APPENDIX J

STATISTICS AND GEOCHEMICAL EVALUATION OF SITE METALS DATA

STATISTICAL
(TIERS 1 AND 2)

Statistical Comparison of Site and Background Data
Motor Pool Area 3100, Parcel 146(7)
Fort McClellan, Alabama

1.0 Introduction

This report provides the Tier 1 and Tier 2 site-to-background comparison results for Motor Pool Area 3100, Parcel 146(7), at Fort McClellan in Calhoun County, Alabama. Tier 1 and Tier 2 evaluations (Shaw E & I, 2003) have been performed on the surface soil, subsurface soil, and groundwater 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 through 3, and described in more detail in the following sections. Site samples used in the site-to-background comparison include 7 surface soil samples (0 to 1 foot below ground surface [bgs]), 13 subsurface soil samples (1 to 13 feet bgs), and 7 groundwater samples that were collected at the site.

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 Motor Pool 3100, Parcel 146(7), 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
Motor Pool Area 3100, Parcel 146(7)
Fort McClellan, Calhoun County, Alabama

Metals	Frequency of Detection	Tier 1 Evaluation[a]	Tier 2 Evaluation: Slippage Test[b]	Tier 2 Evaluation: Wilcoxon Rank Sum Test[b]	Tier 2 Evaluation: Hot Measurement Test[b,c]	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	7 / 7	Passed	NA	NA	NA	
Antimony	0 / 7	NA	NA	NA	NA	
Arsenic	7 / 7	Failed	Passed	Failed	NA	Yes
Barium	6 / 7	Passed	NA	NA	NA	
Beryllium	3 / 7	Failed	Passed	NA[e]	Passed	
Cadmium	1 / 7	Failed	NA[d]	NA[e]	Failed	Yes
Calcium	7 / 7	Failed	Failed	Failed	NA	Yes
Chromium	7 / 7	Failed	Passed	Failed	NA	Yes
Cobalt	4 / 7	Failed	Passed	Failed	NA	Yes
Copper	7 / 7	Failed	Failed	Failed	NA	Yes
Iron	7 / 7	Failed	Passed	Failed	NA	Yes
Lead	7 / 7	Failed	Passed	Passed	NA	
Magnesium	6 / 7	Failed	Passed	Failed	NA	Yes
Manganese	7 / 7	Failed	Passed	Passed	NA	
Mercury	1 / 7	Passed	NA	NA	NA	
Nickel	6 / 7	Failed	Passed	Failed	NA	Yes
Potassium	0 / 7	NA	NA	NA	NA	
Selenium	5 / 7	Failed	Passed	NA[e]	Failed	Yes
Silver	0 / 7	NA	NA	NA	NA	
Sodium	0 / 7	NA	NA	NA	NA	
Thallium	0 / 7	NA	NA	NA	NA	
Vanadium	7 / 7	Passed	NA	NA	NA	
Zinc	5 / 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 Slippage test is not performed on data sets for which the maximum background value is a nondetect.

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

Table 2

Summary of Tier 1 and Tier 2 Site to Background Comparison for Subsurface Soil
Motor Pool Area 3100, Parcel 146(7)
Fort McClellan, Calhoun County, Alabama

Metals	Frequency of Detection	Tier 1 Evaluation[a]	Tier 2 Evaluation: Slippage Test[b]	Tier 2 Evaluation: Wilcoxon Rank Sum Test[b]	Tier 2 Evaluation: Hot Measurement Test[b,c]	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	13 / 13	Failed	Passed	Failed	NA	Yes
Antimony	0 / 13	NA	NA	NA	NA	
Arsenic	13 / 13	Failed	Passed	Failed	NA	Yes
Barium	13 / 13	Passed	NA	NA	NA	
Beryllium	11 / 13	Failed	Passed	Failed	NA	Yes
Cadmium	1 / 13	Failed	Passed	NA[e]	Failed	Yes
Calcium	3 / 13	Failed	Passed	NA[e]	Passed	
Chromium	13 / 13	Failed	Passed	Failed	NA	Yes
Cobalt	8 / 13	Failed	Passed	Failed	NA	Yes
Copper	13 / 13	Failed	Failed	Failed	NA	Yes
Iron	13 / 13	Failed	Failed	Failed	NA	Yes
Lead	13 / 13	Failed	Passed	Failed	NA	Yes
Magnesium	2 / 13	Passed	NA	NA	NA	
Manganese	12 / 13	Failed	Passed	Passed	NA	
Mercury	3 / 13	Passed	NA	NA	NA	
Nickel	9 / 13	Failed	Failed	Failed	NA	Yes
Potassium	8 / 13	Failed	Passed	Failed	NA	Yes
Selenium	13 / 13	Failed	NA[d]	NA[e]	Failed	Yes
Silver	0 / 13	NA	NA	NA	NA	
Sodium	0 / 13	NA	NA	NA	NA	
Thallium	0 / 13	NA	NA	NA	NA	
Vanadium	10 / 13	Passed	NA	NA	NA	
Zinc	12 / 13	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% or more nondetects.

Table 3

Summary of Tier 1 and Tier 2 Site to Background Comparison for Groundwater
Motor Pool 3100 Area, Parcel 146(7)
Fort McClellan, Calhoun County, Alabama

Metals	Frequency of Detection	Tier 1 Evaluation[a]	Tier 2 Evaluation: Slippage Test[b]	Tier 2 Evaluation: Wilcoxon Rank Sum Test[b]	Tier 2 Evaluation: Hot Measurement Test[b,c]	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	7 / 7	Passed	NA	NA	NA	
Antimony	0 / 7	NA	NA	NA	NA	
Arsenic	0 / 7	NA	NA	NA	NA	
Barium	7 / 7	Failed	Passed	Failed	NA	Yes
Beryllium	0 / 7	NA	NA	NA	NA	
Cadmium	0 / 7	NA	NA	NA	NA	
Calcium	7 / 7	Passed	NA	NA	NA	
Chromium	1 / 7	Failed	NA[d]	NA[e]	Passed	
Cobalt	5 / 7	Failed	Passed	NA[e]	Failed	Yes
Copper	1 / 7	Passed	NA	NA	NA	
Iron	7 / 7	Passed	NA	NA	NA	
Lead	0 / 7	NA	NA	NA	NA	
Magnesium	7 / 7	Passed	NA	NA	NA	
Manganese	7 / 7	Failed	Passed	Failed	NA	Yes
Mercury	1 / 7	Failed	NA[d]	NA[e]	Passed	
Nickel	5 / 7	Failed	NA[d]	NA[e]	Failed	Yes
Potassium	4 / 7	Passed	NA	NA	NA	
Selenium	0 / 7	NA	NA	NA	NA	
Silver	0 / 7	NA	NA	NA	NA	
Sodium	7 / 7	Passed	NA	NA	NA	
Thallium	0 / 7	NA	NA	NA	NA	
Vanadium	1 / 7	Passed	NA	NA	NA	
Zinc	7 / 7	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 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 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 (95th UTL) is recommended as a screening value for normally or lognormally distributed analytes and the 95th percentile is recommended as a screening value for nonparametrically distributed analytes (EPA, 1989, 1992, and 1994). Site samples with concentrations above these values are not necessarily contaminated, but should be considered suspect. To perform the test, each analyte's site MDC is compared to the background 95th UTL or 95th percentile, in accordance with the type of background distribution. If the site MDC exceeds the background screening value, then that analyte will undergo a geochemical evaluation. If the MDC does not exceed the background threshold value, then hot-spot contamination is not indicated.

2.1.3 Geochemical Evaluation

If an analyte fails 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 Motor Pool 3100 surface soil, subsurface soil, and groundwater samples. Tables 1 through 3 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 Motor Pool 3100. Five metals (antimony, potassium, silver, sodium, and thallium) have no detected concentrations in surface soil, so no further discussion of these metals is included.

Four metals (aluminum, barium, mercury, and vanadium) have no detected concentrations above their respective background screening values, passing the Tier 1 evaluation. These 4 metals are not tested or discussed further. The remaining 14 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.

Arsenic

Tier 1 Evaluation

Two site samples exceed the background screening value of 13.73 mg/kg.

Tier 2 Evaluation

Slippage Test

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

WRS Test

The p-level of 0.005 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 arsenic 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 one site sample exceeds the maximum background measurement. Because $K < K_c$, beryllium passes the Slippage test.

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

Box Plot
The site and background medians are similar (Figure 1-1). The site 25th percentile, 75th percentile, and maximum are slightly higher than the corresponding background values. The site minimum is higher than that of background.

Hot Measurement Test
The site MDC of beryllium is less than the 95th UTL of 1.189 mg/kg.

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

Cadmium

Tier 1 Evaluation
One site sample exceeds the background screening value of 0.29 mg/kg.

Tier 2 Evaluation
Slippage Test
The Slippage test is not used because the maximum background result for cadmium is a nondetect.

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

Box Plot
The site minimum, 25th percentile, median, and maximum are higher than the corresponding background values (Figure 1-2). The site 75th percentile is slightly lower than that of background. The shape and location of the site box plot reflects the high percentage of nondetects (86 percent) and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test
The site MDC of cadmium exceeds the 95th percentile of 1.2 mg/kg.

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

Calcium

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

Tier 2 Evaluation
Slippage Test
K_c for calcium is 2, and 4 site samples exceed the maximum background measurement. Because $K > K_c$, calcium fails the Slippage test.

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

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

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

Chromium

Tier 1 Evaluation
One site sample exceeds the background screening value of 37.04 mg/kg.

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

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

Box Plot
The site minimum and interquartile range are higher than the corresponding background values (Figure 1-3). The site maximum is lower than that of background.

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

Cobalt

Tier 1 Evaluation
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 0.125 indicates weak agreement between the site and background distributions.

Box Plot
The site minimum and interquartile range are higher than the corresponding background values (Figure 1-3). The site maximum is slightly lower than that of background.

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.

Tier 2 Evaluation
Slippage Test
K_c for copper is 2, and 4 site samples exceed the maximum background measurement. Because $K > K_c$, copper fails the Slippage test.

WRS Test
The p-level of 0.0012 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 1-4).

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

Iron

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

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

WRS Test
The p-level of 0.021 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 lower than that of background.

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

Lead

Tier 1 Evaluation
One site sample exceeds 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 0.406 indicates good agreement between the site and background distributions.

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

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

Magnesium

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

Tier 2 Evaluation
Slippage Test
K_c for magnesium is 2, and 1 site sample exceeds the maximum background measurement. Because $K < K_c$, magnesium 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 1-5).

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

Manganese

Tier 1 Evaluation
One site sample exceeds the background screening value of 1,579 mg/kg.

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

WRS Test
The p-level of 0.22 indicates a good agreement between the site and background distributions.

Box Plot
The site interquartile range and maximum are lower than the corresponding background values (Figure 1-6). The site minimum is greater than that of background.

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

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 1 site sample exceeds the maximum background measurement. Because $K < K_c$, nickel passes the Slippage test.

WRS Test

The p-level of 0.02 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 1-6). 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.

Selenium

Tier 1 Evaluation

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

Tier 2 Evaluation

Slippage Test

K_c for selenium is 2, and 2 site samples exceed the maximum background measurement. Because $K \leq K_c$, 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, interquartile range, and maximum are higher than the corresponding background values (Figure 1-7). 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 95th percentile of 0.563 mg/kg.

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

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 one site sample exceeds the maximum background measurement. Because $K < K_c$, zinc passes the Slippage test.

WRS Test
The p-level of 0.19 indicates weak agreement between the site and background distributions.

Box Plot
The site minimum and 25th percentile are lower than the corresponding background values (Figure 1-7). The site median, 75th percentile, and maximum are higher than the corresponding background values.

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 Motor Pool 3100 subsurface soil. Four metals (antimony, silver, sodium, and thallium) had no detected concentrations in subsurface soil. No further discussion of these metals is included.

Barium, magnesium, mercury, and vanadium had no detected results that exceeded the background screening value, passing the Tier 1 evaluation. They will not be tested or discussed further.

The remaining 15 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
Two 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 no site samples exceed 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 and interquartile range are higher than the corresponding background values (Figure 1-8). The site maximum is lower than that of background.

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
Two site samples exceed the background screening value of 18.3 mg/kg.

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

WRS Test
The p-level of 0.005 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum, 25th percentile, and median are higher than the corresponding background values (Figure 1-8). The site and background 75th percentiles are similar, and the site maximum is less than that of background

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

Beryllium

Tier 1 Evaluation
Seven site samples exceed the background screening value of 0.86 mg/kg.

Tier 2 Evaluation
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 < 0.001 indicates a significant difference in 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 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.

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

WRS Test
The WRS test was not performed because the site data set has 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 shape and location of the site box plot are influenced by the high percentage of nondetects (92 percent) and the replacement values of one-half the reporting limit, rather than detected concentrations.

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.

Calcium

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

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

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

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 site box plot are influenced by the high percentage of nondetects (77 percent) and the replacement values of one-half the reporting limit, rather than detected concentrations.

Hot Measurement Test
The site MDC exceeds the background 95th percentile of 1,710 mg/kg.

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

Chromium

Tier 1 Evaluation
One site sample exceeds the background screening value of 38.25 mg/kg.

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

WRS Test
The p-level of 0.038 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum, 25th percentile, and median are higher than the corresponding background values (Figure 1-10). The site 75th percentile and maximum are similar to the respective background values.

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

Cobalt

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

Tier 2 Evaluation
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 0.005 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 cobalt in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Copper

Tier 1 Evaluation
Twelve site samples exceed the background screening value of 19.43 mg/kg.

Tier 2 Evaluation
Slippage Test
K_c for copper is 2, and 4 site samples exceed the maximum background measurement. Because $K > K_c$, copper fails the Slippage test.

WRS Test
The p-level < 0.001 indicates 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 copper in subsurface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

Iron

Tier 1 Evaluation
Five site samples exceed the background screening value of 44,817 mg/kg.

Tier 2 Evaluation
Slippage Test
K_c for iron is 2, and 4 site samples exceed the maximum background measurement. Because $K > K_c$, iron 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 respective background values (Figure 1-12).

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

Lead

Tier 1 Evaluation
One site sample exceeds the background screening value of 38.53 mg/kg.

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

WRS Test
The p-level < 0.001 indicates a good agreement between the site and background distributions.

Box Plot
The site minimum and interquartile range are higher than the corresponding background values (Figure 1-12). The site maximum is lower than that of background.

Conclusion
Because lead 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.

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

WRS Test
The p-level of 0.74 indicates a good agreement between the site and background distributions.

Box Plot
The site minimum, 25th percentile, and maximum are lower than the corresponding background values (Figure 1-13). The site and background medians are similar, and the site 75th percentile is higher than that of background.

Conclusion
Manganese in subsurface 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 12.89 mg/kg.

Tier 2 Evaluation
Slippage Test
K_c for nickel is 2, and 3 site samples exceed the maximum background measurement. Since $K > K_c$, nickel fails the Slippage test.

WRS Test
The p-level of 0.02 indicates a significant difference between the site and background distributions.

Box Plot
The site minimum, median, 75th percentile, and maximum are higher than the corresponding background values (Figure 1-13). The site and background 25th percentiles are similar.

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
Six site samples exceed 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 < 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 1-14). 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
Thirteen 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 data set contains more than 50 percent nondetects.

Box Plot
The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-14). The shape and location of the background box plot are influenced by the percentage of nondetects (98 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 95th percentile of 0.574 mg/kg.

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

Zinc

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

Tier 2 Evaluation
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 is lower than that of background, and the site interquartile range and maximum are higher than the corresponding background values (Figure 1-15).

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 statistical site-to-background comparison of 23 TAL metals from unfiltered groundwater samples. Eight metals (antimony, arsenic, beryllium, cadmium, lead, selenium, silver, and thallium) had no detected results in the groundwater site samples and are not considered any further.

Nine metals (aluminum, calcium, copper, iron, magnesium, potassium, sodium, vanadium, and zinc) had no detected concentrations that exceeded their respective background screening values. These metals are considered to be within the range of background based on the Tier 1 evaluation. They will not be tested or discussed further.

The remaining six metals are carried forward for Tier 2 evaluation. The results of this evaluation are discussed in detail below.

Table 3 summarizes the Tier 1 and Tier 2 results for groundwater.

Barium

Tier 1 Evaluation
Three site samples exceed the background screening value of 0.127 mg/L.

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 0.14 indicates weak agreement between the site and background distributions.

Box Plot
The site minimum and interquartile range are higher than the corresponding background values (Figure 1-15). The site maximum is lower than that of background.

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

Chromium

Tier 1 Evaluation
No background screening value is available for chromium. One site sample had a detected result.

Tier 2 Evaluation
Slippage Test
The Slippage test is not performed because the maximum background result for chromium is a nondetect.

WRS Test
The WRS test was not performed because the background and site data sets contain more than 50 percent nondetects.

Box Plot
The site and background medians and 25th percentiles are the same (Figure 1-16). The site minimum is higher than that of background, and the site 75th percentile and maximum are lower than the corresponding background values. The shapes and locations of the background and site box plots are influenced by the high percentage of nondetects (100 percent and 86 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 0.0168 mg/L.

Conclusion
Chromium in groundwater passed the Tier 2 evaluation and is considered to be within the range of background.

Cobalt

Tier 1 Evaluation
Two site samples exceed the background screening value of 0.02336 mg/L.

Tier 2 Evaluation
Slippage Test
K_c for cobalt is 2, and 2 site samples exceed the maximum background measurement. Because $K \leq K_c$, cobalt passes the Slippage test.

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

Box Plot
The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-16). The shape and location of the background box plot are influenced by the high percentage of nondetects (94 percent), and the replacement values of one-half the reporting limit rather than detected concentrations.

Hot Measurement Test
The site MDC exceeds the background 95th percentile of 0.0202 mg/L.

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

Manganese

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

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

WRS Test
The p-level of 0.18 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 1-17). The site maximum is less than that of background.

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

Mercury

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

Tier 2 Evaluation
Slippage Test
The Slippage test is not performed because the maximum background result for mercury is a nondetect.

WRS Test
The WRS test was not performed 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 1-22). The shapes and locations of the background and site box plots are influenced by the high percentage of nondetects (100 percent and 89 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 0.000243 mg/L.

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

Nickel

Tier 1 Evaluation
No background screening value is available for nickel. Five site samples have detected concentrations.

Tier 2 Evaluation
Slippage Test
The Slippage test is not performed because the maximum background result for nickel is a nondetect.

WRS Test
The WRS test was not performed because the background and site data sets contain more than 50 percent nondetects.

Box Plot
The site minimum and 75th percentile are lower than the corresponding background values (Figure 1-23). The site 25th percentile, median, and maximum are higher than that of background. The shapes and locations of the background and site box plots are influenced by the high percentage of nondetects (100 percent and 72 percent, respectively) and the replacement values of one-half the reporting limit rather than detected concentrations.

Hot Measurement Test
The site MDC 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.

Sodium

Tier 1 Evaluation
Four site samples exceed the background screening value of 14.846 mg/L.

Tier 2 Evaluation
Slippage Test
K_c for sodium is 3, and no site samples exceed the maximum background measurement. Because $K < K_c$, sodium 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 1-23). The site maximum is lower compared to that of background.

Conclusion
Because sodium in groundwater 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 0.016975 mg/L.

Tier 2 Evaluation
Slippage Test
The Slippage test is not performed because the maximum background result for vanadium is a nondetect.

WRS Test
The WRS test was not performed because the background and site data sets contain more than 50 percent nondetects.

Box Plot
The site minimum and 75th percentile are lower than the corresponding background values (Figure 1-24). The site median, 25th percentile, and maximum are higher compared to those of background. The shapes and locations of the background and site box plots are influenced by the high percentage of nondetects (96 percent and 89 percent, respectively) and the replacement values of one-half the reporting limit rather than detected concentrations.

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

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

4.0 Summary and Conclusions

The statistical methodology used to compare samples taken from Motor Pool 3100, Parcel 146(7), and background data sets for 23 elements in surface soil, subsurface soil, and groundwater 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 through 3 summarize the statistical comparison test results and show the metals carried forward for geochemical evaluation.

5.0 References

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ATTACHMENT 1

Figure 1-1

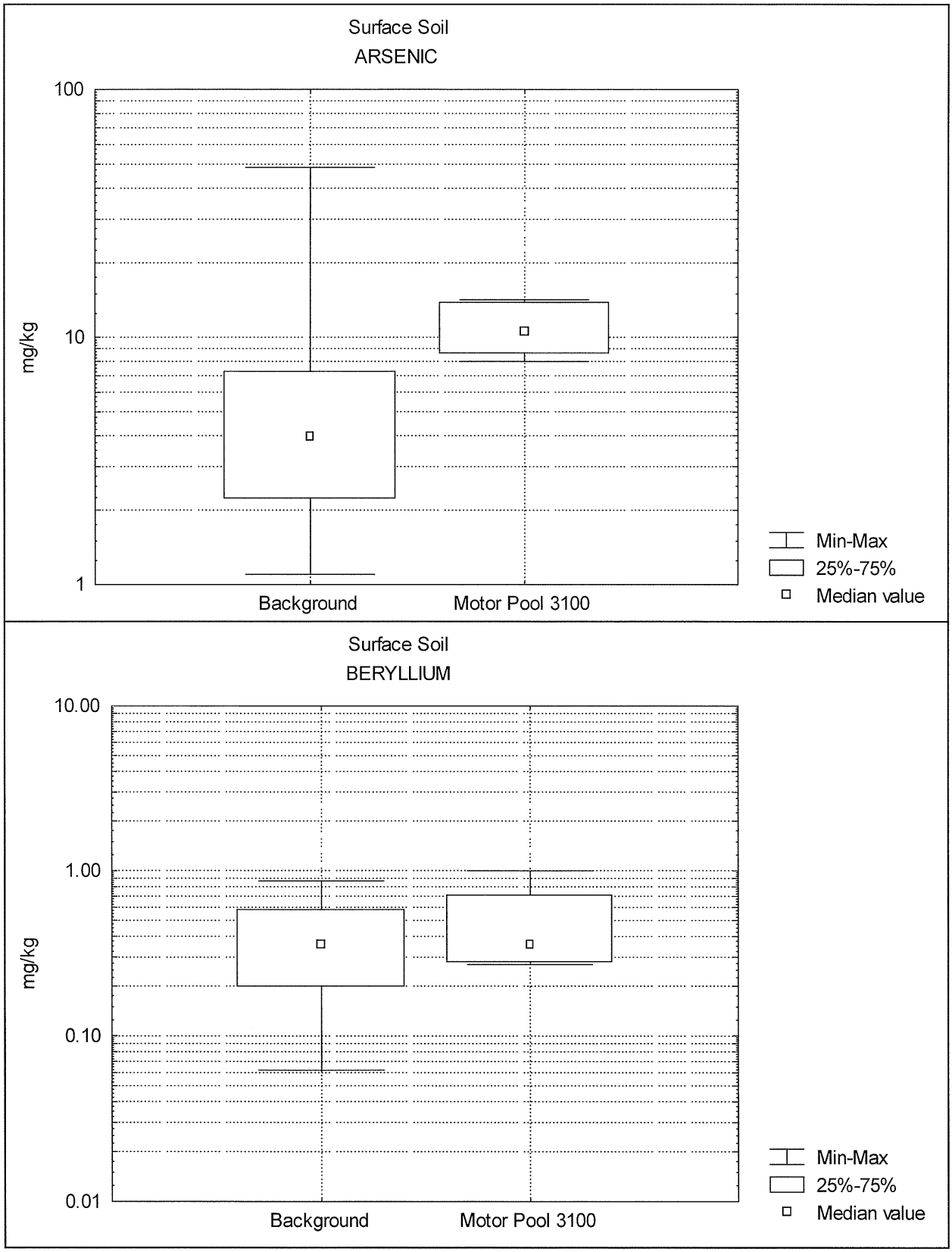

Surface Soil
ARSENIC
100
10
1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value
Surface Soil
BERYLLIUM
10.00
1.00
0.10
0.01
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-2

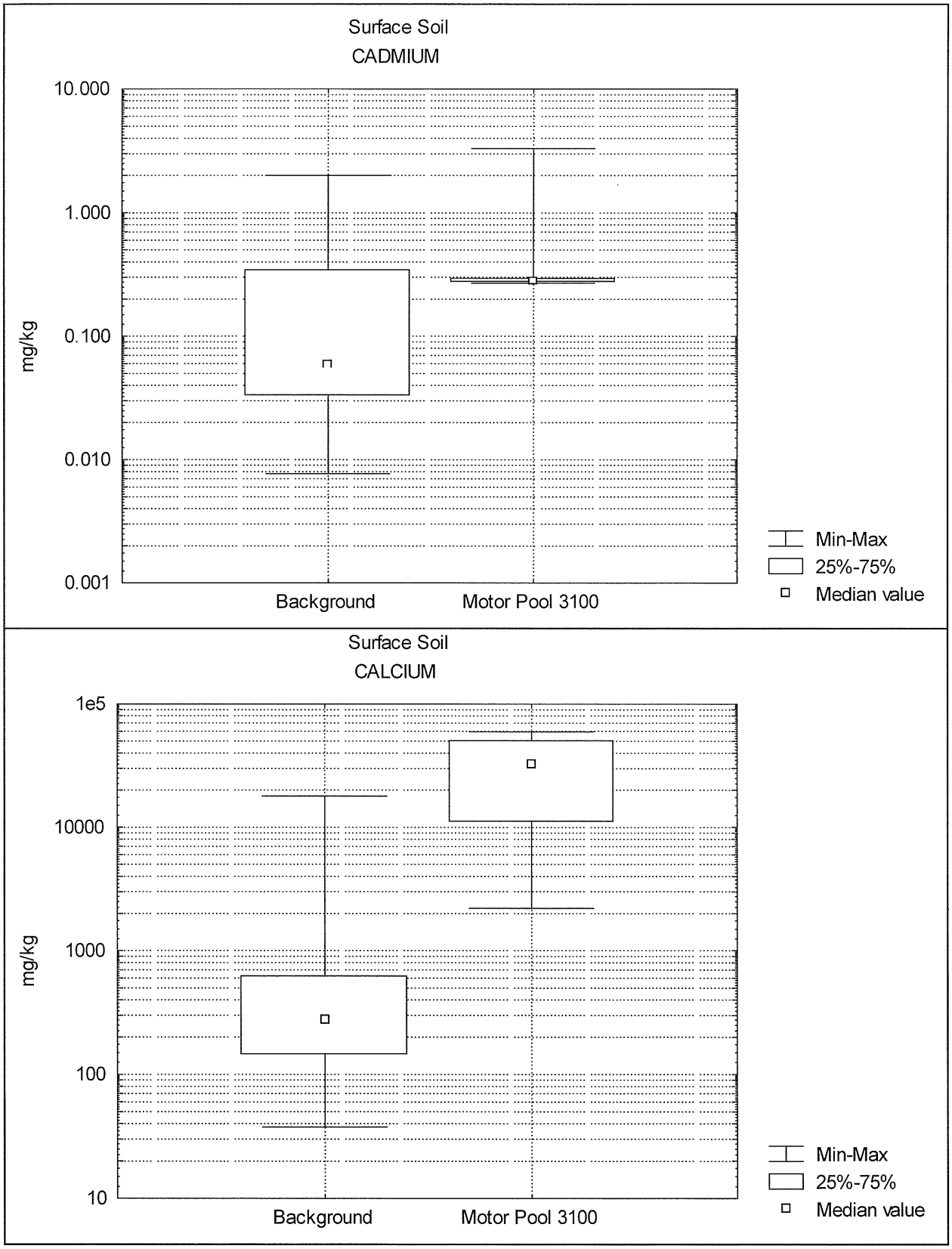
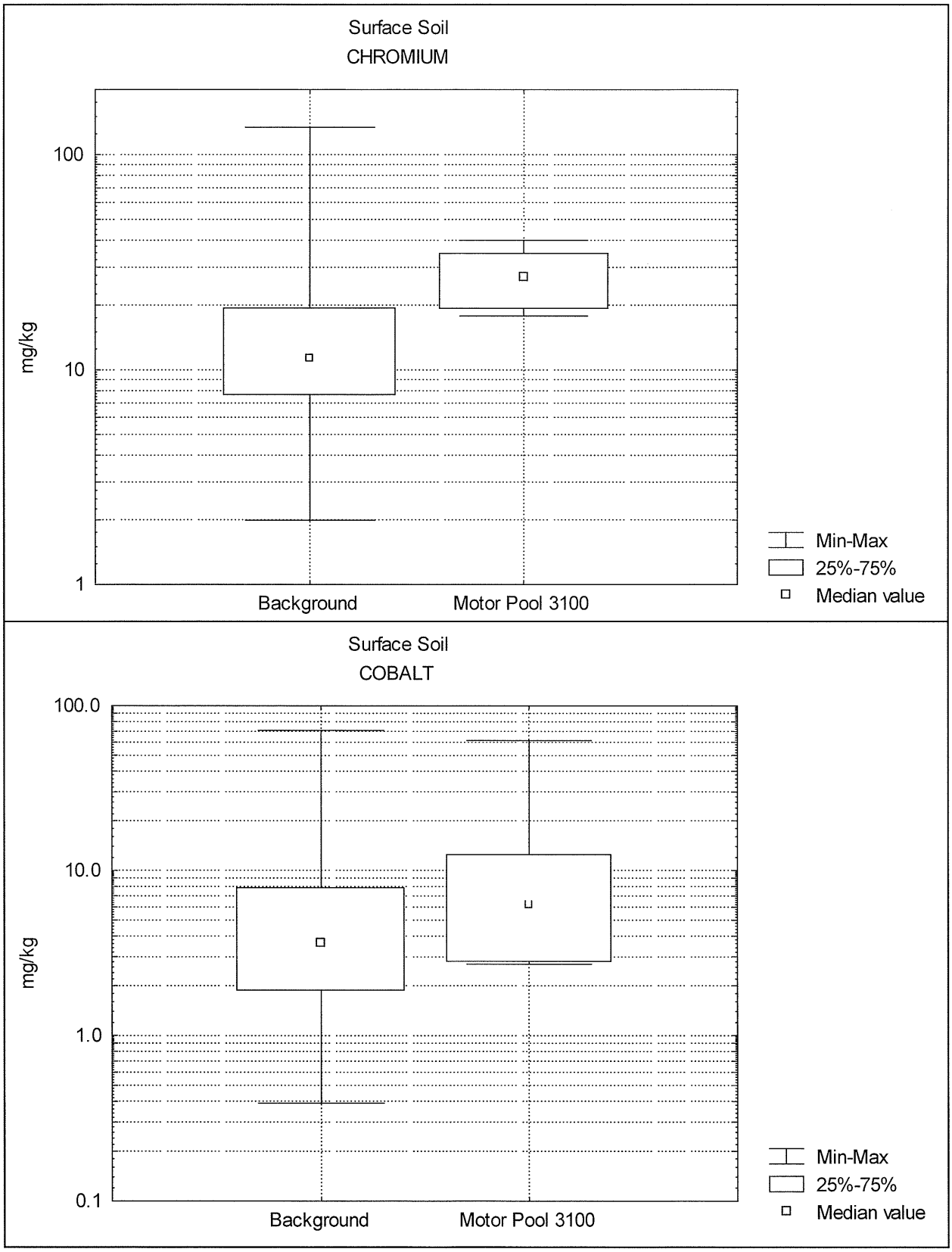

Surface Soil
CADMIUM
10.000
1.000
0.100
0.010
0.001
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value
Surface Soil
CALCIUM
1e5
10000
1000
100
10
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-3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CHROMIUM
100
10
1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value
Surface Soil
COBALT
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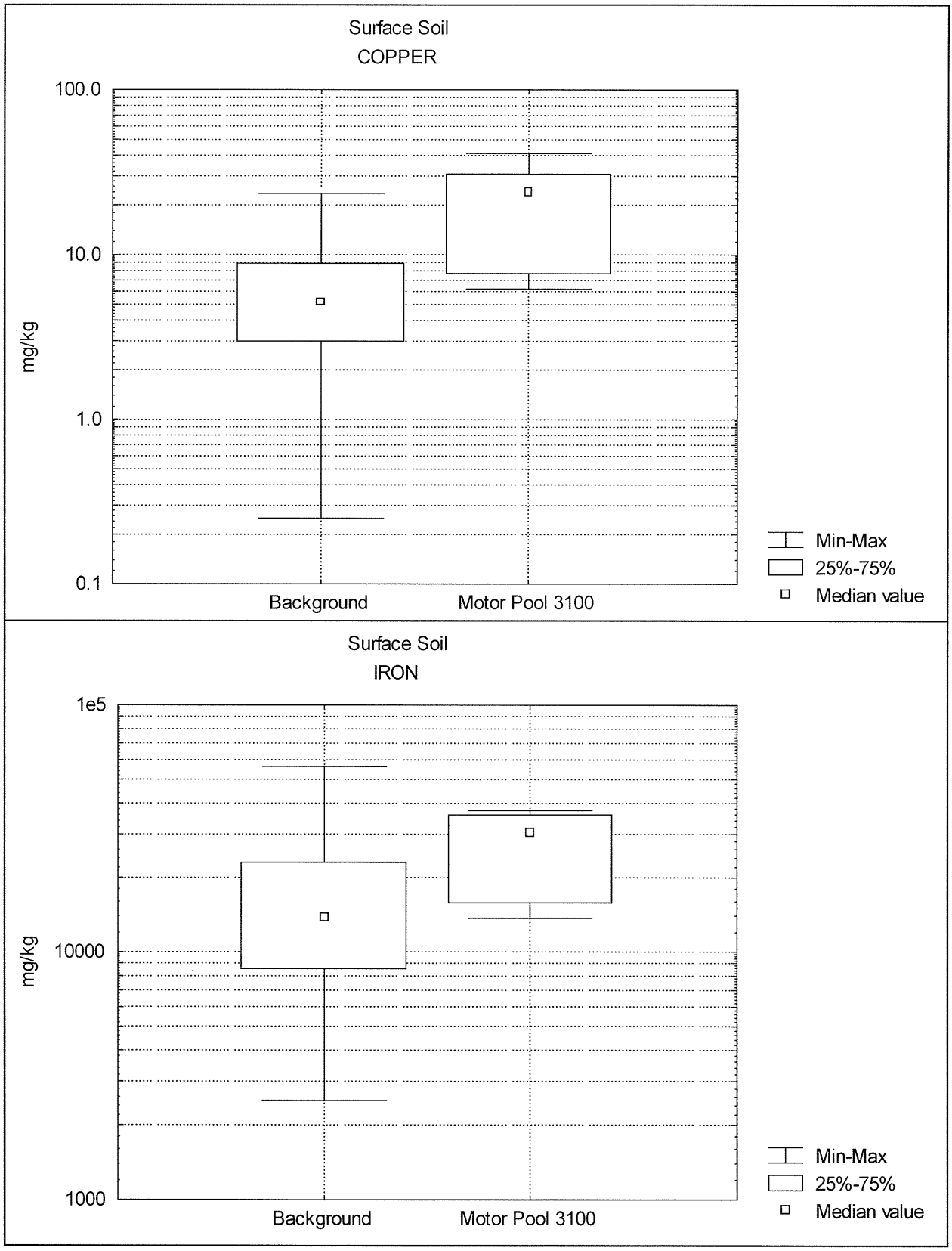
10.0
1.0
0.1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-4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COPPER
100.0
10.0
1.0
0.1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value
Surface Soil
IRON
1e5
10000
1000
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-5

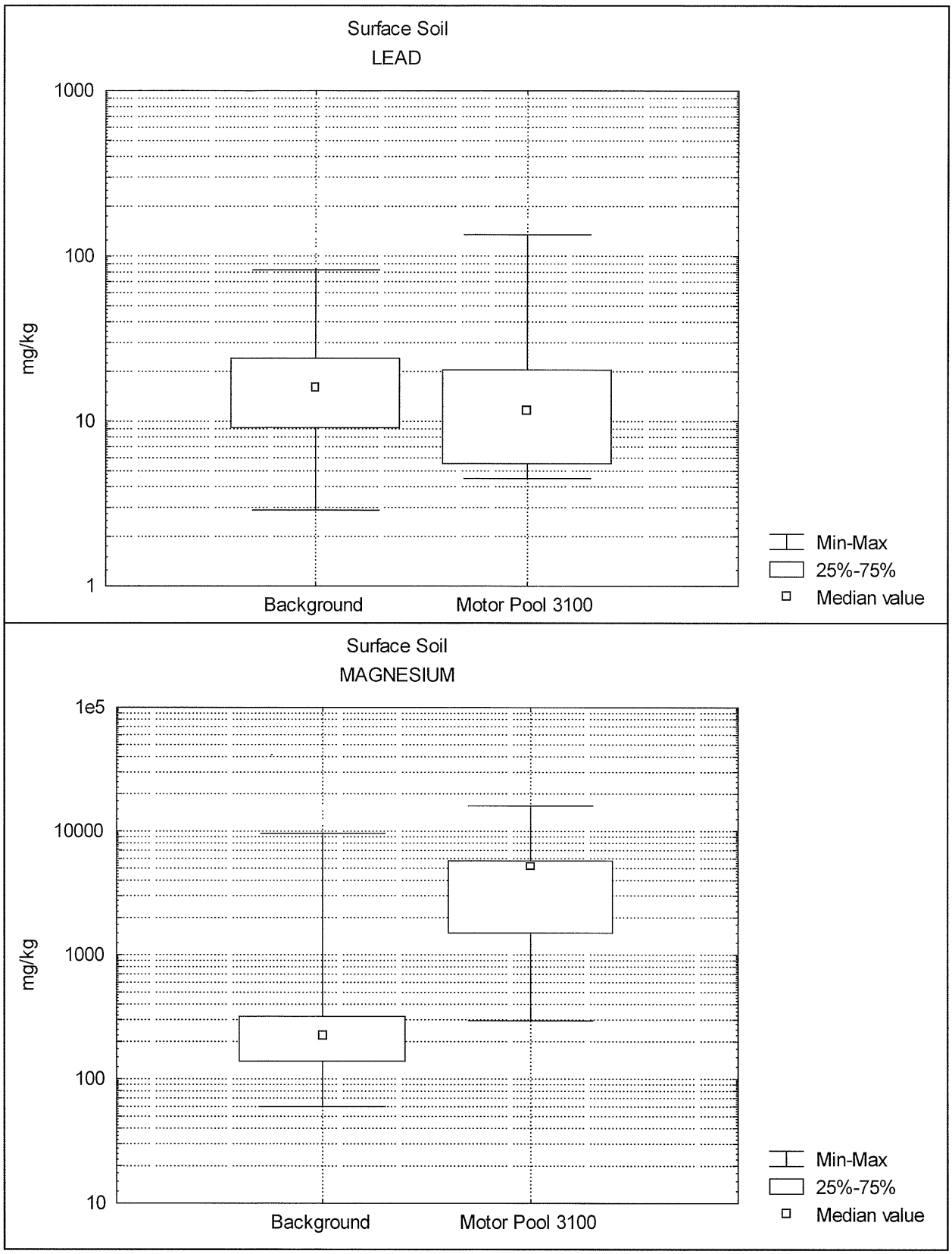
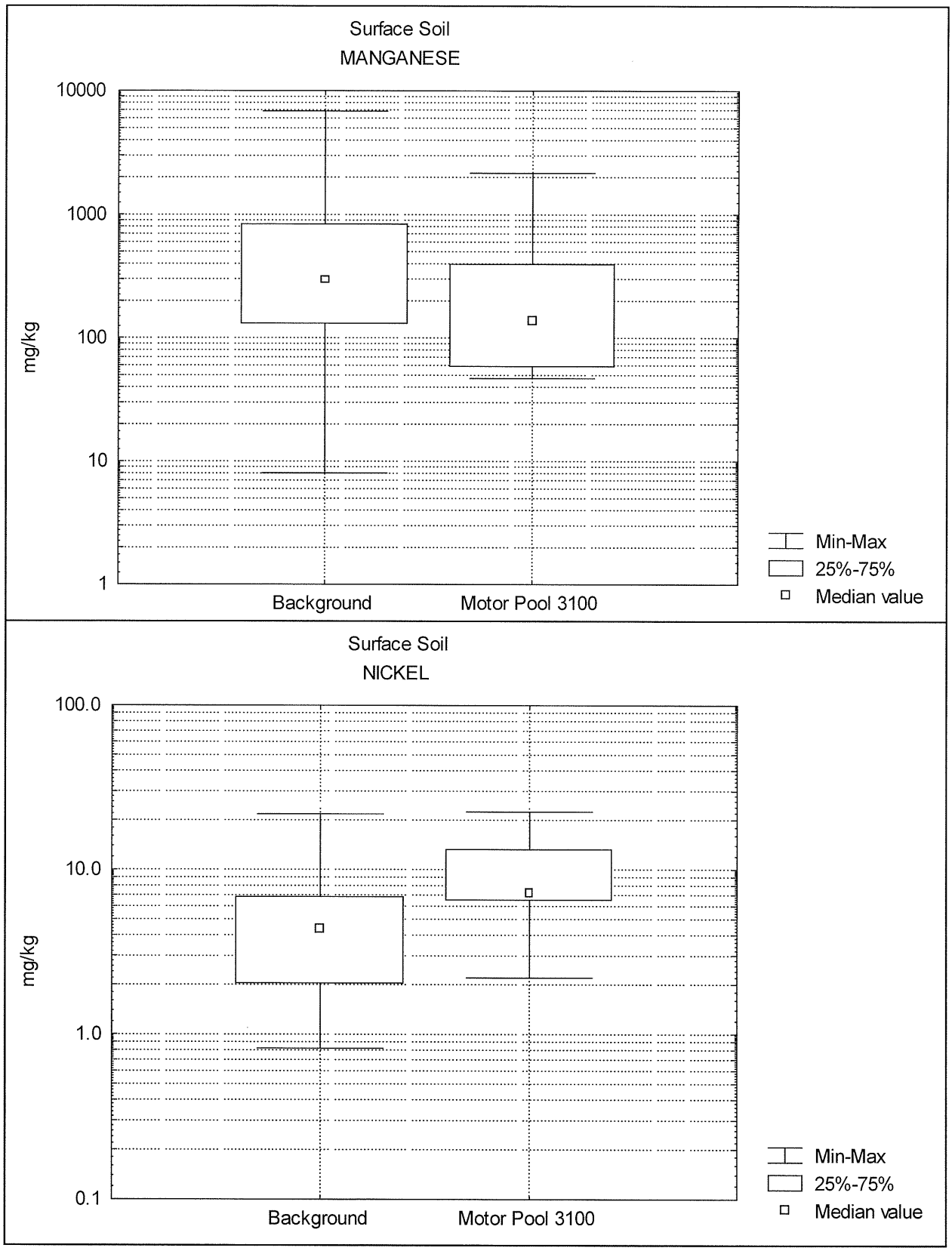

Surface Soil
LEAD
1000
100
10
1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value
Surface Soil
MAGNESIUM
1e5
10000
1000
100
10
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-6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1000
100
10
1
mg/kg
Background
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Min-Max
25%-75%
Median value
Surface Soil
NICKEL
100.0
10.0
1.0
0.1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-7

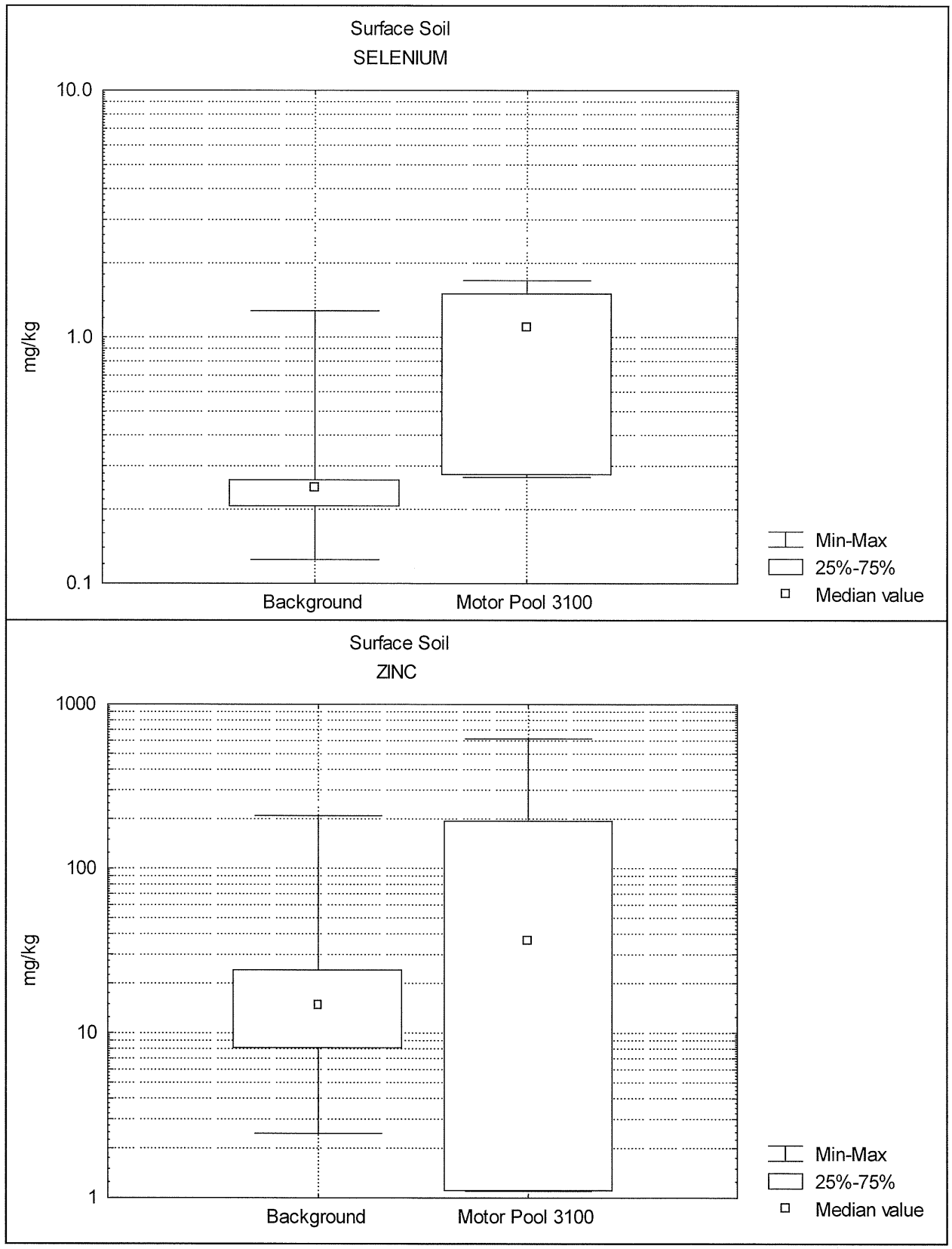
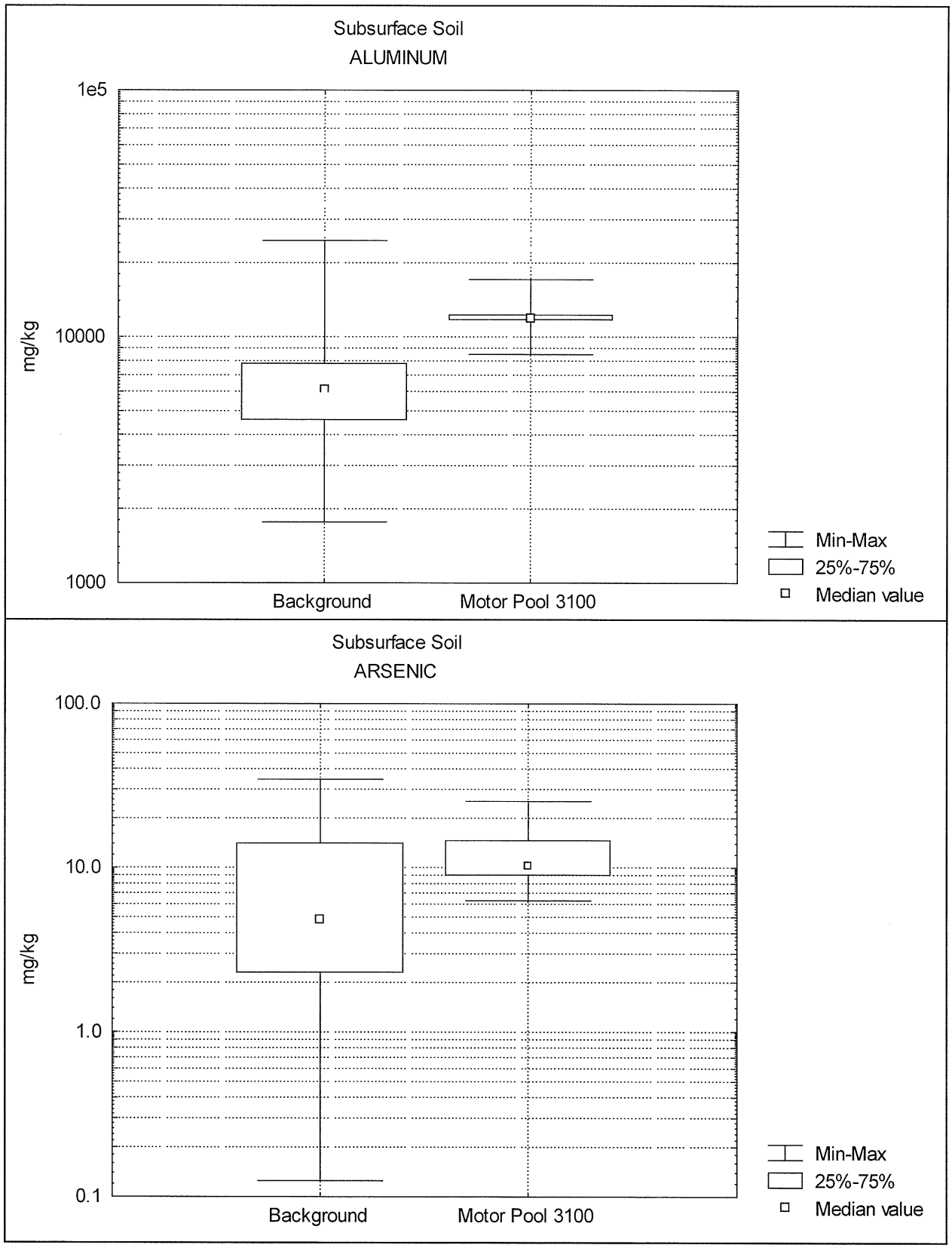

Surface Soil
SELENIUM
10.0
1.0
0.1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value
Surface Soil
ZINC
1000
100
10
1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-8


Subsurface Soil
ALUMINUM
1e5
10000
1000
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value
Subsurface Soil
ARSENIC
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10.0
1.0
0.1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-9

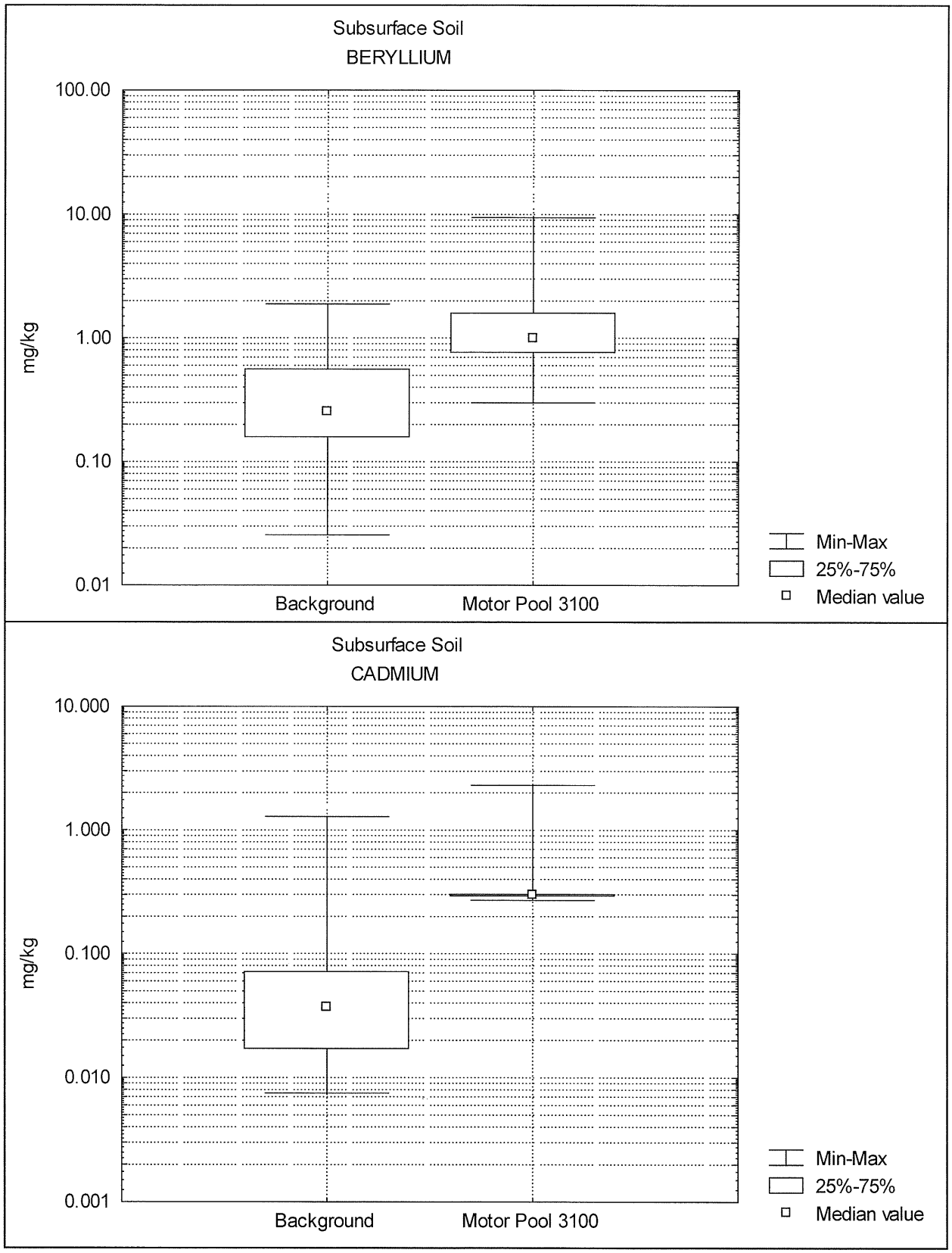
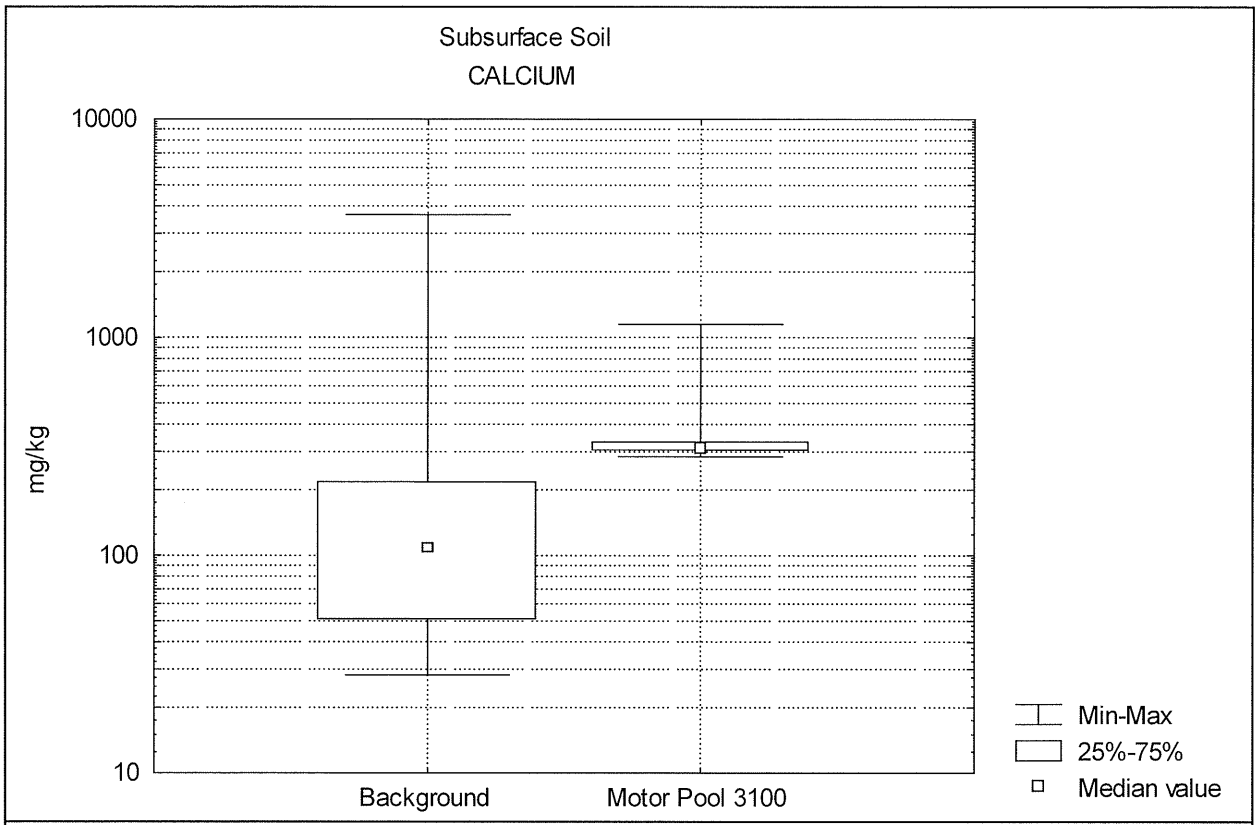

Subsurface Soil
BERYLLIUM
100.00
10.00
1.00
0.10
0.01
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value
Subsurface Soil
CADMIUM
10.000
1.000
0.100
0.010
0.001
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-10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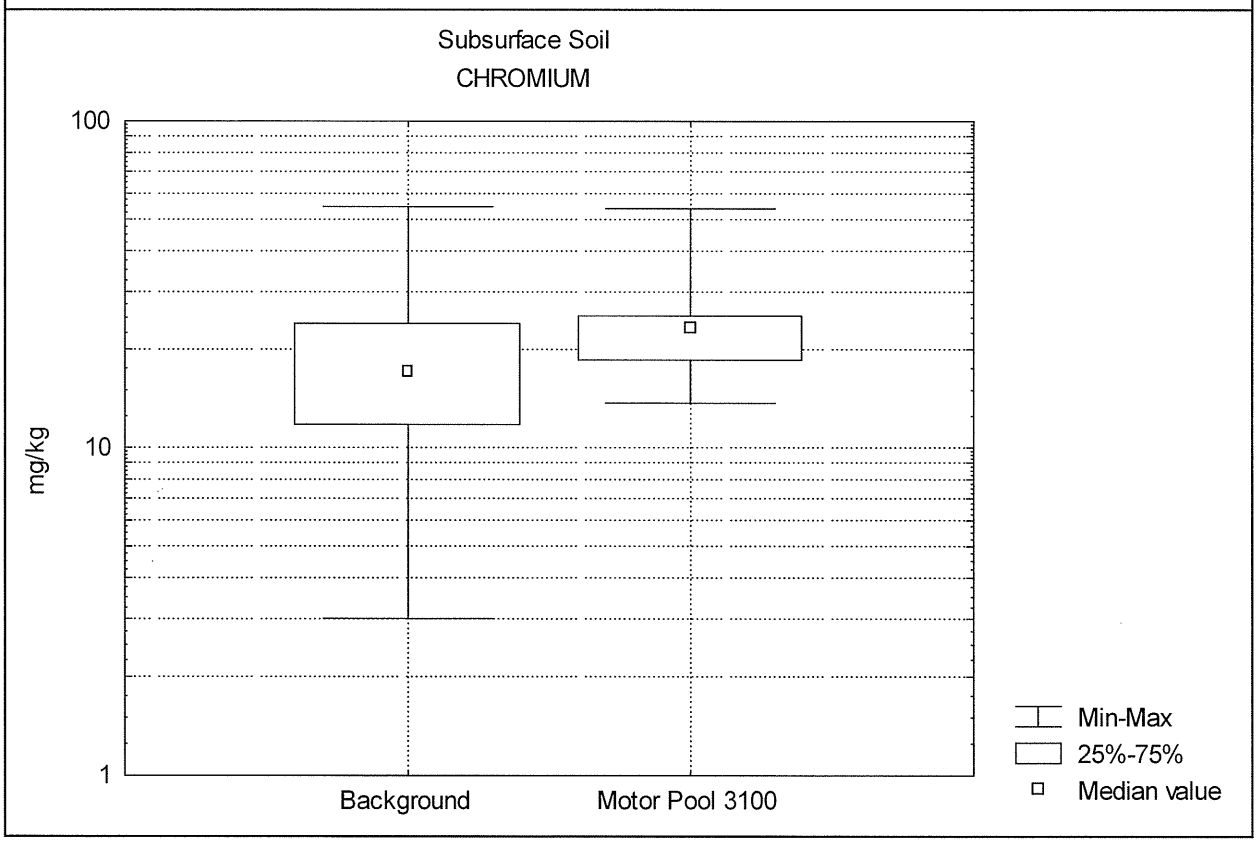
CALCIUM
10000
1000
100
10
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value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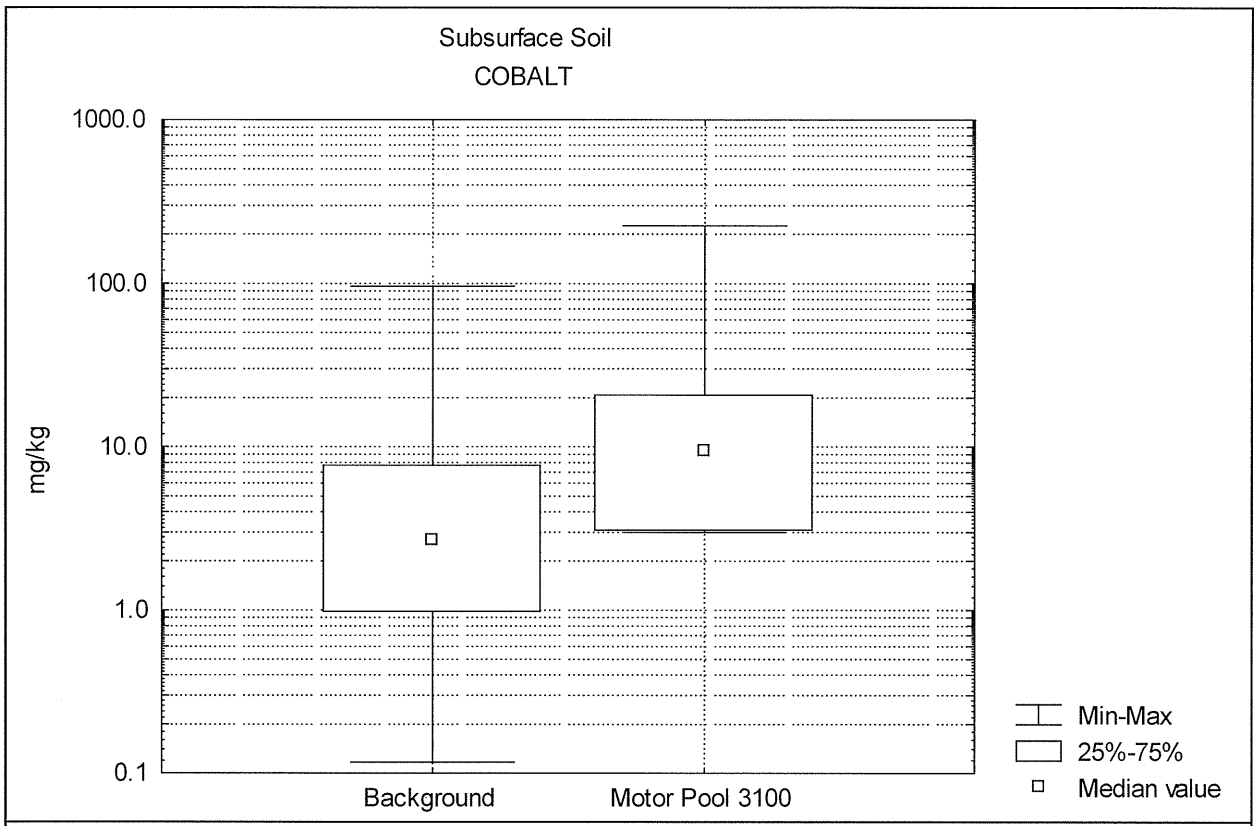
CHROMIUM
100
10
1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-11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COBALT
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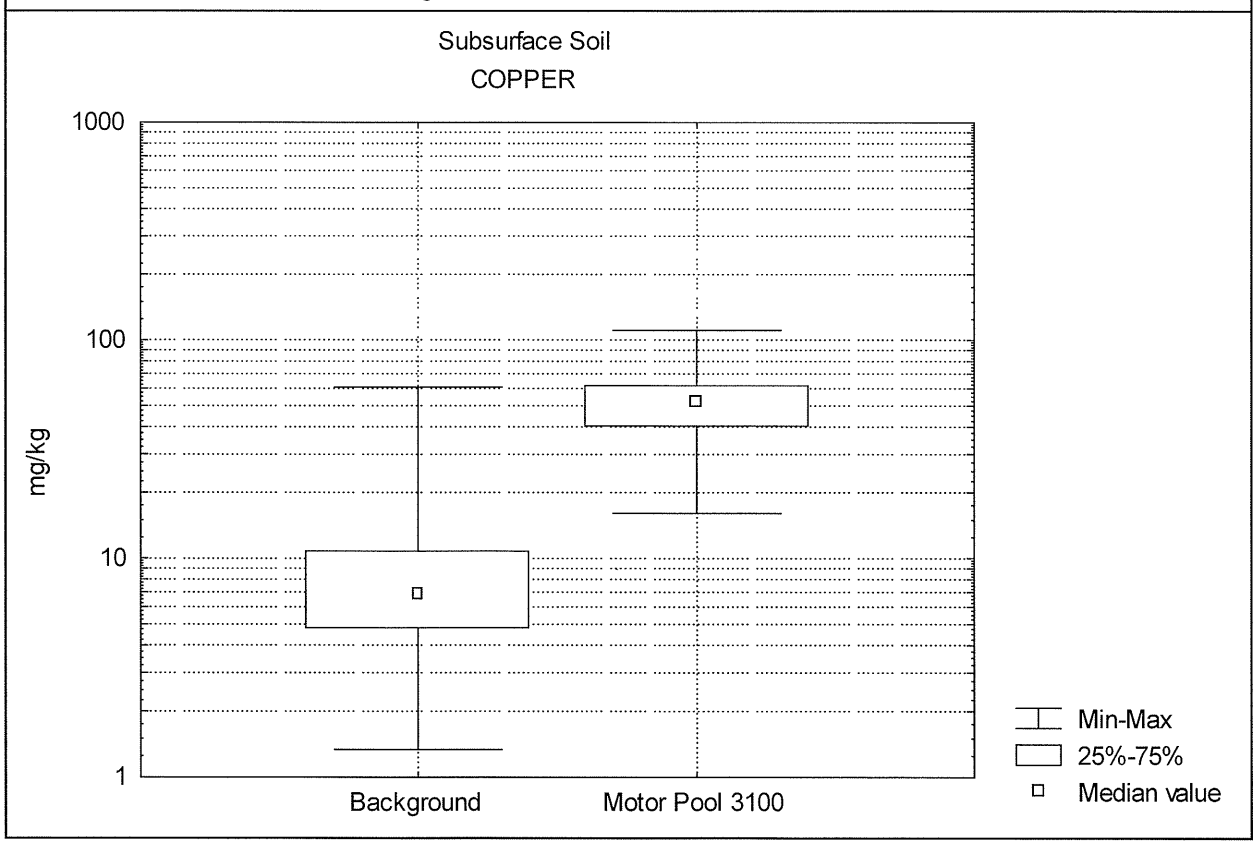
0.1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value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100
10
1
mg/kg
Background
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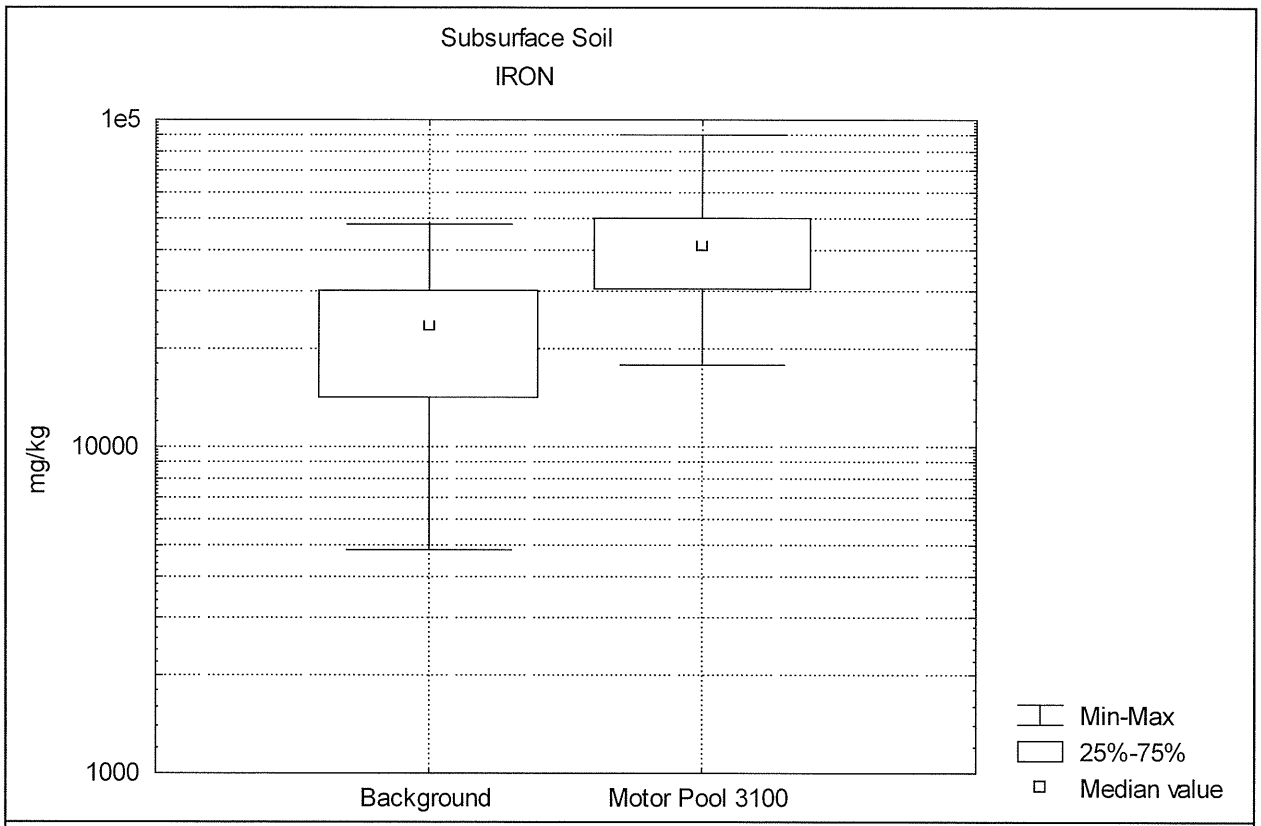
Min-Max
25%-75%
Median value

Figure 1-12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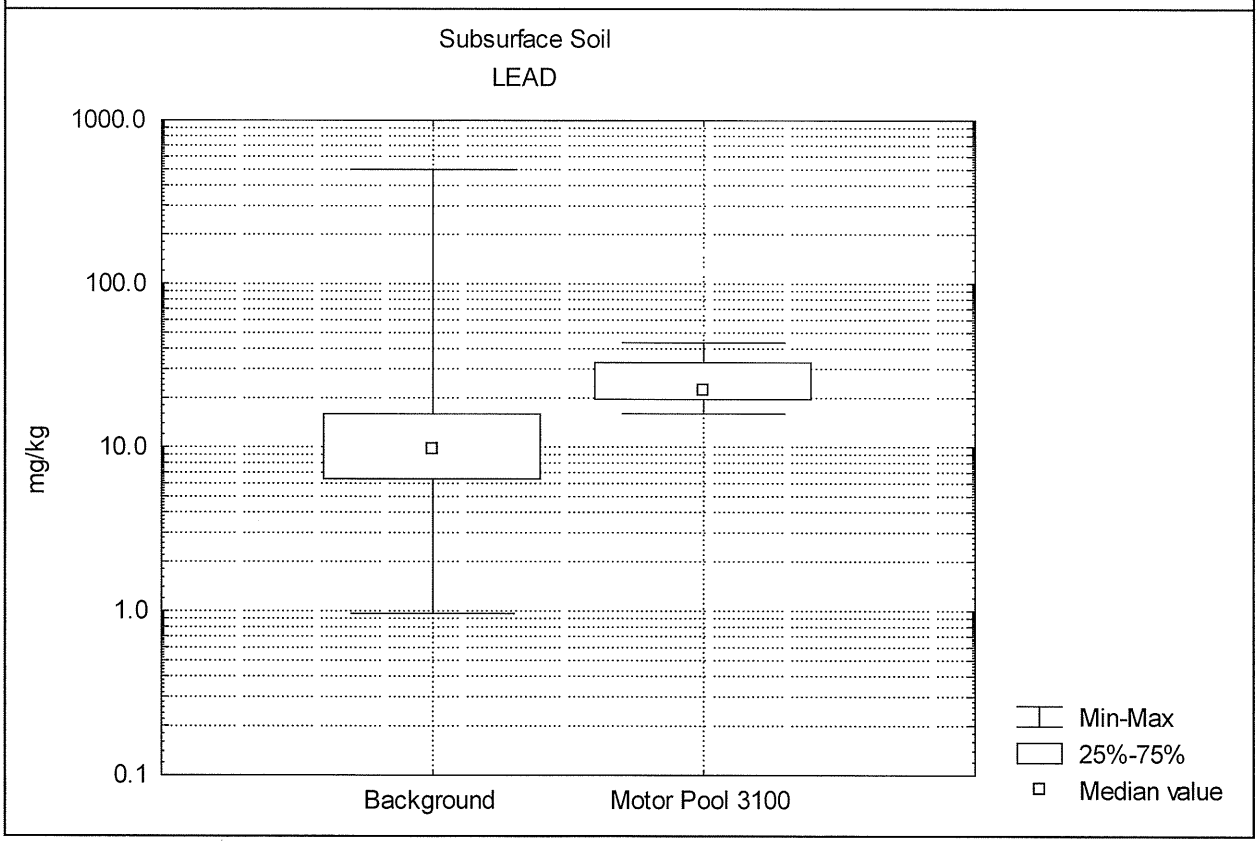
10000
1000
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value


Subsurface Soil
LEAD
1000.0
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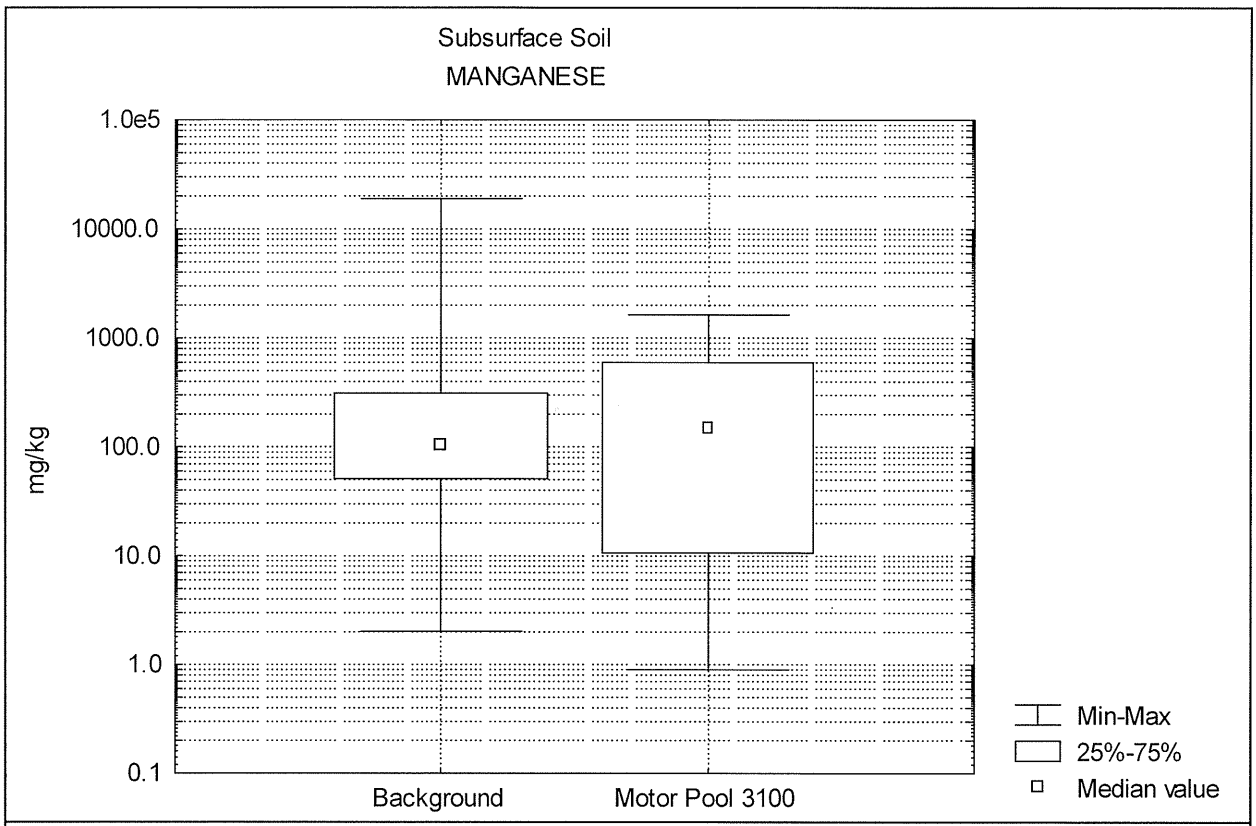
10.0
1.0
0.1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-13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mg/kg
Background
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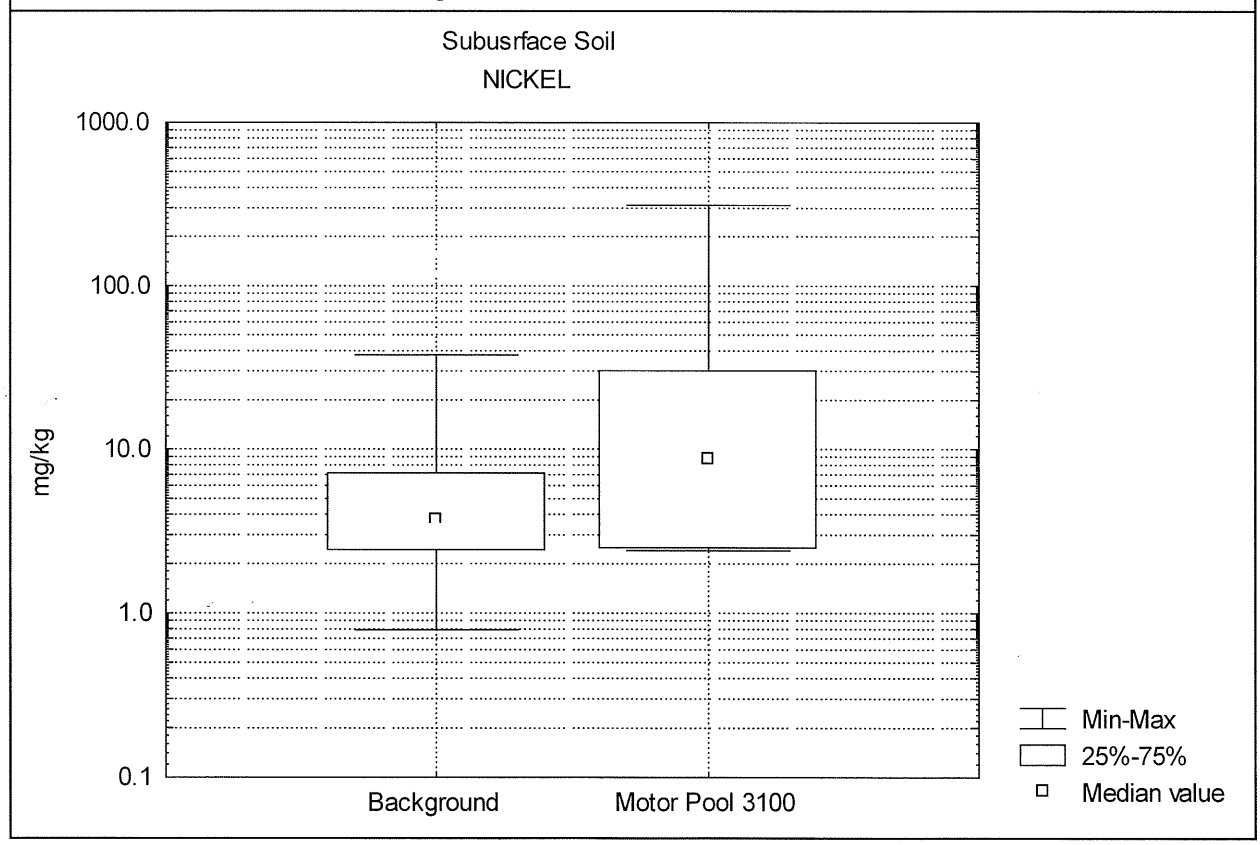
Min-Max
25%-75%
Median value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mg/kg
Background
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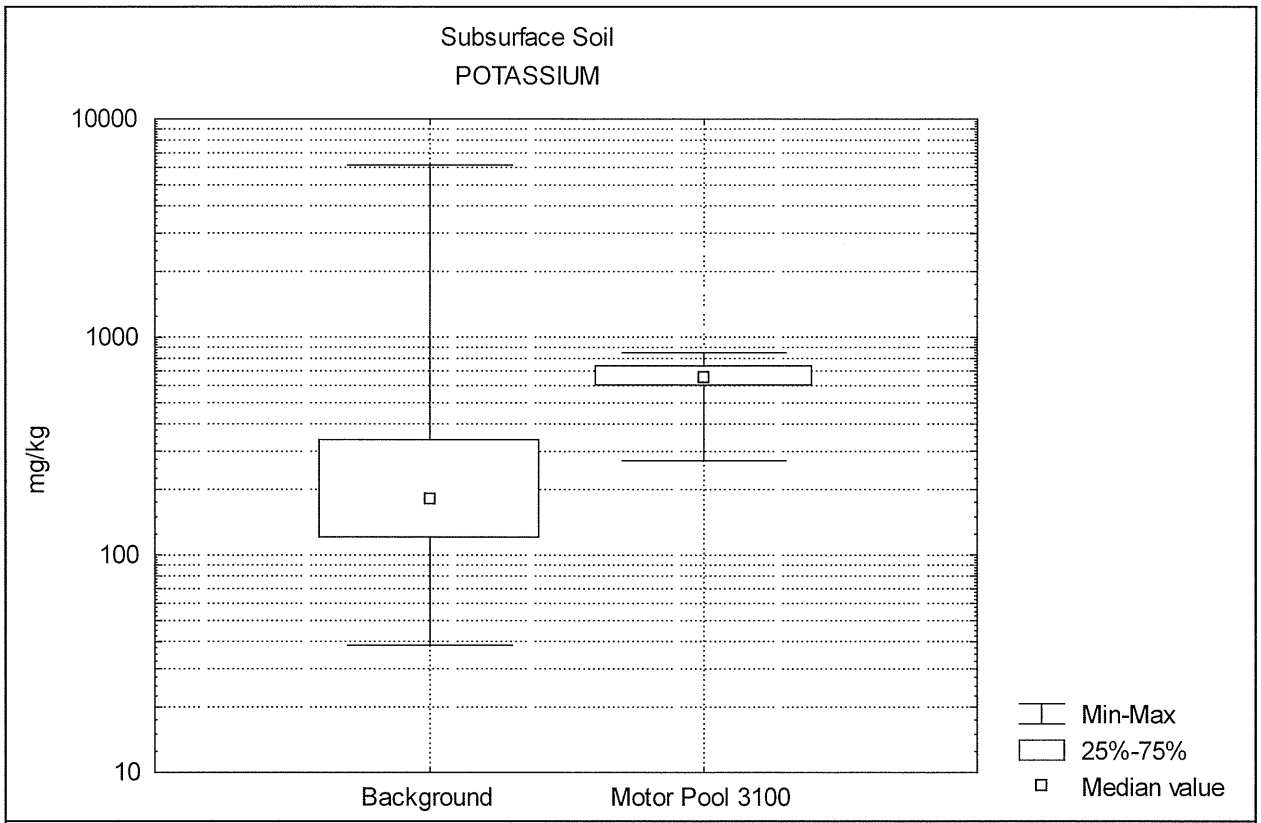
25%-75%
Median value

Figure 1-14


Subsurface Soil
POTASSIUM
10000
1000
100
10
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

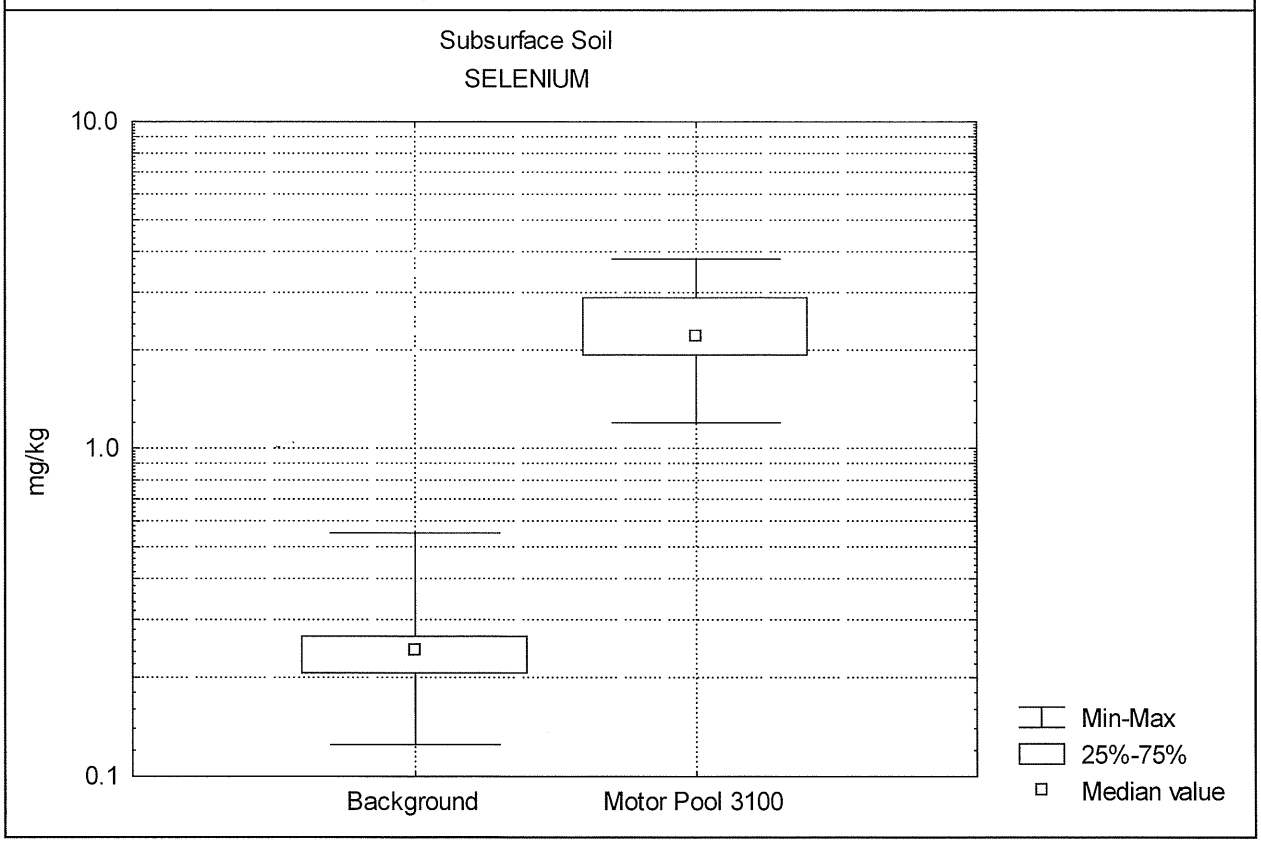
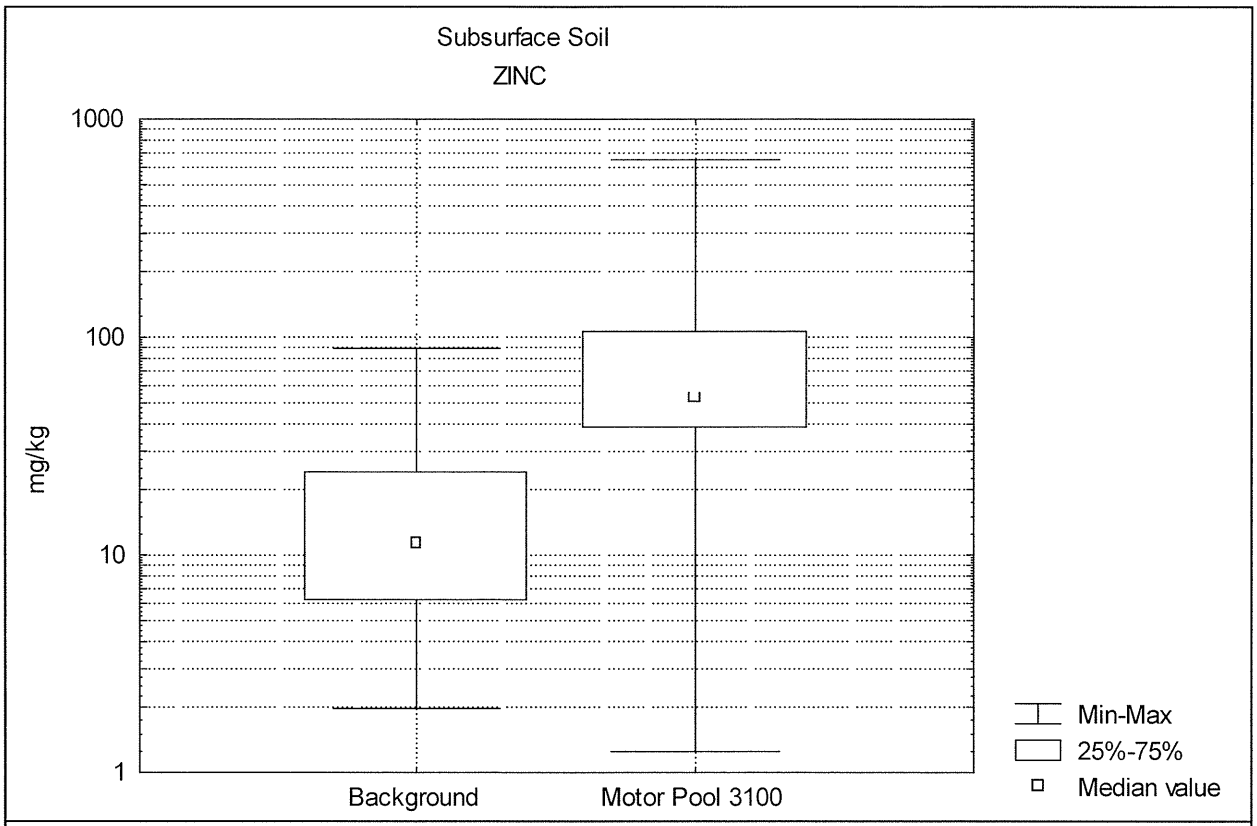

Subsurface Soil
SELENIUM
10.0
1.0
0.1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-15


Subsurface Soil
ZINC
1000
100
10
1
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

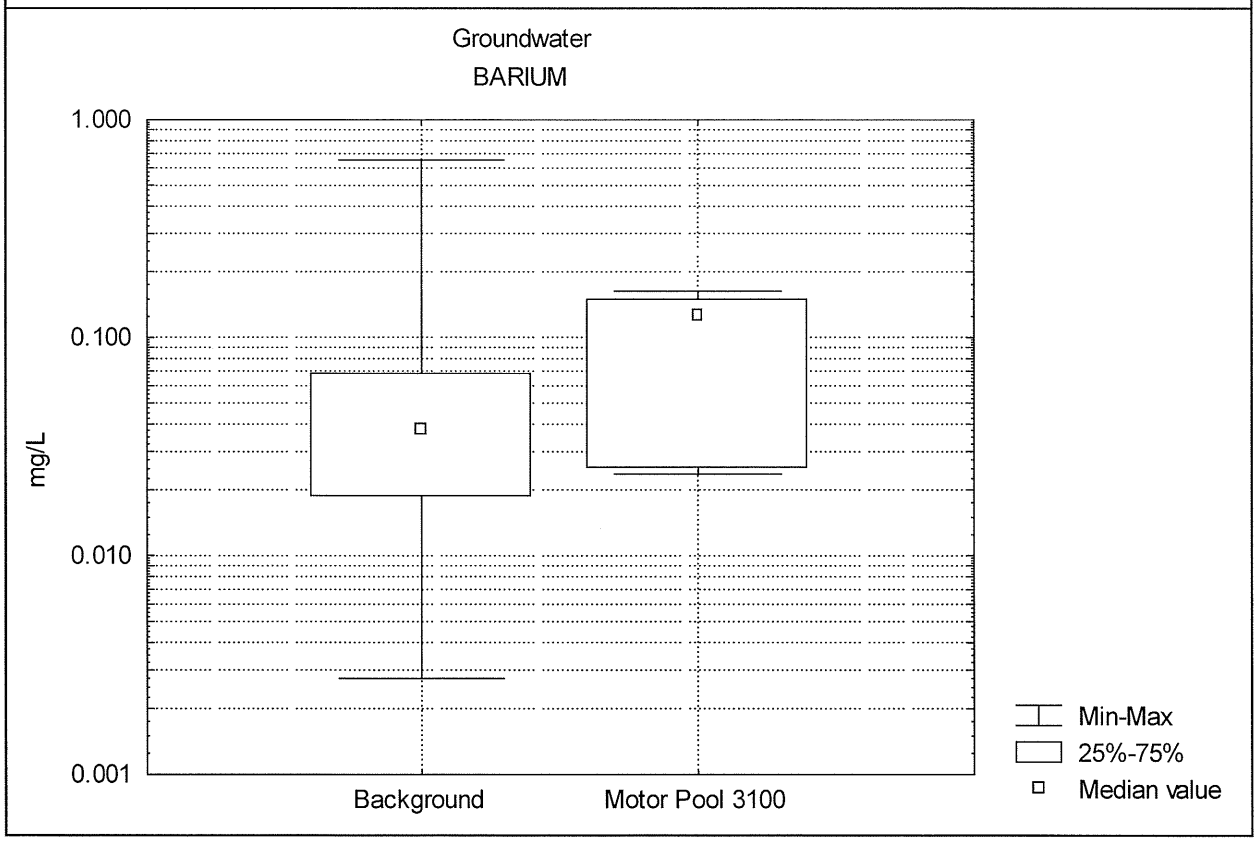

Groundwater
BARIUM
1.000
0.100
0.010
0.001
mg/L
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-16

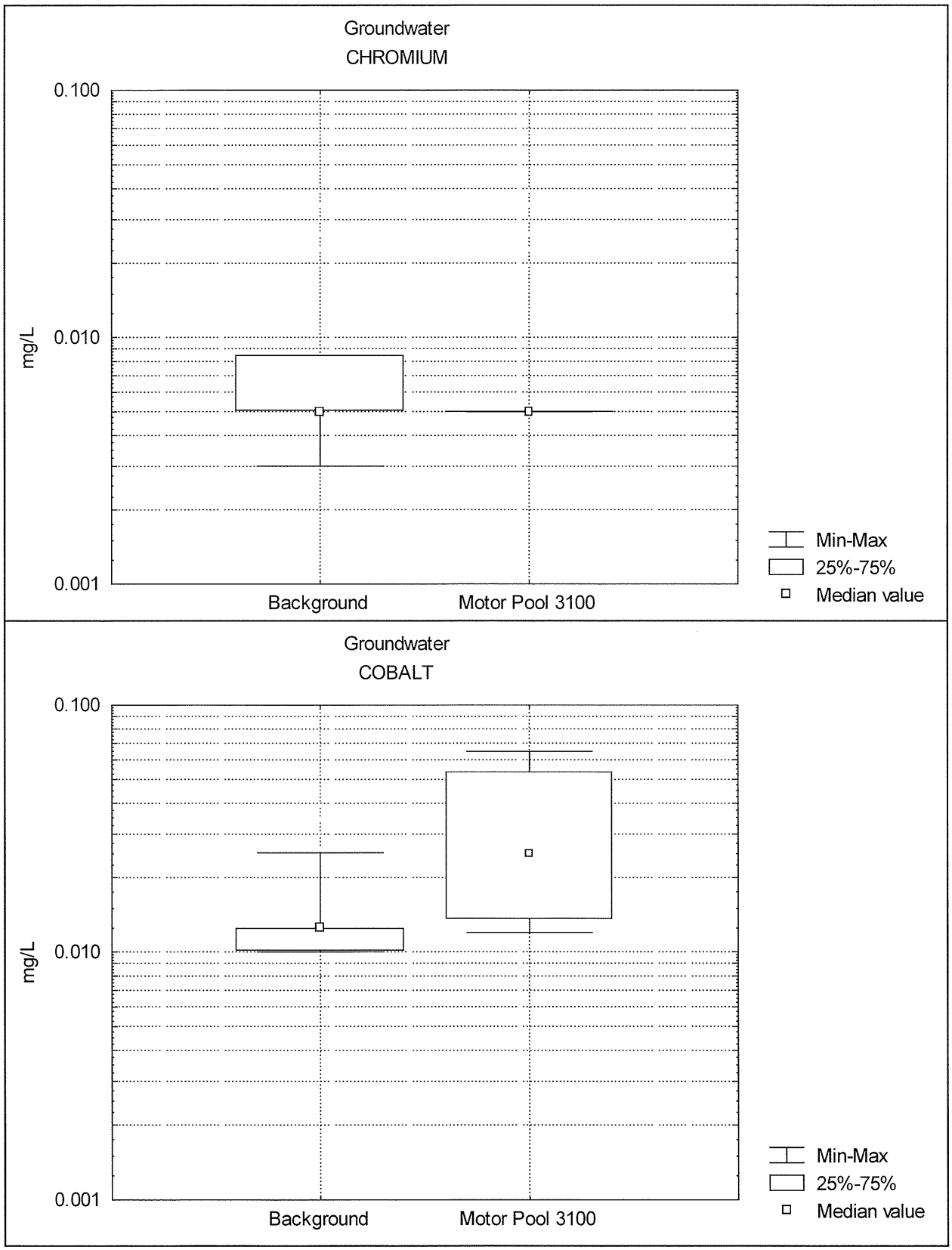

Groundwater
CHROMIUM
0.100
0.010
0.001
mg/L
Background
Motor Pool 3100
Min-Max
25%-75%
Median value
Groundwater
COBALT
0.100
0.010
0.001
mg/L
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-17

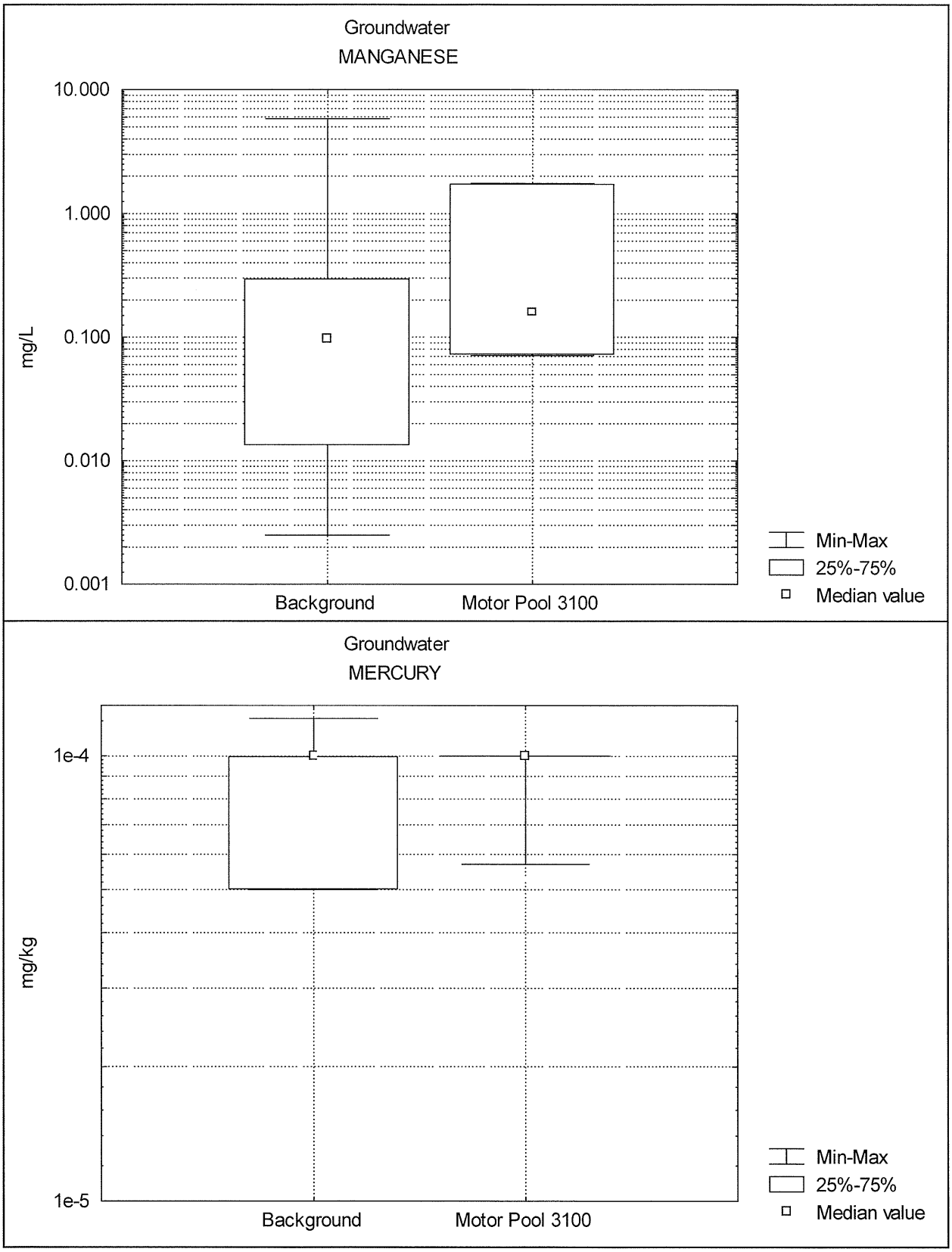
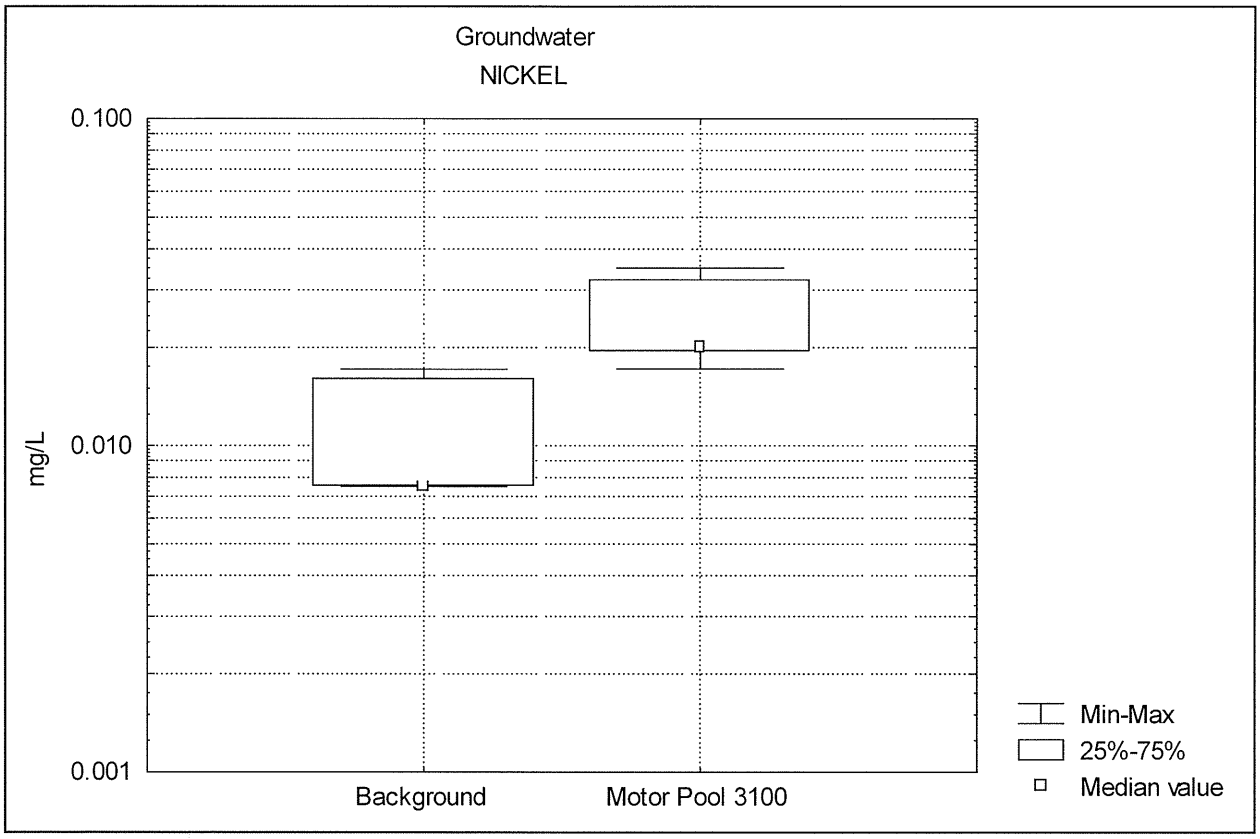

Groundwater
MANGANESE
10.000
1.000
0.100
0.010
0.001
mg/L
Background
Motor Pool 3100
Min-Max
25%-75%
Median value
Groundwater
MERCURY
1e-4
1e-5
mg/kg
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

Figure 1-18


Groundwater
NICKEL
0.100
0.010
0.001
mg/L
Background
Motor Pool 3100
Min-Max
25%-75%
Median value

GEOCHEMICAL
(TIER 3)

Geochemical Evaluation of Metals in Soil and Groundwater
Motor Pool Area 3100, Parcel 146(7)
Fort McClellan, Alabama

1.0 Introduction

This report provides the results of a geochemical evaluation of inorganic constituents in soil and groundwater samples from Motor Pool Area 3100, Parcel 146(7), at Fort McClellan in Calhoun County, Alabama. Fourteen elements in soil and four 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 a depth of 0 to 1 foot below ground surface [bgs]) and thirteen subsurface soil samples (obtained from various depths ranging from 1 to 13 feet bgs) collected in October and November 1998; and seven unfiltered groundwater samples collected in December 1998 and January 1999. 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 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 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 for Motor Pool Area 3100, Parcel 146(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 205(7). 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.

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 ($HAsO_4^{-2}$, $H_2AsO_4^{-}$) (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 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.

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 ($Al_2O_3 \bullet nH_2O$) and hydroxides [$Al(OH)_3$]; and iron oxide (Fe_2O_3), iron hydroxide [$Fe(OH)_3$], and iron oxyhydroxide ($FeO \bullet OH$) 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; they maintain 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 such as $Cr(OH)_2^+$, $Cr(OH)_3^0$, and $Cr(OH)_4^-$, depending on pH (EPRI, 1984). The positive, neutral, and negative charges on these species result in the distribution of chromium on several different types of sorptive surfaces, including clay and iron oxide minerals.

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 Zn/Al ratio. If some samples plot above the linear trend established by the other samples, then those samples have an anomalously high Zn/Al ratio, and most likely contain excess zinc that cannot be explained by these natural processes.

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.

Alternative techniques for assessing the effects of suspended particulates on trace element concentrations are the evaluation of correlations of trace element concentrations versus turbidity, evaluation of correlations of trace element concentrations versus total suspended solids (TSS), and comparison of analyses of filtered versus unfiltered splits of samples. Turbidity and TSS 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. Comparisons of filtered versus unfiltered analyses cannot be performed for the Motor Pool Area 3100 geochemical evaluation, because filtered splits were not obtained for the site samples.

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 (DO) measurements, or the presence of reducing gases such as hydrogen, methane, ethane, or ethene. Anaerobic microbes can also reduce sulfate to sulfide and nitrate to ammonia, resulting in local depressions in sulfate and nitrate concentrations, and local detections of sulfide and ammonia. In areas impacted by chlorinated solvents, additional evidence for the establishment of anaerobic reducing conditions is the presence of *cis*-1,2-dichloroethene 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 aluminum, arsenic, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, magnesium, nickel, potassium, selenium, and zinc in soil samples from Motor Pool Area 3100. Correlation plots are provided in Attachment 1. Table 1 lists the samples identified as containing anomalously high element concentrations, and provides their location codes and depth intervals.

Aluminum

Aluminum is the second most abundant element analyzed in the site soil samples, with a mean concentration of 10,154 milligrams per kilogram (mg/kg) (1.0 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

Table 1

Soil Samples Containing Anomalously High Element Concentrations
Motor Pool Area 3100, Parcel 146(7)
Fort McClellan, Calhoun County, Alabama

Medium	Sample Location	Sample Number	Sample Date	Depth (feet bgs)	Element(s)
Surface Soil	FTA-146-DEP01	CP0024	9-Nov-98	0 - 1	Zinc
Surface Soil	FTA-146-GP05	CP0005	6-Oct-98	0 - 1	Cobalt, Zinc
Subsurface Soil	FTA-146-GP07	CP0012	6-Oct-98	1 - 5	Zinc
Subsurface Soil	FTA-146-GP09	CP0016	6-Oct-98	9 - 13	Beryllium, Cobalt, Nickel, Zinc
Subsurface Soil	FTA-146-GP12	CP0022	7-Oct-98	8 - 12	Selenium

bgs - Below ground surface.

surfaces (Cornell and Schwertmann, 2003). Iron is the most abundant element analyzed in the site soil samples (mean concentration of 39,250 mg/kg; 3.9 weight percent). The site soil boring logs note that reddish brown, yellowish brown, brown, or gray clay or silty clay is the predominant soil type in many of 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). The red, yellow, and brown colors of the site soils are imparted by the iron oxides, which are highly pigmented. Clays and iron oxides tend to exist as very fine particles, so both aluminum and iron are enriched in samples with finer grain sizes.

A plot of aluminum versus iron concentrations provides a qualitative indicator of the relative abundance of clay and iron oxide minerals in site soil (Figure 1). For both surface and subsurface intervals, the site samples contain similar aluminum concentrations as the background samples and lie on the general background trend (Figure 1). The similarity in Al/Fe ratios between the site and background samples indicates a natural source for the aluminum in the site samples. It is important to note that clays and iron oxides adsorb specific trace elements (as discussed in Section 2.1), so the samples that plot on the upper end of the trend in Figure 1 – including 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 2.1, arsenic in oxic soil pore fluid has a strong affinity to adsorb on iron oxides, so 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.

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 concentrations is often observed for uncontaminated samples. The background samples and most of the site samples form a generally linear trend with a positive slope in a plot of beryllium versus iron (Figure 3). Most of the site samples with high beryllium concentrations also have proportionally higher iron content and lie on the background trend. Beryllium in these samples has a natural source. Subsurface soil sample CP0016, however, contains the highest beryllium concentration of both site and background data sets (9.4 mg/kg) but only moderate iron (as well as only moderate aluminum and manganese), and lies above the linear trend established by the other

samples. There may be a component of contamination in this sample, which was collected from sample location FTA-146-GP09 at a depth of 9 to 13 feet bgs (Table 1).

Conclusion

The beryllium concentration in subsurface soil sample CP0016 is anomalously high and may contain a component of contamination (Table 1). Beryllium detected in the other 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 4). Surface soil sample CP0024 and subsurface soil sample CP0016 are the only site samples with detectable cadmium. They have higher cadmium concentrations (3.3 mg/kg and 2.3 mg/kg) than most of the background samples, but they also have high manganese concentrations (2,160 mg/kg and 1,630 mg/kg). Elevated cadmium in these samples is due to the preferential enrichment of manganese oxides, and is natural.

Another perspective of the data sets is provided in Figure 5, which displays the cadmium concentrations of the site and background samples (y-axis) versus their corresponding Cd/Mn ratios (x-axis). If the site samples contained excess cadmium from a contaminant source, then they would exhibit anomalously high Cd/Mn ratios relative to background and would plot to the right of the background samples in Figure 5. However, neither site sample exhibits an anomalous Cd/Mn ratio; they both have Cd/Mn ratios that are within the background range.

Conclusion

Cadmium detected in the site soil samples is naturally occurring.

Calcium

Calcium is a primary component of carbonate minerals and is also associated with clay minerals. Magnesium and calcium have similar chemical properties, and magnesium often substitutes for calcium in minerals. Positive correlations between calcium and magnesium concentrations are thus commonly observed in soil samples. A plot of calcium versus magnesium is provided in Figure 6. The site and background samples exhibit a generally linear trend with a positive slope. The site surface soil samples have higher calcium concentrations than the majority of background samples, but they also contain high magnesium and lie on the linear trend. This indicates that the site samples have Ca/Mg ratios consistent with those of the background samples, and that the calcium is natural. Another perspective of these data is provided in Figure 7, which displays the calcium concentrations of the site and background samples versus their corresponding Ca/Mg ratios. Although the site surface soil samples have elevated calcium concentrations, their Ca/Mg ratios are all within the background range. Subsurface soil samples CP0004 and CP0012 could not be depicted in Figures 6 and 7 due to a lack of detectable magnesium; however, their calcium concentrations (1,150 mg/kg and 596 mg/kg) are well below the background maximum (17,900 mg/kg), and their Ca/Al ratios (0.10 and 0.07) are below the mean background Ca/Al ratio of 0.13.

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

Chromium

As discussed in Section 2.1, chromium can be present in soil pore fluid as various species with different charges, and thus it can adsorb on several different types of minerals including iron oxides and clays. A plot of chromium versus iron reveals a common linear trend for the site and background samples (Figure 8). The site samples with high chromium concentrations also contain high iron concentrations, and lie on the trend established by the other samples. These observations indicate that the elevated chromium in the site samples has a natural source.

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

Cobalt

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 cobalt. A plot of cobalt versus manganese reveals a common linear trend with a positive slope for the background samples and most of the site samples (Figure 9). Most of the site samples with high cobalt concentrations also contain proportionally higher manganese, and lie on the linear background trend. Cobalt in these site samples is naturally occurring. Surface soil sample CP0005 and subsurface soil sample CP0016, however, contain the highest cobalt concentrations of the site data set (61.4 mg/kg and 225 mg/kg, respectively) but only moderate manganese and lie above the background trend. The cobalt concentrations in these two samples are anomalously high relative to the reference element concentrations, and may contain a component of contamination (Table 1).

Conclusion
Cobalt concentrations in surface soil sample CP0005 and subsurface soil sample CP0016 are anomalously high and may contain a component of contamination (Table 1). Cobalt detected in the other 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 iron for the site and background samples is provided in Figure 10. Most of the background samples form a generally linear trend with a positive slope, and the site samples lie on this trend. This indicates that copper in the site samples is associated with iron oxides at ratios consistent with those of the background samples, and is natural.

This conclusion is supported by comparison of site versus background Cu/Fe ratios. Figure 11 displays the copper concentrations of the site and background samples (y-axis) versus their corresponding Cu/Fe ratios (x-axis). If a site sample contained excess copper from a contaminant source, then it would exhibit an anomalously high Cu/Fe ratio relative to background and would plot to the right of the background samples in Figure 11. No such samples are observed in the plot. All of the site samples exhibit Cu/Fe ratios that are within the background range.

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 39,250 mg/kg (3.9 weight percent). The site soil boring logs note that reddish brown, yellowish brown, brown, or gray clay or silty clay is the predominant soil type in many of the sampled intervals. The iron in the samples is dominantly present as iron oxides, which are highly pigmented and impart the red, yellow, and brown colors to the site soils. Iron oxides are common soil-forming minerals, and occur as discrete mineral grains or as coatings on silicate minerals (Cornell and Schwertmann, 2003). Aluminum is the second most abundant element analyzed in the site samples (mean concentration of 10,154 mg/kg; 1.0 weight percent), and is a primary component of 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). Clays and iron oxides tend to exist as very fine particles, so both aluminum and iron are enriched in samples with finer grain sizes.

As discussed in the Aluminum evaluation, a plot of aluminum versus iron concentrations can be used as a qualitative indicator of the relative abundance of clay and iron oxide minerals in site soil (Figure 1). The site and background samples form a common, generally linear trend with a positive slope. Three site samples have higher iron concentrations than the background samples, but their Al/Fe ratios are similar to those of the background samples. Figure 12 displays the iron concentrations of the site and background samples (y-axis) versus their corresponding Fe/Al ratios (x-axis). If a site sample contained excess iron from a contaminant source, then it would exhibit an anomalously high Fe/Al ratio relative to background and would plot to the right of the background samples in Figure 12. No such samples are observed in the plot. All of the site samples exhibit Fe/Al ratios that are within the background range.

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

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

Magnesium

As noted in the Calcium evaluation, magnesium and calcium have similar chemical properties, and magnesium often substitutes for calcium in minerals. Positive correlations between calcium and magnesium concentrations are thus commonly observed in soil samples. The site and background samples exhibit a generally linear trend with a positive slope in a plot of calcium versus magnesium (Figure 6). The site samples with the highest magnesium concentrations also have proportionally higher calcium concentrations, and lie on the linear trend. This indicates a natural source for the elevated magnesium in the site samples. Subsurface soil sample CP0016 could not be depicted in Figure 6 due to a lack of detectable calcium; however, its magnesium concentration of 661 mg/kg is well below the background maximum of 9,600 mg/kg, and its Mg/Al ratio of 0.075 is similar to the mean background Mg/Al ratio of 0.065 and below the maximum background Mg/Al ratio of 1.89. This indicates that the magnesium in sample CP0016 is naturally occurring.

Conclusion

Magnesium detected in the site soil samples is naturally occurring.

Nickel

Nickel concentrations in soil are commonly controlled through adsorption on iron oxides (Kabata-Pendias, 2001), so a positive correlation between nickel and iron concentrations is expected for uncontaminated samples. The background samples and most of the site samples form a linear trend with a positive slope in a plot of nickel versus iron (Figure 13). Most of the site samples with high nickel concentrations also have proportionally higher iron content and lie on the background trend. Nickel in these samples is associated with iron oxides at ratios consistent with those of the background samples, and is natural. Subsurface soil sample CP0016, however, contains the highest nickel concentration of both site and background data sets (312 mg/kg) but only moderate iron (as well as only moderate aluminum and manganese), and lies above the linear trend established by the other samples. There may be a component of contamination in this sample, which was collected from sample location FTA-146-GP09 at a depth of 9 to 13 feet bgs (Table 1).

Conclusion

The nickel concentration in subsurface soil sample CP0016 is anomalously high and may contain a component of contamination (Table 1). Nickel detected in the other 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 14). The site samples have higher potassium concentrations than many of the background samples, but they also have proportionally higher aluminum. This indicates a natural source for potassium in the site samples.

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

Selenium

Selenium is present in oxic soil pore fluid as oxyanions, and has a strong affinity to adsorb on iron oxides, which tend to maintain a net positive surface charge. A positive correlation between selenium and iron concentrations is thus expected for uncontaminated soil samples. A plot of detectable selenium versus iron concentrations is provided in Figure 15. Most of the site samples form a generally linear trend with a positive slope, and the two background samples with detectable selenium lie on this trend. Most of the site samples with high selenium concentrations also exhibit high iron content, which indicates that these samples are preferentially enriched in iron oxides and associated trace elements. Selenium in these samples is natural.

Subsurface soil sample CP0022, however, contains the highest selenium concentration of both site and background data sets (3.8 mg/kg) but low iron (as well as only moderate aluminum and nondetectable manganese), and it lies above the trend established by the other samples. This sample contains an anomalously high Se/Fe ratio relative to the other samples, which suggests that it contains an excess amount of selenium beyond that which can be explained by its natural iron oxide content. A plot of selenium concentrations versus corresponding Se/Fe ratios supports this conclusion (Figure 16). Sample CP0022 has the highest Se/Fe ratio of the site and background samples (2.1E-04) and lies to the right of the other samples, which all have Se/Fe ratios of 9.4E-05 or lower. There may be a component of contamination in this sample, which was collected at sample location FTA-146-GP12 from a depth of 8 to 12 feet bgs (Table 1).

Conclusion
The selenium concentration in subsurface soil sample CP0022 is anomalously high and may contain a component of contamination (Table 1). Selenium detected in the site soil samples is naturally occurring.

Zinc

Zinc in soils is commonly associated with clay minerals and hydrous iron and aluminum oxides (Kabata-Pendias, 2001), so positive correlations for zinc versus aluminum and zinc versus iron are expected for uncontaminated samples. Most of the site samples and background samples form a collinear trend with a positive slope in a plot of zinc versus aluminum (Figure 17). Most of the site samples with high zinc also contain high aluminum, and lie on the linear trend. Zinc in these samples is associated with clays at ratios consistent with those of the background samples, and is natural. Surface soil samples CP0005 and CP0024 and subsurface soil samples CP0012 and CP0016, however, have the highest zinc concentrations of the site data set but only moderate aluminum, and lie above the linear background trend. These samples contain an excess amount of zinc beyond that which can be explained by their natural clay content, and should be considered suspect (Table 1).

Conclusion
Zinc concentrations in surface soil samples CP0005 and CP0024 and subsurface soil samples CP0012 and CP0016 are anomalously high and may contain a component of contamination (Table 1). Zinc detected in the other site soil samples is naturally occurring.

4.0 Results of the Geochemical Evaluation of Multiple Elements in Groundwater

This section presents the results of the geochemical evaluation of barium, cobalt, manganese, and nickel in the seven unfiltered groundwater samples from Motor Pool Area 3100. Correlation plots are provided in Attachment 1.

Field-measured pH readings for the groundwater samples range from 5.36 to 6.8 standard units, with a median of 5.75 and mean of 5.82. These values indicate near-neutral to neutral pH conditions at the sample locations. Field-measured DO readings range from 0.26 to 1.6 mg/L, with a median of 0.64 mg/L and mean of 0.73 mg/L, and ORP readings range from -46 to +100 millivolts (mV), with a median of +83 mV and mean of +57 mV. These values suggest mildly reducing to moderate redox conditions at the sample locations. Turbidity measurements range from 5 to 174 nephelometric turbidity units (NTU), with a median of 35 NTU and mean of 71 NTU. Three of the samples contained a relatively high mass of suspended particulates (112 to 174 NTU for samples CP3005, -10, and -12), but the remaining samples did not (35 NTU and lower). It should be noted that field readings are not available for the background groundwater samples.

Barium

Barium was detected in all seven site groundwater samples. Under natural groundwater conditions, barium is usually present as a divalent cation and tends to concentrate on clay surfaces, which maintain a negative surface charge. Aluminum and iron were detected in all seven samples. As discussed in Section 2.2, aluminum concentrations in excess of approximately 1 mg/L in neutral-pH groundwater indicate the presence of suspended clays. Aluminum will be present in solution at a pH below about 4.0, but all of the Motor Pool Area 3100 pH readings are higher than this and are generally in the neutral range (see the discussion of field readings, above). Iron concentrations in excess of approximately 1 mg/L in neutral-pH, moderate to oxidizing groundwater conditions indicate the presence of suspended iron oxides. A plot of aluminum versus iron can be used as a qualitative indicator of the amount of suspended particulates in the groundwater samples (Figure 18). The majority of site and background samples form a linear trend with a positive slope, indicating that both elements are present in particulate form in these samples. The site samples with the highest aluminum concentrations also exhibit proportionally higher iron, and lie on the linear trend formed by the other samples. Elevated aluminum in these samples is due to the presence of suspended particulates such as clays, and is natural.

Site samples CP3002 and CP3009 both contain low aluminum (0.077 J mg/L and 0.094 J mg/L) but elevated iron (3.36 mg/L and 6.33 mg/L), and lie below and to the right of the linear particulate trend in Figure 18. There are also three background samples with similarly low Al/Fe

ratios. The low Al/Fe ratios indicate that some portion of the iron in these samples is in solution. Considering that only a few low, mostly estimated VOC concentrations were detected in sample CP3002 (1,2,4-trimethylbenzene, 4-methyl-2-pentanone, benzene, ethylbenzene, and toluene); no VOCs were detected in sample CP3009; and that there are background samples with similarly low Al/Fe ratios, it is most likely that the low Al/Fe ratios of samples CP3002 and CP3009 reflect naturally low redox conditions.

Barium and aluminum are poorly correlated in the site data set ($R^2 = 0.13$), which suggests that barium concentrations are not being controlled primarily through adsorption on suspended clays. Barium concentrations are often controlled by equilibrium with the mineral barite ($BaSO_4$), which is sensitive to redox conditions. Under oxidizing conditions, sulfate is the stable form of sulfur, so barium concentrations are limited by the solubility of barite. Under reducing conditions, sulfate can be reduced to sulfide, allowing barium concentrations to increase. Iron is a redox-sensitive element and its concentrations will increase as the redox potential drops below a threshold value. A positive correlation between barium and iron concentrations is commonly observed for groundwater samples that represent reducing conditions. Field readings indicate mildly reducing to moderate redox conditions at the site and, as noted above, the reducing conditions are most likely natural.

A plot of barium versus iron is provided in Figure 19. Most of the background samples form a generally linear trend with a positive slope, and the site samples all lie on this trend. If a site sample contained excess barium as a contaminant, it would exhibit an anomalously high Ba/Fe ratio relative to background and would lie above the background trend. However, no such samples are observed in Figure 19, indicating a natural source for the barium concentrations.

Conclusion

Barium detected in the site groundwater samples is naturally occurring.

Cobalt

Cobalt was detected in five of the seven site groundwater samples. Under oxidizing groundwater conditions, cobalt concentrations are commonly controlled by adsorption on iron oxides and manganese oxides (Hem, 1985). Under reducing conditions, however, the iron oxides and manganese oxides will enter into solution. As a result, the dissolved concentrations of iron and manganese will increase, along with the concentrations of trace elements (such as cobalt) that were adsorbed on the mineral surfaces. Positive correlations for cobalt versus iron concentrations or cobalt versus manganese concentrations can thus be observed for samples that represent reducing or oxidizing groundwater conditions. Field readings indicate mildly reducing to moderate redox conditions at the site and, as noted in the Barium evaluation (above), the reducing conditions are most likely natural.

A plot of cobalt versus manganese is provided in Figure 20. The background samples do not exhibit a positive correlation, but the site samples form a linear trend with a positive slope. Site samples CP3006 and CP3009 contain the highest cobalt concentrations of the site and background samples (0.0532 mg/L and 0.0649 mg/L), but they also contain high manganese (1.75 mg/L and 1.73 mg/L) and lie on the trend established by the other site samples. This suggests that the elevated cobalt has a natural source.

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

Manganese

Manganese was detected in all seven site groundwater samples. Manganese usually displays complex behavior in natural systems because of three possible valence states (+2, +3, and +4), which each have different solubilities and sorptive properties (Hem, 1985). Manganese is similar to iron in that it is soluble under reducing conditions but has very low solubilities under oxidizing conditions. One difference between manganese and iron is that the critical redox potential for dissolution of manganese oxides is higher than the redox potential for dissolution of iron oxides. This means that dissolved manganese concentrations are a more sensitive indicator of local redox depressions than dissolved iron concentrations. Field readings for the site samples indicate mildly reducing to moderate redox conditions. Under these conditions, it is expected that some proportion of the manganese concentrations will be in solution. Reducing conditions may be natural, or they can be caused by the anaerobic microbial degradation of chlorinated solvents or fuels (see Section 2.2). However, six of the seven site samples are nondetect for VOCs, suggesting that the manganese concentrations in the site samples are not being controlled by reductive dissolution caused by VOC contamination.

A plot of manganese versus iron is provided in Figure 21. A generally linear trend with a positive slope is observed for the background samples, and all of the site samples lie on this trend. None of the site samples contains excess manganese relative to background. This indicates a natural source for manganese in the site samples.

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

Nickel

Nickel was detected in five of the seven site groundwater samples, at estimated ("J"-qualified) concentrations below the reporting limit of 0.04 mg/L. Nickel is commonly present as the divalent cation Ni^{2+} when redox conditions are moderate to oxidizing and pH values are below about 9 standard units (Brookins, 1988). This species has an affinity to adsorb on the surfaces of iron oxides such as hydrous ferric oxide (Deutsch, 1997), and a positive correlation between nickel and iron concentrations is commonly observed under these conditions. Field readings for the samples with detectable nickel indicate mildly reducing to moderate redox conditions and pH values of 5.36 to 5.77. The Al/Fe ratios indicate that iron in several site samples is present as suspended iron oxides, although iron is present in solution in samples CP3002 and CP3009 (Figure 18). Given these observations, the nickel concentrations are expected to be at least partly controlled by adsorption on suspended particulates such as iron oxides.

A plot of nickel versus iron is provided in Figure 22. The site samples have higher nickel concentrations than the single background sample with detectable nickel, but they also have higher iron concentrations. This suggests a natural source for the elevated nickel in the site samples. The uncertainty associated with estimated values, coupled with the presence of

dissolved iron in some of the samples, may explain why the site samples do not exhibit a stronger correlation.

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

5.0 Summary

This section summarizes the results of the geochemical evaluations of selected elements in soil and groundwater samples from Motor Pool Area 3100.

Soil. Geochemical evaluation indicates that all detected concentrations of aluminum, arsenic, cadmium, calcium, chromium, copper, iron, magnesium, and potassium in the surface and subsurface soil samples are naturally occurring. In addition, all detected concentrations of beryllium, nickel, and selenium in the surface soil samples are naturally occurring. Anomalously high concentrations of cobalt and zinc are present in at least one surface soil sample each, and anomalously high concentrations of beryllium, cobalt, nickel, selenium, and zinc are present in at least one subsurface soil sample each. These anomalous concentrations are elevated with respect to the corresponding reference element concentrations, and may contain a component of contamination. Table 1 lists the samples that contain anomalously high element concentrations, and provides the corresponding location codes and depth intervals.

Groundwater. Geochemical evaluation indicates that the detected concentrations of barium, cobalt, manganese, and nickel in the site groundwater samples are naturally occurring.

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ATTACHMENT 1

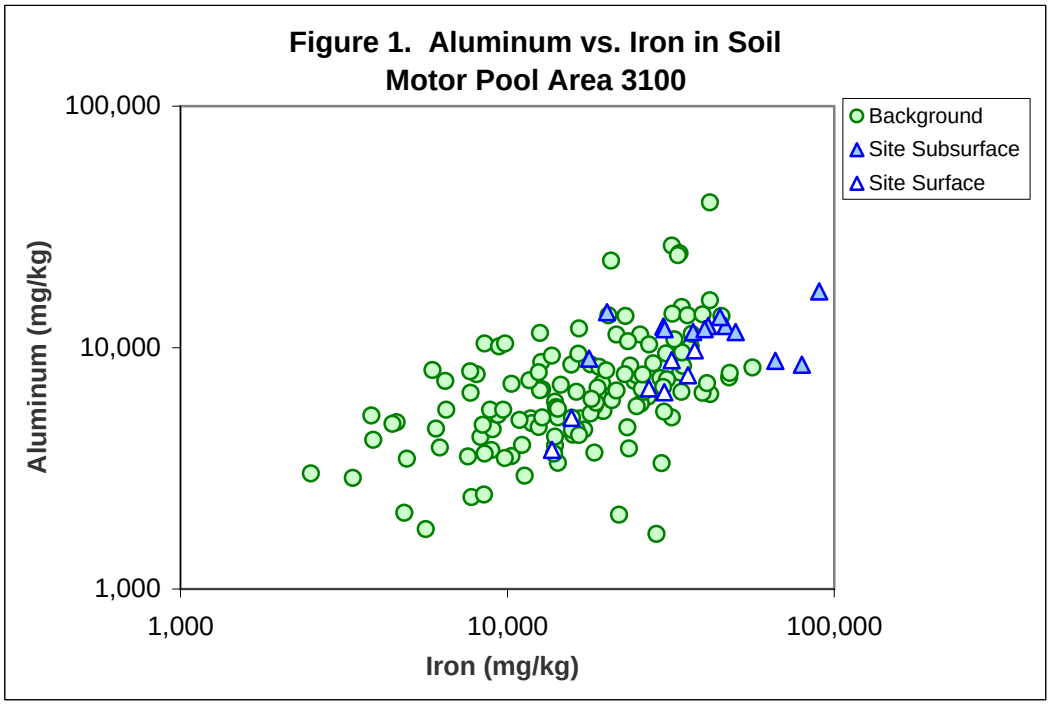
Figure 1. Aluminum vs. Iron in Soil
Motor Pool Area 3100
100,000
10,000
1,000
Aluminum (mg/kg)
1,000
10,000
100,000
Iron (mg/kg)
Background
Site Subsurface
Site Surface

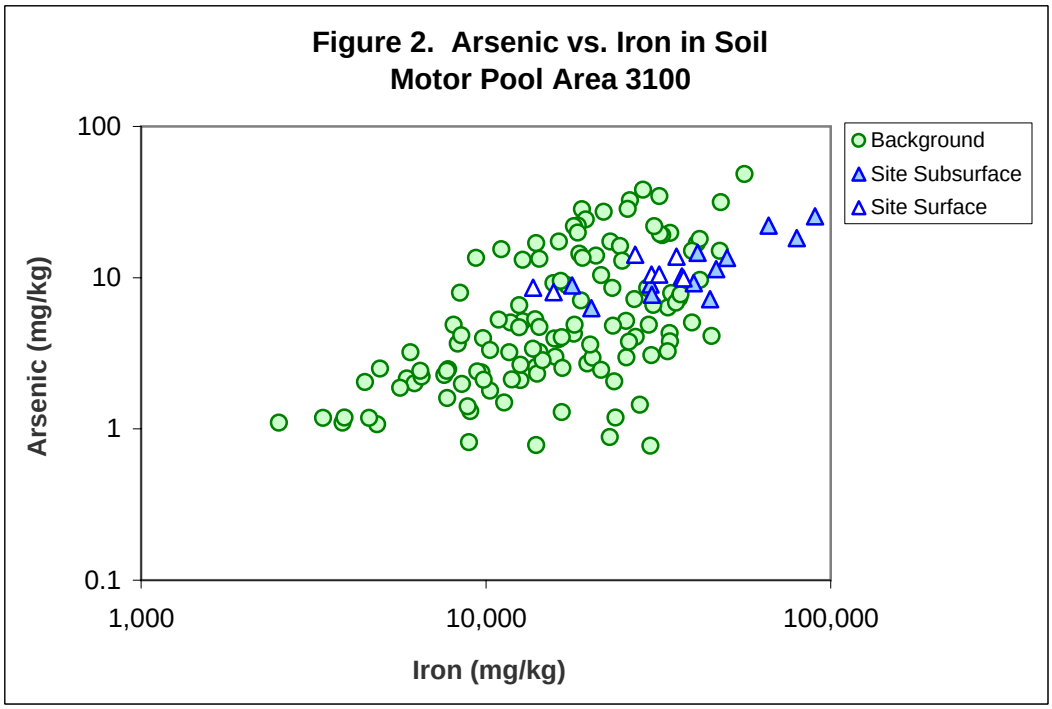
Figure 2. Arsenic vs. Iron in Soil
Motor Pool Area 3100
100
10
1
0.1
Arsenic (mg/kg)
1,000
10,000
100,000
Iron (mg/kg)
Background
Site Subsurface
Site Surface

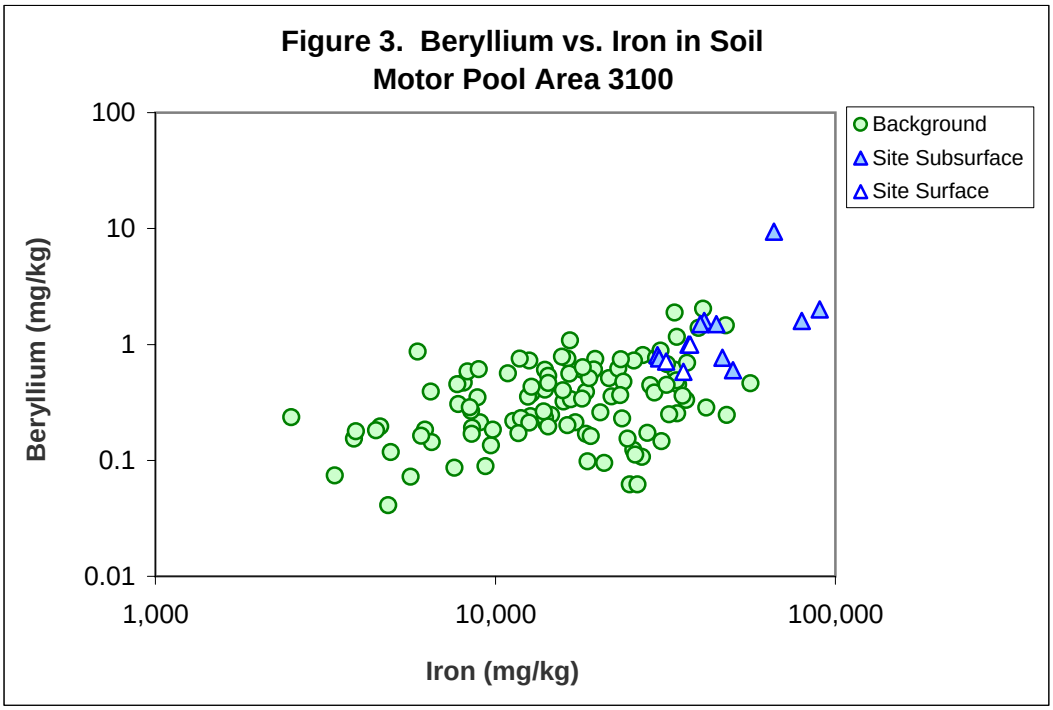
Figure 3. Beryllium vs. Iron in Soil
Motor Pool Area 3100
Beryllium (mg/kg)
100
10
1
0.1
0.01
1,000
10,000
100,000
Iron (mg/kg)
Background
Site Subsurface
Site Surface

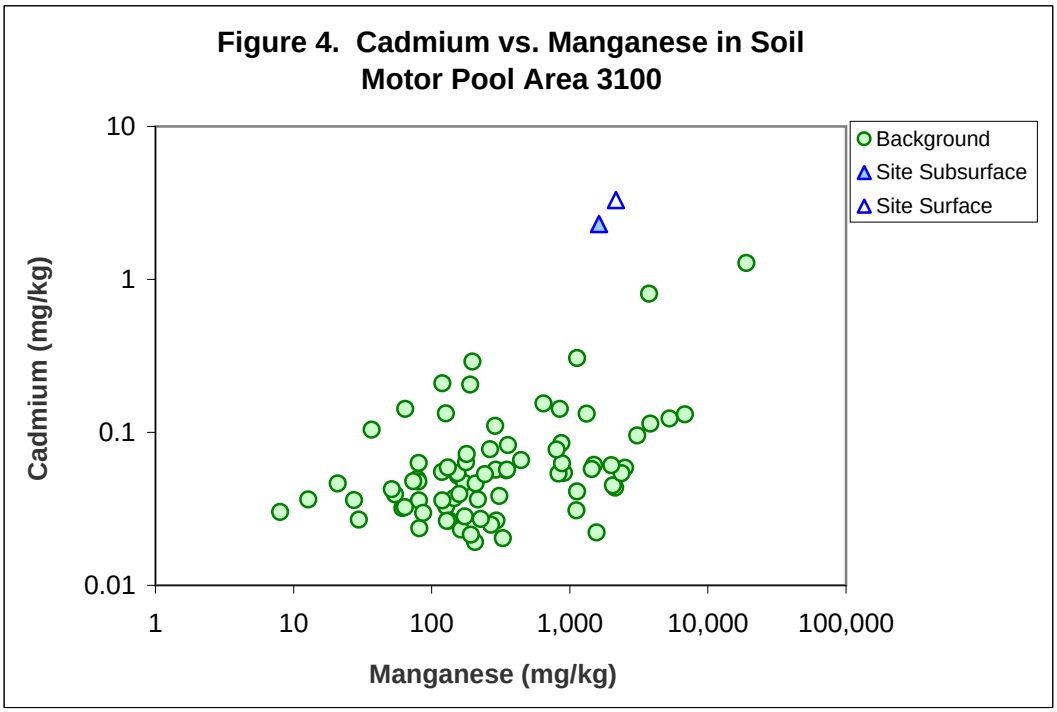
Figure 4. Cadmium vs. Manganese in Soil
Motor Pool Area 3100
Cadmium (mg/kg)
10
1
0.1
0.01
1
10
100
1,000
10,000
100,000
Manganese (mg/kg)
Background
Site Subsurface
Site Surface

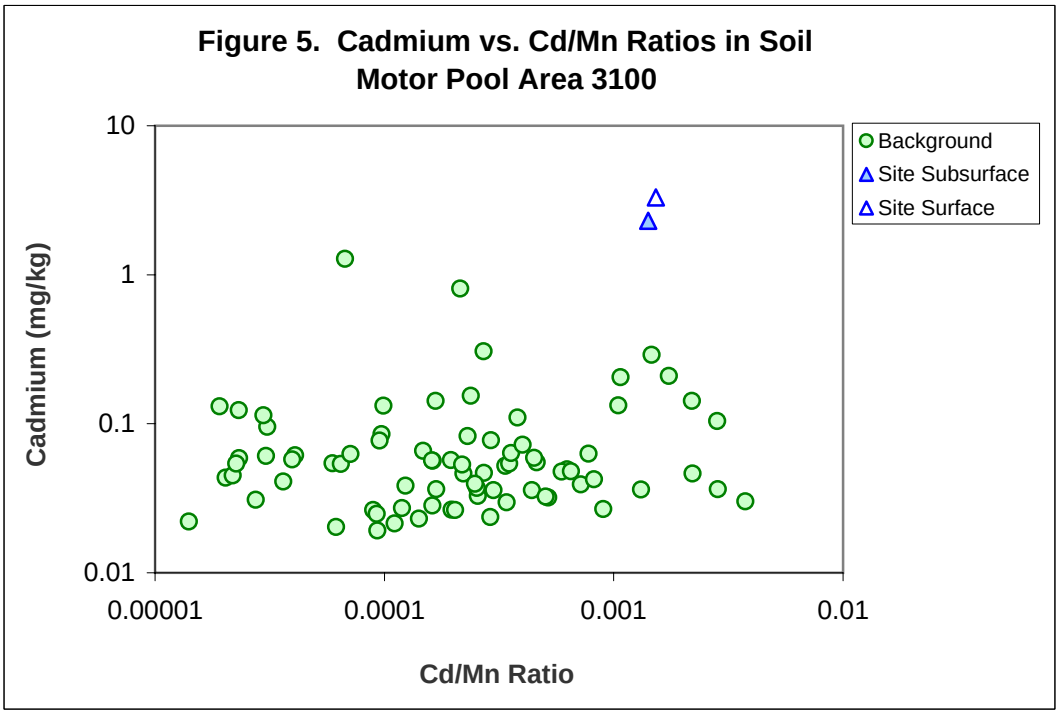
Figure 5. Cadmium vs. Cd/Mn Ratios in Soil
Motor Pool Area 3100
Cadmium (mg/kg)
10
1
0.1
0.01
0.00001
0.0001
0.001
0.01
Cd/Mn Ratio
Background
Site Subsurface
Site Surface

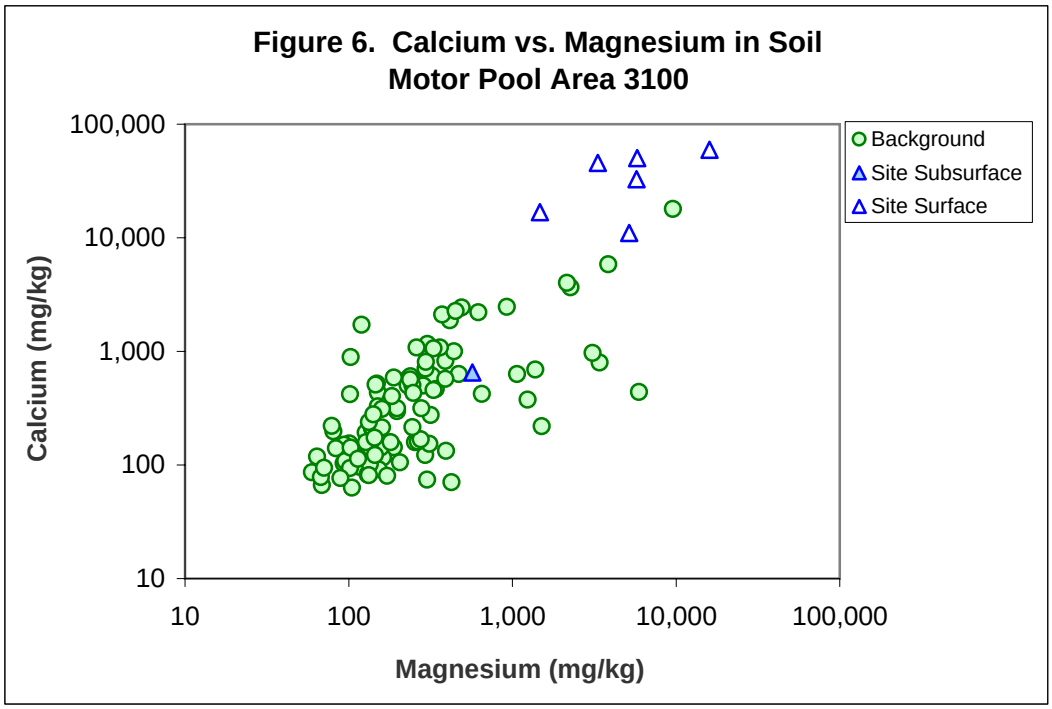
Figure 6. Calcium vs. Magnesium in Soil
Motor Pool Area 3100
Calcium (mg/kg)
100,000
10,000
1,000
100
10
10
100
1,000
10,000
100,000
Magnesium (mg/kg)
Background
Site Subsurface
Site Surface

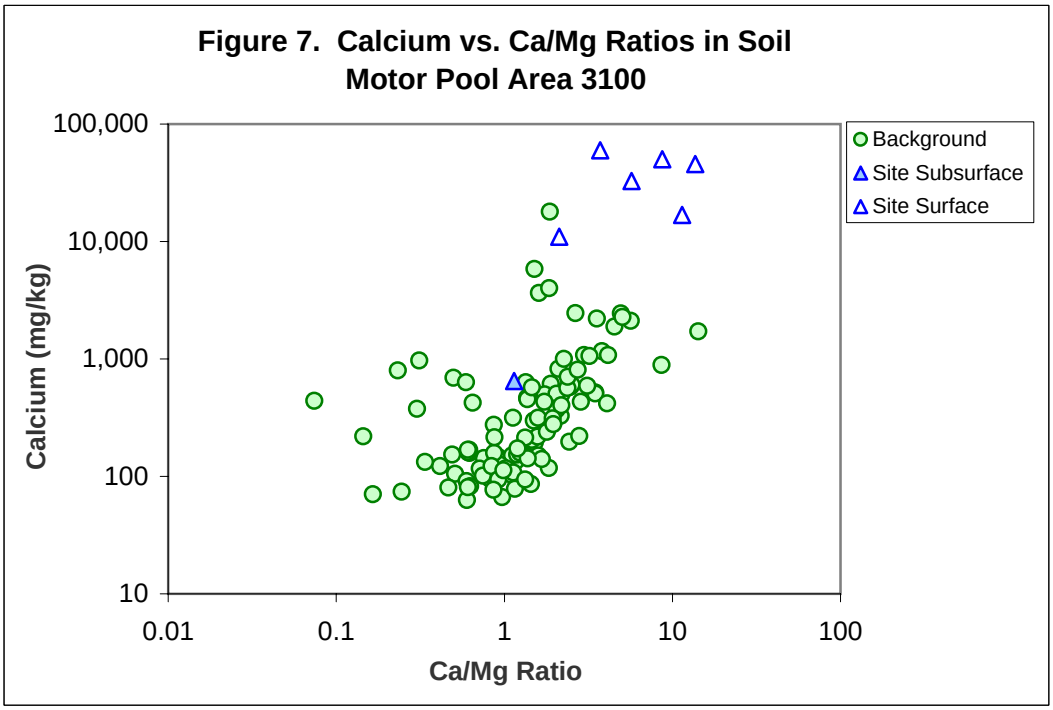
Figure 7. Calcium vs. Ca/Mg Ratios in Soil
Motor Pool Area 3100
100,000
10,000
1,000
100
10
Calcium (mg/kg)
0.01
0.1
1
10
100
Ca/Mg Ratio
Background
Site Subsurface
Site Surface

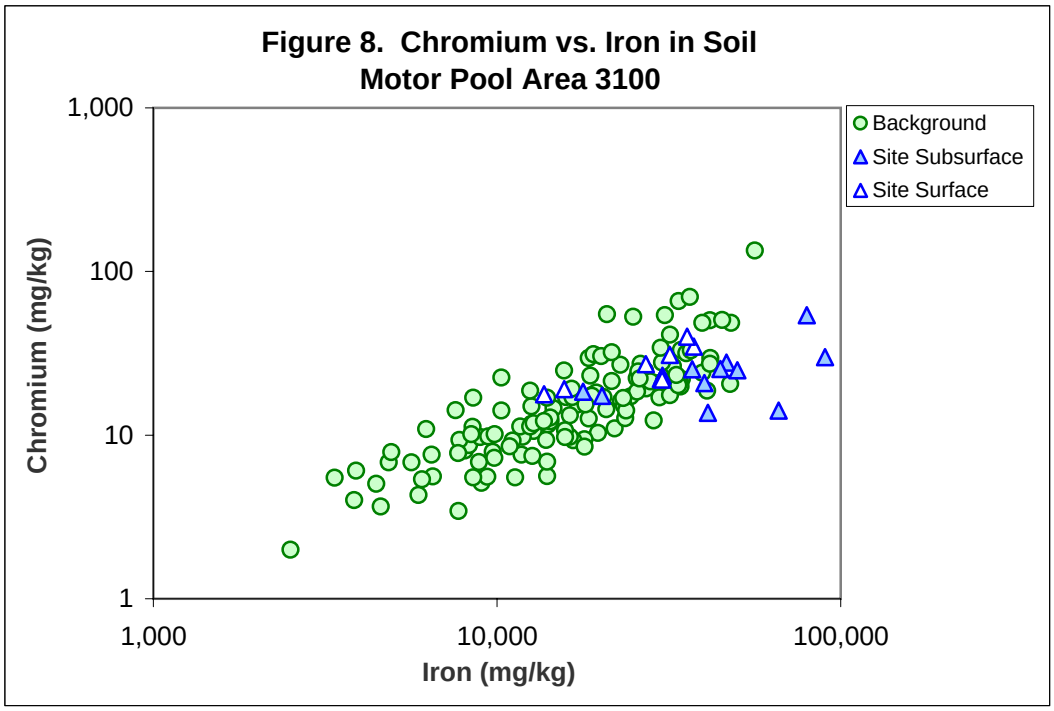
Figure 8. Chromium vs. Iron in Soil
Motor Pool Area 3100
1,000
100
10
1
Chromium (mg/kg)
1,000
10,000
100,000
Iron (mg/kg)
Background
Site Subsurface
Site Surface

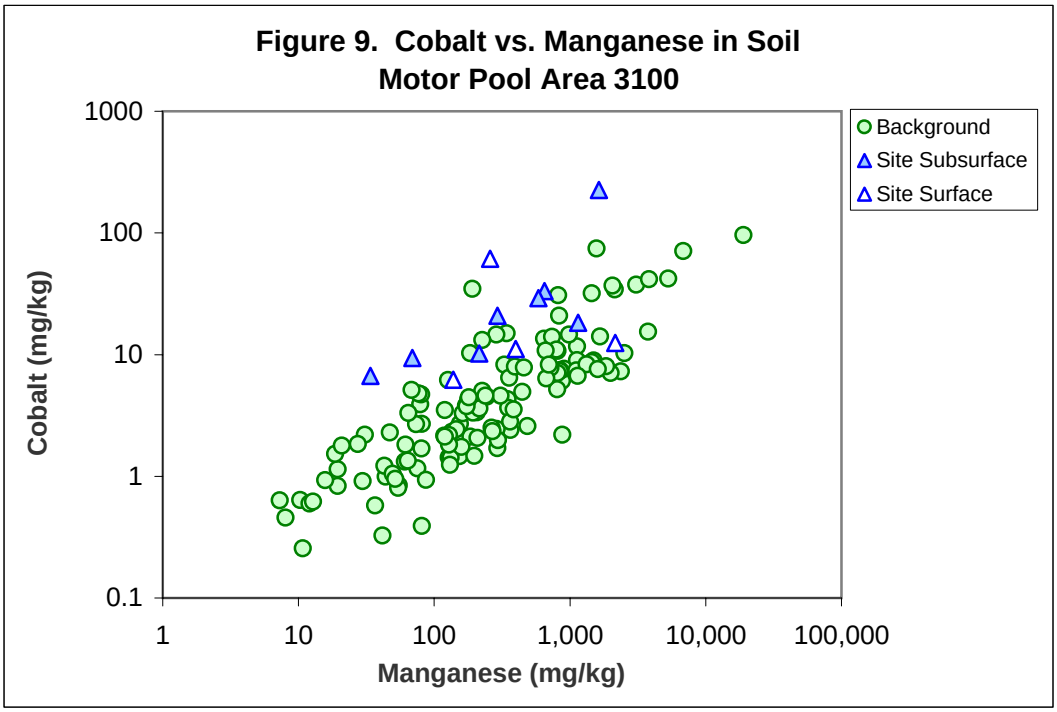
Figure 9. Cobalt vs. Manganese in Soil
Motor Pool Area 3100
Cobalt (mg/kg)
1000
100
10
1
0.1
1
10
100
1,000
10,000
100,000
Manganese (mg/kg)
Background
Site Subsurface
Site Surface

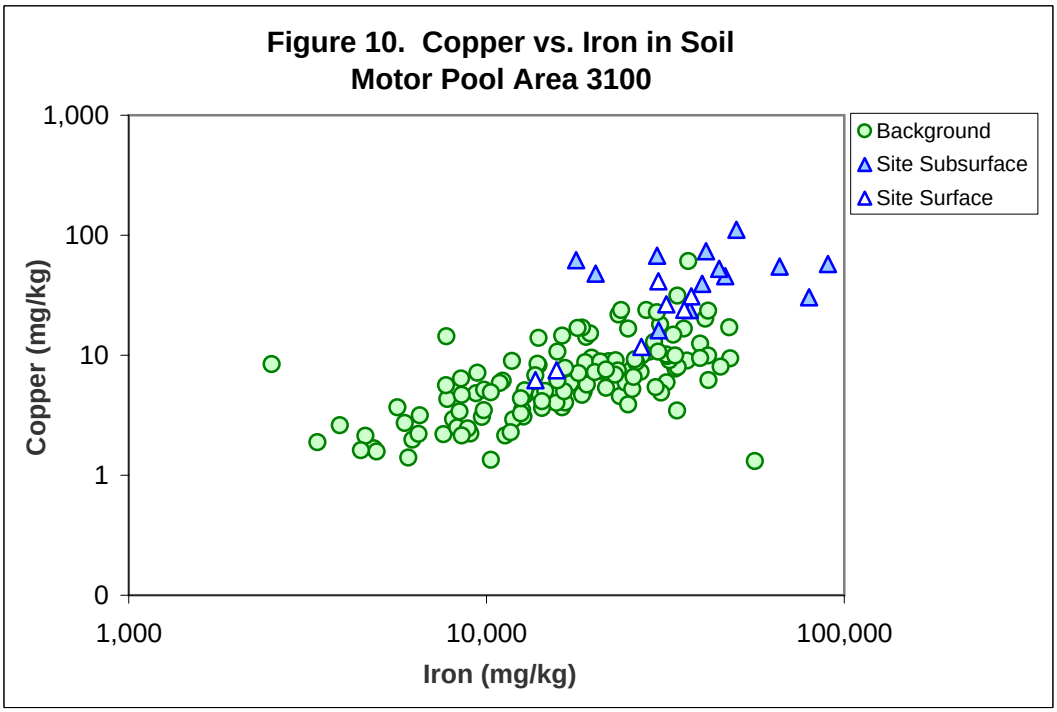
Figure 10. Copper vs. Iron in Soil
Motor Pool Area 3100
Copper (mg/kg)
1,000
100
10
1
0
1,000
10,000
100,000
Iron (mg/kg)
Background
Site Subsurface
Site Surface

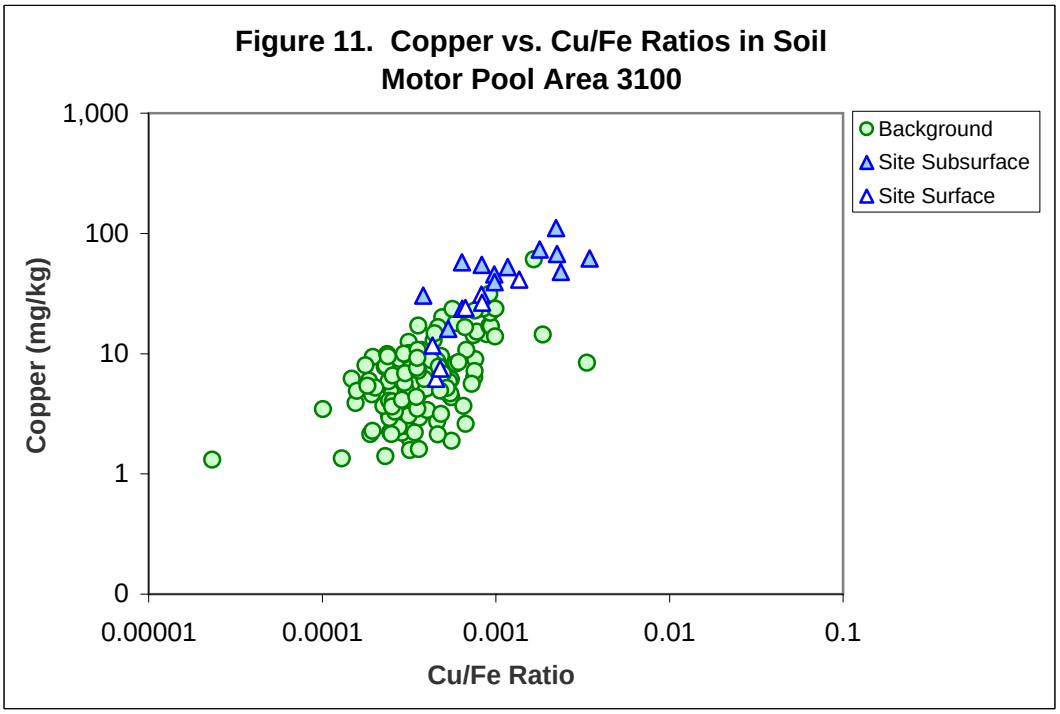
Figure 11. Copper vs. Cu/Fe Ratios in Soil
Motor Pool Area 3100
1,000
100
10
1
0
Copper (mg/kg)
0.00001
0.0001
0.001
0.01
0.1
Cu/Fe Ratio
Background
Site Subsurface
Site Surface

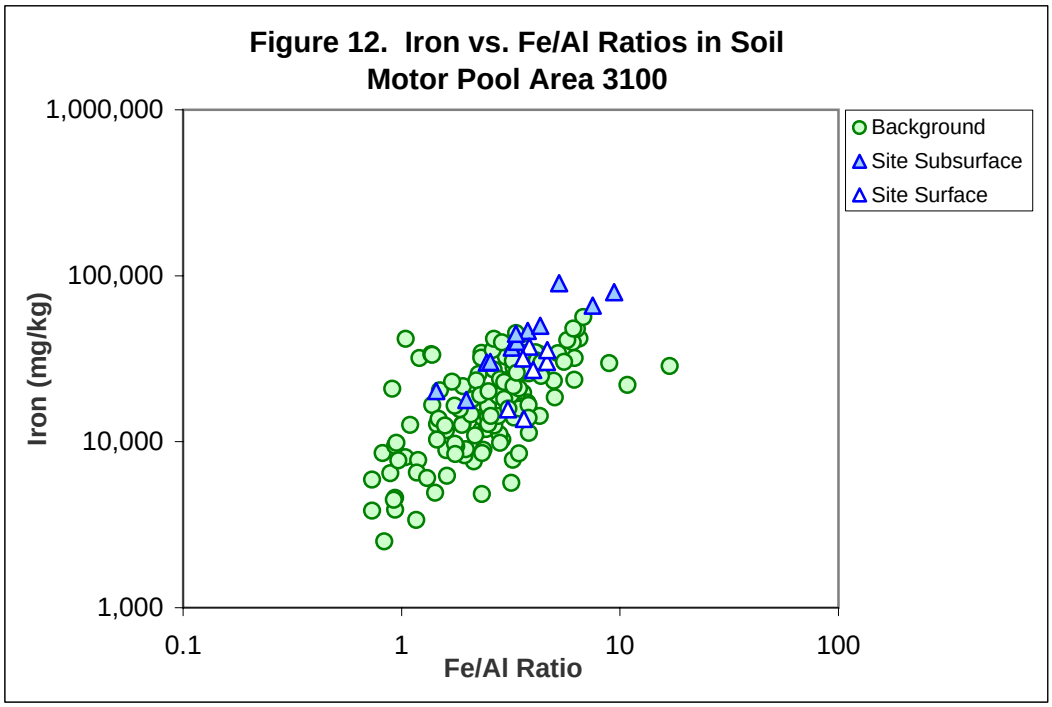
Figure 12. Iron vs. Fe/Al Ratios in Soil
Motor Pool Area 3100
1,000,000
100,000
10,000
1,000
Iron (mg/kg)
0.1
1
10
100
Fe/Al Ratio
Background
Site Subsurface
Site Surface

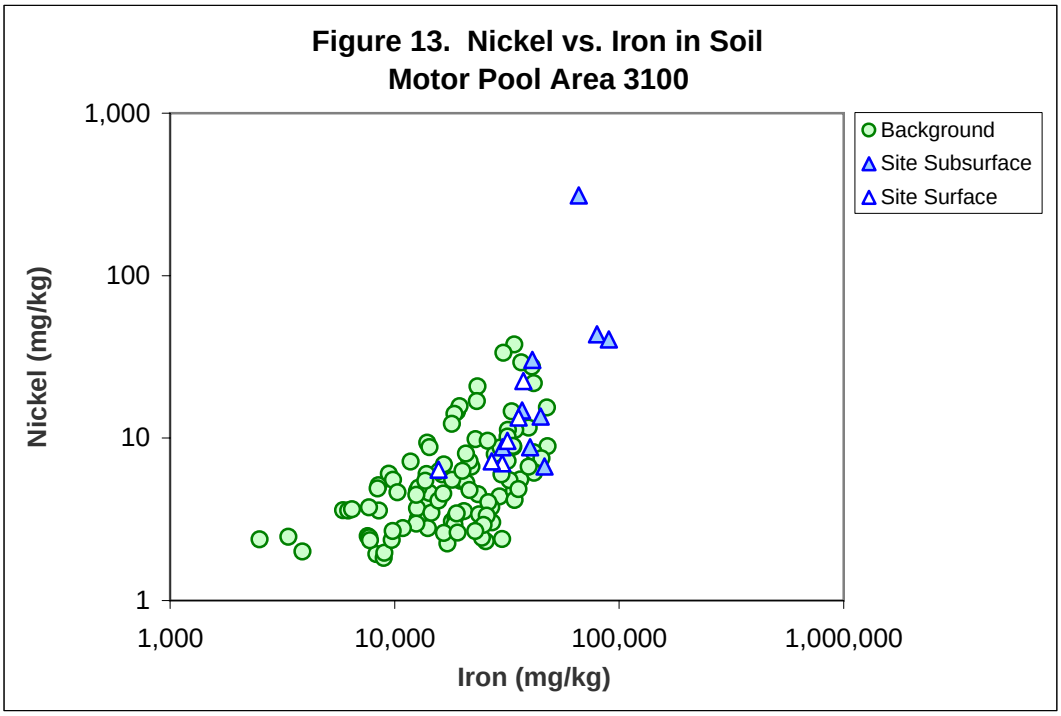
Figure 13. Nickel vs. Iron in Soil
Motor Pool Area 3100
Nickel (mg/kg)
1,000
100
10
1
1,000
10,000
100,000
1,000,000
Iron (mg/kg)
Background
Site Subsurface
Site Surface

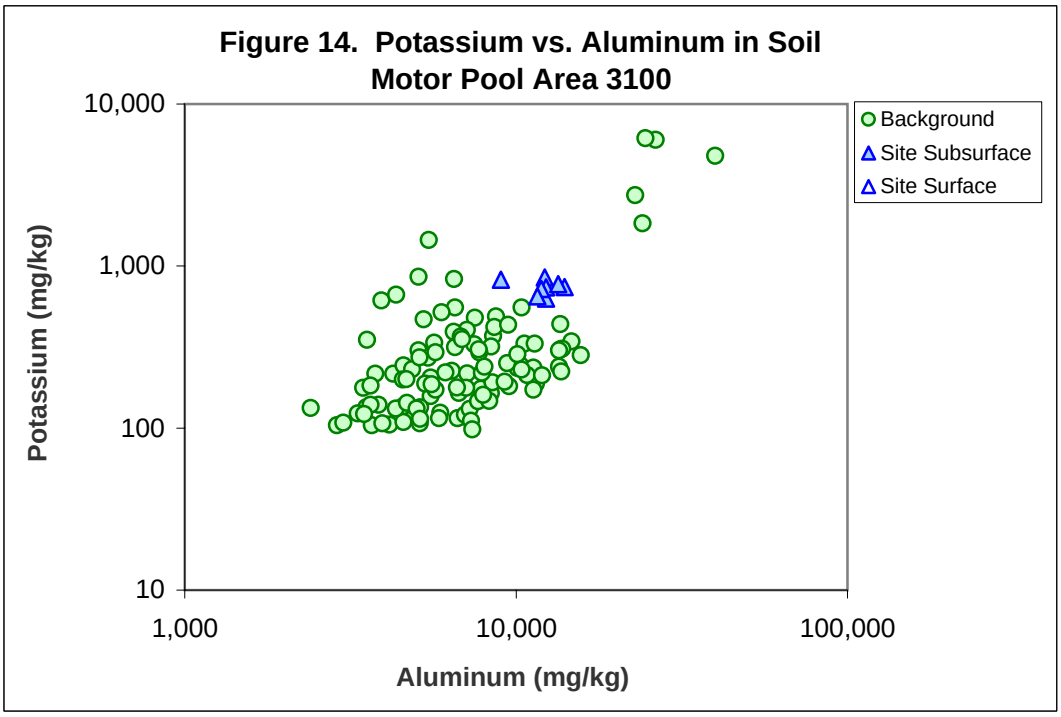
Figure 14. Potassium vs. Aluminum in Soil
Motor Pool Area 3100
Potassium (mg/kg)
10,000
1,000
100
10
1,000
10,000
100,000
Aluminum (mg/kg)
Background
Site Subsurface
Site Surface

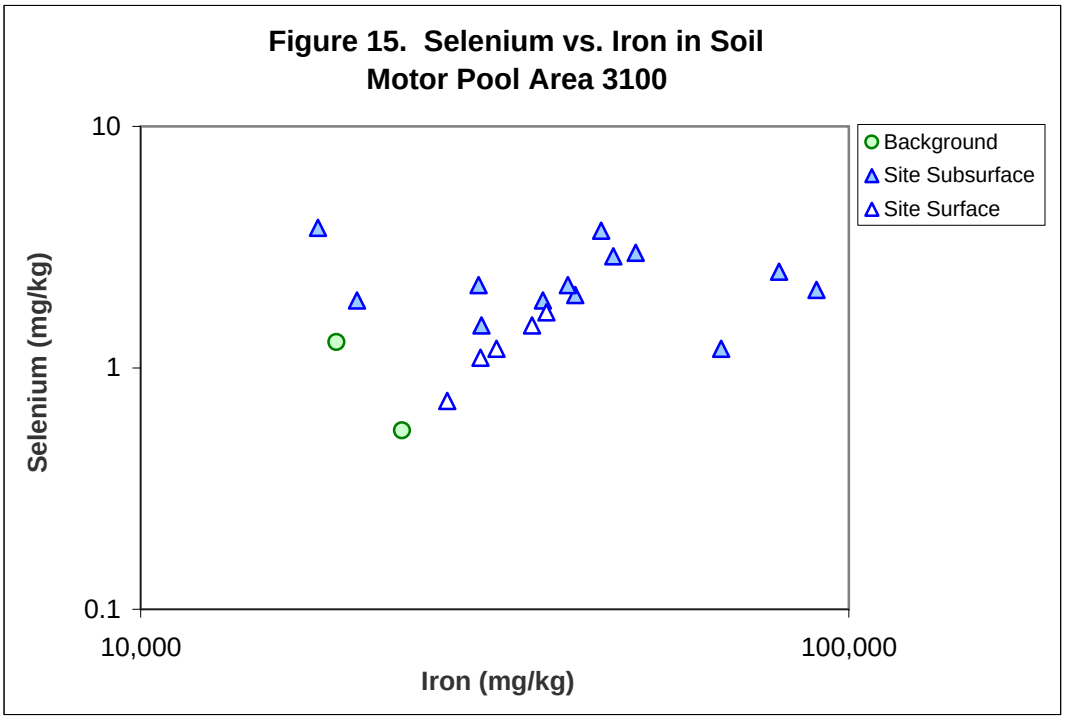
Figure 15. Selenium vs. Iron in Soil
Motor Pool Area 3100
10
1
0.1
Selenium (mg/kg)
10,000
100,000
Iron (mg/kg)
Background
Site Subsurface
Site Surface

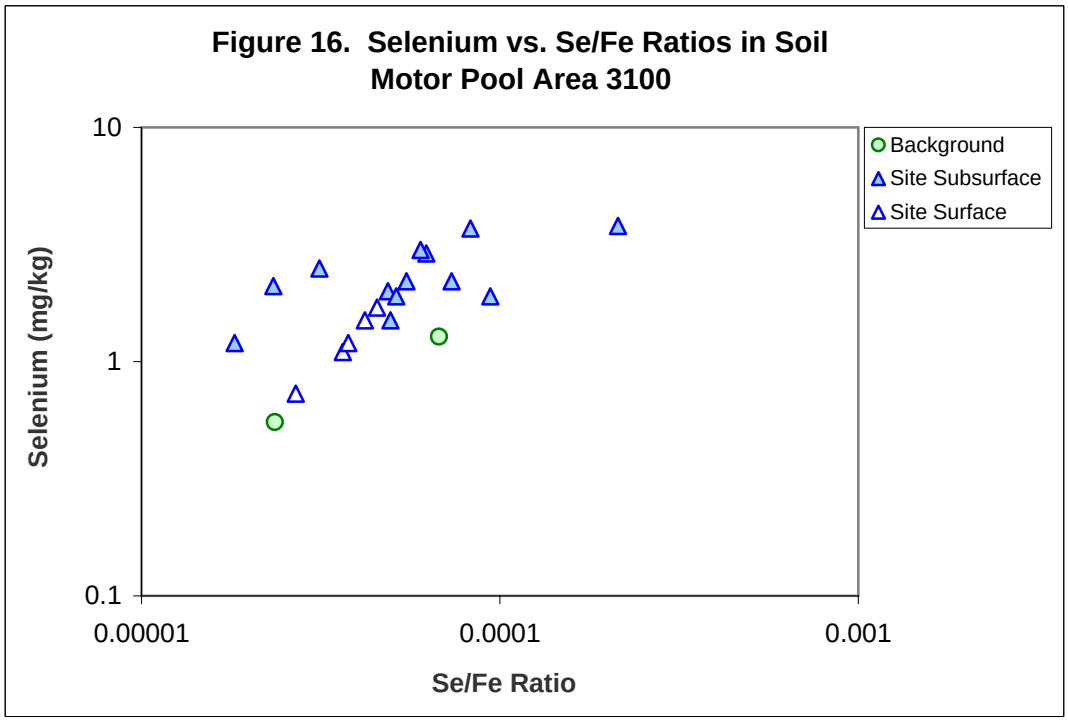
Figure 16. Selenium vs. Se/Fe Ratios in Soil
Motor Pool Area 3100
10
1
0.1
Selenium (mg/kg)
0.00001
0.0001
0.001
Se/Fe Ratio
Background
Site Subsurface
Site Surface

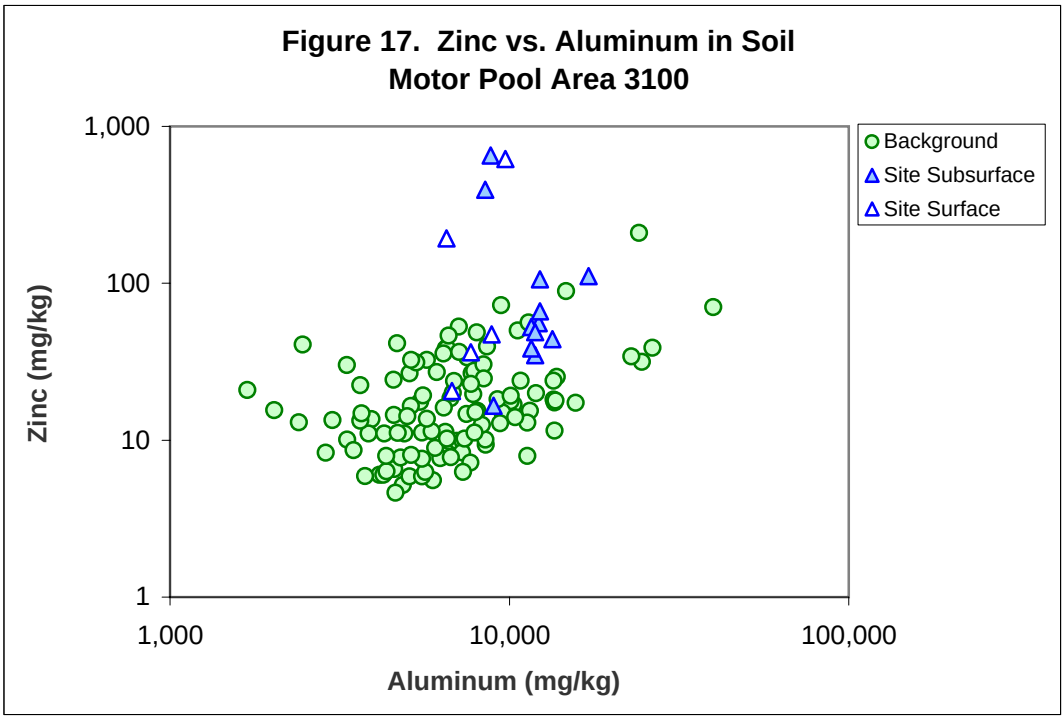
Figure 17. Zinc vs. Aluminum in Soil
Motor Pool Area 3100
1,000
100
10
1
Zinc (mg/kg)
1,000
10,000
100,000
Aluminum (mg/kg)
Background
Site Subsurface
Site Surface

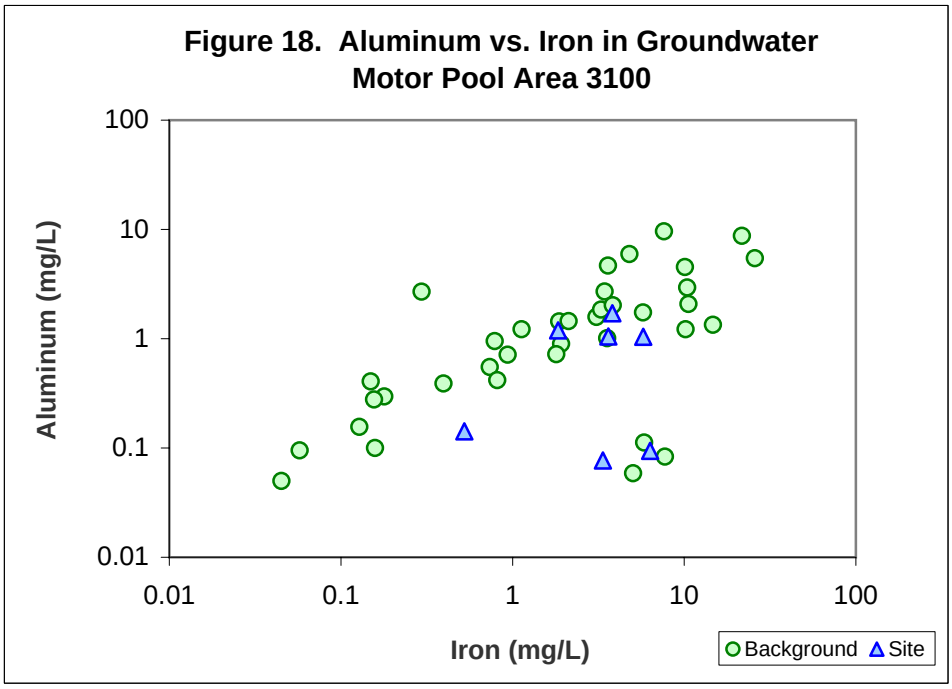
Figure 18. Aluminum vs. Iron in Groundwater
Motor Pool Area 3100
Aluminum (mg/L)
100
10
1
0.1
0.01
0.01
0.1
1
10
100
Iron (mg/L)
Background
Site

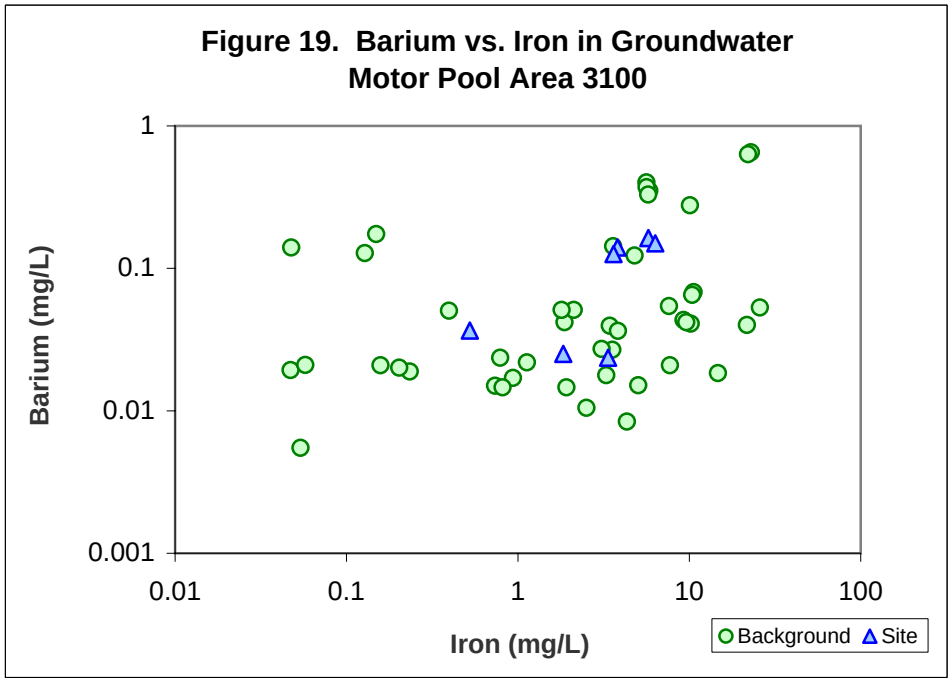
Figure 19. Barium vs. Iron in Groundwater
Motor Pool Area 3100
Barium (mg/L)
1
0.1
0.01
0.001
0.01
0.1
1
10
100
Iron (mg/L)
Background
Site

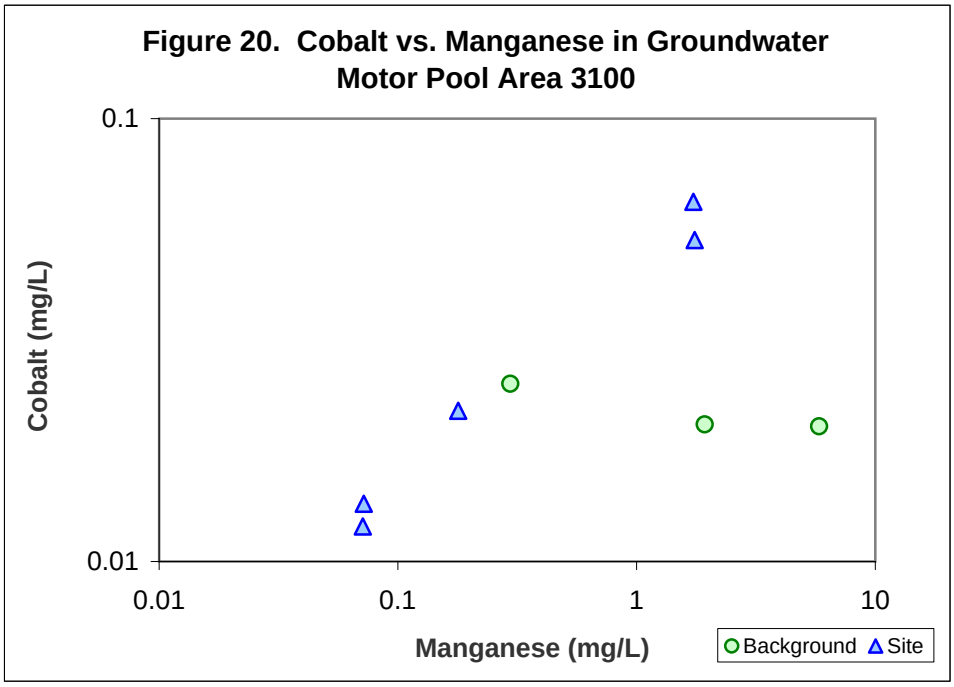
Figure 20. Cobalt vs. Manganese in Groundwater
Motor Pool Area 3100
0.1
0.01
Cobalt (mg/L)
0.01
0.1
1
10
Manganese (mg/L)
Background
Site

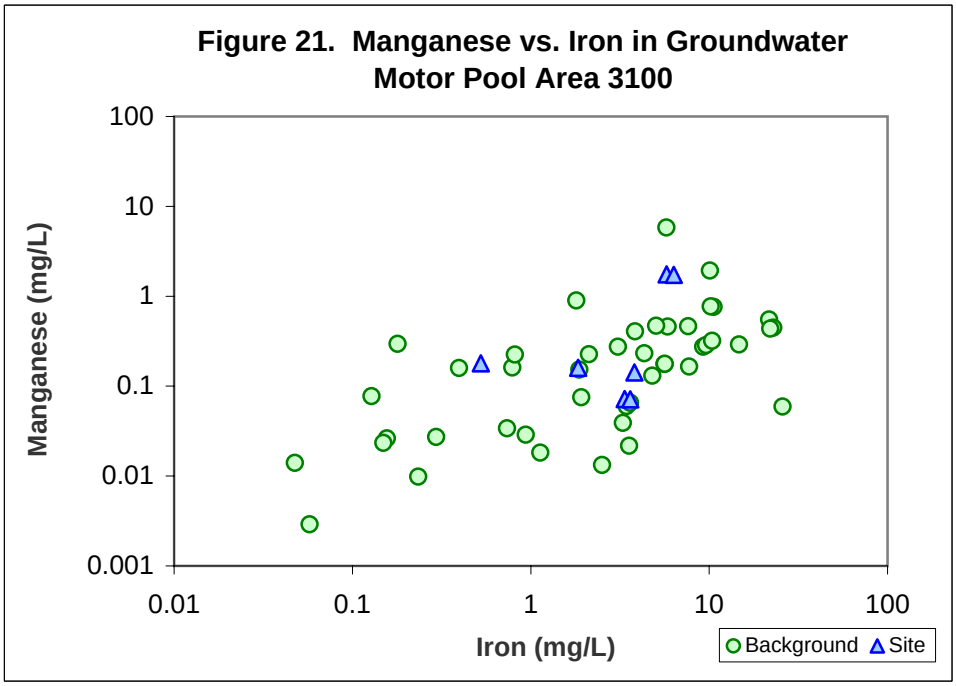
Figure 21. Manganese vs. Iron in Groundwater
Motor Pool Area 3100
100
10
1
0.1
0.01
0.001
Manganese (mg/L)
0.01
0.1
1
10
100
Iron (mg/L)
Background
Site

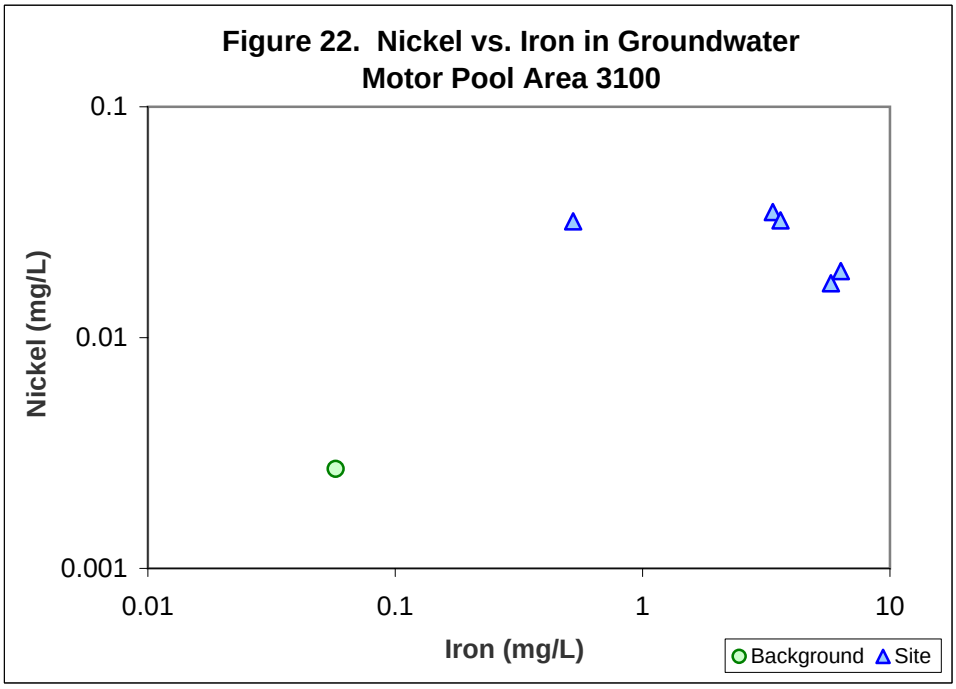
Figure 22. Nickel vs. Iron in Groundwater
Motor Pool Area 3100
0.1
0.01
0.001
Nickel (mg/L)
0.01
0.1
1
10
Iron (mg/L)
Background
Site