Final
Installation-Wide Background Soil Study Report
Former Ramey Air Force Base
Aguadilla, Puerto Rico

Contract Number DACA21-96-D-0018
Task Order No. 0008

April 2004

Shaw® Shaw Environmental, Inc.

200.1e
I02PR087902_03.10_0003

US Army Corps of Engineers
Savannah District

E:\Covers\Ramey\015.cdr(lhall)

Final
Installation-Wide Background Soil Study Report

Former Ramey Air Force Base
Aguadilla, Puerto Rico

Prepared for:

U.S. Army Corps of Engineers
South Atlantic Division
P.O. Box 889
Savannah, Georgia 31402-0889

Prepared by:

Shaw Environmental, Inc.
312 Directors Drive
Knoxville, Tennessee 37923

Contract No. DACA21-96-D-0018
Task Order No. 0008

April 2004

Table of Contents

Page

List of Appendices ii
List of Tables iii
List of Figures iii
List of Acronyms iv
1.0 Introduction 1-1
1.1 Background Study Objectives 1-1
1.2 Facility History and Description 1-2
2.0 Sampling Strategy and Field Investigation 2-1
2.1 Sampling Strategy 2-1
2.2 Field Procedures 2-2
2.3 Sample Location Surveys 2-2
3.0 Methodology for Characterization of Background Distributions 3-1
3.1 Spatial Grouping of Soil Samples 3-1
3.2 Handling of Nondetections 3-1
3.3 Checking Distributional Assumptions 3-2
3.4 Handling of Outliers 3-3
3 5 Calculation of Summary Statistics 3-3
4.0 Background Distributions of Inorganics and PAHs in Soil 4-1
4.1 Inorganics in Surface Soil 4-1
4.2 PAHs in Surface Soil 4-1
4.3 Inorganics in Subsurface Soil 4-1
4.4 PAHs in Subsurface Soil 4-2
4.5 Comparisons of Surface and Subsurface Distributions 4-2
5.0 Summary of the Background Study and Methodology for Site-to-Background Comparisons 5-1
5.1 Summary of the Background Study 5-1
5.2 Methodology for the Comparison of Site and Background Data Sets 5-1
5.2.1 Statistical Procedures 5-2
5.2.1.1 Background Threshold Comparison 5-2
5.2.1.2 Wilcoxon Rank Sum Test 5-3
5.2.1.3 Box-and-Whisker Plots 5-4
5.2.2 Geochemical Evaluations 5-5
5.2.3 Summary of the Site-to-Background Comparison Methodology 5-7
6.0 References 6-1

List of Appendices

Appendix A – Quality Control Summary Report, Analytical Data, Sample Collection Logs, Chain-of-Custody Forms, Laboratory Sample Receipt Forms, and Variance Log

Appendix B – Soil Boring Logs

Appendix C – Survey Data

Appendix D – Probability Plots for Inorganics in Soil

Appendix E – Calculation of Statistical Parameters

List of Tables

Table	Title	Follows Tab
2-1	Sampling and Analysis Program	
4-1	Background Summary Statistics for Inorganics in Surface Soil	
4-2	Background Summary Statistics for PAHs in Surface Soil	
4-3	Background Summary Statistics for Inorganics in Subsurface Soil	
4-4	Background Summary Statistics for PAHs in Subsurface Soil	
4-5	Background Summary Statistics for Inorganics in Combined Soil	
4-6	Background Summary Statistics for PAHs in Combined Soil	

List of Figures

Figure	Title	Follows Tab
1-1	Location Map	
2-1	Background Soil Sample Locations	
4-1	Aluminum vs. Iron in Background Soil, Former Ramey AFB	
4-2	Magnesium vs. Calcium in Background Soil, Former Ramey AFB	
4-3	Arsenic vs. Iron in Background Soil, Former Ramey AFB	
4-4	Vanadium vs. Iron in Background Soil, Former Ramey AFB	
4-5	Chromium vs. Iron in Background Soil, Former Ramey AFB	
4-6	Barium vs. Manganese in Background Soil, Former Ramey AFB	
5-1	Example Box Plot	

List of Acronyms

AFB	Air Force Base
bgs	below ground surface
E&E	Ecology and Environment, Inc,
EPA	U.S. Environmental Protection Agency
IT	IT Corporation
GPS	global positioning system
MDC	maximum detected concentration
msl	mean sea level
PAH	polynuclear aromatic hydrocarbon
PQL	practical quantitation limit
SAP	installation-wide sampling and analysis plan
TAL	target analyte list
TOC	total organic carbon
UCL	upper confidence limit
USDA	U.S. Department of Agriculture
UTL	upper tolerance limit
WRS	Wilcoxon rank sum

1.0 Introduction

This report presents the results of the installation-wide background chemical data study conducted for soil at the former Ramey Air Force Base (AFB), Aguadilla, Puerto Rico (Figure 1-1). Shaw Environmental, Inc. (formerly IT Corporation [IT]) performed this study for the Savannah District of the U.S. Army Corps of Engineers through Total Environmental Restoration Contract Number DAC21-96-D-0018, Task Order Number 8.

This chapter discusses the study objectives and includes a description and history of the former Ramey AFB. Sampling strategy and field procedures are described in Chapter 2.0. Chapter 3.0 summarizes the statistical methodology used to determine background distributions, and Chapter 4.0 presents the background summary statistics for target analyte list (TAL) metals and polynuclear aromatic hydrocarbons (PAH) in soil. Chapter 5.0 summarizes the results of the study and describes the methodology for the comparison of site and background data sets. References cited in the report are listed in Chapter 6.0.

The analytical results and a discussion of data quality are included in Appendix A. Soil boring logs and survey coordinates for the background sample locations are provided in Appendices B and C, respectively. Appendix D contains the probability plots for metals in soil. Statistical tests and parameters employed in the background study are described in detail in Appendix E

1.1 Background Study Objectives

The effectiveness of environmental investigations relies in part on distinguishing site-related impacts from natural and anthropogenic conditions. A powerful way to determine if chemicals or analytes are site-related is to compare their concentrations to a distribution of background concentrations. The objective of this study is to provide background soil chemical data that can be utilized for any Ramey AFB investigation requiring comparison of site data to background. Information obtained from the background study may be used to identify constituents of concern at Ramey AFB sites, determine the nature and extent of site-related contamination, and support human health and ecological risk assessments. In addition, background chemical data may be used to support No Further Action proposals, develop realistic remediation goals, and evaluate the success of remediation efforts.

Surface soil and subsurface soil samples were collected in areas believed to be uninfluenced by Ramey AFB-related contamination and other recent industrial use. Historical records, maps, aerial photographs, and current site conditions were evaluated when selecting the sample

locations. The samples were analyzed for TAL metals and PAH compounds. U.S. Environmental Agency (EPA) guidance was used to screen and select background data, evaluate distributional assumptions, determine to what extent surface and subsurface soil samples could be combined, and characterize distributions

1.2 Facility History and Description

This section presents information pertinent to the background study at the former Ramey AFB. Included are a description of the facility and its operations, local geology and hydrogeology, and site soils.

Former Ramey Air Force Base. The former Ramey AFB occupies approximately 4,357 acres in the northwest corner of the island of Puerto Rico, near the city of Aguadilla (Figure 1-1) The property was acquired by the U. S. Government between 1939 and 1963 and was a fully operational AFB until its deactivation in 1973 (Ecology and Environment, Inc. [E&E], 1997). In March 1974, ownership of most of the property was transferred to the Puerto Rico Industrial Development Company. Since then, the U.S. government has transferred numerous parcels of land to federal and local agencies and private companies. Presently, the U.S. Coast Guard occupies 125 acres, and the Puerto Rico Port Authority now owns and operates a municipal airport and an industrial park on the acreage formerly occupied by the Base. Also currently occupying former Ramey AFB property are the Puerto Rico National Guard, U S. Customs, educational facilities, several privately-owned businesses, and residential property (E&E, 1997) Portions of the former Base are leased to local farmers.

Climate. The climate at Ramey AFB is classified as tropical-maritime, with temperatures ranging from 74 degrees Fahrenheit in January to 80 degrees Fahrenheit in July The average annual precipitation is approximately 60 inches, with the rainy season occurring from May through December (E&E, 1997). Tropical depressions occasionally drift over the area, producing heavy rainfall and occasional flooding. The wind regime is generally under the influence of prevailing easterly trade winds but is also affected by land and sea breezes. Usually the wind is strongest in July and light in autumn (U.S. Department of Agriculture [USDA], 1975).

Topography. The elevation at Ramey AFB ranges from 0 feet above mean sea level (msl) at the north and western coastline to approximately 240 feet above msl. An escarpment is located on the north and west portions of the Base, producing a steep rise in elevation from sea level (the Atlantic Ocean) to approximately 175 feet msl (Figure 1-1). The flightline portion of the Base is flat and higher than much of the facility, with an approximate elevation of 190 to 230 feet msl

(U.S. Geological Survey, 1960). Rough relief occurs in parts of Ramey AFB due to the chemical dissolution of the underlying limestone bedrock. This dissolution has produced such karst features as sinkholes, caves, *mogotes* (haystack hills), dead-end valleys, and many precipitous cliffs (Rodríguez-Martínez, 1995).

Soils. The majority of the soils at Ramey AFB are either of the Bejucos-Jobos association or the Coto-Aceitunas association (USDA, 1975). The Bejucos-Jobos association is comprised of strongly leached soils that have a tight, dominantly clayey subsoil. The majority of soils in this classification are well drained and strongly acidic. The Bejucos soils have a dark yellowish-brown, moderately coarse-textured surface layer and a subsoil that is dominantly fine-textured and mottled below a depth of approximately 37 inches. The Jobos soils have a dark grayish-brown, coarse-textured surface layer and a thick, mottled, red and strong brown, compact, fine-textured subsoil.

The Coto-Aceitunas association consists of slightly leached and strongly leached porous soils that are dominantly clayey throughout (USDA, 1975). The major soils of this association are underlain by hard, fragmented limestone and are characterized as deep, gently sloping to sloping, well-drained and moderately permeable. The Coto soils are reddish-brown, slightly acidic, and fine-textured; the Aceitunas soils are dark reddish brown, fine- to moderately fine-textured, and very strongly acidic.

Surface soil (0 to 1 foot below ground surface [bgs]) and subsurface soil (1 to 3 feet bgs) samples were collected primarily across the western, north central, and northeastern portions of the facility during the background study. Surface soil at these locations consists principally of reddish brown to brown, fine to medium-grained sand with some clay and trace amounts of limestone fragments; the subsurface soil is comprised primarily of reddish brown to brown clay with some sand and limestone fragments (Appendix B).

Geology. Ramey AFB is located in the North Coast physiographic region in the Aguadilla area. The coastal plains parallel nearly the entire northern coastline and include most of the area north of the towns of Aguadilla, Moca, San Sebastion, and Lares. The site is underlain by alluvial and terrace deposits that are characterized as unstratified, fine- to medium-grained quartz sand, and light- to moderate-brown clays. These unconsolidated materials are between 0 and 100 feet thick (Monroe, 1969).

The surficial deposits are underlain by limestone of Miocene age and are located in a broad limestone belt that comprises Puerto Rico's best developed karst region. The geologic formation

found beneath the coastal sediments is the Early Miocene Aymamón Limestone. The upper member of this formation is characterized as very pale orange to bright yellow chalk containing fossils and interbedded with hard, vuggy, very pale orange to white limestone, some of which is fossiliferous (Monroe, 1969). The lower member of the Aymamón consists of white to very pale orange, very pure fossiliferous limestone; it is generally indurated into finely crystalline, dense limestone, and is locally a recemented solution breccia (Monroe, 1966, 1969). The Aymamón formation is estimated to be up to 1,000 feet thick beneath the site (Rodríguez-Martínez, 1995). The middle and upper parts of the formation are highly permeable, with as much as 25 percent total porosity (Rodríguez-Martínez, 1995). Underlying the Aymamón Limestone is the Aguada Limestone, which is characterized as a hard, thick-bedded calcarenite interbedded with chalky limestone and marl (Monroe, 1969).

The Aymamón is present beneath the site as a buff to yellow-tan, soft, moderately to heavily weathered, porous and pitted limestone with some iron staining (E&E, 1997). Hardness and color varies slightly with depth. Cuttings from various depths were also observed to contain fossils. A loss of air circulation during drilling activities, likely due to increased secondary porosity and void space, was generally noted between 150 and 200 feet bgs.

Unconsolidated soils encountered during the drilling activities in 1996 at Landfill Areas 1 and 2 (Figure 1-1) were visually characterized and consisted primarily of brown to orange-brown silty sandy clay and sandy clay (E&E, 1997). Some travertine and clear calcite crystals were observed in rock cuttings at approximately 135 feet bgs at Landfill Area 1. Groundwater at Landfill Area 1 was encountered between approximately 214 and 240 feet bgs and flowed toward the east. At Landfill Area 2, where agricultural crops are grown, a thin (1- to 2-foot thick) veneer of brown silt loam overlies the orange-brown silty sandy clays and sandy clays. Groundwater at Landfill Area 2 was encountered between approximately 211 and 223 feet bgs and flowed north and northwest toward the ocean.

Hydrogeology. Most groundwater at Ramey AFB occurs within the water table aquifer that extends throughout the North Coast Province. An underlying artesian aquifer, which is an important source of water in North-Central Puerto Rico, becomes fragmented and unproductive in the site vicinity. The water table aquifer in the North Coast Province extends from the water table surface to the top of the freshwater/saline-water interface and is a gradational zone 75 to 115 feet thick. The water table aquifer is primarily located within the Aymamón and Aguada limestones, although it is present in the uppermost portion of the alluvial aquifer in coastal areas. In the immediate vicinity of the site, the fresh water table is situated in the Aymamón limestone

only a few feet above sea level (E&E, 1997). Groundwater in the underlying Aguada Limestone is saline within the site boundary.

Estimated hydraulic conductivities within the Aymamón Limestone range from 57 to 570 feet per day and decrease with depth (E&E, 1997). The decrease in hydraulic conductivity with depth is likely related to the maximum effective depth to which karstification will occur within the aquifer. Transmissivity estimates are sparse because no rigorous aquifer tests have been conducted within the area. Available transmissivity estimates for the freshwater zone of the water table aquifer range from 200 to more than 280,000 feet per day. The high transmissivity values potentially reflect cavernous porosity and enhanced dissolution along bedding planes, joints, and fractures.

Surface Water Hydrology. Surface water at Landfill Area 1 drains toward an adjacent sinkhole along channels. These narrow drainage channels are approximately 30 feet deep, with exposed bedrock at the bottom There are swallows along the course of the channels allowing for direct transport of storm water to the underlying groundwater. The easternmost channel has begun to expose landfill material, which is being transported into the sinkhole during storm events. Ponded storm water can remain in the sinkhole for up to a week after a storm, and high-water marks as high as 12 feet have been observed in the sinkhole (E&E, 1997).

Inspection of a 1966 map of the Base indicates that the storm flow channels that received runoff from the aircraft apron terminated into a naturally occurring low area (E&E, 1997). The sanitary fill from the Base was placed in the low area as well. A comparison of the 1966 map with current conditions indicates that the 5-acre, 35-foot-deep sinkhole next to Landfill Area 1 has probably developed during the last 30 years so that now it is gradually capturing the western edge of Landfill Area 1.

Water Supply. Potable water at the former Ramey AFB is supplied by the Puerto Rico Aqueduct and Sewer Authority. This agency reports that domestic water supply in the vicinity of Ramey AFB is obtained from several surface water reservoirs located between 5 and 10 miles south and southeast, and upgradient of the Base. A site visit and file review by E&E revealed no indication of private supply wells for domestic use (E&E, 1997). Private potable supply wells are unlikely in the vicinity of the site due to the depth of groundwater below the ground surface. The former Ramey AFB maintained a supply well (or wells) and a water tower for potable use, but this equipment has fallen into extreme disrepair and appears unusable (E&E, 1997).

2.0 Sampling Strategy and Field Investigation

This chapter discusses the rationale for selecting sample locations and describes the field sampling methods. The background sampling rationale and analytical program were initially presented in the background study work plan (IT, 2000a). The analytical program for samples collected during this study is provided in Table 2-1. Figure 2-1 displays the background sample locations. Analytical results are provided in Appendix A and are evaluated in Chapter 4.0.

2.1 Sampling Strategy

Background samples should be located close enough to investigation sites to be representative of local conditions, but they should not be contaminated with the specific constituents for which they are being used to establish background distributions. Sample locations were carefully selected in areas expected to be uninfluenced by AFB-related contamination and other recent industrial use (Figure 2-1). Historical records, aerial photographs, facility and topographic maps, and current site conditions were evaluated during the sample location selection process.

Nineteen surface soil (0 to 1 foot bgs) samples, two field duplicate surface soil samples, nineteen subsurface soil (1 to 3 feet bgs) samples, and two field duplicate subsurface soil samples were collected from nineteen locations in support of the background chemical data study. Twenty sample locations were proposed in the work plan, but several locations had to be moved due to the presence of limestone bedrock at or near the ground surface. Access to replacement background sampling areas was limited, and shallow bedrock was encountered at many sample locations at depths ranging from 3 inches bgs to 3 feet bgs (Appendix B). The limited access to physically distinct background locations with sufficient soil profile for sampling purposes thus restricted the number of samples that could be obtained.

All of the background samples were analyzed for TAL metals and PAHs. Metals are naturally occurring constituents in soil, and are primarily associated with minerals formed from the chemical and physical weathering of the parent rock. PAHs are a class of organic compounds that form from natural as well as anthropogenic combustion of organic matter (including fossil fuels), and they may also be present in soil. Specific sources of PAHs include motor vehicle exhaust; emissions from coal-, oil-, or wood-burning stoves, furnaces, incinerators, coke ovens and power plants; and asphalt processing and use. Natural sources include forest fires and grass or range-land fires. PAHs are generally ubiquitous in the environment, and background levels in urban, rural, and agricultural soils have been compiled (Agency for Toxic Substances and

Disease Registry, 1995). With the exception of PAHs, it was assumed for the purposes of this study that the soil is naturally free from organic compound contamination.

2.2 Field Procedures

Field activities were performed in accordance with the installation-wide sampling and analysis plan (SAP) (IT, 2000b), installation-wide safety and health plan (IT, 2000c) and the site-specific safety and health plan provided in the background study work plan (IT, 2000a). A sample collection log was completed for each sample submitted for chemical analysis (Appendix A). Sampling equipment was decontaminated between sampling locations in accordance with the SAP (IT, 2000b).

Background soil samples were collected at nineteen locations from May 2 through May 7, 2003. One surface soil sample (0 to 1 foot bgs) and one subsurface soil sample (1 to 3 feet bgs or refusal) were collected at each location using a stainless-steel hand auger. Drilling logs were completed for each soil boring and include descriptions of the soils encountered at each depth interval (Appendix B). Bedrock was encountered in boreholes BGSO04 (at a depth of 3 inches bgs), BGSO05 (2.5 feet bgs), BGSO08 (1.5 feet bgs), BGSO09 (2.5 feet bgs), BGSO10 (2 feet bgs), BGSO14 (2.1 feet bgs), BGSO18 (2 feet bgs), BGSO19 (1 7 feet bgs), and BGSO20 (2.4 feet bgs) Location BGSO04 was deleted from the sampling program because a suitable alternate location could not be established in an area likely unaffected by past or current site activities, physically distinct from the other sample locations, and characterized by sufficient soil profile for sampling purposes. Borings BGSO02, BGSO03, BGSO05, BGSO06, BGSO07, BGSO08, BGSO16, and BGSO17 were relocated to areas where thicker soil cover was anticipated, such as sinkholes or depressions.

The soil samples were homogenized in a stainless-steel bowl before placing into the appropriate sample containers, in accordance with Section 6.6.1 of the SAP (IT, 2000b). Each borehole was backfilled with excess soil after sampling was completed. The location was measured from fixed points in the area and a sketch of the site was drawn on the drilling log. A total of 21 surface soil samples and 21 subsurface soil samples were submitted to an off-site laboratory for TAL metals and PAH analyses. The samples included two field duplicate surface soil samples obtained from locations BGSO01 and BGSO07, and two field duplicate subsurface soil samples obtained from locations BGSO02 and BGSO05.

2.3 Sample Location Surveys

Each soil sample location was documented by tape-measuring from fixed points such as building corners, manholes, and valve boxes; photographing the location with a digital camera; and

surveying with global positioning system (GPS) instruments. A minimum of three points were measured for greater precision and photographs were taken from two directions. The GPS was referenced to a known point (BNQ A on the airfield) for which latitude and longitude were available. The GPS unit was checked against the GPS coordinates established for the airfield at two locations (BNQ A and BNQ C) and was found to be within 0.001 minute of the fixed locations. The GPS data are provided in Appendix C.

3.0 Methodology for Characterization of Background Distributions

This chapter describes the methodology used to characterize background distributions of TAL metals and PAHs in soil at the former Ramey AFB. Only the analytical results for regular environmental samples were used in this background study; field duplicate analyses were excluded.

Background concentrations of naturally occurring constituents form a distribution of values over a given spatial area. The characterization of background can be defined as the process of describing the statistical distribution of concentration values from samples obtained at representative locations. The statistical methodology used here to characterize background distributions is based on published EPA guidance (EPA, 1989, 1992, 1994, 1995, 1997). Key issues addressed in the background characterization methodology are as follows:

- Appropriate spatial grouping of soil samples
- Handling of nondetections
- Checking distributional assumptions
- Handling of outliers
- Calculation of summary statistics.

The following sections explain how these key issues are addressed.

3.1 Spatial Grouping of Soil Samples

Nineteen soil samples were collected from a depth of 0 to 1 foot bgs. The resulting analyses were grouped together and are referred to as "surface soils." Nineteen soil samples were collected from a depth of 1 to 3 feet bgs (or auger refusal). Analyses of these samples were grouped together and are referred to as "subsurface soils."

Separate summary statistics were calculated for the surface soil data set ($n = 19$), subsurface soil data set ($n = 19$), and the combined soil data set ($n = 38$). This approach allows future users of the background characterizations the option of using the most appropriate data set for specific applications.

3.2 Handling of Nondetections

A certain proportion of nondetections are common in background data sets. A variety of methods to deal with nondetections have been proposed, each of which has advantages and disadvantages with respect to introducing unwanted bias into the description of background. In

accordance with EPA guidance, nondetections were replaced with a value equal to one-half of the practical quantitation limit (PQL) for that analyte (EPA, 1989).

For each analyte in surface, subsurface, and combined soil, the existing data were rank-ordered and examined for the presence of nondetects with elevated reporting limits. A 95th upper tolerance limit (UTL) is calculated for each analyte during the characterization of background distributions and is the recommended background screening value for use in site-to-background comparisons (Section 3.5) The 95th UTL is a statistic that extrapolates a reasonable upper threshold to the actual background distribution, based on a limited sample. It is important to ensure that the 95th UTL is not biased toward higher values because of elevated nondetects. Accordingly, nondetects whose replacement values (one-half the PQL) lie in the top ten percent of the distribution were eliminated from the data set as "high nondetects."

3.3 Checking Distributional Assumptions

The specific statistical procedures used to analyze the data and the parameters used to describe background distributions are all dependent on the type of distributions. The selection of an appropriate type of statistical distribution for characterizing background distributions in this report is based on EPA guidance (EPA, 1989, 1992). This guidance recommends that environmental concentration data first be tested for a lognormal distribution because trace element data generally follow this type of model (EPA, 1992). Lognormality is tested by taking the logarithm (log-transform) of the data and testing for normality. If lognormality cannot be demonstrated, then normality testing is performed on the untransformed data. If neither a normal nor a lognormal distribution can be demonstrated, then the distribution is characterized as nonparametric.

The EPA recommends several statistical procedures for determining whether the distribution of concentration data is normal or lognormal (EPA, 1992). One such recommended procedure used here is the Shapiro-Wilk test. The test returns a "p-level" value between zero and one, indicating the goodness of fit. A p-level of 0.05 or greater indicates an acceptable fit to a normal model at the 95 percent confidence level; in other words, there is only a one-in-twenty chance of falsely identifying the distribution as normal when it really is not. If the Shapiro-Wilk test indicates that a data set is neither normal nor lognormal at this confidence level, then the data are assumed to have a nonparametric distribution. Data sets with greater than 15 percent nondetects are automatically treated as nonparametric distributions as per EPA guidance (EPA, 1989).

An additional procedure recommended by EPA (1989) is to graph the data on probability plots (also known as "cumulative distribution curves"). A procedure for generating probability plots is

provided in Appendix E. Normal distributions will appear as a linear array of points. Lognormal distributions will appear as a linear array of points if a logarithmic scale is used for concentrations on the x-axis.

3.4 Handling of Outliers

Outliers are defined as data points whose values are anomalously high relative to the rest of the data set (EPA, 1989). Possible reasons for outliers are as follows:

- Improper sampling, analytical error, or laboratory contamination
- Errors in transcription of data values, decimal points, or units
- The presence of actual contamination in the sample
- A true natural value that is unusually high.

The EPA has provided guidance on the conditions under which it is acceptable to remove outlier values from background data sets (EPA, 1992) The agency states that:

> *If a test designates an observation as a statistical outlier, the sample should not be treated as such until a specific reason for the abnormal measurement can be determined Valid reasons may, for example, include contaminated sampling equipment, laboratory contamination of the sample, or errors in transcription of the data values Once a specific reason is documented, the sample should be excluded from any further statistical analysis If a plausible reason cannot be found, the sample should be treated as a true but extreme value, <u>not</u> to be excluded from further analysis*

Sample locations were carefully selected to avoid potentially contaminated areas, and the analytical results were validated and found to be free of errors. Under these conditions, there is no justification to remove any statistical outliers.

3.5 Calculation of Summary Statistics

A complete description of each background distribution is provided. These descriptions include the number of valid samples, percent nondetects, distribution type (normal, lognormal, or nonparametric), minimum value, maximum value, arithmetic mean, geometric mean, median, standard deviation, and a concentration that is representative of the upper range of the background distribution for use as a background screening value.

The arithmetic mean, geometric mean, and median are all measures of the central tendency of a distribution. These three values are provided for each analyte in the Ramey AFB background data set, but it is important to note that the preferred measure of central tendency depends on the distribution of a given analyte. The arithmetic mean is the most appropriate measure of central

tendency for normal distributions; the geometric mean, for lognormal distributions; and the median, for nonparametric distributions (see also the discussion on "Calculations of Statistical Parameters" in Appendix E).

Nonparametric techniques are used to describe background distributions for data sets that do not have normal or lognormal distributions, as well as any data set with greater than 15 percent nondetects (EPA, 1989). If nondetect values are greater than 50 percent of the data set, then the median is expressed as less than the reporting limit.

It is important to select the background screening value carefully so that the probability of falsely identifying site samples as contaminated or uncontaminated is minimized. Ideally, a site sample with a concentration above the screening value would have a low probability of being a member of the background distribution, and may be an indicator of contamination. The EPA (1989, 1994) has suggested the use of a UTL as a background screening value. The UTL establishes a concentration range that is constructed to contain a specified proportion of the population with a specified confidence. The proportion of the population included is referred to as the "coverage," and the probability with which the tolerance interval includes the proportion is referred to as the "tolerance coefficient." The EPA-recommended coverage value of 95 percent and tolerance coefficient value of 95 percent (EPA, 1989) are used in this report to calculate the UTLs. A coverage of 95 percent means that random uncontaminated site samples will exceed the screening value less than 5 percent of the time. A tolerance coefficient of 95 percent means that one has a 95 percent confidence that the 95th UTL will contain at least 95 percent of the true background distribution.

There are several different methods that can be used to calculate 95th UTLs, which are appropriate for different distributional shapes and different sample sizes. The procedures used to calculate 95th UTLs for this background study are described in Appendix E. A parametric 95th UTL is provided as a measure of the upper range for normal and lognormal distributions. A 95th upper confidence limit (UCL) of the 95th percentile is provided as a measure of the upper range for nonparametric distributions; this statistic is equivalent to a nonparametric 95th UTL.

The 95th UCL of the 95th percentile is calculated using a bootstrap technique as recommended in EPA, 1997. Bootstrap procedures are nonparametric techniques that operate on the actual data rather than statistical parameters (such as mean and standard deviation), and do not require assumptions regarding the statistical distribution of the underlying population. In the bootstrap procedure, repeated sub-samples are drawn with replacement from the given set of observations. The process is then repeated a large number of times, and each time an estimate of the 95th

percentile is computed. The set of estimates thus obtained are then used to compute a 95th UCL of the 95th percentile.

The complete descriptions of background distributions that are provided in this report are sufficient to allow the calculation of most statistical parameters (such as the standard error of the mean, UCL of the mean, two standard deviations above the mean, coefficient of variation, etc.). The descriptions can also be used to support comparisons of site and background data sets. There are two general types of site-to-background comparisons. Parametric comparisons, such as the analysis of variance and two-sample *t* test, require the means and standard deviations of the distributions that are being compared. Nonparametric comparison tests, such as the Wilcoxon rank sum test, require the actual data rather than summary statistics For these purposes, the actual data are provided in Appendix A.

4.0 Background Distributions of Inorganics and PAHs in Soil

This chapter discusses the analytical results of the background study for inorganics and PAHs in surface and subsurface soil. Nineteen surface soil and nineteen subsurface soil samples were obtained at nineteen locations from May 7 through May 12, 2003, and were analyzed for twenty-three inorganics and sixteen PAH compounds. Results of the summary statistics calculations for inorganics and PAHs in surface, subsurface, and combined soils are presented in Tables 4-1 through 4-6.

4.1 Inorganics in Surface Soil

Antimony, selenium, and thallium were 100 percent nondetect in the surface soil data set (Table 4-1). Beryllium, cadmium, magnesium, silver, and sodium were detected in some samples, with nondetects ranging from 5 to 84 percent The remaining 15 elements were detected in all of the 19 samples. Elements with the highest median concentrations were iron, aluminum, calcium, and manganese, in that order. Most of the elemental distributions were either nonparametric or normal.

4.2 PAHs in Surface Soil

Naphthalene was 100 percent nondetect in the surface soil samples (Table 4-2). Phenanthrene was detected in all 19 samples, and the remaining 14 PAH compounds were detected in some of the samples, with nondetects ranging from 5 to 89 percent. Fluoranthene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(a)pyrene, and pyrene exhibit the highest median concentrations of the surface soil data set. All but two of the PAH distributions were classified as nonparametric, primarily due to the high percentage of nondetects.

It is important to note that the acenaphthylene and naphthalene analytical results for sample number ZA0037 are nondetects with PQLs of 400 micrograms per kilogram. This reporting limit is one to two orders of magnitude higher than the other nondetects and detected concentrations in the surface soil samples, and consequently these two results were screened out of the background data set as high nondetects. The resultant sample size for acenaphthylene and naphthalene is 18, versus 19 for the other PAH compounds.

4.3 Inorganics in Subsurface Soil

Antimony and thallium were 100 percent nondetect in the subsurface soil data set (Table 4-3). Cadmium, selenium, silver, and sodium were detected in some samples, with nondetects ranging

from 84 to 95 percent. The remaining 17 elements were detected in all of the 19 samples. Elements with the highest median concentrations were iron, aluminum, calcium, and manganese, in that order. Most of the elemental distributions were either lognormal or nonparametric.

4.4 PAHs in Subsurface Soil

Naphthalene was 100 percent nondetect in the subsurface soil samples (Table 4-4). The remaining 15 PAH compounds were detected in some of the samples, with nondetects ranging from 53 to 95 percent. All of the median values were expressed as less than their respective reporting limits, due to the high percentages of nondetects (greater than 50 percent for all PAHs). All of the PAH distributions were classified as nonparametric, also because of the high percentage of nondetects.

4.5 Comparisons of Surface and Subsurface Distributions

Comparisons of the distributions of inorganic constituents in surface versus subsurface samples reveal only minor differences (Tables 4-1 and 4-3). The subsurface soil interval contains the higher maximum detected concentration for 12 elements—including aluminum, iron, magnesium, and manganese—but in most cases the differences between the maxima are insignificant (10 percent or less). The subsurface soil interval also contains the higher median concentration for 13 elements—including aluminum and iron—but the differences between the medians are insignificant (10 percent or less) in several cases.

The distributions of PAH compounds in surface versus subsurface soil differ primarily because one surface soil sample (ZA0037, collected from sample location BGSO15) contains elevated detected concentrations of several PAH compounds, and because the surface soil data set has higher percentages of detected concentrations for 15 of the 16 PAH compounds. In comparison, most of the subsurface soil samples contain nondetects or low detected concentrations, many of which are near or below the reporting limit. These differences result in significantly higher summary statistics for surface soil, most notably for the maximum and arithmetic mean (the geometric mean and median are less sensitive to a few high values).

The PAH compounds are industrial contaminants but they also naturally form as combustion products during forest and grassland fires. Additional sources include atmospheric fallout from fossil fuel power plants and automotive exhaust, and runoff from asphalt surfaces. They have low mobilities in the soil environment, so they tend to remain where they have formed or settled from atmospheric sources. The presence of PAH compounds in the upper soil column would be expected if the area was subjected to fires or was located downwind from fires. Examination of the soil boring log for location BGSO15 reveals nothing unusual about the soil that might

suggest industrial contamination, and the sample location was carefully selected for its distance from AFB-related industrial operations. For these reasons, the sample was retained in the data set as being representative of background PAH concentrations (although its acenaphthylene and naphthalene results were screened out as high nondetects, as explained in Section 4.2).

Geochemical Evaluation of Inorganics in Soil. Evaluation of geochemical correlation plots is a useful method for comparing the inorganics distributions in surface versus subsurface soil. The plots are based on the natural associations of trace elements with specific minerals in the soil 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 element 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 (see also Section 5.2).

The evaluation includes the generation of plots in which detected arsenic concentrations in a set of samples are plotted on the y-axis, and the corresponding detected iron concentrations are plotted on the x-axis. The slope of a best-fit line through the samples is equal to the average arsenic/iron background ratio. As described in Section 5.2, evaluation of these correlation plots is important in comparisons of site versus background data sets, to distinguish between potentially contaminated samples and samples that contain only naturally occurring element concentrations. 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 samples with elevated arsenic concentrations plot above the trend displayed by the uncontaminated samples, then there is evidence that those samples have an excess contribution of arsenic, and contamination may be indicated.

Each trace element is associated with one or more minerals in the soil matrix. Vanadium and selenium, along with arsenic, form anionic species in solution, and are associated with iron oxides. Divalent metals such as barium, cadmium, lead, and zinc tend to form cationic species in solution and are attracted to clay mineral surfaces. 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

Correlation plots of selected elements in Ramey AFB background soil are provided in Figures 4-1 through 4-6. Aluminum is a primary component of common soil-forming minerals such as clays, feldspars, and micas. Iron oxides are also common soil-forming minerals. 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 thus serves as a qualitative indicator of the relative abundance of these minerals in soil (Figure 4-1). Calcium and magnesium have similar chemical properties, and magnesium often substitutes for calcium in minerals. A plot of magnesium versus calcium is provided in Figure 4-2. As discussed above, arsenic and vanadium both have a strong affinity to adsorb on iron oxides, if a soil sample has a high percentage of iron oxides, then it is expected to have proportionally higher concentrations of associated trace elements such as arsenic and vanadium (Figures 4-3 and 4-4). Chromium concentrations in soil are commonly controlled through adsorption on iron oxide surfaces. Figure 4-5 provides a plot of chromium versus iron. Manganese oxides are also common soil-forming minerals, and have an affinity to adsorb divalent cations such as barium, cobalt, and lead (Kabata-Pendias, 2001); a plot of barium versus manganese is provided in Figure 4-6. In each of these plots, the surface soil samples are depicted as blue triangles and the subsurface soil samples are depicted as green circles.

All of the correlation plots exhibit a common linear trend with a positive slope for the surface and subsurface samples. As seen in Figures 4-1 through 4-6, there is a great degree of overlap between the surface and subsurface soils, although the median concentrations of aluminum, arsenic, chromium, iron, and vanadium in the surface samples are shifted to slightly lower concentrations relative to the subsurface samples. This is most likely due to dilution of the surface soil minerals with naturally occurring organic carbon from decomposing vegetation, and/or wind-blown silica sand. This could not be verified because the samples were not analyzed for organic carbon and silica. However, the surface samples maintain the same elemental ratios as the subsurface samples, and they also lie on the subsurface soil trend. This suggests that the surface and subsurface soil samples represent the same population and that it is

appropriate to combine the two intervals for purposes of defining a single background soil distribution.

Summary Statistics for Combined Soil. For inorganics, comparison of summary statistics and geochemical evaluation of trace versus major elements suggest that the distributions based on the combined surface and subsurface soil data sets should be considered the primary reference for background (Table 4-5). The combined distributions are based on 38 samples versus 19 samples each for surface and subsurface soil, so greater confidence can be placed in their summary statistics. Summary statistics based on the combined soil data sets are also provided for the PAH compounds (Table 4-6). There may be specific applications in which the use of surface or subsurface background distributions may be more appropriate, so separate descriptions of these distributions are provided as well (Tables 4-1 through 4-4).

5.0 Summary of the Background Study and Methodology for Site-to-Background Comparisons

This chapter summarizes the methodology and results of the installation-wide background soil study at the former Ramey AFB, Aguadilla, Puerto Rico. The methodology for site-to-background comparisons to be used at the former Ramey AFB is also presented and discussed.

5.1 Summary of the Background Study

Background soil samples were collected at the former Ramey AFB in accordance with the installation-wide background soil study work plan (IT, 2000a) and the SAP (IT, 2000b) A total of 19 surface soil samples, 19 subsurface soil samples, and 4 field duplicate samples were collected and analyzed for TAL metals and PAH compounds Sample locations were carefully chosen to avoid AFB-related contamination, other industrial use, and proximity to sites undergoing separate investigation and remediation

Background distributions were characterized for TAL metals and PAHs in surface soil, subsurface soil, and combined soil. The statistical methodology employed during this study was based on published EPA guidance (EPA, 1989, 1992, 1994, 1995, 1997). This report provides summary statistics for each constituent, including the number of valid samples, percent nondetects, minimum value, maximum value, distribution type, arithmetic mean, geometric mean, median, standard deviation, and 95th UTL

5.2 Methodology for the Comparison of Site and Background Data Sets

Naturally occurring elements in soil often approximate lognormal distributions, and their concentrations can span two to three orders of magnitude. No background study can capture the entire range of element concentrations, nor can a single background concentration adequately represent the entire background population. Reasonable upper limits of background distributions may be established, but they may still be exceeded by naturally occurring concentrations in any given site data set It is recommended that the comparison of site data to a background threshold value be performed only in conjunction with other tests, and that it never be used as the sole criterion to determine if an analyte is a chemical of potential concern (U S. Navy, 2002). Site-to-background comparisons should consider the distributions of each element, and should include geochemical evaluations to distinguish between potentially contaminated samples versus uncontaminated samples with naturally high concentrations. Background data are most useful when employed in site-to-background comparisons that incorporate the entire available

background data set. The following sections describe the methodology that will be applied to compare site and background data sets for Ramey AFB site investigations.

5.2.1 Statistical Procedures

The statistical phase of Ramey AFB site-to-background comparisons will consist of a background threshold comparison, the nonparametric Wilcoxon rank sum (WRS) test, and box-and-whisker plots. For each medium of interest, each inorganic analyte in the site data set will undergo the three statistical procedures in parallel.

Contamination can be caused by a variety of processes that yield different spatial distributions of elevated constituent 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 multiple simultaneous tests is recommended for comparison of site and background distributions (EPA, 1989, 1992, 1994; U.S. Navy, 2002).

The WRS test is sensitive to slight but pervasive contamination, but is not sensitive to localized or more extreme hot-spot situations. The background threshold comparison is effective in identifying localized contamination, but is not sensitive to slight but pervasive contamination. The WRS test and background threshold comparison are thus complementary. In addition to these tests, box plots are useful for visually comparing the site and background distributions

5.2.1.1 Background Threshold Comparison

The background threshold comparison consists of comparing each site measurement with a concentration value that is representative of the upper limit of the background distribution. Ideally, a site sample with a concentration above the background threshold 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 UTL is recommended as a screening value for normally or lognormally distributed analytes and the 95th UCL of the 95th percentile is recommended as a screening value for nonparametrically distributed analytes (EPA, 1989, 1992, 1994). Site samples with concentrations above these values are not necessarily contaminated, but should be considered suspect.

To perform the test, each analyte's site maximum detected concentration (MDC) will be compared to the background 95th UTL. If the site MDC exceeds the background screening value, then that analyte will be retained for geochemical evaluation. If the MDC does not exceed the background screening value, then hot-spot contamination is not indicated. The remaining statistical procedures will be carried out in parallel with this comparison, to determine if slight but pervasive contamination is present at the site. Background screening values and summary statistics for 23 elements in surface soil, subsurface soil, and combined (surface and subsurface) soil at Ramey AFB are provided in Tables 4-1, 4-3, and 4-5.

5.2.1.2 Wilcoxon Rank Sum Test

The WRS test has been recommended for use in site-to-background comparisons (EPA, 2000; U.S. Navy, 2002). For Ramey AFB site-to-background comparisons, the WRS test will be 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 would lack sufficient power to yield reliable results. Likewise, the test will not be performed on data sets of size $n \leq 4$; in such cases the test would lack sufficient power to identify differences between the two samples.

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 midrank. Next, the sum of the ranks of smaller data set m is calculated. Then the test statistic Z is determined,

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

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 0.05, then there is a statistically significant difference between the medians at the 95 percent confidence level. A Type I error involves rejecting the null hypothesis when it is true. If the p-level is greater than 0.05, then there is no reasonable justification to reject the null hypothesis at the 95 percent confidence level. It can therefore be concluded that the medians of the two data sets are similar, and can be assumed to be drawn from the same population.

If the p-level is less than 0.05, then the medians of the two distributions are significantly different at the 95 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. If the p-level is greater than 0.05, then pervasive site contamination is not suspected. As previously discussed, the background threshold comparison will be performed in parallel with the WRS test, to detect potential hot-spot contamination.

5.2.1.3 Box-and-Whisker Plots

A quick, effective graphical method recommended by the EPA to visualize and compare two or more groups of data is the box plot (EPA, 1989, 1992). An example box plot is provided in Figure 5-1. 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 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 will be 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 two-sample test. As described in Section 5.2.1.2, 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. If the site median is higher than the background median, then slight but pervasive contamination may be indicated. If the site median is below the background median, then slight but pervasive contamination is not suspected.

The use of a lognormal vertical concentration axis may be useful for elements that have large ranges and lognormal distributions. It should be noted that comparison of the box plots will be hindered if there is a high percentage of nondetects, particularly when there are differences in reporting limits between the two data sets. Interpretation of the plots should consider the relative differences in the sizes of the two data sets being compared. The larger of the two sets will tend to have higher maximum concentrations if both sets are drawn from the same population.

5.2.2 Geochemical Evaluations

If an element fails one or both of the statistical tests described in Section 5.2.1, then a geochemical evaluation will be performed to determine if the elevated concentrations are caused by natural processes. Analytes that are demonstrated through geochemical evaluation to be naturally occurring will not be retained for further evaluation or risk assessment.

The importance of geochemical evaluations in distinguishing between naturally occurring element concentrations and contamination has been recognized in the industry (EPA, 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. The geochemical evaluations will be performed as described below.

Trace element distributions in soil tend to have very large ranges (two or three orders of magnitude are not uncommon), and are highly right-skewed, resembling lognormal distributions. Accurate characterization of the upper tails of broadly skewed distributions requires a large number of background samples, which are usually not available. The detection of a high trace element concentration may reflect a naturally elevated background concentration, or it may reflect potential contamination. Mineralogy and soil chemistry dictate that naturally occurring elements in soil and sediment exist in predictable proportion to other elements. Trace element concentrations are expected to covary with major element concentrations, and these relationships can be visualized with correlation plots. Sediment studies in particular have made effective use of these relationships to distinguish between naturally occurring and anthropogenic concentrations.

Aluminum is typically used in sediment studies as a normalizer of trace element concentrations because it is naturally abundant; anthropogenic contribution is uncommon; and it is a primary component of clay minerals, which concentrate many trace elements (Windom et al., 1989; Hanson et al., 1993; Daskalakis and O'Connor, 1995). Iron is also an important reference

element because of the relative abundance of iron oxide minerals, with which many trace elements associate, and thus it has also been used as a normalizer in sediment studies (Daskalakis and O'Connor, 1995; Schiff and Weisberg, 1997). Manganese oxides have an affinity to adsorb specific elements, so manganese is also used as a reference element in some cases if its abundance in soil or sediment is high enough and it is not a contaminant of concern at the site (Kabata-Pendias, 2001). Some trace elements, including mercury, selenium, and copper, have also been correlated with total organic carbon (TOC); however, associations with TOC are often much less significant than those with reference elements and TOC is often increased through anthropogenic inputs (Windom et al., 1989; Daskalakis and O'Connor, 1995).

Correlation of Major Elements and Trace Elements. The geochemical evaluation for soil is based on the natural associations of trace elements with specific minerals in the soil matrix. As an example, arsenic in most uncontaminated oxic soil 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 element 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 arsenic concentrations in a set of samples are plotted on the y-axis, and the corresponding iron concentrations are plotted on the x-axis. The slope of a best-fit line through the samples is equal to the average arsenic/iron background ratio. If the samples with the highest arsenic concentrations plot on the same linear trend as the other samples, then it is most probable that the elevated concentrations are natural, and are caused by the preferential enrichment of iron oxides in those samples. If the site samples with elevated arsenic concentrations plot above the trend displayed by the uncontaminated

samples, then there is evidence that those samples have an excess contribution of arsenic, and contamination may be indicated.

Each trace element is associated with one or more minerals in the soil matrix, and correlation plots of trace elements versus major elements will be constructed as demonstrated in Section 4.5. Vanadium and selenium, along with arsenic, form anionic species in solution, and are associated with iron oxides. Divalent metals such as barium, cadmium, lead, and zinc tend to form cationic species in solution and are attracted to clay mineral surfaces. 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. Soils formed from the weathering of limestone would be expected to contain a high proportion of calcium carbonate. Trace elements such as lead and zinc may substitute for calcium in carbonate minerals, and plots of calcium versus lead or zinc may be constructed in those instances.

All available soil boring logs and field observations are examined as part of the geochemical evaluation, as the descriptions of soil lithology provide useful information about likely mineralogical controls on trace element concentrations. For example, soil samples characterized by finer grain sizes are likely to be enriched in clays and iron oxides (which tend to exist as very fine particles) and thus would contain naturally elevated concentrations of aluminum, iron, and associated trace elements.

All available background data are incorporated in the correlation plots, and provide a baseline against which the site data are compared. If there is no contamination present, the plot is expected to exhibit a generally linear trend with a positive slope (as seen in Figures 4-1 through 4-6). Potential contamination is readily identified by anomalous site samples that plot above the trend. Nondetect samples are not included in the correlation plots. Their replacement values (such as one-half the reporting limit) are assumed quantities that have no meaning in the geochemical context, and they obscure the relationships that the correlation plots attempt to depict.

5.2.3 Summary of the Site-to-Background Comparison Methodology

To detect potential hot-spot contamination, site data will be compared to the background screening values provided in Tables 4-1, 4-3, and 4-5. Potential contamination that is slight but pervasive will be identified with the WRS test. Box plots will be used to visually compare the site and background distributions and to properly interpret the results of the WRS test. Any

element that fails one or both quantitative statistical tests will be retained for geochemical evaluation.

Correlation plots will be constructed to compare the relationships of trace elements versus major elements. Naturally occurring trace elements typically maintain a constant ratio with the major elements with which they associate, thereby defining a linear trend on the plots; contaminated samples would contain an excess concentration of trace element(s) and would plot off the linear trend. All available soil boring logs and field observations will be examined as part of the geochemical evaluations.

6.0 References

Agency for Toxic Substances and Disease Registry, 1995, ***Toxicological Profile for Polycyclic Aromatic Hydrocarbons***, U.S. Department of Health and Human Services, August.

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

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

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

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

Ecology and Environment, Inc. (E&E), 1997, ***Draft Site Investigation Report for Landfill Areas 1 and 2, Former Ramey Air Force Base, Aguadilla, Puerto Rico***, September.

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

Hanson, P J , D.W. Evans, D.R. Colby, and V.S. Zdanowicz, 1993, "Assessment of Elemental Contamination in Estuarine and Coastal Environments Based on Geochemical and Statistical Modeling of Sediments," ***Marine Environmental Research***, Vol. 36, pp. 237-266

IT Corporation (IT), 2000a, ***Final Work Plan for the Installation-Wide Background Soil Study, Former Ramey Air Force Base, Aguadilla, Puerto Rico***, prepared for the U.S. Army Corps of Engineers, South Atlantic Division, May.

IT Corporation (IT), 2000b, ***Final Former Ramey Air Force Base Installation-Wide Sampling and Analysis Plan, Aguadilla, Puerto Rico***, Revision 1, prepared for the U.S. Army Corps of Engineers, South Atlantic Division, February.

IT Corporation (IT), 2000c, ***Final Safety and Health Plan, Ramey Air Force Base, Aguadilla, Puerto Rico***, prepared for the U.S. Army Corps of Engineers, South Atlantic Division, February.

Kabata-Pendias, A., 2001, ***Trace Elements in Soil and Plants***, Third Edition, CRC Press, Boca Raton, Florida.

Monroe, W. H., 1969, ***Geologic Map of the Aguadilla Quadrangle, Puerto Rico***, U.S. Geological Survey, Miscellaneous Geologic Investigations Map, I-0569, January 1.

Monroe, W. H., 1966, "Formation of Tropical Karst Topography by Limestone Solution and Reprecipitation," ***Caribbean Journal of Science***, Vol. 6, pp. 1-7.

Myers, J., and K. Thorbjornsen, 2004, "Identifying Metals Contamination in Soil: A Geochemical Approach," ***Soil & Sediment Contamination: an International Journal***, Vol. 13, No. 1, in press.

Rodríguez-Martínez, J., 1995, ***Hydrogeology of the North Coast Limestone Aquifer System of Puerto Rico***, U.S. Geological Survey Water-Resources Investigations Report 94-4249.

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

U.S. Department of Agriculture (USDA), 1975, ***Soil Survey of Mayaguez Area of Western Puerto Rico***, Soil Conservation Service, December.

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

U.S. Environmental Protection Agency (EPA), 1997, "The Lognormal Distribution in Environmental Applications," Technical Support Center Issue, EPA/600/R-97/006, December.

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

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

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

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

U.S. Geological Survey, 1960, Aguadilla, Isabela, and Moca Quadrangle topographic map.

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

Windom, H.L., S.J. Schropp, F.D. Calder, J.D. Ryan, R.G. Smith, Jr., L.C. Burney, F.G. Lewis, and C.H. Rawlinson, 1989, "Natural Trace Metal Concentrations in Estuarine and Coastal Marine Sediments of the Southeastern United States," ***Environmental Science & Technology***, Vol. 23, No. 3, pp. 314-320.

TABLES

Table 2-1

Sampling and Analysis Program
Installation-Wide Background Soil Study
Former Ramey AFB, Aguadilla, Puerto Rico

	Total Number of Samples Analyzed	
Parameter	**TAL Metals**	**PAHs**
Analytical Method.	EPA SW-6010B/7471	EPA SW-8270 [a]
Surface Soil	19	19
Subsurface Soil	19	19

[a] PAHs were analyzed by EPA method SW8270-low, please see the Variance Log in Appendix A

Note Surface soil samples were collected from 0 to 1 foot below ground surface, and subsurface soil samples were collected from 1 to 3 feet below ground surface

EPA - U S Environmental Protection Agency

PAH - Polynuclear aromatic hydrocarbon

TAL - Target analyte list

Table 4-1

Background Summary Statistics for Inorganics in Surface Soil (mg/kg)
Installation-Wide Background Soil Study
Former Ramey AFB, Aguadilla, Puerto Rico

Element	*n*	Percent Nondetect	Distribution Type	Minimum	Maximum	Arithmetic Mean	Geometric Mean	Median	Standard Deviation	95th UTL
Aluminum	19	0	Normal	2,920	22,100	12,320	11,310	12,900	4,640	23,560
Antimony	19	100	Nonparametric	< 11 9	< 18 6	< 13 9	< 13 5	< 13 3	NA	< 18 6
Arsenic	19	0	Normal	. 3	28	15 6	14 0	15 8	6 60	31 6
Barium	19	0	Lognormal	9 6	72 1	33 1	30 2	31 3	14 5	89 9
Beryllium	19	5	Normal	0 26	1 3	0.720	0 669	0 73	0 263	1 36
Cadmium	19	84	Nonparametric	0 32	<1 6	0 530	0 518	< 1.1	0.111	0 88
Calcium	19	0	Lognormal	672	192,000	18,240	4,670	4,180	43,160	243,600
Chromium	19	0	Normal	27.6	210	116	106	129	46 0	228
Cobalt	19	0	Normal	2 4	20 1	10 7	9 95	10 8	3 53	19 2
Copper	19	0	Nonparametric	5 6	259	25 7	13 7	11 4	56 8	360 5
Iron	19	0	Normal	6,200	50,900	27,550	25,020	25,200	11,100	54,490
Lead	19	0	Lognormal	5 6	41	19 2	17.5	16.3	8 35	52.6
Magnesium	19	16	Nonparametric	215	969	505	463	504	212	1,055
Manganese	19	0	Nonparametric	122	2,040	870	784	837	374	2,390
Mercury	19	0	Nonparametric	0 035	0 22	0 0734	0 0629	0 054	0 0502	0.26
Nickel	19	0	Normal	4 7	32 2	16 3	14 9	16 1	6 62	32.4
Potassium	19	0	Lognormal	231	1,090	558	523	490	213	1,270
Selenium	19	100	Nonparametric	< 0 99	< 1 6	< 1 2	< 1 2	< 1 1	NA	< 1 6
Silver	19	89	Nonparametric	1	3 9	1 25	1 18	< 2 2	0 644	5 06
Sodium	19	95	Nonparametric	226	< 1,550	547	536	< 1,110	97 0	< 1,550
Thallium	19	100	Nonparametric	< 2	< 3 1	< 2 3	< 2 3	< 2 2	NA	< 3 1
Vanadium	19	0	Normal	13 6	100	55 2	50 6	53	21 4	107
Zinc	19	0	Lognormal	9 3	71 1	25 8	21 7	18 3	16 0	92 9

Note: Surface soil samples were obtained from 0 to 1 foot below ground surface
mg/kg - Milligram(s) per kilogram
UTL - Upper tolerance limit

Table 4-2

Background Summary Statistics for PAHs in Surface Soil (ug/kg)
Installation-Wide Background Soil Study
Former Ramey AFB, Aguadilla, Puerto Rico

Analyte	*n*	Percent Nondetect	Distribution Type	Minimum	Maximum	Arithmetic Mean	Geometric Mean	Median	Standard Deviation	95th UTL
Acenaphthene	19	84	Nonparametric	< 3 5	260	15.73	2.62	< 3 6	59 2	368
Acenaphthylene	18	83	Nonparametric	1	10	2 20	1.88	< 3.6	1 97	13.3
Anthracene	19	47	Nonparametric	1	420	25 0	3 06	1 8	95 7	594
Benzo(a)anthracene	19	16	Nonparametric	< 3 6	1,200	82.7	14.3	14	272	1,670
Benzo(a)pyrene	19	32	Nonparametric	< 3 5	1,000	70.1	10 9	13	227	1,390
Benzo(b)fluoranthene	19	16	Nonparametric	2 3	680	58 1	14 6	14	153	925
Benzo(ghi)perylene	19	32	Nonparametric	< 3 5	590	45 4	9 06	5 9	133	822
Benzo(k)fluoranthene	19	16	Nonparametric	2 1	1,000	67 6	10 4	8 3	227	1,410
Chrysene	19	11	Nonparametric	2	1,200	80 6	11 7	9 6	272	1,670
Dibenzo(a,h)anthracene	19	89	Nonparametric	< 3 5	140	9 96	2.59	< 3 6	31 7	195
Fluoranthene	19	5	Lognormal	1 6	2,400	155	17.8	15	546	1,230
Fluorene	19	84	Nonparametric	2 9	140	9 24	2 43	< 3 6	31.7	199
Indeno(1,2,3-cd)pyrene	19	53	Nonparametric	< 3 5	680	49 1	7 38	< 3.7	154	947
Naphthalene	18	100	Nonparametric	< 3 5	< 5	< 3 7	< 3 7	< 3 6	NA	< 5
Phenanthrene	19	0	Nonparametric	1	1,700	101	8 38	6 1	387	2,410
Pyrene	19	5	Lognormal	1 6	2,400	151	16 0	13	546	1,090

Notes. (1) Surface soil samples were obtained from 0 to 1 foot below ground surface
(2) Acenaphthylene and naphthalene results for sample ZA0037 are high nondetects and were deleted from the background data set Please see Sections 3 2 and 4 2 for details
ug/kg - Microgram(s) per kilogram.
UTL - Upper tolerance limit

Table 4-3

Background Summary Statistics for Inorganics in Subsurface Soil (mg/kg)
Installation-Wide Background Soil Study
Former Ramey AFB, Aguadilla, Puerto Rico

Element	*n*	Percent Nondetect	Distribution Type	Minimum	Maximum	Arithmetic Mean	Geometric Mean	Median	Standard Deviation	95th UTL
Aluminum	19	0	Lognormal	9,480	28,500	17,820	17,010	17,300	5,480	36,720
Antimony	19	100	Nonparametric	< 12 3	< 15.1	< 13 6	< 13 6	< 13 6	NA	< 15.1
Arsenic	19	0	Lognormal	11 9	32	19.3	18 6	19 6	5 66	37 6
Barium	19	0	Lognormal	13 2	75 5	34 9	31 2	31 6	17 0	104
Beryllium	19	0	Nonparametric	0 43	1 6	0 955	0 869	0.94	0 400	1 69
Cadmium	19	84	Nonparametric	0 25	< 1 3	0 514	0.498	< 1 1	0 113	< 1 3
Calcium	19	0	Nonparametric	732	78,900	13,370	3,990	2,190	24,000	98,500
Chromium	19	0	Normal	68 1	233	150	142	143	48.6	268
Cobalt	19	0	Lognormal	4 4	20 8	12 0	11 2	11 9	4 50	29 6
Copper	19	0	Lognormal	9 1	24 5	13 7	13 2	12 8	3 73	24 1
Iron	19	0	Lognormal	22,100	51,700	37,610	36,430	35,100	9,580	68,910
Lead	19	0	Normal	8 3	22 6	14 4	13 8	13 6	4 21	24 6
Magnesium	19	0	Lognormal	237	1,040	455	424	408	193	1,040
Manganese	19	0	Lognormal	116	2,210	886	742	834	508	3,730
Mercury	19	0	Nonparametric	0 038	0 23	0 0725	0 0635	0 056	0 0494	0 28
Nickel	19	0	Lognormal	10 7	33.1	21 5	20 5	20 5	6 66	44 6
Potassium	19	0	Lognormal	397	1,040	615	597	613	157	1,090
Selenium	19	95	Nonparametric	0 82	< 1 2	0 569	0 566	< 1 1	0 0670	< 1 2
Silver	19	89	Nonparametric	0 59	6 9	1 39	1 19	< 2 3	1 34	9 32
Sodium	19	89	Nonparametric	275	< 1,260	532	521	< 1,110	93 8	< 1,260
Thallium	19	100	Nonparametric	< 2 1	< 2 5	< 2 3	< 2 3	< 2 3	NA	NA
Vanadium	19	0	Lognormal	46	102	73 9	71 9	71 3	17 2	128
Zinc	19	0	Lognormal	10 1	46 8	19 2	17 6	15 9	9 19	46 8

Note Subsurface soil samples were obtained from 1 to 3 feet below ground surface
mg/kg - Milligram(s) per kilogram
UTL - Upper tolerance limit

Table 4-4

Background Summary Statistics for PAHs in Subsurface Soil (ug/kg)
Installation-Wide Background Soil Study
Former Ramey AFB, Aguadilla, Puerto Rico

Analyte	*n*	Percent Nondetect	Distribution Type	Minimum	Maximum	Arithmetic Mean	Geometric Mean	Median	Standard Deviation	95th UTL
Acenaphthene	19	95	Nonparametric	3	< 4	1 93	1.92	< 3 7	0 265	< 4
Acenaphthylene	19	95	Nonparametric	< 3 6	9.6	2 28	2 04	< 3 7	1 77	12.9
Anthracene	19	89	Nonparametric	0 82	13	2 40	1.98	< 3 7	2 58	17 7
Benzo(a)anthracene	19	74	Nonparametric	< 3 6	86	8.11	3.26	< 3 8	19 3	117
Benzo(a)pyrene	19	84	Nonparametric	< 3 6	70	6 47	2 74	< 3.8	15 7	95.2
Benzo(b)fluoranthene	19	74	Nonparametric	< 3.6	74	7 15	3 14	< 3 8	16 5	101
Benzo(ghi)perylene	19	84	Nonparametric	< 3 6	68	5 89	2.60	< 3 8	15 1	93 8
Benzo(k)fluoranthene	19	74	Nonparametric	< 3 6	62	5 68	2 69	< 3 8	13 7	85 6
Chrysene	19	74	Nonparametric	2 7	74	6 46	2.79	< 3 8	16 5	102
Dibenzo(a,h)anthracene	19	95	Nonparametric	< 3 6	23	2.98	2 13	< 3 7	4.85	31 9
Fluoranthene	19	63	Nonparametric	1 1	120	9 51	3 02	< 3 8	27 0	166
Fluorene	19	95	Nonparametric	2.3	< 4	1 89	1 89	< 3.7	0.113	< 4
Indeno(1,2,3-cd)pyrene	19	84	Nonparametric	< 3 6	60	5 85	2 70	< 3 8	13 4	81 3
Naphthalene	18	100	Nonparametric	< 3.6	< 4	< 3 8	< 3 8	< 3.7	NA	< 4
Phenanthrene	19	53	Nonparametric	1	49	4.43	2 11	< 3 7	10 8	68
Pyrene	19	58	Nonparametric	0 95	130	9 92	2 84	< 3 8	29 3	181

Note Subsurface soil samples were obtained from 1 to 3 feet below ground surface
ug/kg - Microgram(s) per kilogram
UTL - Upper tolerance limit.

Table 4-5

Background Summary Statistics for Inorganics in Combined Soil (mg/kg)
Installation-Wide Background Soil Study
Former Ramey AFB, Aguadilla, Puerto Rico

Element	*n*	Percent Nondetect	Distribution Type	Minimum	Maximum	Arithmetic Mean	Geometric Mean	Median	Standard Deviation	95th UTL
Aluminum	38	0	Normal	2,920	28,500	15,070	13,870	14,650	5,730	27,370
Antimony	38	100	Nonparametric	< 11 9	< 18 6	< 13 5	< 13 4	< 13.4	NA	< 18 6
Arsenic	38	0	Normal	3	32	17 5	16 1	16 45	6.36	31 1
Barium	38	0	Lognormal	9 6	75 5	34 0	30 7	31 45	15.6	83 6
Beryllium	38	3	Lognormal	0 26	1 6	0 838	0.763	0.805	0.355	2 01
Cadmium	38	84	Nonparametric	0 25	< 1.6	0 522	0.508	< 1 1	0.111	< 1.6
Calcium	38	0	Nonparametric	672	192,000	15,810	4,310	2,960	34,540	193,600
Chromium	38	0	Normal	27.6	233	133	123	131 5	49.7	240
Cobalt	38	0	Normal	2 4	20.8	11 3	10 6	11 05	4.05	20.0
Copper	38	0	Nonparametric	5 6	259	19 7	13 5	12 15	40 2	251
Iron	38	0	Normal	6,200	51,700	32,580	30,190	32,800	11,430	57,120
Lead	38	0	Lognormal	5 6	41	16 8	15.5	16.05	6 96	36 6
Magnesium	38	8	Lognormal	215	1,040	480	443	428	202	1,050
Manganese	38	0	Nonparametric	116	2,210	878	763	835.5	440	2,390
Mercury	38	0	Nonparametric	0 035	0 23	0 0730	0.0632	0 054	0 0491	0 26
Nickel	38	0	Normal	4 7	33 1	18 9	17.5	18 65	7 05	34.0
Potassium	38	0	Lognormal	231	1,090	586	559	580	187	1,100
Selenium	38	97	Nonparametric	0 82	< 1 6	0 569	0 566	< 1 1	0 0650	< 1.6
Silver	38	89	Nonparametric	0 59	6 9	1 32	1 18	< 2 2	1 04	7 42
Sodium	38	92	Nonparametric	226	< 1,550	539	528	<1,110	94.4	< 1,550
Thallium	38	100	Nonparametric	< 2	< 3 1	< 2.3	< 2.3	< 2 2	NA	< 3 1
Vanadium	38	0	Normal	13.6	102	64 5	60 3	65 5	21 4	110
Zinc	38	0	Nonparametric	9 3	71 1	22 5	19 6	16 75	13 3	70 9

mg/kg - Milligram(s) per kilogram
UTL - Upper tolerance limit

Table 4-6

Background Summary Statistics for PAHs in Combined Soil (ug/kg)
Installation-Wide Background Soil Study
Former Ramey AFB, Aguadilla, Puerto Rico

Analyte	*n*	Percent Nondetect	Distribution Type	Minimum	Maximum	Arithmetic Mean	Geometric Mean	Median	Standard Deviation	95th UTL
Acenaphthene	38	89	Nonparametric	3	260	8 83	2 24	< 3 7	41.9	255
Acenaphthylene	37	89	Nonparametric	1	10	2.24	1 96	< 3 7	1 85	12 8
Anthracene	38	68	Nonparametric	0 82	420	13 7	2.46	< 3.7	67.8	414
Benzo(a)anthracene	38	45	Nonparametric	< 3 6	1,200	45 4	6 83	6 6	194	1,200
Benzo(a)pyrene	38	58	Nonparametric	< 3 5	1,000	38.3	5.46	< 3 9	162	999
Benzo(b)fluoranthene	38	45	Nonparametric	2 3	680	32.6	6 78	6 3	111	684
Benzo(ghi)perylene	38	58	Nonparametric	< 3 5	590	25 7	4 85	< 3 9	95 7	576
Benzo(k)fluoranthene	38	45	Nonparametric	2 1	1,000	36 7	5 30	2 6	162	998
Chrysene	38	42	Nonparametric	2	1,200	43 5	5 70	2 85	194	1,210
Dibenzo(a,h)anthracene	38	92	Nonparametric	< 3 5	140	6 47	2 35	< 3 7	22 7	138
Fluoranthene	38	34	Nonparametric	1 1	2,400	82 4	7 34	4.1	388	2,390
Fluorene	38	89	Nonparametric	2 3	140	5 57	2 14	< 3 7	22 4	133
Indeno(1,2,3-cd)pyrene	38	68	Nonparametric	< 3 5	680	27 5	4 46	< 3.8	110	665
Naphthalene	37	100	Nonparametric	< 3 5	< 5	< 3 7	< 3 7	< 3.7	NA	< 5
Phenanthrene	38	26	Nonparametric	1	1,700	52 9	4.21	< 3 9	275	1,650
Pyrene	38	32	Nonparametric	0 95	2,400	80 3	6 74	3 75	388	2,390

Note· Acenaphthylene and naphthalene results for surface soil sample ZA0037 are high nondetects and were deleted from the background data set Please see Sections 3 2 and 4 2 for details
ug/kg - Microgram(s) per kilogram
UTL - Upper tolerance limit

FIGURES

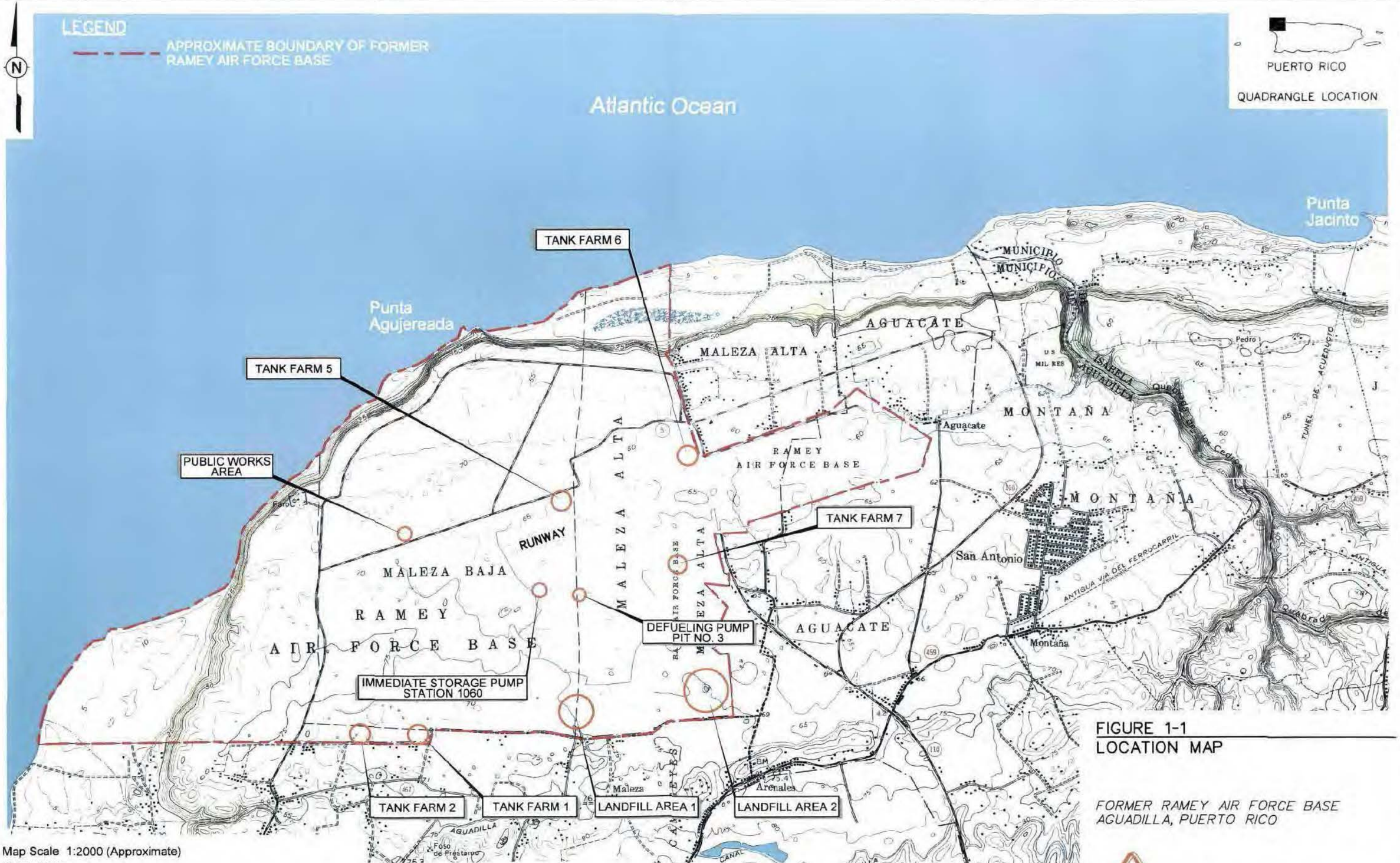


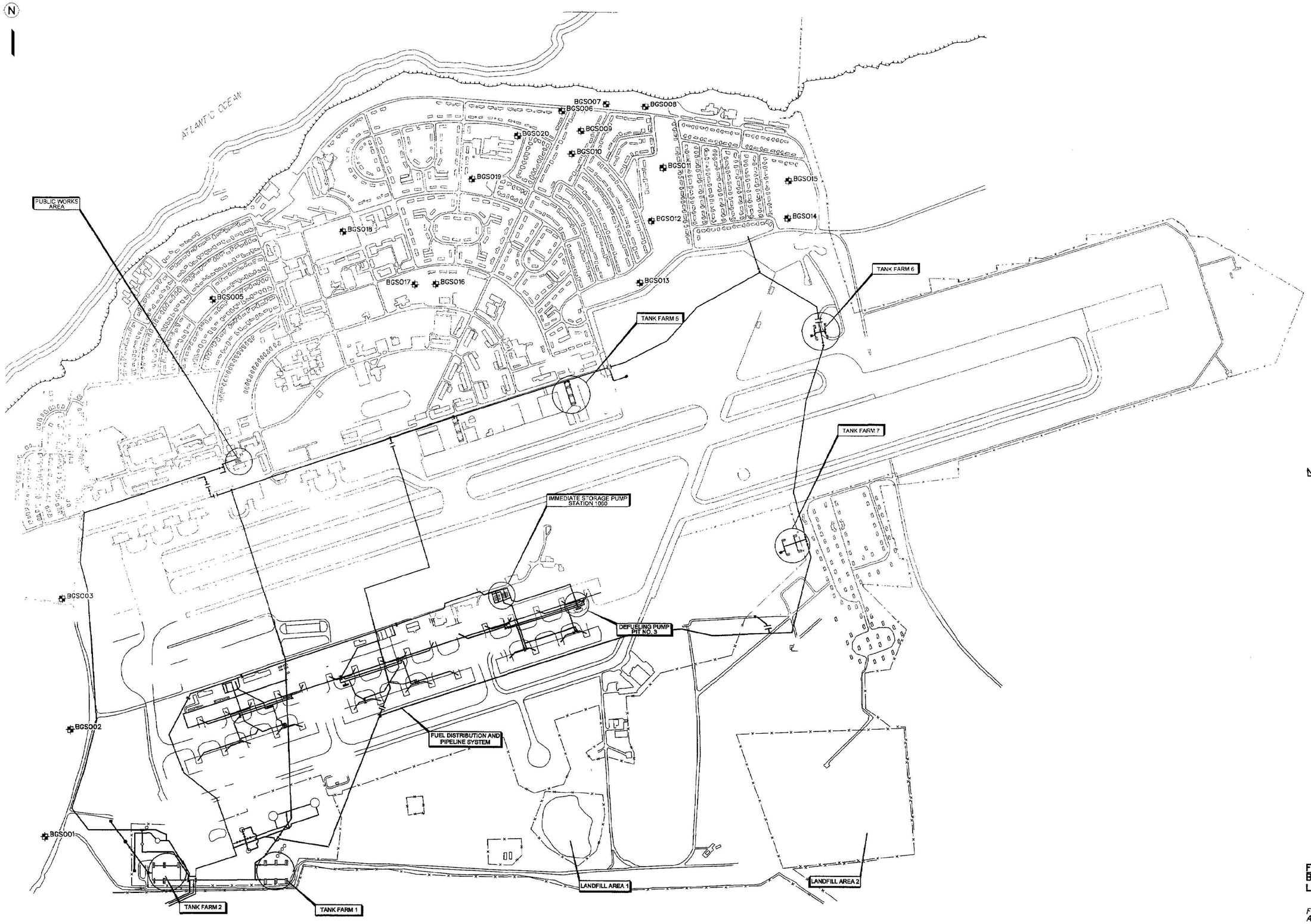
FIGURE 1-1
LOCATION MAP

FORMER RAMEY AIR FORCE BASE
AGUADILLA, PUERTO RICO

INITIATOR: K.THORBJORNSEN	TECH. REVIEW: K.THORBJORNSEN
CADD REVIEW: C.BENTLEY	PROJ. MGR.: G.QUARLES
STARTING DATE: 03SEP03	DWG. NO.: 783146-bkgnd-0002.dgn
DRAWN BY: C.E.TUMLIN	PROJ. NO.: 783146

r2c2-color-tabloid.pltd
Standard_Color_Mod.tbl
09/09/2003
09:20:00 AM

0.8333 ft / IN.
ctumlin
783146-bkgnd-0002.dgn



LEGEND

- BGS016 — SOIL BORING
- FENCE
- FUEL DISTRIBUTION AND PIPELINE SYSTEM

NOTES

1. ALL SAMPLE LOCATIONS ARE APPROXIMATE.

SCALE
0 500 1000 FEET

FIGURE 2-1
BACKGROUND SOIL SAMPLE LOCATIONS

FORMER RAMEY AIR FORCE BASE
AGUADILLA, PUERTO RICO

Shaw™
Shaw Environmental, Inc.

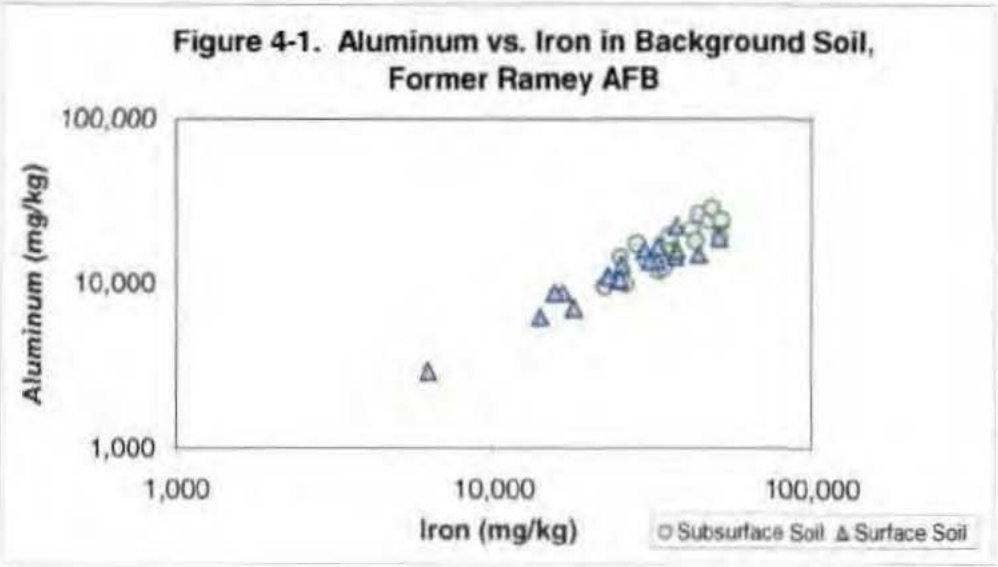


Figure 4-1. Aluminum vs. Iron in Background Soil, Former Ramey AFB
100,000
10,000
1,000
Aluminum (mg/kg)
1,000
10,000
100,000
Iron (mg/kg)
Subsurface Soil
Surface Soil

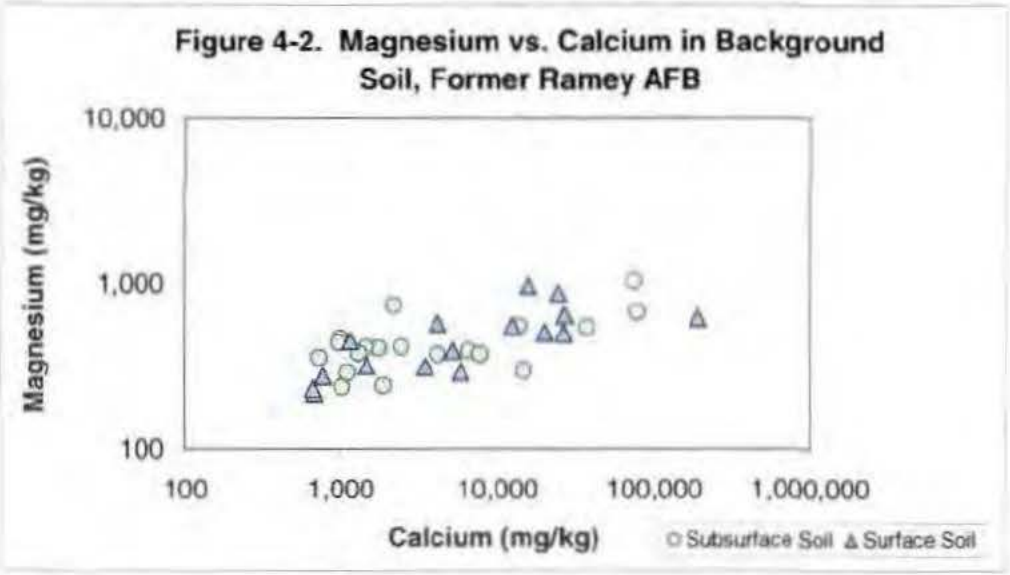


Figure 4-2. Magnesium vs. Calcium in Background Soil, Former Ramey AFB
10,000
1,000
100
Magnesium (mg/kg)
100
1,000
10,000
100,000
1,000,000
Calcium (mg/kg)
Subsurface Soil
Surface Soil

Figure 4-3. Arsenic vs. Iron in Background Soil, Former Ramey AFB

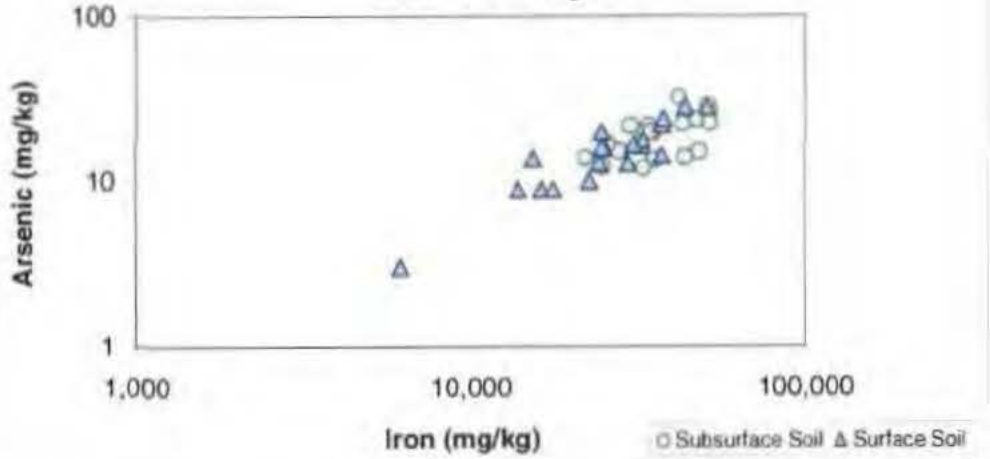
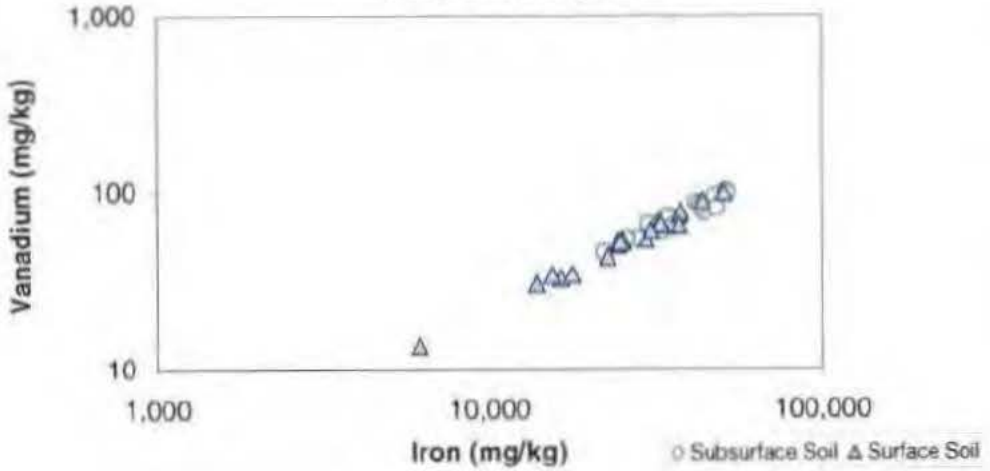


Figure 4-4. Vanadium vs. Iron in Background Soil, Former Ramey AFB



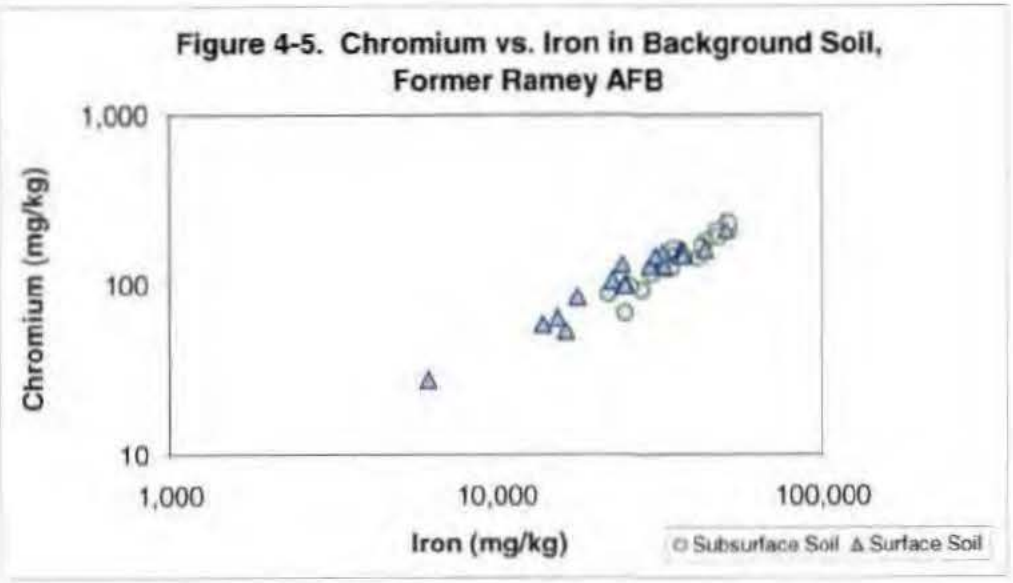


Figure 4-5. Chromium vs. Iron in Background Soil, Former Ramey AFB
1,000
100
10
Chromium (mg/kg)
1,000
10,000
100,000
Iron (mg/kg)
Subsurface Soil
Surface Soil

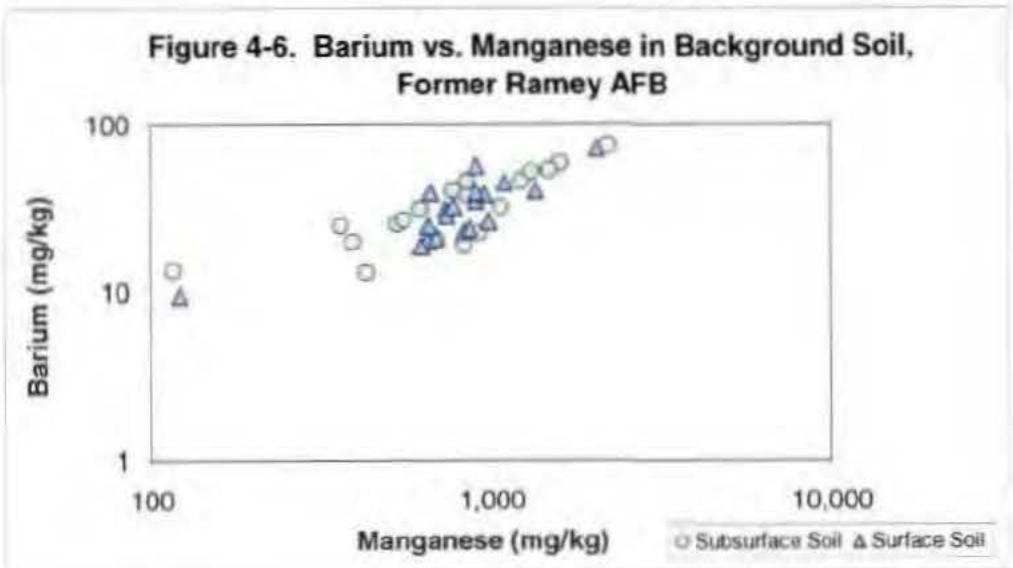


Figure 4-6. Barium vs. Manganese in Background Soil, Former Ramey AFB
100
10
1
Barium (mg/kg)
100
1,000
10,000
Manganese (mg/kg)
Subsurface Soil
Surface Soil

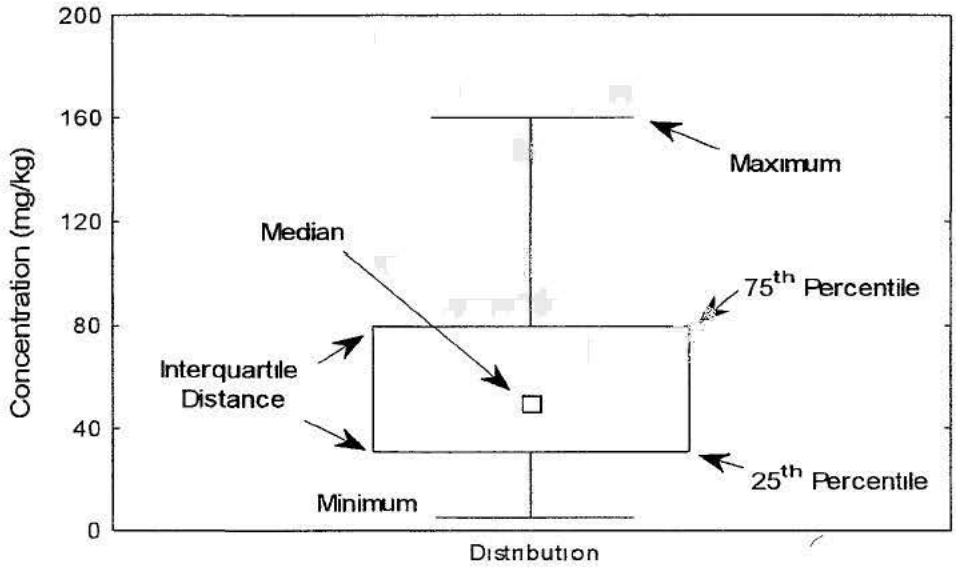



Figure 5-1
Example Box Plot