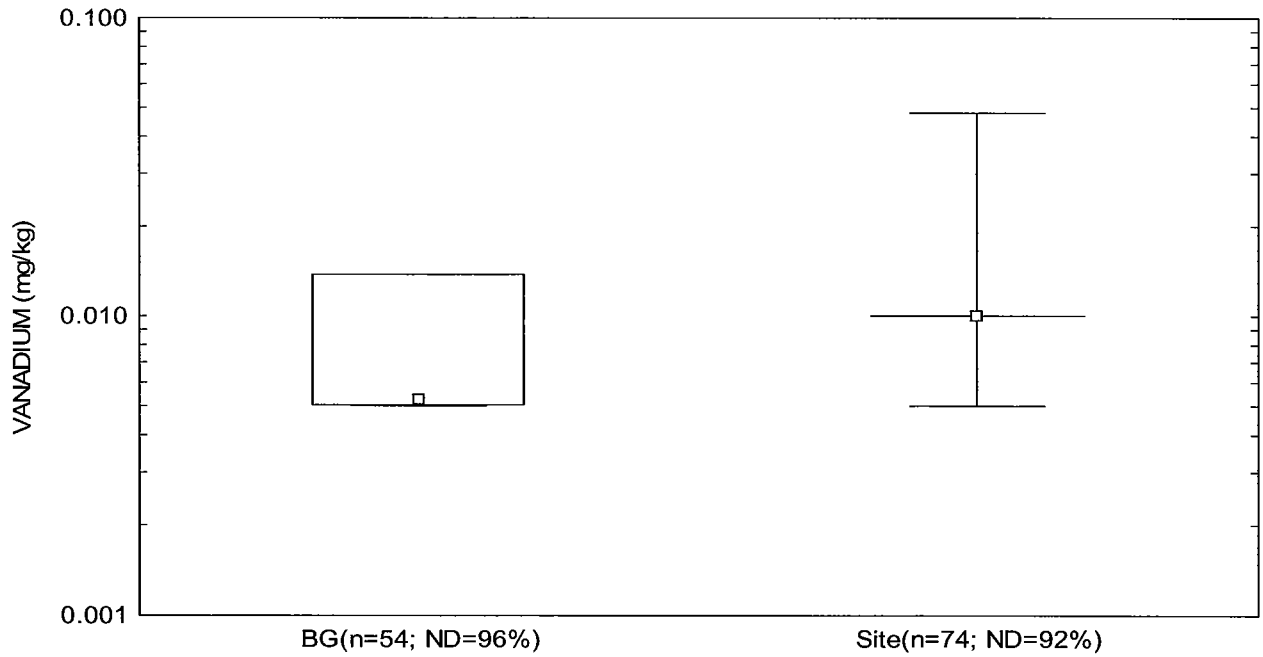


Figure 1-57. Box Plot Comparison for Zinc in Groundwater
Area T-5, Ft. McClellan

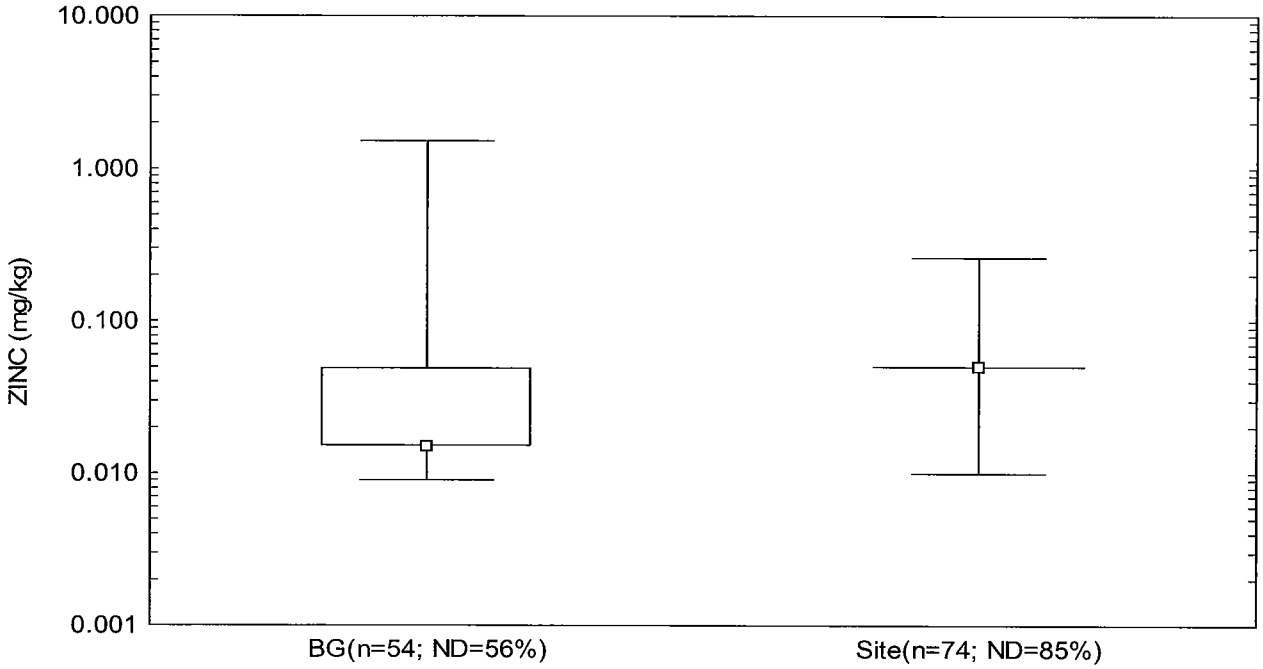


Figure 1-58. Box Plot Comparison for Cadmium in Sediment
Area T-5, Ft. McClellan
(WRS Test p-level < 0.001)

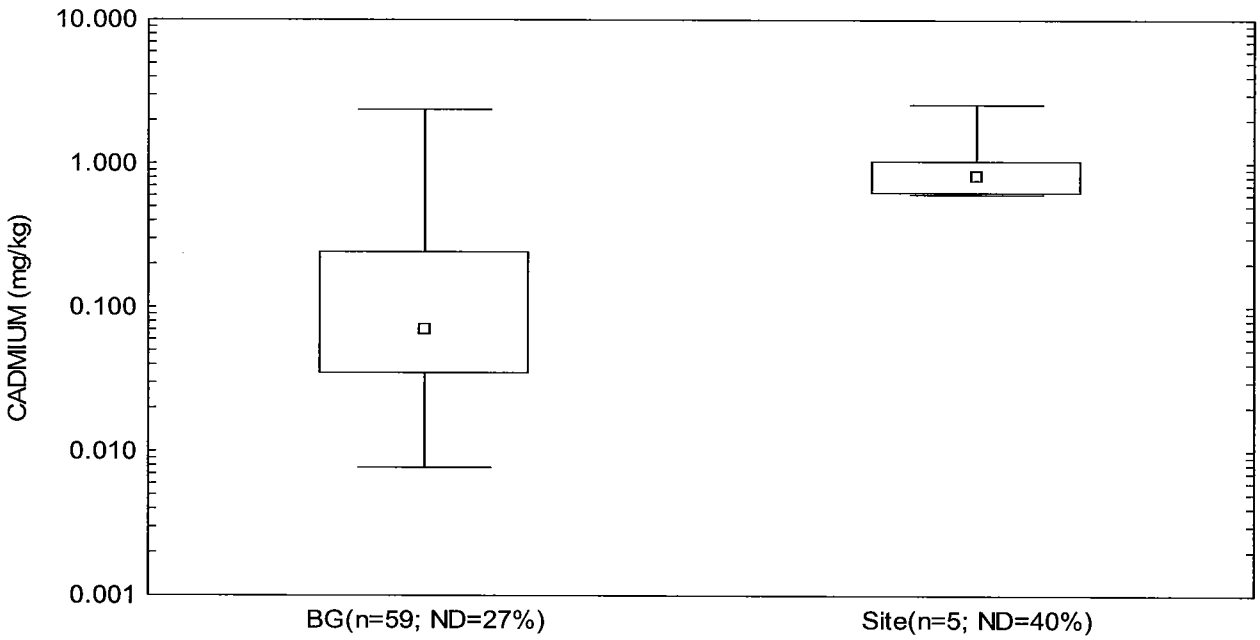


Figure 1-59. Box Plot Comparison for Chromium in Sediment
Area T-5, Ft. McClellan
(WRS Test p-level = 0.137)

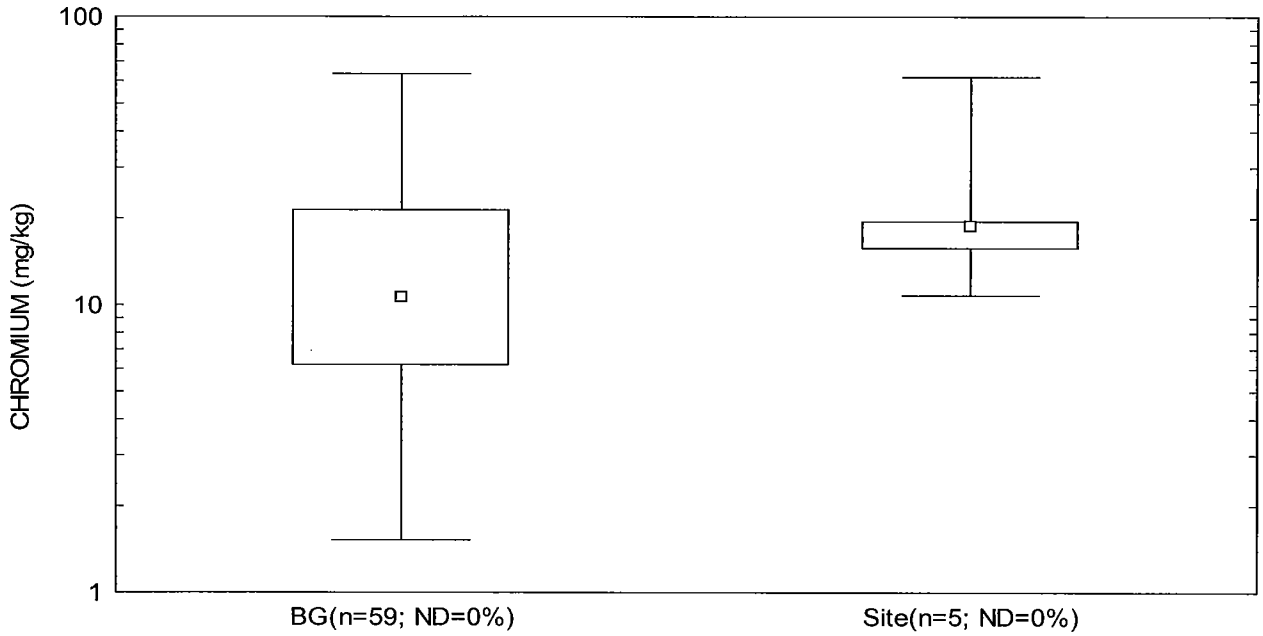


Figure 1-60. Box Plot Comparison for Cobalt in Sediment
Area T-5, Ft. McClellan
(WRS Test p-level = 0.28)

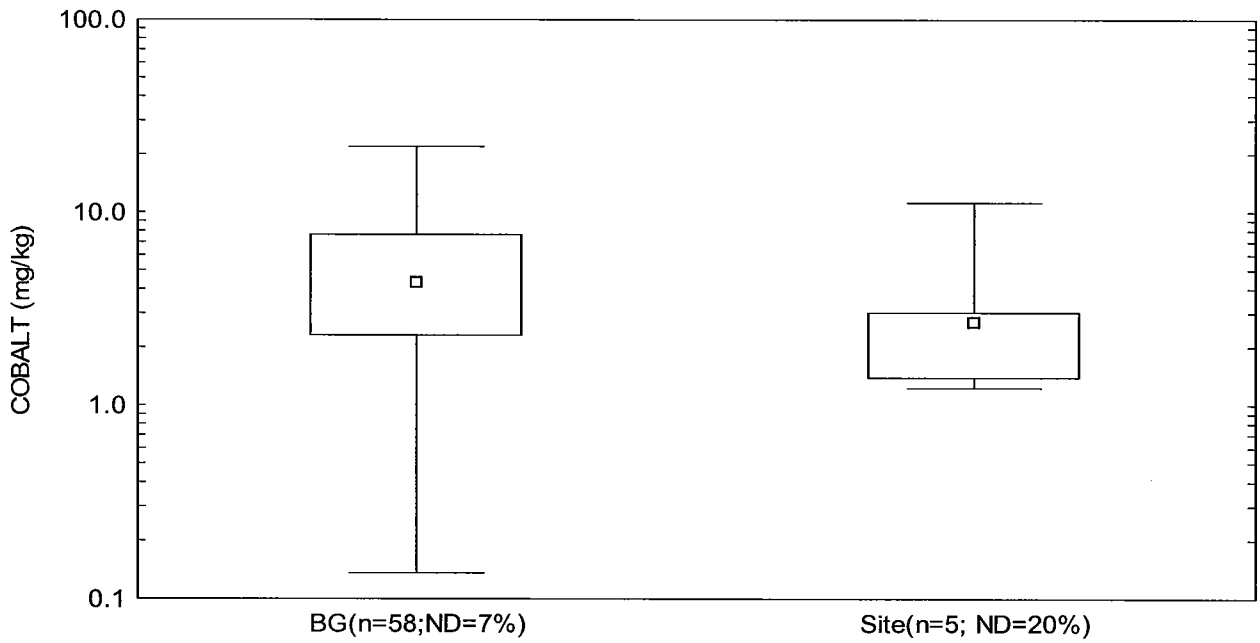


Figure 1-61. Box Plot Comparison for Copper in Sediment
Area T-5, Ft. McClellan
(WRS Test p-level = 0.004)

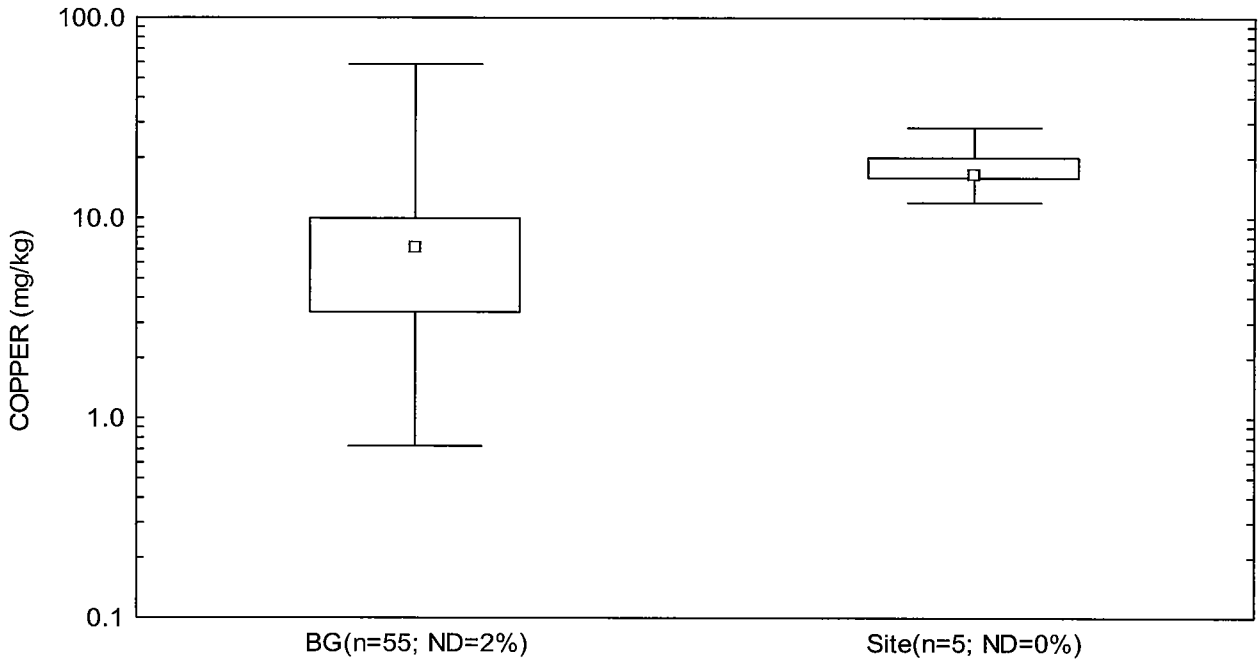


Figure 1-62. Box Plot Comparison for Zinc in Sediment
Area T-5, Ft. McClellan
(WRS Test p-level = 0.107)

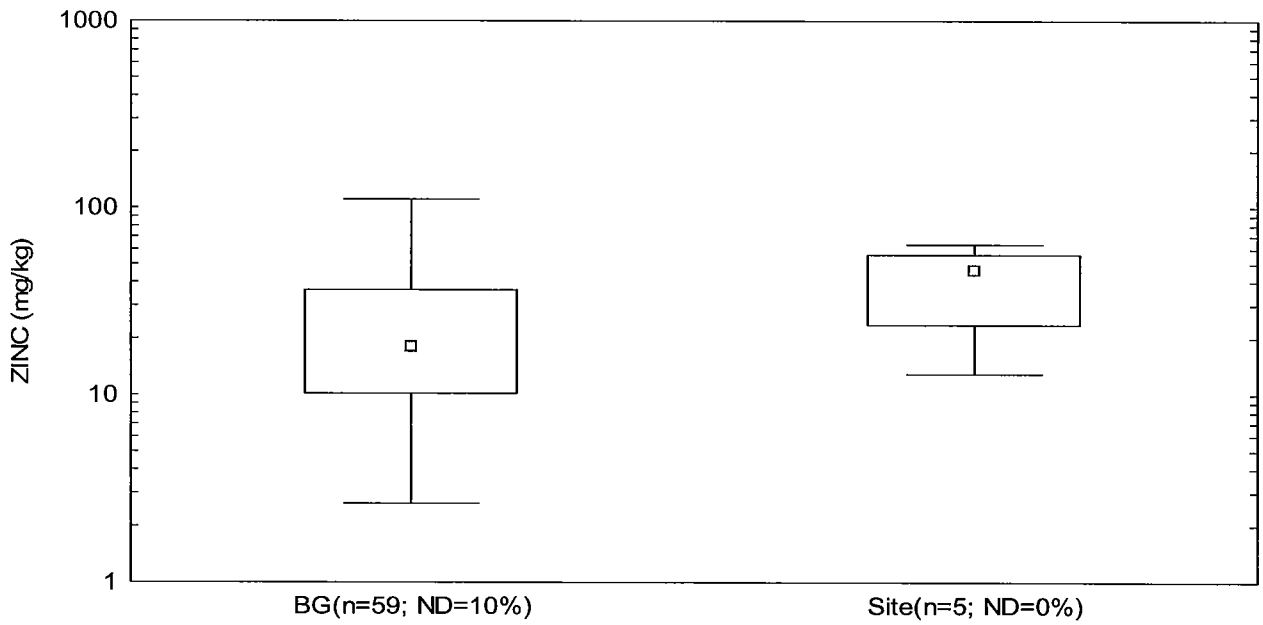
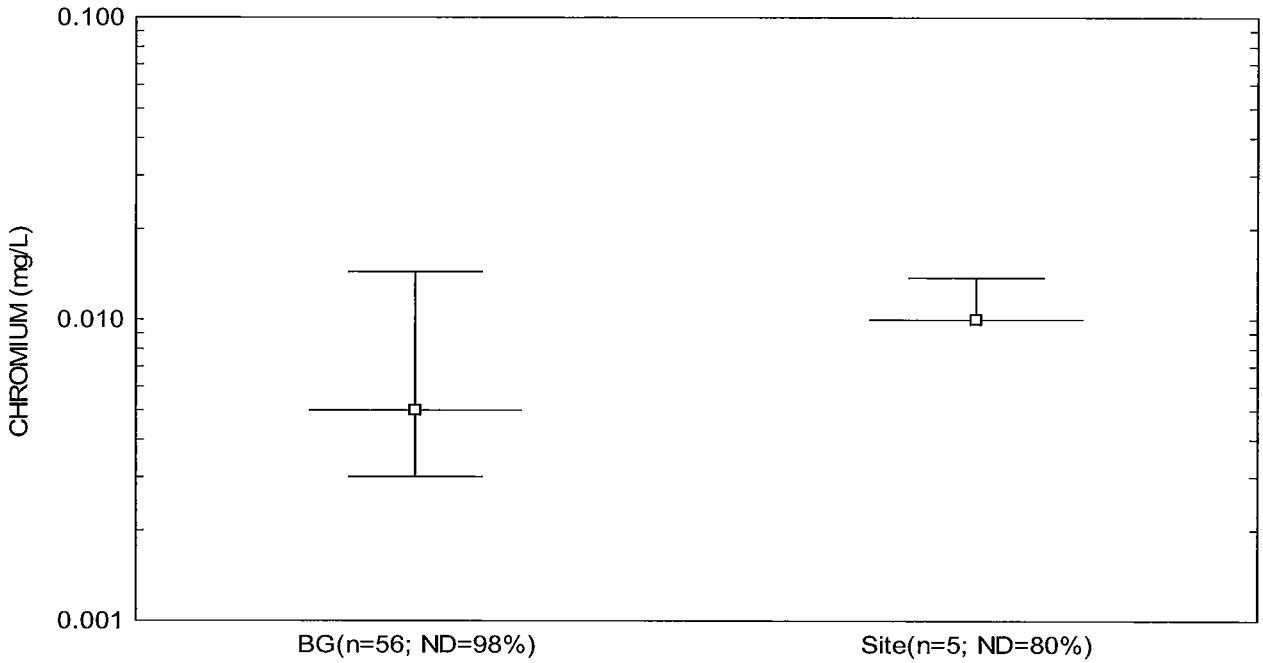


Figure 1-63. Box Plot Comparison for Chromium in Surface Water
Area T-5, Ft. McClellan



GEOCHEMICAL
(TIER 3)

Geochemical Evaluation of Metals in Site Media
Training Area T-5 Sites
Fort McClellan, Alabama

1.0 Introduction

This report provides the results of a geochemical evaluation of inorganic constituents in soil, sediment, groundwater, and surface water samples from the Training Area T-5 Sites located at Fort McClellan in Calhoun County, Alabama. Twenty elements in soil, four elements in sediment, nine elements in groundwater, and one element in surface water failed statistical comparison to background. A geochemical evaluation was performed to determine if the elevated concentrations are naturally occurring or if they contain a component of contamination.

Site samples included in the evaluation consist of 53 surface soil samples (obtained from depths of 0 to 0.5 or 0 to 1 foot below ground surface [bgs]) and 37 subsurface soil samples (obtained from various depths ranging from 1 to 12 feet bgs) collected from January 2001 through June 2003; 5 sediment samples collected in February 2002 and January 2003; 74 groundwater samples collected from April 2001 to April 2003; and 5 surface water samples collected in February 2002 and January 2003. All of the site samples were analyzed for the full suite of 23 target analyte list (TAL) metals. Installation-wide background data for TAL metals in soil, sediment, groundwater, and surface water are provided in the background study report (Science Applications International Corporation, 1998) and are used in the following evaluation.

2.0 Geochemical Evaluation Methodology

Statistical site-to-background comparisons for trace elements in soil commonly have high false-positive error rates. A large number of background samples is required to adequately characterize the upper tails of most trace element distributions, which are typically right skewed and span a wide range of concentrations, but such a large background data set is not always feasible. Higher false positive error rates are expected if the site sample size is greater than the background sample size. The presence of estimated concentrations and nondetects with differing reporting limits can also cause statistical comparison tests to fail.

Statistical tests consider only the absolute concentrations of individual elements, and they disregard the interdependence of element concentrations and the geochemical mechanisms controlling element behavior. However, it is well established that trace elements are naturally associated with specific soil-forming minerals, and the preferential enrichment of a sample with

these minerals will result in elevated trace element concentrations. It is thus important to be able to identify these naturally high concentrations and distinguish them from potential contamination.

If an analyte fails statistical comparison to background as described in the "Statistical Comparison of Site and Background Data for Training Area T-5," then a geochemical evaluation is performed to determine if the elevated concentrations are caused by natural processes. Recent publications indicate that geochemical evaluations are assuming a larger role in environmental investigations (e.g., U.S. Environmental Protection Agency, 1995; Barclift, *et al*., 2000; U.S. Navy, 2002 and 2003; Myers and Thorbjornsen, 2004). A properly executed geochemical evaluation can reveal the mechanisms responsible for naturally high element concentrations, and can identify the samples with anomalously high concentrations that may reflect site-related contamination. This section describes the geochemical evaluation techniques that were employed in the site-to-background comparison for Training Area T-5. Additional supporting information on these techniques is provided in the installation-wide work plan (IT Corporation, 2002) and Shaw Environmental's technical memorandum dated June 24, 2003.

It should be noted that the geochemical evaluations rely in part on professional judgment and qualitative assessment is a necessary part of the process. Samples that plot off the linear trend on a correlation plot are certainly suspect, but because all uncertainty cannot be eliminated from the evaluation, such plots cannot be construed as definitive proof of contamination. However, anomalous samples should be flagged as suspect and their results used as a basis for further investigation, risk assessment, or remediation, as appropriate. The combination of statistical evaluations (Tiers 1 and 2) and geochemical evaluation (Tier 3) as presented in this appendix is effective in reducing the occurrences of decision errors relative to consideration of statistics or geochemistry alone.

2.1 Soil and Sediment

Trace elements naturally associate with specific soil-forming minerals, and geochemical evaluations are predicated on these known associations. For example, in most uncontaminated oxic soils, arsenic exhibits an almost exclusive association with iron oxide minerals (Bowell, 1994; Schiff and Weisberg, 1997). Arsenic exists in oxic soil pore fluid as oxyanions such as $HAsO_4^{-2}$ and $H_2AsO_4^{-}$ (Brookins, 1988), and these negatively charged species have a strong affinity to adsorb on iron oxides, which tend to maintain a net positive surface charge (Electric Power Research Institute [EPRI], 1986). (In this report the term "iron oxide" encompasses oxides, hydroxides, oxyhydroxides, and hydrous oxides of iron.) This association is expressed as

a positive correlation between arsenic concentrations and iron concentrations for uncontaminated samples: soil samples with a low percentage of iron oxides will contain proportionally lower arsenic concentrations, and soil samples that are enriched in iron oxides will contain proportionally higher arsenic concentrations. Although there is variability in the absolute concentrations of arsenic and iron in soil at a site, the As/Fe ratios of the samples will be relatively constant if no contamination is present (Daskalakis and O'Connor, 1995). Samples that contain excess arsenic from a contaminant source (e.g., arsenic-bearing compounds such as the chemical warfare agent lewisite or certain herbicides) will exhibit anomalously high As/Fe ratios compared to the uncontaminated samples.

To perform the geochemical evaluation, correlation plots are constructed to explore the elemental associations and identify potentially contaminated samples. The detected concentrations of the trace element of interest (dependent variable) are plotted against the detected concentrations of the reference element (independent variable), which represents the mineral to which the trace element may be adsorbed. In the case of arsenic, the arsenic concentrations for a given set of samples would be plotted on the y-axis and the corresponding iron concentrations would be plotted on the x-axis. If no contamination is present, then the samples will exhibit a generally linear trend and the samples with the highest arsenic concentrations will lie on this trend. This indicates that the elevated arsenic is due to the preferential enrichment of iron oxides in those samples, and that the arsenic has a natural source. If, however, the samples with high arsenic concentrations have low or moderate iron concentrations (anomalously high As/Fe ratios), then they will lie above the linear trend established by the other samples. This would indicate that the anomalous samples contain excess arsenic beyond that which can be explained by the natural iron oxide content, and such samples may contain a component of contamination.

The reference elements against which trace elements are evaluated reflect the affinity that the trace elements have for specific minerals. The concentrations of iron, aluminum, and manganese serve as qualitative indicators of the amounts of iron oxide, clay, and manganese oxide minerals in the soil samples. Along with arsenic, selenium and vanadium are present in oxic soil pore fluid as anions, and have an affinity to adsorb on iron oxides, which tend to maintain a net positive surface charge. Concentrations of arsenic, selenium, or vanadium in a set of samples can be evaluated through comparison to the corresponding iron concentrations. Barium, cadmium, lead, and zinc are typically present in soil as divalent cations and have an affinity to adsorb on clay minerals, which tend to maintain a net negative surface charge. Concentrations of barium, cadmium, lead, or zinc can be evaluated through comparison to the corresponding

aluminum concentrations. Manganese oxides have a strong affinity to adsorb barium, cobalt, and lead (Kabata-Pendias, 2001), so concentrations of these elements can be compared to the corresponding manganese concentrations, as long as there is enough manganese present in the soil to form discrete manganese oxides.

Over a limited range of concentrations, the adsorption of a trace element on a mineral surface can usually be described by a linear isotherm. Over a wider range of concentrations, a two-parameter curved fit (such as a Freundlich or Langmuir isotherm) may be more appropriate for some trace elements. In this report the elemental correlations are referred to as "linear trends," although though there may be some degree of curvature to the natural relationship.

It is important to note that some trace elements have very strong affinities for a particular type of mineral, whereas other elements will partition themselves between several minerals. For instance, vanadium has a particularly strong affinity for iron oxides, so correlation coefficients for vanadium versus iron in uncontaminated samples are usually very high, and this is expressed on a correlation plot as a highly linear trend. In contrast, chromium will form several co-existing aqueous species with different charges [$Cr(OH)_2^+$, $Cr(OH)_3^0$, and $Cr(OH)_4^-$] that will adsorb on several different types of minerals including clays and iron oxides. This behavior will yield lower correlation coefficients for chromium versus iron or chromium versus aluminum relative to the coefficients observed for vanadium versus iron, and more scatter may be observed on the correlation plots. Some elements are more selective than others with respect to adsorption on specific mineral surfaces, and this selectivity is dependent on site-specific conditions, including soil pH, redox conditions, and concentrations of competing elements.

2.2 Groundwater and Surface Water

Elevated concentrations of inorganic constituents in groundwater and surface water samples may be due to naturally high dissolved concentrations, the presence of suspended particulates in the samples, reductive dissolution, or contamination resulting from site activities. The effects of suspended particulates and reductive dissolution are discussed below.

Effects of Suspended Particulates. Under natural conditions, metal concentrations are commonly controlled through adsorption on suspended particulates. The most common suspended particulates in groundwater samples are clay minerals, hydrous aluminum oxides ($Al_2O_3 \bullet nH_2O$), and aluminum hydroxides [$Al(OH)_3$], hereafter referred to as "clays"; and iron oxide (Fe_2O_3), hydrous iron oxide, iron hydroxide [$Fe(OH)_3$], and iron oxyhydroxide ($FeO \bullet OH$) minerals, hereafter referred to as "iron oxides." Aluminum is a primary component of all clay

minerals, which have low solubilities over the neutral pH range (6 to 8). Measured concentrations of aluminum greater than approximately 1 milligram per liter (mg/L) indicate the presence of suspended clay minerals (Hem, 1985; Stumm and Morgan, 1996); the higher the aluminum concentration, the greater the mass of suspended clay minerals in the sample. Iron oxides also have very low solubilities under neutral pH conditions, but they are redox-sensitive. Measured iron concentrations above approximately 1 mg/L under neutral-pH, moderate to oxidizing redox conditions indicate the presence of suspended iron oxides (Hem, 1985).

The same concepts involved in the evaluation of soil and sediment data also apply to groundwater and surface water data: samples containing trace elements adsorbed on suspended clay particulates should show a positive correlation with aluminum concentrations, and samples containing trace elements adsorbed on suspended iron oxides should show a positive correlation with iron concentrations. These correlations are evaluated by generating x-y plots of the concentrations of an elevated trace metal versus aluminum or iron (depending on the trace element). Divalent cations such as barium, lead, and zinc have an affinity to adsorb on clay surfaces, which tend to maintain a net negative charge (EPRI, 1984; Brookins, 1988). Concentrations of barium, lead, or zinc in a set of samples can be evaluated through comparison to the corresponding aluminum concentrations. Under oxidizing conditions, elements such as arsenic, selenium, and vanadium are usually present as oxyanions and have a strong affinity to adsorb on iron oxide surfaces, which tend to maintain a net positive charge (Pourbaix, 1974; Hem, 1985; Brookins, 1988; Bowell, 1994). Concentrations of arsenic, selenium, or vanadium can be evaluated through comparison to the corresponding iron concentrations. Chromium can exist as a mixture of aqueous species with different charges [$Cr(OH)_2^+$, $Cr(OH)_3^o$, and $Cr(OH)_4^-$], depending on pH (EPRI, 1984), so it can be distributed on several different types of sorptive surfaces, including clay and iron oxide minerals.

As an example geochemical evaluation for groundwater or surface water, the detected concentrations of zinc would be plotted on the y-axis and the corresponding detected concentrations of aluminum would be plotted on the x-axis. A linear trend with a positive slope (positive correlation) indicates that the zinc in those samples is associated with suspended clay minerals at a relatively constant ratio, and that the zinc is natural. A sample that plots above the linear trend contains excess zinc beyond that which can be explained by the suspended clay content and may contain a component of contamination.

Over a limited range of concentrations, the adsorption of a trace element on a mineral surface can usually be described by a linear isotherm. Over a wider range of concentrations, a two-

parameter curved fit (such as a Freundlich or Langmuir isotherm) may be more appropriate for some trace elements. In this report the elemental correlations are referred to as "linear trends," although though there may be some degree of curvature to the natural relationship.

In addition to the evaluation of trace-versus-major element correlations, the effects of suspended particulates can be assessed via the evaluation of element-versus-turbidity correlations, element-versus-total suspended solids (TSS) correlations, and the comparison of filtered versus unfiltered splits. Evaluations of turbidity and TSS measurements provide additional lines of evidence that support the conclusions drawn from the evaluation of trace-versus-major element correlations. However, turbidity and TSS measurements are qualitative and cannot distinguish between suspended iron oxides, clay minerals, and natural organic material. Consequently, they do not provide the mechanistic information afforded by the correlations of trace elements versus aluminum or trace elements versus iron. Comparisons of filtered versus unfiltered splits of samples are highly informative and permit the identification of elements that are present as suspended particulates versus those that are in true solution. However, filtered-versus-unfiltered comparisons cannot be performed for this report because filtered splits were not obtained for the T-5 groundwater and surface water samples, with the exception of groundwater sample TK3010, which was collected from well CWM-180-MW05 on March 21, 2003.

Effects of Reductive Dissolution. Iron and manganese oxides concentrate several trace elements such as arsenic, selenium, and vanadium on mineral surfaces, as discussed above. In soils and sedimentary aquifers, these elements are almost exclusively associated with iron and manganese oxide minerals and grain coatings, as long as the redox conditions are moderate to oxidizing.

The release of organic contaminants such as jet fuel, gasoline, or chlorinated solvents can establish local reducing environments caused by anaerobic microbial degradation of the organic compounds. The establishment of local reducing conditions can drive the dissolution of iron and manganese oxides, which become soluble as the redox potential drops below a threshold value. Dissolution of these oxide minerals can mobilize the trace elements that were adsorbed on the oxide surfaces, which is a process termed "reductive dissolution." Several investigations have documented the mobilization of arsenic, selenium, and other trace elements under locally reducing redox conditions (Sullivan and Aller, 1996; Nickson *et al.*, 2000; Belzile *et al.*, 2000).

Evidence for reductive dissolution includes low Al/Fe ratios and correlation between elevated trace elements (arsenic, selenium, and vanadium in particular) versus lower redox conditions.

Low redox conditions can be identified by local depressions in oxidation-reduction potential (ORP) or dissolved oxygen (DO) measurements, or the presence of reducing gases such as hydrogen, methane, ethane, or ethene. Anaerobic microbes can also reduce sulfate to sulfide and nitrate to ammonia, resulting in local depressions in sulfate and nitrate concentrations, and local detections of sulfide and ammonia. In areas impacted by chlorinated solvents, additional evidence for the establishment of anaerobic reducing conditions is the presence of *cis*-1,2-dichloroethene (DCE) and/or vinyl chloride, which are reductive dechlorination products resulting from the microbial degradation of trichloroethene (TCE) or tetrachloroethene under anaerobic conditions.

3.0 Results of the Geochemical Evaluation of Multiple Metals in Soil

This section presents the results of the geochemical evaluation of aluminum, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silver, vanadium, and zinc in soil samples from Training Area T-5. Correlation plots are provided in Attachment 1. Table 1 lists the samples identified as containing anomalously high element concentrations, and it includes their location codes.

Aluminum

Aluminum is the second most abundant of the 23 elements analyzed in the site soil samples, with a mean concentration of 15,320 mg/kg (1.5 weight percent). Aluminum is a primary component of common soil-forming minerals such as clays, feldspars, and micas. Aluminum also substitutes for ferric iron in iron oxide minerals, and it can adsorb on iron oxide surfaces (Cornell and Schwertmann, 2003). Iron is the most abundant element analyzed in the site soil samples (mean concentration of 27,830 mg/kg, or 2.8 weight percent) and is dominantly present as iron oxides. Iron oxides are common soil-forming minerals, and they occur as discrete mineral grains or as coatings on silicate minerals (Cornell and Schwertmann, 2003). The Training Area T-5 soil boring logs note that yellowish orange, reddish orange, reddish brown, or brown clay or clay and silt are the predominant soil types in many of the sampled intervals. The red color of the site soils is imparted by the iron oxides, which are highly pigmented.

Clays and iron oxides tend to exist as very fine particles, so both aluminum and iron are enriched in samples with finer grain sizes. A plot of aluminum versus iron concentrations provides a qualitative indicator of the relative abundance of clay and iron oxide minerals in site soil (Figure 1). Installation-wide background soil samples are represented by circles (“BG”), site subsurface (deep) soil samples are represented by filled triangles (“Site DS”), and site surface soil samples are represented by open triangles (“Site SS”). The site and background samples form a common, generally linear trend with a positive slope in Figure 1. The site samples with the highest aluminum concentrations also contain proportionally higher iron content and lie on the background trend. Another perspective of the data sets is provided in Figure 2, which displays the aluminum concentrations of the site and background samples (y-axis) versus their corresponding Al/Fe ratios (x-axis). As seen in the plot, the site samples exhibit Al/Fe ratios that

Table 1

Samples Containing Anomalous Element Concentrations
Training Area T-5
Fort McClellan, Alabama

Medium	Sample Location	Sample Number	Sample Date	Element(s)
Surface Soil	CWM-180-DEP01	TK0016	27-JAN-2003	Cadmium
Surface Soil	CWM-182-DEP03	TE0016	07-NOV-2001	Copper
Surface Soil	CWM-182-DEP04	TE0017	07-NOV-2001	Copper
Surface Soil	CWM-511-DEP01	TP0007	07-NOV-2001	Cadmium, Copper
Surface Soil	CWM-511-DEP02	TP0008	07-NOV-2001	Cadmium, Zinc
Surface Soil	CWM-511-MW06	TP0011	29-OCT-2002	Cadmium
Surface Soil	CWM-513-DEP01	TR0005	08-NOV-2001	Cadmium
Surface Soil	CWM-516-MW02	TRR0003	24-OCT-2001	Barium
Sediment	CWM-182-SW/SD02	TE1002	20-JAN-2003	Chromium

are consistent with those of the background samples. These observations indicate a natural source for the aluminum detected in the site samples. It is important to note that clays and iron oxides adsorb specific trace elements (as discussed in Section 2.1), so the samples that plot on the upper end of the trend in Figure 1 – including many of the site samples – are expected to contain proportionally higher concentrations of trace elements.

Conclusion
Aluminum detected in the site soil samples is naturally occurring.

Arsenic

As discussed in Section 2.1, arsenic is present in oxic soil pore fluid as oxyanions and has a strong affinity to adsorb on iron oxides, which tend to maintain a net positive surface charge. A positive correlation between arsenic and iron concentrations is expected for uncontaminated samples under those conditions. A plot of arsenic versus iron is provided in Figure 3. The site samples with high arsenic concentrations also have high iron concentrations. All of the site samples exhibit As/Fe ratios that are consistent with those of the background samples. This indicates a natural source for the arsenic detected in the site samples.

Conclusion
Arsenic detected in the site soil samples is naturally occurring.

Barium

Manganese oxides are naturally occurring minerals in soil, and they are present as discrete mineral grains or as coatings on other minerals. Manganese oxides have a strong affinity to adsorb divalent cations (such as Ba^{2+}, Co^{2+}, and Pb^{2+}), due to the large surface area and high negative surface charges of these minerals. If a soil sample contains a high proportion of manganese oxides, then it is expected to contain naturally high concentrations of manganese and associated trace elements such as barium. A plot of barium versus manganese reveals a common, generally linear trend with a positive slope for the background samples and most of the site samples (Figure 4). Most of the site samples with high barium concentrations also contain proportionally higher manganese content, and they lies on the background trend. These site samples exhibit Ba/Mn ratios that are consistent with those of the background samples, indicating a natural source for their barium concentrations. Surface soil sample TRR0003, however, contains the highest barium concentration of the site surface soil samples (374 mg/kg) but only moderate manganese (as well as only moderate aluminum and iron), and it lies above the background trend in Figure 4.

Another perspective of the data sets is provided in Figure 5, which displays the barium concentrations of the site and background samples (y-axis) versus their corresponding Ba/Mn ratios (x-axis). As seen in the plot, most of the site samples exhibit Ba/Mn ratios that are within the background range. Surface soil sample TRR0003, however, lies to the right of the background samples. This sample contains an excess amount of barium beyond that which can be explained by its natural manganese oxide content, and it may contain a component of contamination (Table 1). There is one subsurface soil sample with a slightly elevated Ba/Mn ratio, but its barium concentration (27.2 mg/kg) is significantly lower than the background 95th

upper tolerance limit (UTL) of 320 mg/kg and well below the background mean of 125 mg/kg. Any contamination in this sample, if present, would not be significant.

Conclusion
The barium concentration in surface soil sample TRR0003 is anomalously high and may contain a component of contamination (Table 1). Barium detected in the other site soil samples is naturally occurring.

Beryllium

Beryllium can substitute for aluminum in minerals, and positive correlations between beryllium and the clay fraction of soils have been observed (Kabata-Pendias, 2001). A plot of beryllium versus aluminum is provided in Figure 6. The site and background samples form a common, generally linear trend with a positive slope, and the samples that have the highest beryllium concentrations also have high aluminum. The site samples exhibit Be/Al ratios that are consistent with those of the background samples, indicating a natural source for their beryllium concentrations.

Conclusion
Beryllium detected in the site soil samples is naturally occurring.

Cadmium

Cadmium is commonly present in soil as a divalent cation (Cd^{2+}) and has an affinity to adsorb on manganese oxide minerals (Kabata-Pendias, 2001), which tend to maintain a strong negative surface charge. If a soil sample contains a high proportion of manganese oxides, then it will have naturally high concentrations of manganese and associated trace elements, such as cadmium. Many of the background samples exhibit such a positive correlation in a plot of cadmium versus manganese (Figure 7). Only five site surface soil samples contain detectable cadmium, and four of these detections exceed the background maximum detected concentration (MDC) of 1.28 mg/kg. The site samples contain only moderate amounts of manganese (as well as only moderate aluminum and iron). The anomalously high Cd/Mn ratios of these samples indicate that they may contain a component of contamination(Table 1).

It should be noted that the site samples are characterized by higher reporting limits relative to the background samples: the site reporting limits for the five detections range from 1.04 mg/kg to 1.32 mg/kg, whereas the reporting limits for the background nondetects range from 0.015 mg/kg to 4.01 mg/kg, with a median of 0.054 mg/kg and mean of 0.427 mg/kg [reporting limit data are unavailable for the background detected concentrations]. Additionally, 19 of the 80 background detections are estimated ("J"-qualified) concentrations below the reporting limit. The difference (up to two orders of magnitude) in reporting limits between the data sets, combined with the uncertainty associated with the estimated background concentrations, may explain why the site samples exhibit higher Cd/Mn ratios relative to the background samples.

Conclusion
The five cadmium detections in the site samples are anomalously high and may contain a component of contamination (Table 1).

Calcium

Soils at Fort McClellan are derived in part from the weathering of limestone and dolomite, which are composed of calcium carbonate and calcium magnesium carbonate minerals, respectively. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) have similar chemical properties, and magnesium often substitutes for calcium in minerals. Positive correlations between calcium and magnesium concentrations are thus commonly observed in uncontaminated soil samples. A plot of calcium versus magnesium is provided in Figure 8. The site samples exhibit Ca/Mg ratios that are consistent with those of the background samples. Several of the site and background samples have elevated calcium concentrations, but they also have proportionally higher magnesium and form a common linear trend with a positive slope. The presence of unweathered or partially weathered limestone and dolomite fragments in site soil is a likely explanation for the elevated calcium and magnesium concentrations observed in these samples.

Conclusion

Calcium detected in the site soil samples is naturally occurring.

Chromium

As discussed in Section 2.1, chromium can be present in soil as various species with different charges, and thus it can adsorb on several different types of minerals including iron oxides and clays. A plot of chromium versus iron reveals a common linear trend with a positive slope for the site and background samples (Figure 9). The site samples with high chromium concentrations also contain proportionally higher iron concentrations, and they lie on the trend established by the other samples. If a sample contained excess chromium from a contaminant source, it would have an anomalously high Cr/Fe ratio and would lie above the linear background trend. However, no such samples are observed in the plot. Chromium in the site samples is associated with iron oxides at ratios consistent with those of the background samples and is natural.

Conclusion

Chromium detected in the site soil samples is naturally occurring.

Cobalt

Manganese oxides are naturally occurring minerals in soil, and they are present as discrete mineral grains or as coatings on other minerals. Manganese oxides have a strong affinity to adsorb divalent cations (such as Ba^{2+}, Co^{2+}, and Pb^{2+}), due to the large surface area and high negative surface charges of these minerals. If a soil sample contains a high proportion of manganese oxides, then it is expected to contain naturally high concentrations of manganese and associated trace elements such as cobalt. A plot of cobalt versus manganese reveals a collinear trend for the site and background samples (Figure 10). The site samples with the highest cobalt concentrations also contain proportionally higher manganese concentrations, and they lie on the trend established by the other samples. Cobalt in the site samples is associated with manganese oxides at ratios consistent with those of the background samples, and it is natural.

This conclusion is supported by a comparison of cobalt concentrations versus Co/Mn ratios (Figure 11). If a sample contained excess cobalt from a contaminant source, then it would exhibit an anomalously high Co/Mn ratio relative to background and would plot to the right of

the background samples in Figure 11. However, all of the site samples with elevated cobalt have Co/Mn ratios that are within the background range. There is one subsurface soil sample with a slightly elevated Co/Mn ratio relative to the background samples, but its cobalt concentration (1.15 J mg/kg) is well below the background 95th UTL of 54.7 mg/kg and background mean of 8.6 mg/kg. Any contamination in this sample, if present, would be insignificant.

Conclusion
Cobalt detected in the site soil samples is naturally occurring.

Copper

Cations such as copper (Cu^{2+}), cadmium (Cd^{2+}), and nickel (Ni^{2+}) have an affinity to adsorb on the surfaces of iron oxides under the pH range of typical soils (5 to 8 standard units), with adsorption increasing as pH approaches neutrality (Cornell and Schwertmann, 2003). The cations bind to surface hydroxyl groups (OH^-), giving rise to metal-surface complexes. Because of this affinity for cation adsorption, positive correlations are commonly observed for copper versus iron concentrations in uncontaminated soil samples. Samples that contain a high proportion of iron oxides are therefore expected to contain naturally high concentrations of cations such as copper. Figure 12 provides a plot of copper versus iron for the site and background samples. Most of the background samples form a generally linear trend with a positive slope, and the majority of site samples lie on this trend. Copper in these samples is associated with iron oxides at ratios consistent with those of the background samples, and it is natural. There are a few site samples, however, with anomalously high Cu/Fe ratios relative to background, and these samples may contain a component of contamination.

This conclusion is supported by a comparison of the site and background Cu/Fe ratios. Figure 13 displays the copper concentrations of the site and background samples (y-axis) versus their corresponding Cu/Fe ratios (x-axis). If a site sample contains excess copper from a contaminant source, it will exhibit an anomalously high Cu/Fe ratio relative to background and will plot to the right of the background samples in Figure 13. Although most of the site samples exhibit Cu/Fe ratios that are within the background range, there are three surface soil samples with Cu/Fe ratios that exceed the background Cu/Fe ratio range. Elevated copper in these samples should be considered suspect (Table 1).

Conclusion
Copper concentrations in three surface soil samples are anomalously high and may contain a component of contamination (Table 1). Copper detected in the other site samples is naturally occurring.

Iron

Iron is the most abundant element analyzed in the site soil samples, with a mean concentration of 27,830 mg/kg (2.8 weight percent). The Training Area T-5 soil boring logs note that yellowish orange, reddish orange, reddish brown, or brown clay or clay and silt are the predominant soil types in many of the sampled intervals. The iron in the samples is dominantly present as iron oxides, which are highly pigmented and impart the red color to the site soils. Iron oxides are common soil-forming minerals, and they occur as discrete mineral grains or as coatings on silicate minerals (Cornell and Schwertmann, 2003). As explained in the Aluminum evaluation, a

plot of aluminum versus iron can be used to qualitatively assess the relative abundance of clays and iron oxides in site soil (Figure 1). The background samples form a generally linear trend with a positive slope, and the site samples lie on this trend. All of the site samples exhibit Fe/Al ratios that are within the range of background Fe/Al ratios (Figure 14). These observations indicate a natural source for the iron detected in the site samples. Clay and iron oxide minerals adsorb specific trace elements (as discussed in Section 2.1), so the samples that plot on the upper end of the trend in Figure 1 – including many of the site samples – are expected to contain proportionally higher concentrations of trace elements.

Conclusion
Iron detected in the site soil samples is naturally occurring.

Lead

Manganese oxides are naturally occurring minerals in soil, and they are present as discrete mineral grains or as coatings on other minerals. Manganese oxides have a strong affinity to adsorb divalent cations (such as Ba^{2+}, Co^{2+}, and Pb^{2+}), due to the large surface area and high negative surface charges of these minerals. If a soil sample contains a high proportion of manganese oxides, then it is expected to contain high concentrations of manganese and associated trace elements such as lead. A plot of lead versus manganese reveals a linear trend with a positive slope for the site and background samples (Figure 15). Lead in most of the site samples is associated with manganese oxides at ratios consistent with those of the background samples and is natural.

This conclusion is supported by a comparison of lead concentrations versus the corresponding Pb/Mn ratios (Figure 16). If a site sample contained excess lead from a contaminant source, then it would exhibit an anomalously high Pb/Mn ratio relative to background and would plot to the right of the background samples in Figure 16. However, all of the site samples with elevated lead have Pb/Mn ratios that are within the background range. There is one subsurface soil sample with a slightly elevated Pb/Mn ratio relative to the background samples, but its lead concentration (19.9 mg/kg) is below the background 95th percentile of 28.8 mg/kg and is similar to the background mean of 20.0 mg/kg. Additionally, the Pb/Fe ratio of this sample is within the range of background Pb/Fe ratios. Any contamination in this sample, if present, would not be significant.

Conclusion
Lead detected in the site soil samples is naturally occurring.

Magnesium

Soils at Fort McClellan are derived in part from the weathering of limestone and dolomite, which are composed of calcium carbonate and calcium magnesium carbonate minerals, respectively. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) have similar chemical properties, and magnesium often substitutes for calcium in minerals. Positive correlations between calcium and magnesium concentrations are thus commonly observed in uncontaminated soil samples. A plot of calcium versus magnesium reveals that the site samples have Ca/Mg ratios that are similar to those of the background samples (Figure 8). Several of the site and background samples have elevated magnesium concentrations, but they also have proportionally higher calcium and form a common

linear trend with a positive slope. The presence of unweathered or partially weathered limestone and dolomite fragments in site soil is a likely explanation for the elevated calcium and magnesium concentrations observed in these samples.

Conclusion
Magnesium detected in the site soil samples is naturally occurring.

Manganese
The manganese detected in the site soil samples is dominantly present as manganese oxide minerals, which have a strong affinity to adsorb specific trace elements such as barium and cobalt (Kabata-Pendias, 2001). If a sample contains a high percentage of manganese oxides, then it will have naturally high concentrations of manganese and associated trace elements. For example, the positive correlations observed for cobalt versus manganese in the site samples indicates a natural source for these two elements (Figure 10).

Conclusion
Manganese detected in the site soil samples is naturally occurring.

Mercury
Mercury in soil can adsorb on the surfaces of iron oxide and clay minerals, but its concentrations are commonly controlled through organic complex formation (Kabata-Pendias, 2001). As a result, weak correlations for mercury versus iron or mercury versus aluminum are often observed, even in uncontaminated soil samples. Most of the background samples form a weak linear trend with a positive slope in a plot of mercury versus aluminum (Figure 17). The site samples exhibit no correlation, but they all lie on the background trend. All of the site mercury detections, which range from 0.027 J mg/kg to 0.107 J mg/kg, are well below the background MDC of 0.322 mg/kg. These observations suggest a natural source for the mercury detected in the site samples.

Conclusion
Mercury detected in the site soil samples is naturally occurring.

Nickel
Nickel has an affinity to adsorb on clay minerals (Kabata-Pendias, 2001), so a positive correlation between nickel and aluminum concentrations is often observed for uncontaminated soil samples. The site and background samples form a common, generally linear trend with a positive slope in a plot of nickel versus aluminum (Figure 18). The site samples with high nickel concentrations also have high aluminum content and they lie on the linear trend. Nickel in the site samples is associated with clays at ratios consistent with those of the background samples, which is confirmed by a plot of
nickel concentrations versus Ni/Al ratios (Figure 19). These observations indicate a natural source for nickel in the site samples .

Conclusion
Nickel detected in the site soil samples is naturally occurring.

Potassium

Potassium (K^+) is a common component of soil-forming minerals such as clays, often occurring as part of the mineral structure and as loosely adsorbed cations. Clays, which contain aluminum as a primary component, are characterized by large surface-area-to-volume ratios and strong negative surface charges. As a result, the major cations, such as potassium, are attracted to these mineral surfaces and take part in cation exchange reactions. Positive correlations between potassium and aluminum concentrations are thus typically observed for uncontaminated soil samples. A plot of potassium versus aluminum reveals a common linear trend with a positive slope for the site and background samples (Figure 20). The site samples with high potassium concentrations also have proportionally higher aluminum content, and they lie on the trend established by the other samples. These observations indicate a natural source for the potassium in the site samples.

Conclusion

Potassium detected in the site soil samples is naturally occurring.

Selenium

As noted in Section 2.1, selenium is present in oxic soil pore fluid as oxyanions and has an affinity to adsorb on iron oxides, which tend to maintain a net positive surface charge. Positive correlations between selenium and iron concentrations are thus commonly observed for uncontaminated soil samples. A plot of selenium versus iron is provided in Figure 21. Many site samples have estimated selenium concentrations below the reporting limit, and the uncertainty associated with such values explains the lack of correlation observed at the lower end of the concentration range. However, the site samples with selenium concentrations above the background MDC of 1.28 mg/kg form a linear trend with a positive slope. Selenium in these samples is associated with iron oxides at a relatively constant ratio, which is confirmed by a plot of selenium concentrations versus Se/Fe ratios (Figure 22). These samples form a vertical trend in Figure 22, and exhibit a narrow range of Se/Fe ratios. These observations indicate a natural source for the elevated selenium detected in the site samples.

Conclusion

Selenium detected in the site soil samples is naturally occurring.

Silver

A plot of silver versus aluminum is provided in Figure 23. The three site samples with detectable silver have higher concentrations than most of the background samples, but they are also characterized by high aluminum concentrations. The site detections are all below the background MDC of 1.87 mg/kg, and the Ag/Al ratios of the site samples are within the background range of Ag/Al ratios. These observations suggest a natural source for the silver detected in the site samples. It is likely that these site samples are preferentially enriched in clay minerals and associated trace elements, and that the silver is natural. It is important to note that all three site detections are estimated (J-qualified) values below the reporting limit, and that such values are highly uncertain. In comparison, the background detections are mostly unestimated concentrations ranging from 0.019 to 1.87 mg/kg, with a mean of 0.151 mg/kg (14 of the 82 background detections are estimated values). Additionally, the site samples are characterized by higher reporting limits relative to the background samples: the site reporting limits for the three

detections range from 2.19 to 2.38 mg/kg, whereas the reporting limits for the background nondetects range from 0.016 to 1.2 mg/kg, with a mean of 0.293 mg/kg [reporting limit data are unavailable for the background detected concentrations]. The uncertainty associated with the estimated site concentrations, combined with the difference (up to two orders of magnitude) in reporting limits between the data sets, likely explains why the site samples exhibit higher Ag/Fe ratios relative to many of the background samples.

Conclusion
Silver detected in the site soil samples is naturally occurring.

Vanadium

As discussed in Section 2.1, vanadium is present in oxic soil pore fluid as oxyanions and has a strong affinity to adsorb on iron oxides, which tend to maintain a net positive surface charge. A positive correlation between vanadium and iron concentrations is expected for uncontaminated samples under those conditions. A plot of vanadium versus iron reveals a common linear trend for the site and background samples (Figure 24). The site samples with the highest vanadium concentrations also contain the highest iron concentrations and lie on the trend established by the other samples. Vanadium in the site samples is associated with iron oxides at a relatively constant ratio and is natural.

Conclusion
Vanadium detected in the site soil samples is naturally occurring.

Zinc

Zinc in soil is commonly associated with iron oxides (Kabata-Pendias, 2001), so positive correlations for zinc concentrations versus iron concentrations are expected for uncontaminated samples. The background samples and most of the site samples form a common trend with a positive slope in a plot of zinc versus iron (Figure 25). Zinc in these samples is associated with iron oxides at ratios consistent with those of the background samples and is natural. Surface soil sample TP0008 contains relatively high zinc (126 mg/kg) but only moderate iron (as well as only moderate aluminum and manganese), and it lies above the background trend in Figure 25. This sample exhibits an anomalously high Zn/Fe ratio relative to the background samples, as confirmed by a plot of zinc concentrations versus Zn/Fe ratios (Figure 26). All of the site samples except TP0008 have Zn/Fe ratios that are within the background range. Sample TP0008 may contain excess zinc from a contaminant source (Table 1).

Conclusion
Zinc concentrations in surface soil samples TP0008 is anomalously high and may contain a component of contamination (Table 1). Zinc detected in the other site soil samples is naturally occurring.

4.0 Results of the Geochemical Evaluation of Metals in Sediment

This section presents the results of the geochemical evaluation of cadmium, chromium, copper, and zinc in sediment samples from Training Area T-5. Although aluminum and iron passed

statistical comparison to background, they are the primary reference elements and an evaluation of their site concentrations is included to confirm the absence of reference element contamination. Correlation plots are provided in Attachment 1. Table 1 lists the samples identified as containing anomalously high element concentrations, and it includes their location codes.

Aluminum and Iron

Aluminum is a primary component of common minerals such as clays, feldspars, and micas. Iron oxides are also common minerals in soil and sediment, and they occur as discrete mineral grains or as coatings on silicate minerals (Cornell and Schwertmann, 2003). Clays and iron oxides tend to exist as very fine particles, so both aluminum and iron are enriched in samples with finer grain sizes. A plot of aluminum versus iron concentrations provides a qualitative indicator of the relative abundance of these minerals in site sediment (Figure 27). The background samples form a generally linear trend with a positive slope, and all of the site samples lie on this trend. The site samples exhibit Al/Fe ratios that are consistent with those of the background samples, which indicates a natural source for the aluminum and iron detected in the site samples.

Conclusion

Aluminum and iron concentrations detected in the site sediment samples are naturally occurring.

Cadmium

Cadmium is commonly present in soil as a divalent cation (Cd^{2+}) and has an affinity to adsorb on clay minerals (Kabata-Pendias, 2001), which tend to maintain a net negative surface charge. If a soil sample contains a high proportion of clay minerals, then it will have naturally high concentrations of aluminum and associated trace elements such as cadmium. A plot of cadmium versus aluminum is provided in Figure 28. The three site samples with detectable cadmium exhibit Cd/Al ratios that are similar to those of the background samples. This indicates that the cadmium detected in the site samples is natural.

Another perspective of the data sets is provided in Figure 29, which displays the cadmium concentrations of the site and background samples versus their corresponding Cd/Al ratios. If a sample contained excess cadmium from a contaminant source, then it would exhibit an anomalously high Cd/Al ratio relative to background and would plot to the right of the background samples in Figure 29. However, no such samples are observed. The three site samples exhibit Cd/Al ratios that are within the background range.

It should be noted that the site samples are characterized by higher reporting limits relative to the background samples: the site reporting limits range from 1.22 mg/kg to 1.41 mg/kg, whereas the reporting limits for the background nondetects range from 0.0154 mg/kg to 1.2 mg/kg, with a median of 0.122 mg/kg and mean of 0.503 mg/kg [reporting limit data are unavailable for the background detected concentrations]. Additionally, two of the three site detections are estimated (J-qualified) concentrations below the reporting limit. The uncertainty associated with the estimated site concentrations, combined with the difference (up to two orders of magnitude) in reporting limits between the data sets, likely explains why the site samples exhibit higher Cd/Al ratios relative to many of the background samples.

Conclusion
Cadmium detected in the site sediment samples is naturally occurring.

Chromium

As discussed in Section 2.1, chromium can be present in soil and sediment as various species with different charges, and thus it can adsorb on several different types of minerals including iron oxides and clays. A plot of chromium versus iron reveals a common linear trend with a positive slope for the background samples and most of the site samples (Figure 30). Chromium in these samples is associated with iron oxides at ratios consistent with those of the background samples, indicating that the chromium has a natural source. Site sample TE1002, however, has the highest chromium concentration in the site data set (61.8 mg/kg) but only moderate iron, and it lies slightly above the background trend in Figure 30.

Another perspective of the data sets is provided in Figure 31, which is a plot of chromium concentrations versus Cr/Fe ratios. As seen in the plot, four of the five site samples have Cr/Fe ratios that are well within the background range. Sample TE1002 has the highest Cr/Fe ratio of the site and background samples and it lies to the right of the other samples in the plot. This sample contains excess chromium beyond that which can be explained by its natural iron oxide content, and it may contain a component of contamination (Table 1).

Conclusion
The chromium concentration in sample TE10002 is anomalously high and may contain a component of contamination (Table 1). Chromium detected in the other site sediment samples is naturally occurring.

Copper

Cations such as copper (Cu^{2+}), cadmium (Cd^{2+}), and nickel (Ni^{2+}) have an affinity to adsorb on the surfaces of iron oxides under circum-neutral pH conditions (5 to 8 standard units), with adsorption increasing as pH approaches neutrality (Cornell and Schwertmann, 2003). The cations bind to surface hydroxyl groups (OH^-), giving rise to metal-surface complexes. Because of this affinity for cation adsorption, positive correlations are commonly observed for copper versus iron concentrations in uncontaminated sediment samples. Samples that contain a high proportion of iron oxides are therefore expected to contain naturally high concentrations of cations such as copper. Figure 32 provides a plot of copper versus iron for the site and background samples. Most of the background samples form a generally linear trend with a positive slope, and all of the site samples lie on this trend. Copper in the site samples is associated with iron oxides at ratios consistent with those of the background samples, and it is natural.

Conclusion
Copper detected in the site sediment samples is naturally occurring.

Zinc

Zinc has an affinity to adsorb on the surfaces of manganese oxides (Kabata-Pendias, 2001). If a soil sample contains a high proportion of manganese oxides, then it will have naturally high

concentrations of manganese and associated trace elements such as zinc. A plot of zinc versus manganese is provided in Figure 33. All of the site samples exhibit Zn/Mn ratios that are consistent with those of the background samples. If a site sample contained zinc as a contaminant, it would have an anomalously high Zn/Mn ratio and would lie above the background trend in the plot. No such samples are observed, which indicates a natural source for the zinc detected in the site samples.

Conclusion
Zinc detected in the site sediment samples is naturally occurring.

5.0 Results of the Geochemical Evaluation of Metals in Groundwater

This section presents the results of the geochemical evaluation of barium, beryllium, calcium, chromium, cobalt, lead, manganese, nickel, and vanadium in the 74 unfiltered groundwater samples from Training Area T-5. Correlation plots are provided in Attachment 1.

Field Readings. Field-measured pH readings for the groundwater samples range from 4.12 to 10.97 standard units, with a median of 6.57 and mean of 6.45. These values indicate near-neutral pH conditions at most of the sample locations, although conditions are slightly acidic or slightly alkaline at a few locations. Field-measured DO readings range from 0.18 mg/L to 13.3 mg/L, with a median of 3.59 mg/L and mean of 4.62 mg/L, and ORP readings range from -180 millivolts (mV) to +416 mV, with a median of +136 mV and mean of +135 mV. These values suggest moderate to oxidizing redox conditions at the majority of sample locations, although conditions were reducing at some locations at the time of sample collection. Turbidity measurements range from 0.4 turbidity units (NTU) to 999 NTU, with a median of 7.5 NTU and mean of 31 NTU. Four samples contained a high mass of suspended particulates (126 NTU to 999 NTU for samples TT3014, TPP3005, TE3003, and TK3010), but the remaining seventy samples did not (44 NTU and lower). It should be noted that field readings are not available for the background groundwater samples. Examination of the aluminum and iron concentrations permits a qualitative assessment of the redox conditions in both the site and background samples.

Aluminum and Iron. Aluminum was detected in 50 of the 74 site groundwater samples, at concentrations ranging from an estimated 0.055 mg/L to 26.1 mg/L, and iron was detected in all 74 samples, at concentrations ranging from an estimated 0.00799 mg/L to 59.6 mg/L. As discussed previously, aluminum concentrations in excess of approximately 1 mg/L in neutral-pH groundwater indicate the presence of suspended clays. Aluminum will be present in solution at a pH below about 4.0, but all of the T-5 pH readings are higher than this and most are in the neutral range (see the discussion of field readings, above). Iron concentrations in excess of approximately 1 mg/L in neutral-pH, moderate to oxidizing groundwater conditions indicate the

presence of suspended iron oxides. Iron is a redox-sensitive element, and its dissolved concentrations will increase under reducing conditions. Reducing conditions can be natural, or they can be induced by the anaerobic microbial degradation of chlorinated solvents and fuels (see Section 2.2). Field readings for the T-5 data set indicate moderate to oxidizing conditions at most locations, although reducing conditions are indicated for some locations. Iron in the site samples is thus expected to be present either in particulate form or in solution, or some mixture thereof, depending upon the sample.

A plot of aluminum versus iron can be used as a qualitative indicator of the amount of suspended particulates in the groundwater samples, as well as an indicator of the redox conditions at the sample locations (Figure 34). A linear trend with a positive slope is typically observed when the aluminum and iron concentrations are present in particulate form, and just such a trend is observed in Figure 34 for most of the site and background samples. The site samples with the highest aluminum concentrations exhibit proportionally higher iron and lie on the linear trend formed by the other samples. This indicates that the elevated aluminum is due to the presence of suspended clay particulates, and is natural.

This conclusion is corroborated by the field-measured turbidity readings. A linear trend with a positive slope is apparent in a plot of unfiltered aluminum concentrations versus turbidity (Figure 35), and the samples with the highest aluminum exhibit proportionally higher turbidity. Sample TK3010, which has the highest aluminum concentration of the site and background data sets (26.1 mg/L), also has the highest turbidity reading of the site samples (999 NTU). A filtered split was obtained for this sample, and the filtered aluminum concentration is 2.06 mg/L. The filtered/unfiltered ratio of 0.08 indicates that the aluminum in the sample is present primarily as filterable particulates. The positive correlation for unfiltered aluminum concentrations versus turbidity, low filtered/unfiltered ratio for sample TK3010, and relatively constant Al/Fe ratios for the majority of samples with detectable aluminum support the contention that the elevated aluminum in the site samples is associated with suspended clay particulates, and is natural.

There are several site samples that lie below the linear particulate trend in Figure 34. There are also 24 site samples with detectable iron and nondetectable aluminum that cannot be depicted in the plot. The low Al/Fe ratios of these samples reflect reducing conditions and indicate that some portion of the iron in these samples is in solution. Reducing conditions can be natural, or they may be induced by the degradation of organic contaminants. Although there are several T-5 groundwater samples with low estimated concentrations of *cis*-1,2-DCE [vinyl chloride was not detected in any T-5 samples], which suggests the potential for VOC-induced reductive

dissolution at those locations, no relationship is observed between elevated iron concentrations and VOC contamination in the site data set. Only three of the site samples with iron concentrations above 1 mg/L also contain significant VOC contamination (0.5 mg/L or higher). Additionally, the presence of several background samples with low Al/Fe ratios suggests that reducing conditions are natural at FTMC. Thirteen of the forty-eight background samples with detectable iron are nondetect for aluminum, and three background samples with both detectable iron and detectable aluminum lie below the linear particulate trend of Figure 34.

Moderate to oxidizing redox conditions are indicated for the majority of site samples, based on their relatively constant Al/Fe ratios. Given these observations, it is expected that the trace element concentrations will be controlled at least in part by adsorption on the surfaces of suspended minerals.

Barium

Barium was detected in 72 of the 74 site groundwater samples. Barium is not correlated with aluminum in the site samples, which suggests that it is not associated with suspended particulates. Barium concentrations are often controlled by equilibrium with the mineral barite ($BaSO_4$), which is sensitive to redox conditions. Under oxidizing conditions, sulfate is the stable form of sulfur, so barium concentrations are limited by the solubility of barite. Under reducing conditions, sulfate can be reduced to sulfide, allowing barium concentrations to increase. As discussed previously, the field readings and Al/Fe ratios of the site samples indicate moderate to oxidizing redox conditions at most of the sample locations, but reducing conditions are indicated for some locations. No relationship is observed between low redox conditions and VOC contamination in the site samples, and the low Al/Fe ratios of several background samples suggest that reducing conditions may be natural at some Fort McClellan sites.

Manganese oxides are redox-sensitive, and dissolved manganese concentrations will increase as the redox potential decreases (see the Manganese evaluation, below). A plot of barium versus manganese is provided in Figure 36. The site and background samples form a common, generally linear trend with a positive slope. The site samples with the highest barium concentrations also contain proportionally higher manganese, which likely reflects the reducing conditions at those locations. If a site sample contained excess barium from a contaminant source, it would exhibit an anomalously high Ba/Mn ratio relative to the background samples. However, no such samples are observed. All of the site samples exhibit Ba/Mn ratios that are within the background range, which indicates a natural source for their barium concentrations.

<u>Conclusion</u>
Barium detected in the site groundwater samples is naturally occurring.

Beryllium

Beryllium was detected in only 1 of the 74 site groundwater samples. Beryllium is commonly present as the divalent cation (Be^{2+}) under natural conditions (Brookins, 1988). As discussed in Section 2.2, cationic species such as beryllium have an affinity to adsorb on the surfaces of

suspended clay minerals, which tend to maintain a net negative surface charge. If an uncontaminated sample contains a high proportion of suspended clay minerals, then it is expected to contain naturally high concentrations of aluminum and proportionally higher concentrations of associated trace elements such as beryllium. A plot of beryllium versus aluminum reveals a common linear trend with a positive slope for the site and background samples (Figure 37). Site sample TK3010 contains the highest beryllium of both data sets (0.00637 J mg/L) as well as the highest aluminum (26.1 mg/L). As noted previously, sample TK3010 is characterized by high turbidity (999 NTU) and a low filtered/unfiltered aluminum ratio (0.08), which indicates that the sample has a high proportion of filterable particulates. The filtered split of sample TK3010 is nondetect for beryllium (reporting limit of 0.01 mg/L), which supports the contention that beryllium in the sample is associated with suspended particulates and is not in solution. The positive correlation between beryllium and aluminum for the site and background samples, the similar Be/Al ratios of the site and background samples, and the decrease in beryllium and aluminum concentrations upon filtration for sample TK3010 indicate a natural source for the beryllium detected in sample TK3010.

Conclusion
Beryllium detected in the site groundwater samples is naturally occurring.

Calcium
Calcium was detected in all 74 groundwater samples. Calcium and magnesium are both major dissolved constituents in groundwater, and they are derived from the weathering of carbonate and silicate minerals. Their concentrations often covary in uncontaminated samples. A plot of calcium versus magnesium reveals a common trend for the site and background samples (Figure 38). The site samples exhibit Ca/Mg ratios that are within the background range, and their calcium concentrations are well below the background MDC of 452 mg/L. These observations suggest a natural source for the calcium detected in the site samples.

Conclusion
Calcium detected in the site groundwater samples is naturally occurring.

Chromium
Chromium was detected in only 5 of the 74 groundwater samples, at concentrations near or below the reporting limit of 0.02 mg/L. As noted in Section 2.2, chromium can be present in groundwater as a mixture of aqueous species with different charges, and thus it can adsorb on different surfaces, including clay and iron oxide minerals. Plots of detectable chromium concentrations versus aluminum and iron are provided in Figures 39 and 40. The background samples are 100 percent nondetect for chromium, so they do not appear in the plots. The chromium concentrations in three of the samples are low, estimated (J-qualified) values below the reporting limit, and the uncertainty associated with such values likely explains the weak correlation. The two highest concentrations, however, are observed in samples with proportionally higher aluminum and iron concentrations. This suggests that the elevated chromium in the site samples is due to the presence of suspended particulates such as clays and iron oxides, and the relatively consistent Cr/Al and Cr/Fe ratios of the site samples indicate that the chromium is natural.

Conclusion
Chromium detected in the site groundwater samples is naturally occurring.

Cobalt

Cobalt was detected in only 10 of the 74 groundwater samples. Under oxidizing groundwater conditions, cobalt concentrations are commonly controlled by adsorption on iron oxides and manganese oxides (Hem, 1985). Under reducing conditions, however, the iron oxides and manganese oxides will enter into solution. As a result, the dissolved concentrations of iron and manganese will increase, along with the concentrations of trace elements (such as cobalt) that were sorbed on the mineral surfaces. As discussed previously, the T-5 field readings and Al/Fe ratios suggest moderate to oxidizing conditions at many of the sample locations, and thus iron is expected to be present primarily in particulate form at these locations. The field readings also indicate reducing conditions at some locations, however, and thus the iron in these samples is expected to be present in solution. No relationship is observed between VOC concentrations and low redox conditions, which suggests that the reducing conditions may be natural at most locations.

A plot of cobalt versus iron is provided in Figure 41. Eight of the ten site cobalt detections are estimated (J-qualified) concentrations below the reporting limit, and the uncertainty associated with such values likely explains the weak correlation observed in the plot. These eight detections are all below the background MDC of 0.0252 mg/L, which suggests that they are natural. Site samples TK3008 and TK3010 contain the highest cobalt concentrations of the site and background data sets (0.0495 mg/L and 0.0358 mg/L, respectively), but they also contain the highest iron concentrations (25.6 mg/L and 59.6 mg/L). Sample TK3010 is characterized by high turbidity (999 NTU) and a low filtered/unfiltered iron ratio (0.06), which indicates that the sample has a high proportion of filterable particulates such as iron oxides. The filtered split of sample TK3010 is nondetect for cobalt, which supports the contention that the cobalt in the sample is associated with suspended particulates.

No filtered split was obtained for sample TK3008. The absence of detectable aluminum in the sample (reporting limit of 0.2 mg/L) indicates that the iron and cobalt are at least partially in solution. Only three low, estimated (J-qualified) concentrations of VOCs were detected in sample TK3008 (1,2,4-trimethylbenzene, chloroform, and toluene; all below the reporting limit), and there are several background samples with similarly low Al/Fe ratios. This suggests that the reducing conditions at the TK3008 sample location may be natural. The Co/Fe ratio of the sample is consistent with those of the background samples, which indicates that it does not contain excess cobalt relative to background (Figure 41).

The similar Co/Fe ratios of the site and background samples indicate a natural source for the cobalt detected in the site samples.

Conclusion
Cobalt detected in the site groundwater samples is naturally occurring.

Lead

Lead was detected in only 8 of the 74 site groundwater samples. As discussed in Section 2.2, cationic species such as lead have an affinity to adsorb on the surfaces of suspended clay minerals, which tend to maintain a net negative surface charge. If an uncontaminated sample contains a high proportion of suspended clay minerals, then it is expected to contain naturally high concentrations of aluminum and associated trace elements such as lead. A plot of lead versus aluminum reveals a common trend for the site and background samples (Figure 42). The site and background samples with elevated lead concentrations (above approximately 0.008 mg/L) also have proportionally higher aluminum content, and they form a linear trend with a positive slope in the plot. This includes site sample TK3010, which contains the highest lead of both data sets (0.0571 mg/L) as well as the highest aluminum (26.1 mg/L). As noted previously, sample TK3010 is characterized by high turbidity (999 NTU) and a low filtered/unfiltered aluminum ratio (0.08), which indicates that the sample has a high proportion of filterable particulates. The filtered/unfiltered lead ratio of sample TK3010 is 0.06, which supports the contention that lead in the sample is associated with suspended particulates and is not in solution. The positive correlation between lead and aluminum for the site and background samples, the similar Pb/Al ratios of the site and background samples, and the significant decrease in lead and aluminum concentrations upon filtration for sample TK3010 indicate a natural source for the lead detected in the T-5 samples.

Conclusion

Lead detected in the site groundwater samples is naturally occurring.

Manganese

Manganese was detected in 70 of the 74 site groundwater samples. Manganese usually displays complex behavior in natural systems because of three possible valence states (+2, +3, and +4), which each have different solubilities and sorptive properties (Hem, 1985). Manganese is similar to iron in that it is soluble under reducing conditions but has very low solubilities under oxidizing conditions. One difference between manganese and iron is that the critical redox potential for dissolution of manganese oxides is higher than the redox potential for dissolution of iron oxides. This means that dissolved manganese concentrations are a more sensitive indicator of local redox depressions than dissolved iron concentrations. Reducing conditions can be natural, or they can be induced by the anaerobic microbial degradation of chlorinated solvents and fuels (see Section 2.2). As discussed previously, the T-5 field readings and Al/Fe ratios suggest moderate to oxidizing conditions at many of the sample locations, and thus manganese is expected to be present in particulate form at these locations. However, the field readings and low Al/Fe ratios of some samples indicate reducing conditions, and thus the manganese in these samples is expected to be present in solution. No direct relationship is observed between VOC concentrations and low redox conditions, however, which suggests that the reducing conditions may be natural at most locations. Additionally, the presence of several background samples with low Al/Fe ratios suggests that reducing conditions are natural at Fort McClellan. A plot of manganese versus ORP for the site samples is provided in Figure 43, and it shows the expected negative trend between manganese concentrations and redox conditions. The samples with the highest manganese concentrations also have the lowest ORP values.

A plot of manganese versus iron is provided in Figure 44. The background samples form a weak linear trend with a positive slope, and most of the site samples lie on the background trend. Many of the site samples with elevated manganese also have proportionally higher iron, and they exhibit Mn/Fe ratios that are within the background range. Manganese detected in these samples has a natural source. There are several samples that lie slightly above the background trend in Figure 44, but all except two of these samples have manganese concentrations that are below the background MDC of 5.82 mg/L. Any contamination in these samples, if present, would not be significant.

Samples TT3005 and TPP3003 contain 6.19 mg/L manganese and 7.07 mg/L manganese, respectively, and their Al/Fe ratios are 0.015 and 0.012. Given these ratios, which reflect mildly reducing conditions, most of the manganese in the two samples is expected to be in solution. As stated previously, no relationship is observed between low redox and the presence of organic contamination in the samples, which suggests that VOC-induced reductive dissolution is not the cause of the elevated manganese. Sample TT3005 contains only estimated (J-qualified) concentrations of acetone, carbon disulfide, and methylene chloride (all values are below the reporting limit). Sample TPP3003 contains estimated (J-qualified) concentrations of 1,1,2,2-tetrachloroethane and 1,2-dichloroethane, as well as unestimated concentrations of *cis*-1,2-DCE and TCE. The summed VOC concentrations are 0.34074 mg/L for sample TT3005 (acetone accounts for 0.34 mg/L, or 99 percent, of the total) and 0.01659 mg/L for sample TPP3003. These totals are one to two orders of magnitude lower than the maximum VOC concentration of 5.4021 mg/L, which is observed in a sample (TP3001) with 4.06 mg/L manganese, 10.6 J mg/L iron, and a Mn/Fe ratio that is within the background range. There are also several other site samples with similar or higher VOC concentrations than those of samples TT3005 and TPP3003, and these other samples exhibit Mn/Fe ratios that are within the background range. Given all of these observations, it is likely that the elevated manganese concentrations in samples TT3005 and TPP3003 reflect naturally low redox.

Conclusion

Manganese detected in the site groundwater samples is naturally occurring.

Nickel

Nickel was detected in only 9 of the 74 site groundwater samples. Nickel is commonly present as the divalent cation (Ni^{2+}) under moderate to oxidizing redox conditions and pH values below about 8 (Brookins, 1988). As discussed in Section 2.2, cationic species have an affinity to adsorb on the surfaces of suspended clay minerals, which tend to maintain a net negative surface charge. If an uncontaminated sample contains a high proportion of suspended clay minerals, then it is expected to contain naturally high concentrations of aluminum and proportionally higher concentrations of associated trace elements such as nickel. A plot of nickel versus aluminum reveals a linear trend with a positive slope for the T-5 samples ($R^2 = 0.82$) (Figure 45). The background samples are not depicted because they are 100 percent nondetect for nickel. However, the CBR Proficiency Area, Range K, and Range 23A site samples with detectable nickel are provided for reference purposes. Most of these reference samples and all of the T-5 samples form a common linear trend with a shallow positive slope. Two of the Range K samples lie below the trend, but they both contain estimated (J-qualified) nickel concentrations below the reporting limit; the uncertainty associated with such values may explain their low Ni/Al ratios.

T-5 sample TK3010 contains the highest nickel of all the samples (0.0505 mg/L) as well as the highest aluminum (26.1 mg/L). As noted previously, sample TK3010 is characterized by high turbidity (999 NTU) and a low filtered/unfiltered aluminum ratio (0.08), which indicates that the sample has a high proportion of filterable particulates such as clays. The filtered split of sample TK3010 is nondetect for nickel (reporting limit of 0.02 mg/L), which supports the contention that nickel in the sample is associated with suspended particulates and is not in solution. The positive correlation between nickel and aluminum for the T-5 and reference samples, the similar Ni/Al ratios of the T-5 and reference samples, and the decrease in nickel and aluminum concentrations upon filtration for sample TK3010 indicate a natural source for the nickel detected in the site samples.

T-5 samples TK3009 and TRR3001 contain detectable nickel (0.0382 mg/L and 0.0334 mg/L) but are nondetect for aluminum, and these samples could not be depicted in Figure 45. A plot of nickel versus iron is provided in Figure 46. The T-5 samples exhibit a linear trend with a positive slope ($R^2 = 0.66$). If samples TK3009 and TRR3001 contained excess nickel from a contaminant source, then they would have anomalously high Ni/Fe ratios relative to the other samples and would lie above the other samples in the plot. However, samples TK3009 and TRR3001 exhibit Ni/Fe ratios that are consistent with those of the other samples, which suggests that their nickel concentrations are naturally occurring.

It is important to note that the site reporting limit of 0.02 mg/L for nickel is below the reporting limit of many background samples. The reporting limit for the 1997 background groundwater samples is 0.015 mg/L (33 of 60 samples), but the reporting limit for the 1994-1995 background samples is 0.0321 mg/L (24 of 60 samples) and the reporting limit for the 1996 background samples is 0.0343 mg/L (3 of 60 samples). The absence of detectable nickel in the background samples, therefore, should not be construed as proof of contamination in the site samples with detectable nickel.

Conclusion

Nickel detected in the site groundwater samples is naturally occurring.

Vanadium

Vanadium was detected in only 6 of the 74 site groundwater samples. As discussed in Section 2.2, vanadium is typically present in oxic groundwater as anionic species and has an affinity to adsorb on the surfaces of iron oxides, which tend to maintain a net positive surface charge. If an uncontaminated sample contains a large proportion of suspended iron oxides, then it will contain naturally high concentrations of iron and associated trace elements such as vanadium. A plot of vanadium versus iron is provided in Figure 47. Comparison to background is hindered by the high percentage of nondetects in the background data set. Five of the six site vanadium detections are estimated (J-qualified) concentrations below the reporting limit, and the uncertainty associated with such values likely explains the lack of correlation observed in the plot. These five detections are all below the background MDC of 0.0114 mg/L, which suggests that they are natural. Site sample TK3010 contains the highest vanadium of the site and background data sets (0.048 mg/L), but it also contains the highest iron (59.6 mg/L) and aluminum (26.1 mg/L). Sample TK3010 is characterized by high turbidity (999 NTU) and a low

filtered/unfiltered iron ratio (0.06), which indicates that the sample has a high proportion of filterable particulates such as iron oxides. The filtered/unfiltered vanadium ratio of sample TK3010 is 0.14, which supports the contention that the vanadium in the sample is primarily associated with suspended particulates. If sample TK3010 contained excess vanadium from a contaminant source, it would lie above the trend of the other samples, rather than to the right of the samples, in Figure 47. The fact that the sample with highest vanadium contains proportionally higher iron and aluminum, however, indicates that the elevated vanadium is natural.

Conclusion
Vanadium detected in the site groundwater samples is naturally occurring.

6.0 Results of the Geochemical Evaluation of Mercury in Surface Water

This section presents the results of the geochemical evaluation of mercury in the five unfiltered surface water samples from Training Area T-5. Correlation plots are provided in Attachment 1.

Field-measured pH readings for the surface water samples range from 4.8 to 7.54 standard units, with a median of 5.43 and mean of 5.72. These values indicate neutral to slightly acidic pH conditions at the sample locations. Field-measured DO readings range from 8.9 mg/L to 13.06 mg/L, with a median of 9.68 mg/L and mean of 10.49 mg/L; ORP readings are available only for samples TE2001 (CWM-182-SW/SD01) and TP2004 (CWM-511-SW/SD04), and they are +135 mV and +178 mV, respectively. These values suggest oxidizing redox conditions at the sample locations. Turbidity measurements range from 0 NTU to 14.3 NTU, with a median of 4.9 NTU and mean of 6.8 NTU. These values indicate that the site samples did not contain a significant mass of suspended particulates. It should be noted that field readings are not available for the background surface water samples.

Mercury

Mercury was detected in only one of the five site surface water samples. A plot of mercury versus manganese is provided in Figure 48. The background samples are not depicted because they are 100 percent nondetect for mercury. However, samples with detectable mercury in the Bains Gap Road Ranges, Former Tank Ranges, and Iron Mountain Road Ranges data sets are provided for reference purposes. Most of the reference samples exhibit no correlation because they represent estimated mercury concentrations below the reporting limit, and such values are highly uncertain. T-5 sample TP2003 also contains an estimated mercury concentration (0.0264 J mg/L), but it contains higher manganese than most of the other samples. The single Former Tank Ranges sample contains the highest mercury of the samples in the plot, as well as an approximately proportional amount of manganese.

No organic contaminants were detected in sample TP2003. It is important to note that the site reporting limit of 0.0005 mg/L is higher than the background reporting limits. The reporting limit for the 1997 background surface water samples is 0.0002 mg/L (55 of 64 samples), the reporting limit for the 1992 and 1994 background samples is 0.0001 mg/L (8 of 64 samples), and the reporting limit for the 1995 background sample is 0.000243 mg/L (1 of 64 samples). Based on the low, estimated nature of the mercury concentration in sample TP2003, the lack of organic contamination in the sample, and the differences in reporting limits between the site and background data sets, it is likely that the mercury detected in the sample does not reflect site-related contamination.

Conclusion
Mercury detected in the site surface water samples is naturally occurring.

7.0 Summary

This section summarizes the results of the geochemical evaluation of selected elements in soil, sediment, groundwater, and surface water samples from Training Area T-5. Table 1 lists the samples that contain anomalously high element concentrations and provides the corresponding location codes.

Surface Soil. For the surface soil interval, most of the TAL metals failed statistical comparison to background except antimony, lead, manganese, mercury, sodium, and thallium. Geochemical evaluation indicates that all detected concentrations of aluminum, arsenic, beryllium, calcium, chromium, cobalt, iron, magnesium, nickel, potassium, selenium, silver, and vanadium are naturally occurring. Anomalous concentrations of barium, cadmium, copper, and zinc are present in at least one surface soil sample each, and these concentrations may contain a component of contamination (Table 1).

Subsurface Soil. For the subsurface soil interval, most of the TAL metals failed statistical comparison to background except antimony, cadmium, sodium, and thallium. Geochemical evaluation indicates that all detected concentrations of aluminum, arsenic, barium, beryllium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silver, vanadium, and zinc are naturally occurring.

Sediment. Only cadmium, chromium, copper, and zinc in the site sediment data set failed statistical comparison to background. Geochemical evaluation indicates that the detected concentrations of cadmium, copper, and zinc in the site samples are naturally occurring. The chromium concentration in sample TE1002 is anomalously high and may contain a component

of contamination (Table 1). Chromium concentrations detected in the other site samples are naturally occurring.

Groundwater. Barium, beryllium, calcium, chromium, cobalt, lead, manganese, nickel, and vanadium in the T-5 groundwater data set failed statistical comparison to background. Geochemical evaluation indicates that the detected concentrations of these nine elements in the site groundwater samples are naturally occurring.

Surface Water. Mercury was the only element in the T-5 surface water data set to fail statistical comparison to background. Geochemical evaluation indicates that the single detected concentration of mercury in the site surface water data set is naturally occurring.

8.0 References

Barclift, D., J. Heath, and A. Drucker, 2000, "Focus on Environmental Background Data Analysis," ***Soil Sediment & Groundwater***, August/September, pp. 10-17.

Belzile, N., Y. W. Chen, and R. Xu, 2000, "Early diagenetic behavior of selenium in freshwater sediments," ***Applied Geochemistry***, Vol. 15, No. 10, pp. 1439-1454.

Bowell, R. J., 1994, "Sorption of arsenic by iron oxides and oxyhydroxides in soils," ***Applied Geochemistry***, Vol. 9, No. 3, pp. 279-286.

Brookins, D. G., 1988, ***Eh-pH Diagrams for Geochemistry***, Springer-Verlag.

Cornell, R. M. and U. Schwertmann, 2003, ***The Iron Oxides: Structure, Properties, Reactions, Occurrences and Uses***, Second Edition, Wiley-VCH, Weinheim.

Daskalakis, K. D. and T. P. O'Connor, 1995, "Normalization and Elemental Sediment Contamination in the Coastal United States," ***Environmental Science & Technology***, Vol. 29, No. 2, pp. 470-477.

Electric Power Research Institute (EPRI), 1984, ***Chemical Attenuation Rates, Coefficients, and Constants in Leachate Migration, Volume 1: A Critical Review***, EPRI EA-3356, Palo Alto, California.

Electric Power Research Institute (EPRI), 1986, ***Speciation of Selenium and Arsenic in Natural Waters and Sediments, Volume 2: Arsenic Speciation***, EPRI EA-4641, Palo Alto, California.

Hem, J. D., 1985, ***Study and Interpretation of the Chemical Characteristics of Natural Water***, U. S. Geological Survey, Water Supply Paper 2254, 3rd Edition.

IT Corporation, 2002, ***Draft Installation-Wide Work Plan, Fort McClellan, Calhoun County, Alabama, Revision 2***, Prepared for the U.S. Army Corps of Engineers, Mobile District, February.

Kabata-Pendias, A., 2001, ***Trace Elements in Soils and Plants,*** Third Edition, CRC Press.

Myers, J. and K. Thorbjornsen, 2004, "Identifying Metals Contamination in Soil: A Geochemical Approach," ***Soil & Sediment Contamination***, Vol. 13, No. 1, pp. 1-16.

Nickson, R. T., J. M. McArthur, P. Ravenscroft, W. G. Burgess, and K. M. Ahmed, 2000, "Mechanism of arsenic release to groundwater, Bangladesh and West Bengal," ***Applied Geochemistry***, Vol. 15, No. 4, pp. 403-413.

Pourbaix, M., 1974, ***Atlas of Electrochemical Equilibria in Solutions***, National Association of Corrosion Engineers, Houston, Texas.

Science Applications International Corporation, 1998, ***Final Background Metals Survey Report, Fort McClellan, Anniston, Alabama***, July.

Schiff, K. and S. B. Weisberg, 1997, "Iron as a Reference Element for Determining Trace Metal Enrichment in California Coastal Shelf Sediments," *in*: S. Weisberg, C. Francisco, and D. Hallock (editors), ***Southern California Coastal Water Research Project Annual Report 1995-96***, pp. 68-78.

Stumm, W. and J. Morgan, 1996, ***Aquatic Chemistry***, Third Edition, Wiley-Interscience, New York.

Sullivan, K. A. and R. C. Aller, 1996, "Diagenetic cycling of arsenic in Amazon shelf sediments," ***Geochimica et Cosmochimica Acta***, Vol. 60, No. 9, pp. 1465-1477.

U.S. Environmental Protection Agency, 1995, ***Determination of Background Concentrations of Inorganics in Soils and Sediments at Hazardous Waste Sites***, Office of Research and Development, EPA/540/S-96/500, December.

U.S. Navy, 2002, ***Guidance for Environmental Background Analysis, Volume 1: Soil***, NFESC User's Guide UG-2049-ENV, Naval Facilities Engineering Command, Washington, D.C., April.

U.S. Navy, 2003, ***Guidance For Environmental Background Analysis, Volume II: Sediment***, NFESC User's Guide UG-2054-ENV, Naval Facilities Engineering Command, Washington, D.C., April.

ATTACHMENT 1

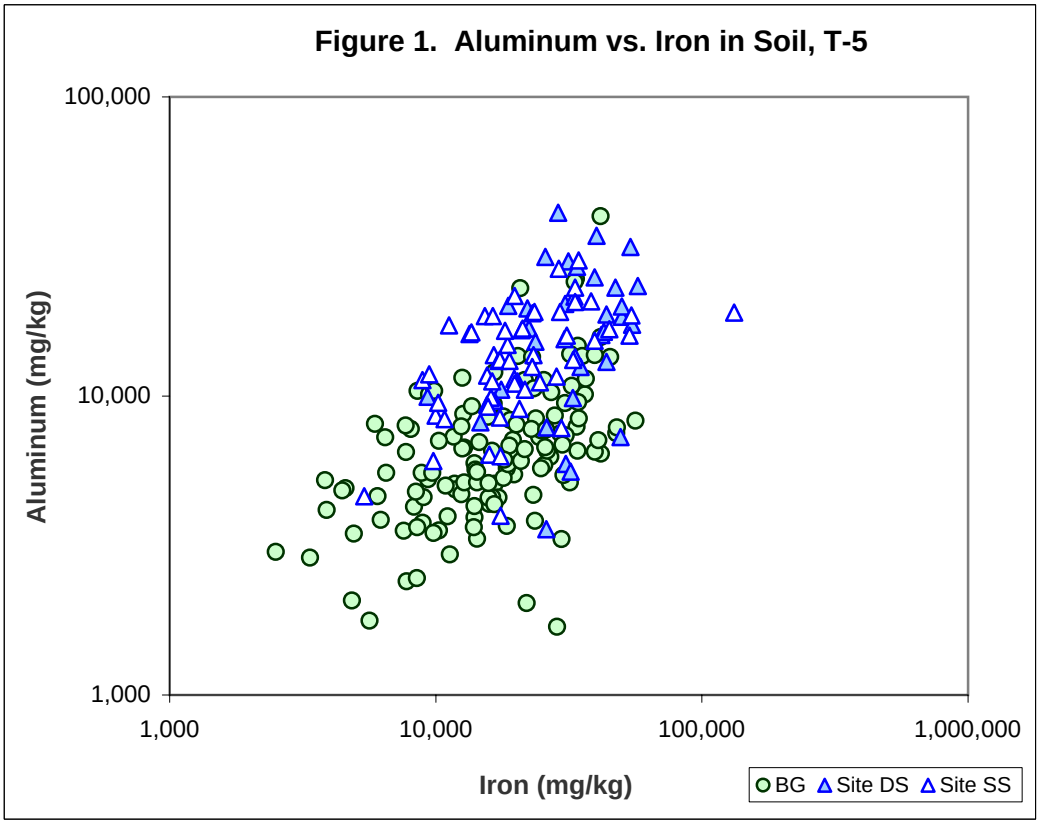


Figure 1. Aluminum vs. Iron in Soil, T-5
100,000
10,000
1,000
Aluminum (mg/kg)
1,000
10,000
100,000
1,000,000
Iron (mg/kg)
BG
Site DS
Site SS

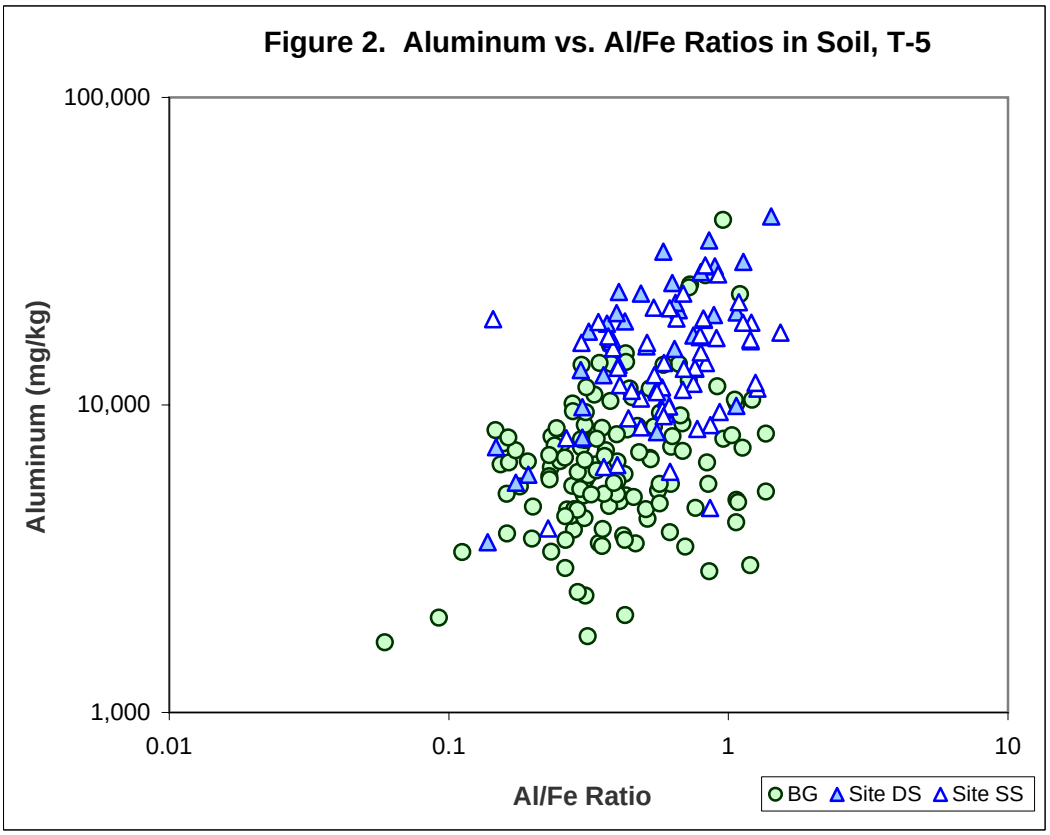


Figure 2. Aluminum vs. Al/Fe Ratios in Soil, T-5
100,000
10,000
1,000
Aluminum (mg/kg)
0.01
0.1
1
10
Al/Fe Ratio
BG
Site DS
Site SS

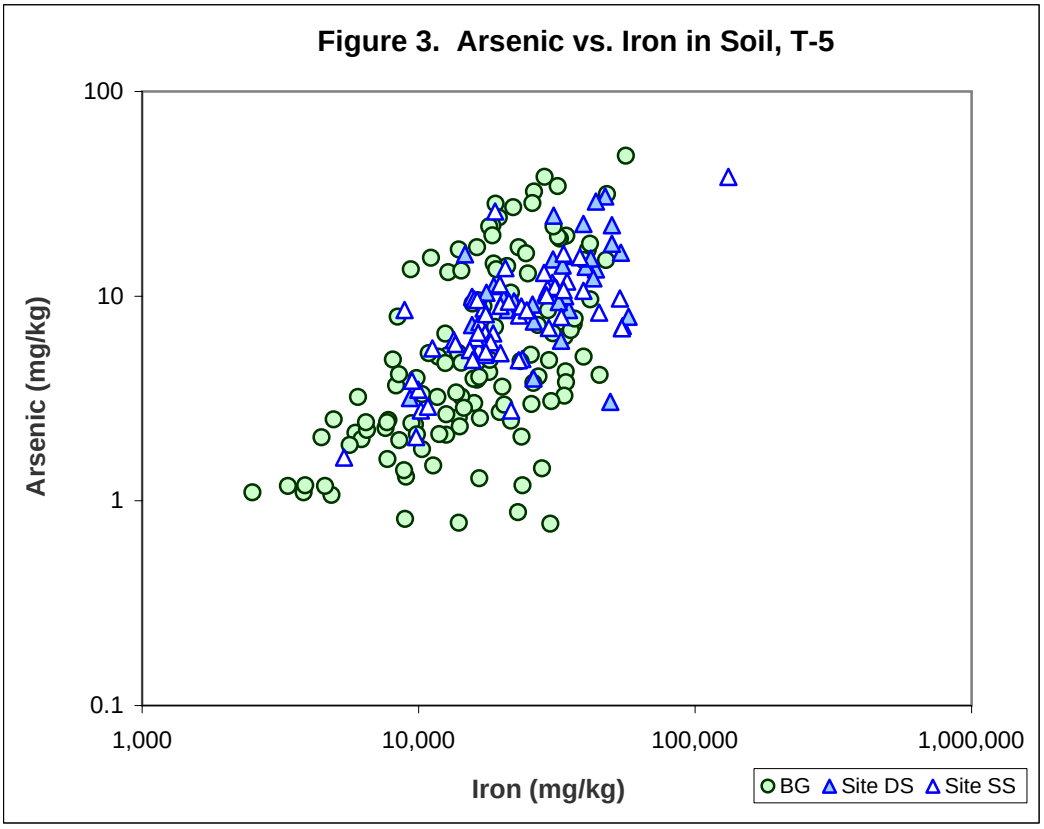


Figure 3. Arsenic vs. Iron in Soil, T-5
100
10
1
0.1
Arsenic (mg/kg)
1,000
10,000
100,000
1,000,000
Iron (mg/kg)
BG
Site DS
Site SS

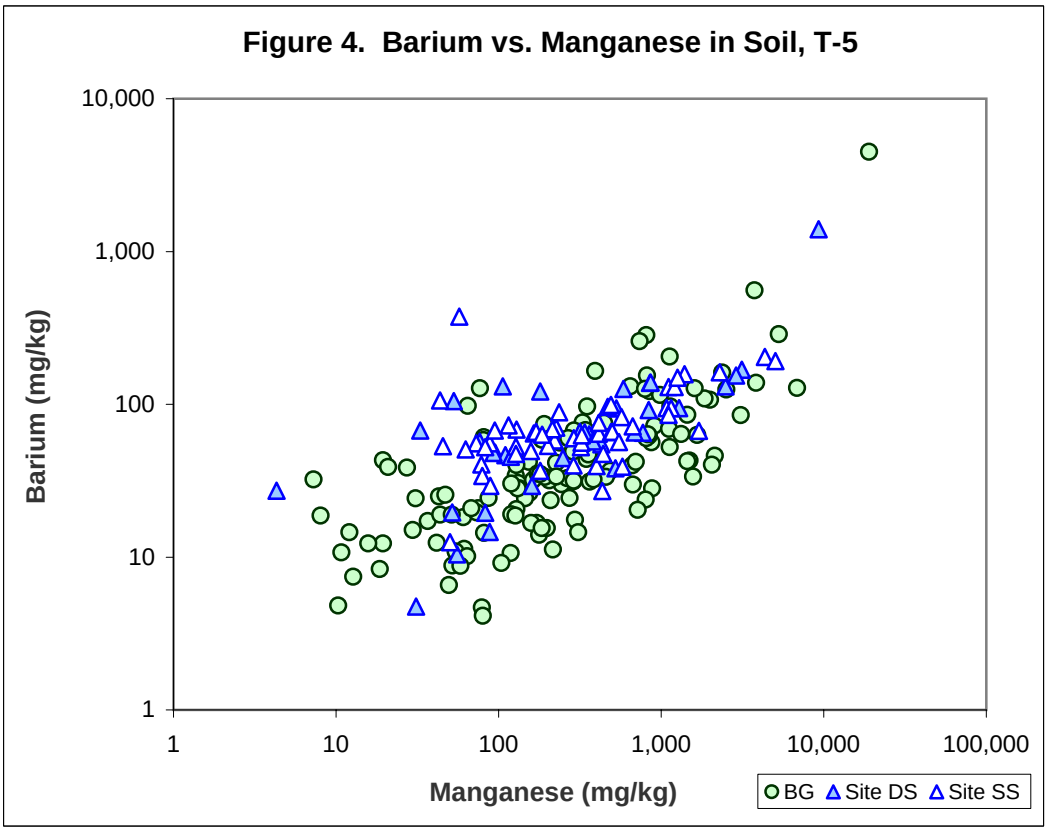


Figure 4. Barium vs. Manganese in Soil, T-5
10,000
1,000
100
10
1
Barium (mg/kg)
1
10
100
1,000
10,000
100,000
Manganese (mg/kg)
BG
Site DS
Site SS

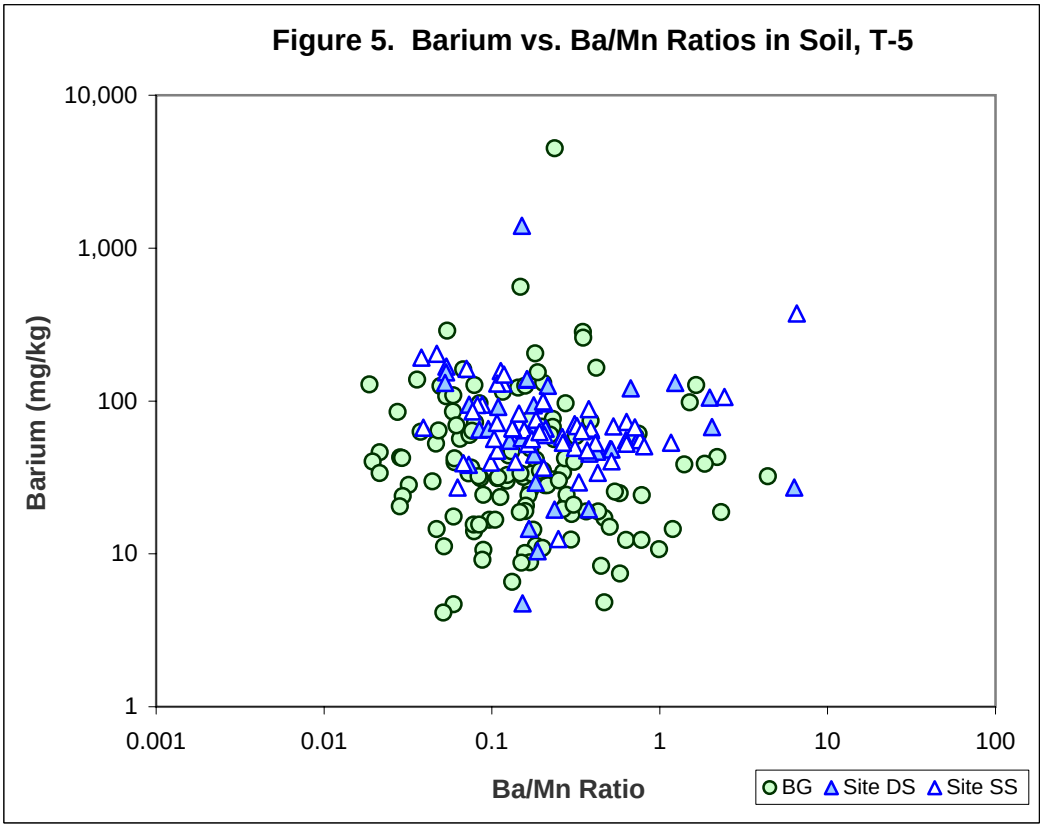


Figure 5. Barium vs. Ba/Mn Ratios in Soil, T-5
10,000
1,000
100
10
1
Barium (mg/kg)
0.001
0.01
0.1
1
10
100
Ba/Mn Ratio
BG
Site DS
Site SS

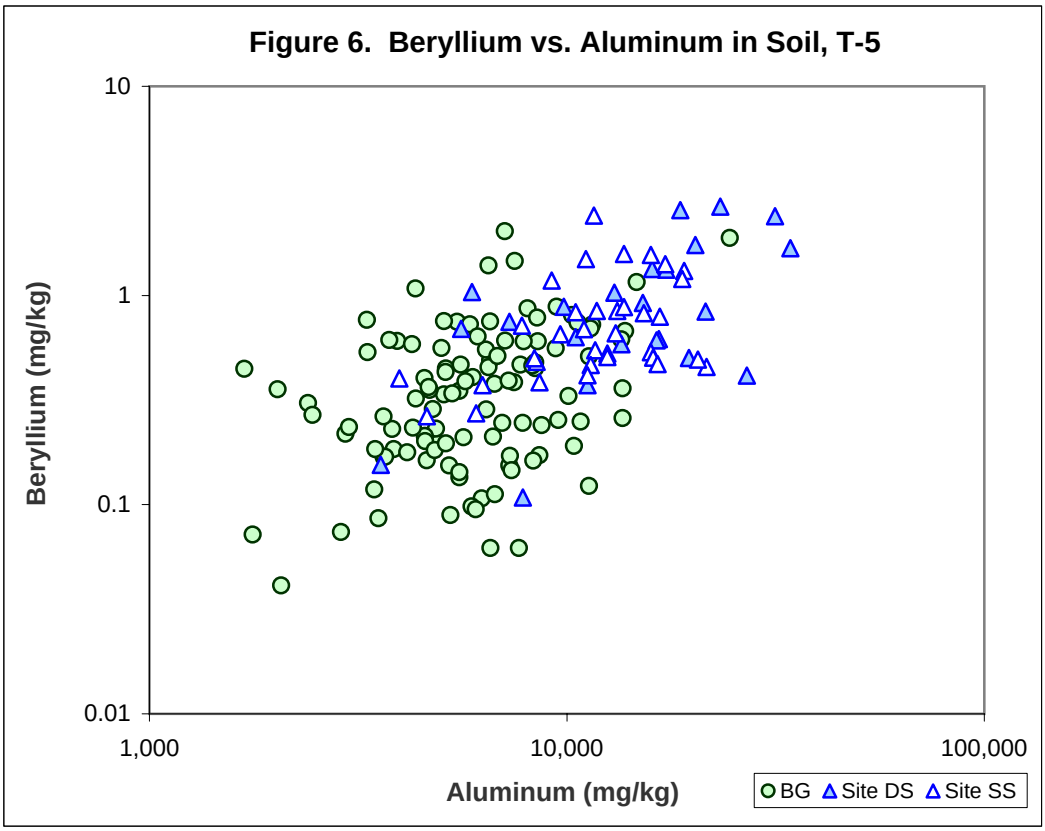


Figure 6. Beryllium vs. Aluminum in Soil, T-5
10
1
0.1
0.01
Beryllium (mg/kg)
1,000
10,000
100,000
Aluminum (mg/kg)
BG
Site DS
Site SS

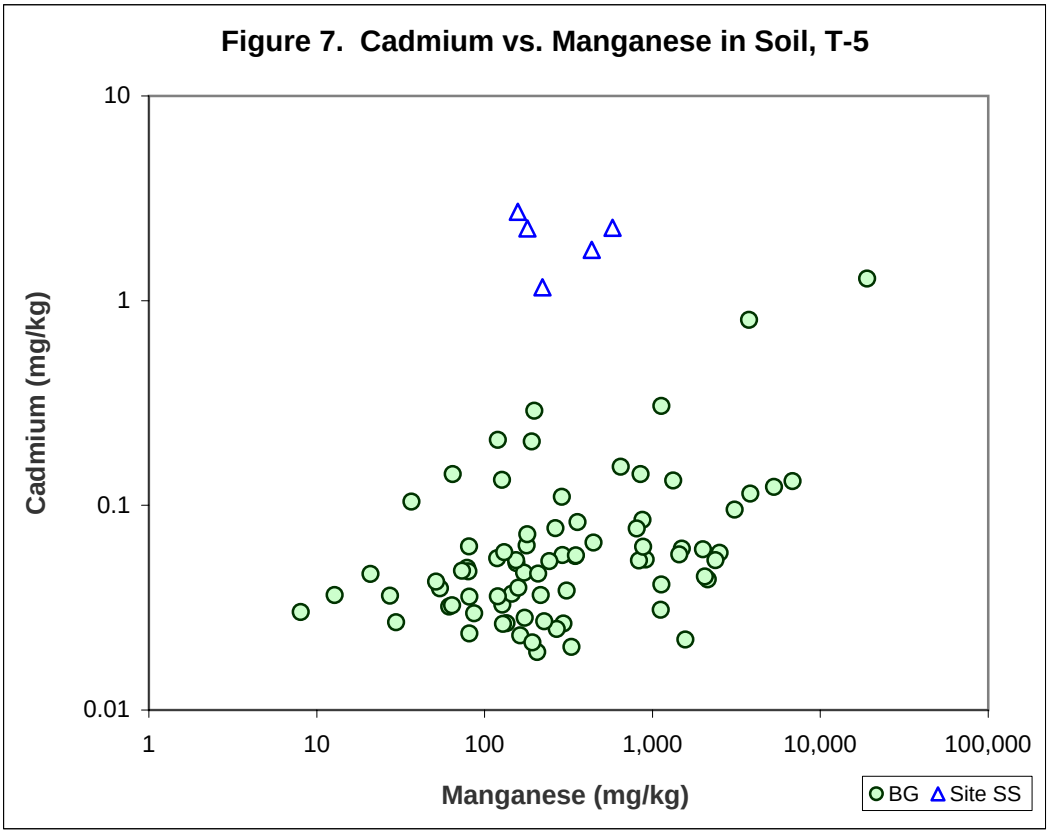


Figure 7. Cadmium vs. Manganese in Soil, T-5
Cadmium (mg/kg)
10
1
0.1
0.01
1
10
100
1,000
10,000
100,000
Manganese (mg/kg)
BG
Site SS

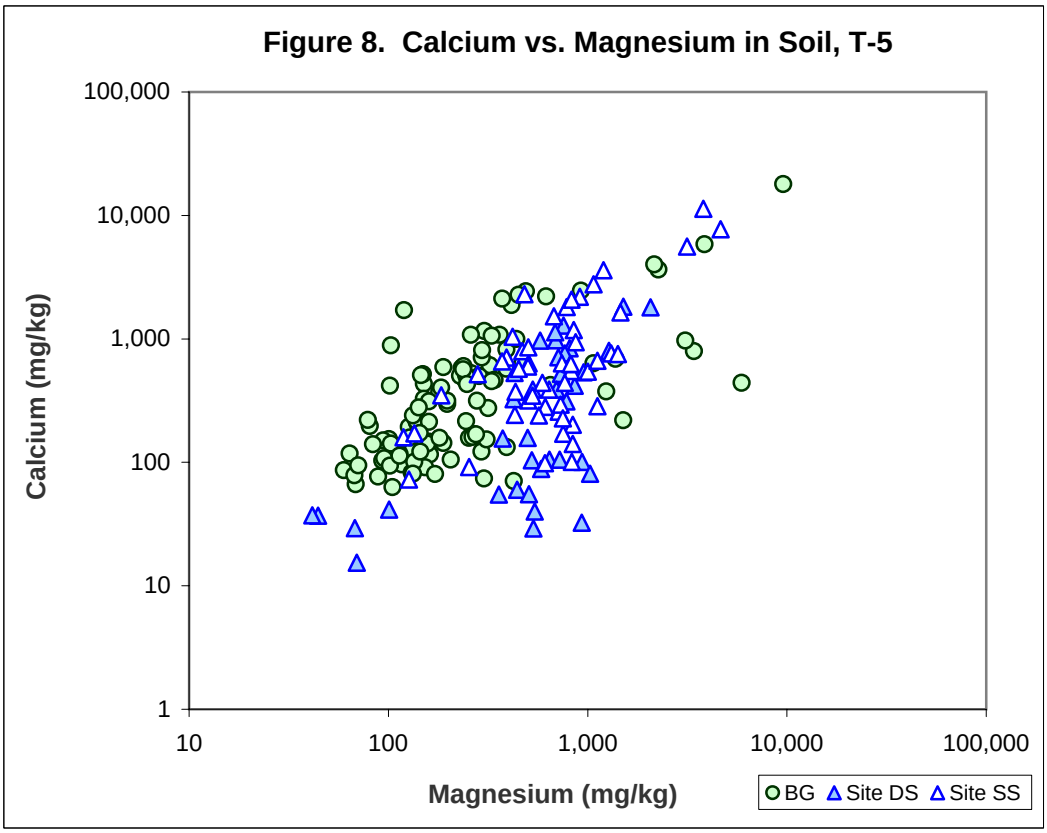


Figure 8. Calcium vs. Magnesium in Soil, T-5
Calcium (mg/kg)
100,000
10,000
1,000
100
10
1
10
100
1,000
10,000
100,000
Magnesium (mg/kg)
BG
Site DS
Site SS

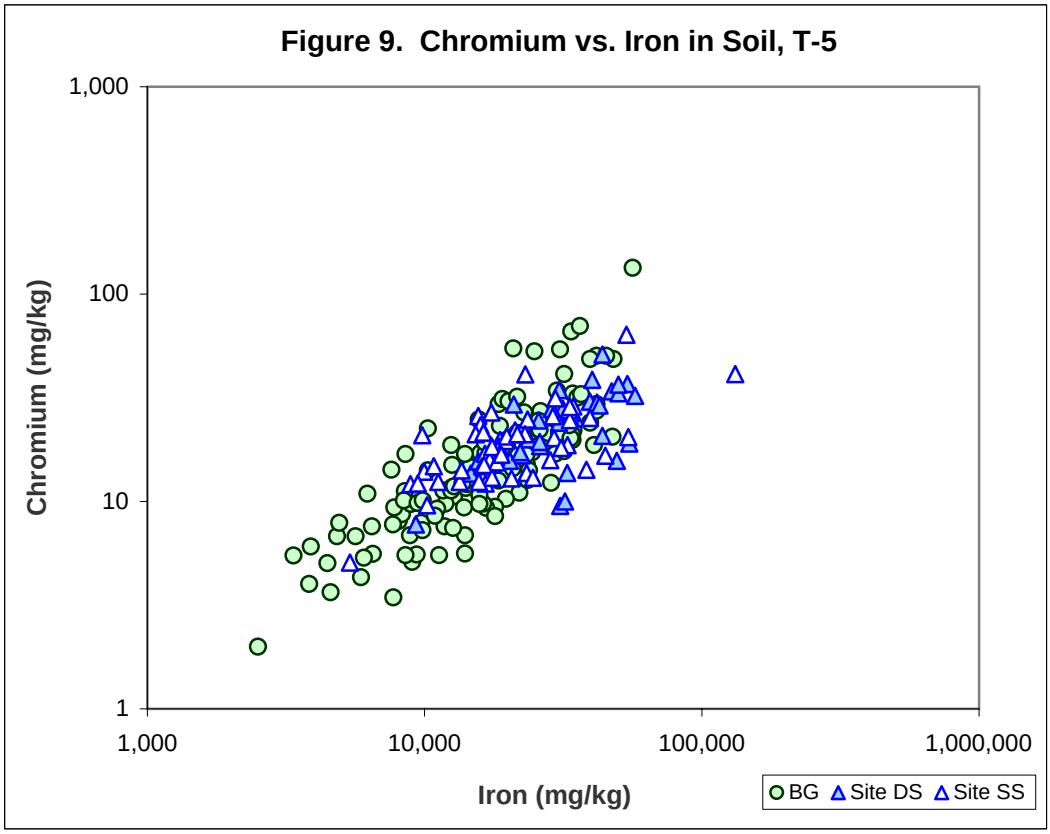


Figure 9. Chromium vs. Iron in Soil, T-5
1,000
100
10
1
Chromium (mg/kg)
1,000
10,000
100,000
1,000,000
Iron (mg/kg)
BG
Site DS
Site SS

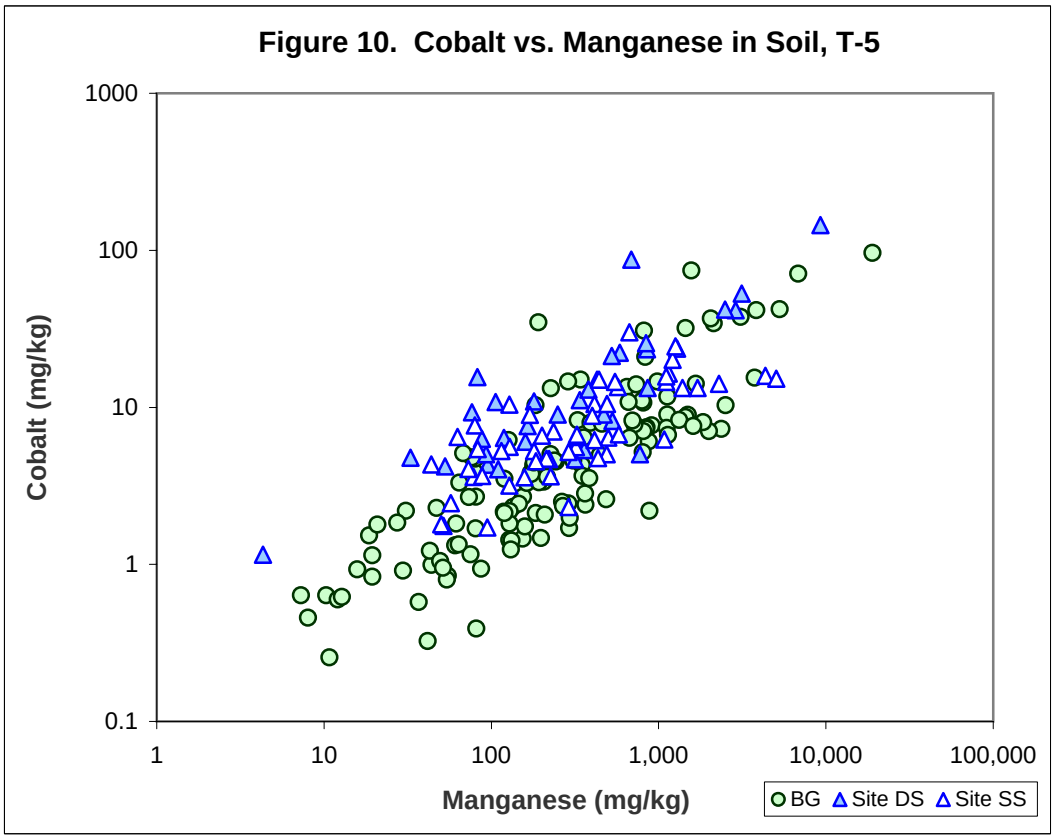


Figure 10. Cobalt vs. Manganese in Soil, T-5
1000
100
10
1
0.1
Cobalt (mg/kg)
1
10
100
1,000
10,000
100,000
Manganese (mg/kg)
BG
Site DS
Site SS

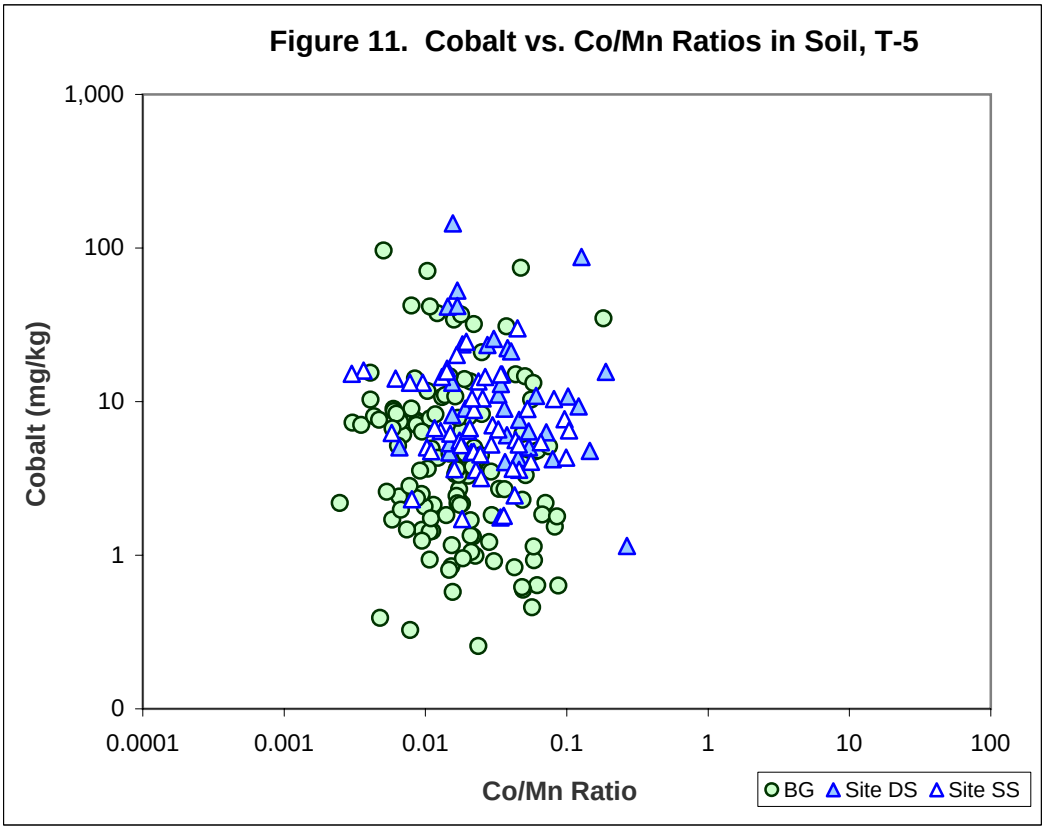


Figure 11. Cobalt vs. Co/Mn Ratios in Soil, T-5
1,000
100
10
1
0
Cobalt (mg/kg)
0.0001
0.001
0.01
0.1
1
10
100
Co/Mn Ratio
BG
Site DS
Site SS

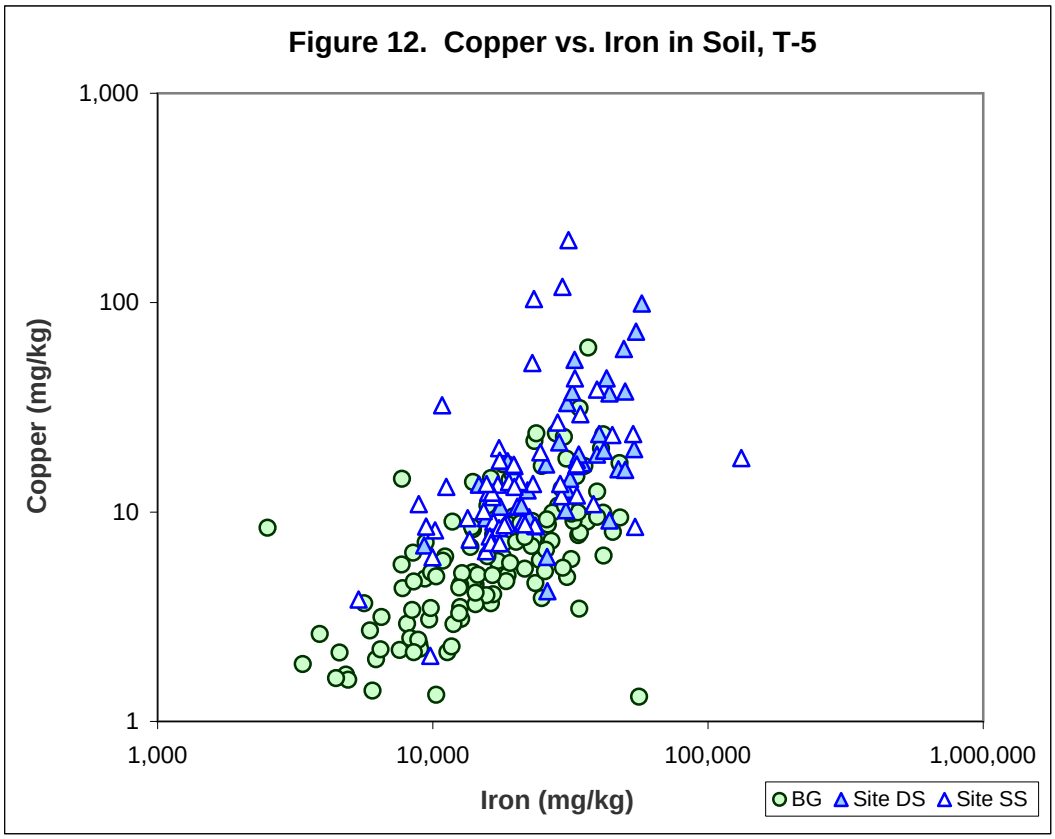


Figure 12. Copper vs. Iron in Soil, T-5
1,000
100
10
1
Copper (mg/kg)
1,000
10,000
100,000
1,000,000
Iron (mg/kg)
BG
Site DS
Site SS

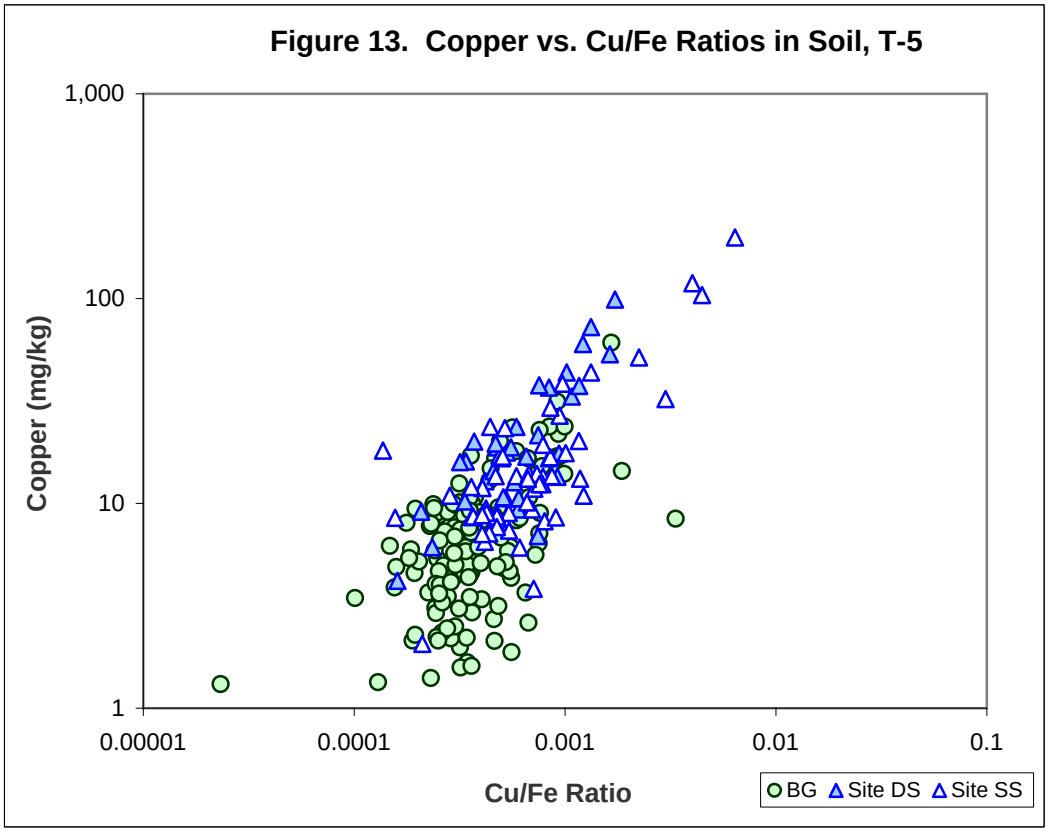


Figure 13. Copper vs. Cu/Fe Ratios in Soil, T-5
1,000
100
10
1
Copper (mg/kg)
0.00001
0.0001
0.001
0.01
0.1
Cu/Fe Ratio
BG
Site DS
Site SS

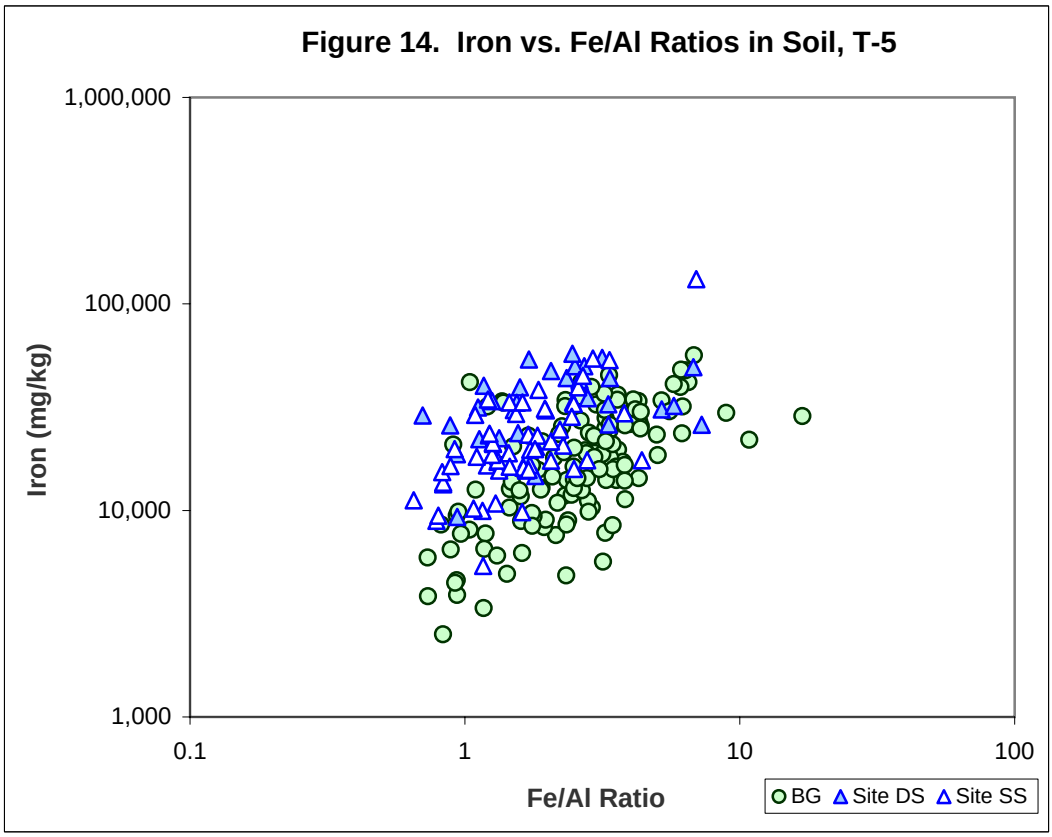


Figure 14. Iron vs. Fe/Al Ratios in Soil, T-5
1,000,000
100,000
10,000
1,000
Iron (mg/kg)
0.1
1
10
100
Fe/Al Ratio
BG
Site DS
Site SS

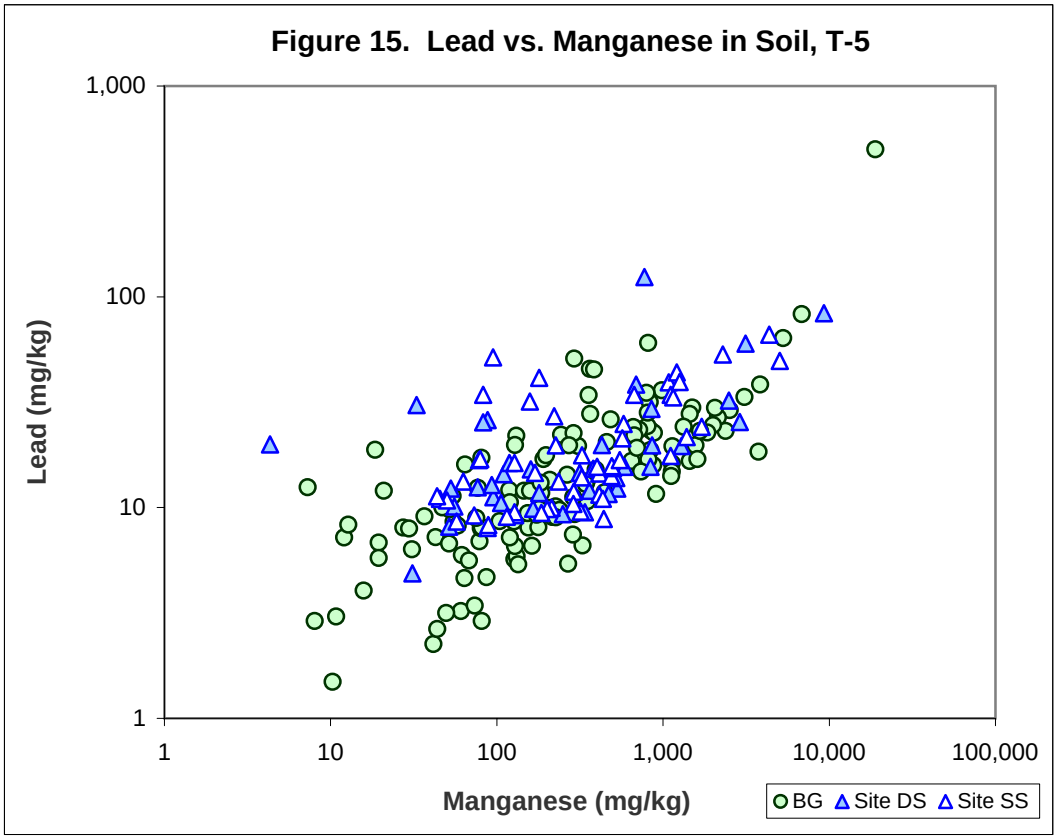


Figure 15. Lead vs. Manganese in Soil, T-5
1,000
100
10
1
Lead (mg/kg)
1
10
100
1,000
10,000
100,000
Manganese (mg/kg)
BG
Site DS
Site SS

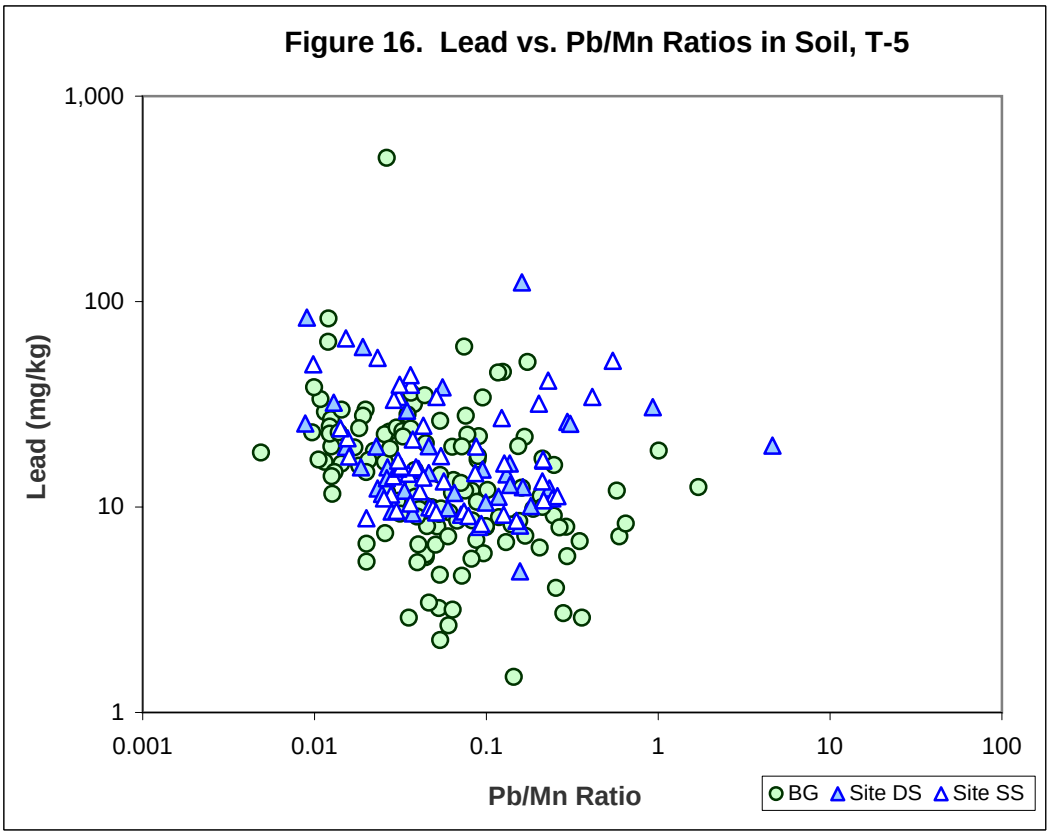


Figure 16. Lead vs. Pb/Mn Ratios in Soil, T-5
1,000
100
10
1
Lead (mg/kg)
0.001
0.01
0.1
1
10
100
Pb/Mn Ratio
BG
Site DS
Site SS

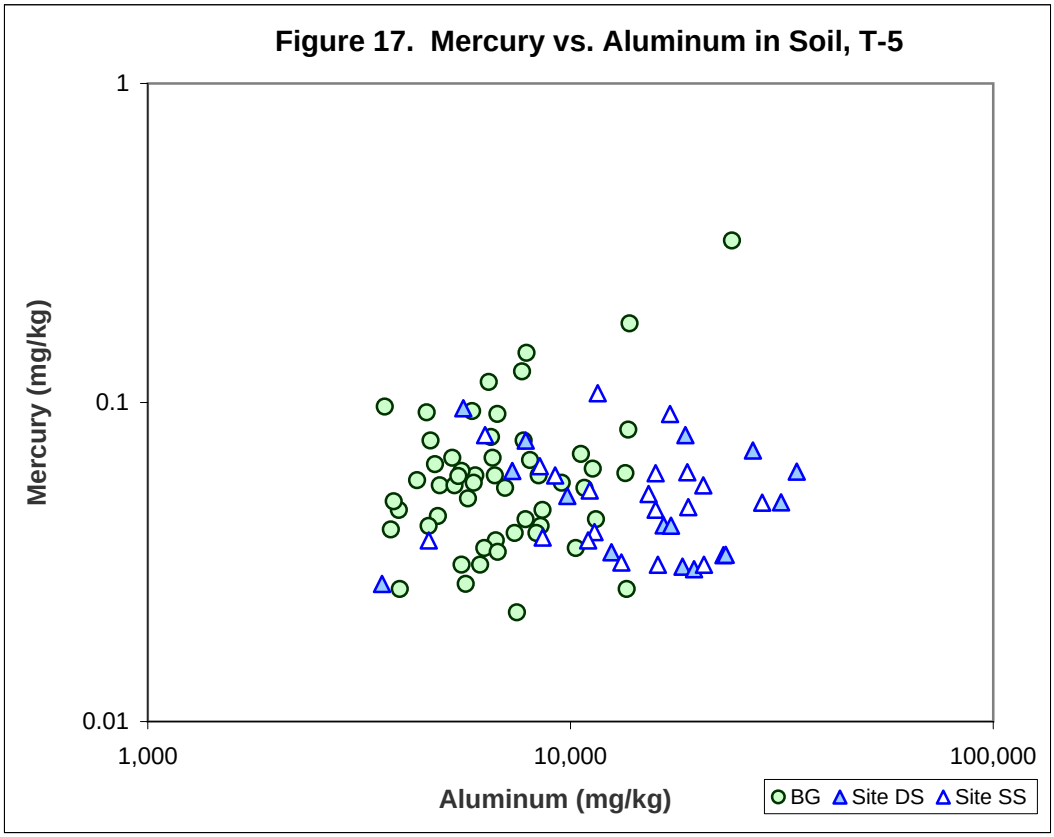


Figure 17. Mercury vs. Aluminum in Soil, T-5
1
0.1
0.01
Mercury (mg/kg)
1,000
10,000
100,000
Aluminum (mg/kg)
BG
Site DS
Site SS

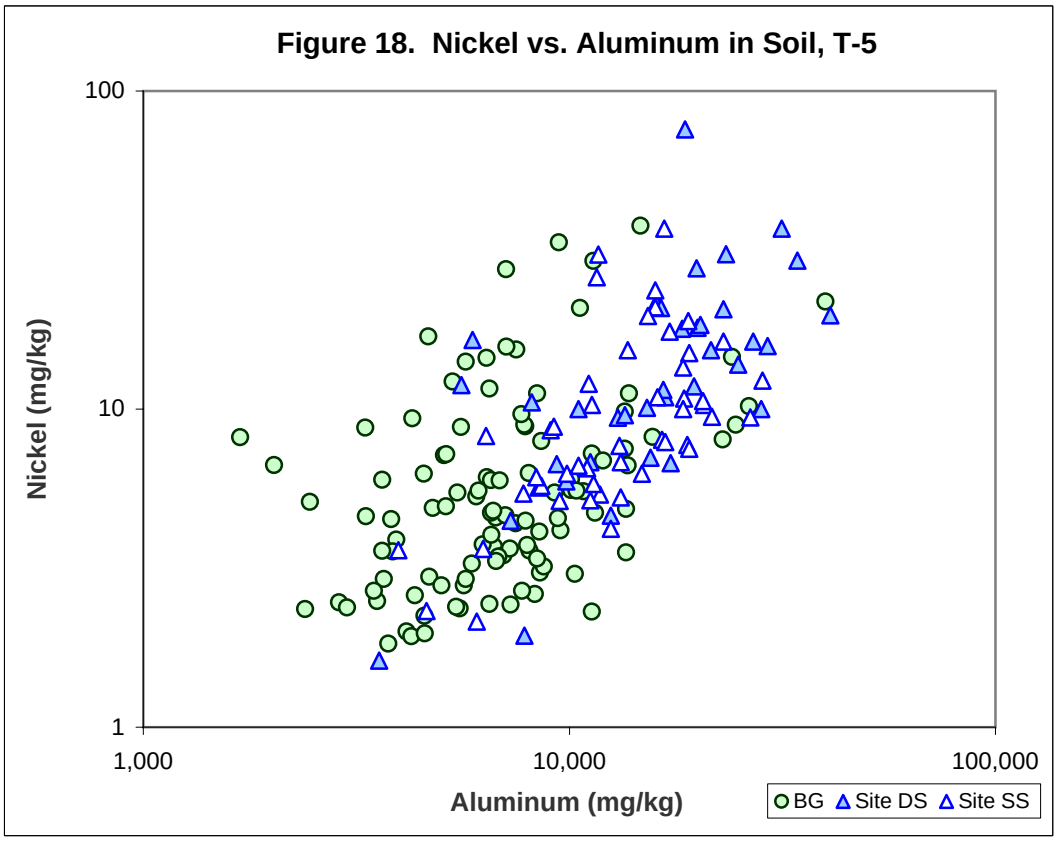


Figure 18. Nickel vs. Aluminum in Soil, T-5
100
10
1
Nickel (mg/kg)
1,000
10,000
100,000
Aluminum (mg/kg)
BG
Site DS
Site SS

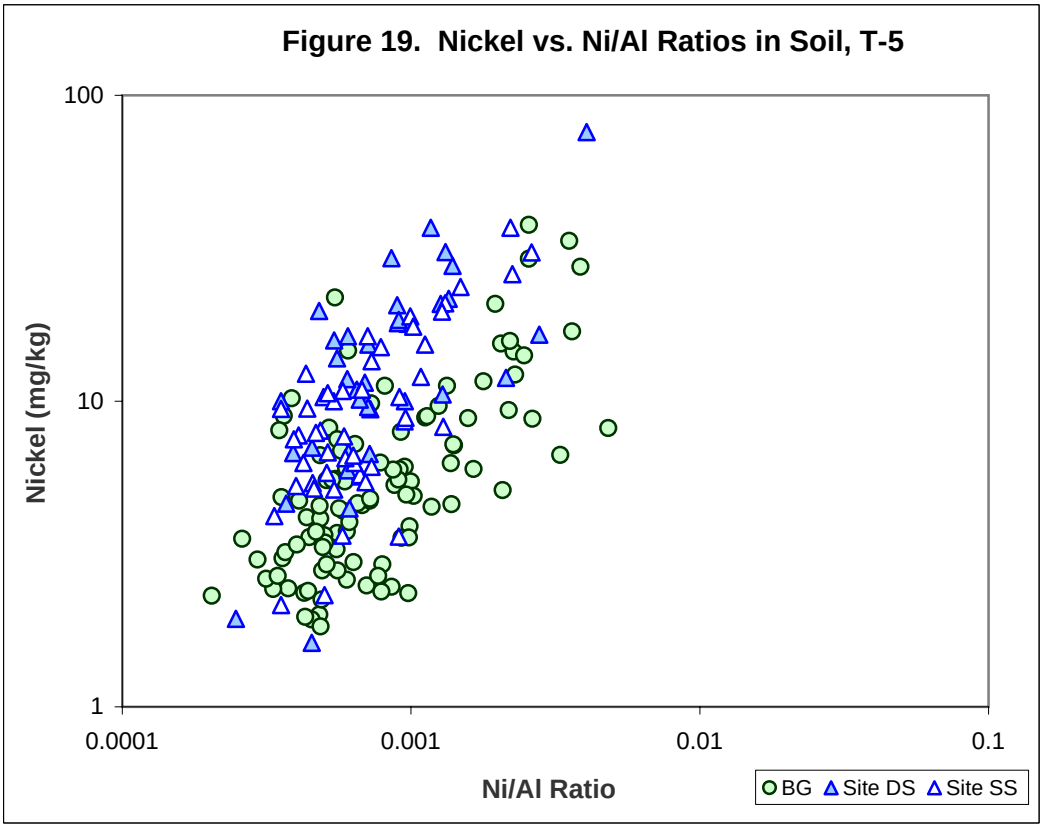


Figure 19. Nickel vs. Ni/Al Ratios in Soil, T-5
100
10
1
Nickel (mg/kg)
0.0001
0.001
0.01
0.1
Ni/Al Ratio
BG
Site DS
Site SS

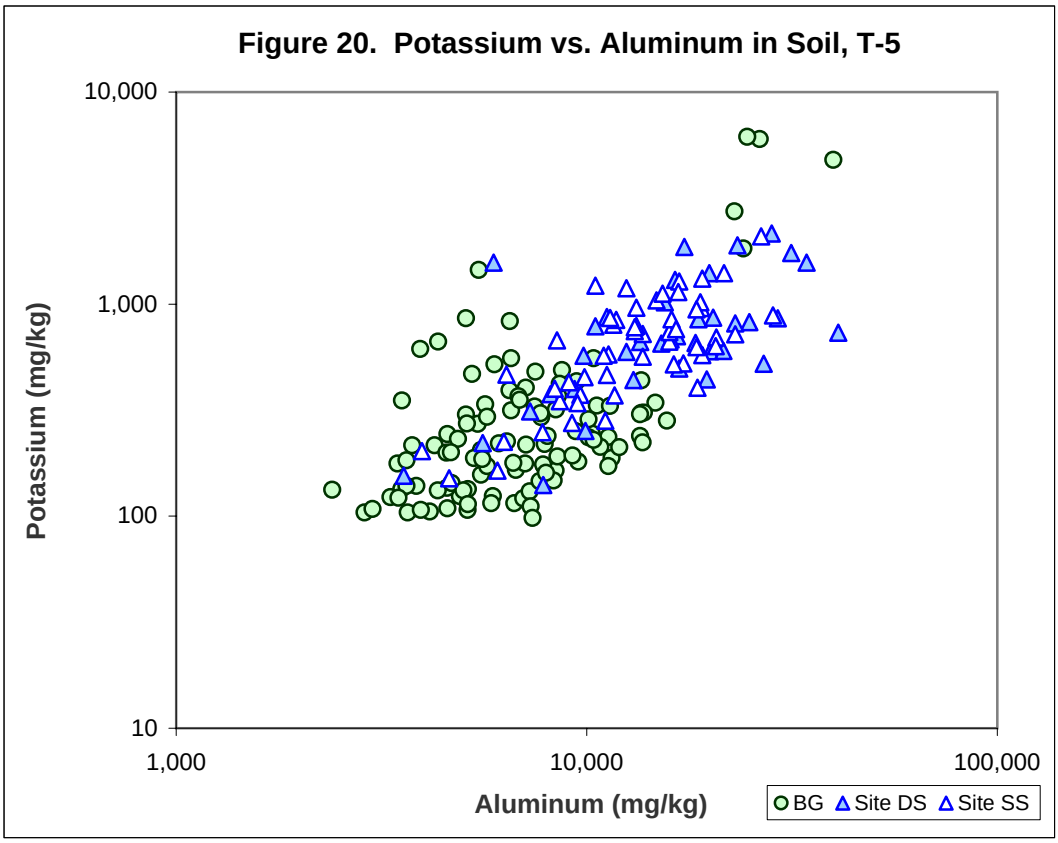


Figure 20. Potassium vs. Aluminum in Soil, T-5
10,000
1,000
100
10
Potassium (mg/kg)
1,000
10,000
100,000
Aluminum (mg/kg)
BG
Site DS
Site SS

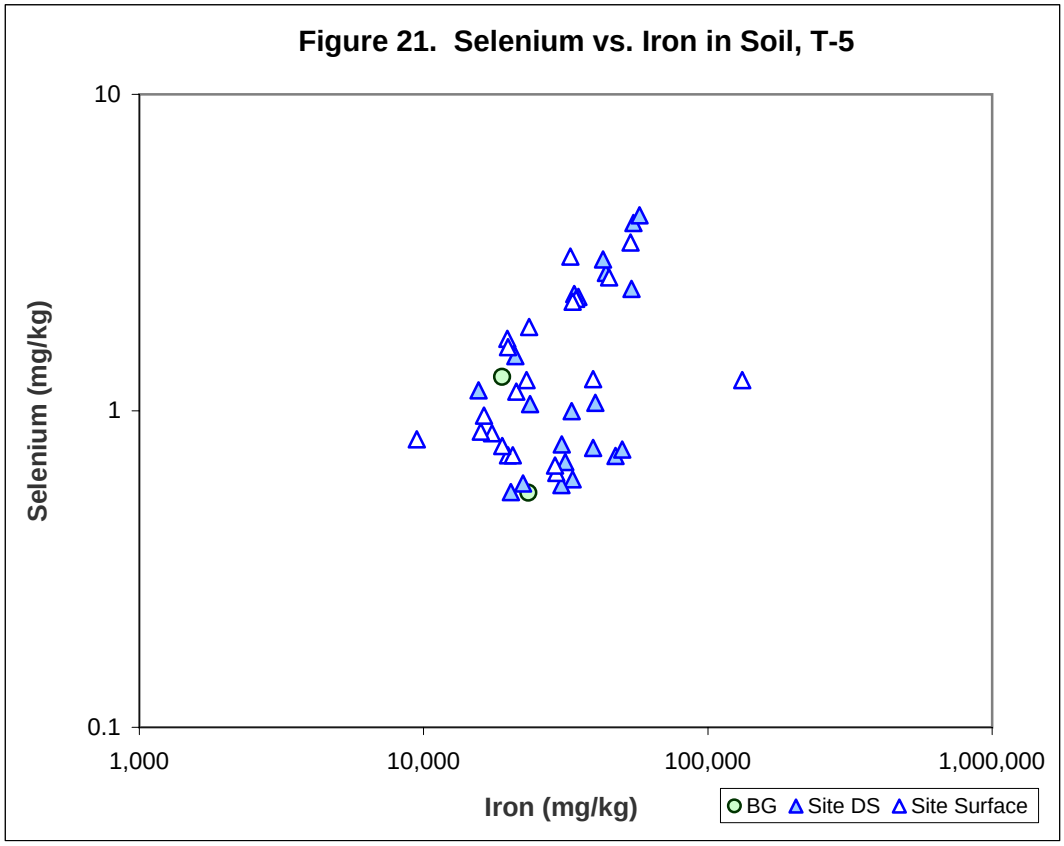


Figure 21. Selenium vs. Iron in Soil, T-5
10
1
0.1
Selenium (mg/kg)
1,000
10,000
100,000
1,000,000
Iron (mg/kg)
BG
Site DS
Site Surface

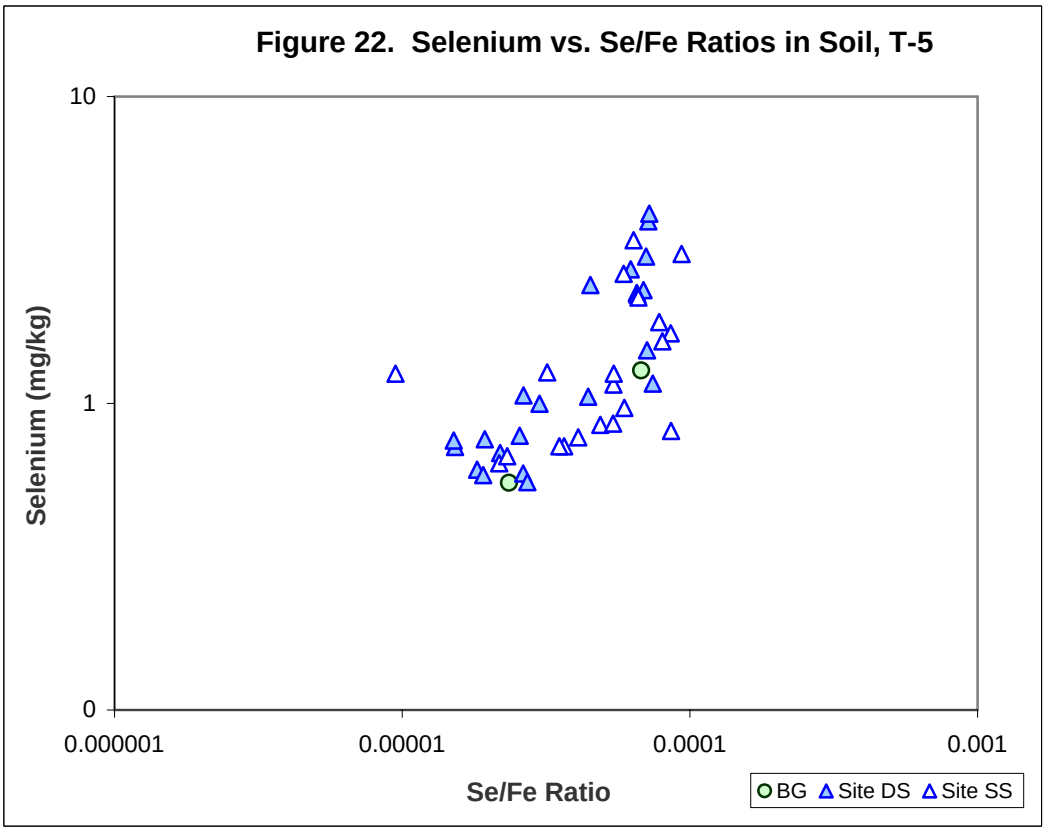


Figure 22. Selenium vs. Se/Fe Ratios in Soil, T-5
10
1
0
Selenium (mg/kg)
0.000001
0.00001
0.0001
0.001
Se/Fe Ratio
BG
Site DS
Site SS

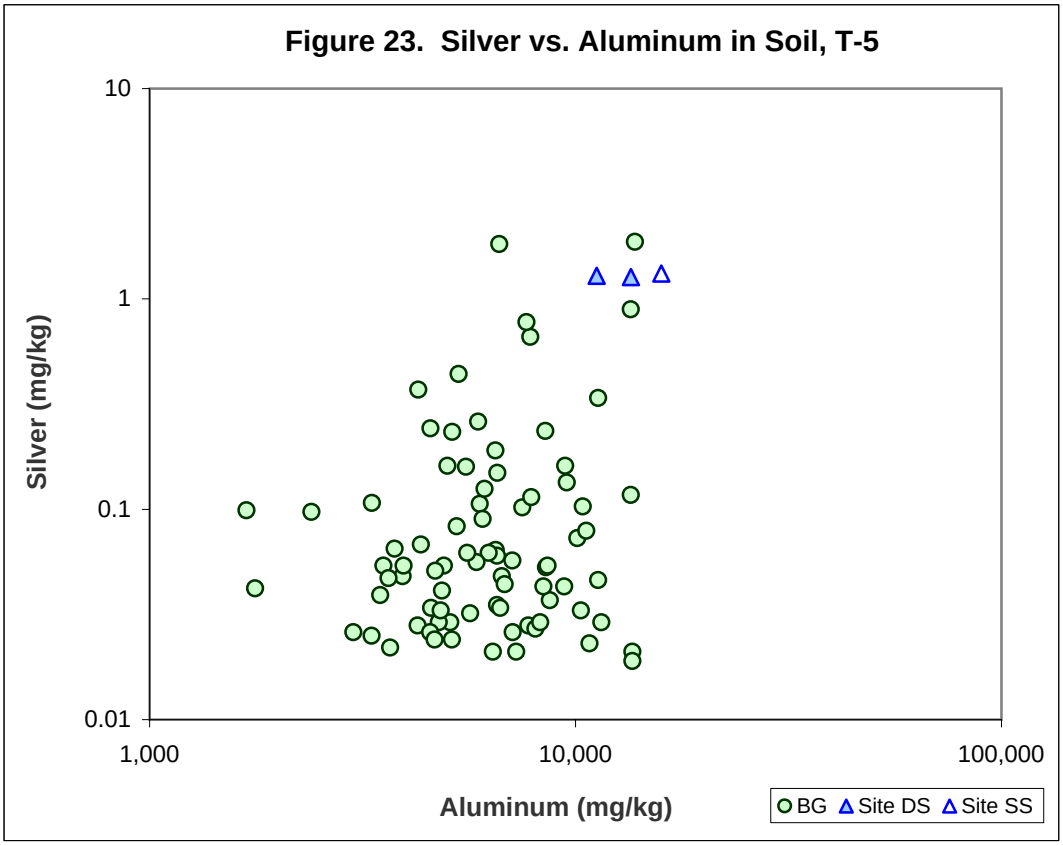


Figure 23. Silver vs. Aluminum in Soil, T-5
10
1
0.1
0.01
Silver (mg/kg)
1,000
10,000
100,000
Aluminum (mg/kg)
BG
Site DS
Site SS

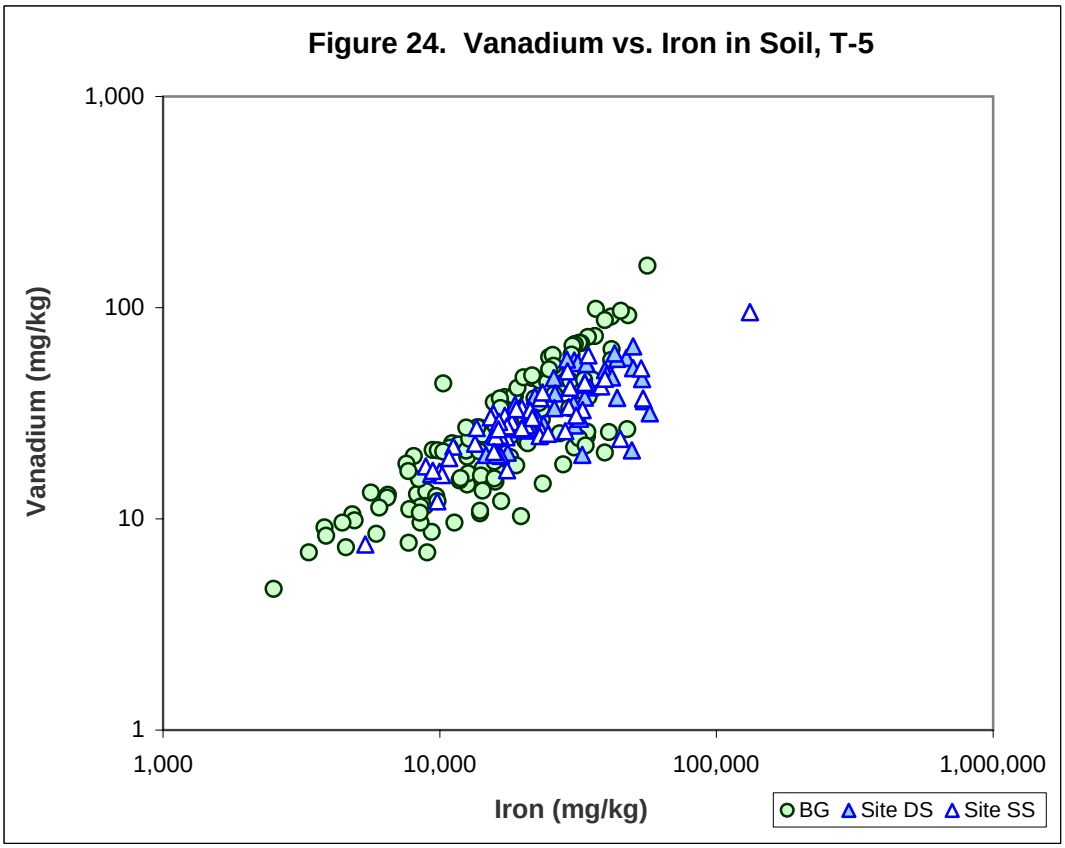


Figure 24. Vanadium vs. Iron in Soil, T-5
1,000
100
10
1
Vanadium (mg/kg)
1,000
10,000
100,000
1,000,000
Iron (mg/kg)
BG
Site DS
Site SS

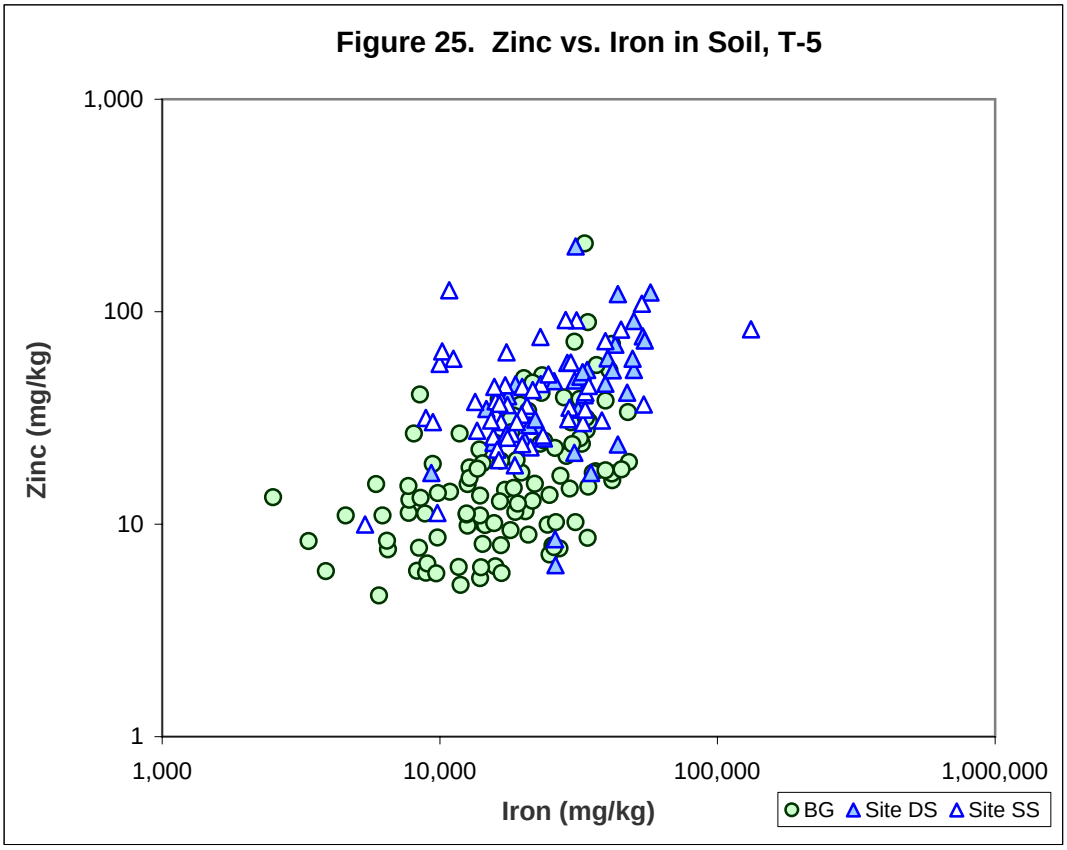


Figure 25. Zinc vs. Iron in Soil, T-5
1,000
100
10
1
Zinc (mg/kg)
1,000
10,000
100,000
1,000,000
Iron (mg/kg)
BG
Site DS
Site SS

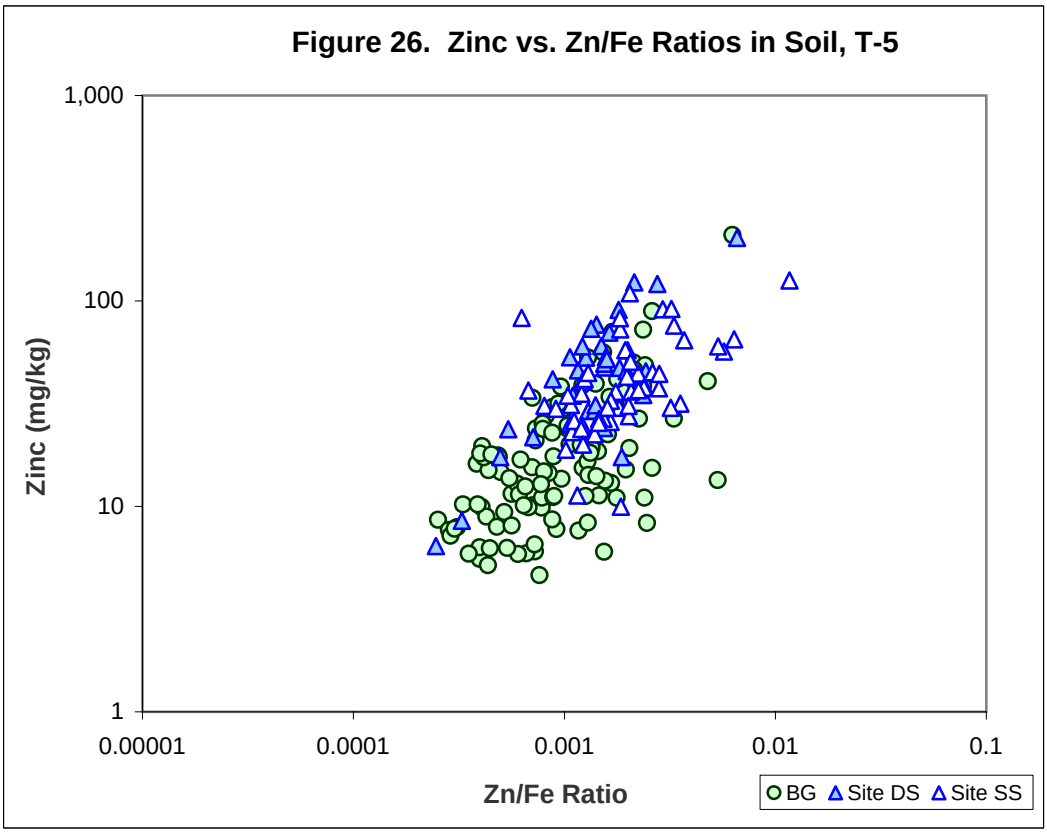


Figure 26. Zinc vs. Zn/Fe Ratios in Soil, T-5
1,000
100
10
1
Zinc (mg/kg)
0.00001
0.0001
0.001
0.01
0.1
Zn/Fe Ratio
BG
Site DS
Site SS

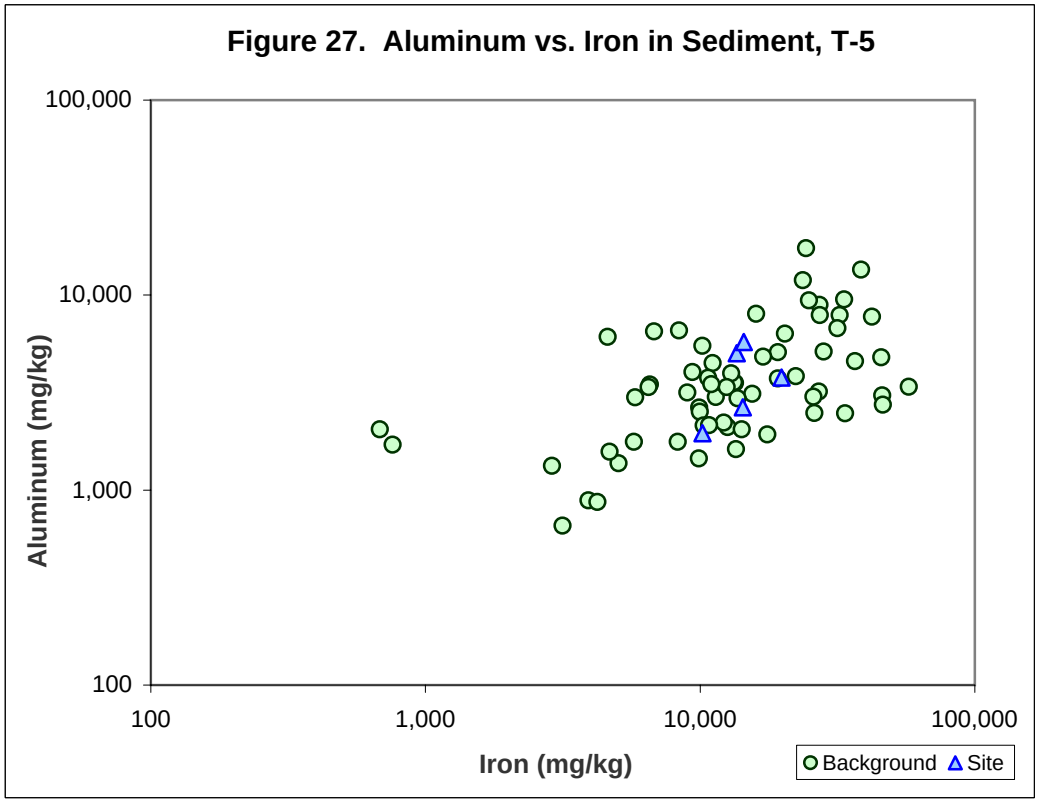


Figure 27. Aluminum vs. Iron in Sediment, T-5
100,000
10,000
1,000
100
Aluminum (mg/kg)
100
1,000
10,000
100,000
Iron (mg/kg)
Background
Site

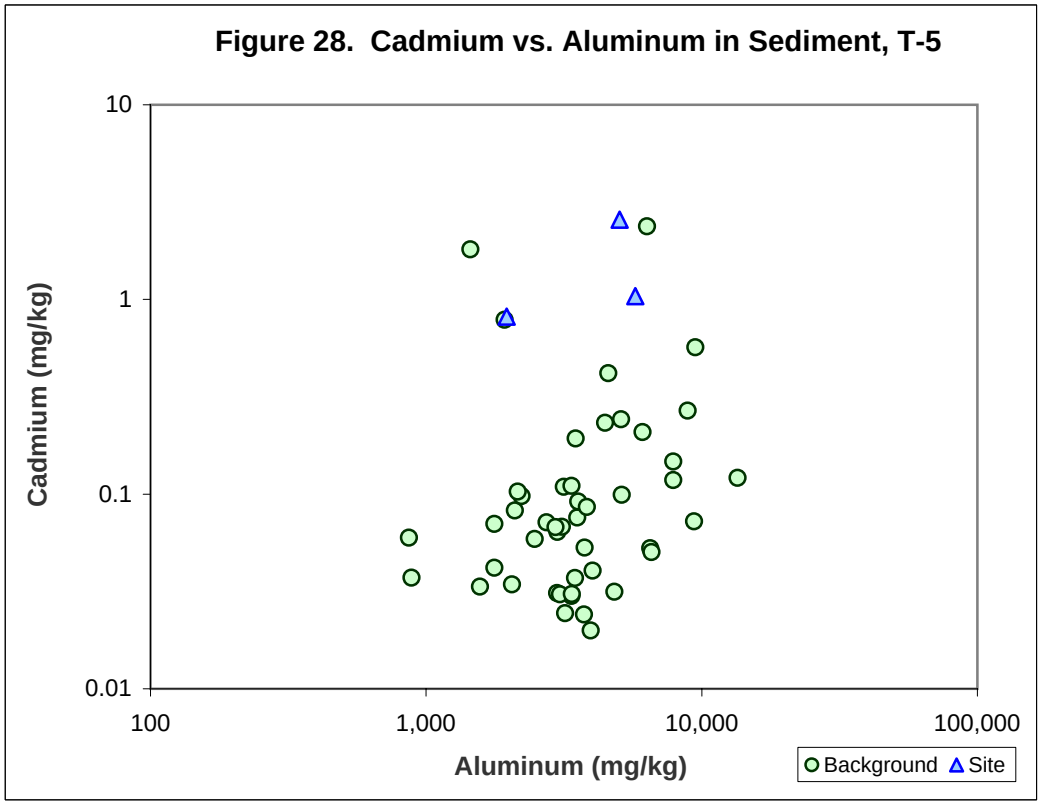


Figure 28. Cadmium vs. Aluminum in Sediment, T-5
10
1
0.1
0.01
Cadmium (mg/kg)
100
1,000
10,000
100,000
Aluminum (mg/kg)
Background
Site

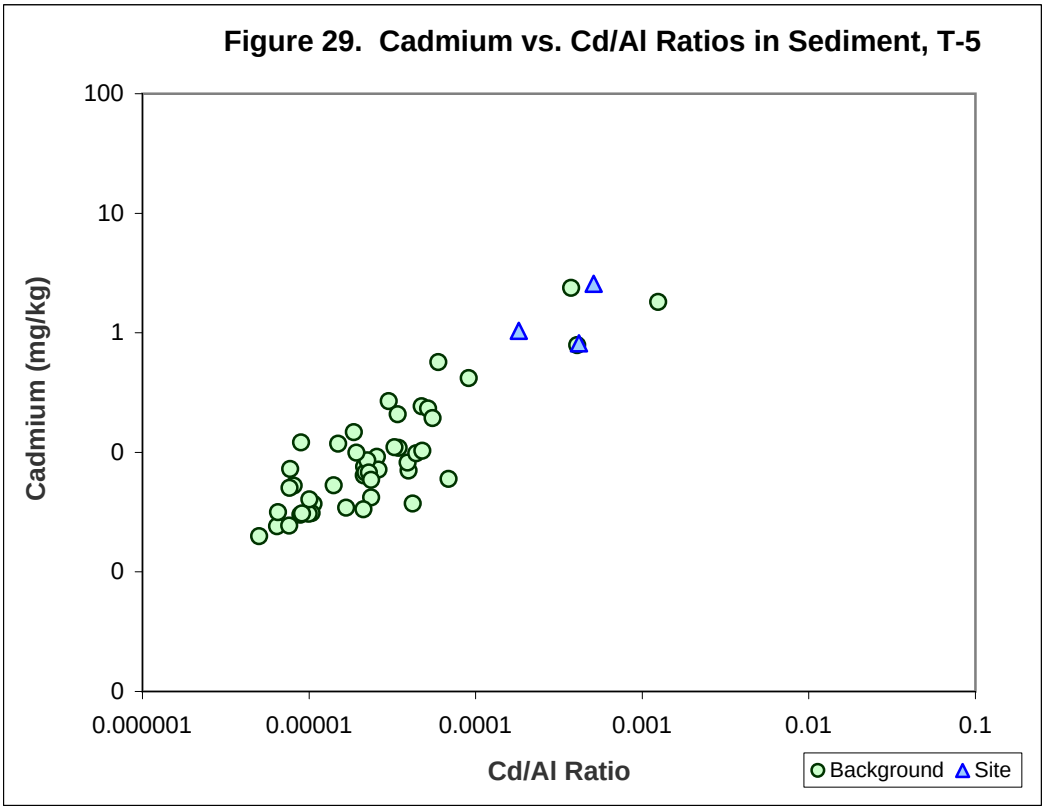


Figure 29. Cadmium vs. Cd/Al Ratios in Sediment, T-5
Cadmium (mg/kg)
100
10
1
0
0
0
0.000001
0.00001
0.0001
0.001
0.01
0.1
Cd/Al Ratio
Background
Site

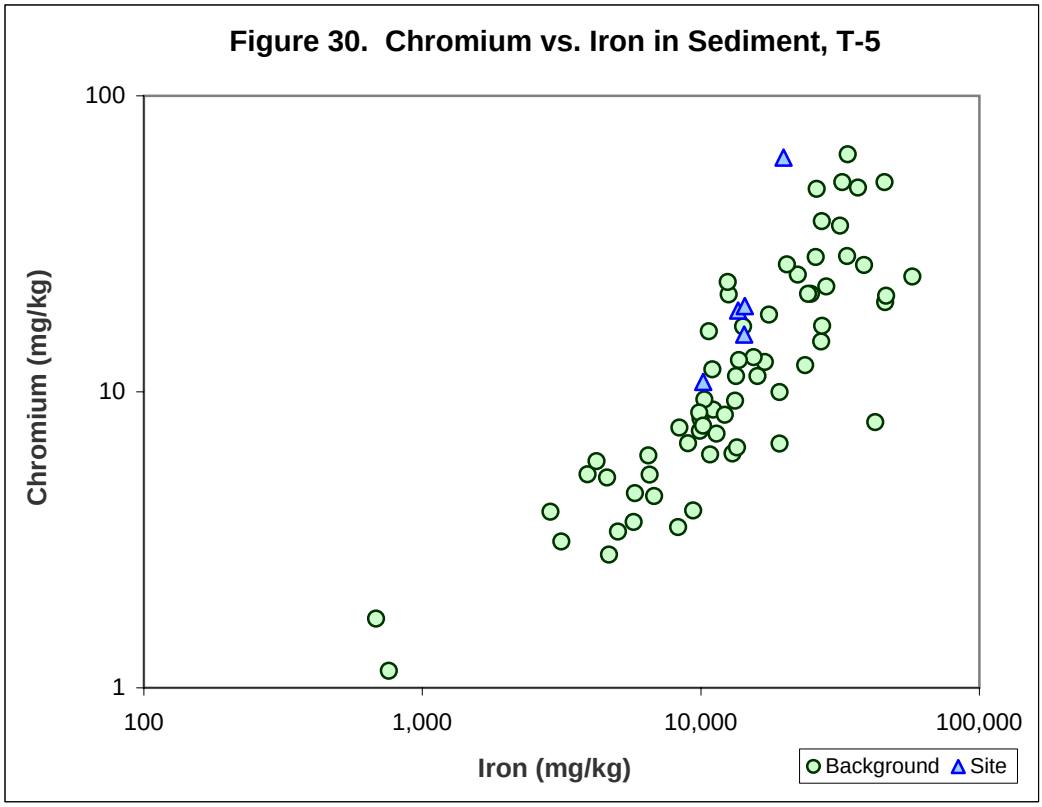


Figure 30. Chromium vs. Iron in Sediment, T-5
Chromium (mg/kg)
100
10
1
100
1,000
10,000
100,000
Iron (mg/kg)
Background
Site

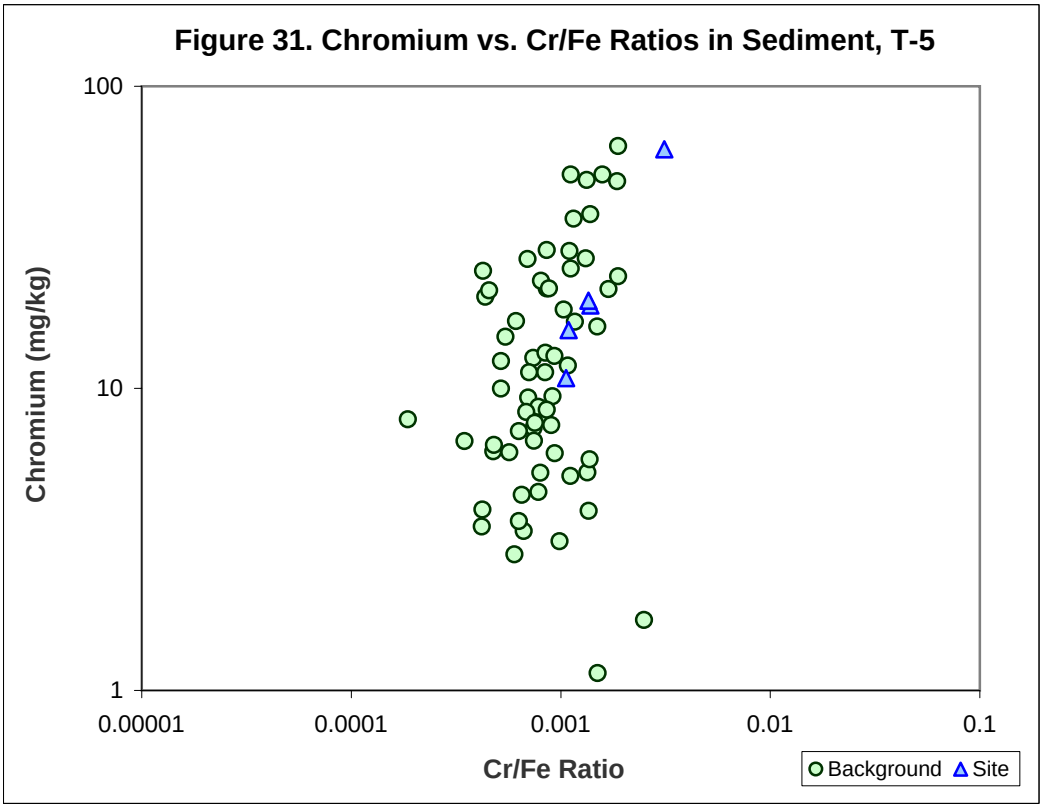


Figure 31. Chromium vs. Cr/Fe Ratios in Sediment, T-5
Chromium (mg/kg)
100
10
1
0.00001
0.0001
0.001
0.01
0.1
Cr/Fe Ratio
Background
Site

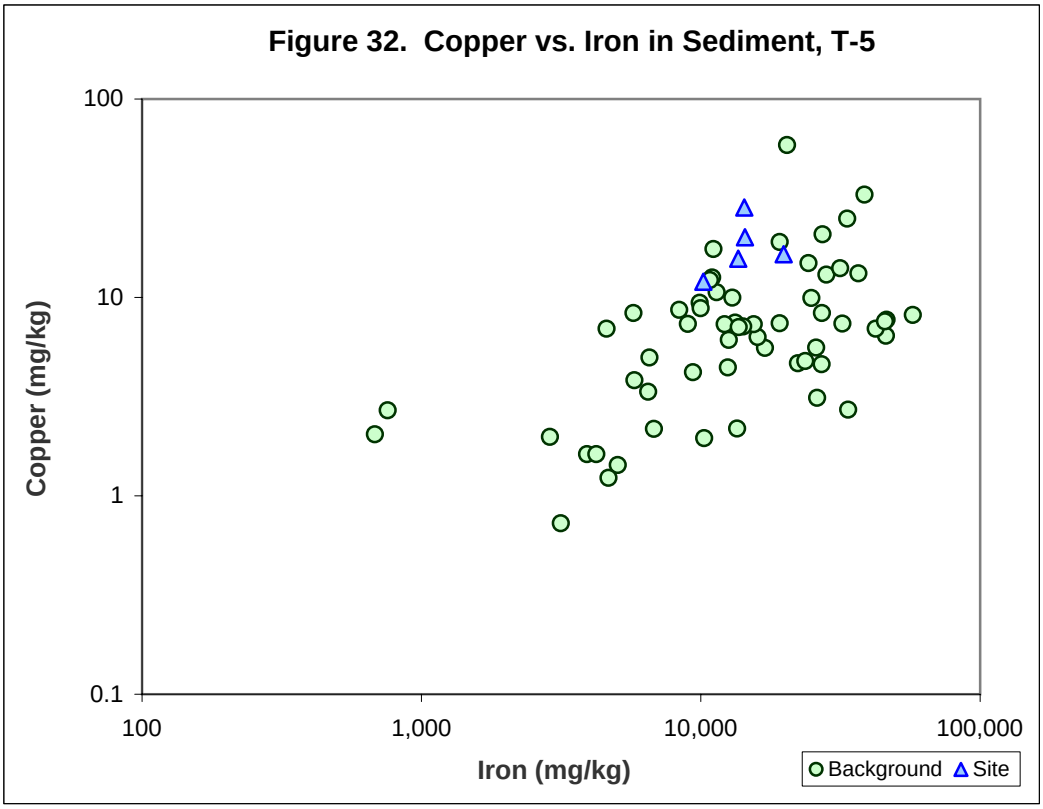


Figure 32. Copper vs. Iron in Sediment, T-5
Copper (mg/kg)
100
10
1
0.1
100
1,000
10,000
100,000
Iron (mg/kg)
Background
Site

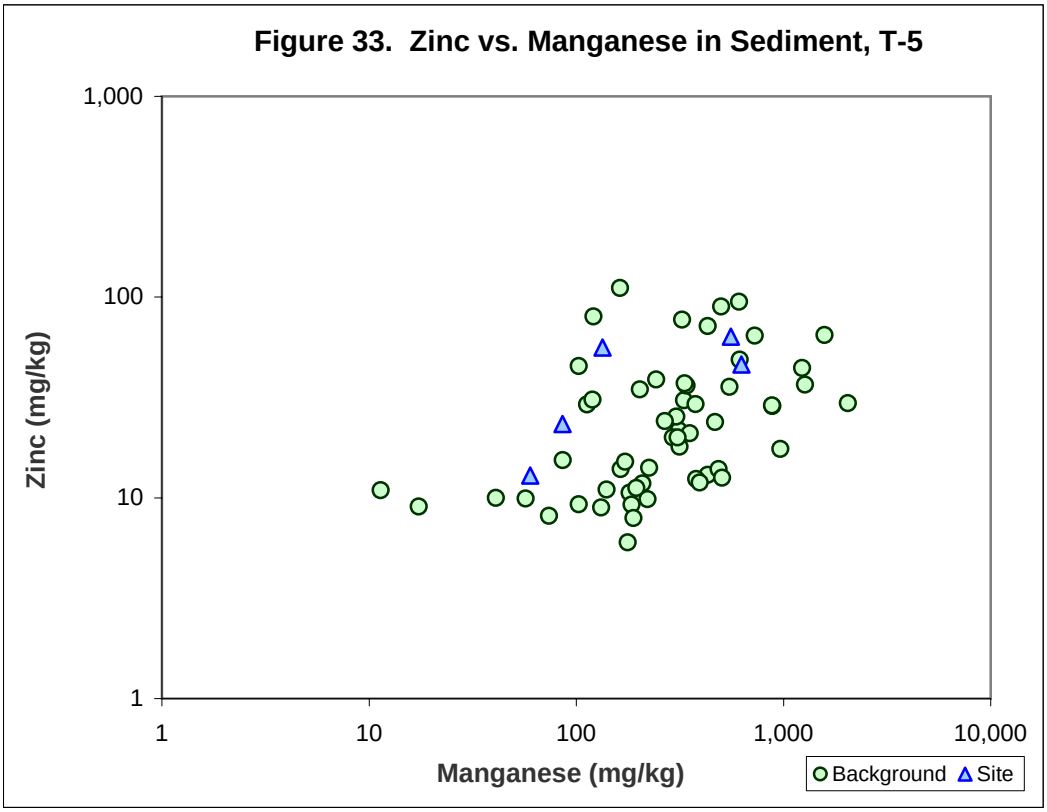


Figure 33. Zinc vs. Manganese in Sediment, T-5
1,000
100
10
1
Zinc (mg/kg)
1
10
100
1,000
10,000
Manganese (mg/kg)
Background
Site

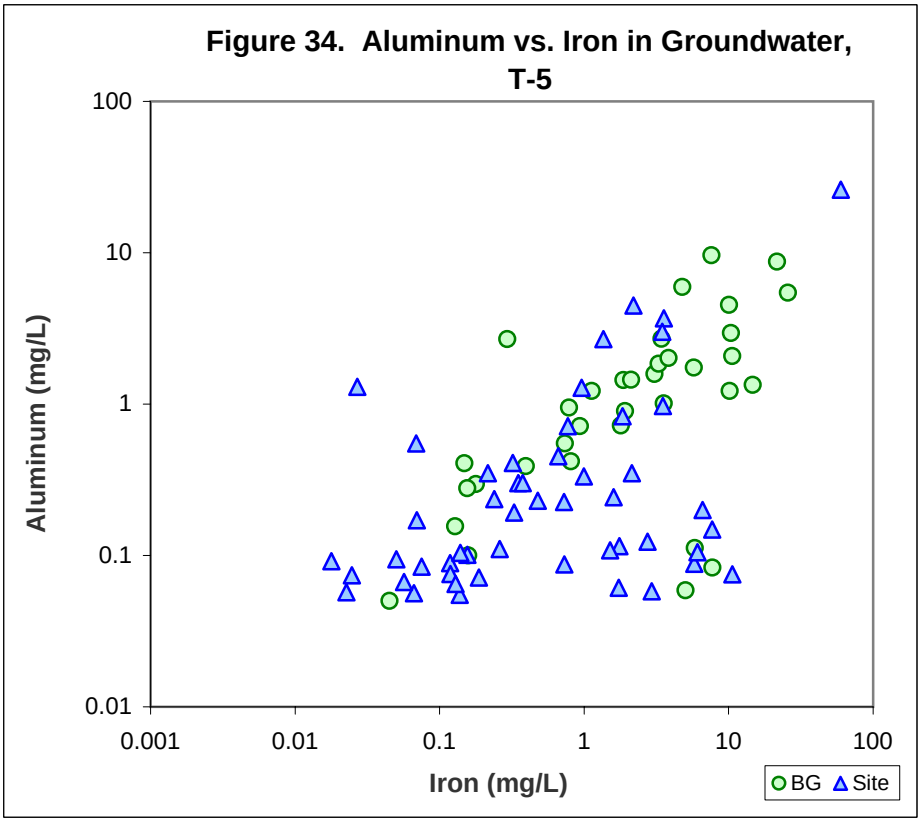


Figure 34. Aluminum vs. Iron in Groundwater, T-5
Aluminum (mg/L)
100
10
1
0.1
0.01
0.001
0.01
0.1
1
10
100
Iron (mg/L)
BG
Site

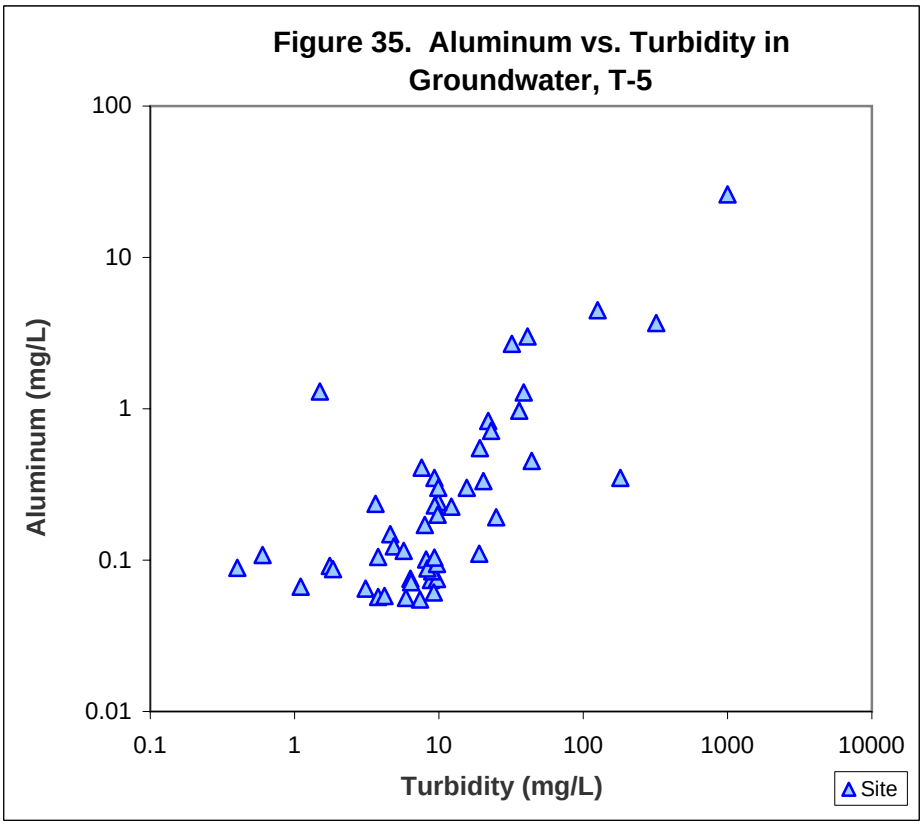


Figure 35. Aluminum vs. Turbidity in Groundwater, T-5
Aluminum (mg/L)
100
10
1
0.1
0.01
0.1
1
10
100
1000
10000
Turbidity (mg/L)
Site

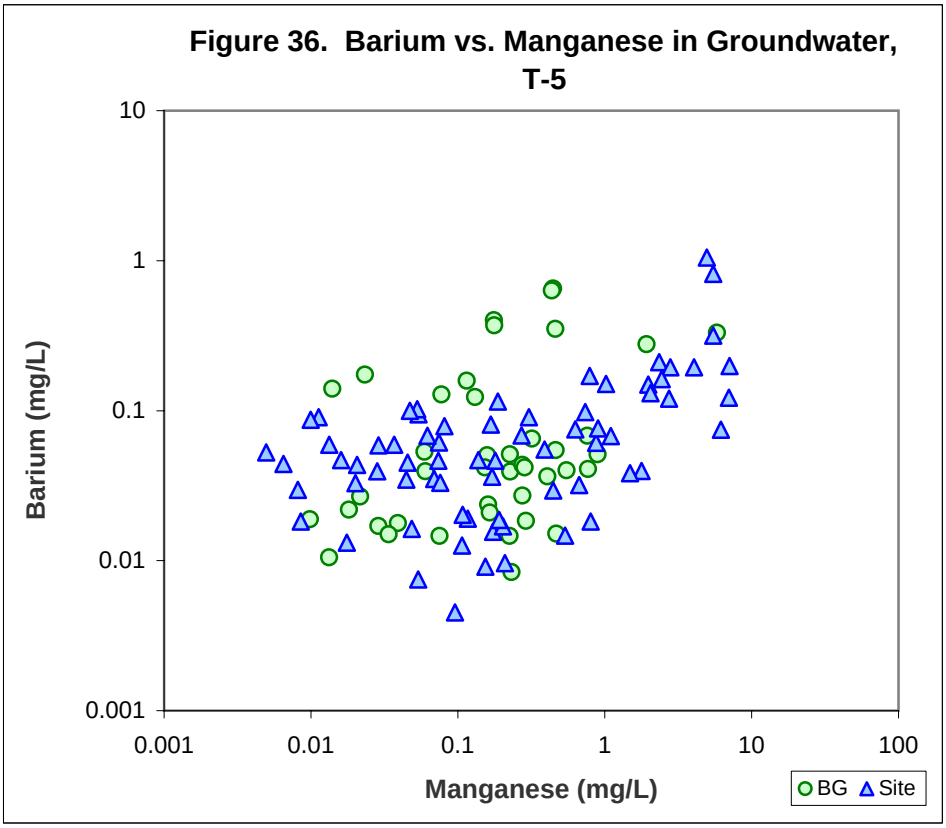


Figure 36. Barium vs. Manganese in Groundwater, T-5
10
1
0.1
0.01
0.001
Barium (mg/L)
0.001
0.01
0.1
1
10
100
Manganese (mg/L)
BG
Site

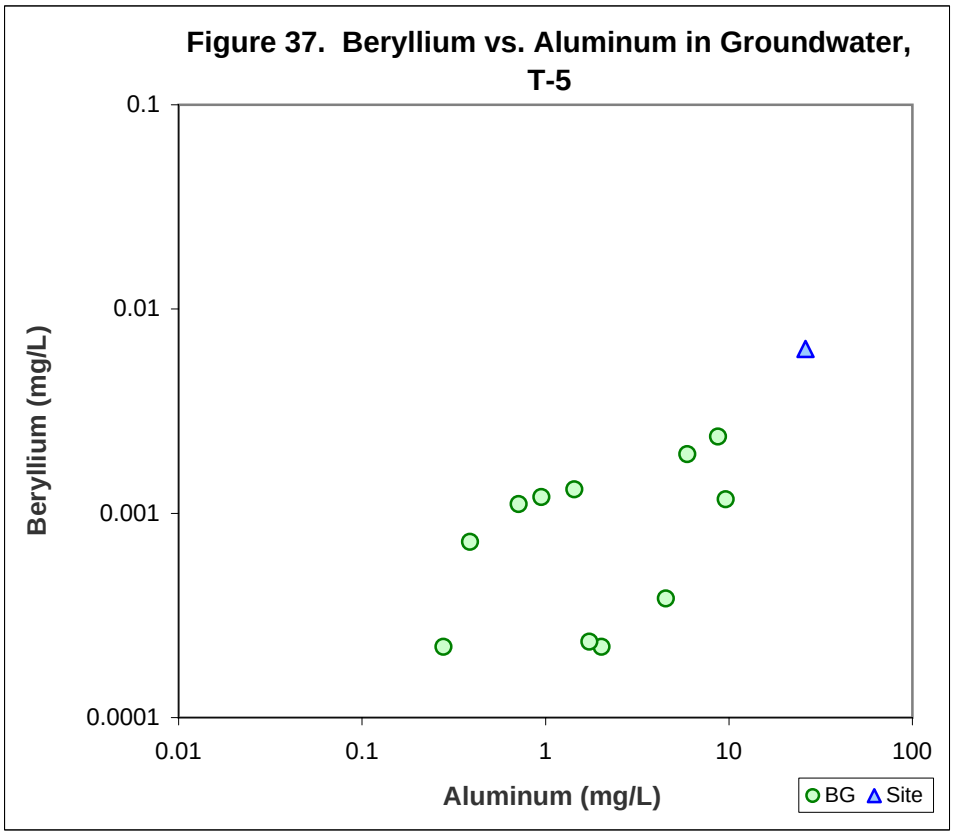


Figure 37. Beryllium vs. Aluminum in Groundwater, T-5
0.1
0.01
0.001
0.0001
Beryllium (mg/L)
0.01
0.1
1
10
100
Aluminum (mg/L)
BG
Site

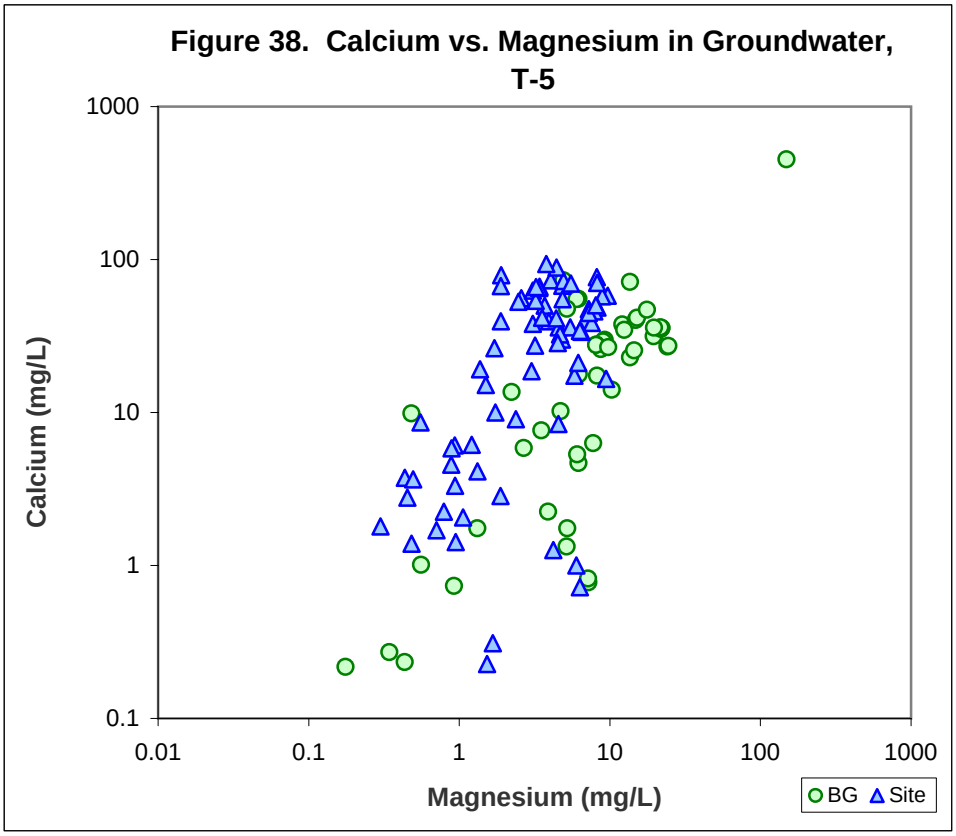


Figure 38. Calcium vs. Magnesium in Groundwater, T-5
1000
100
10
1
0.1
Calcium (mg/L)
0.01
0.1
1
10
100
1000
Magnesium (mg/L)
BG
Site

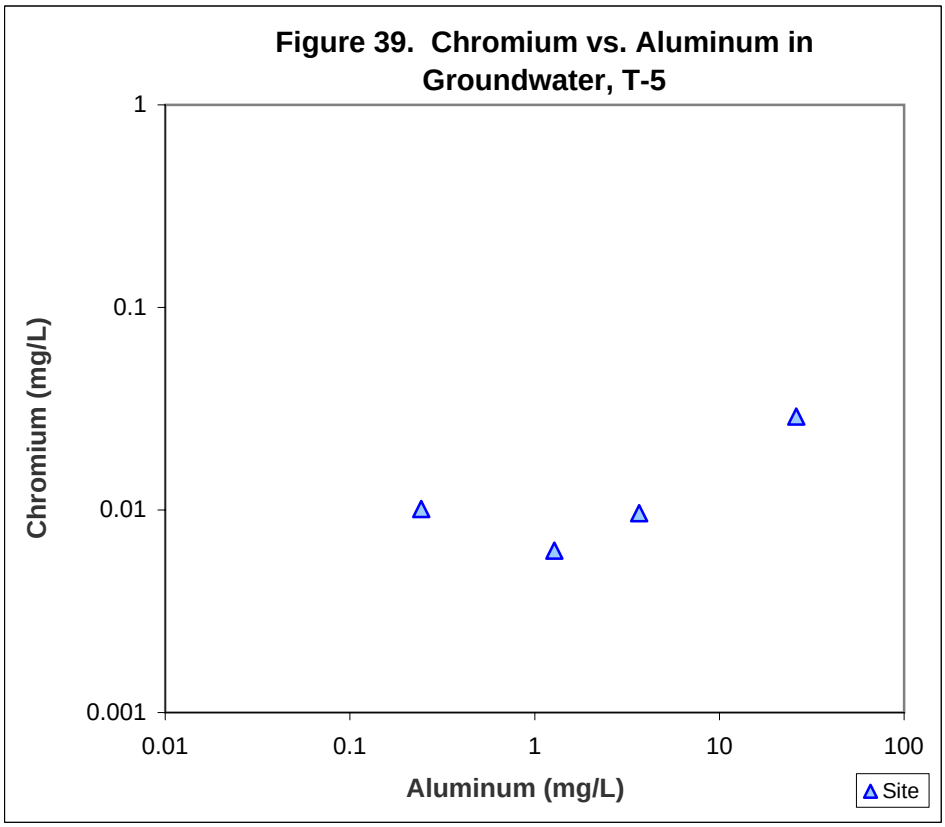


Figure 39. Chromium vs. Aluminum in Groundwater, T-5
1
0.1
0.01
0.001
Chromium (mg/L)
0.01
0.1
1
10
100
Aluminum (mg/L)
Site

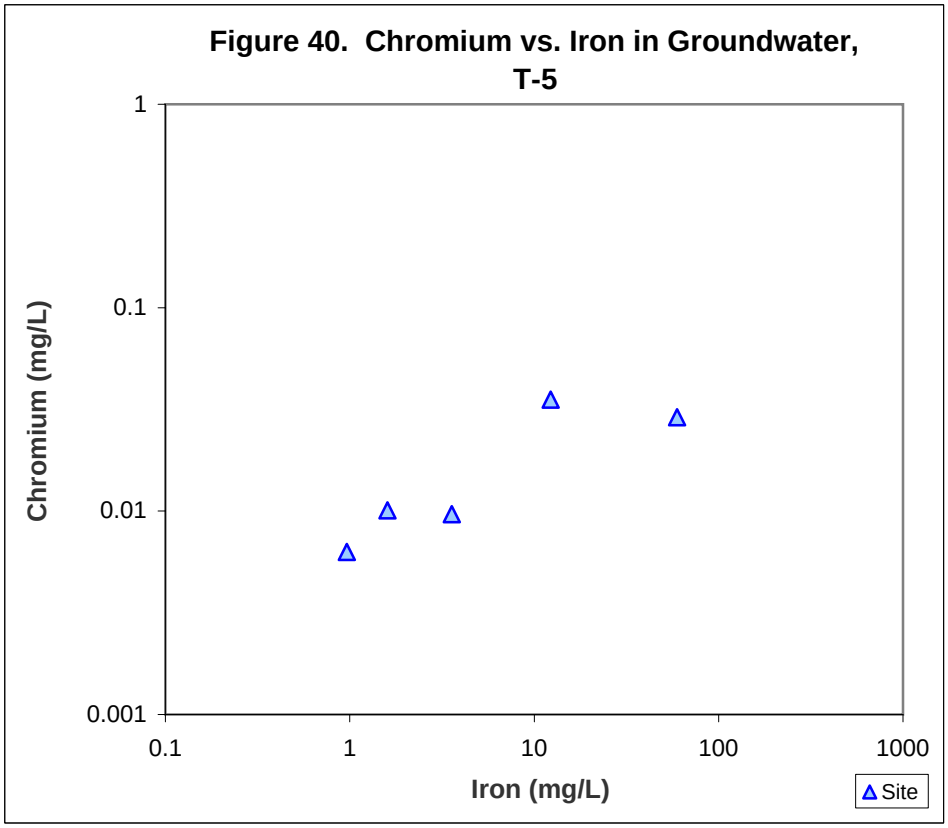


Figure 40. Chromium vs. Iron in Groundwater, T-5
Chromium (mg/L)
1
0.1
0.01
0.001
0.1
1
10
100
1000
Iron (mg/L)
Site

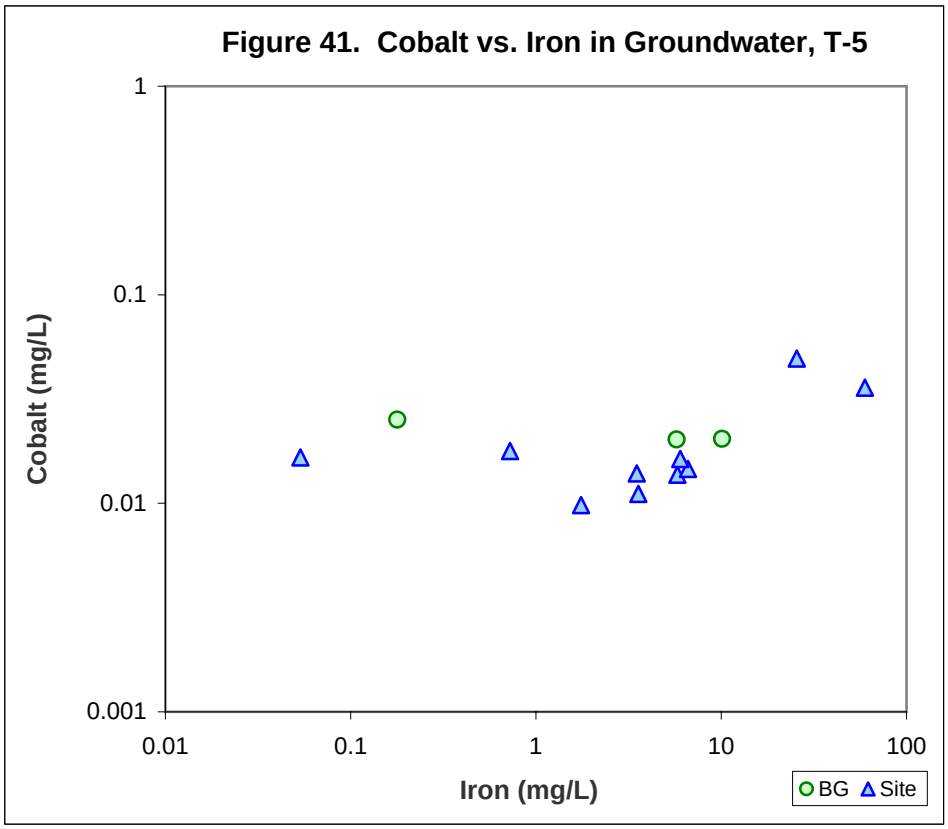


Figure 41. Cobalt vs. Iron in Groundwater, T-5
Cobalt (mg/L)
1
0.1
0.01
0.001
0.01
0.1
1
10
100
Iron (mg/L)
BG
Site

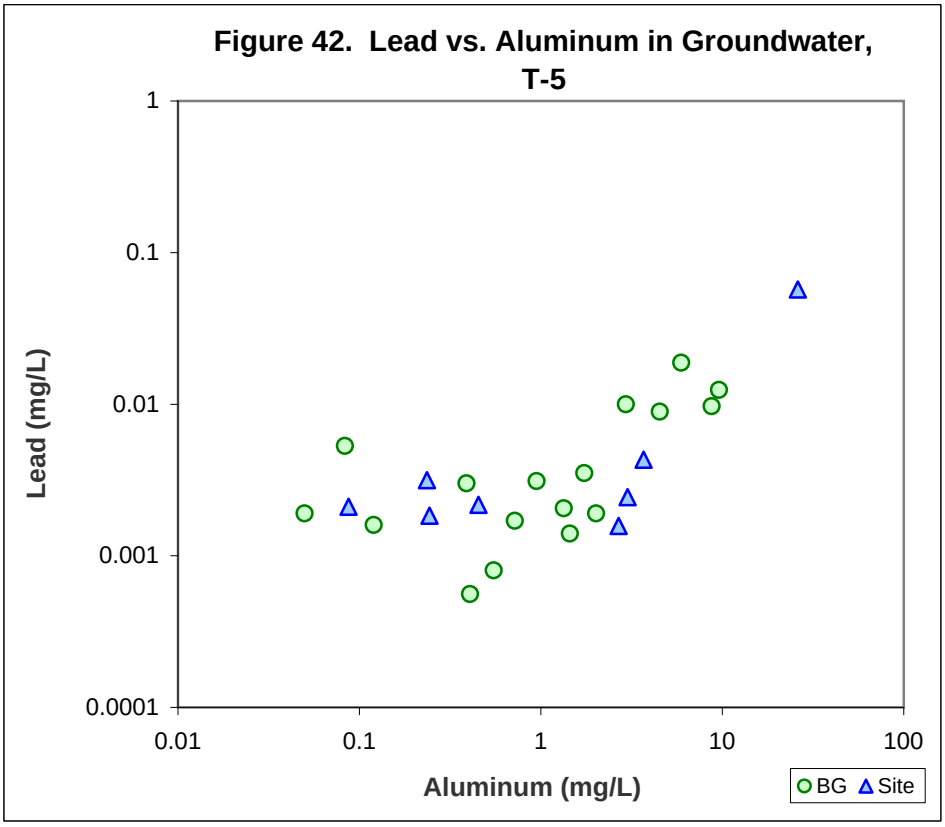


Figure 42. Lead vs. Aluminum in Groundwater, T-5
Lead (mg/L)
1
0.1
0.01
0.001
0.0001
0.01
0.1
1
10
100
Aluminum (mg/L)
BG
Site

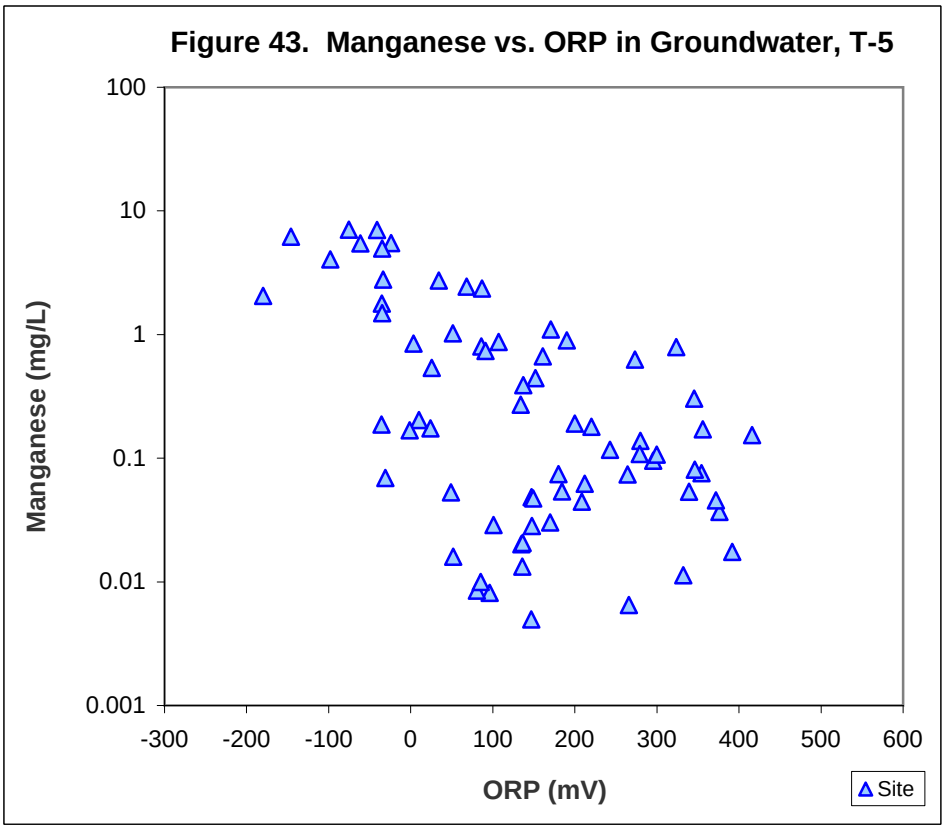


Figure 43. Manganese vs. ORP in Groundwater, T-5
Manganese (mg/L)
100
10
1
0.1
0.01
0.001
-300
-200
-100
0
100
200
300
400
500
600
ORP (mV)
Site

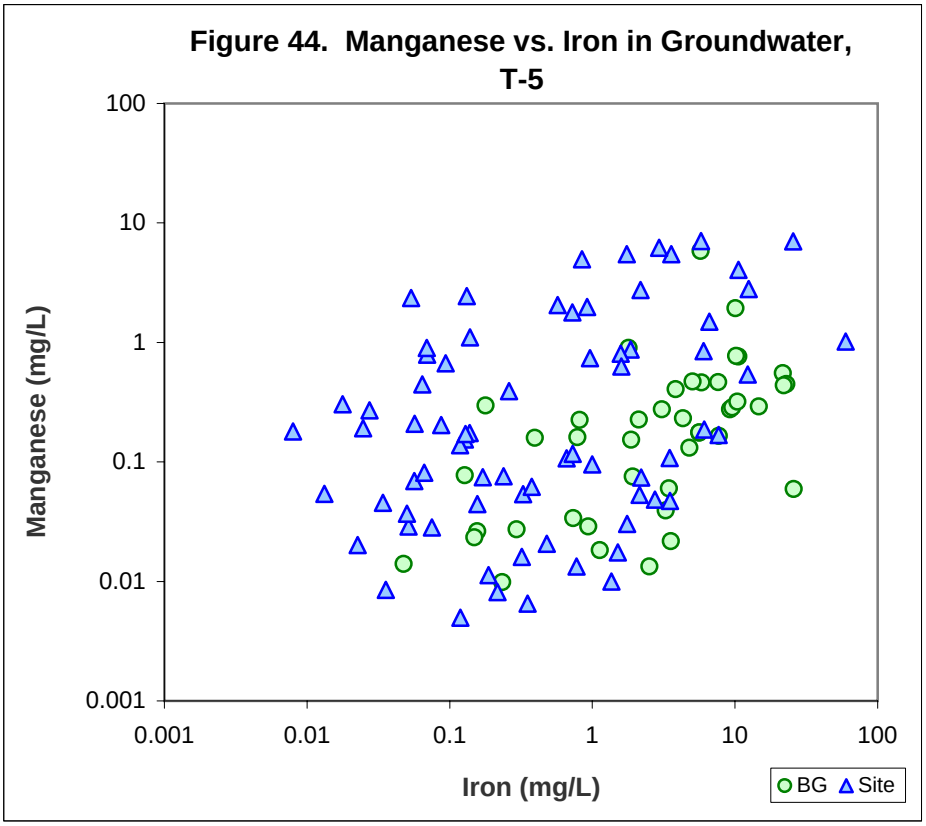


Figure 44. Manganese vs. Iron in Groundwater, T-5
Manganese (mg/L)
100
10
1
0.1
0.01
0.001
0.001
0.01
0.1
1
10
100
Iron (mg/L)
BG
Site

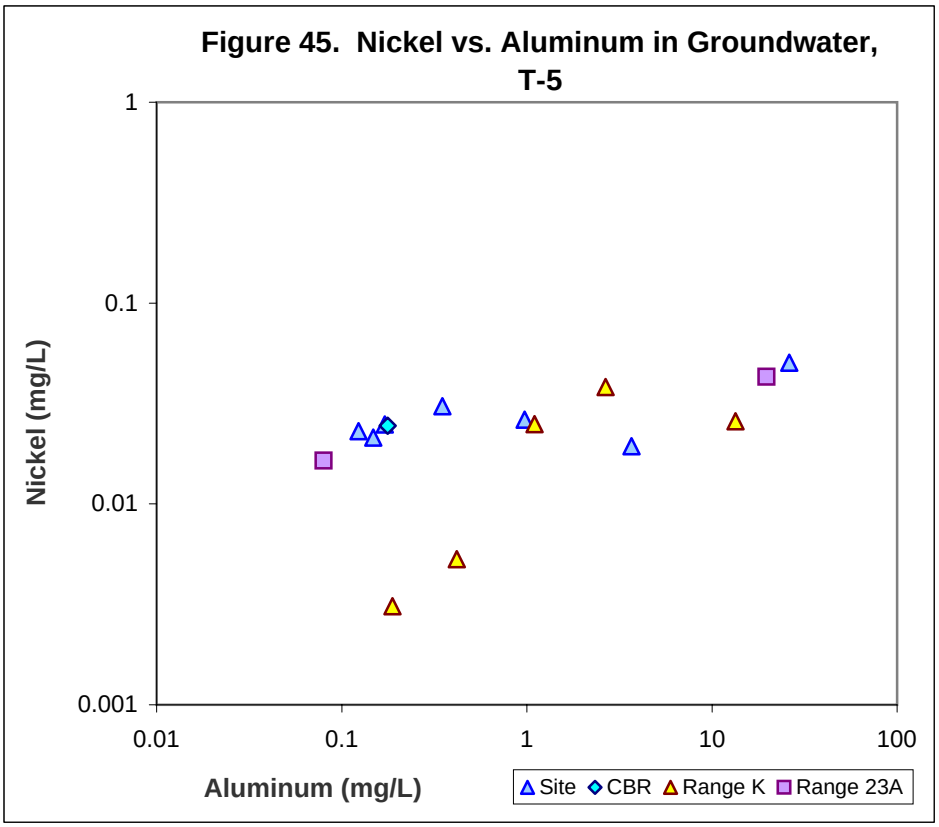


Figure 45. Nickel vs. Aluminum in Groundwater, T-5
Nickel (mg/L)
1
0.1
0.01
0.001
0.01
0.1
1
10
100
Aluminum (mg/L)
Site
CBR
Range K
Range 23A

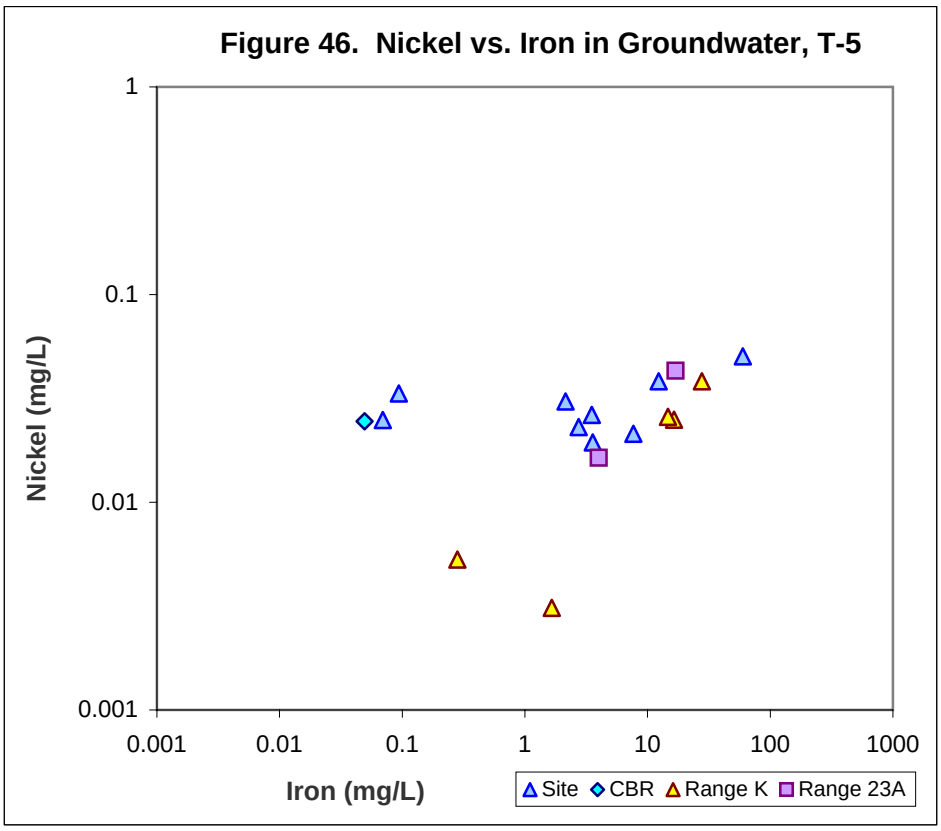


Figure 46. Nickel vs. Iron in Groundwater, T-5
Nickel (mg/L)
1
0.1
0.01
0.001
0.001
0.01
0.1
1
10
100
1000
Iron (mg/L)
Site
CBR
Range K
Range 23A

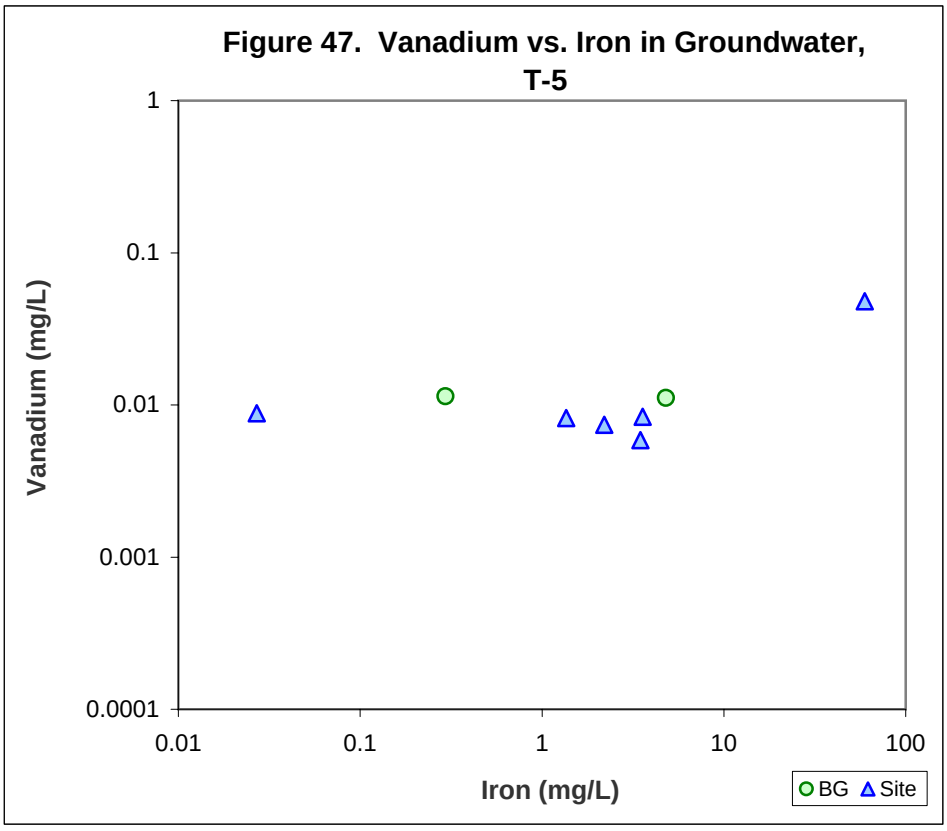


Figure 47. Vanadium vs. Iron in Groundwater, T-5
Vanadium (mg/L)
1
0.1
0.01
0.001
0.0001
0.01
0.1
1
10
100
Iron (mg/L)
BG
Site

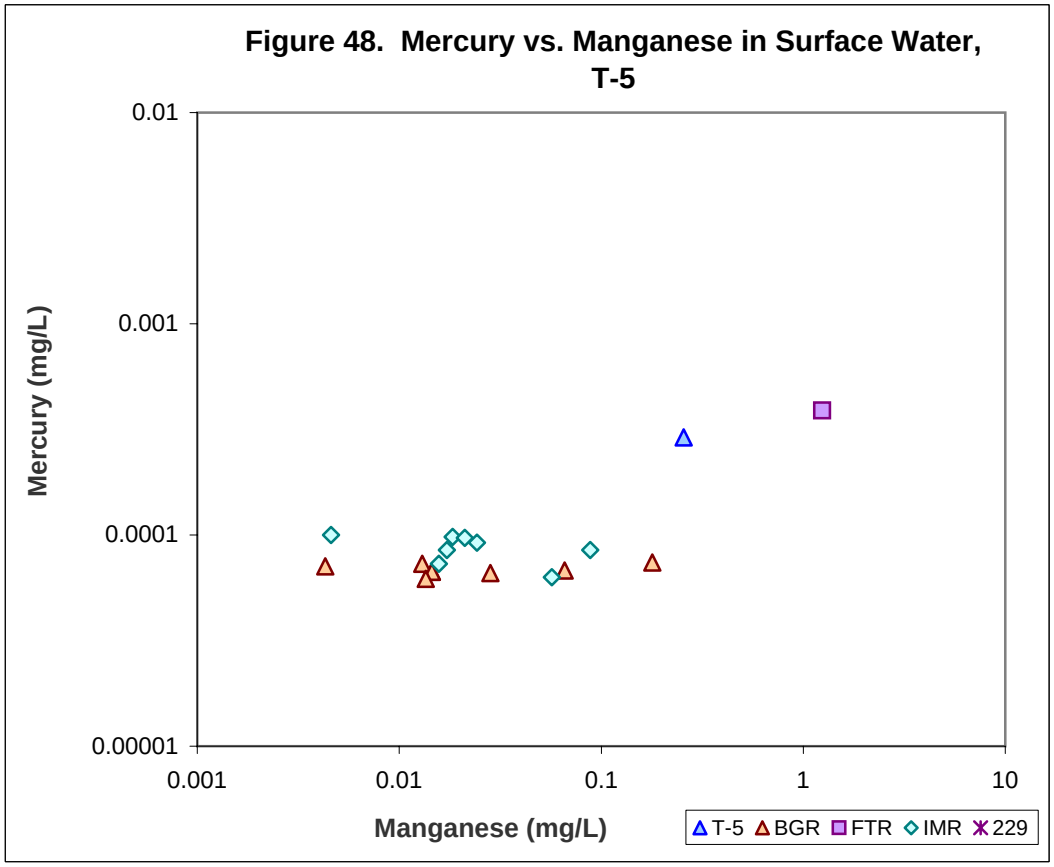


Figure 48. Mercury vs. Manganese in Surface Water, T-5
Mercury (mg/L)
0.01
0.001
0.0001
0.00001
0.001
0.01
0.1
1
10
Manganese (mg/L)
T-5
BGR
FTR
IMR
229