

**APPENDIX J**

**STATISTICAL AND GEOCHEMICAL EVALUATION  
OF SITE METALS DATA**

**STATISTICAL  
(TIERS 1 AND 2)**

# **Statistical Comparison of Site and Background Data Fill Area West of Range 19, Parcel 233(7) Fort McClellan, Alabama**

## **1.0 Introduction**

This report provides the Tier 1 and Tier 2 (Shaw Environmental, Inc. [Shaw], 2003) site-to-background comparison results for the Fill Area West of Range 19, Parcel 233(7), at Fort McClellan in Calhoun County, Alabama. 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 (Science Applications International Corporation [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). If either or both of these statistical tests cannot be done, the evaluation will include the hot measurement test.

The methodology and results of the Tier 1 and Tier 2 comparisons are summarized in Tables 1 through 3 and described in more detail in the following sections. Site samples used in the statistical site-to-background comparison include 7 surface soil samples (0 to 2 feet below ground surface [bgs]), 6 subsurface soil samples (8 to 12 feet bgs), and 1 groundwater sample.

Background distributions and screening values have been established for target analyte list metals in surface soil, subsurface soil, and groundwater for Fort McClellan (SAIC, 1998).

## **2.0 Comparison Methodology**

This section describes the statistical techniques that were employed in the Parcel 233 site-to-background comparison.

### **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 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

**Table 1**

**Summary of Tier 1 and Tier 2 Site to Background Comparison for Surface Soil  
Fill Area West of Range 19, Parcel 233(7)  
Fort McClellan, Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation <sup>a</sup>	Tier 2 Evaluation			Carried Forward for Tier 3 Geochemical Evaluation
			Slippage Test <sup>b</sup>	Wilcoxon Rank Sum Test <sup>b</sup>	Hot Measurement Test <sup>b,c</sup>	
Aluminum	7 / 7	Passed	NA	NA	NA	
Antimony	0 / 7	NA	NA	NA	NA	
Arsenic	7 / 7	Passed	NA	NA	NA	
Barium	7 / 7	Failed	Passed	Failed	NA	Yes
Beryllium	7 / 7	Failed	Failed	Failed	NA	Yes
Cadmium	0 / 7	NA	NA	NA	NA	
Calcium	7 / 7	Passed	NA	NA	NA	
Chromium	7 / 7	Passed	NA	NA	NA	
Cobalt	7 / 7	Failed	Passed	Failed	NA	Yes
Copper	7 / 7	Failed	Passed	Failed	NA	Yes
Iron	7 / 7	Passed	NA	NA	NA	
Lead	7 / 7	Failed	Passed	Passed	NA	
Magnesium	7 / 7	Passed	NA	NA	NA	
Manganese	7 / 7	Failed	Passed	Failed	NA	Yes
Mercury	7 / 7	Failed	Passed	NA <sup>d</sup>	Passed	
Nickel	7 / 7	Failed	Passed	Failed	NA	Yes
Potassium	7 / 7	Passed	NA	NA	NA	
Selenium	0 / 7	NA	NA	NA	NA	
Silver	1 / 7	Passed	NA	NA	NA	
Sodium	0 / 7	NA	NA	NA	NA	
Thallium	1 / 7	Passed	NA	NA	NA	
Vanadium	7 / 7	Passed	NA	NA	NA	
Zinc	7 / 7	Failed	Passed	Failed	NA	Yes

NA = not applicable

a Tier 1 evaluation 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 Wilcoxon Rank Sum (WRS) test cannot be performed.

d WRS test is not performed on data sets containing 50 percent or more nondetects.

Table 2

**Summary of Tier 1 and Tier 2 Site to Background Comparison for Subsurface Soil  
Fill Area West of Range 19, Parcel 233(7)  
Fort McClellan, Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation <sup>a</sup>	Tier 2 Evaluation			Carried Forward for Tier 3 Geochemical Evaluation
			Slippage Test <sup>b</sup>	Wilcoxon Rank Sum Test <sup>b</sup>	Hot Measurement Test <sup>b,c</sup>	
Aluminum	6 / 6	Passed	NA	NA	NA	
Antimony	0 / 6	NA	NA	NA	NA	
Arsenic	6 / 6	Passed	NA	NA	NA	
Barium	6 / 6	Failed	Passed	Failed	NA	Yes
Beryllium	5 / 6	Failed	Passed	Failed	NA	Yes
Cadmium	1 / 6	Failed	Passed	NA <sup>e</sup>	Failed	Yes
Calcium	1 / 6	Passed	NA	NA	NA	
Chromium	6 / 6	Passed	NA	NA	NA	
Cobalt	6 / 6	Failed	Passed	Failed	NA	Yes
Copper	6 / 6	Failed	Passed	Failed	NA	Yes
Iron	6 / 6	Failed	Passed	Failed	NA	Yes
Lead	6 / 6	Passed	NA	NA	NA	
Magnesium	6 / 6	Passed	NA	NA	NA	
Manganese	6 / 6	Failed	Passed	Failed	NA	Yes
Mercury	6 / 6	Failed	Passed	NA <sup>e</sup>	Passed	
Nickel	6 / 6	Failed	Passed	Failed	NA	Yes
Potassium	6 / 6	Failed	Passed	Failed	NA	Yes
Selenium	1 / 6	Failed	NA <sup>d</sup>	NA <sup>e</sup>	Passed	
Silver	1 / 6	Failed	NA <sup>d</sup>	NA <sup>e</sup>	Passed	
Sodium	0 / 6	NA	NA	NA	NA	
Thallium	2 / 6	Passed	NA	NA	NA	
Vanadium	6 / 6	Passed	NA	NA	NA	
Zinc	6 / 6	Failed	Failed	Failed	NA	Yes

NA = not applicable

a Tier 1 evaluation 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 Wilcoxon Rank Sum (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 percent or more nondetects.

**Table 3**

**Summary of Tier 1 and Tier 2 Site to Background Comparison for Groundwater  
Fill Area West of Range 19, Parcel 233(7)  
Fort McClellan, Calhoun County, Alabama**

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

NA = not applicable

a Tier 1 evaluation 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 Wilcoxon Rank Sum (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 with sample sizes less than 5.

versus background distributions (U.S. Environmental Protection Agency [EPA], 1989, 1992, 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 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  $K \leq K_c$ , 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,

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

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, 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 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 (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, 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 this appendix report.

## **3.0 Results of the Site-to-Background Comparisons**

This section presents the results of the site-to-background comparisons for 23 target analyte list (TAL) metals in the surface soil, subsurface soil, and groundwater samples from Parcel 233. Tables 1 through 3 summarize the Tier 1 and Tier 2 test results for each medium as discussed in the following sections. Statistical test results are discussed in detail below. Box plots are also discussed below and are provided in Attachment 1.

### **3.1 Surface Soil**

Twenty-three TAL metals were evaluated in the Range 30 surface soil. Four metals (antimony, cadmium, selenium, and sodium) had no detected concentrations in surface soil. No further discussion of these metals is included.

Ten metals (aluminum, arsenic, calcium, chromium, iron, magnesium, potassium, silver, thallium, and vanadium) had no detected concentrations above their respective background screening values, passing the Tier 1 evaluation. These metals are considered within the range of background and will not be tested or discussed any further.

The remaining nine metals underwent Tier 2 evaluation. The statistical test results and box plots are discussed in detail below.

Table 1 summarizes the Tier 1 and Tier 2 test results for surface soil.

### **Barium**

#### Tier 1 Evaluation

Four site samples exceed the background screening value of 123.94 milligrams per kilogram (mg/kg).

#### Slippage Test

$K_c$  for barium is 2, and one site sample exceeds the maximum background measurement. Because  $K < K_c$ , barium passes the slippage test.

### WRS Test

The p-level of 0.003 indicates a significant difference between the site and background distributions.

### Box Plot

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

### 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

Five site samples exceed the background screening value of 0.8 mg/kg.

### Slippage Test

$K_c$  for beryllium is 2, and 5 site samples exceed the maximum background measurement. Because  $K > K_c$ , beryllium fails the slippage test.

### WRS Test

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

### Box Plot

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

### Conclusion

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

## **Cobalt**

### Tier 1 Evaluation

Five site samples exceed the background screening value of 15.15 mg/kg.

### Slippage Test

$K_c$  for cobalt is 2, and 1 site sample exceeds the maximum background measurement. Because  $K < K_c$ , cobalt passes the slippage test.

### WRS Test

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

### Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-2).

### 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

Four site samples exceed the background screening value of 12.71 mg/kg.

### Slippage Test

$K_c$  for copper is 2, and 1 site sample exceeds the maximum background measurement. Because  $K < K_c$ , copper passes the slippage test.

### WRS Test

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

### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-2). The site and background maximum values are similar.

### Conclusion

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

## **Lead**

### Tier 1 Evaluation

One site sample exceeds the background screening value of 40.05 mg/kg.

### Slippage Test

$K_c$  for lead is 2, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , lead passes the slippage test.

### WRS Test

The p-level of 0.678 indicates strong agreement between the site and background distributions.

### Box Plot

The site and background medians are similar (Figure 1-3). The site minimum and 25<sup>th</sup> percentile are higher than the corresponding background values. The site maximum and 75<sup>th</sup> percentile are the lower than the corresponding background values.

### Conclusion

Lead in surface soil passed the Tier 2 statistical comparison to background and is considered to be within the range of background.

## **Manganese**

### Tier 1 Evaluation

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

### Slippage Test

$K_c$  for manganese is 2, and one site sample exceeds the maximum background measurement. Because  $K < K_c$ , manganese passes the slippage test.

### WRS Test

The p-level of 0.0014 indicates a significant difference between the site and background distributions.

### Box Plot

The site minimum and interquartile range are significantly higher than their respective background values (Figure 1-3). The site maximum is slightly higher compared to that of background.

### Conclusion

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

## **Mercury**

### Tier 1 Evaluation

One site sample exceeds the background screening value of 0.08 mg/kg.

### Slippage Test

$K_c$  for mercury is 2, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , mercury passes the slippage test.

### WRS Test

The WRS test was not performed because the background data set has more than 50 percent nondetects.

### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-4). The site maximum is less than that of background. The shape and location of the background box plot are influenced by the percentage of nondetects (66 percent) and the replacement values of one-half the reporting limit, rather than detected concentrations.

### Hot Measurement Test

The site MDC is less than the background 95th percentile of 0.125 mg/kg.

### Conclusion

Mercury in surface soil passed the Tier 2 evaluation and is considered to be within the range of background.

## **Nickel**

### Tier 1 Evaluation

Six site samples exceed the background screening value of 10.33 mg/kg.

### Slippage Test

$K_c$  for nickel is 2, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , nickel passes the slippage test.

### WRS Test

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

### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-4). The site maximum is similar to that of background.

### Conclusion

Because nickel in surface soil 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 40.64 mg/kg.

### Slippage Test

$K_c$  for zinc is 2, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , zinc passes the slippage test.

### WRS Test

The p-level of 0.0024 indicates a significant difference between the site and background distributions.

### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-5). The site maximum is considerably lower than that of background.

### 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 Parcel 233 subsurface soil. Two metals, antimony and sodium, had no detected concentrations. No further discussion of these metals is included.

Eight metals (aluminum, arsenic, calcium, chromium, lead, magnesium, thallium, and vanadium) had no detected concentrations above their respective background screening values. Because these metals passed the Tier 1 evaluation they are considered within the range of background, and will not be tested or discussed further.

The remaining 13 metals underwent Tier 2 evaluation. The statistical tests and box plots are discussed in detail below.

Table 2 summarizes the Tier 1 and Tier 2 test results for subsurface soil.

## **Barium**

### Tier 1 Evaluation

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

### Slippage Test

$K_c$  for barium is 2, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , barium passes the slippage test.

### WRS Test

The p-level of 0.127 indicates a weak agreement between the site and background distributions.

### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-5). The site maximum is significantly lower than that of background.

### 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

Four site samples exceed the background screening value of 0.86 mg/kg.

### Slippage Test

$K_c$  for beryllium is 2, and 2 site samples exceed the maximum background measurement. Because  $K \leq K_c$ , beryllium passes the slippage test.

### WRS Test

The p-level of 0.00194 indicates a significant difference between the site and background distributions.

### Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-6).

### Conclusion

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

## **Cadmium**

### Tier 1 Evaluation

One site sample exceeds the background screening value of 0.22 mg/kg.

### Slippage Test

$K_c$  for cadmium is 2, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , cadmium passes the slippage test.

### WRS Test

The WRS test is not performed because the site data set has more than 50 percent nondetects.

### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-6). The site maximum appears slightly lower than that of background.

### Hot Measurement Test

The site MDC exceeds the background 95th percentile of 0.62 mg/kg.

### Conclusion

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

## **Cobalt**

### Tier 1 Evaluation

Three site samples exceed the background screening value of 17.54 mg/kg.

### Slippage Test

$K_c$  for cobalt is 2, and one site sample exceeds the maximum background measurement. Because  $K < K_c$ , cobalt passes the slippage test.

### WRS Test

The p-level of 0.002 indicates a significant difference between the site and background distributions.

### Box Plot

The site minimum, interquartile range, and maximum are elevated compared to that of background (Figure 1-7).

### 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

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

### Slippage Test

$K_c$  for copper is 2, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , copper passes the slippage test.

### WRS Test

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

### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-7). The site maximum is lower than that of background.

### 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

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

### Slippage Test

$K_c$  for iron is 2, and one site sample exceeds the maximum background measurement. Because  $K < K_c$ , iron passes the slippage test.

### WRS Test

The p-level of 0.002 indicates a significant difference between the site and background distributions.

### Box Plot

The site minimum, interquartile range, and maximum are elevated compared to that of background (Figure 1-8).

### Conclusion

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

## **Manganese**

### Tier 1 Evaluation

One site sample exceeds the background screening value of 1,355 mg/kg.

### Slippage Test

$K_c$  for manganese is 2, and one site sample exceeds the maximum background measurement. Because  $K < K_c$ , manganese passes the slippage test.

### WRS Test

The p-level of 0.007 indicates a significant difference between the site and background distributions.

### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-8). The site maximum is similar to that of background.

### 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

One site sample exceeds the background screening value of 0.07 mg/kg.

### Slippage Test

$K_c$  for mercury is 2, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , mercury passes the slippage test.

### WRS Test

The WRS test was not performed because the background data set has more than 50 percent nondetects.

### Box Plot

The site minimum, 25th percentile, and median are higher than that of the corresponding background values (Figure 1-9). The site maximum is less than that of background, and the site 75th percentile is just slightly higher than that of background. The shape and location of the background box plot are influenced by the percentage of nondetects (53 percent) and the replacement values of one-half the reporting limit, rather than detected concentrations.

### Hot Measurement Test

The site MDC is less than the background 95th percentile of 0.094 mg/kg.

### Conclusion

Mercury in subsurface soil passed the Tier 2 evaluation and is considered to be within the range of background.

## **Nickel**

### Tier 1 Evaluation

Five site samples exceed the background screening value of 12.89 mg/kg.

### Slippage Test

$K_c$  for nickel is 2, and two site samples exceed the maximum background measurement. Because  $K \leq K_c$ , nickel passes the slippage test.

### WRS Test

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

### Box Plot

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

### 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

Three site samples exceed the background screening value of 710.74 mg/kg.

### Slippage Test

$K_c$  for potassium is 2, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , potassium passes the slippage test.

### WRS Test

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

### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-10). The site maximum is less than that of background.

### 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

One site sample exceeds the background screening value of 0.47 mg/kg.

### Slippage Test

The maximum result in background is a nondetect, so the slippage test is not done.

### WRS Test

The WRS test was not performed because the background and site data sets are more than 50 percent nondetect.

### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-10). The site maximum is less than that of background. The shape and location of the background and site box plots are influenced by the high percentage of nondetects (98 percent and 83 percent, respectively) and the replacement values of one-half the reporting limit, rather than detected concentrations.

### Hot Measurement Test

The site MDC is less than the background 95th percentile of 0.574 mg/kg.

### Conclusion

Selenium in subsurface soil passed the Tier 2 evaluation and is considered to be within the range of background.

## **Silver**

### Tier 1 Evaluation

One site sample exceeds the background screening value of 0.24 mg/kg.

### Slippage Test

The maximum result in background is a nondetect, so the slippage test is not done.

#### WRS Test

The WRS test was not performed because the site data set has more than 50 percent nondetects.

#### Box Plot

The site minimum and interquartile range are significantly higher than the corresponding background values (Figure 1-11). The site and background maximums are similar. The shape and location of the site box plot are influenced by the high percentage of nondetects (83 percent) and the replacement values of one-half the reporting limit, rather than detected concentrations.

#### Hot Measurement Test

The site MDC is less than the background 95th percentile of 0.88 mg/kg.

#### Conclusion

Silver in subsurface soil passed the Tier 2 evaluation and is considered to be within the range of background.

### **Zinc**

#### Tier 1 Evaluation

Five site samples exceed the background screening value of 34.86 mg/kg.

#### Slippage Test

$K_c$  for zinc is 2, and 4 site samples exceed the maximum background measurement. Because  $K > K_c$ , zinc fails the slippage test.

#### WRS Test

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

#### Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-11).

#### 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 in unfiltered groundwater samples.

Thirteen metals (aluminum, antimony, arsenic, beryllium, cadmium, copper, lead, magnesium, mercury, selenium, silver, thallium, and vanadium) had no detected results in the site samples and are not discussed any further.

Eight metals had no detected concentrations that exceeded their respective background screening values, passing the Tier 1 evaluation. These metals (barium, calcium, cobalt, iron, manganese, potassium, sodium, and zinc) are considered to be within the range of background, and will not be included in any further evaluation or discussion.

The remaining metals (chromium and nickel) underwent Tier 2 evaluation. The results of the statistical tests are discussed in detail below and summarized in Table 3.

## **Chromium**

### Tier 1 Evaluation

There is no background screening value for chromium, and one site sample has a detected result.

### Slippage Test

The maximum background value for chromium is a nondetect, so the slippage test was not performed.

### WRS Test

The WRS test was not performed because the site data set consists of only one sample and the background data set contains more than 50 percent nondetects.

### Box Plot

Because the site data set contains only one sample, box plots were not created.

### 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 Tier 3 geochemical evaluation.

## **Nickel**

### Tier 1 Evaluation

There is no background screening value for nickel, and the site sample has a detected result.

### Slippage Test

The maximum background value for nickel is a nondetect, so the slippage test was not performed.

### WRS Test

The WRS test was not performed because the site data set consists of only one sample and the background data set contains more than 50 percent nondetects.

### Box Plot

Because the site data set contains only one sample, box plots were not created.

### Hot Measurement Test

The site MDC of nickel exceeds the background 95th percentile of 0.0343 mg/L.

### Conclusion

Because nickel in groundwater 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 site data from the Fill Area West of Range 19, Parcel 233(7), and the background data for 23 elements in surface soil, subsurface soil, and groundwater 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, and box-and-whisker plots were prepared to visually compare the two data sets and properly interpret the WRS test results. If the slippage test and/or the WRS test could not be performed, the hot measurement test was included as part of the Tier 2 statistical evaluation. Analytes that underwent Tier 2 evaluation and failed any component of the statistical site-to-background comparison are carried forward for Tier 3 geochemical evaluation to determine if natural processes can explain the elevated concentrations.

Tables 1 through 3 summarize the comparison test results and show the metals carried forward for geochemical evaluation.

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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

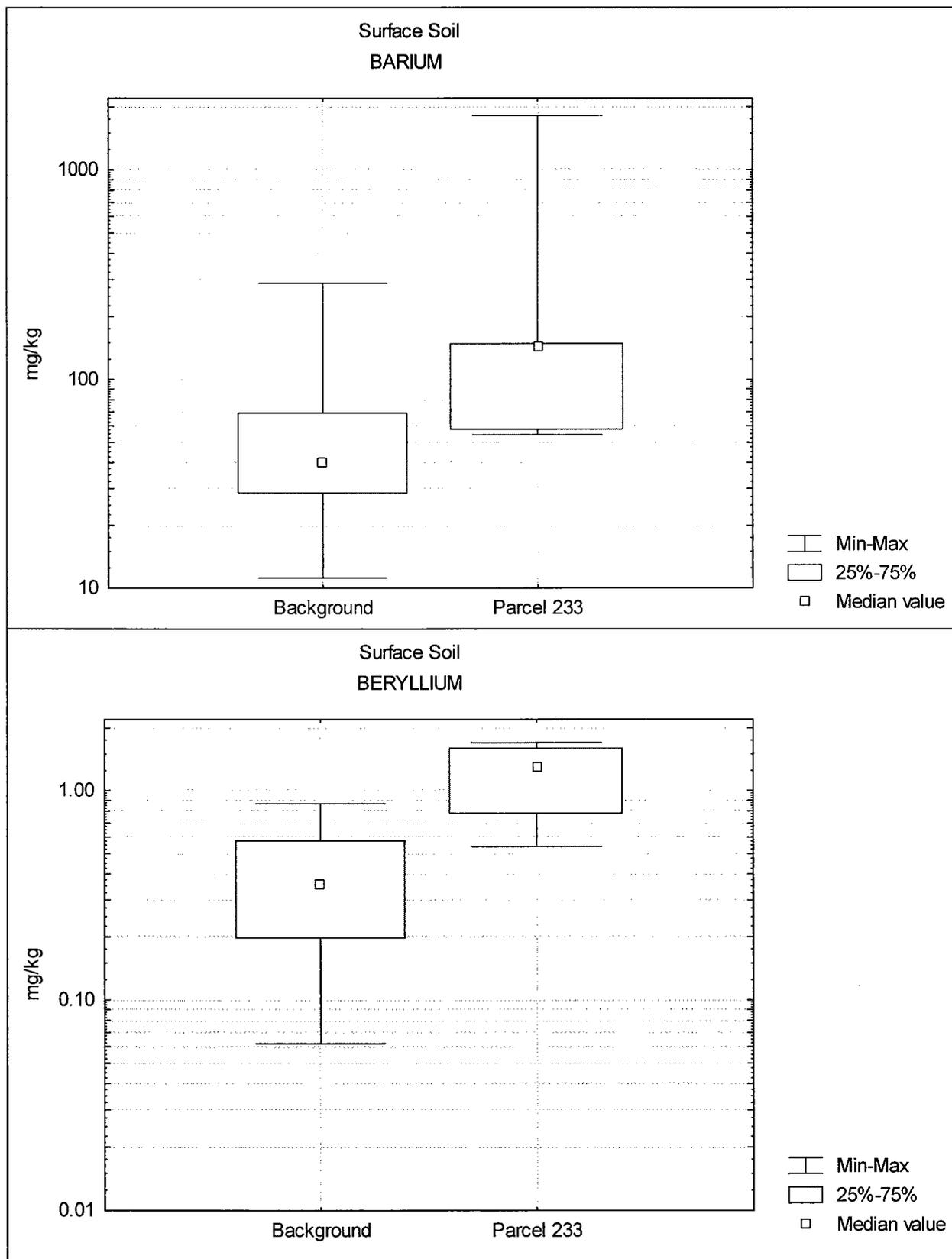


Figure 1-2

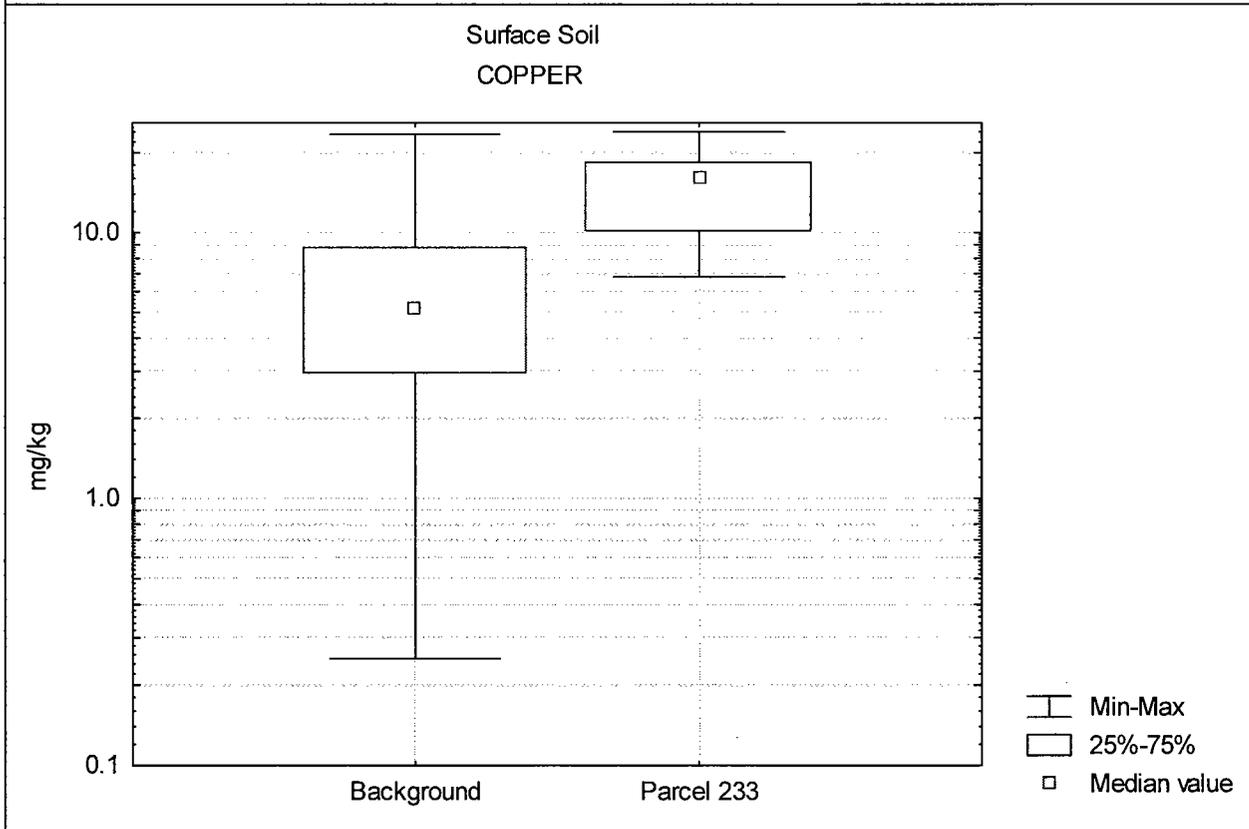
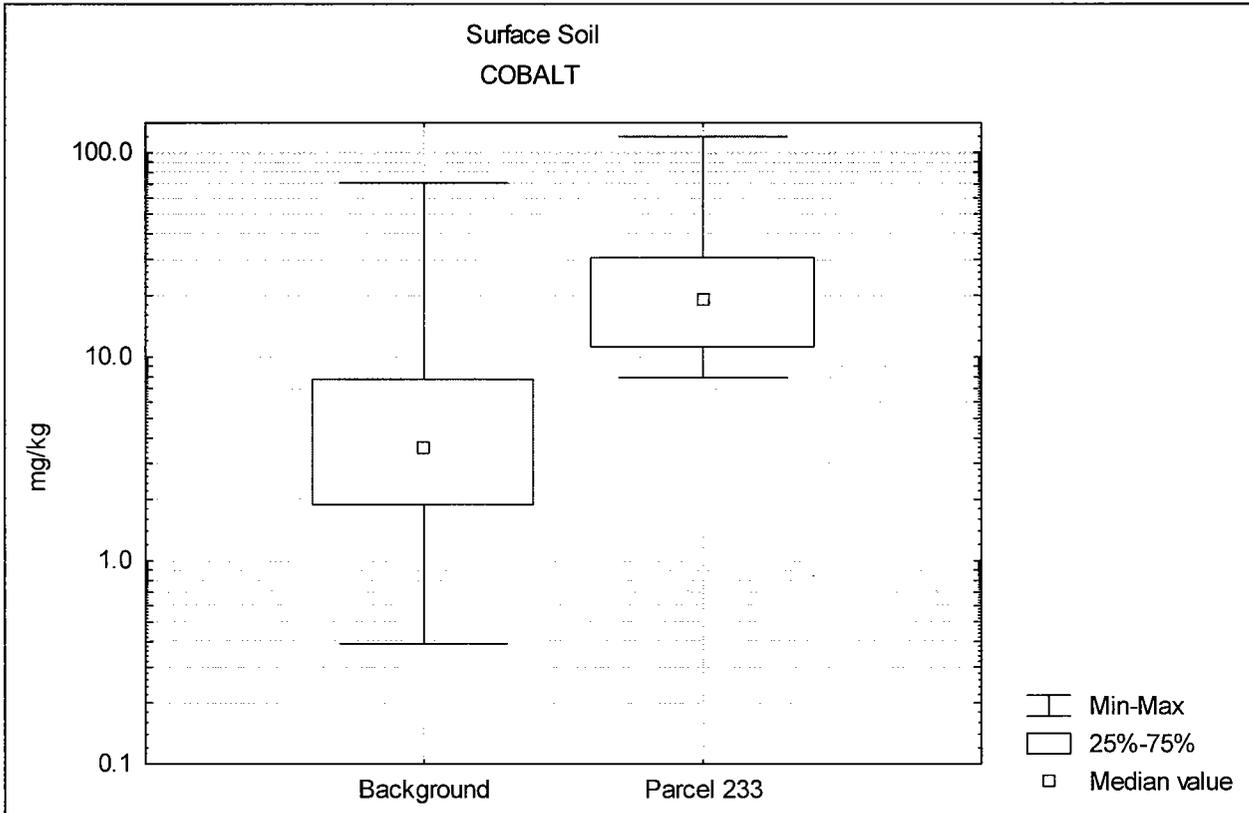


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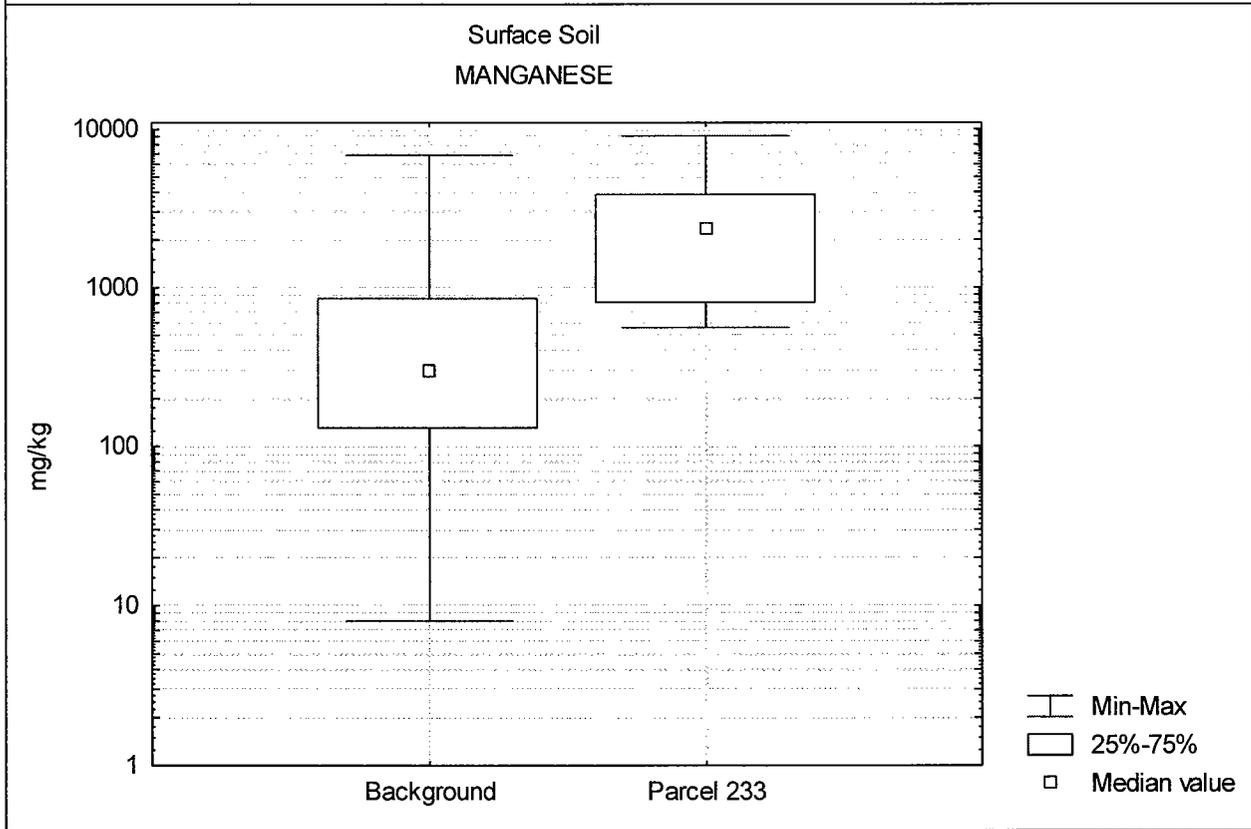
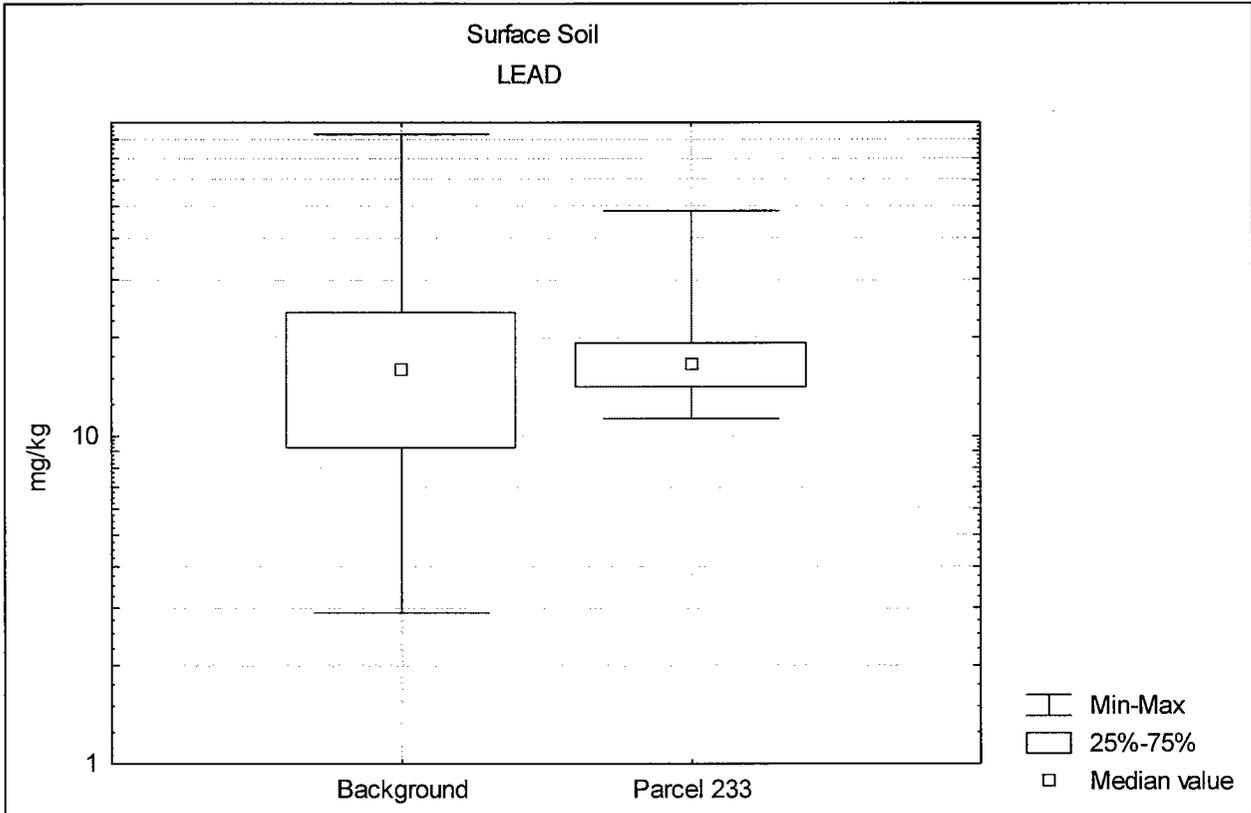


Figure 1-4

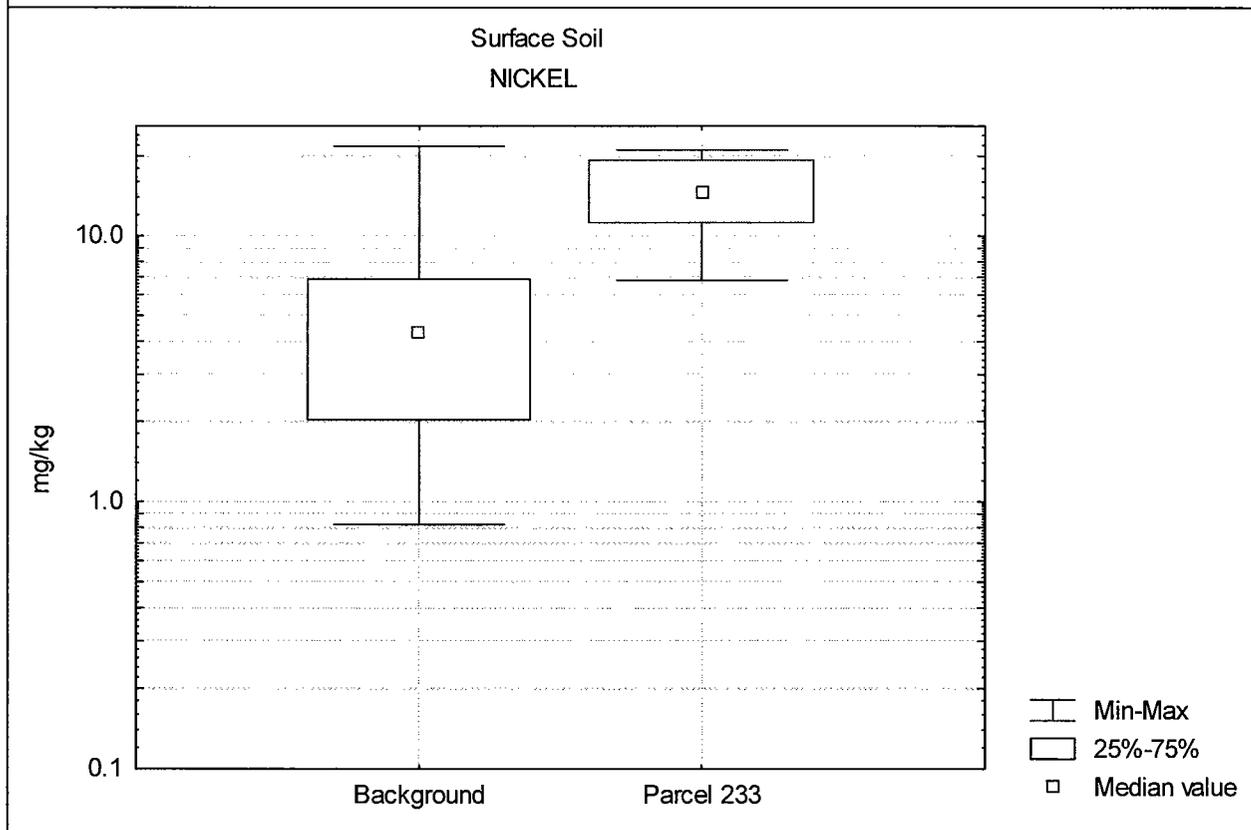
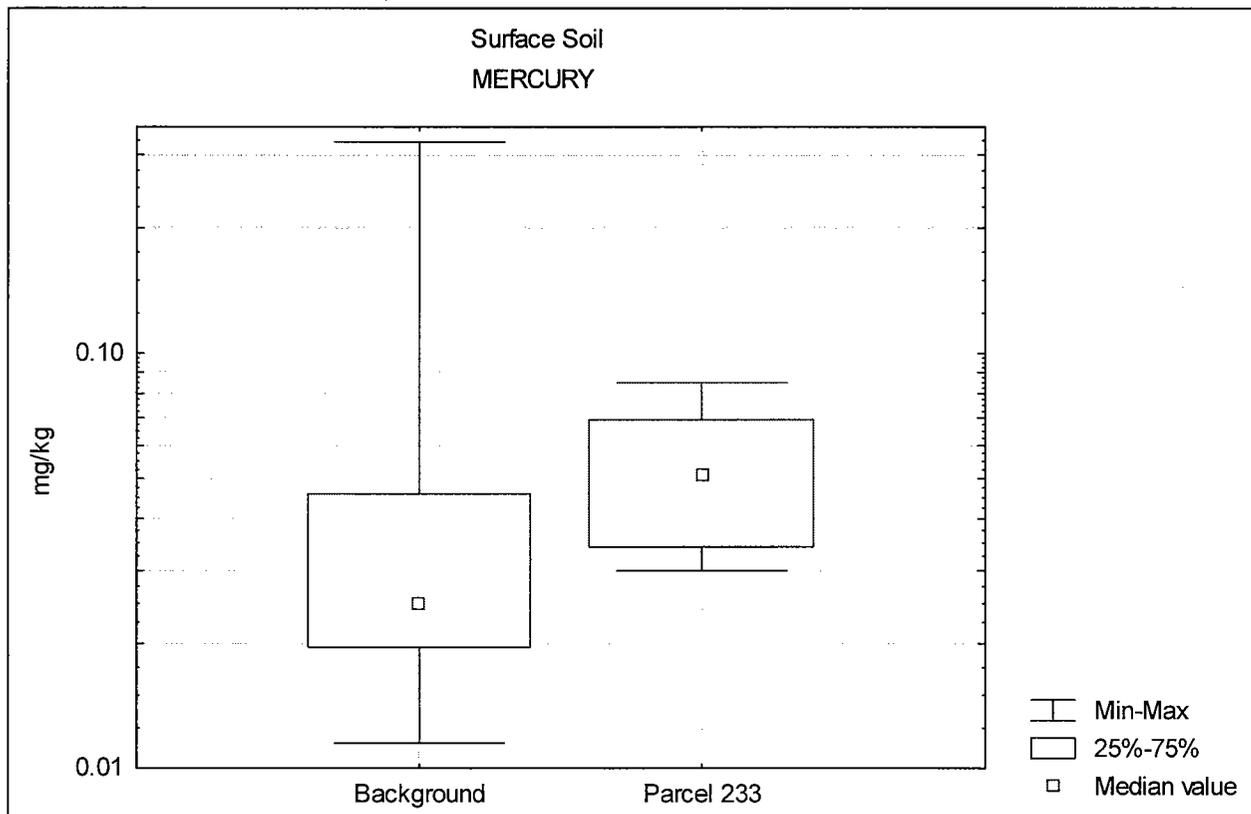


Figure 1-5

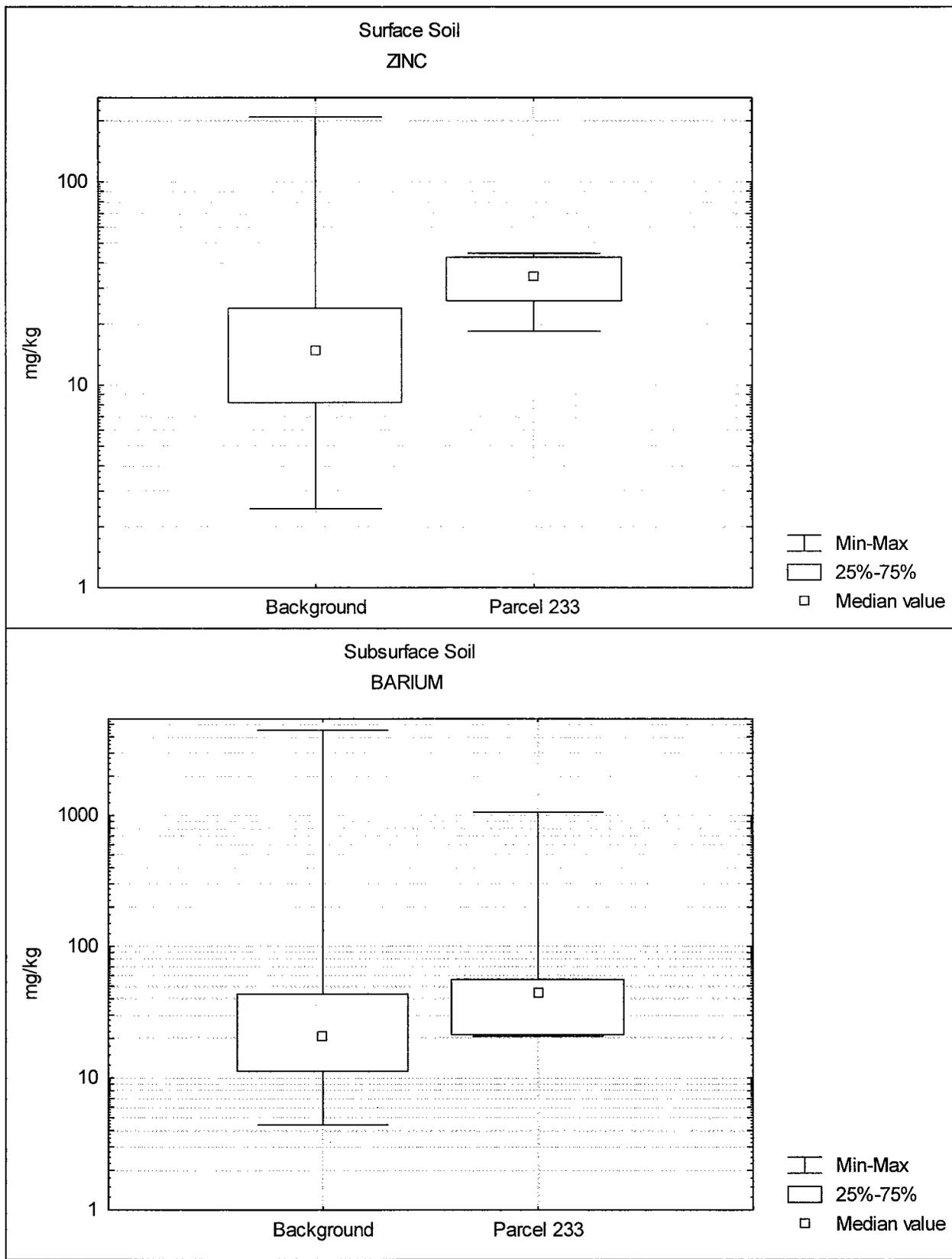


Figure 1-6

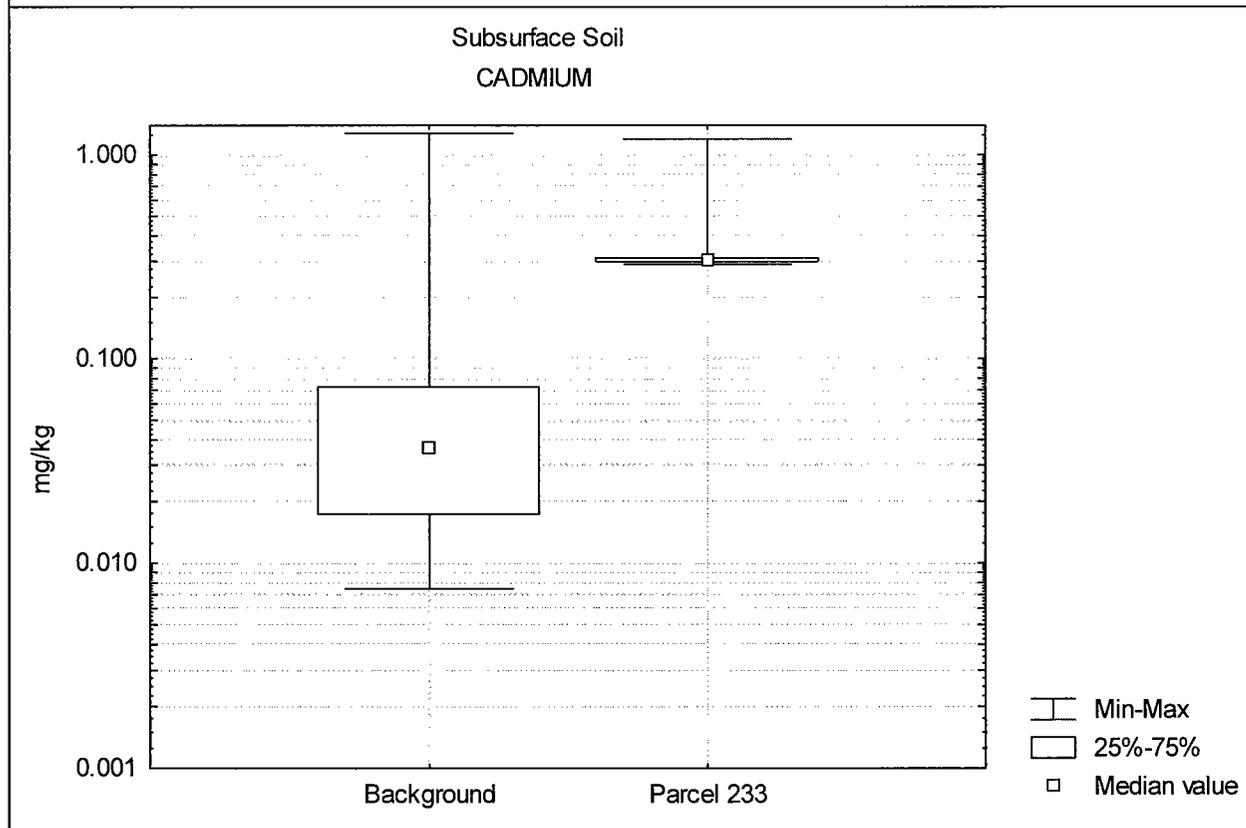
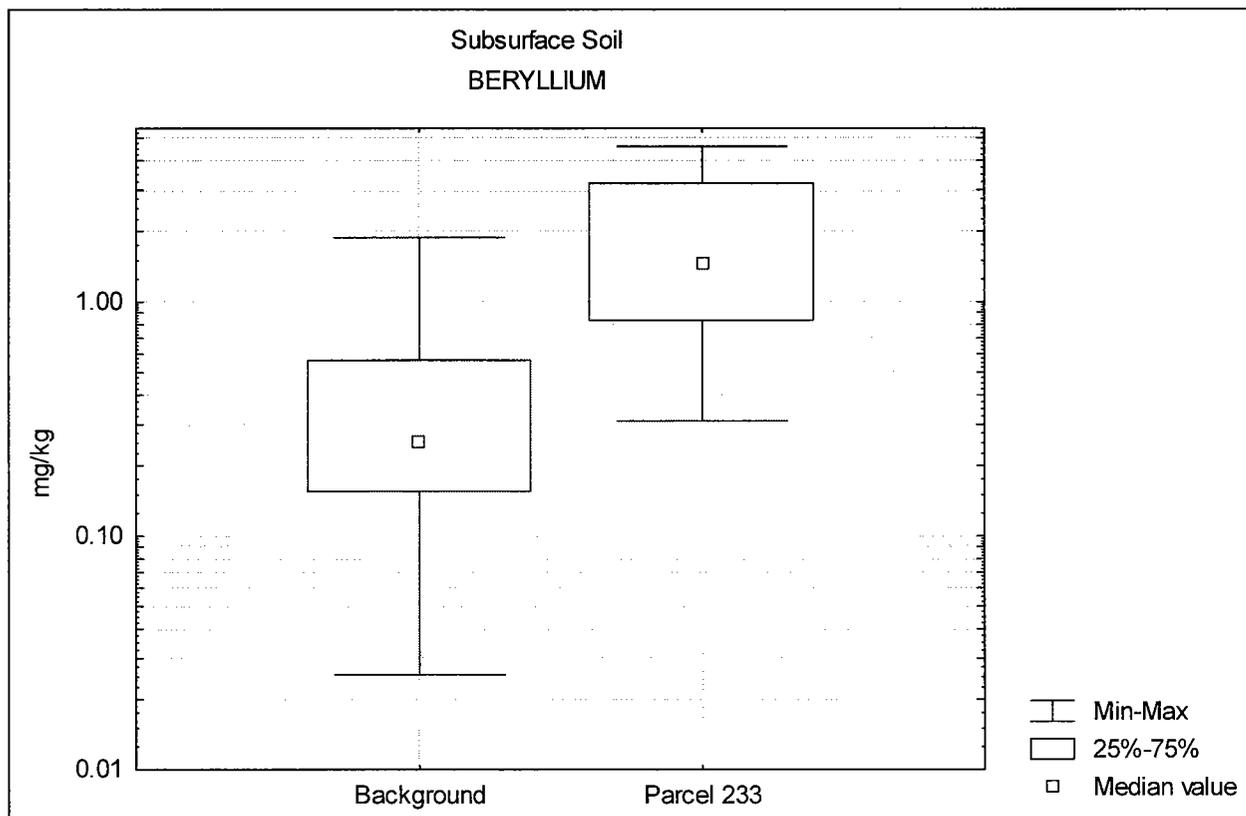


Figure 1-7

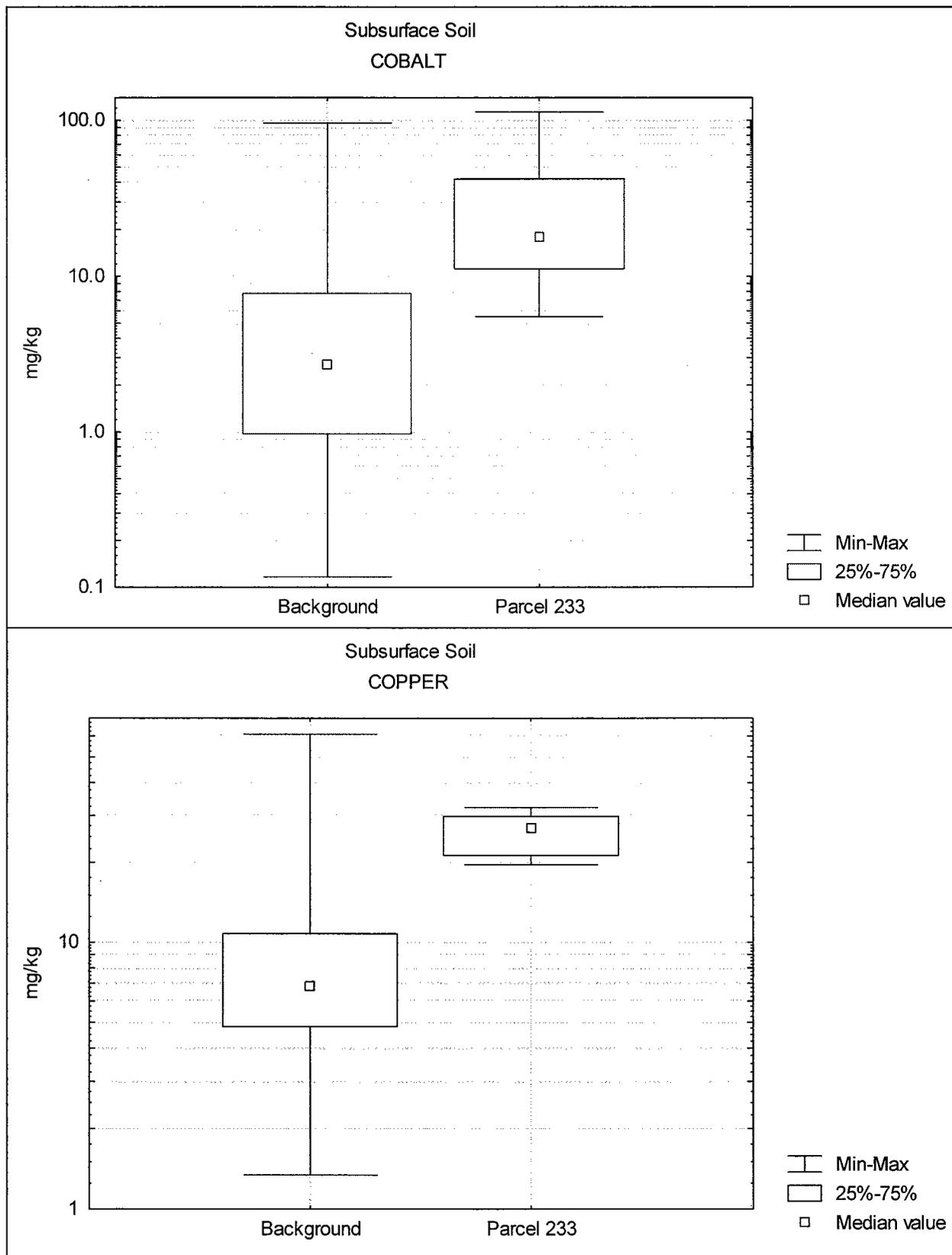


Figure 1-8

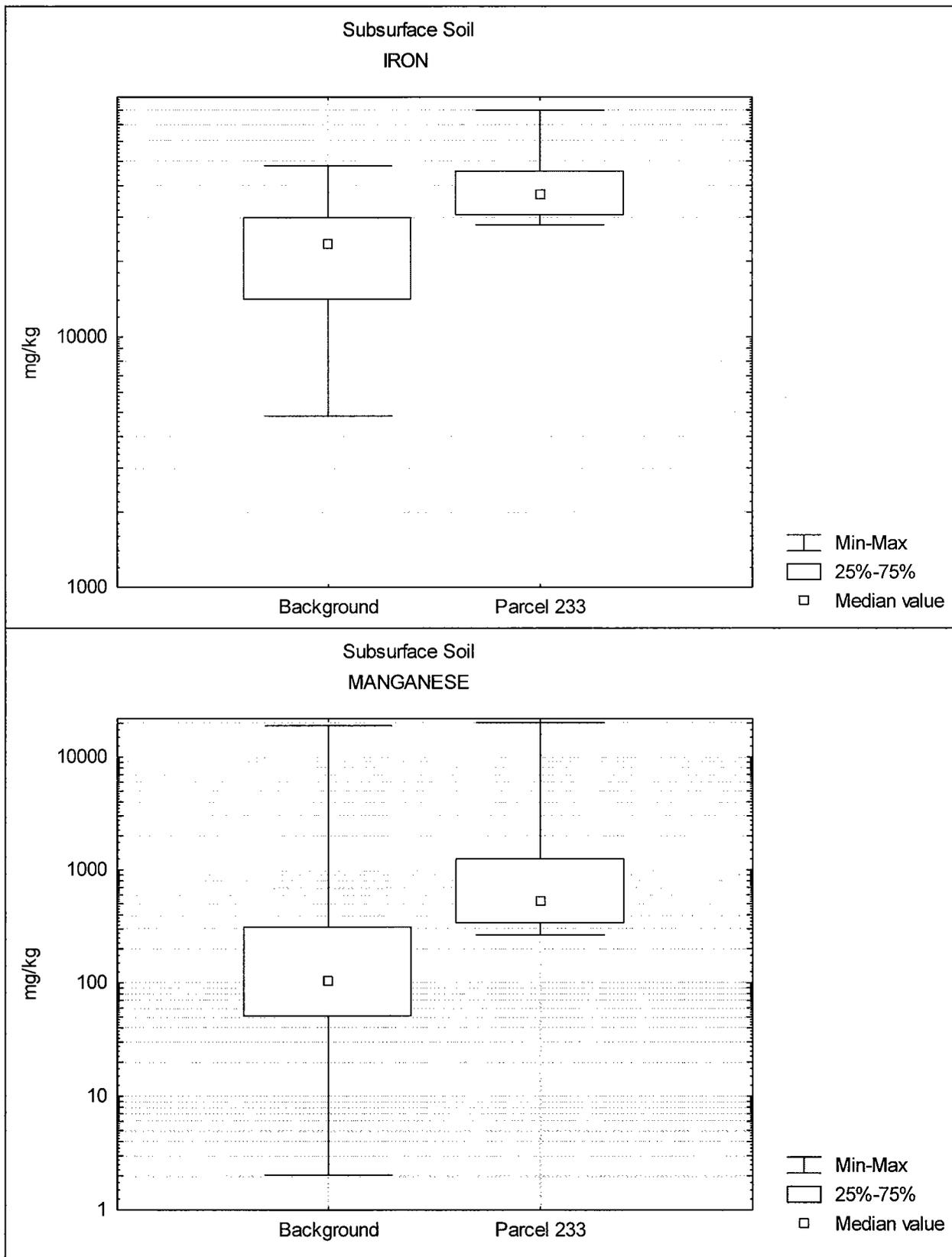


Figure 1-9

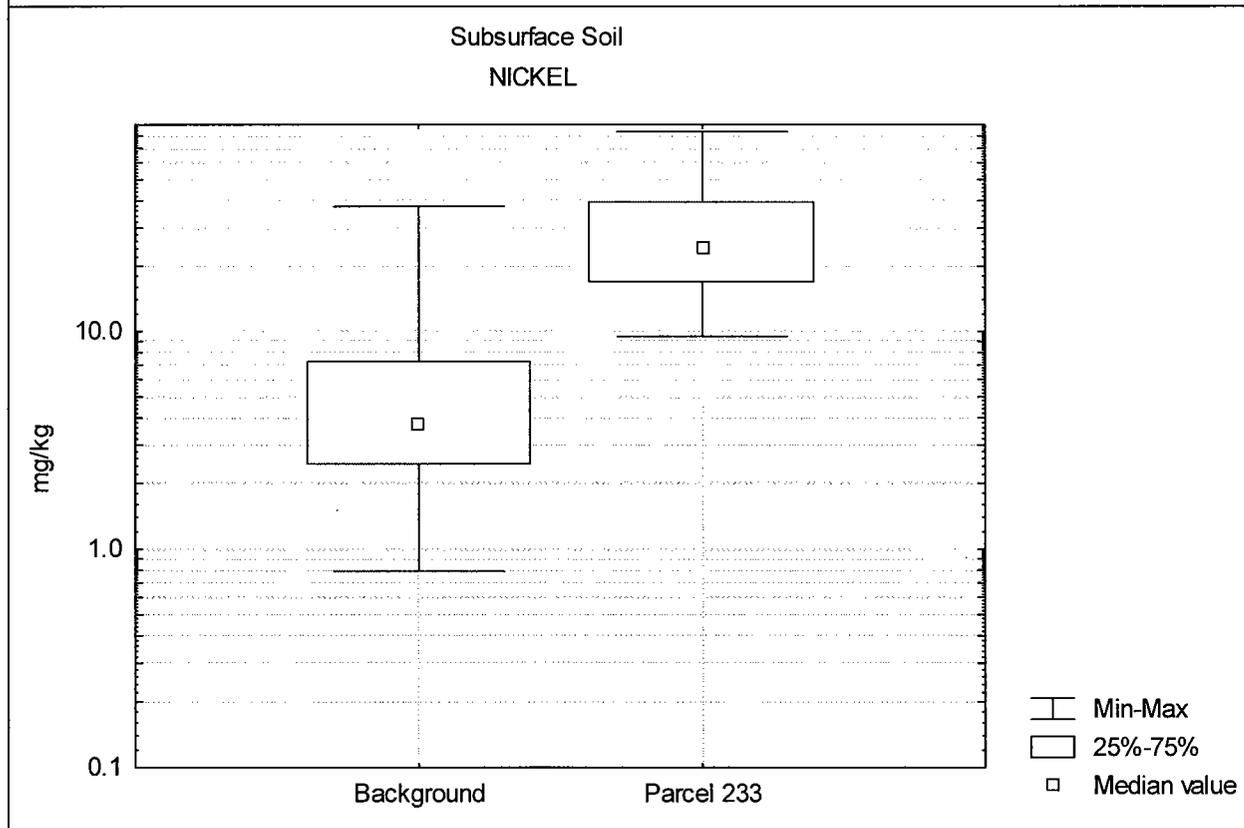
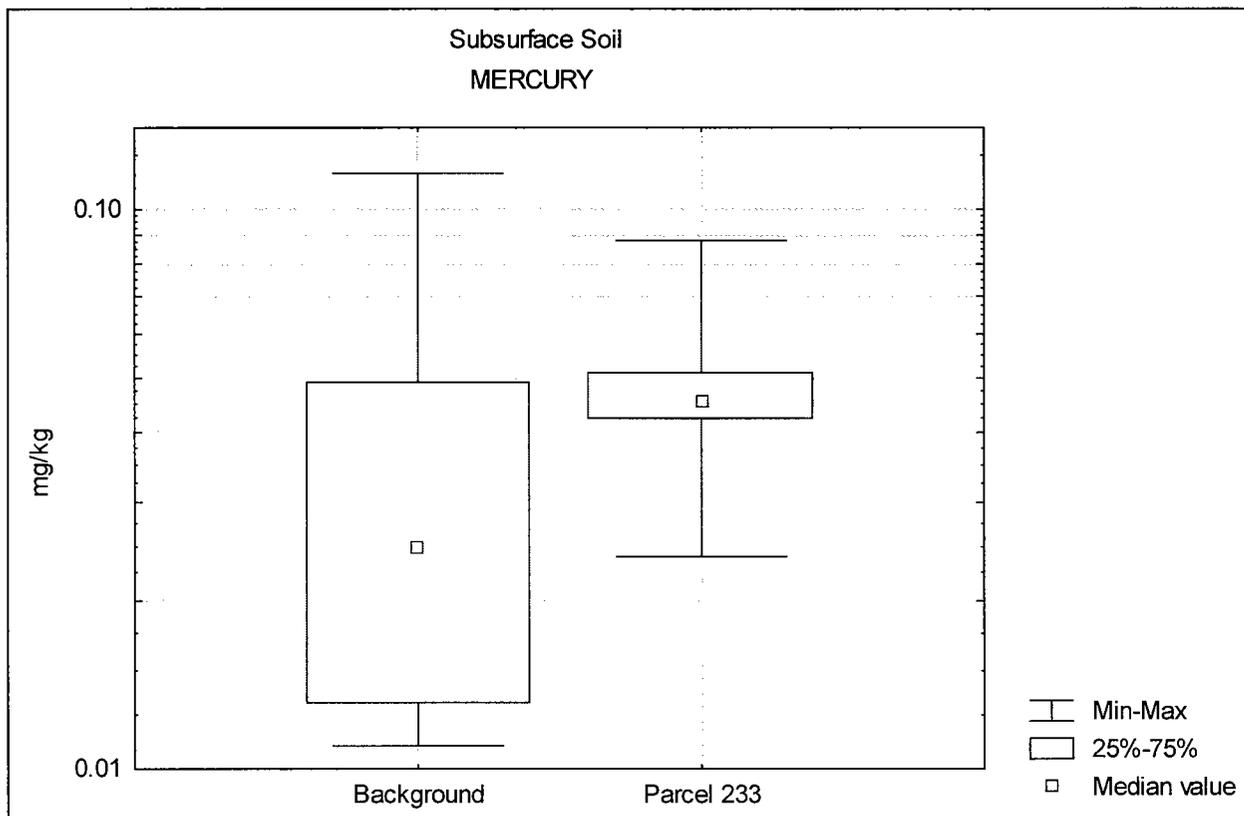


Figure 1-10

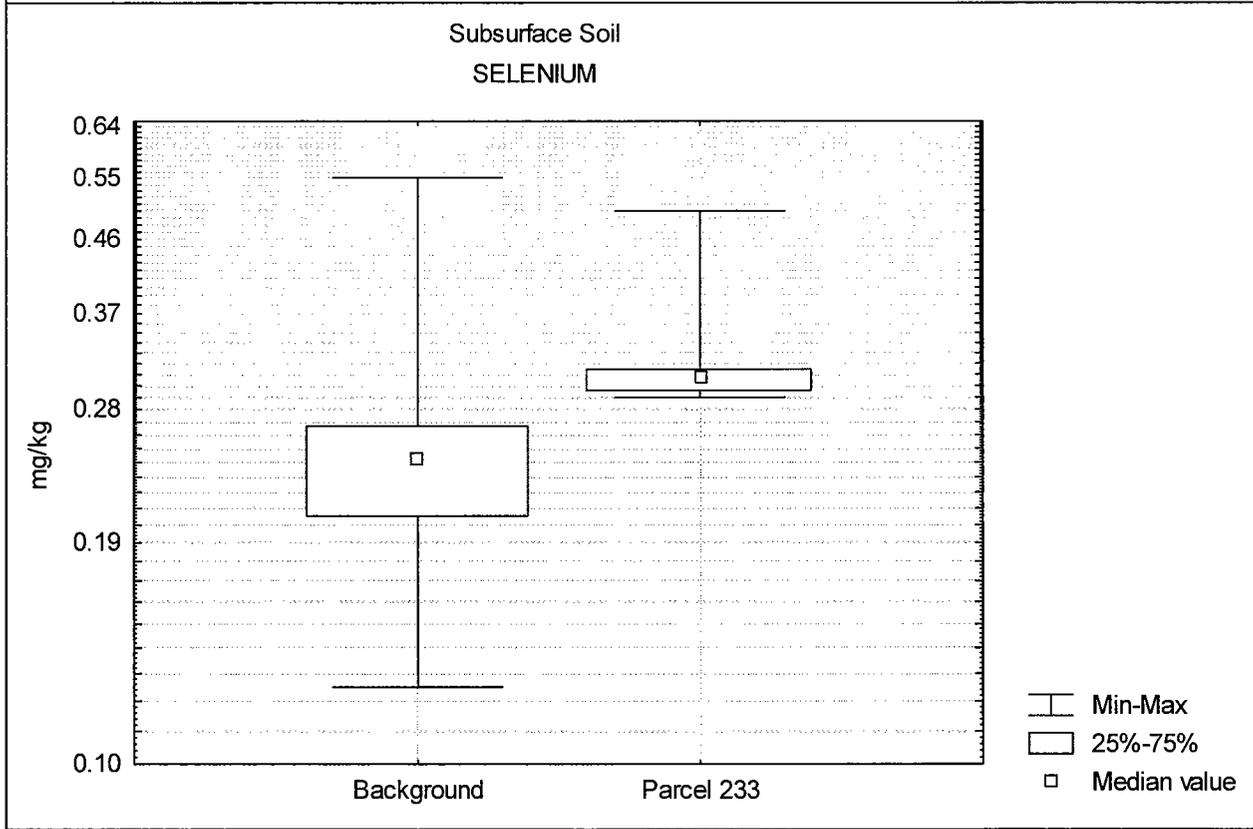
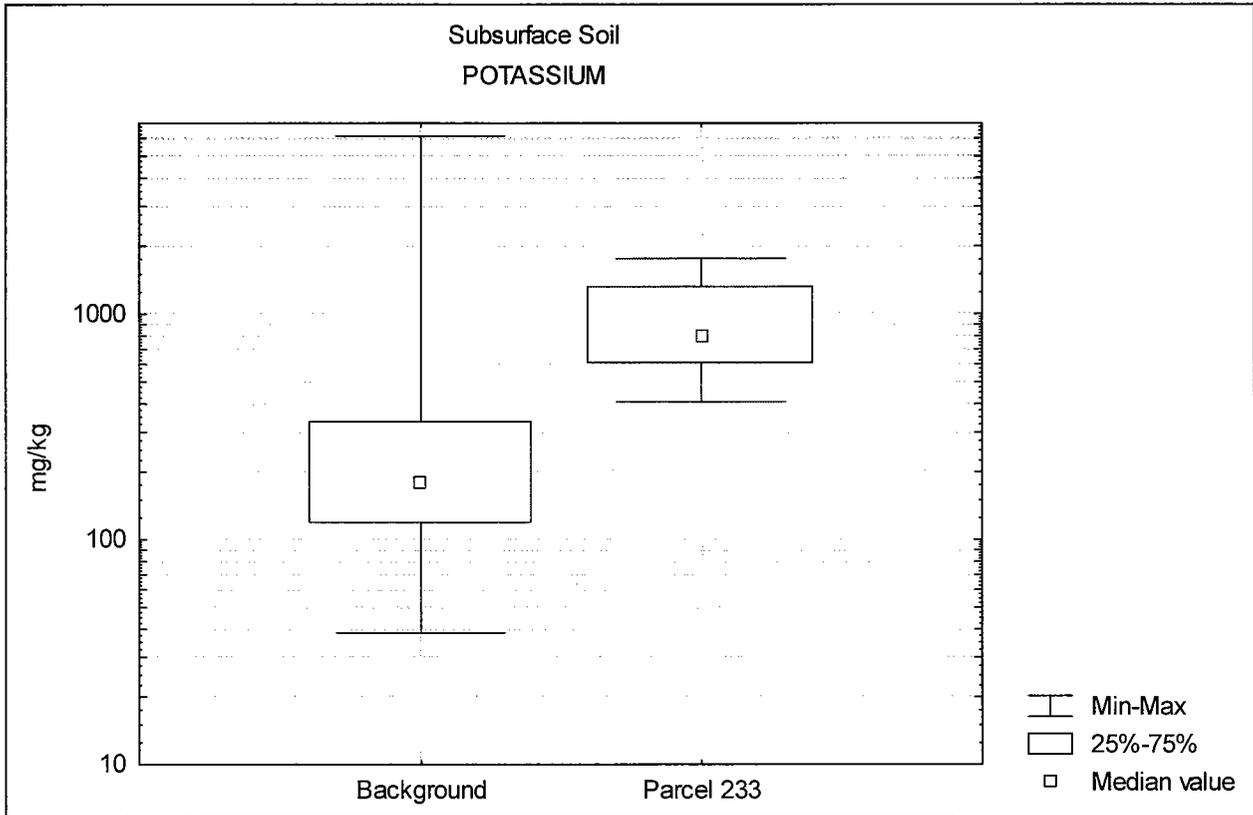
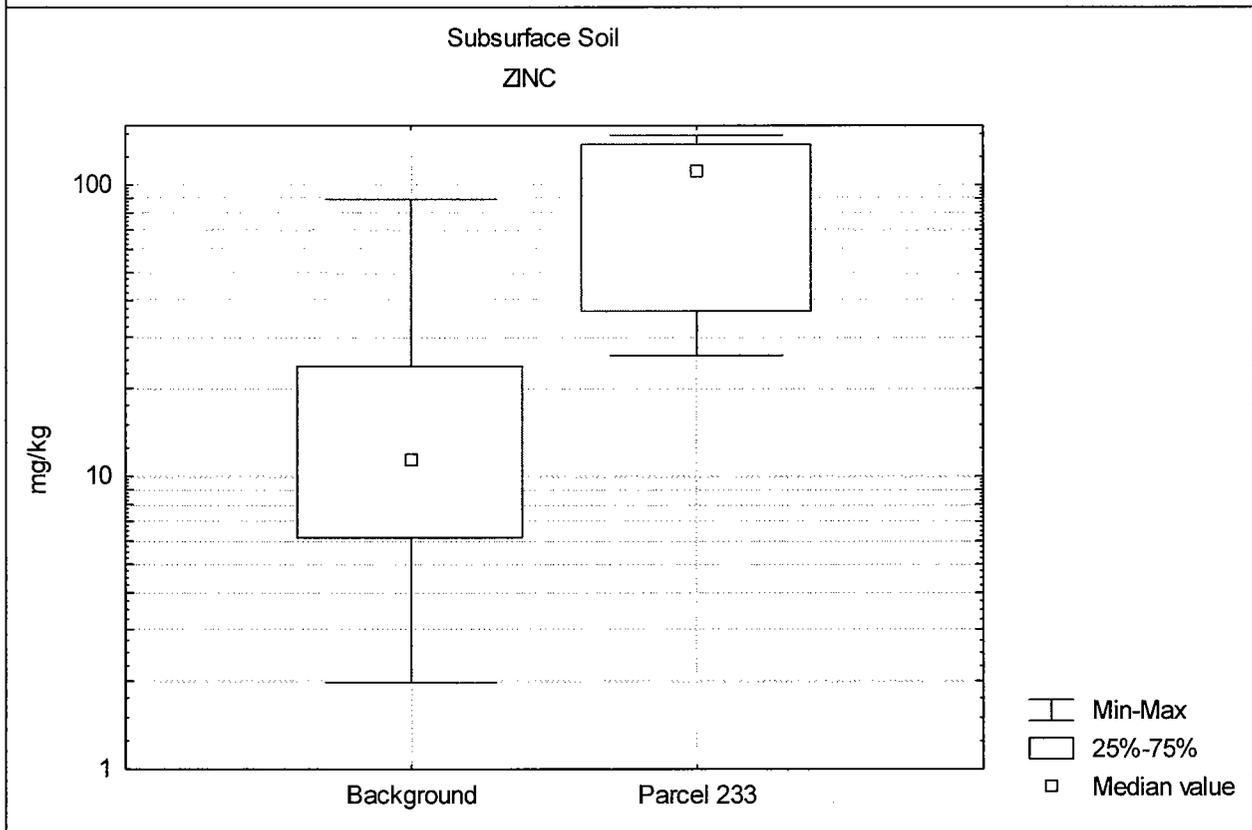
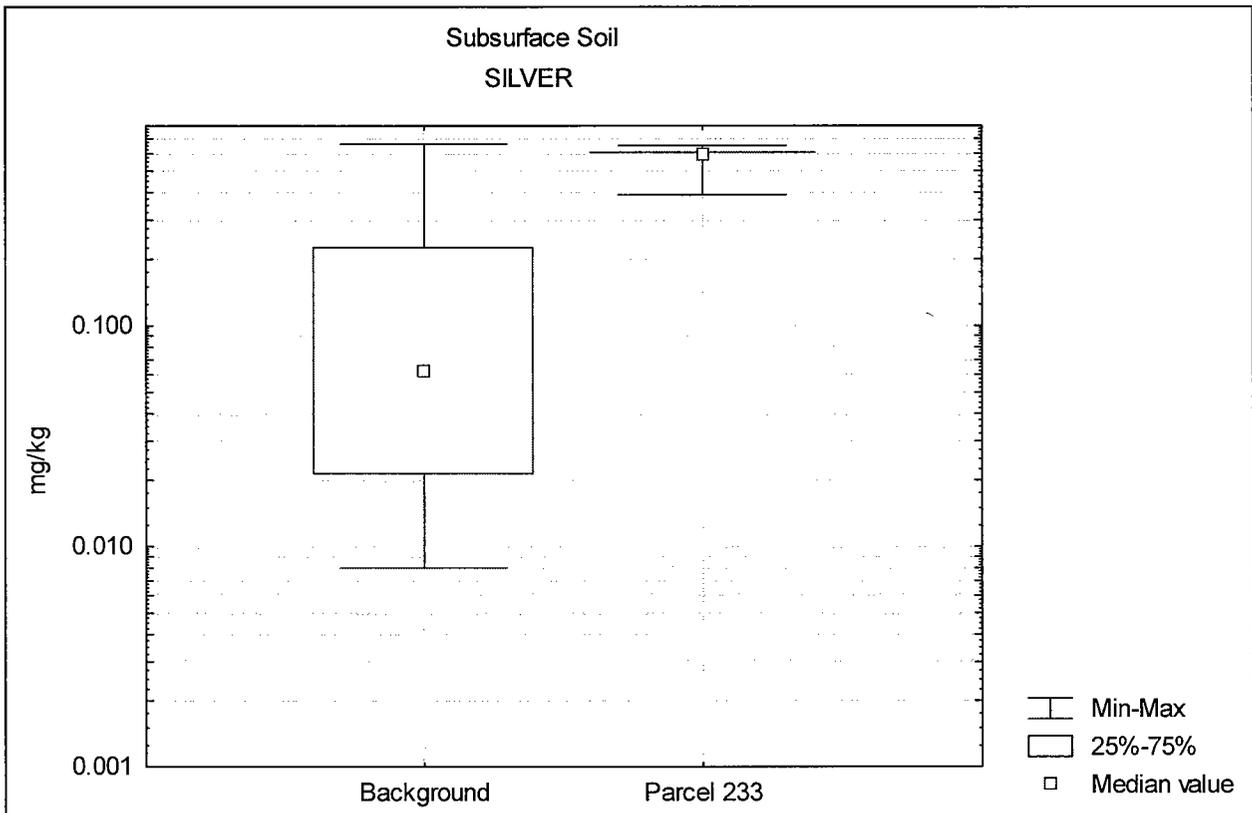


Figure 1-11



**GEOCHEMICAL  
(TIER 3)**

# **Geochemical Evaluation of Metals in Soil and Groundwater Fill Area West of Range 19, Parcel 233(7) Fort McClellan, Alabama**

## **1.0 Introduction**

This report provides the results of a geochemical evaluation of inorganic constituents in soil, groundwater, and surface water samples from the Fill Area West of Range 19, Parcel 233(7), at Fort McClellan in Calhoun County, Alabama. Ten elements in soil and two elements in groundwater 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 seven surface soil samples (obtained from depth of 0 to 1 foot below ground surface [bgs]) collected in February and June 2000; six subsurface soil samples (depths of 8 to 12 feet bgs) collected in February 2000; and one unfiltered groundwater sample collected in July 2000. Installation-wide background data for TAL metals in soil and groundwater are provided in the background study report (Science Applications International Corporation, 1998) and are used in the following evaluation.

## **2.0 Geochemical Evaluation Methodology**

Naturally occurring trace element concentrations in environmental media commonly exceed regulatory screening criteria. Trace element distributions in uncontaminated soil tend to have very large ranges (two to three orders of magnitude are not uncommon), and are highly right-skewed, resembling lognormal distributions. These 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 the Fill Area West of Range 19, Parcel 233(7)” then a geochemical evaluation is performed to determine if the elevated concentrations are caused by natural processes. The importance of geochemical evaluations in distinguishing between site and background data sets has been recognized in the industry (U.S. Environmental Protection Agency, 1995; Barclift, *et al.*, 2000; U.S. Navy, 2002; Myers and Thorbjornsen, 2004). When properly evaluated, geochemistry can provide mechanistic explanations for

apparently high, yet naturally occurring, constituents. Anomalous samples that may represent contamination can also be readily distinguished from uncontaminated samples. This section describes the geochemical evaluation techniques that were employed in the site-to-background comparisons for Parcel 233(7).

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**

The geochemical evaluation is based on the natural associations of trace elements with specific minerals in the soil or sediment matrix. As an example, arsenic in most uncontaminated oxic soils is almost exclusively associated with iron oxide minerals (Bowell, 1994; Schiff and Weisberg, 1997). (The term “iron oxide” is used here to include oxides, hydroxides, oxyhydroxides, and hydrous oxides of iron.) This association of arsenic with iron oxides is a result of the adsorptive behavior of this particular trace metal in an oxic soil environment. Arsenic is present in oxic soil pore fluid as negatively charged oxyanions ( $\text{HAsO}_4^{-2}$ ,  $\text{H}_2\text{AsO}_4^-$ ) (Brookins, 1988). These anions have strong affinities to adsorb on the surfaces of iron oxides, which maintain a strong positive surface charge (Electric Power Research Institute, 1986). If a soil sample has a high percentage of iron oxides, then it is expected to have a proportionally higher concentration of arsenic.

The absolute concentrations of arsenic and iron can vary by several orders of magnitude at a site, but the arsenic/iron ratios in the samples are usually quite constant as long as no contamination is present (Daskalakis and O'Connor, 1995). If a sample has some naturally occurring arsenic plus additional arsenic from an herbicide or some other source, then it will have an anomalously high ratio relative to the other uncontaminated samples. These ratios thus serve as a powerful technique for identifying contaminated samples.

The evaluation includes the generation of plots in which detected arsenic concentrations in a set of samples are plotted on the y-axis, and the corresponding detected iron concentrations are plotted on the x-axis. The slope of a best-fit line through the samples is equal to the average arsenic/iron background ratio. If the samples with the highest arsenic concentrations plot on the same linear trend as the other samples, then it is most probable that the elevated concentrations are natural, and are caused by the preferential enrichment of iron oxides in those samples. If the site samples with elevated arsenic concentrations plot above the trend displayed by the uncontaminated samples, then there is evidence that those samples have an excess contribution of arsenic, and contamination may be indicated.

Each trace element is associated with one or more minerals in the soil matrix. Vanadium and selenium, along with arsenic, form anionic species in solution and are associated with iron oxides, which maintain a positive surface charge. Divalent metals such as barium, cadmium, lead, and zinc tend to form cationic species in solution and are attracted to clay mineral surfaces, which maintain a negative surface charge. These trace elements would be evaluated against aluminum, which is a major component of clay minerals. Manganese oxides also have an affinity to adsorb divalent cations such as barium, cobalt, and lead (Kabata-Pendias, 2001). These trace elements would be evaluated against manganese.

## **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. This section discusses the major geochemical processes considered during the evaluation of groundwater and surface water analytical data.

**Effects of Suspended Particulates.** The presence of trace elements adsorbed on suspended particulates can greatly increase trace element concentrations as reported by an analytical laboratory. These adsorbed trace elements are not in true solution, and can be removed by settling or filtration. 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).

The most common suspended particulates in groundwater samples are clay minerals; hydrous aluminum oxides ( $\text{Al}_2\text{O}_3 \cdot n\text{H}_2\text{O}$ ) and hydroxides [ $\text{Al}(\text{OH})_3$ ]; and iron oxide ( $\text{Fe}_2\text{O}_3$ ), iron hydroxide [ $\text{Fe}(\text{OH})_3$ ], and iron oxyhydroxide ( $\text{FeO} \cdot \text{OH}$ ) minerals, collectively referred to as “iron oxides.” All clay minerals contain aluminum and have low solubilities over a neutral pH range of 6 to 8. Measured concentrations of aluminum in excess of ~1 milligram per liter (mg/L) indicate the presence of suspended clay minerals (Hem, 1985; Stumm and Morgan, 1996), with higher aluminum concentrations being a qualitative indicator of the mass of suspended clay minerals. Iron also has a very low solubility under neutral pH and moderate to oxidizing redox conditions, so that measured iron concentrations in excess of ~1 mg/L under these conditions indicate the presence of suspended iron oxides (Hem, 1985).

The presence of suspended clay or iron oxides in groundwater samples has particular importance in the interpretation of trace element concentrations. Most clay particles maintain a negative surface charge under neutral pH conditions, and have a strong tendency to adsorb positively charged (cationic) aqueous species. Iron oxides display the opposite behavior, maintaining a positive surface charge under neutral pH conditions, and have a strong tendency to adsorb negatively charged (anionic) aqueous species.

Barium, lead, and zinc are usually present in groundwater as divalent cations and thus tend to concentrate on clay surfaces (Electric Power Research Institute, 1984; Brookins, 1988). Arsenic, selenium, and vanadium are usually present under oxidizing conditions as oxyanions, and thus tend to concentrate on iron oxide surfaces (Bowell, 1994; Hem, 1985; Pourbaix, 1974; Brookins, 1988).

Chromium can be present in groundwater as a mixture of aqueous species with different charges, depending on pH (Electric Power Research Institute, 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.

As an example, the concentrations of zinc (y-axis) would be plotted against aluminum (x-axis). If all of the samples display a common linear trend, then it is most likely that the zinc concentrations are due to the presence of suspended clay minerals in the samples. The slope of a best-fit line through the points is equal to the average zinc/aluminum ratio. If some samples plot above the linear trend established by the other samples, then those samples have an anomalously

high zinc/aluminum ratio, and most likely contain excess zinc that cannot be explained by these natural processes.

Alternative techniques for assessing the effects of suspended particulates on trace element concentrations are the evaluation of correlations of trace element concentrations versus turbidity, and comparison of analyses of filtered versus unfiltered splits of samples. Turbidity measurements are qualitative, and do not distinguish between suspended clay minerals, iron oxides, and natural organic material, so this approach lacks the resolution provided by trace element versus aluminum or trace element versus iron correlations.

If the concentrations of trace elements in unfiltered samples are correlated with aluminum or iron, then they are most likely adsorbed to the surfaces of suspended particulates. If these correlations are linear, then the elevated concentrations are most likely natural.

***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 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 by local depressions in oxidation-reduction potential (ORP) 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 *cis*-1,2-dichloroethene and/or vinyl chloride, which are reductive dechlorination products resulting from the microbial degradation of trichloroethene or tetrachloroethene under anaerobic conditions.

### **3.0 Results of the Geochemical Evaluation of Multiple Elements in Soil**

This section presents the results of the geochemical evaluation of barium, beryllium, cadmium, cobalt, copper, iron, manganese, nickel, potassium, and zinc in soil samples from Parcel 233(7). Correlation plots are provided in Attachment 1.

#### **Barium**

Manganese oxides have an affinity to adsorb divalent cations such as barium, cobalt, and lead (Kabata-Pendias, 2001). 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. A plot of barium versus manganese concentrations is provided in Figure 1. The site surface soil samples are represented by open triangles, the site subsurface soil samples are represented by filled triangles, and the background soil samples are represented by filled circles. The site and background samples form a collinear trend in the plot ( $R^2 = 0.86$  and  $0.99$  for the site surface and subsurface intervals, respectively). The site samples with the highest barium concentrations also contain the highest manganese concentrations, and lie on the trend established by the other samples. These observations indicate that barium in the site samples is associated with manganese oxides at a relatively constant ratio, and is natural.

#### Conclusion

Barium detected in the site soil samples is naturally occurring.

#### **Beryllium**

Beryllium concentrations in soil are commonly controlled through adsorption on iron oxides (Vesely, *et al.*, 2002), so a positive correlation between beryllium and iron would be expected for uncontaminated samples. A plot of beryllium versus iron is provided in Figure 2. The background samples form a generally linear trend with a positive slope, and all of the site samples lie on the trend. The site sample with the highest beryllium concentration also has the highest iron content, and lies on the background trend. These observations indicate that beryllium in the site samples is associated with iron oxides at ratios consistent with those of the background samples, and is natural.

#### Conclusion

Beryllium detected in the site soil samples is naturally occurring.

#### **Cadmium**

Cadmium is commonly present in soils as a divalent cation, and has an affinity to adsorb on manganese oxides (Kabata-Pendias, 2001). A positive correlation between cadmium and manganese is thus expected for uncontaminated samples. The background samples form a

generally linear trend with a positive slope in a plot of cadmium versus manganese (Figure 3). Subsurface soil sample KZ0008 is the only site sample with detectable cadmium. It has a higher cadmium concentration (1.2 J mg/kg) than most of the background samples, but it also the highest manganese concentration of both data sets (20,200 mg/kg) (as well as high iron) and lies on the background trend. Cadmium in this sample is associated with manganese oxides at a ratio consistent with those of the background samples, and is natural.

#### Conclusion

Cadmium detected in the site soil samples is naturally occurring.

#### **Cobalt**

Manganese oxides have an affinity to adsorb divalent cations such as barium, cobalt, and lead (Kabata-Pendias, 2001). 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. A plot of cobalt versus manganese reveals a common linear trend with a positive slope for the site and background samples ( $R^2 = 0.93$  and  $0.92$  for the site surface and subsurface intervals, respectively) (Figure 4). The site samples with the highest cobalt concentrations also contain proportionally higher manganese, and lie on the linear trend. Cobalt in the site samples is associated with manganese oxides at a relatively constant ratio, and is natural.

#### Conclusion

Cobalt detected in the site soil samples is naturally occurring.

#### **Copper**

Copper in soil has an affinity to adsorb on the surfaces of minerals such as clays and iron oxide minerals (Kabata-Pendias, 2001). Most of the background samples form a linear trend with a positive slope in a plot of copper versus iron, and the site samples all lie on this trend (Figure 5). The site samples with the highest copper concentrations also contain high iron, and lie on the trend established by the other samples. These observations indicate that copper in the site samples is associated with iron oxides at ratios consistent with those of the background samples, and is natural.

#### Conclusion

Copper detected in the site soil samples is naturally occurring.

#### **Iron**

Iron is the most abundant element analyzed in the site soil samples, with a mean concentration of 33,238 mg/kg (3.3 weight percent). The iron is dominantly present as iron oxides, which are common soil-forming minerals that occur as discrete mineral grains or as coatings on silicate minerals (Cornell and Schwertmann, 2003). Aluminum is a primary component of other common soil-forming minerals such as clays, feldspars, and micas. Aluminum also substitutes for ferric iron in iron oxide minerals, and can adsorb on iron oxide surfaces (Cornell and Schwertmann, 2003). Iron oxides and clays tend to exist as very fine particles, so both iron and aluminum are enriched in samples with finer grain sizes. The Parcel 233(7) soil boring logs note that red, yellowish red, and brownish red clay with some silt or brown, brownish yellow, and yellowish red silt with some sand are the predominant soil types in many of the sampled

intervals, which indicates that the site samples contain a high percentage of fine-grained material. The colors of the site soils are imparted by the iron oxides, which are highly pigmented. The site boring logs note the presence of “iron concretions” and “iron staining” in several of the subsurface soil intervals.

A plot of iron versus aluminum concentrations can be used to qualitatively assess the relative abundance of iron oxide and clay minerals in site soil (Figure 6). The site samples exhibit higher iron concentrations than many of the background samples, but most of the site samples lie on the general background trend. Subsurface soil sample KZ0008, collected from 10 to 12 feet bgs at sample location PPMP-233-GP03, contains the highest iron concentration of the site and background data sets (79,800 mg/kg) and lies above the background trend. No organic contamination was detected in this sample, and the boring log for this location specifically notes the presence of iron staining within the sampled interval. These observations indicate that sample KZ0008 is enriched in iron oxides relative to the background samples, and that the iron has a natural source.

It is important to note that iron oxides and clays adsorb specific trace elements (as discussed in Section 2.1), so samples that plot on the upper end of the trend in Figure 6 are expected to contain proportionally higher concentrations of trace elements.

#### Conclusion

Iron detected in the site soil samples is naturally occurring.

#### **Manganese**

Manganese oxide minerals are common in soil and are present as discrete grains or as coatings on silicate mineral grains. The presence of manganese oxides in soil is an important control on trace element concentrations, because these minerals have a strong affinity to adsorb divalent cations such as barium, cobalt, and lead. Positive correlations are thus expected between manganese and associated trace elements in uncontaminated soil samples. The positive correlations observed for barium vs. manganese and cobalt vs. manganese, and the absence of outliers plotting off the linear trends on the correlation plots, indicate a natural source for these three elements (Figures 1 and 4).

#### Conclusion

Manganese in the site soil samples is naturally occurring.

#### **Nickel**

Nickel is commonly associated with iron oxides in soils (Kabata-Pendias, 2001). A plot of nickel versus iron reveals a generally linear trend with a positive slope for the background samples, and all of the site samples lie on this trend (Figure 7). The site sample with the highest nickel concentration is also characterized by the highest iron concentration, and lies on the linear trend. Nickel in the site samples is associated with iron oxides at ratios consistent with those of the background samples, and is natural.

### Conclusion

Nickel detected in the site soil samples is naturally occurring.

### **Potassium**

Potassium and magnesium are common constituents of soil-forming minerals such as clays. A plot of potassium versus magnesium is provided in Figure 8. The site surface soil samples are highly linear ( $R^2 = 0.85$ ), and they all lie on the background trend. Most of the site subsurface soil samples also lie on the background trend. The subsurface sample with the highest potassium (1,760 mg/kg) lies slightly above the trend, but it is well below the background maximum of 6,150 mg/kg. Potassium in the site samples is natural.

### Conclusion

Potassium detected in the site soil samples is naturally occurring.

### **Zinc**

Zinc in soil has an affinity for multiple sorptive surfaces, including clays, iron oxides, and manganese oxides (Kabata-Pendias, 2001). A plot of zinc versus iron is provided in Figure 9. The site and background samples form a common linear trend with a positive slope. The site samples with high zinc also contain high iron, and lie on the trend established by the other samples. Zinc in the site samples is associated with iron oxides at ratios consistent with those of the background samples, and is natural.

### Conclusion

Zinc detected in the site soil samples is naturally occurring.

## ***4.0 Results of the Geochemical Evaluation of Chromium and Nickel in Groundwater***

This section presents the results of the geochemical evaluation of chromium and nickel in the single unfiltered groundwater sample from Parcel 233(7). Correlation plots are provided in Attachment 1.

The field-measured pH reading for the single site groundwater sample is 4.43, indicating acidic conditions at the sample location. The field-measured ORP reading of +165 millivolts suggests oxidizing conditions at the sample location. The turbidity measurement of 9.67 nephelometric turbidity units indicates that the sample did not contain a significant mass of suspended particulates. It should be noted that field readings are not available for the background samples.

### **Chromium**

Chromium was detected in the site groundwater sample at a concentration of 0.13 J mg/L. Comparison to background is hindered by the high percentage of nondetects in the background data set. However, groundwater samples with detectable chromium that were collected at other Ft. McClellan sites are included in the following evaluation for comparative purposes. These

sites include Range J (Parcel 202[7]) and the Former Tank Ranges (Parcels 92[Q], 93[Q], 107[Q], 133[Q], and 134[Q]). In addition, the project database was queried for groundwater samples from monitoring wells located within 0.25 mile of Parcel 233(7). All of these non-Parcel 233(7) samples are referred to as the “reference” samples.

As noted in Section 2.2, chromium can be present in groundwater as a mixture of aqueous species with different charges, depending on pH, and thus chromium can have an affinity for several different types of sorptive surfaces, including clay and iron oxide minerals. Plots of chromium versus iron and chromium versus aluminum are provided in Figures 10 and 11. In both figures, the reference samples and single background sample form a generally linear trend with a positive slope. The reference samples with high chromium concentrations exhibit proportionally higher iron and aluminum, and lie on the trend formed by the other samples. Chromium detected in these samples is associated with suspended particulates (such as clays and iron oxides) at a relatively constant ratio, and is natural. Parcel 233(7) sample KZ3004, however, contains the highest chromium of all the samples depicted on the plot, but contains only moderate iron and aluminum and lies above the trends formed by the other samples. There may be a component of contamination in this sample.

#### Conclusion

The chromium concentration in groundwater sample KZ3004 is anomalously high relative to the iron and aluminum concentrations, and may contain a component of contamination.

#### **Nickel**

Nickel was detected in the site groundwater sample at a concentration of 0.0704 J mg/L. Comparison to background is hindered by the high percentage of nondetects in the background data set, so the reference data employed in the chromium evaluation (above) were also used in the evaluation of nickel. A plot of nickel versus iron reveals a linear trend with a shallow positive slope for the reference samples and single background sample (Figure 12). This linear correlation is expected due to the high affinity for nickel adsorption on iron oxides. The reference samples with high nickel concentrations exhibit proportionally higher iron, and lie on the trend formed by the other samples. Nickel detected in these samples is associated with suspended iron oxides at a relatively constant ratio, and is natural. Parcel 233(7) sample KZ3004, however, contains the highest nickel of all the samples depicted on the plot, but contains only moderate iron (as well as only moderate aluminum) and lies above the linear trend. There may be a component of contamination in this sample.

#### Conclusion

The nickel concentration in groundwater sample KZ3004 is anomalously high relative to the iron concentration, and may contain a component of contamination.

### **5.0 Summary**

This section summarizes the results of the geochemical evaluations of selected elements in soil and groundwater samples from Parcel 233(7).

**Soil.** Geochemical evaluation indicates that all of the barium, beryllium, cadmium, cobalt, copper, iron, manganese, nickel, potassium, and zinc concentrations detected in the site surface and subsurface soil samples are naturally occurring.

**Groundwater.** Geochemical evaluation indicates that the chromium and nickel concentrations detected in groundwater sample KZ3004 are anomalously high relative to the reference element concentrations, and may contain a component of contamination.

## **6.0 References**

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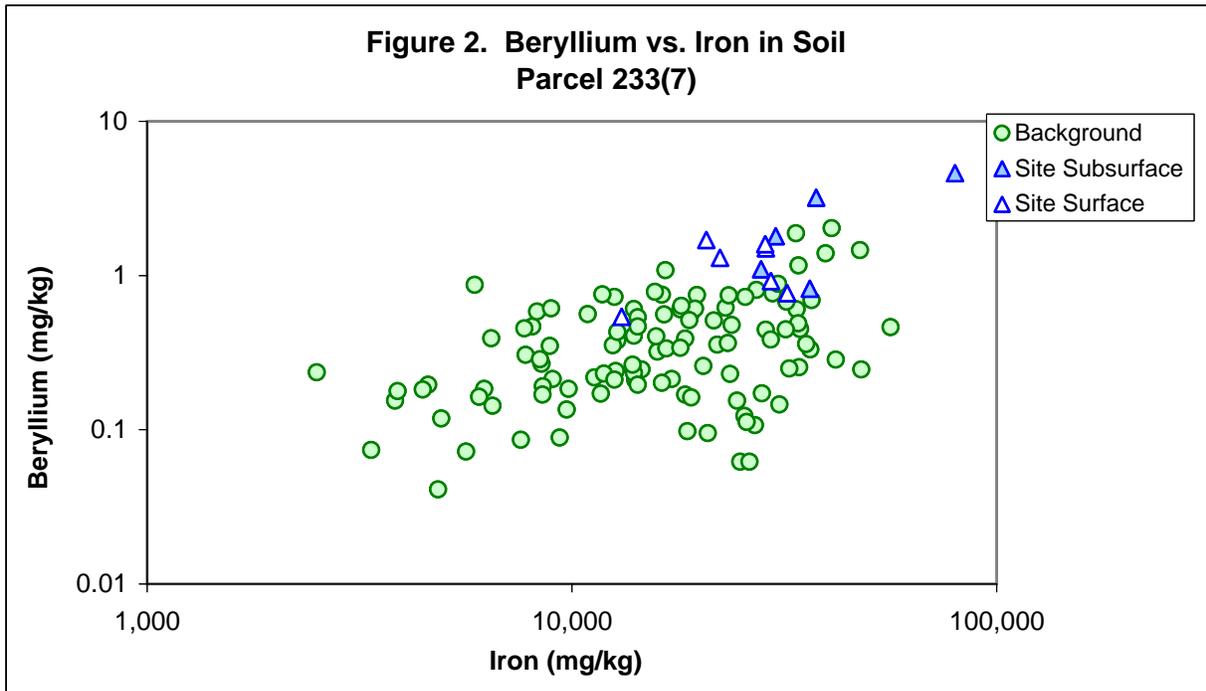
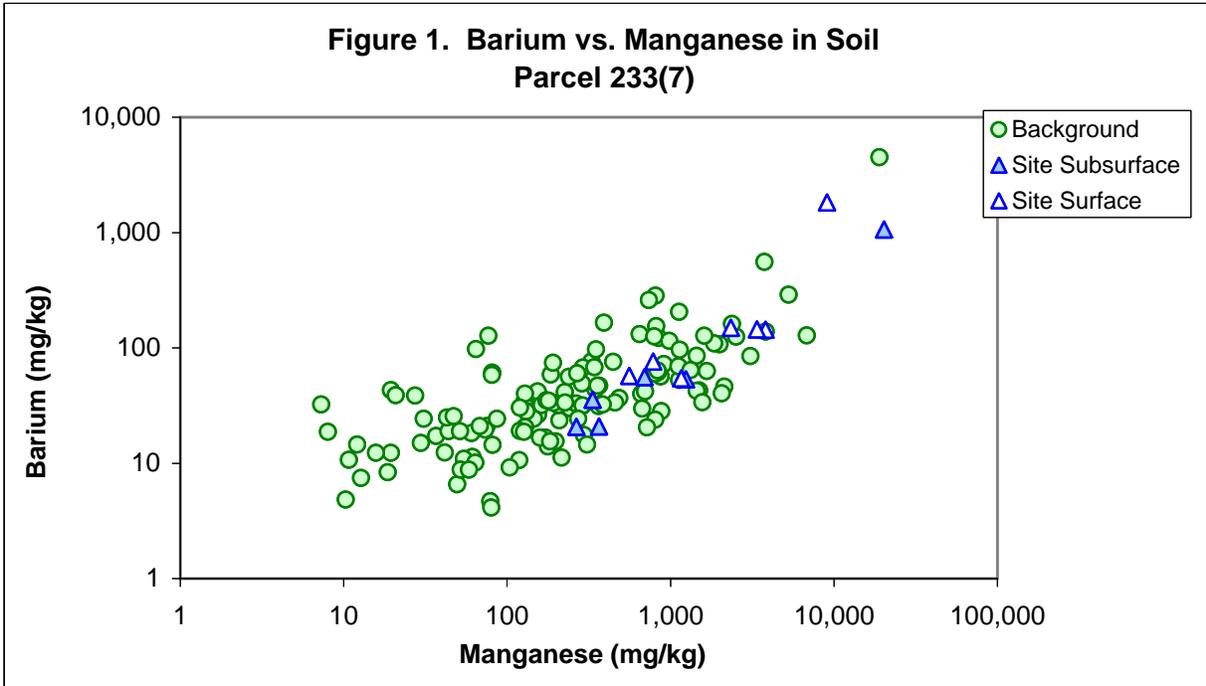
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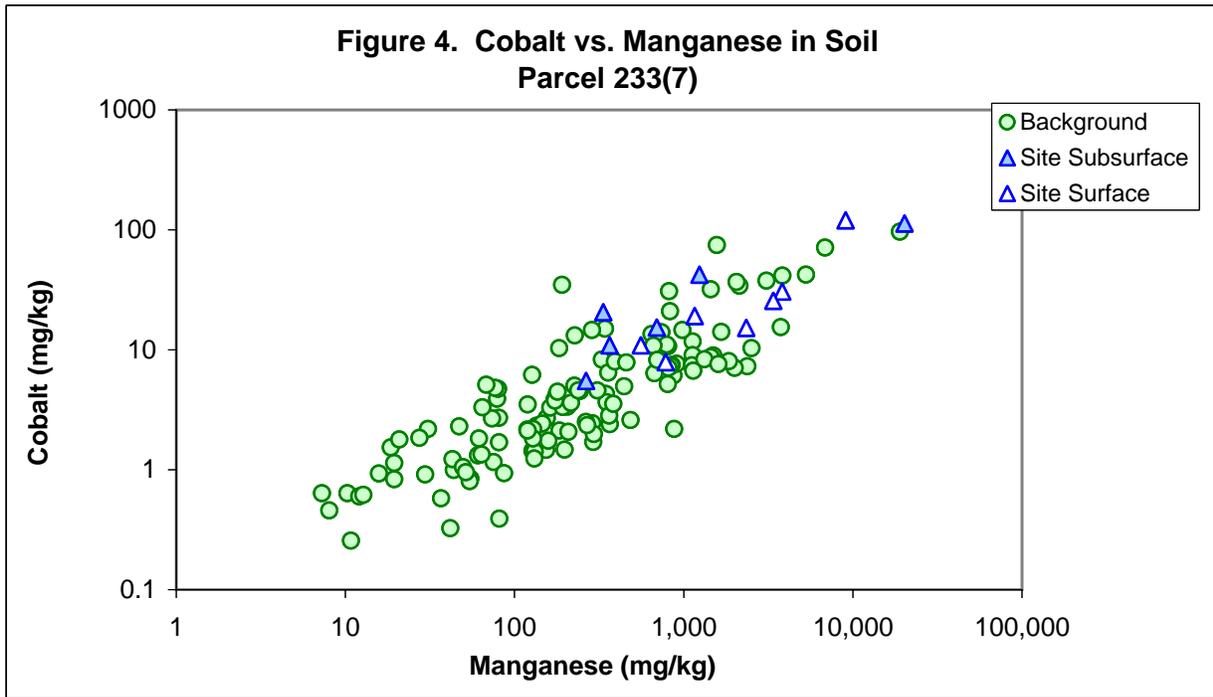
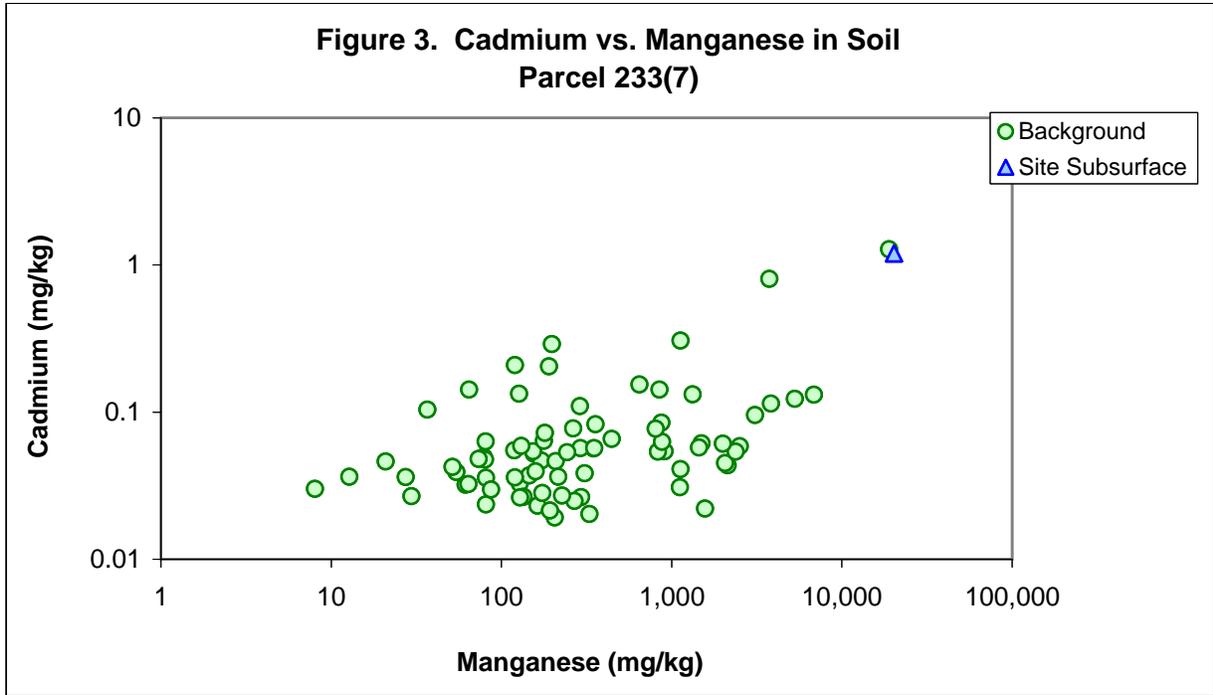
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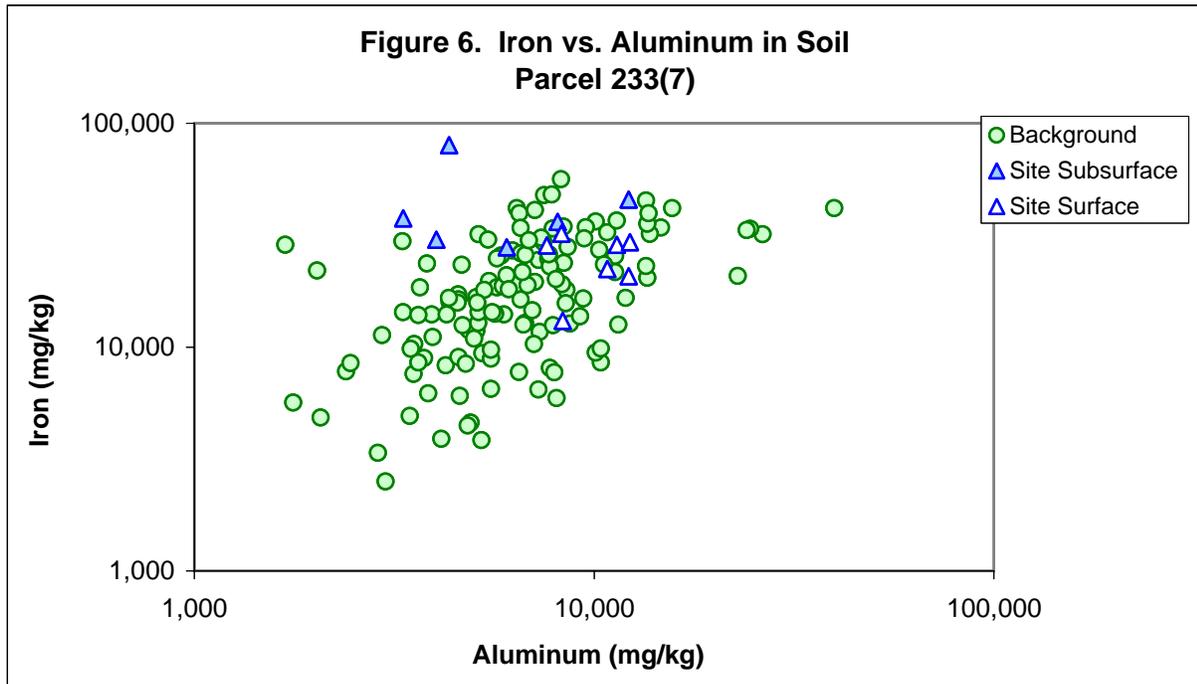
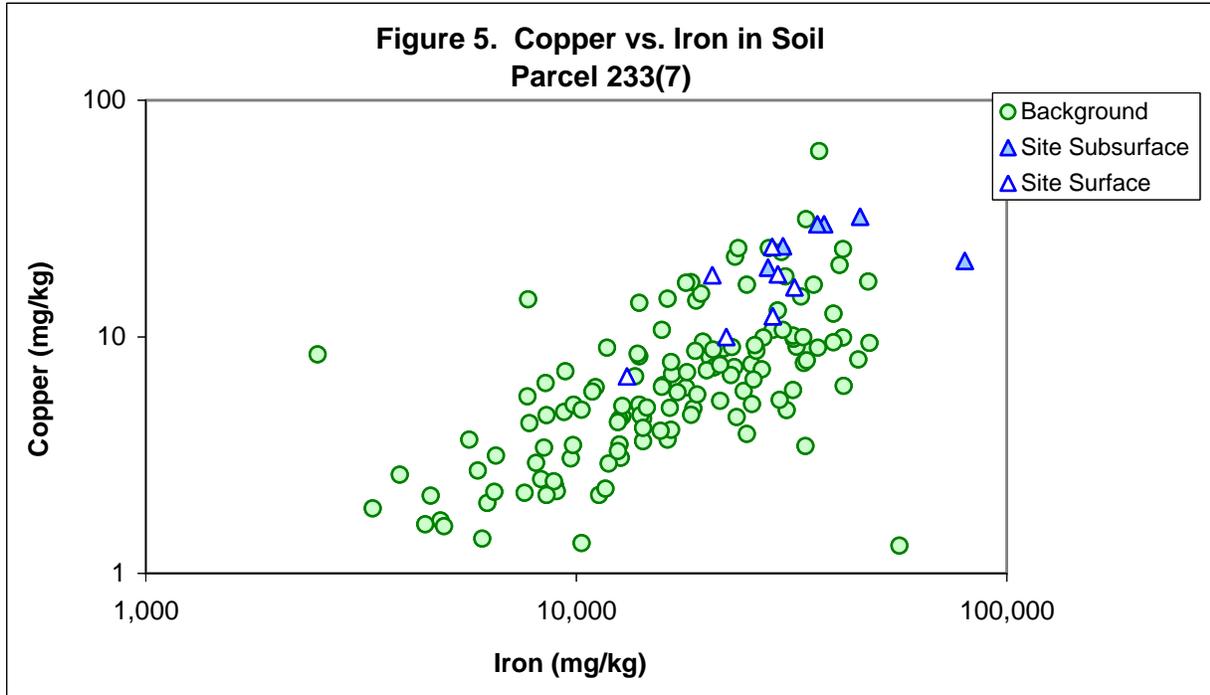
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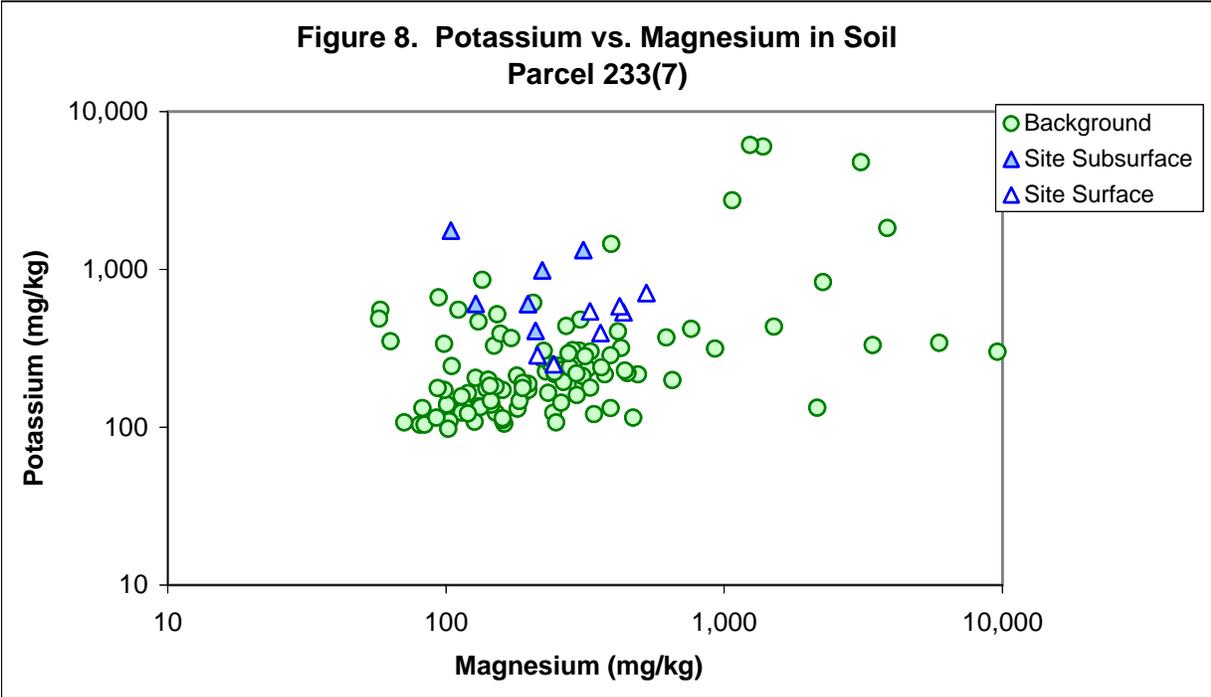
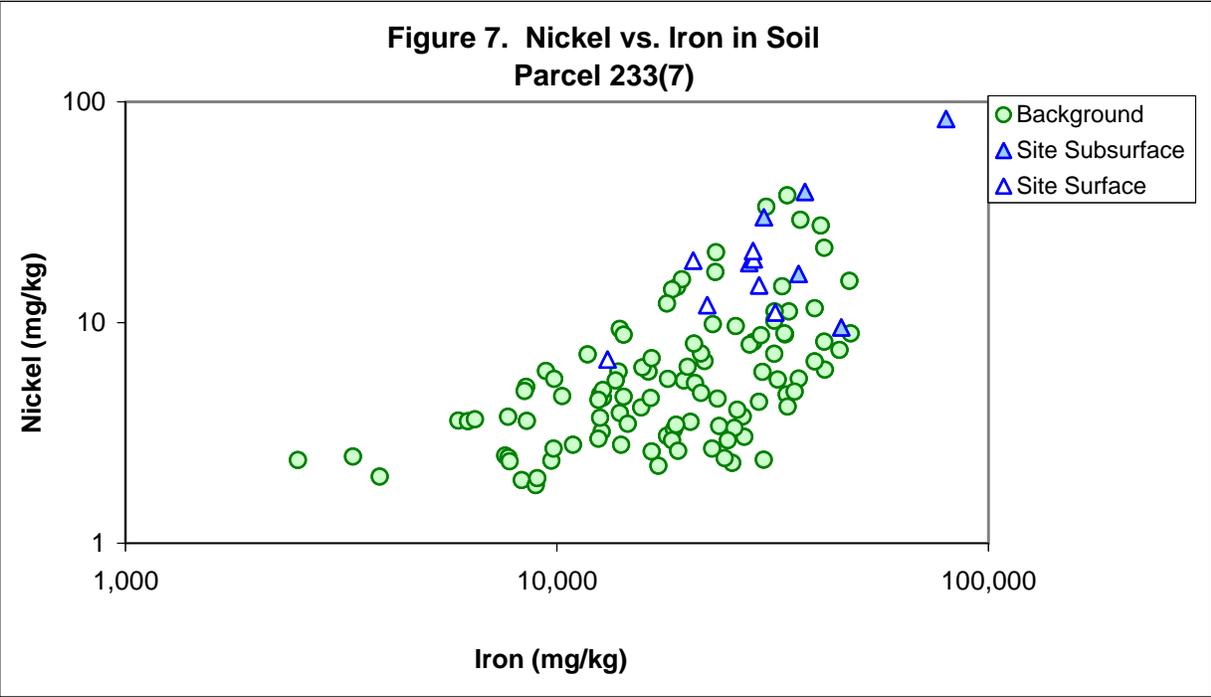
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**ATTACHMENT 1**



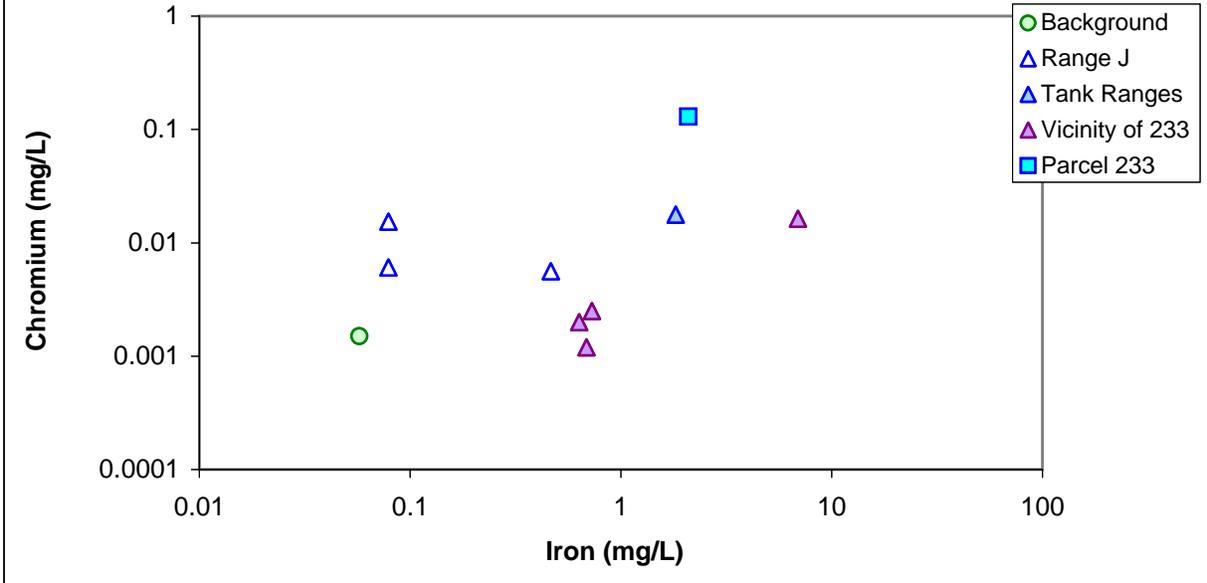




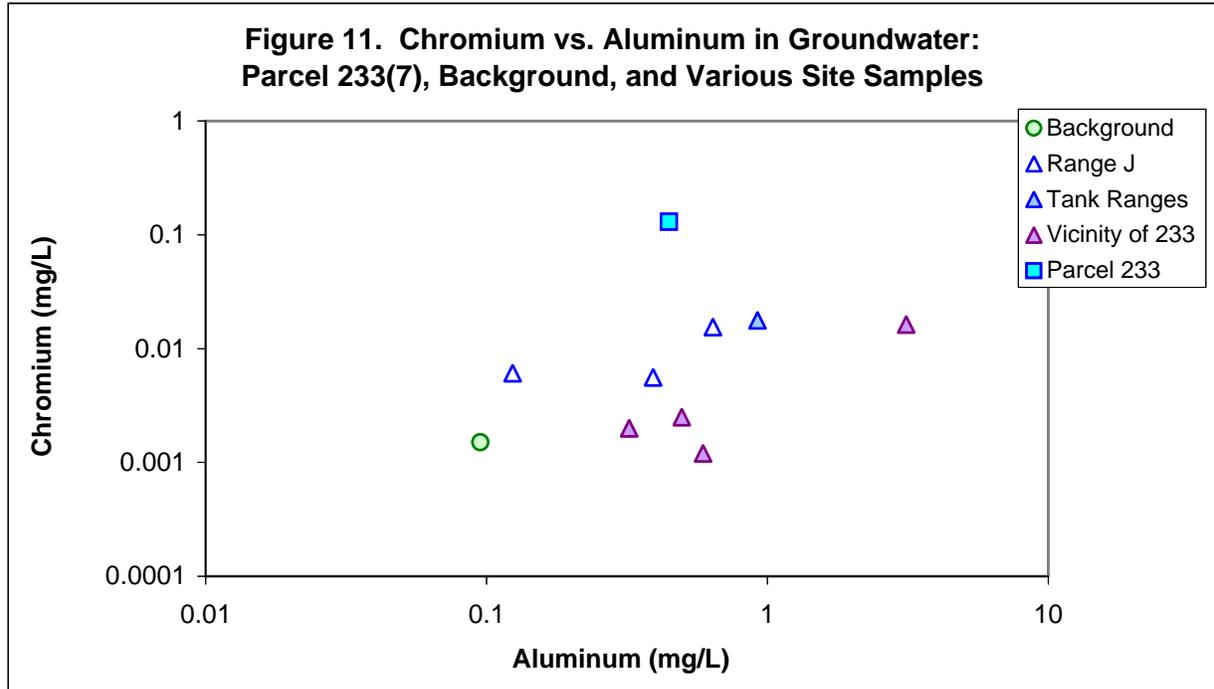




**Figure 10. Chromium vs. Iron in Groundwater:  
Parcel 233(7), Background, and Various Site Samples**



**Figure 11. Chromium vs. Aluminum in Groundwater:  
Parcel 233(7), Background, and Various Site Samples**



**Figure 12. Nickel vs. Iron in Groundwater:  
Parcel 233(7), Background, and Various Site Samples**

