

**APPENDIX G**

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

**STATISTICAL  
(TIERS 1 AND 2)**

# **Statistical Comparison of Site and Background Data Sinkholes at Pelham Range Fort McClellan, Alabama**

## **1.0 Introduction**

This report provides the Tier 1 and Tier 2 site-to-background comparison results for the Sinkholes at Pelham Range at Fort McClellan in Calhoun County, Alabama. Tier 1 and Tier 2 evaluations (Shaw E & I, 2003) have been performed on the surface soil and subsurface soil 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, the Wilcoxon Rank Sum Test (WRS), and Hot Measurement Test.

The methodology and results of the Tier 1 and Tier 2 comparisons are summarized in Tables 1 and 2, and described in more detail in the following sections. Site samples collected and used in the site-to-background comparison include 7 surface soil samples (0 to 1 foot below ground surface [bgs]) and 11 subsurface soil samples (1 to 8 feet bgs).

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

## **2.0 Comparison Methodology**

This section describes the statistical techniques that were employed in the Sinkholes at Pelham Range 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 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  
Sinkholes at Pelham Range  
Fort McClellan, Calhoun County, Alabama**

<b>Metals</b>	Frequency of Detection	Tier 1 Evaluation <sup>a</sup>	Slippage Test <sup>b</sup>	Wilcoxon Rank Sum Test <sup>b</sup>	Hot Measurement Test <sup>b,c</sup>	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	7 / 7	Failed	Passed	Failed	NA	Yes
Antimony	0 / 7	NA	NA	NA	NA	
Arsenic	7 / 7	Passed	NA	NA	NA	
Barium	7 / 7	Failed	Passed	Failed	NA	Yes
Beryllium	5 / 7	Failed	Passed	Passed	NA	
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	Passed	NA	
Copper	7 / 7	Failed	Passed	Failed	NA	Yes
Iron	7 / 7	Passed	NA	NA	NA	
Lead	7 / 7	Failed	Passed	Failed	NA	Yes
Magnesium	7 / 7	Passed	NA	NA	NA	
Manganese	7 / 7	Passed	NA	NA	NA	
Mercury	6 / 7	Failed	Passed	NA <sup>d</sup>	Failed	Yes
Nickel	7 / 7	Failed	Passed	Failed	NA	Yes
Potassium	6 / 7	Passed	NA	NA	NA	
Selenium	4 / 7	Failed	Passed	NA <sup>d</sup>	Failed	Yes
Silver	0 / 7	NA	NA	NA	NA	
Sodium	2 / 7	Passed	NA	NA	NA	
Thallium	0 / 7	NA	NA	NA	NA	
Vanadium	7 / 7	Passed	NA	NA	NA	
Zinc	7 / 7	Failed	Passed	Failed	NA	Yes

NA = not applicable; MDC = maximum detected concentration; UTL = upper tolerance limit

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

Table 2

Summary of Tier 1 and Tier 2 Site to Background Comparison for Subsurface Soil  
Sinkholes at Pelham Range  
Fort McClellan, Calhoun County, Alabama

Metals	Frequency of Detection	Tier 1 Evaluation <sup>a</sup>	Slippage Test <sup>b</sup>	Wilcoxon Rank Sum Test <sup>b</sup>	Hot Measurement Test <sup>b,c</sup>	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	11 / 11	Failed	Passed	Failed	NA	Yes
Antimony	0 / 11	NA	NA	NA	NA	
Arsenic	11 / 11	Failed	Passed	Failed	NA	Yes
Barium	11 / 11	Passed	NA	NA	NA	
Beryllium	9 / 11	Passed	NA	NA	NA	
Cadmium	0 / 11	NA	NA	NA	NA	
Calcium	11 / 11	Passed	NA	NA	NA	
Chromium	11 / 11	Passed	NA	NA	NA	
Cobalt	11 / 11	Passed	NA	NA	NA	
Copper	11 / 11	Failed	Passed	Failed	NA	Yes
Iron	11 / 11	Passed	NA	NA	NA	
Lead	11 / 11	Passed	NA	NA	NA	
Magnesium	11 / 11	Failed	Passed	Failed	NA	Yes
Manganese	11 / 11	Passed	NA	NA	NA	
Mercury	8 / 11	Passed	NA	NA	NA	
Nickel	11 / 11	Failed	Passed	Failed	NA	Yes
Potassium	11 / 11	Failed	Passed	Failed	NA	Yes
Selenium	3 / 11	Failed	NA <sup>e</sup>	NA <sup>d</sup>	Failed	Yes
Silver	0 / 11	NA	NA	NA	NA	
Sodium	2 / 11	Passed	NA	NA	NA	
Thallium	0 / 11	NA	NA	NA	NA	
Vanadium	11 / 11	Failed	Passed	Passed	NA	
Zinc	11 / 11	Failed	Passed	Failed	NA	Yes

NA = not applicable; MDC = maximum detected concentration; UTL = upper tolerance limit

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 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.

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  $K \leq K_c$ , 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 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 75<sup>th</sup> percentile and the bottom of the box represents the 25<sup>th</sup> 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 95<sup>th</sup> upper tolerance limit (95<sup>th</sup> UTL) is recommended as a screening value for normally or lognormally distributed analytes and the 95<sup>th</sup> 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 95<sup>th</sup> UTL or 95<sup>th</sup> 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 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 separately.

## **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 Sinkholes at Pelham Range surface soil and subsurface soil samples. Tables 1 and 2 summarize the Tier 1 and Tier 2 test results for each media as discussed in the following sections, and the box plots discussed are provided in Attachment 1.

### **3.1 Surface Soil**

Twenty-three TAL metals were evaluated in the surface soil data set from Sinkholes at Pelham Range. Four metals (antimony, cadmium, silver, and thallium) have no detected concentrations in surface soil, so no further discussion of these metals is included.

Nine metals (arsenic, calcium, chromium, iron, magnesium, manganese, potassium, sodium, and vanadium) have no detected concentrations above their respective background screening values, passing the Tier 1 evaluation. These metals are not tested or discussed further. The remaining 10 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

Two site samples exceed the background screening value of 16,306 mg/kg.

#### Tier 2 Evaluation

##### Slippage Test

The critical value,  $K_c$ , for aluminum is 2. No site samples exceed the maximum background measurement ( $K = 0$ ). Because  $K < K_c$ , aluminum passes the Slippage test.

##### WRS Test

The p-level of 0.029 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 1-1). The site maximum is lower than that of background.

### Conclusion

Because aluminum in surface 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 123.94 mg/kg.

### Tier 2 Evaluation

#### 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 0.034 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 1-1). The site maximum is lower than that of background.

### 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

One site sample exceeds the background screening value of 0.8 mg/kg.

### Tier 2 Evaluation

#### Slippage Test

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

#### WRS Test

The WRS test p-level of 0.83 indicates excellent agreement between the site and background distributions.

### Box Plot

The site 25<sup>th</sup> percentile, median, and maximum are less than the corresponding background values (Figure 1-2). The site and background 75<sup>th</sup> percentiles are similar, and the site minimum is higher than that of background.

### Conclusion

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

### **Cobalt**

#### Tier 1 Evaluation

One site sample exceeds the background screening value of 15.15 mg/kg.

#### Tier 2 Evaluation

##### Slippage Test

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

##### WRS Test

The p-level of 0.43 indicates good agreement between the site and background distributions.

##### Box Plot

The site median is just slightly higher than that of background (Figure 1-2). The site minimum and 25<sup>th</sup> percentile are higher than the corresponding background values. The site maximum is lower than that of background, and the site and background 75<sup>th</sup> percentiles are similar.

### Conclusion

Cobalt in surface soil is considered to be within the range of background.

### **Copper**

#### Tier 1 Evaluation

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

#### Tier 2 Evaluation

##### 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, interquartile range, and maximum are higher than the corresponding background values (Figure 1-3).

### 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

Two site samples exceed the background screening value of 40.05 mg/kg.

### Tier 2 Evaluation

#### Slippage Test

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

#### WRS Test

The p-level of 0.196 indicates weak agreement between the site and background distributions.

#### Box Plot

The site minimum and interquartile range are higher than the corresponding background range (Figure 1-3). The site and background maximums appear to be the same.

#### Conclusion

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

## **Mercury**

### Tier 1 Evaluation

Three site samples exceed the background screening value of 0.08 mg/kg.

### Tier 2 Evaluation

#### 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 is not performed because the background data set contains 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 high 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 of mercury exceeds the 95<sup>th</sup> percentile of 0.125 mg/kg.

#### Conclusion

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

## **Nickel**

### Tier 1 Evaluation

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

### Tier 2 Evaluation

#### 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 of 0.066 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 1-4). The site maximum is lower than that of background.

#### Conclusion

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

## **Selenium**

### Tier 1 Evaluation

Four site samples exceed the background screening value of 0.48 mg/kg.

### Tier 2 Evaluation

#### Slippage Test

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

#### WRS Test

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

#### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-5). The site maximum is less than that of background. The shape and location of the background box plot are influenced by the high percentage of nondetects (99 percent), and the replacement values of one-half the reporting limit rather than detected concentrations.

#### Hot Measurement Test

The site MDC of selenium exceeds the background 95<sup>th</sup> 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.

## **Zinc**

### Tier 1 Evaluation

Three site samples exceed the background screening value of 40.64 mg/kg.

### Tier 2 Evaluation

#### 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 0.01 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 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 the Sinkholes at Pelham Range subsurface soil. Four metals (antimony, cadmium, silver, and thallium) had no detected concentrations in subsurface soil. No further discussion of these metals is included.

Ten metals (barium, beryllium, calcium, chromium, cobalt, iron, lead, manganese, mercury, and sodium) had no detected results that exceed the background screening value. Passing the Tier 1 evaluation, these metals are considered to be within the range of background. They will not be tested or discussed further.

The remaining 9 metals are carried forward for Tier 2 evaluation and the test results are discussed below in detail.

Table 2 summarizes the Tier 1 and Tier 2 evaluation of subsurface soil.

## **Aluminum**

### Tier 1 Evaluation

Four site samples exceed the background screening value of 13,591 mg/kg.

## Tier 2 Evaluation

### Slippage Test

The critical value,  $K_c$ , for aluminum is 2, and one site sample exceeds the maximum background measurement. Because  $K < K_c$ , aluminum 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 1-6).

### Conclusion

Because aluminum in subsurface 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 18.3 mg/kg.

### Tier 2 Evaluation

#### Slippage Test

$K_c$  for arsenic is 2, and 3 site samples exceed the maximum background measurement. Because  $K > K_c$ , arsenic fails the Slippage test.

#### WRS Test

The p-level of 0.16 indicates a weak agreement between the site and background distributions.

#### Box Plot

The site median is slightly higher than that of background (Figure 1-6). The site minimum, 25<sup>th</sup> percentile, 75<sup>th</sup> percentile, and maximum are higher compared to the same background values.

#### Conclusion

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

## **Copper**

### Tier 1 Evaluation

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

### Tier 2 Evaluation

#### 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 of 0.19 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 1-7). 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.

## **Magnesium**

### Tier 1 Evaluation

One site sample exceeds the background screening value of 766.24 mg/kg.

### Tier 2 Evaluation

#### Slippage Test

$K_c$  for magnesium is 2, and no site samples exceed the maximum background measurement. Since  $K < K_c$ , magnesium 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 and interquartile range are higher than the corresponding background values (Figure 1-7). The site maximum is less than that of background.

### Conclusion

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

## **Nickel**

### Tier 1 Evaluation

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

### Tier 2 Evaluation

#### Slippage Test

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

### WRS Test

The p-level of 0.14 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 1-8). The site maximum is less than that of background.

### 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

One site sample exceeds the background screening value of 710.74 mg/kg.

### Tier 2 Evaluation

#### Slippage Test

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

### WRS Test

The p-level of 0.0656 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 1-8). 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

Two site samples exceed the background screening value of 0.47 mg/kg.

### Tier 2 Evaluation

#### Slippage Test

The Slippage test is not performed because the maximum detected background result for selenium is a nondetect.

### WRS Test

The WRS test is not evaluated because the background and site data sets contain more than 50 percent nondetects.

### Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-9). The shapes and locations of the background and site box plots are influenced by the percentage of nondetects (98 percent and 73 percent, respectively) and the replacement values of one-half the reporting limit rather than detected concentrations.

### Hot Measurement Test

The site MDC of selenium exceeds the background 95<sup>th</sup> 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.

## **Vanadium**

### Tier 1 Evaluation

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

### Tier 2 Evaluation

#### Slippage Test

$K_c$  for vanadium is 2, and no site samples exceed the maximum background measurement. Since  $K < K_c$ , vanadium passes the Slippage test.

### WRS Test

The p-level of 0.667 indicates a strong agreement between the site and background distributions.

### Box Plot

The site minimum, 25<sup>th</sup> percentile, median, and maximum are lower than the corresponding background values (Figure 1-9). The site 75<sup>th</sup> percentile is slightly higher than that of background.

### Conclusion

Vanadium in subsurface soil is considered to be within the range of background.

## **Zinc**

### Tier 1 Evaluation

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

### Tier 2 Evaluation

#### Slippage Test

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

### WRS Test

The p-level of 0.027 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 and background maximums are similar.

## Conclusion

Because zinc in subsurface soil 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 samples taken from Sinkholes at Pelham Range and background data sets for 23 elements in surface soil and subsurface soil include 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. For elements with data sets that did not allow for either the Slippage test or WRS test to be performed, the Hot Measurement test was used. Analytes that failed these statistical tests, Tier 2 evaluation, are carried forward for Tier 3 geochemical evaluation to determine if natural processes can explain the elevated concentrations.

Tables 1 and 2 summarize the statistical 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.

Shaw Environmental and Infrastructure (Shaw E&I), 2003, *Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2*, Technical Memorandum, 24 June 2003 by Paul Goetchius.

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

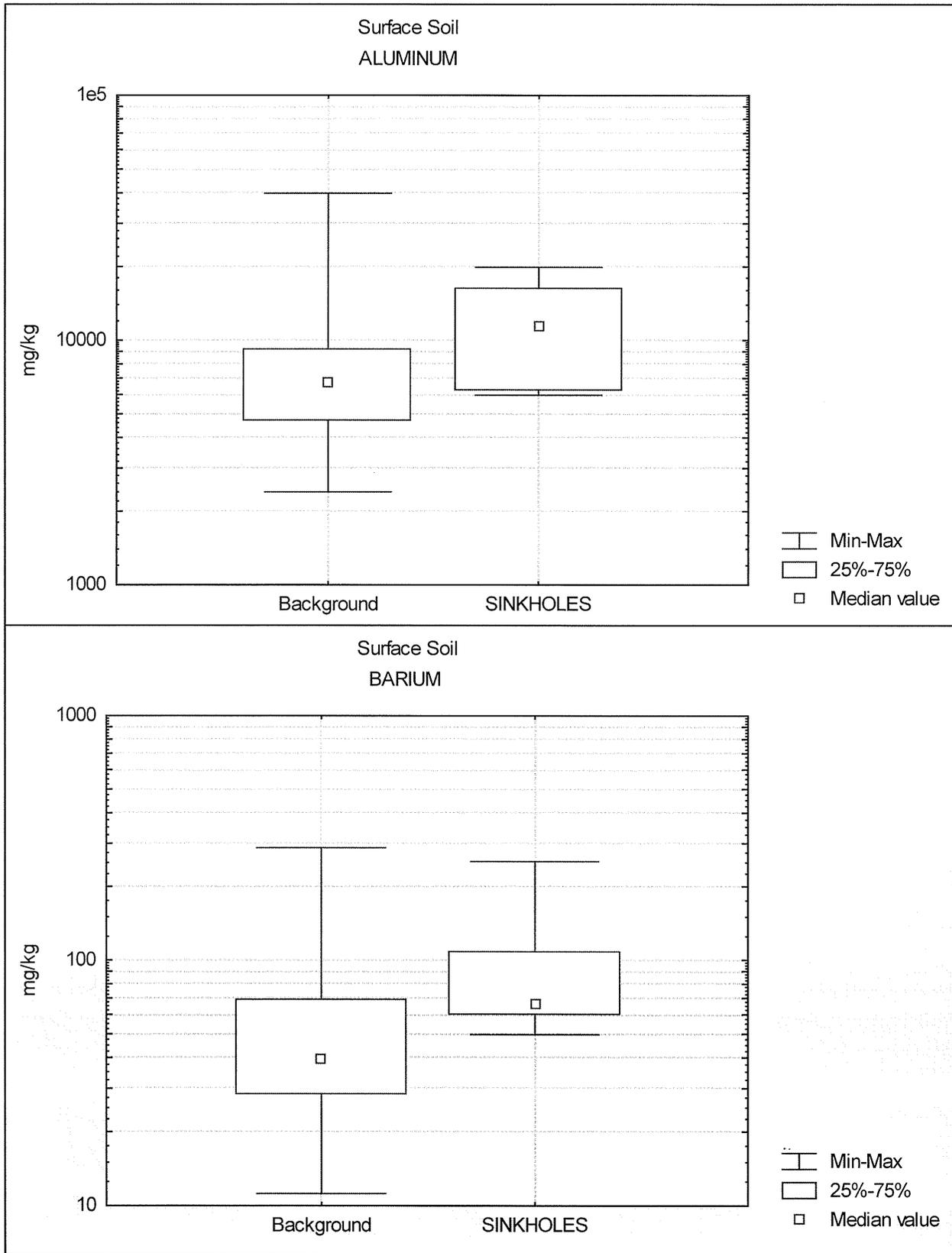


Figure 1-2

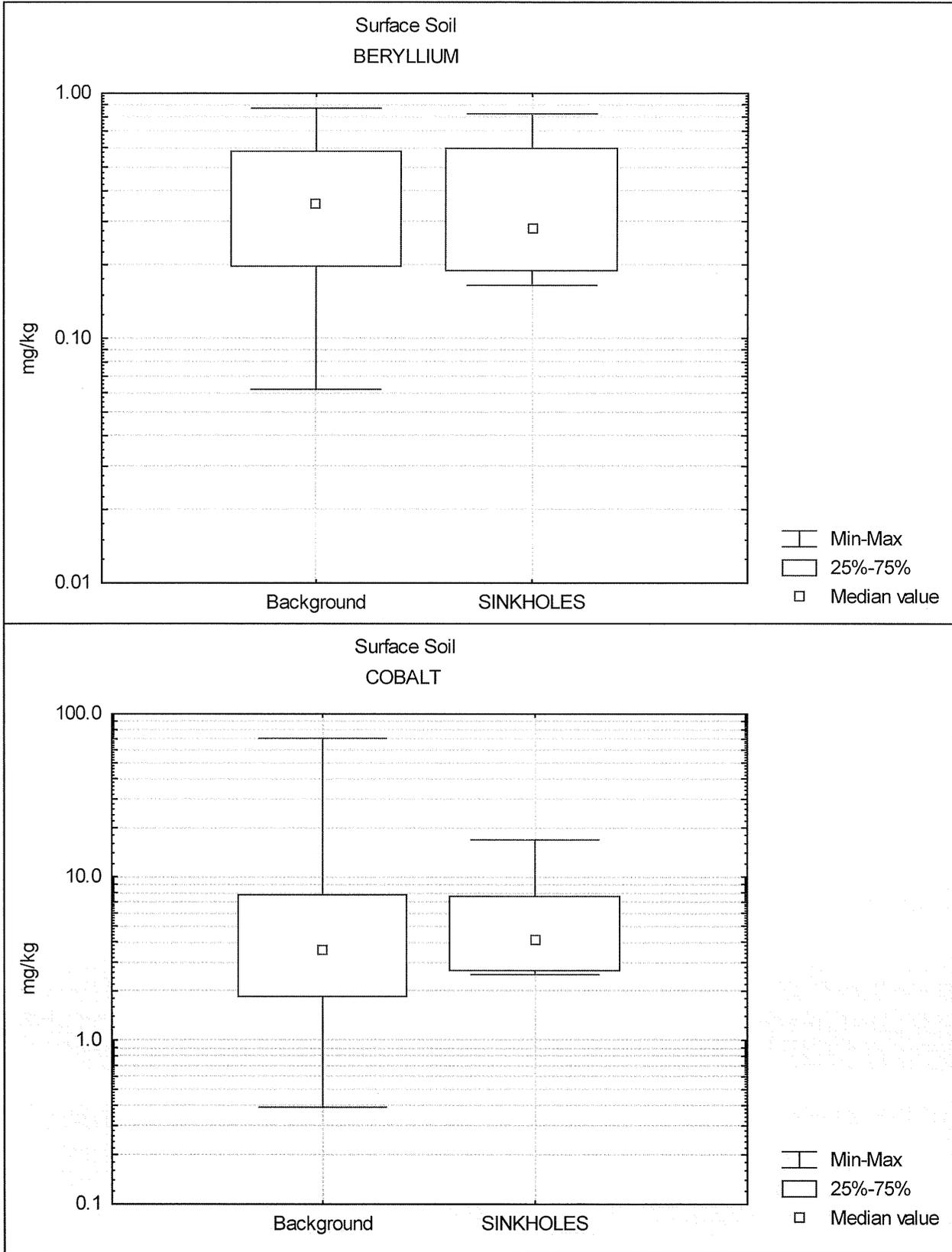


Figure 1-3

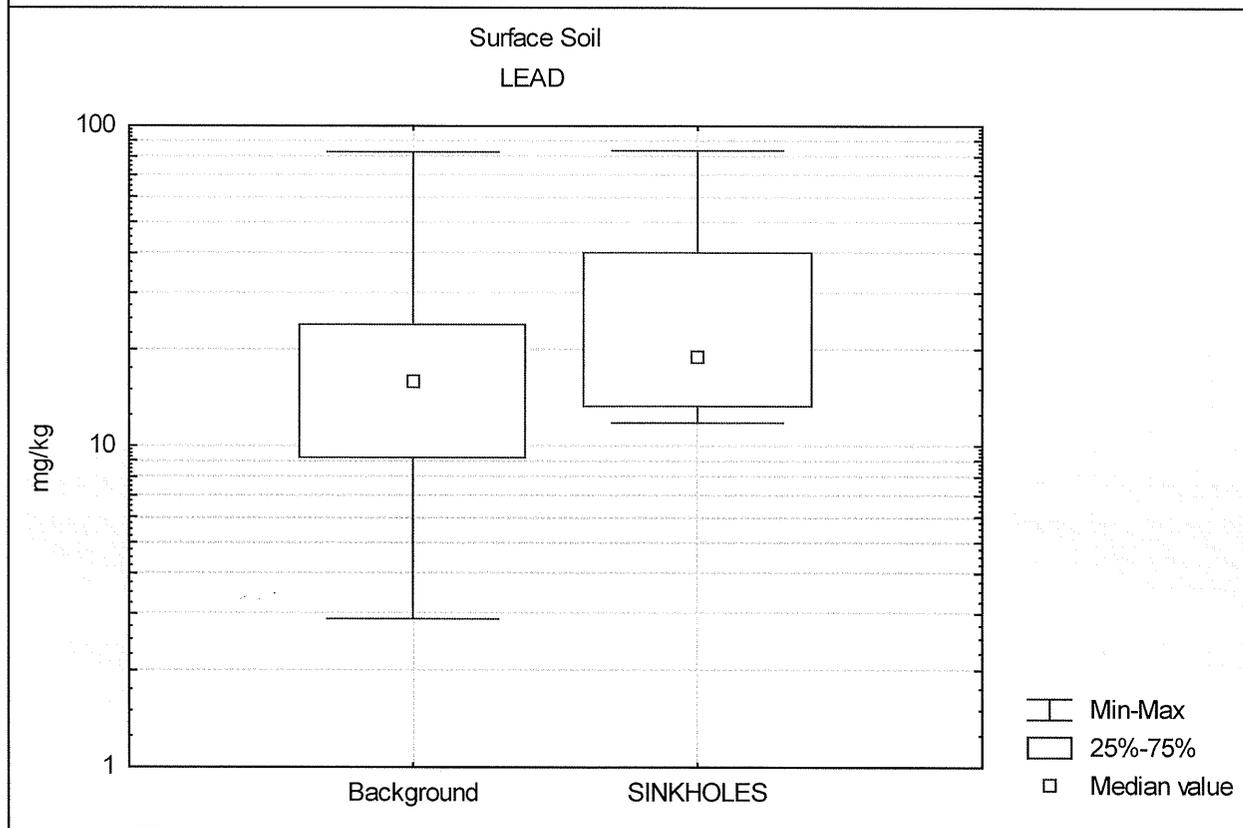
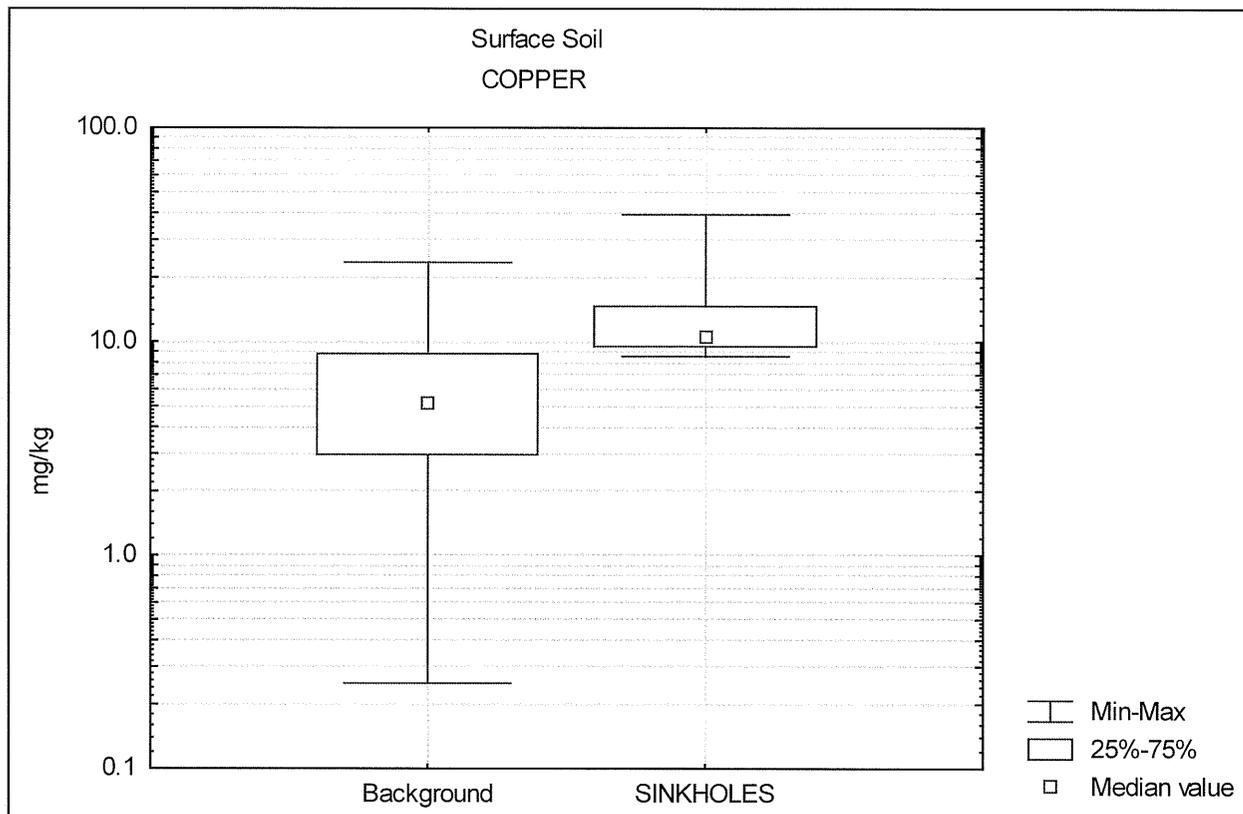


Figure 1-4

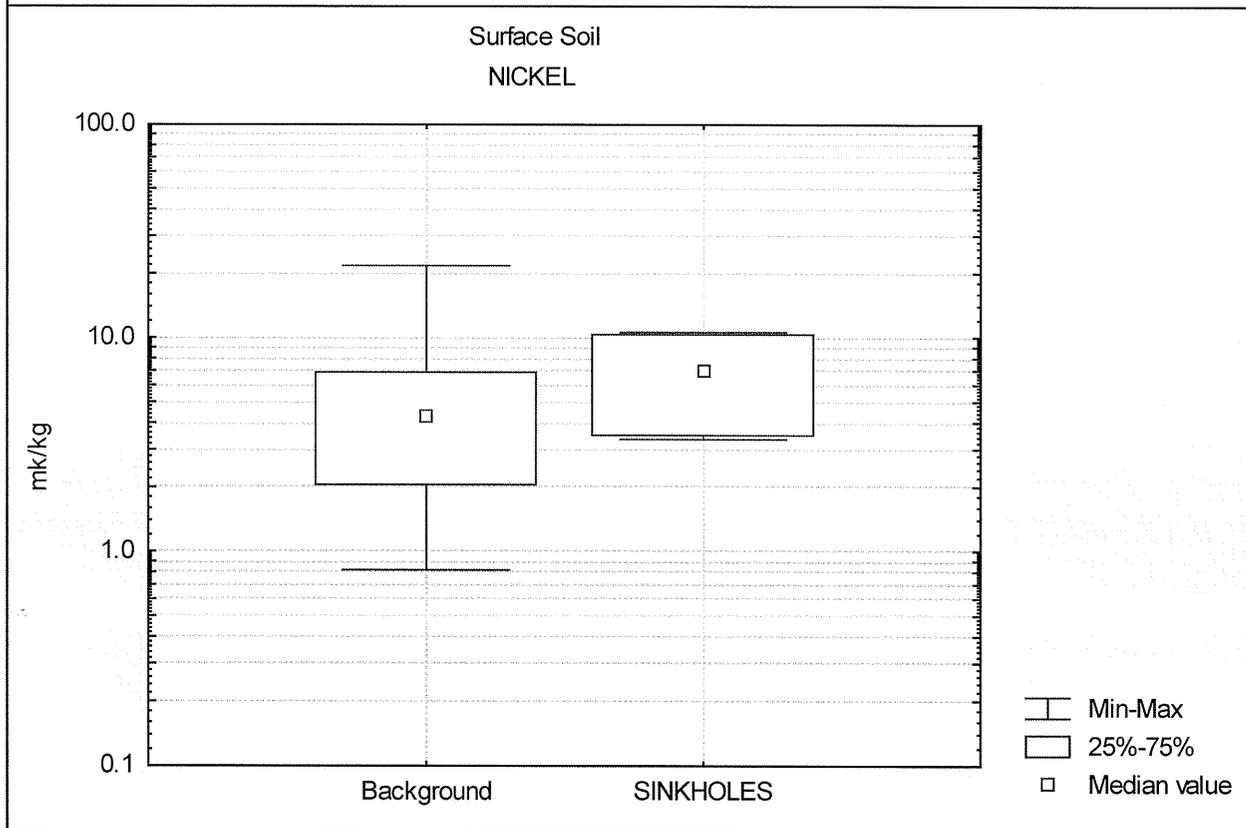
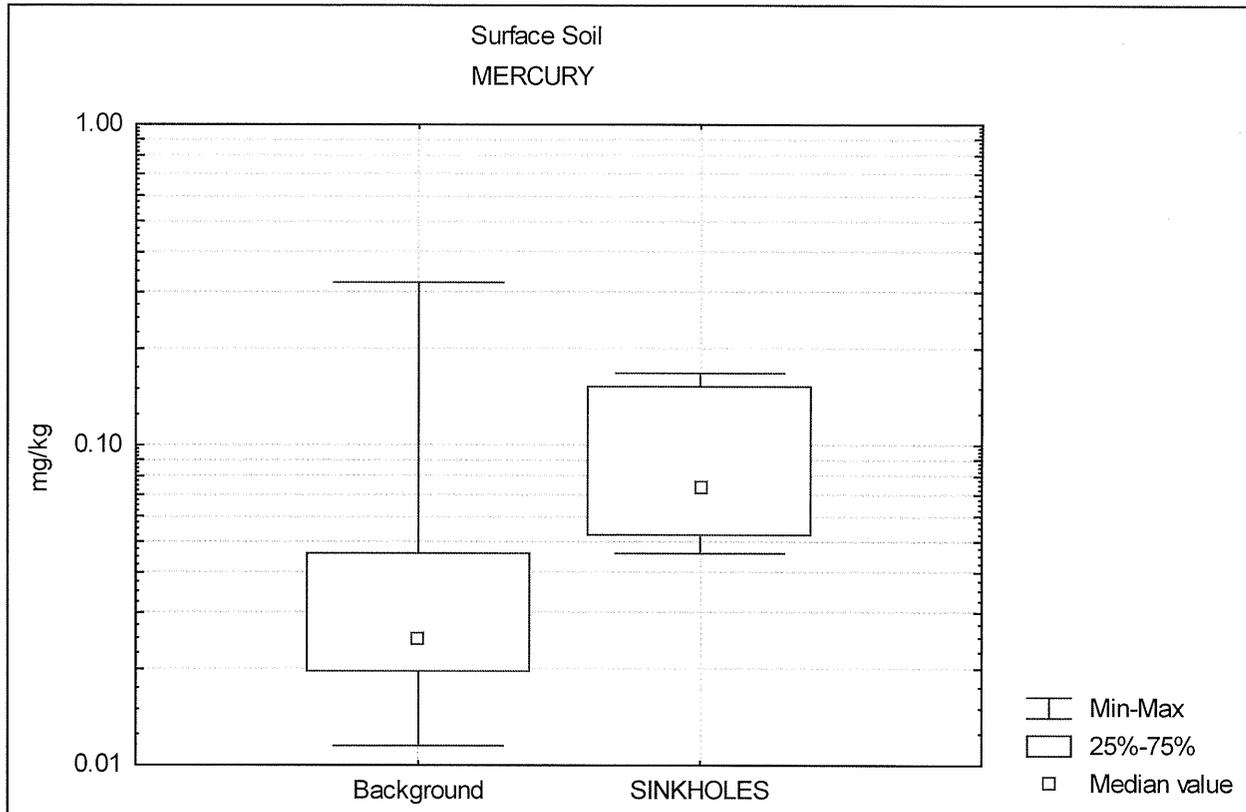


Figure 1-5

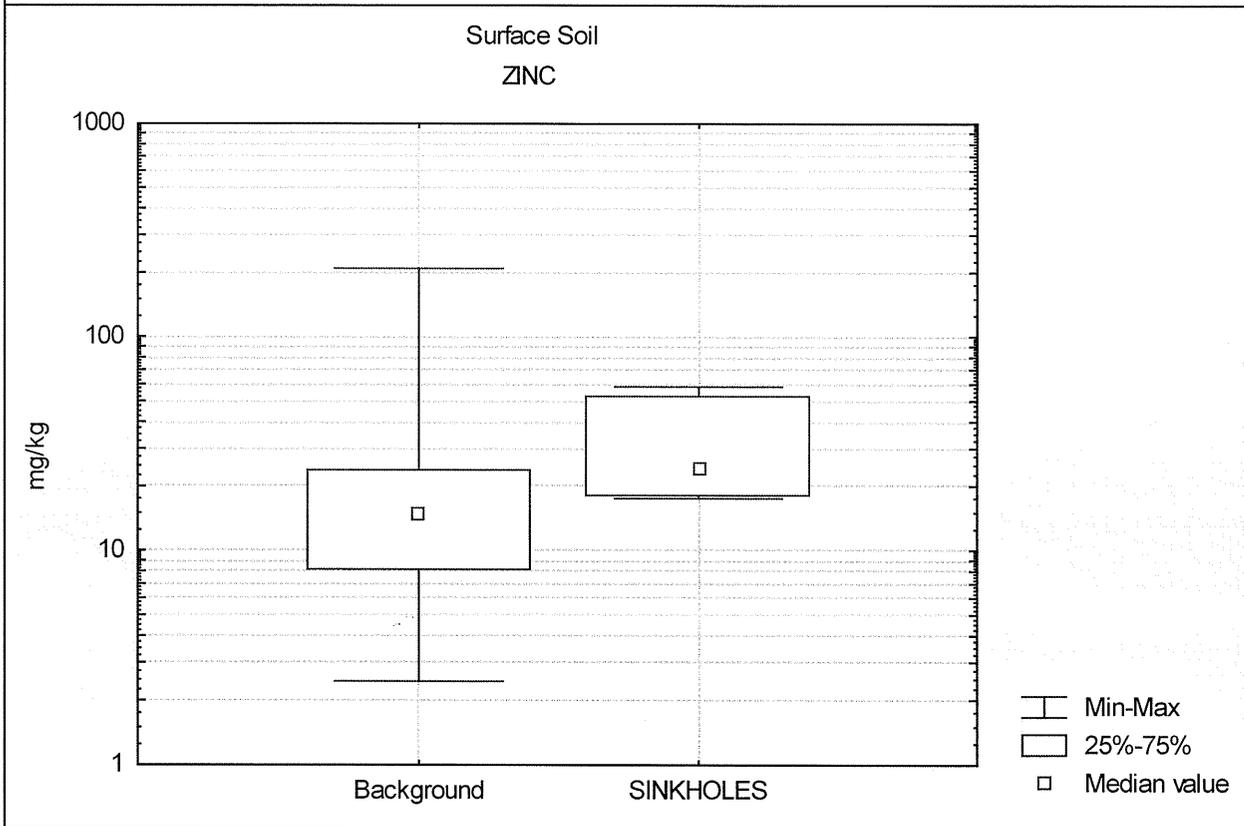
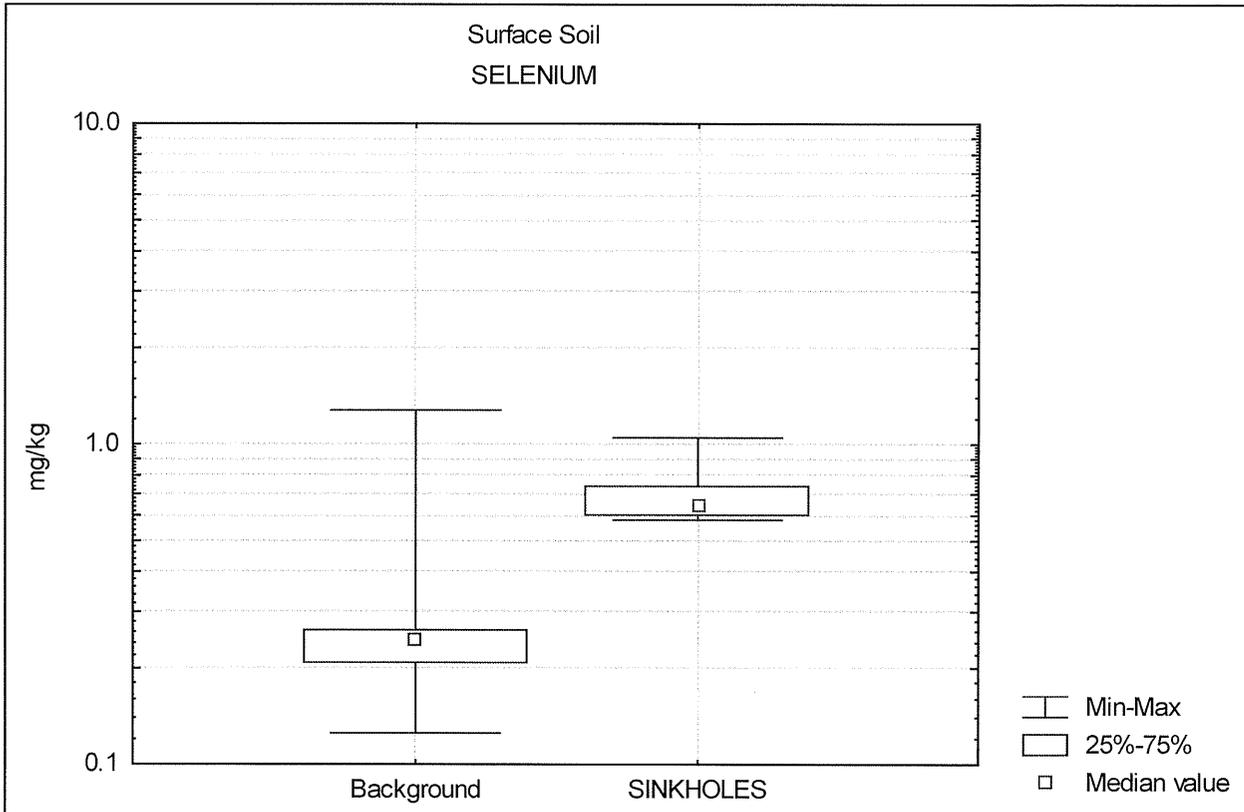


Figure 1-6

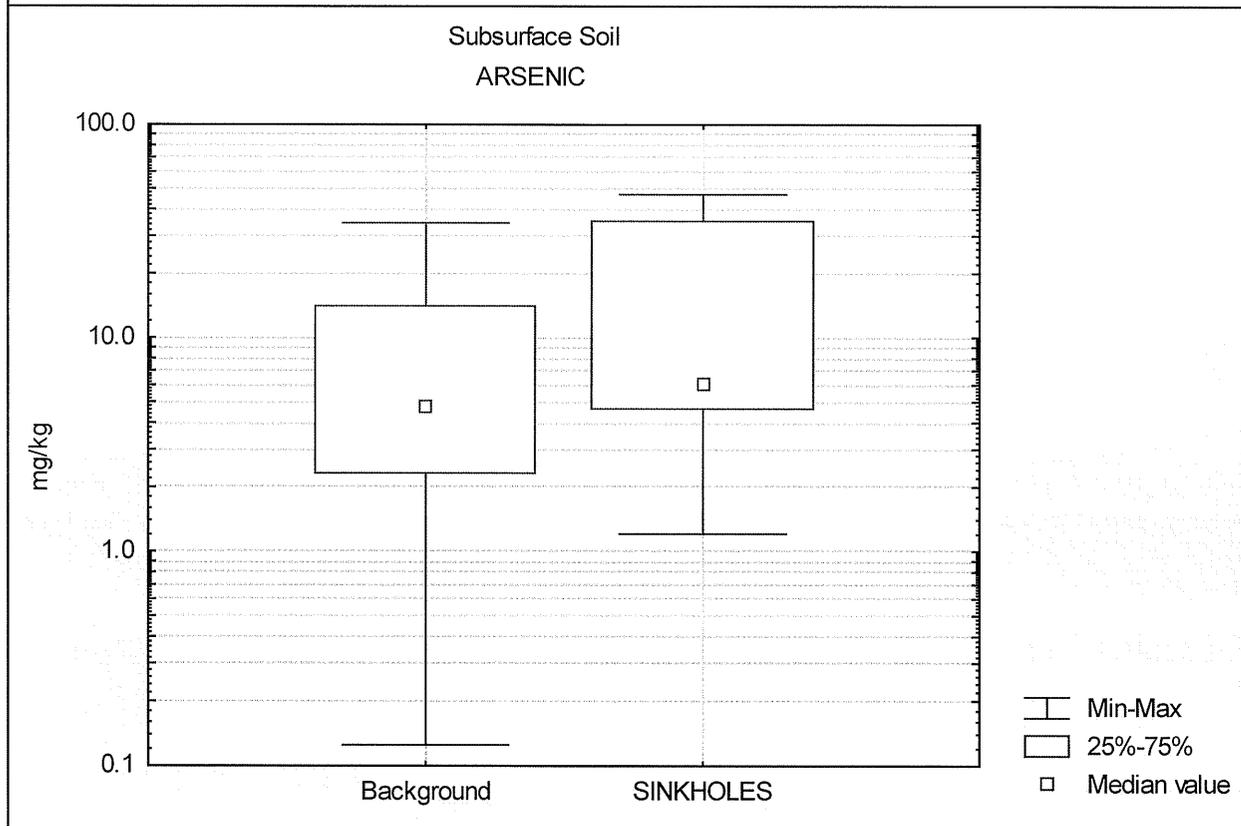
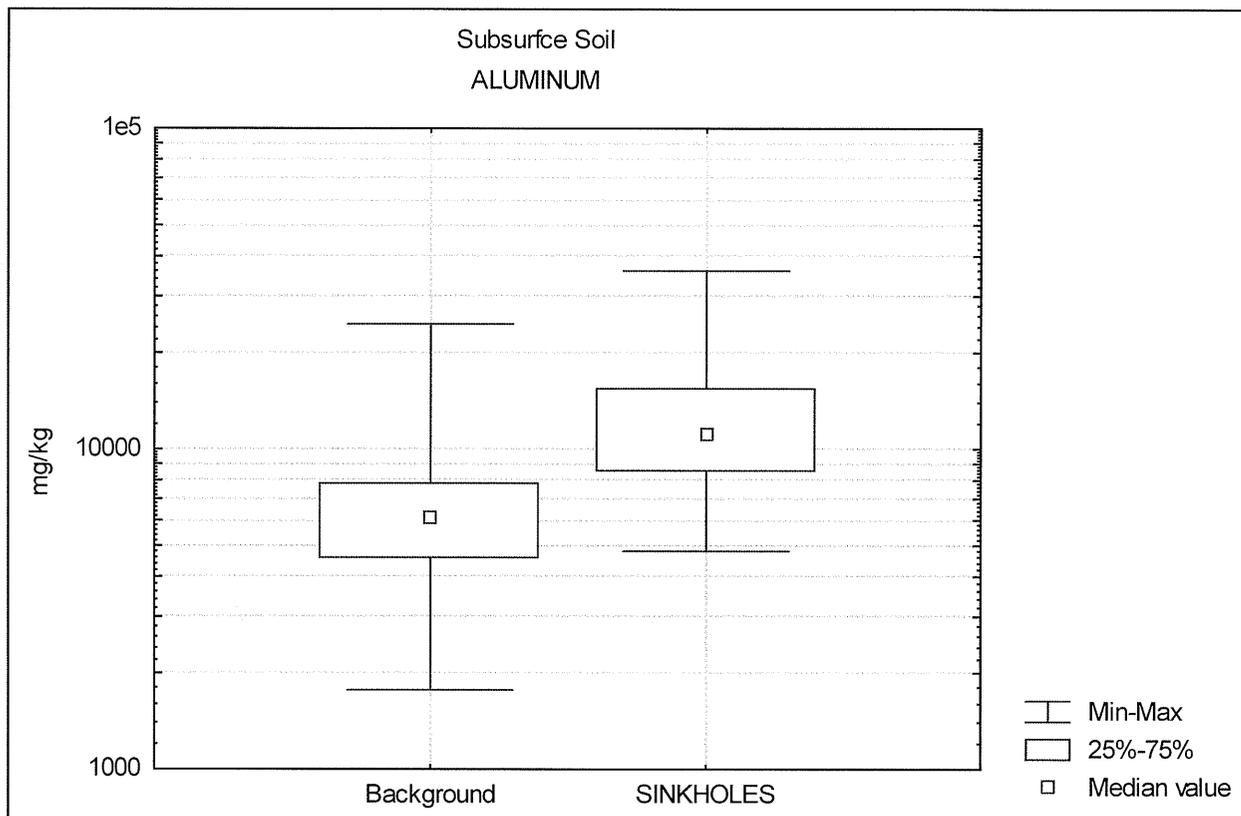


Figure 1-7

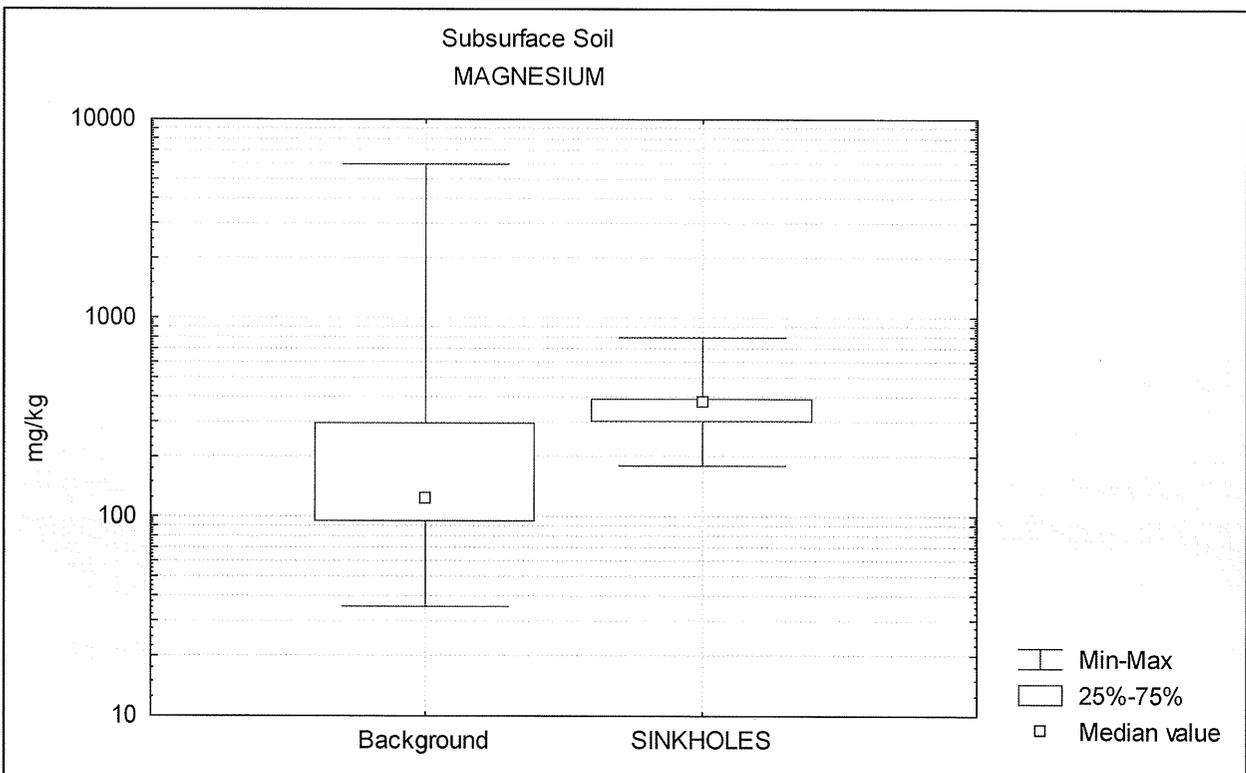
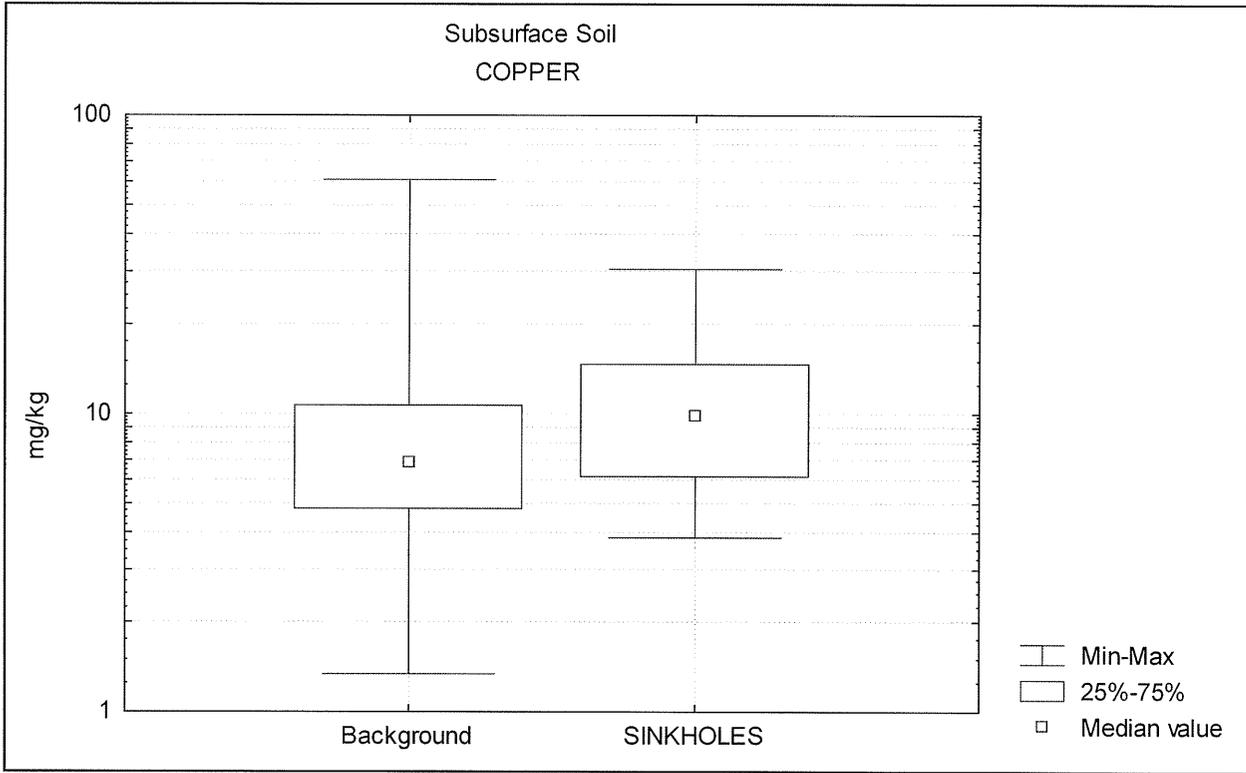


Figure 1-8

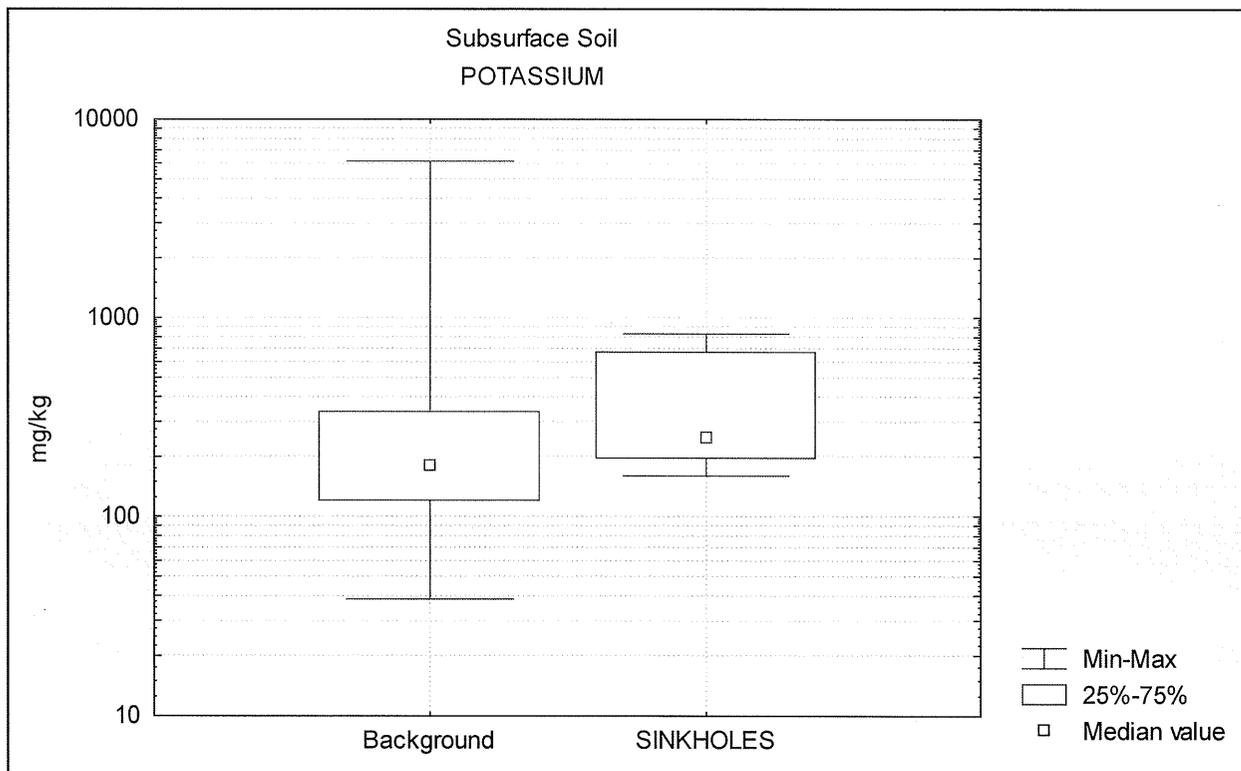
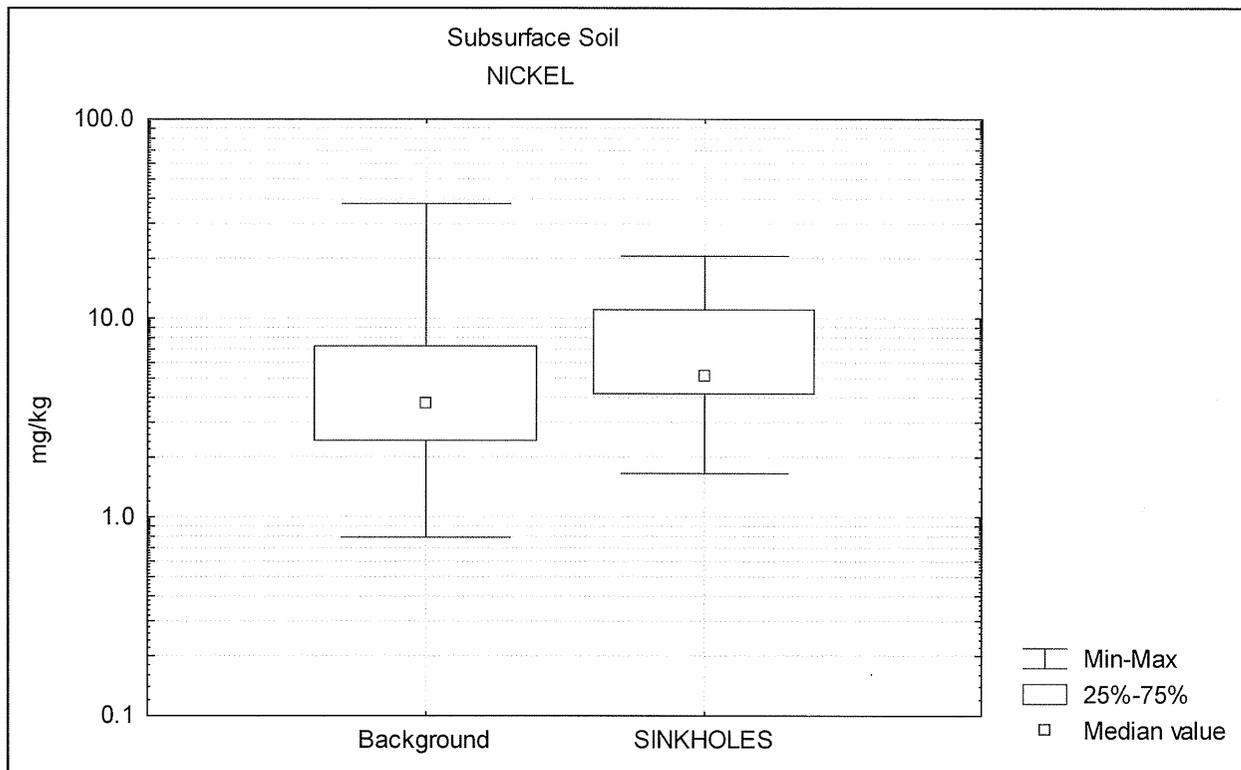


Figure 1-9

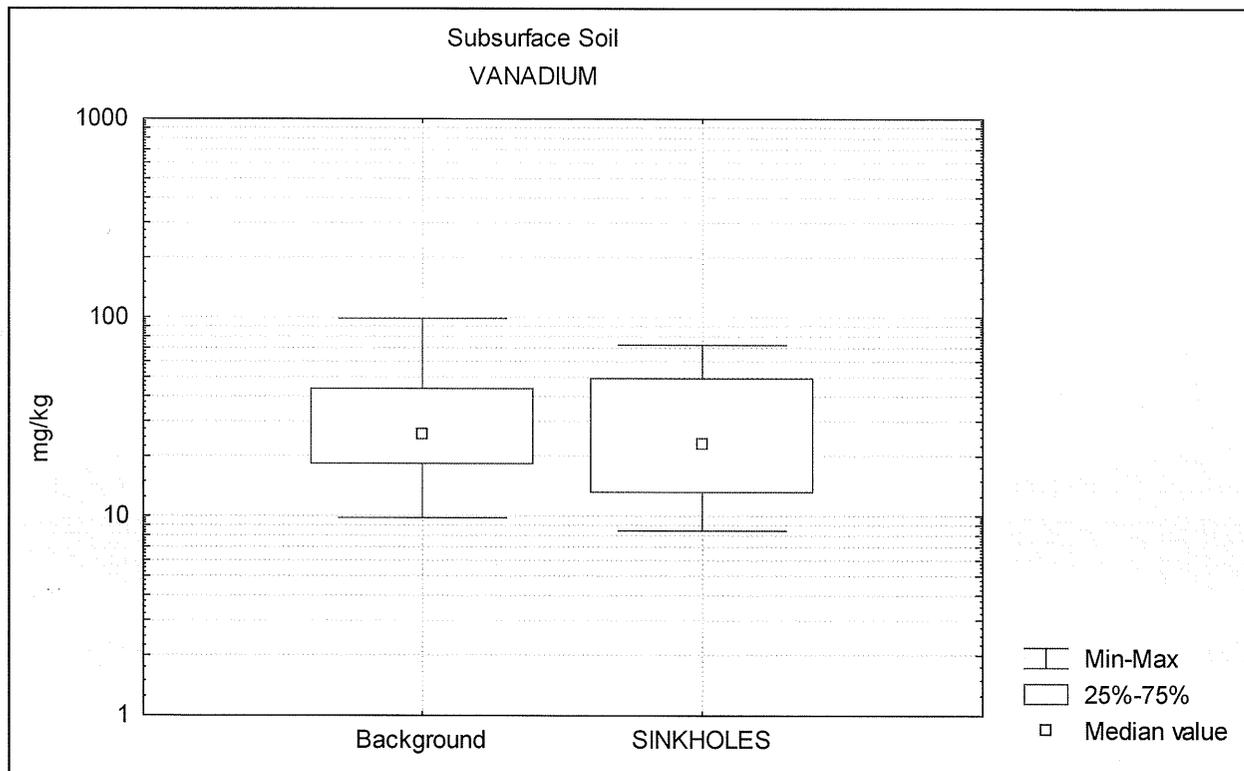
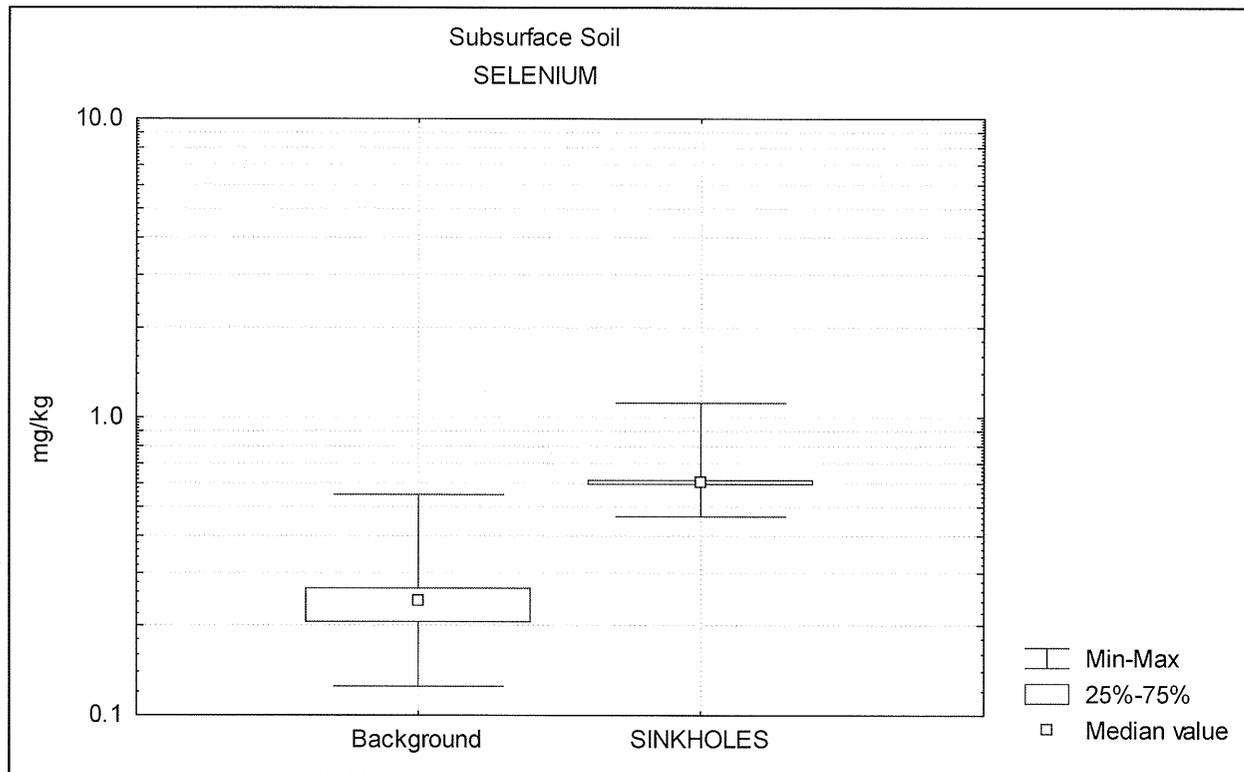
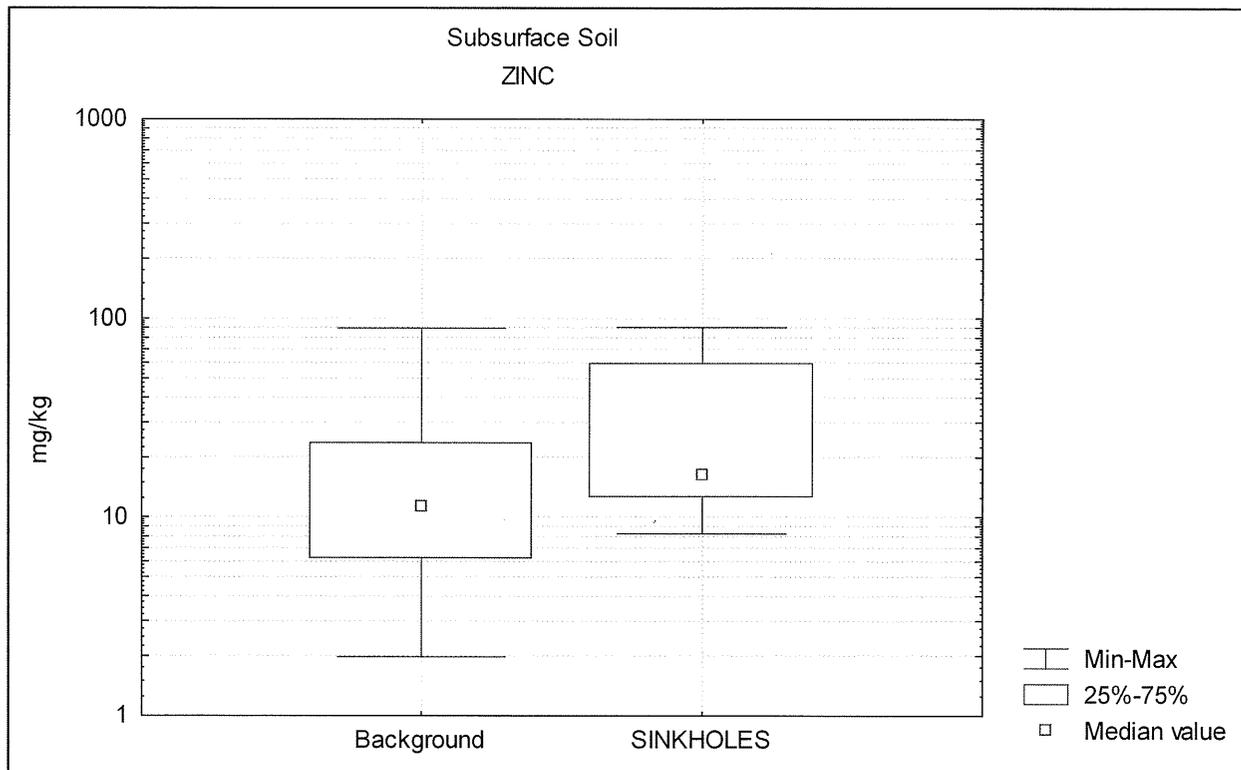


Figure 1-10



**GEOCHEMICAL**  
**(TIER 3)**

# **Geochemical Evaluation of Metals in Soil Sinkholes at Pelham Range Fort McClellan, Alabama**

## **1.0 Introduction**

This report provides the results of a geochemical evaluation of inorganic constituents in soil samples from the Sinkholes at Pelham Range at Fort McClellan in Calhoun County, Alabama. Eleven elements in soil 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 depths of 0 to 0.5 and 0 to 1 foot below ground surface [bgs]) and eleven subsurface soil samples (various depths ranging from 1 to 8 feet bgs) collected from July 2001 through June 2002. 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 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 or fail statistical comparison to background data sets. Trace element distributions in uncontaminated soil and sediment 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 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, Sinkholes at Pelham Range,” 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 comparison for the Sinkholes at Pelham Range. Additional supporting information on these techniques are 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.

**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 ( $\text{HAsO}_4^-$ ,  $\text{H}_2\text{AsO}_4^-$ ) (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 As/Fe 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 As/Fe 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 As/Fe 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.

These trends may be linear or may have some curvature to them. The adsorption of a trace element on a mineral surface can usually be described by a linear isotherm over a limited range of concentrations, but a two-parameter curved fit (such as a Freundlich or Langmuir isotherm) can be more appropriate for some trace elements over a broader range of concentrations. The trace-versus-major element correlations are referred to as “linear trends” for convenience in this report, even though there may be some degree of curvature to the natural relationship.

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.

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

This section presents the results of the geochemical evaluation of aluminum, arsenic, barium, copper, lead, magnesium, mercury, nickel, potassium, selenium, and zinc in soil samples from the Sinkholes at Pelham Range. Figures are provided in Attachment 1.

#### **Aluminum**

Aluminum is the second most abundant element analyzed in the site soil samples, with a mean concentration of 12,859 milligrams per kilogram (mg/kg) (approximately 1.3 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 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 13,367 mg/kg; 1.3 weight percent). The site soil boring logs note that brown, yellowish brown, reddish orange, or gray clay or clay with some silt; and brown or gray silt are the predominant soil types in the sampled intervals. The iron in the site samples is mostly present as iron oxides, which are common soil-forming minerals and which 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 clay and iron oxide minerals in site soil (Figure 1). For both surface and subsurface intervals, the site samples contain higher aluminum concentrations than most of the background samples and lie on or slightly above the general background trend (Figure 1). This indicates that the site samples are naturally enriched in clay minerals relative to the background samples. It is important to note that clays and iron oxides adsorb specific trace elements (as discussed in Section 2.0), so the samples that plot on the upper end of the trend in Figure 1 – including several 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 2.0, 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 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 reveals a common linear trend with a positive slope for the site and background samples (Figure 2). The site samples with the highest arsenic concentrations also contain proportionally higher iron concentrations, and lie on the linear trend. These observations indicate that arsenic in the site samples is associated with iron oxides at ratios consistent with those of the background samples, and is natural.

#### Conclusion

Arsenic detected in the site soil samples is naturally occurring.

#### **Barium**

Manganese oxides are naturally occurring minerals in soil, and 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 barium. A plot of barium versus manganese reveals a common linear trend with a positive slope for the site and background samples (Figure 3). This indicates that the barium in the site samples is associated with manganese oxides at ratios consistent with those of the background samples, and is natural.

Another perspective of the data sets is provided in Figure 4, which displays the barium concentrations of the site and background samples (y-axis) versus their corresponding Ba/Mn ratios (x-axis). If a site sample contained excess barium from a contaminant source, then it would exhibit an anomalously high Ba/Mn ratio relative to background and would plot to the right of the background samples in Figure 4. However, no such samples are observed in the plot. All of the site samples exhibit Ba/Mn ratios that are within the background range.

#### Conclusion

Barium detected in the site soil samples is naturally occurring.

#### **Copper**

Copper in soil has an affinity for different sorptive surfaces including aluminum hydroxides, clays, iron oxides, and manganese oxides (Kabata-Pendias, 2001); as a result, correlations of copper concentrations versus aluminum, iron, or manganese concentrations are not always strong, even in uncontaminated samples. A plot of copper versus aluminum for the site and background samples is provided in Figure 5. Most of the background samples form a generally linear trend with a positive slope, and the site samples lie on this trend. The site samples with the highest copper concentrations also have high aluminum content, and lie on the trend established by the other samples. These observations indicate that copper in the site samples is associated with clays (and other aluminum-bearing minerals) at ratios consistent with those of the background samples, and is natural.

#### Conclusion

Copper detected in the site soil samples is naturally occurring.

#### **Lead**

Manganese oxides are naturally occurring minerals in soil, and 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 common linear trend with a positive slope for the site and background samples (Figure 6). The site sample with the highest lead concentration also contains high manganese, and lies on the linear background trend. These observations indicate that lead in the site samples is associated with manganese oxides at ratios consistent with those of the background samples, and is natural.

Another perspective of the data sets is provided in Figure 7, which displays the lead concentrations of the site and background samples (y-axis) versus their corresponding Pb/Mn ratios (x-axis). 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 7. However, no such samples are observed in the plot. All of the site samples have Pb/Mn ratios that are within the background range.

#### Conclusion

Lead detected in the site soil samples is naturally occurring.

## **Magnesium**

Magnesium ( $Mg^{2+}$ ) 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 are characterized by large surface-area-to-volume ratios and strong negative surface charges. As a result, the major cations, such as magnesium, are attracted to these mineral surfaces and take part in cation exchange reactions. Positive correlations between magnesium and aluminum concentrations are thus typically observed for uncontaminated soil samples. A plot of magnesium versus aluminum reveals a generally linear trend for most of the background samples and a strong linear trend for the site samples ( $R^2 = 0.84$  and  $0.97$  for the site surface and subsurface intervals) (Figure 8). The site samples with the highest magnesium concentrations also have proportionally higher aluminum concentrations, and lie on the trend established by the other samples. These observations indicate a natural source for the elevated magnesium in the site samples.

The background samples show a weaker correlation for magnesium versus aluminum ( $R^2 = 0.11$ ) relative to the site samples. The site samples were all collected from a small area within the facility, whereas the background samples represent a much broader area with different soil types developed from the weathering of different source rocks. These differences most likely explain the poorer magnesium-vs.-aluminum correlation in the background samples.

### Conclusion

Magnesium 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 9). The site samples lie on the background trend, which indicates that the mercury in these samples is associated with clays at ratios consistent with those of the background samples, and is natural. This conclusion is supported by comparison of the site and background Hg/Al ratios (Figure 10). Although two of the site surface soil samples have elevated mercury concentrations, their Hg/Al ratios are within the background range.

### Conclusion

Mercury detected in the site soil samples is naturally occurring.

## **Nickel**

Nickel is commonly present in soil as the divalent cation ( $Ni^{2+}$ ) and has an affinity to adsorb on clay minerals, which maintain a net negative surface charge. A positive correlation between nickel and aluminum concentrations is thus expected for uncontaminated soil samples. Most of the background samples and all of the site samples form a linear trend with a positive slope in a plot of nickel versus aluminum ( $R^2 = 0.66$  and  $0.74$  for the site surface and subsurface intervals) (Figure 11). The site samples with the highest nickel concentrations also have proportionally

higher aluminum content and lie on the background trend. The elevated nickel in these samples is due to the preferential enrichment of clay minerals, and is natural.

#### Conclusion

Nickel detected in the site soil samples is naturally occurring.

#### **Potassium**

Potassium is a common constituent of minerals such as clays, which also contain aluminum as a primary component. Positive correlations between potassium and aluminum concentrations are commonly observed for uncontaminated soil samples. The site and background samples form a common, generally linear trend in a plot of potassium versus aluminum (Figure 12). The site samples with the highest potassium concentrations also have proportionally higher aluminum content. These observations indicate a natural source for potassium in the site samples.

#### Conclusion

Potassium detected in the site soil samples is naturally occurring.

#### **Selenium**

Selenium was detected in only four surface soil samples and three subsurface soil samples, and all concentrations are estimated (“J”-qualified) values below the reporting limit. As noted in Section 2.0, 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 commonly observed for uncontaminated soil samples. However, the site samples exhibit strong negative and weak positive correlations for selenium versus iron in the surface ( $R^2 = -0.90$ ) and subsurface ( $R^2 = 0.22$ ) intervals. This may be due in part to the uncertainty associated with estimated values. Both surface and subsurface intervals show weak positive correlations for selenium versus aluminum ( $R^2 = 0.14$  and  $0.10$ ) (Figure 13). The site samples with higher selenium concentrations also contain high aluminum, and all of the site samples are below the maximum background selenium detection of 1.28 mg/kg. These observations suggest that selenium in the site samples has a natural source.

#### Conclusion

Selenium detected in the site soil samples is naturally occurring.

#### **Zinc**

Zinc in soils is commonly associated with clay minerals and hydrous aluminum and iron oxides (Kabata-Pendias, 2001), so positive correlations for zinc versus aluminum and zinc versus iron are expected for uncontaminated samples. The site samples and most of the background samples form a collinear trend with a positive slope in a plot of zinc versus aluminum (Figure 14). The site samples with high zinc concentrations also contain high aluminum concentrations, and lie on the linear background trend. Zinc in the site samples is associated with clays (and other aluminum-bearing minerals) 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 Summary

This section summarizes the results of the geochemical evaluation of selected elements in soil samples from the Sinkholes at Pelham Range.

**Soil.** Geochemical evaluation indicates that all detected concentrations of aluminum, arsenic, barium, copper, lead, magnesium, mercury, nickel, potassium, selenium, and zinc in the surface and subsurface soil samples are naturally occurring.

## 5.0 References

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

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

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: An International Journal*, Vol. 13, No. 1, pp. 1-16.

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

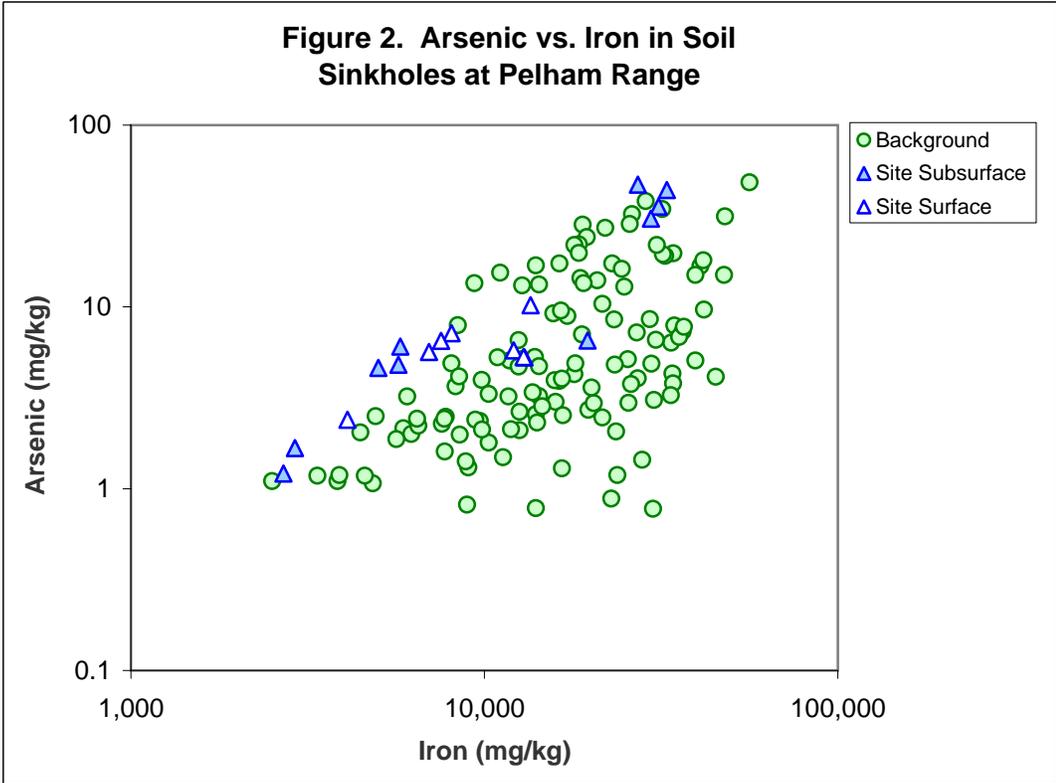
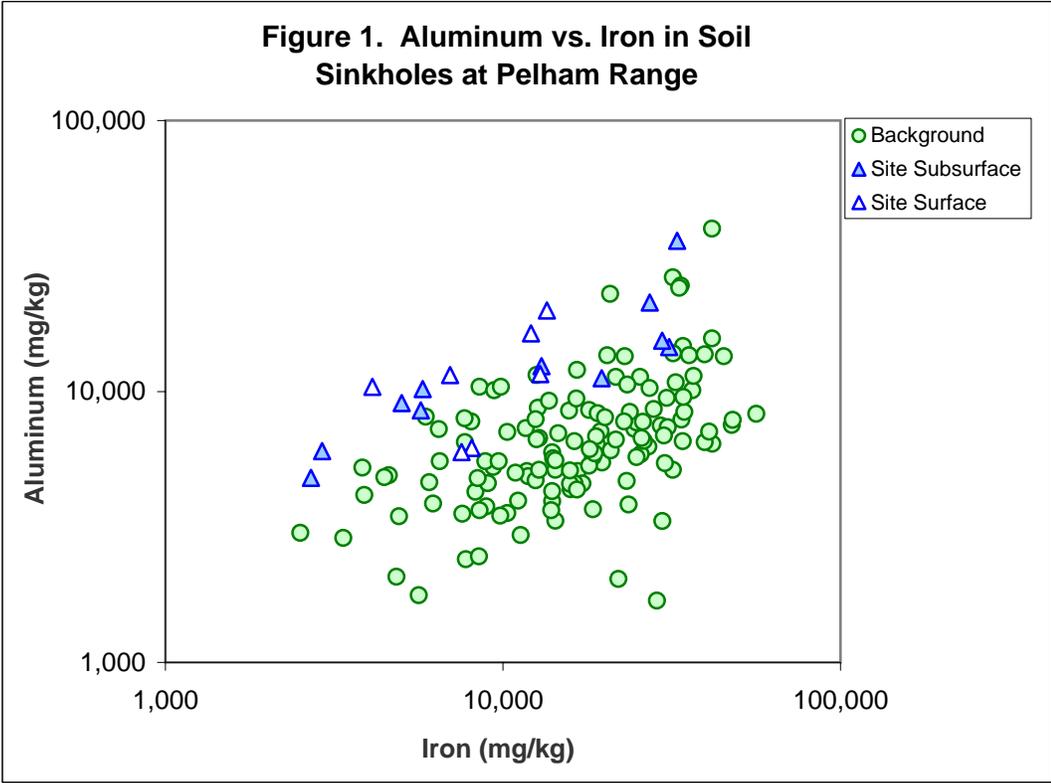
Schiff, K. and S. B. Weisberg, 1997, "Iron as a Reference Element for Determining Trace Metal Enrichment in California Coastal Shelf Sediments," in: S. Weisberg, C. Francisco, and D.

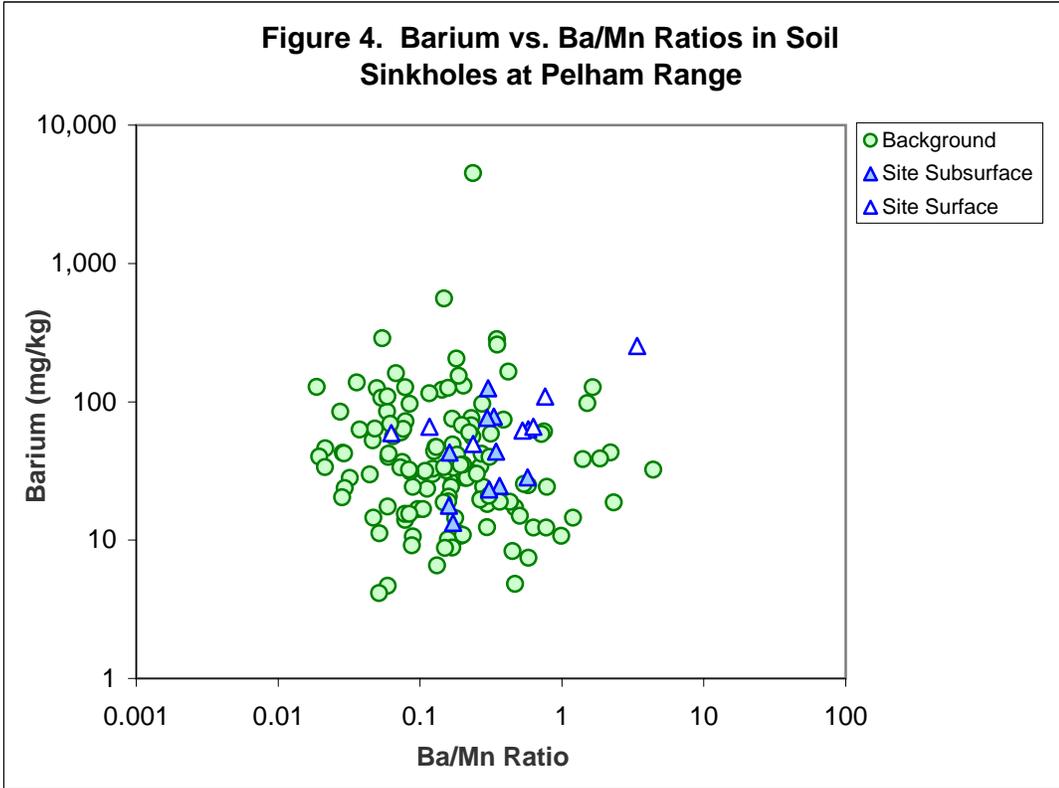
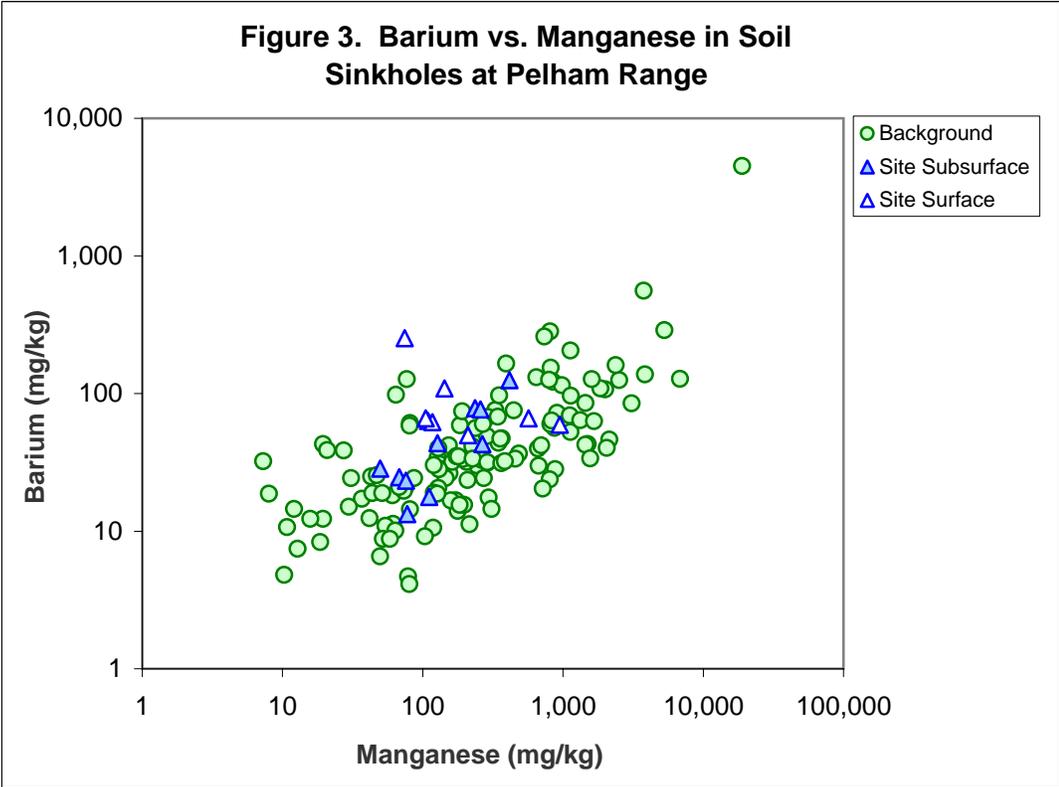
Hallock (editors), *Southern California Coastal Water Research Project Annual Report 1995-96*, pp. 68-78.

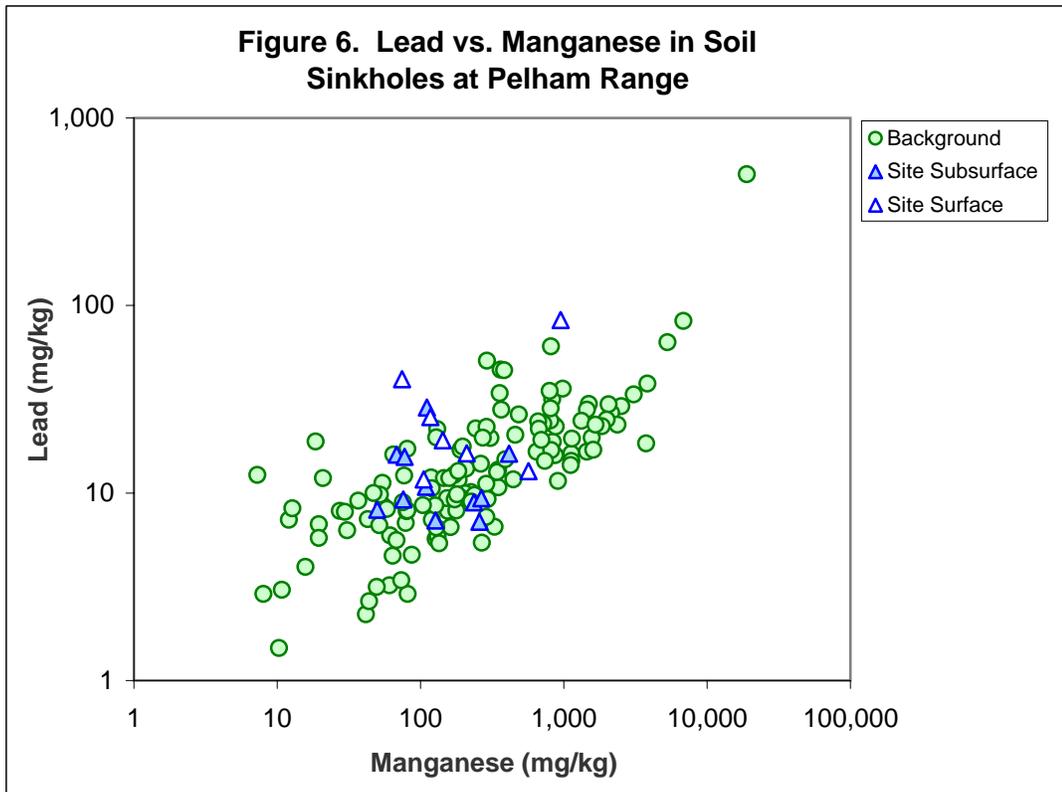
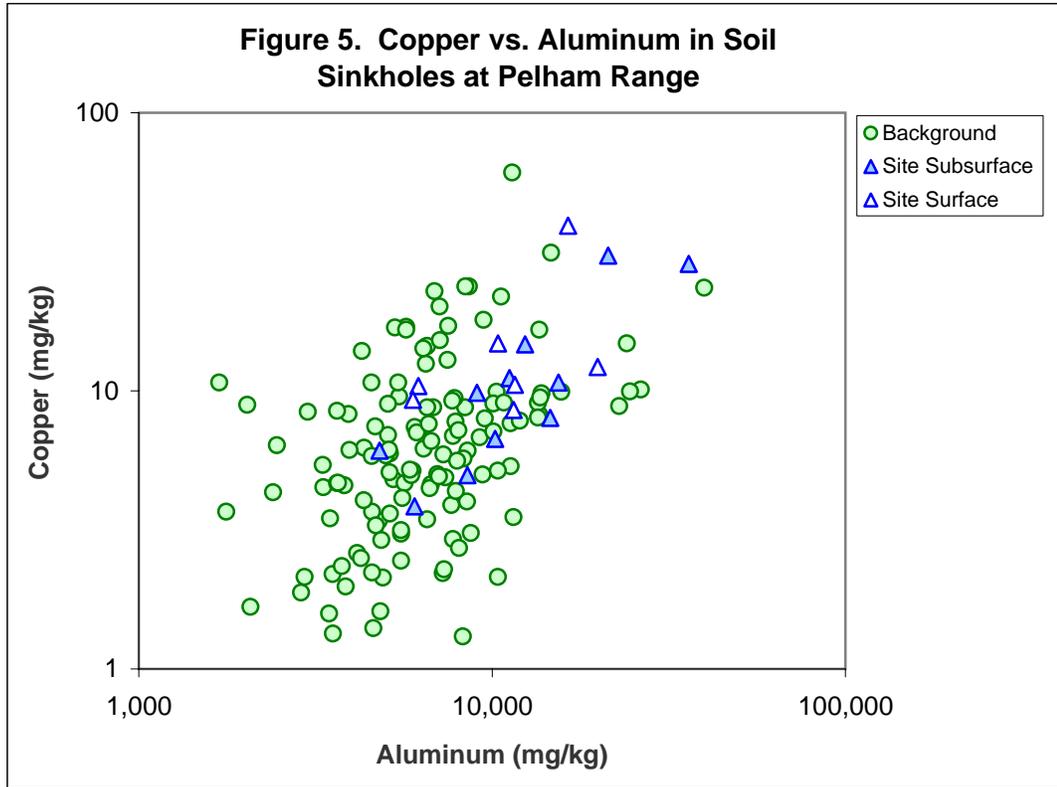
U.S. Environmental Protection Agency, 1995, *Determination of Background Concentrations of Inorganics in Soils and Sediments at Hazardous Waste Sites*, Office of Research and Development, EPA/540/S-96/500, December.

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.

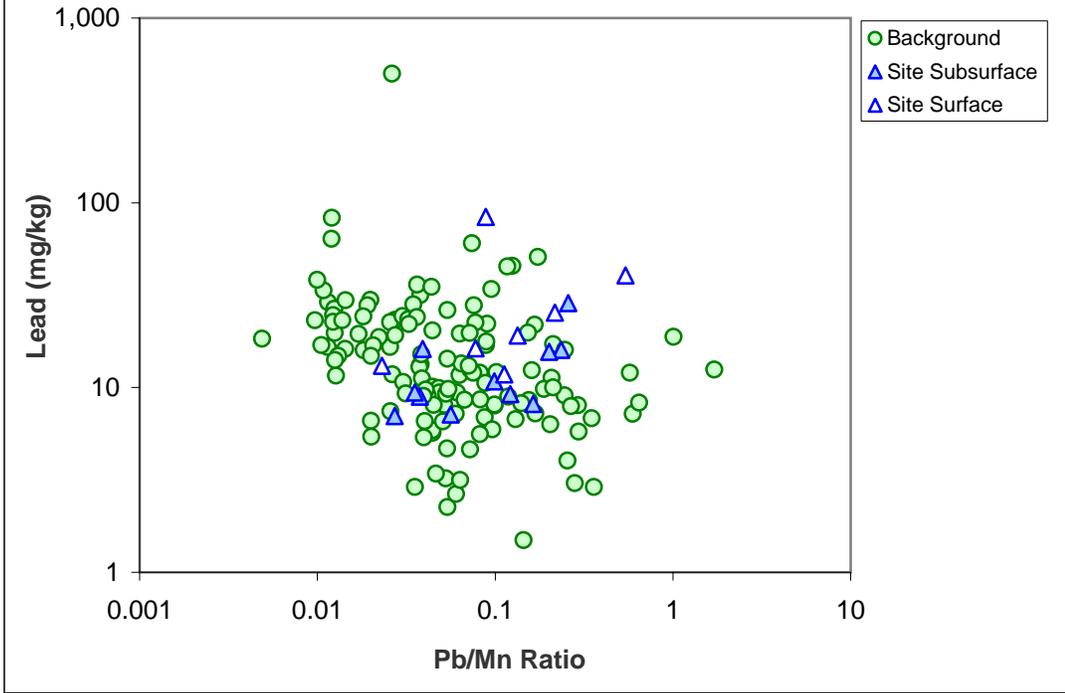
**ATTACHMENT 1**



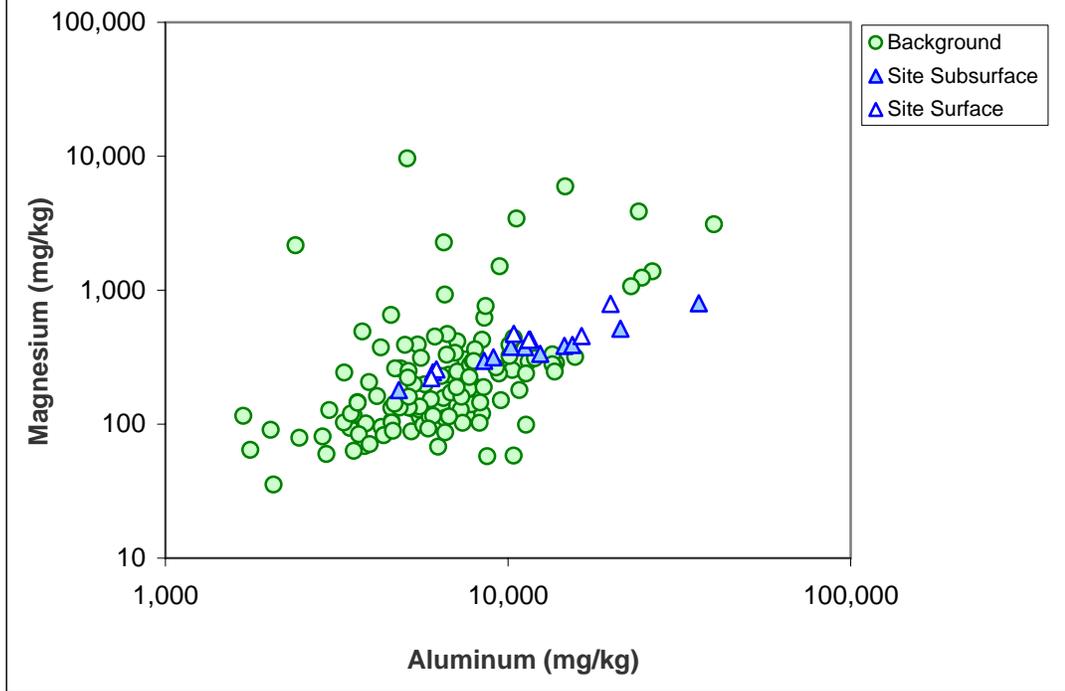




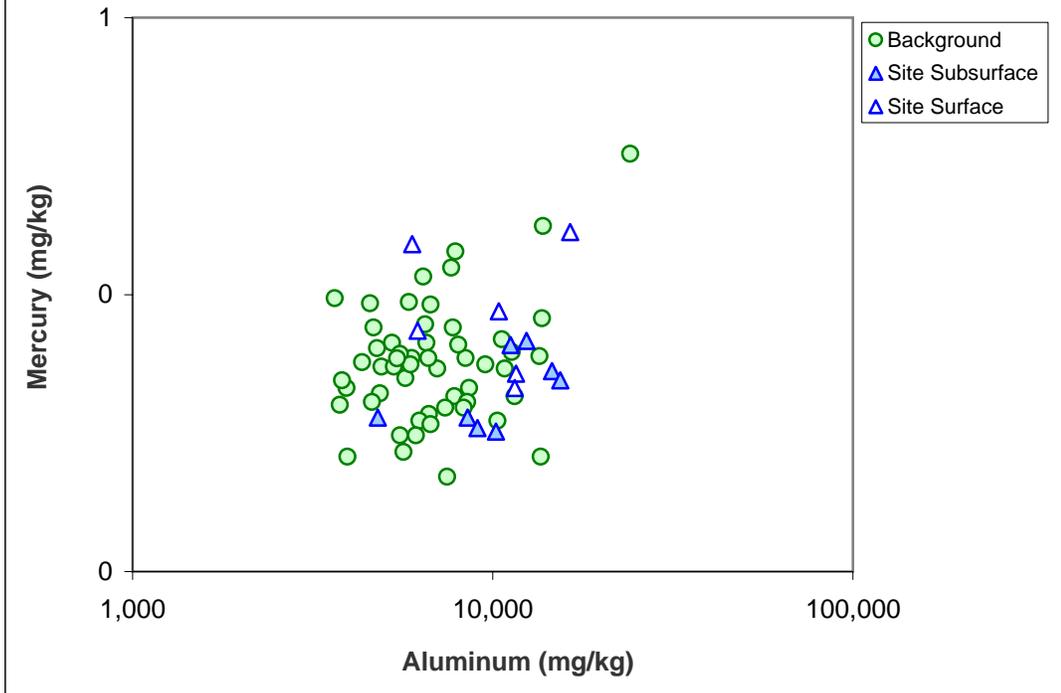
**Figure 7. Lead vs. Pb/Mn Ratios in Soil Sinkholes at Pelham Range**



**Figure 8. Magnesium vs. Aluminum in Soil Sinkholes at Pelham Range**



**Figure 9. Mercury vs. Aluminum in Soil Sinkholes at Pelham Range**



**Figure 10. Mercury vs. Hg/Al Ratios in Soil Sinkholes at Pelham Range**

