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OVERVIEW OF THE CHEMICALS OF CONCERN IDENTIFICATION PROCESS
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
HUMAN HEALTH RISK ASSESSMENT
OPERABLE UNIT 3

January 18, 1995

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1 0 INTRODUCTION

The purpose of this document is to present an overview of the Chemicals of Concern (COC) selection process for Rocky Flats Environmental Technology Site (RFETS) Operable Unit 3 (OU 3) by presenting the methodology used to select COCs in TM 4 (DOE, 1994). The discussion of the process will focus on the list of COCs provided by EPA in their comments on TM 4 (EPA, 1995). Little emphasis is given to the selection of COCs for surface soils (IHSS 199) because there were not comments by EPA on the surface soil COCs. Information regarding the selection of COCs in surface soils is provided in Sections 3 0 and 4 0 of TM 4 (DOE, 1994).

The COC selection process identifies the chemicals detected in OU 3 that contribute significant potential risks to human receptors. The objective of the process is to identify those chemicals in a particular medium that, based on concentration and toxicity, contribute significantly to risks calculated for exposure scenarios involving that medium (EPA, 1989). The COCs will be used in the HHRA for OU 3 to quantify risks associated with exposure to environmental media. The COC selection process was agreed upon by EPA, CDPHE, and DOE and is based on Risk Assessment Guidance for Superfund (EPA, 1989), the Rocky Flats IAG between the State of Colorado (CDPHE), the U.S. Environmental Protection Agency (EPA), and the Department of Energy (DOE), January 1991 (IAG, 1991), and site-specific guidance (CDPHE/EPA/DOE, 1994, CDPHE/EPA, 1993, DOE, 1993a, EPA, 1994).

The COC selection process, as specified by the EPA, CDPHE, and DOE, is outlined in Figure 1-1 and includes the following steps:

- Statistical comparison of site data to background data (Section 2 0)
- Elimination of essential nutrients (Section 3 0)
- Elimination of chemicals detected infrequently (less than 5 percent detection frequency) and less than 1,000 times a risk-based concentration (Sections 4 0 and 5 0)
- Concentration-Toxicity screen (Section 6 0)
- Comparison to Preliminary Remediation Goals (PRGs) (Section 7 0)
- Weight-of-evidence evaluation (Section 8 0)

According to the RFETS COC selection process guidance (CDPHE/EPA/DOE, 1994), COCs are selected using all data, for a particular medium, from an operable unit. However, for OU 3, the selection of COCs on an OU-wide basis is not appropriate based on spatial, exposure, physical processes, and hydrologic differences (A discussion of these factors is provided in Subsection 2.1). Therefore, on the basis of these factors, the remaining sections address the selection of COCs on an IHSS-by-IHSS basis.

2.0 STATISTICAL COMPARISON TO BACKGROUND

The purpose of this step of the COC selection process is to identify chemicals with concentrations or activities in OU 3 that are significantly greater than corresponding concentrations or activities in background. The term "background data" is used to represent the data collected and summarized in the BGCR (DOE, 1993c) and the Rock Creek surface soil data used in the statistical comparison tests. The statistical comparison methodology includes a data-presentation step and a series of statistical comparison tests that are performed for each analyte. The statistical methodology for OU-to-background comparisons was agreed upon by EPA, CDPHE, and DOE (DOE, 1993a, EPA, 1993, DOE, 1994a, EG&G, 1994) and is based on site-specific guidance developed by Gilbert (1993).

2.1 Selection of Data Sets

All chemical data collected during the OU 3 field sampling program, as well as supplemental chemical data (Jefferson County Remedy Acres surface soil data and 1983/1984 sediment data from Great Western Reservoir and Standley Lake), were considered initially for the COC selection process. During the February 14, 1994 meeting, the treatment of subsurface core data in the COC selection process was discussed. It was decided by all parties that if the core data are not associated with an exposure pathway, the data do not need to be compared to background data for the risk assessment. Subsurface sediments in Great Western Reservoir were included because of the possibility that the reservoir may be drained and could be converted to residential, recreational, or commercial/industrial land uses thereby disturbing the subsurface sediments during construction activities.

Statistical tests are performed only after the data have been prepared and meet requirements for statistical analysis (Gilbert, 1993, CDPHE/EPA, 1993, DOE, 1993). After evaluating the OU 3 and existing background data sets (i.e., groundwater, sediment, and surface-water background data in Background Geochemical Characterization Report [BGCR] [DOE, 1993c] and Rock Creek surface-soil background data [DOE, 1993e]), the statistical comparison methodology was only used for

OU 3 surface-soil data The explanation why the statistical tests were not applied to specific media was presented in the May 3, 1994 meeting and is described in the following paragraphs

The comparability of data sets for rigorous statistical tests is important for reliable statistical findings (Gilbert, 1993) The results of the statistical tests using the background and OU 3 data sets in the BGCR (DOE, 1993c) for sediment, surface water, and groundwater were not plausible or conclusive This consideration is based on a variety of factors OU 3 data sets for reservoir sediments and surface water represent different environmental conditions and flow regimes than the stream background data sets -- no reservoir background data were available The majority of OU 3 samples for surface water and sediment were collected from reservoirs, and the BGCR data for sediment and surface water were collected from streams Too few surface water samples were collected in the streams in each IHSS (eight total samples for all three IHSSs combined) and the stream sediments (8, 14, and 4 samples respectively for IHSS 200, 201, and 202) to perform a valid statistical analysis on an IHSS-by-IHSS basis The Gilbert process statistical tests were evaluated in a preliminary fashion for the stream sediment data, however, as Gilbert suggests, the results were determined implausible based on the reasons provided in Table 2-1 (this information was discussed during the May 3, 1994 meeting with EPA, CPDHE, and DOE)

While the background groundwater data set is composed of data collected from 49 wells (157 total samples), the OU 3 groundwater data were obtained from only 2 wells (sampled eight times each) Rigorous statistical comparisons would not be valid when comparing the results of 2 wells to 49 wells In addition, the wells designated as background represent different environmental conditions and groundwater flow regimes Also, the groundwater data were not collected to characterize the aquifers within OU 3 Groundwater sample analyses results from the two monitoring wells exhibit differences in groundwater chemistry between the two well locations The results show differences from the wells in the BGCR (DOE, 1993) which are likely due to variations in water chemistry exhibited by different aquifers Since the OU 3 monitoring wells are located in different hydrogeologic conditions than the BGCR wells, the data are not directly compatible These results are illustrated on the Piper diagram presented in TM 4 (see Figure 8-13) and were discussed in the May 3, 1994 meeting

It should be noted that it is possible to conduct the statistical tests for these media There are at least four samples for most media by IHSS (see Table 2-1) and it is possible to run the Gilbert process with so few samples even though the power of the tests may not provide a good level of comfort However, the uncertainty introduced by so few samples regarding the results of the tests is likely greater than the uncertainty in the WOE Evaluation The WOE Evaluation uses a variety of information and analyses rather than tests that may or may not accurately reflect conditions at OU

3 The results of the statistical tests would be inconclusive or implausible based on knowledge of conditions in OU 3. As is allowed for in Gilbert's flow chart, the WOE evaluation would be performed.

According to the RFETS COC selection process guidance (CDPHE/EPA/DOE, 1994), COCs are selected using all data, for a particular medium, from an operable-unit. However, for OU 3, the selection of COCs on an OU-wide basis is not appropriate based on spatial, exposure, physical processes, and hydrologic differences. Therefore, COCs were selected on an IHSS-basis. The following points support selection of COCs on an IHSS-by-IHSS basis:

- Performing the concentration-toxicity screen on an IHSS-by-IHSS basis is the *most conservative approach* because it provides opportunity for more compounds to be retained as COCs in the detection-frequency screen. Non-detected data from one IHSS may contribute to lower the overall detection frequency below five percent and eliminate the chemical as a COC. Because of this artifact, a chemical detected greater than five percent of the time in one IHSS, may be eliminated as a COC.
- Performing the concentration-toxicity screen on an IHSS-by-IHSS basis is the *most conservative approach* because it provides opportunity for more compounds to be retained as COCs in the concentration-toxicity screen. For the entire OU data set, the maximum concentrations for arsenic and beryllium would represent the top 99 percent of the concentration-toxicity score excluding many other chemicals. However, in IHSSs that have smaller maximum concentrations, other chemicals may contribute to the top 99 percent of the concentration-toxicity score and pass the screen (i.e., be retained). As an example, the maximum arsenic sediment concentrations are as follows: 9.4 mg/kg in IHSS 200, 17.7 mg/kg in IHSS 201, and 10.4 mg/kg in IHSS 202. Using the arsenic concentration in IHSS 201 as the maximum OU 3 arsenic concentration, it would contribute almost 50% more to the concentration-toxicity score than if the 9.4 mg/kg and 10.4 mg/kg values were used on an individual IHSS basis.
- Each IHSS represents a distinct geographic location that is 1 to 2 miles from the other IHSSs. From a demographic and exposure perspective, different populations would likely frequent different reservoirs and it is not reasonable to aggregate the data in a manner that is inconsistent with exposure patterns. Consideration of population dynamics in the HHRA is discussed in EPA Guidance (EPA, 1989).

- Potential background, RFETS-related, and other anthropogenic sources of metals concentrations are different (e.g., Clear Creek Superfund site, mineral deposits, other commercial, industrial, or agricultural sources) These factors introduce much uncertainty when making comparisons to background by the Gilbert process or the WOE evaluation
- The source of water for each IHSS are from different watersheds Mower Reservoir receives 100 percent of its water from the RFETS drainage basin, while Great Western Reservoir receives only 25 to 35 percent and Standley Lake receives only 5 to 10 percent
- Exposure scenarios will differ between the IHSSs For example, Great Western Reservoir may be drained, exposing the surface and potentially the subsurface sediments, while Standley Lake and Mower Reservoir will continue to be used for drinking water and irrigation purposes Further, Standley Lake is widely used for recreation while Great Western is not and Mower is privately owned and used mainly for irrigation

The ability to effectively communicate risk to the public will be complicated by OU 3-wide COCs For example additional effort would be required to explain to the public that plutonium in Standley Lake is not a problem (i.e., no $^{239/240}\text{Pu}$ activities exceed the 10^{-6} PRG), when it has been identified as a COC COCs identified in each IHSS accomplish the purpose of the COC selection process-- focus the assessment on those chemicals that will contribute significantly to potential risks

2.2 Data Presentation

The data-presentation step, as recommended by Gilbert (1993), is used to enhance the understanding and interpretation of the statistical tests, it graphically displays the background and OU 3 data sets and compares the magnitude, variability, and degree of their overlap Several graphical data-presentation techniques were used to display the background and OU 3 data, including histograms, box plots, and probability plots Probability plots are also an important component of the WOE evaluation (see Section 8.0)

2.3 Statistical Tests

Five statistical tests were performed only for the surface soil data for each analyte

- 1 Hot-Measurement test
- 2 Gehan test
- 3 Quantile test
- 4 Slippage test
- 5 t-test

If any one of the statistical tests performed for a given comparison indicated a significant difference between OU 3 and background data, then the analyte was considered to be a Potential Chemical of Concern (PCOC) and professional judgement was applied to determine if the statistical results were plausible (Gilbert, 1993). Each of these statistical tests is based on different statistical hypotheses and assumptions. The purpose and method of each statistical test are briefly described in the following subsections. The hypothesis tested, test description, and assumptions made for each statistical test are described in detail. A description of these tests is provided in Subsection 3.1.2 in TM 4 (DOE, 1994). Results of the statistical comparison tests are presented in Appendix B of TM 4 (DOE, 1994).

2.4 Professional Judgement

The background-comparison methodology as developed by Gilbert (1993), emphasizes evaluating the output of all statistical tests using professional judgement to determine if the results of the tests indicate contamination at the OU -- professional judgement is applied "to provide supporting evidence for accepting or rejecting the results of the screening and statistical tests." Specific guidance from EPA and CDPHE (EPA/CDPHE 1993) limits this step to the following types of data evaluations:

- Spatial distribution--tools such as spatial plots and compound-specific mobility considerations
- Temporal distribution--tools such as time-series plots
- Pattern-recognition concepts--tools useful in identifying anomalies as well as confirming "fingerprint" associations

The concepts discussed by Gilbert and included in the EPA-approved strawman were applied in the WOE Evaluation (performed as the last step of the COC selection process (Section 8.0)).

3 0 ESSENTIAL NUTRIENTS

The following inorganics were eliminated from all environmental media by this step of the COC selection process

- Calcium
- Iron
- Magnesium
- Potassium
- Sodium

These nutrients are eliminated because they are considered an essential element in the diet (EPA, 1989)

If the EPA Region VIII Identification of Contaminants of Concern guidance (EPA, 1994) (comparing OU 3 concentrations to the recommended daily allowance and safe and adequate daily intake values) is followed, manganese, zinc, and copper would also be eliminated as COCs at this step. TM 4 does not reflect the use of this guidance--these chemicals were eliminated in other steps of the COC selection process.

4 0 DETECTION FREQUENCY

Chemicals that are infrequently detected may be artifacts in the data because of sampling or analytical problems and therefore may not be site-related (EPA, 1989). Detection frequencies for each chemical not eliminated by the first two steps of the COC selection process were evaluated by medium and IHSS. Chemicals that were not detected in any samples within a medium and IHSS were eliminated as COCs for that medium and IHSS. Chemicals detected in less than 5 percent of the samples for a medium within an IHSS were identified and further evaluated in an RBC comparison as described in Section 5 0.

Beryllium in Well 49292 was not detected in any of the eight samples and, therefore, was eliminated as a COC. Arsenic, beryllium, 239/240-plutonium, and 233/234-uranium in IHSS 200, 201, and 202 sediments and in IHSS 200 groundwater (Well 49192) were all detected greater than five percent of the time. These PCOCs are discussed in Section 6 0.

5 0 RBC COMPARISON

Each chemical that had a detection frequency between zero and 5 percent was further evaluated to determine if the samples with results above detection limits represent potential areas of localized contamination. For this step, the maximum detected value for each chemical was compared to a Risk-Based Concentration (RBC) (RBCs are the same as PRGs, therefore, the term PRG will be used for the remainder of this document to eliminate confusion). The PRGs used in this step are based on a residential exposure scenario for surface soil, sediment, and groundwater and were calculated based on the methodology presented in Programmatic Preliminary Remediation Goals (DOE, 1994b). For surface water, the PRGs are based on a recreational exposure scenario because any exposure to unfiltered surface water is assumed to occur through recreational use of the reservoirs. If the maximum detected value did not exceed 1,000 times the PRG, the chemical was eliminated as a COC. No chemicals in the OU 3 database (regardless of detection frequency) were found at levels 1,000 times the PRG. Thus, temporal analysis was not performed on any analyte and there are no special-case COCs for OU 3.

Chemicals without oral and inhalation toxicity values cannot be evaluated in the PRG screen. These chemicals were evaluated in the weight-of-evidence evaluation described in Subsection 3.7 of TM 4 and all were eliminated based on the results of the WOE process.

6 0 CONCENTRATION-TOXICITY SCREEN

The concentration-toxicity screen is used to identify the chemicals within each medium and IHSS that are most likely to contribute significantly to risks (i.e., the top 99 percent of the risk). The concentration-toxicity screen is performed for each medium by each of the three IHSSs in OU 3. The concentration-toxicity screen was performed following EPA guidance (EPA, 1989). However, the EPA Region VIII Contaminants of Concern Identification guidance (EPA, 1994) was also followed in that all chemicals exceeding a PRG were retained as PCOCs.

The first part of the screen was to calculate an individual risk factor for each chemical not eliminated by previous steps in the COC selection process. The chemical risk factor was calculated either by multiplying the maximum chemical concentration by the corresponding slope factor for carcinogens, or by dividing the maximum chemical concentration by the corresponding reference dose (RfD) for chemicals with noncarcinogenic effects. For chemicals with both oral and inhalation toxicity values, the more conservative toxicity factors (i.e., greater slope factor for carcinogens and lower RfD for chemicals with noncarcinogenic effects) were used to calculate the chemical risk factors.

The individual risk factors were then summed by medium and IHSS to obtain a total risk factor, according to the end point of toxicity (carcinogenic or noncarcinogenic effects) Radionuclide and nonradionuclide chemicals were summed separately because units for slope factors and concentrations/activities in environmental media are different for these two classes of chemicals The ratio of each individual chemical risk factor to the total risk factor approximates the relative risk for that medium and IHSS due to each chemical The chemicals whose combined ratios sum to 0.99 (99 percent) of the total risk were considered likely to contribute significantly to the overall risk All other chemicals, except those with maximum concentrations exceeding the PRG, were eliminated as COCs

Chemicals without oral or inhalation toxicity values cannot be evaluated in the concentration-toxicity screen step The chemicals without toxicity values that were detected in OU 3 were evaluated further using a weight-of-evidence evaluation to determine if levels of the chemicals in OU 3 were elevated over background conditions The results of this evaluation are included in the discussions of the weight-of-evidence evaluation in Subsections 5.6, 6.6, and 7.6 of TM 4 for sediment, surface water, and groundwater, respectively

The results of the concentration-toxicity screen are included in Appendix D of TM 4 (DOE, 1994)

The following PCOCs passed the concentration-toxicity screen and were retained as PCOCs

- ²⁴¹Am in sediment (all IHSSs)
- ²⁴¹Am in subsurface sediment (IHSS 200 only)
- Arsenic and beryllium in IHSS 200, 201, and 202 sediment
- Arsenic and beryllium in IHSS 200 subsurface sediment
- Arsenic and beryllium in IHSS 200 groundwater
- Arsenic in IHSS 201 groundwater
- U-233/234 in IHSS 200 groundwater
- U-233/234 in IHSS 201 groundwater

Again, beryllium was not detected in IHSS 201 groundwater

7.0 PRG SCREEN

The chemicals remaining at this point in the COC selection process were evaluated further using the PRG screen The PRGs were calculated based on the methodology presented in Programmatic Preliminary Remediation Goals (DOE, 1994b) and included in Attachment 1 of Appendix E of TM 4 (DOE, 1994) Any chemicals with maximum detected values less than the

corresponding PRG were eliminated as COCs. However, chemicals with maximum detected values greater than a PRG (regardless if they passed or failed the concentration-toxicity screen) were carried through the weight-of-evidence evaluation described in Section 3.7 of TM 4 (DOE, 1994) and Section 8.0 of this document. This step is consistent with the EPA Region VIII guidance (EPA, 1994) in retaining chemicals in the risk assessment that exceed the PRG. Beryllium in IHSS 200 surface sediments is the only chemical which failed the concentration-toxicity screen and is greater than the PRG. Beryllium was eliminated in the WOE evaluation.

The results of the PRG screen are included in Appendix E of TM 4.

The following PCOCs maximum concentrations do not exceed the PRG and were eliminated as COCs:

- Americum-241 in surface sediment for IHSS 200 (maximum activity = 0.2 pCi/g), IHSS 201 (0.1 pCi/g), and IHSS 202 (0.1 pCi/g) do not exceed the residential PRG (2.37 pCi/g)
- Americum-241 in subsurface sediment for IHSS 200 (1.0 pCi/g), does not exceed the construction scenario PRG (655 pCi/g)
- Arsenic in IHSS 200 subsurface sediment (maximum concentration = 10.4 mg/kg) does not exceed the construction scenario PRG (681 mg/kg)
- Uranium-233/234 in IHSS 201 groundwater does not exceed the residential PRG (0.87 vs 2.98 pCi/L)

The following PCOCs maximum concentrations do exceed the PRG and are assessed in the WOE Evaluation:

- Arsenic in IHSS 200, 201, and 202 surface sediment (9.4, 17.7, and 10.4 mg/kg vs 0.37 mg/kg)
- Beryllium in IHSS 200, 201, and 202 surface sediment grab samples (1.6, 1.6, and 1.5 mg/kg vs 0.15 mg/kg)
- Arsenic and Beryllium in IHSS 200 groundwater (6.9 ug/L vs 0.05 ug/L for As and 1.6 ug/L vs 0.02 ug/L)

- Arsenic in IHSS 201 groundwater (3.8 ug/L vs 0.05 ug/L)
- Uranium-233/234 in IHSS 200 groundwater (4.6 vs 2.98 pCi/L)

Beryllium was not detected (zero detections out of 8 samples) in IHSS 201 groundwater

The results of the PRG screen for sediment, surface water, and groundwater are included in Appendix E of TM 4

8.0 WEIGHT-OF-EVIDENCE EVALUATION

8.1 Introduction

Gilbert (1993) recommends the use of professional judgement to "provide supporting evidence for accepting or rejecting the results of the screening and statistical tests. The basic question is: Do the results of the statistical tests make sense in light of what is known about the geology, hydrology, and geochemistry of the OU?" Gilbert considers whether the underlying assumptions for performing the statistical tests are valid. Because some of the underlying assumptions were not met and the results of the tests were considered inconclusive (see Subection 2.1), the Gilbert process was not performed for sediment, surface water, and groundwater. In order to assess whether the OU 3 concentration data was significantly different from background an alternative approach for comparing site to background data was used for sediment, surface water, and groundwater. The alternative approach is referred to as the "weight-of-evidence evaluation" because it relies on a series of data evaluation steps and involves the use of professional scientific judgement. The WOE evaluation involves the application of a variety of data analysis techniques in lieu of a rigorous, quantitative statistical testing scheme. These techniques correspond with the EPA-accepted professional judgement analytical techniques (ie, spatial analysis, temporal analysis, and pattern recognition). The use of the WOE Evaluation for groundwater, surface water (streams and reservoir), and sediment (streams and reservoir) data and the reasons why the application of the statisticals was not appropriate were discussed at the May 3, 1994 meeting with EPA, CDPHE, and DOE (see Attachment 3). EPA and CDPHE committed to discuss the use of the WOE Evaluation approach for metals with their internal resources and provide input to DOE by May 10, 1994. No input from EPA or CPDHE was received. However, to meeting the IAG schedule commitments, the COC selection process proceeded without additional input.

Following the Gilbert process allows for application of professional judgement arguments after the performance of the statistical tests (see Figure 8-1). Because the results of the statistical tests

were implausible and inconclusive for sediment, surface water, and groundwater, only the professional judgement steps of the Gilbert process were used for those media. Regardless whether the WOE Evaluation was applied as the first step in the process or the last, the resulting COCs would be the same (see results of the CDPHE Conservative Screen for OU 3 where the WOE step was used first in selecting PCOCs). If applied first, arsenic and beryllium would be eliminated as PCOCs before the concentration-toxicity and PRG screens. If the WOE evaluation is applied last, these chemicals would be eliminated as PCOCs.

This section discusses in detail the WOE evaluation for the chemical concentration data for the following chemicals included as COCs in EPA's informal review comments memo (EPA, 1994a)

- Arsenic and beryllium in sediment
- Arsenic and beryllium in groundwater
- ^{233/234}U in groundwater

Much of this information is included in TM 4 (DOE, 1994) and also is discussed in the Response to Comments (Attachment 1). However, this document contains additional information that has been added to help clarify the WOE evaluation results.

8.2 Weight-of-evidence Evaluation Process

The weight-of-evidence evaluation is consistent with those professional judgement evaluations approved by EPA in their October 25, 1993 memorandum commenting on the Strawman (DOE, 1993, EPA, 1993) document of the Gilbert process. These professional judgement evaluations include

- Spatial analysis combined with the evaluation of physical processes affecting deposition and the evaluation of contribution of various water sources to OU 3 reservoirs
- Temporal analysis of data to identify seasonal variations or sampling anomalies
- Pattern recognition

Additionally, to supplement the analyses above, several other evaluation steps were performed

- Evaluation of data populations using probability plot analysis

- Comparisons of means, standard deviations, and ranges of OU 3 concentration data to concentration data from the Background Geochemical Characterization Report (BGCR) (DOE, 1993c)
- Comparisons of means, standard deviations, and ranges of OU 3 concentration data to benchmark concentration data. The benchmark data collection activities are described in Subsection 8.3
- Comparison to the CDPHE Phase I Public Health Exposures Studies Material of Concern list. This comparison was not used to eliminate COCs and was performed after the identification of the COCs was complete. The purpose was solely to support the decision that had already been made.

Spatial Analyses

Spatial analyses were performed for analytes in OU 3 sediments by evaluating patterns of concentrations at discrete sample points in each IHSS. Analytes showing a distinct spatial orientation rather than being randomly distributed may be designated as potential sources or potential hot spots. The physical processes, for example, sedimentation near the inflow of a stream into a lake, affecting concentration distribution and the contribution of various water sources to OU 3 reservoirs are considered.

Temporal Analysis

The PCOC concentration data in sediment were also evaluated over time to discern any anomalous trend or pattern. Concentration levels sharply elevated at one point in time may indicate a historical release event contributing to concentrations above background. Sediment core profiles (Figure 8-5) were analyzed for some analytes to evaluate if possible patterns existed throughout the sediment layer. Analyte profiles with discernible peaks may indicate source discharges from the RFETS or other sources of contamination.

Probability Plot Analysis

A software package, PROBLOT, was used to assess populations within the OU 3 data sets (see Appendix A). PROBLOT is conventionally used in the minerals exploration industry to guide investigators seeking anomalous mineral deposits (i.e., significantly above background) for extraction (Sinclair, 1986, Sinclair, 1976, Stanley, 1987). Concentration data (detects only) for

those chemicals with sufficient data (15 samples above detection limits for a given analyte and IHSS) were lognormally transformed and plotted on a cumulative frequency graph. Based on the cumulative frequency distribution, the number of populations for a given data set were identified. If one population was identified, it was inferred to represent a background population based on the comparison to background and benchmark data and the physicochemical processes occurring in the reservoirs. If two populations existed, it is possible that the higher population is the result of contamination. With two populations having low concentrations and concentrations that do not vary significantly between each other, however, the two populations may be explained by natural physical processes and not necessarily contamination.

Comparison of OU 3 Data to Benchmark Data

The three steps described above (spatial, temporal, and probability plot analyses) all indicate that concentrations of arsenic in OU 3 surface sediments are representative of naturally occurring conditions rather than contamination. To confirm this conclusion, concentrations of arsenic in surface sediments for each of the three IHSSs were compared to available background and literature benchmark data. This final step in the weight-of-evidence approach involves comparing the OU 3 data to background and benchmark data in a less formal, quantitative manner than using the five statistical tests included in the Gilbert methodology. However, it is important to remember, this step alone cannot eliminate arsenic as a COC. The benchmark data comparison in conjunction with the other weight-of-evidence evaluations provides the rationale that arsenic is not a COC.

The results of the evaluation steps were considered together to assess if a chemical was retained as a COC - the results of one evaluation step did not, by itself, characterize a chemical as a COC or eliminate a chemical as a COC. Applying multiple evaluation steps is similar to the reasons for Gilbert's recommendation of using a family of statistical tools because no one statistical test exists that can adequately address the various types of data characteristics (Gilbert, 1993). To eliminate chemicals as COCs by this step, convincing evidence was needed to support the conclusion that detected levels of the chemical in OU 3 are representative of background conditions. If convincing evidence were not provided, the chemical is retained as a COC.

8.3 Benchmark Data Collection Activities

A search was performed to gather benchmark literature data for the comparison of OU 3 sediment and surface-water data. More than 20 sources were contacted to obtain benchmark data for sediments and surface water, as shown in Table 8-1.

The term "benchmark data" is used in TM 4 to represent the data compiled from literature and other data sources referenced in Table 8-1 to represent background conditions within the Front Range and Colorado. The data-gathering effort focused on obtaining reservoir and lake data in the Front Range and Colorado.

Benchmark data differ from background data sets, which are appropriate for statistical comparison. The term "background data" is used to represent the data collected and summarized in the Background Geochemical Characterization Report (DOE, 1993c) and the Rock Creek surface soil data. Data from the Background Geochemical Characterization Report were used to make comparisons to OU 3 data in the weight-of-evidence evaluation. The Rock Creek soil data were used in the statistical comparison tests.

The benchmark data that were primarily used for sediment comparisons include four lakes in the Rocky Mountain National Park: Lake Husted, Lake Louise, Lake Haiyaha, and the Loch (Heit, et al., 1984). Based on a professional judgement assessment, these lakes were not likely influenced by man-made sources of contamination. Sediment data were also available from Cherry Creek Reservoir (DRCOG, 1994). In addition, background sediment stream data from the Lowry Landfill Superfund site were also used (EPA, 1992).

During the benchmark data-collection activities, information was also collected from lakes outside of Colorado for comparative purposes. The results of this information can be used to support the comparison to background and Colorado benchmark data. For example, in some cases the OU 3 COC data is within the range of the background data, the Colorado benchmark data, and the out-of-state benchmark data--there are no anomalous values.

Data from Superfund sites and other impacted areas were also collected. The purpose of using information from contaminated sites is to place the OU 3 concentration/activity levels in perspective with other investigated sites. Contamination at these sites tend to be greater by a factor of 5, 10, or 100 or more times background concentrations. As an example, the maximum arsenic concentration in surface sediment is 17.7 mg/kg compared to a maximum BGCR background value of 17.3 mg/kg, while the Warm Springs Pond Superfund site is 1900 mg/kg. Contamination is not subtle, however, as shown in this example, the difference between the maximum OU 3 surface sediment concentration and the maximum background stream sediment concentration is subtle.

8 4 Arsenic in Sediment

This subsection presents the results of the weight-of-evidence evaluation applied to arsenic measured in OU 3 surface sediments. A summary of the analytical results for arsenic in the OU 3 sediments (for each IHSS) is presented in Table 8-2. Table 8-2 shows the summary statistics (before the COC selection was performed) by IHSS, including number of detects, number of samples, frequency of detection, minimum nondetected value, maximum nondetected value, minimum detected value, maximum detected value, arithmetic mean, standard deviation, normal 95 percent upper confidence limit (UCL), and lognormal 95 UCL. The summary statistics are used to provide the analyst the makeup of the data set (i.e., the frequency of detection and magnitude of concentration) before the COC selection process is performed. The use of summary statistics is part of an exploratory analysis phase that involved using visual and graphical presentations of the data.

8 4 1 Spatial Analysis

Arsenic concentrations were plotted at every sediment sample location in each IHSS (see Figures 8-2, 8-3, and 8-4). The maps show that the arsenic concentrations tend to be slightly higher in the samples collected in the middle of the reservoir than along the exposed shoreline and stream sediment samples. However, along the shoreline, in the streams, and in the middle areas of the reservoirs the arsenic levels are apparently randomly distributed - suggesting a natural population.

Natural limnological phenomena explain the slightly elevated concentrations in the center of the reservoirs. The finer particles of sediment tend to have the highest concentrations of organic matter and thus higher arsenic concentrations (Davis and Kent, 1990). These finer-sediment particles in the water column also tend to deposit in the center of the lake where flow velocities can no longer support particle suspension. The metals in OU 3 tend to exhibit this natural concentration distribution of higher concentrations in the center of the lake (Table 8-3). The shoreline sediments are exposed most of the year and the finer-grained particles are preferentially removed by wind and water erosion (i.e., resulting in lower concentrations).

Since Mower Reservoir (IHSS 202) receives 100 percent of its water input from the Rocky Flats Plant drainage area, and Great Western Reservoir (IHSS 201) and Standley Lake (IHSS 202) receive 65 percent to more than 90 percent, respectively, of water input from Clear Creek (ASI, 1990) one might expect significantly higher concentrations in Mower Reservoir if RFETS-related contamination were present. However, the arsenic concentrations in Mower Reservoir sediment are

not significantly greater than Great Western Reservoir or Standley Lake (based on the results of statistical tests, Standley Lake is significantly higher than Mower Reservoir for the sediments in the middle of the reservoir and Great Western Reservoir and Mower Reservoir are not significantly different, there is no difference in the nearshore sediments arsenic concentrations between any of the reservoirs), this suggests that arsenic originates from background sources and was deposited in the IHSS reservoirs by natural processes

Mower Reservoir also has less area/volume to dilute concentrations compared to Standley Lake yet the concentrations in Standley Lake are higher (realizing Standley lake receives 90% of its water from Clear Creek and Mower receives 100% from the Rocky Flats drainage)

8 4 2 Temporal Analysis

The arsenic concentration data in sediment were also evaluated over time to discern any anomalous trend or pattern. Arsenic concentrations in sediment core profiles did not show any consistent peaks or patterns (see Figure 8-5). The concentrations of arsenic in the sediment core samples range from 3.6 mg/kg to 36.2 mg/kg. Table 8-4 list the minimum, mean, and maximum concentration and the depth for core samples.

Sedimentation rates estimated for the reservoirs are as follows: 0.7 to 0.8 inches per year (in/yr) for IHSS 201, 0.9 in/yr for IHSS 200, 0.3 in/yr for IHSS 202.

Figure 8-6 compares arsenic concentrations in a sediment core to plutonium and other selected analytes. While $^{239/240}\text{Pu}$ exhibits a distinct peak suggesting deposition of contamination associated with a specific time period, arsenic and the other analytes do not show such peaks.

8 4 3 Probability Plot Analysis

According to the geochemical analysis using PROBPLOT, only one population is seen for arsenic in each of the three reservoirs (see Figures 8-7, 8-8, and 8-9). Figure 8-7 shows the PROBPLOT output for arsenic in Great Western Reservoir (IHSS 200). Because of low concentrations (comparable to benchmark data) and the lack of separate populations, arsenic in OU 3 samples is identified as falling within the background population. Although Standley Lake (IHSS 201) has a maximum that is almost twice that of Great Western Reservoir (IHSS 200) and Mower Reservoir (IHSS 202), the means are essentially equal and fall within benchmark data.

8 4 4 Comparison of OU 3 Data to Benchmark Data

This evaluation step for arsenic involved the use of a visual data-presentation technique (Figure 8-10) where the magnitude of concentrations of the OU 3 data for streams and reservoir sediment are presented with the Rocky Flats background data for stream sediments and relevant benchmark data from the literature. The top portion of Figure 8-10 is a tabulation of these data, the bottom segment profiles the data to promote comparison of individual data points as well as ranges. The data presented in Figure 8-10 include sediment data from Rocky Mountain National Park lakes, the Great Lakes, Adirondack lakes, Cherry Creek Reservoir in Colorado, Missoula Lake bed sediments, worldwide data, and data from Superfund sites. The purpose of using information from contaminated sites (the Warm Springs Pond Superfund site and the Clear Creek Superfund site), in addition to nonimpacted sites, is to place OU 3 levels in perspective with other investigated sites.

Figure 8-10 illustrates the following

- The arsenic concentrations for OU 3 sediments between the IHSSs are consistent (the means 5.3, 4.9, 4.8, 7.0, 4.9, and 5.2 mg/kg are very consistent). All reported concentrations are less than 17.7 milligrams per kilogram (mg/kg) and there are no apparent spurious data that would suggest anomalous concentrations.
- The Rocky Mountain National Park arsenic concentration means range from 1.4 to 8.4 mg/kg compared to a range of OU 3 means, 4.9 to 7.0 mg/kg.
- The OU 3 mean concentrations are bounded by the lake data (2 to 5 mg/kg, 5 to 7 mg/kg mean of 6.6 mg/kg and maximum of 9.2 mg/kg for the Great Lakes, Adirondack lake, and Lake Michigan, respectively).
- The Cherry Creek reservoir mean concentration, 5.57 mg/kg, is slightly higher than the mean values for the OU 3 reservoirs and creeks.
- The range of OU 3 arsenic concentrations in reservoirs (1.2 to 17.7 mg/kg) is comparable with the ranges of the BGCR (DOE, 1993c) data (sediments that are not impacted)—0.39 to 17.3 mg/kg. Additionally, the OU 3 and background data are within the range, and comparable to, the expected worldwide ranges (0.1 to 55 mg/kg, mean of 7.2 mg/kg [Dragun, 1988]).
- The profile of the OU 3 mean concentrations of arsenic in OU 3 sediments (4.76 to 6.96 mg/kg, range of 1.2 to 17.7 mg/kg) shows concentrations comparable to

ranges of Lowry Landfill Superfund site stream sediments that are assumed not to be impacted (0.9 to 17 mg/kg) and a mean concentration of 5.0 mg/kg

- Both the OU 3 data and the benchmark data are distinguishable from the data representing arsenic contamination (e.g., Warm Springs Pond, and Clear Creek). Arsenic concentrations in OU 3 are not within the upper end of the ranges of heavily polluted sites (Warm Springs Pond and Clear Creek). The maximum arsenic concentration in OU 3 sediments ranges from 6.8 mg/kg to 17.7 mg/kg, compared with 46 mg/kg at the Clear Creek Superfund site (CDPHE, 1990) and 1,910 mg/kg at the Warm Springs Pond Superfund site (EPA, 1988).
- All data (OU 3, background, and benchmark data) are greater than the 10^{-6} PRG (based on residential exposure) of 0.37 mg/kg.

8.4.5 Conclusions from the Weight-of-Evidence Evaluation

Based on the full weight of the evidence presented in this section--the lack of discernible spatial or temporal trends, the results of the probability plot analysis, the similarity of the OU 3 arsenic concentrations to background and benchmark arsenic concentrations--arsenic has been eliminated as a COC in surface sediment for the three IHSSs.

8.5 Beryllium in Sediment

A summary of the analytical results for beryllium in sediments (surface and subsurface sediments for IHSS 200 and surface sediments only for IHSSs 201 and 202) is presented in Table 8-2.

8.5.1 Spatial Analysis

Beryllium concentrations were plotted at every sediment sample location in each IHSS on maps generated by GIS (Figures 8-2, 8-3, and 8-4). Beryllium exhibited narrow ranges of concentrations in all three IHSSs (i.e., difference between minimum and maximum detected values was less than 1.5 mg/kg for all IHSSs). The concentrations range from 0.24 to 1.60 mg/kg in IHSS 200, 0.15 to 1.60 mg/kg in IHSS 201, and 0.41 to 1.50 mg/kg for IHSS 202. The maps show that, in general, the samples associated with the upper end of the concentrations ranges tend to be those collected in the middle of the reservoir. However, along the shoreline, in the streams, and in the middle areas of the reservoirs the beryllium levels are apparently randomly distributed. There is no

discernible pattern of beryllium concentration in sediments, thus suggesting a natural, randomly distributed population

Natural limnological phenomena explain the slightly elevated concentrations in the center of the reservoirs. The finer particles of sediment tend to have the highest concentrations of organic matter and thus higher beryllium concentrations (Davis and Kent, 1990). The metals in OU 3 tend to exhibit this natural concentration distribution. The shoreline sediments are exposed most of the year and the finer-grained particles are preferentially removed by wind and water erosion. These finer-sediment particles in the water column also tend to deposit in the center of the lake where flow velocities can no longer support particle suspension.

8.5.2 Temporal Analysis

Beryllium concentrations in sediment core profiles from IHSSs 200 through 202 do not show any consistent peaks or patterns (Figure 8-11 shows selected core profiles for the three IHSSs). The core data include maximum depths of 28 inches, 34 inches, and 20 inches for IHSSs 200, 201, and 202, respectively. These depths correspond to the year 1965, or earlier. As noted for the surface sediments, beryllium also exhibits narrow ranges of concentrations in subsurface sediments for the three IHSSs (i.e., difference between minimum and maximum detected concentrations are 1.8 mg/kg, 1.3 mg/kg, and 0.9 mg/kg for IHSS 200, 201, and 202, respectively). The concentrations of beryllium in the subsurface sediment core samples range from 0.53 to 2.30 mg/kg for IHSS 200, 0.34 to 1.60 mg/kg for IHSS 201, and 0.64 to 1.54 mg/kg for IHSS 202.

8.5.3 Probability Plot Analysis

According to the geochemical analysis using PROBLOT, only one population is seen for beryllium in surface sediments for each of the three reservoirs. Figures included in Appendix A show PROBLOT outputs for beryllium in IHSS 200, 201, and 202. Because of overall low concentrations (maximum value of 1.60 mg/kg detected in IHSS 200 and 201, maximum value of 1.5 mg/kg in IHSS 202) which are similar or below background and benchmark concentrations (see Section 8.5.4), and the lack of separate populations, beryllium in OU 3 samples is identified as falling within the background population.

8.5.4 Comparison of OU 3 Data to Benchmark Data

The three steps described above (spatial, temporal, and probability plot analyses) all indicate that concentrations of beryllium in OU 3 surface sediments are representative of naturally occurring

conditions rather than contamination from RFETS. To confirm this conclusion, concentrations of beryllium in OU 3 surface sediments were compared to available background and literature benchmark data. This final step in the weight-of-evidence approach involves comparing the OU 3 data to background and benchmark data in a less formal, quantitative manner than using the five statistical tests included in the Gilbert methodology. However, this step alone cannot eliminate beryllium as a COC. The benchmark data comparison in conjunction with the other weight-of-evidence evaluations provides the rationale that beryllium is not a COC.

This evaluation step for beryllium involved the use of a visual data-presentation technique (Figure 8-12) where the magnitude of concentrations of the OU 3 data for streams and reservoir sediment are presented with the BGCR and Lowry Landfill Superfund Site background data for stream sediments, and relevant benchmark data from the literature. The top portion of Figure 8-12 is a tabulation of these data, the bottom segment profiles the data to promote comparison of individual data points as well as ranges. The benchmark data presented in Figure 8-12 include sediment data from Rocky Mountain National Park lakes and Cherry Creek Reservoir in Colorado. In addition, the risk-based PRG for beryllium is presented.

Figure 8-12 illustrates the following

- The beryllium concentrations for OU 3 surface sediments are consistent between the IHSSs. All reported concentrations are less than or equal to 1.6 milligrams per kilogram (mg/kg) and there are no apparent spurious data that would suggest anomalous concentrations.
- The range of OU 3 beryllium concentrations in reservoir surface sediments (0.15 to 1.6 mg/kg) is comparable to the range of beryllium in the BGCR (DOE, 1993c) data (i.e., stream sediments that are not impacted by activities at RFETS)—0.15 to 1.3 mg/kg (standard deviation of 1.69).
- The range of concentrations of beryllium in OU 3 surface sediments (0.15 to 1.6 mg/kg) shows concentrations comparable to ranges of stream sediment data from samples collected to represent background conditions for the Lowry Landfill Superfund Site that are assumed not to be impacted by contamination (0.23 to 2.0 mg/kg).
- Mean concentrations of beryllium in reservoir samples from the three IHSSs (0.85, 0.70 and 1.06 mg/kg for IHSSs 200, 201, and 202, respectively) are all lower than

mean concentrations in Rocky Mountain National Park lake samples (3.9, 5.0, 9.3, and 7.4 mg/kg for Lake Husted, Lake Louise, Lake Haiyaha, and The Loch, respectively) and Cherry Creek Reservoir (4.03 mg/kg)

- Minimum values for the BGCR and Lowry background data (0.15 and 0.23 mg/kg, respectively) are equal to or exceed the PRG for beryllium (0.15 mg/kg), mean values for the Rocky Mountain National Park lakes all exceed the PRG

8.5.5 Conclusions from the Weight-of-Evidence Evaluation

Based on the full weight of the evidence presented in this section, the similarity of the OU 3 mean concentrations to background and benchmark, the probability plot analysis, and the lack of discernible spatial trends, beryllium has been eliminated as a COC in surface sediment for the three IHSSs

8.6 Americium-241 in Sediment

Americium-241 in sediment does not exceed the 10^{-6} PRG based on residential exposure in the surface and subsurface sediments in all three IHSSs and, therefore was eliminated as a COC

8.7 Arsenic In Groundwater

Two groundwater wells were installed during the OU 3 field investigation one immediately downstream of Great Western Reservoir (IHSS 200, Well 49192) and one immediately downstream of Standley Lake (IHSS 201, Well 49292) The wells were installed to evaluate the potential for contaminants to migrate from the surface-water bodies to shallow groundwater (DOE, 1992)

The analytes remaining after the PRG screen were assessed by using the weight-of-evidence evaluation approach to determine if any analytes were consistently detected above background and therefore should be considered as COCs The approach for evaluating these chemicals in groundwater included the following

- Comparison of OU 3 data to background groundwater data for both upper and lower hydrostratigraphic units (UHSU and LHSU, respectively) at the RFETS, and literature benchmark data (comparison of means and ranges of concentrations)
- Temporal analysis of anomalies in the OU 3 data

- Evaluation of measurement uncertainty
- Geochemical evaluations of hydrologic setting

Concentrations of analytes that exceeded the PRGs were compared to the background data presented in the Background Geochemical Characterization Report (DOE, 1993c). Analytes for which the OU 3 mean and range were less than the comparative background groundwater data were eliminated as COCs. The background groundwater monitoring wells were selected to be representative of the upper hydrostratigraphic unit (UHSU) (Rocky Flats alluvium, the colluvium, valley fill alluvium, weathered claystone), and the lower hydrostratigraphic unit (LHSU) (the unweathered Arapahoe and Laramie formation bedrock).

A Piper diagram showing major-ion chemistry for the OU 3 groundwater wells and background UHSU and LHSU is presented in Figure 8-13. The concentrations of major anions (as meq/L [milliequivalents per liter]) are given as percentages of the total milliequivalents per liter. According to Figure 8-13, Well 49192 (IHSS 200) has a water chemistry similar to the UHSU, whereas Well 49292 (IHSS 201) has a water chemistry more similar to the LHSU.

A number of reasons exist for spatial changes and differences in groundwater chemistry. Some changes may be due to the natural evolution of groundwater chemistry along a flow path, such as an increase in TDS content in the downgradient direction. Other changes in water chemistry may be the result of ion-exchange processes, oxidation/reduction reactions, or mineral precipitation/dissolution processes. However, the similarity of the water typing for the OU 3 wells compared to the background data groupings indicates that the BGCR provides a suitable data set for determining if the OU 3 data are consistently above background, in conjunction with the temporal, analytical uncertainty, and geochemical evaluations.

Summary statistics for arsenic, beryllium, and $^{233/234}\text{U}$ in groundwater are presented in Table 8-5. Also included in Table 8-5 are the minimum, maximum, arithmetic mean, standard deviation, and mean plus two standard deviations for the background data. Based on the water typing information (Figure 8-13), data for Well 49192 (IHSS 200) have been compared to the background data for the UHSU, and data for Well 49292 (IHSS 201) have been compared to the background data for the LHSU. Benchmark values presented by Dragun (1988) for those chemicals with available data have also been included in Table 8-5.

The measurement uncertainty has been considered in determining if the OU 3 groundwater results significantly exceed background. "Under optimum conditions, the analytical results for major

analytes in groundwater have an accuracy of ± 2 to ± 10 percent. That is, the difference between the reported result and the actual concentration in the sample at the time of analysis should be between 2 and 10 percent of the actual value" (Hem, 1985). Analytes present in concentrations above 100 mg/L generally can be determined with an accuracy of better than ± 5 percent. The limits of precision (reproducibility) are similar. For analytes present in concentrations below 1 mg/L, the accuracy is generally not better than ± 10 percent and can be poorer (Hem, 1985). Except for the major anions and cations, most of the analytes for OU 3 are present in concentrations less than 1 mg/L. Therefore, the analytical accuracy can be estimated to be ± 10 percent. To address analytical uncertainty as well as sampling uncertainty, the OU 3 mean has also been compared to the value of the background mean plus two standard deviations.

Arsenic was eliminated as a groundwater COC for IHSS 201 based on the following (see Table 8-5 and Figure 8-14)

- The mean concentration of total arsenic in IHSS 201 (2.5 $\mu\text{g/L}$) is less than the mean concentration of total arsenic in the LHSU (2.76 $\mu\text{g/L}$)
- The range of concentrations of total arsenic in IHSS 201 (2.7 to 3.8 $\mu\text{g/L}$) is less than the range of concentrations for the LHSU (0.35 to 7 $\mu\text{g/L}$)
- The maximum value of total arsenic in IHSS 201 (3.8 $\mu\text{g/L}$) is below the maximum benchmark value (30 $\mu\text{g/L}$)

A comparison of IHSS 200 arsenic groundwater data to background and benchmark data indicates the following (see Table 8-5 and Figure 8-14)

- The mean (2.99 $\mu\text{g/L}$) for total arsenic is greater than that for the background UHSU (1.95 $\mu\text{g/L}$). However, the mean (2.99 $\mu\text{g/L}$) is within two standard deviations of the background mean (mean + 2 standard deviations = 5.37 $\mu\text{g/L}$)
- The maximum total arsenic value detected in Well 49192 (6.9 $\mu\text{g/L}$) is similar to the maximum detected in the UHSU background data (5 $\mu\text{g/L}$)
- The maximum value for total arsenic (6.9 $\mu\text{g/L}$) is less than the maximum value found in literature for groundwater (30 $\mu\text{g/L}$ [Dragun, 1988])

Because arsenic is present in Well 49192 (IHSS 200) at concentrations that are similar to, but not below the background mean and maximum, arsenic has been evaluated further using temporal variability, analytical uncertainty, and geochemical analyses to determine if it should be retained on the COC list for IHSS 200 groundwater

In reviewing the data from Well 49192, one anomaly was noted three of the eight sample rounds had elevated amounts of total suspended solids (TSS) On January 29, 1993, April 29, 1993, and November 18, 1993, TSS were 840, 1300, and 948 mg/L, respectively On the five other sample dates, the TSS were all less than 160 mg/L The elevated amount of TSS, in conjunction with elevated total aluminum and total iron (over one order of magnitude greater than the other five sampling rounds), indicates that the sampling technique on those days may be suspect (see Figure 8-15) The correlation coefficients between TSS and aluminum and TSS and iron are 0.99 and 0.96, respectively A review of the background TSS data for both the UHSU and the LHSU shows a small percentage (less than 10 percent) of TSS values greater than 500 mg/L It is possible that when the sampling bailer was lowered in the well, the bailer may have hit the bottom of the well and dislodged sediments into the water column Other total metal analyses are also higher during these three sample events

The three greatest detections (6.9 µg/L, 5.2 µg/L, and 3.5 µg/L) of arsenic correlate with the three sampling events exhibiting elevated TSS (Figure 8-15) When the arithmetic mean for the well OU 3 data is recalculated, excluding the data from these three sampling events, the OU 3 mean (1.67 µg/L, recalculated) is less than the UHSU background mean (as seen in Figure 8-14)

Based on the similarity of the OU 3 and the UHSU background means (less than two standard deviations of the background mean), the OU 3 mean being less than the LHSU background mean, the analytical and sampling uncertainty, and the potential for sampling error (three rounds with high values of TSS), arsenic concentrations in OU 3 groundwater were determined to be not above background, therefore, arsenic has been eliminated as a COC in OU 3 groundwater This conclusion is supported by the Phase I Health Studies, which did not identify arsenic as a material of concern (CDPHE, 1991b)

8.8 Beryllium in Groundwater

Beryllium was eliminated as a COC based on a comparison of detected values to BGCR groundwater data (DOE, 1993c) Table 8-5 summarizes the OU 3 analytical results for beryllium in groundwater (IHSS 200 and 201, monitoring wells were not installed in IHSS 202) and the BGCR

analytical results for groundwater. In addition, literature benchmark data for groundwater is included on Table 8-5.

Table 8-5 indicates the following:

- Beryllium was not detected in any of the 8 samples from IHSS 201 analyzed for total metals or the 8 samples from IHSS 201 analyzed for dissolved metals, the detection limits for these samples was 1 µg/L, the contract required reporting limit for beryllium in water samples is 5 µg/L.
- The mean concentration of total beryllium for IHSS 200 (0.91 µg/L) is essentially equal to the mean concentrations of the UHSU (1.07 µg/L).
- The range of concentrations detected in total beryllium samples for IHSS 200 (1.1 to 1.6 µg/L) is within the range of concentrations for the UHSU (0.4 to 4.8 µg/L), beryllium was not detected in any of the samples from IHSS 200 analyzed for dissolved metals (detection limit of 1 µg/L).
- The maximum detected value of beryllium in IHSS 200 (1.6 µg/L) is approximately one order of magnitude less than the maximum benchmark value (10 µg/L).
- The minimum values of beryllium detected in the UHSU and LHSU exceed the risk-based PRG (0.0198 µg/L).

Based on the comparison of OU 3 data to background and benchmark data, beryllium was eliminated as a groundwater COC in IHSS 200 and 201.

8.9 Uranium-233/234 in Groundwater

Uranium-233/234 was eliminated as a COC based on a comparison of detected values to BGCR groundwater data (DOE, 1993c). Table 8-5 summarizes the OU 3 analytical results for ^{233/234}U in groundwater (IHSS 200 and 201, monitoring wells were not installed in IHSS 202) and the BGCR analytical results for groundwater.

Table 8-5 indicates the following:

- The mean concentration of total $^{233/234}\text{U}$ for IHSS 200 (4.00 pCi/L) is less than the mean concentrations of the UHSU (15.62 pCi/L), the mean concentration of dissolved $^{233/234}\text{U}$ for IHSS 200 (2.75 pCi/L) is less than the mean concentration of the UHSU (6.23 pCi/L)
- The mean concentration of total $^{233/234}\text{U}$ for IHSS 201 (0.755 pCi/L) is less than the mean concentrations of the UHSU and LHSU (15.62 pCi/L and 0.77 pCi/L, respectively), the mean concentration of dissolved $^{233/234}\text{U}$ in IHSS 201 (0.694 pCi/L) is less than the mean concentrations of the UHSU and LHSU (6.23 pCi/L and 1.64 pCi/L, respectively)
- The range of concentrations detected in total $^{233/234}\text{U}$ samples for IHSS 200 (3.4 to 4.6 pCi/L) is within the range of concentrations for the UHSU (0.0 to 164 pCi/L), the range of concentrations detected in dissolved $^{233/234}\text{U}$ for IHSS 200 (0.26 to 4.84 pCi/L) is within the range of concentrations for the UHSU and LHSU (-0.02 to 199.5 pCi/L and -0.01 to 15.33 pCi/L, respectively)
- The range of concentrations detected in total $^{233/234}\text{U}$ samples for IHSS 201 (0.64 to 0.87 pCi/L) is within the range of concentrations for the UHSU and LHSU (0.0 to 164 pCi/L and 0.15 to 1.52 pCi/L, respectively), the range of concentrations detected in dissolved $^{233/234}\text{U}$ for IHSS 201 (0.31 to 1.2 pCi/L) is within the range of concentrations for the UHSU and LHSU (-0.02 to 199.5 pCi/L and -0.01 to 15.33 pCi/L, respectively)

Based on the comparison of OU 3 data to background data, $^{233/234}\text{U}$ was eliminated as a groundwater COC in IHSSs 200 and 201

9.0 SUMMARY

Based on the results of the COC Selection Process applied to the OU 3 analytical data the following chemicals are COCs for OU 3

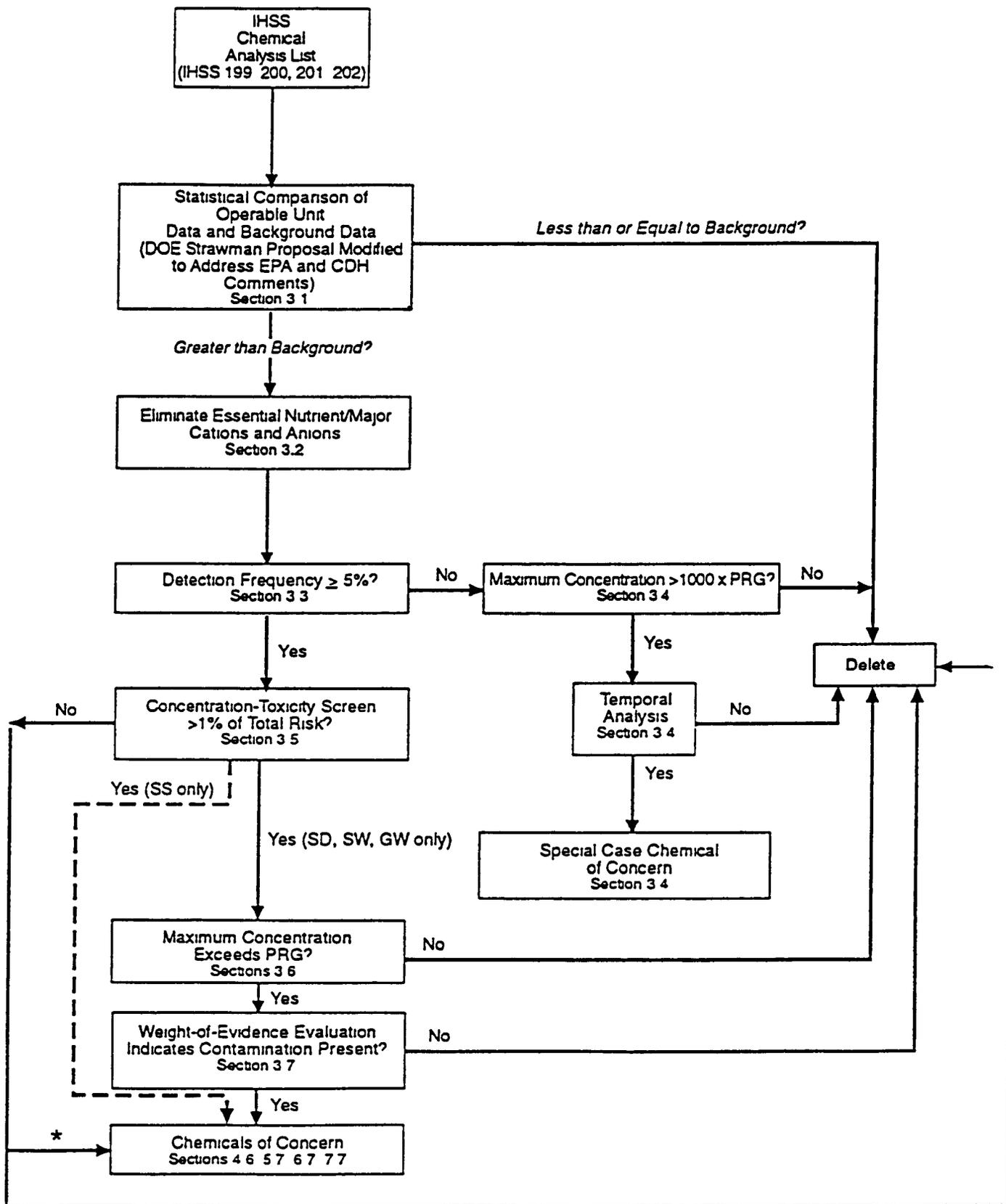
- $^{239/240}\text{Pu}$ and ^{241}Am in surface soil (IHSS 199)
- $^{239/240}\text{Pu}$ in Great Western Reservoir surface sediments (IHSS 200)

Additional information regarding chemicals not found on EPA's list of proposed COCs can be found in TM 4 (DOE, 1994)

100 REFERENCES

- CDPHE/EPA/DOE, 1994 Colorado Department of Public Health and Environment, United States Environmental Protection Agency, and United States Department of Energy Presentation on the Conservative Screen Process for Identification of Source Areas and Data Aggregation for Calculation of Exposure Point Concentrations June 3, 1994
- CDPHE/EPA, 1993 Colorado Department of Public Health and Environment, United States Environmental Protection Agency Background Comparisons approval letter from CDPHE and EPA Resumption of Baseline Risk Assessment Work Letter from Joan Sowinski (CDPHE) and Robert L Duprey (EPA) to James K Hartman (DOE) November 18, 1993
- CDPHE, 1990 Colorado Department of Public Health and Environment Clear Creek Phase II Remedial Investigation Final Report September 21, 1990
- Davis and Kent, 1990 J A Davis and D B Kent Surface Complexation Modeling in Aqueous Geochemistry In Mineral-Water Interface Geochemistry M G Hochella and A F White, eds Mineralogical Society of America, *Reviews in Mineralogy*, Volume 23, pp 177-260 1990
- DOE, 1994a United States Department of Energy Technical Memorandum No 4, Human Health Risk Assessment for Operable Unit 3, Rocky Flat Environmental Technology Site Chemicals of Concern Identification Environmental Restoration Program Golden, Colorado February 28, 1992
- DOE, 1994b United States Department of Energy Rocky Flats Plant Site-wide Quality Assurance Project Plan for CERCLA Remedial Investigations/Feasibility Studies and RCRA Facility Investigations/Corrective Measures Studies Activities January 5, 1994
- DOE, 1993a United States Department of Energy Strawman of the statistical background comparison methods
- DOE, 1993a United States Department of Energy Guidance for Conducting Statistical Comparison of RFI/RI Data and Background Data at the Rocky Flats Plant Document No 93-RF-14529, 11/30/93 November 30, 1993
- DOE, 1993b United States Department of Energy Background Geochemical Characterization Report September 30, 1993
- DOE, 1992 United States Department of Energy RFI/RI Work Plan for OU 3 Rocky Flats Plant Environmental Restoration Program (Manual 21100-WP-OU3 1, 2/28/92) Golden, Colorado February 28, 1992
- Dragun, 1988 James Dragun The Soil Chemistry of Hazardous Materials Hazardous Materials Control Research Institute Silver Springs, MD 1988
- EPA, 1995 United States Environmental Protection Agency Review comments on TM 4 January 4, 1995
- EPA, 1994 United States Environmental Protection Agency Correspondence from Martin Hestmark (EPA) to Richard Schassburger (DOE) regarding Operable Unit 3 comparison to background March 24, 1994

- EPA, 1994 United States Environmental Protection Agency Region VIII Evaluating and Identifying Contaminants of Concern for Human Health Document No RA-03 September 1994
- EPA, 1993 United States Environmental Protection Agency EPA comments on the strawman of the statistical background comparison methods
- EPA, 1989 United States Environmental Protection Agency Risk Assessment Guidance for Superfund Volume 1 Part A Office of Emergency and Remedial Response EPA/540/6-90/008 October, 1990
- EPA, 1988 United States Environmental Protection Agency Warm Springs Pond OU F Draft Remedial Investigation Report 1988
- EG&G, 1994 EG&G Rocky Flats, Inc Methodology for Statistical Comparisons of Data to Background EG&G Memorandum 94-RF-02971-SG-179-94 Golden, Colorado March 14, 1994
- Gilbert, 1993 Richard O Gilbert Recommended process for implementation by Rocky Flats Plant (RFP) to compare environmental restoration site analytical results obtained in operable units (OU) to background concentrations July 30, 1993
- Gilbert, 1987 Richard O Gilbert Statistical Methods for Environmental Pollution Monitoring New York Van Nostrand Reinhold Publishers 1987
- Heit, et al , 1985 Merrill Heit, Catherine Klusek, and Jill Baron Evidence of Deposition of Anthropogenic Pollutants in Remote Rocky Mountain Lakes *Water, Air and Soil Pollution* 22 (1984) 403-416 D Reidel Publishing Company
- IAG, 1991 Rocky Flat Interagency Agreement Between the State of Colorado, the Environmental Protection Agency, and the Department of Energy January, 1991
- Sinclair, 1986 A J Sinclair Statistical Interpretation of Soil Geochemical Data in Exploration Geochemistry Design and Interpretation of Soil Surveys Society of Economic Geologists, El Paso TX, pp 97-116 1986
- Stanley, 1987 C R Stanley PROBPLOT An Interactive Computer Program to Fit Mixtures of Normal (or Lognormal) Distributions with Maximum Likelihood Optimization Procedures Association of Exploration Geochemists, Special Volume No 14, 1987



* Professional Judgement

SS = Surface Soil
SD = Sediments
SW = Surface Water
GW = Groundwater

Source Adapted from COPHE EPA 199-

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Figure 1-1
HUMAN HEALTH RISK ASSESSMENT
CHEMICALS OF CONCERN
SELECTION PROCESS

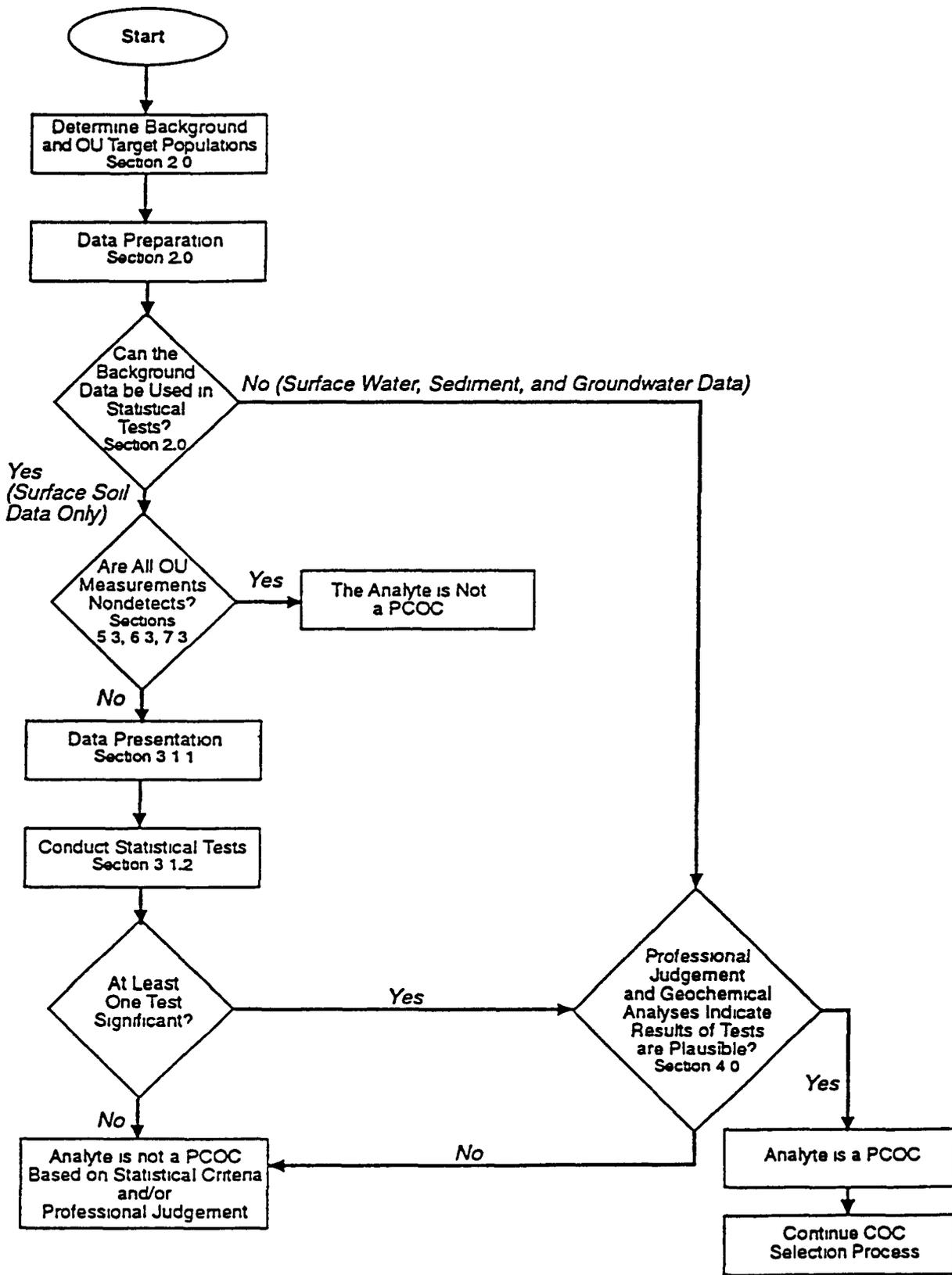


Figure 8-1
FLOWCHART FOR COMPARING OU
DATA TO BACKGROUND

Figure 8-5 Sediment Core Plots- Arsenic

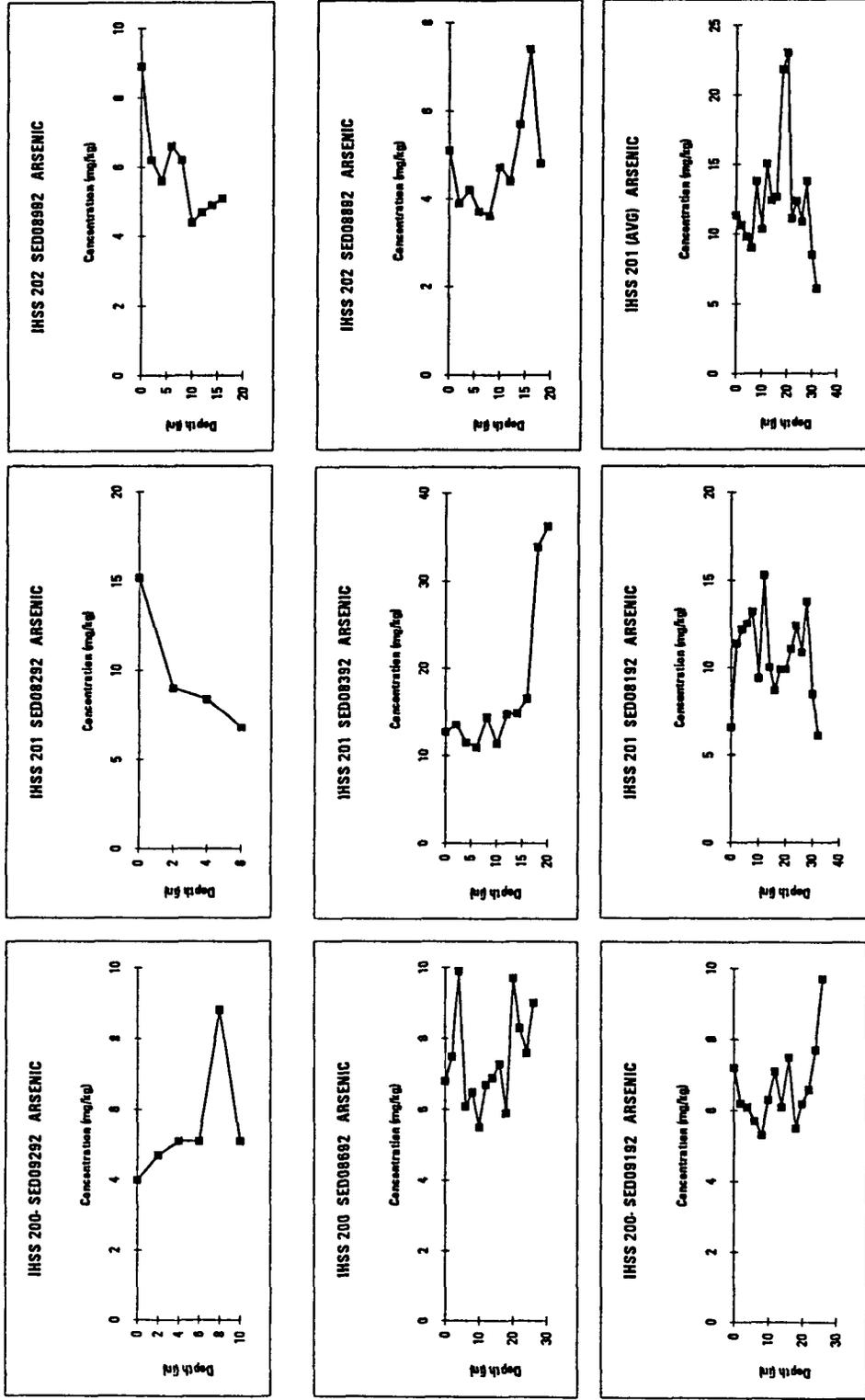


Figure 8.6a Sediment Core Plots

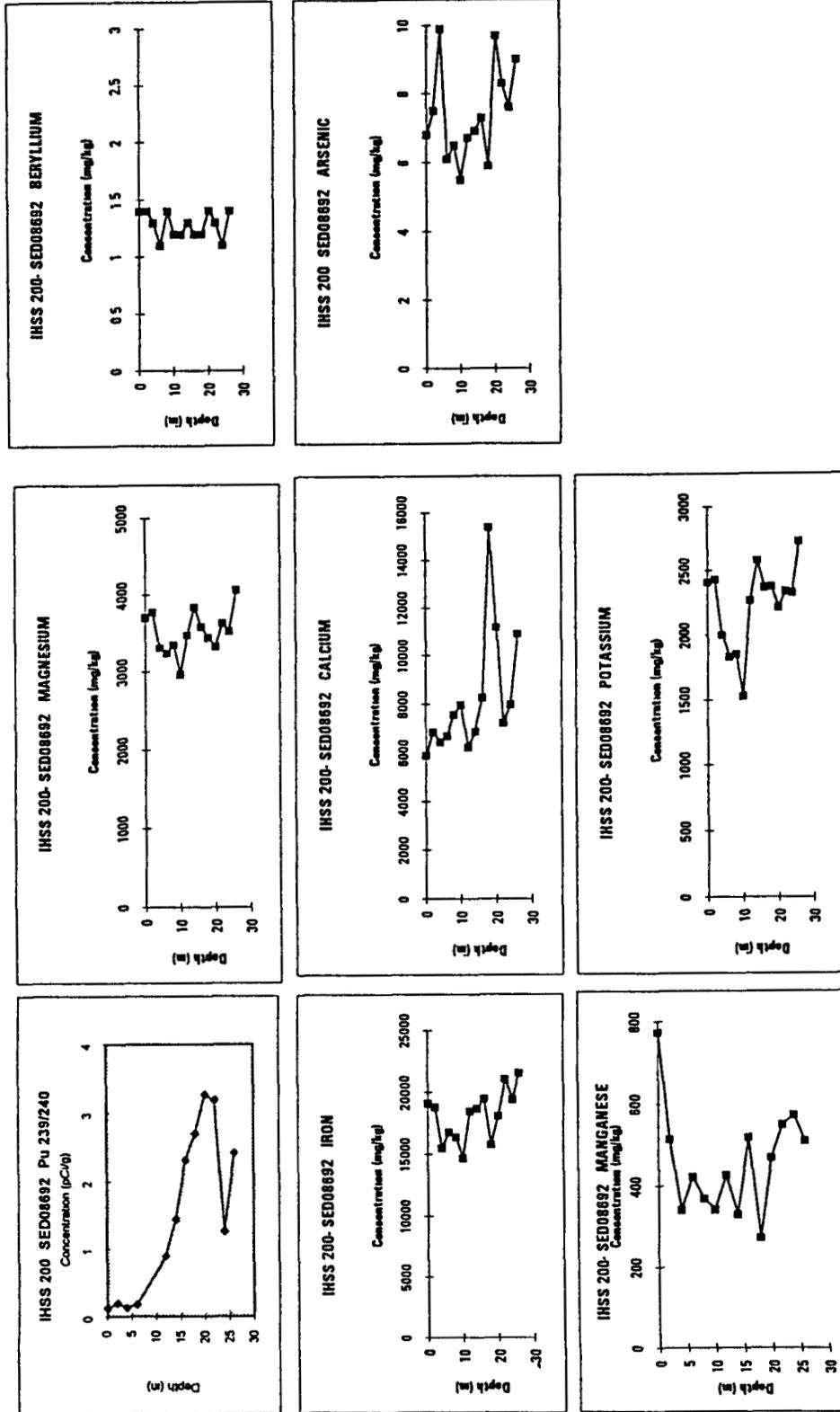


Figure 8 6b Sediment Core Plots

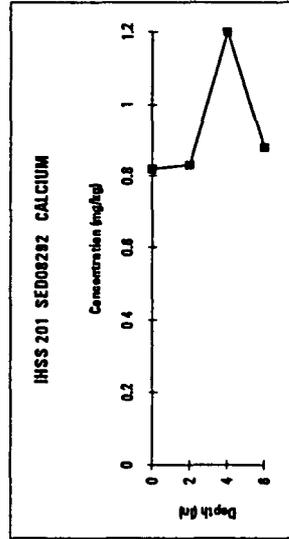
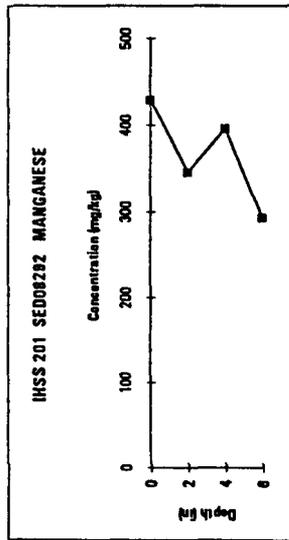
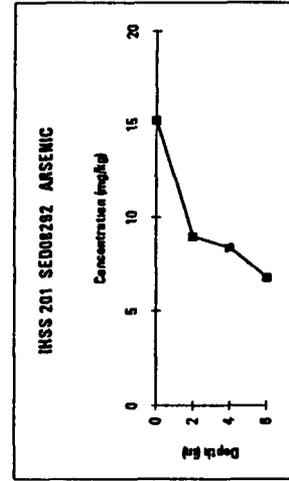
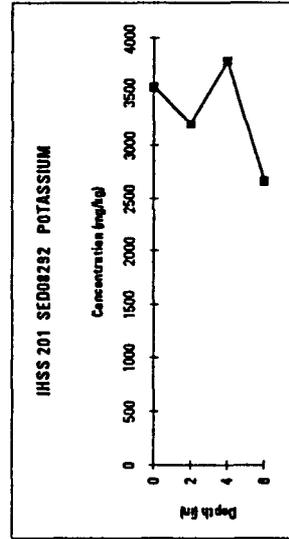
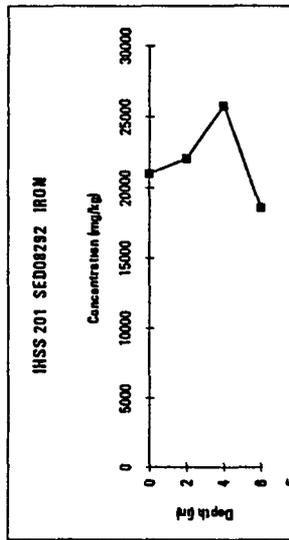
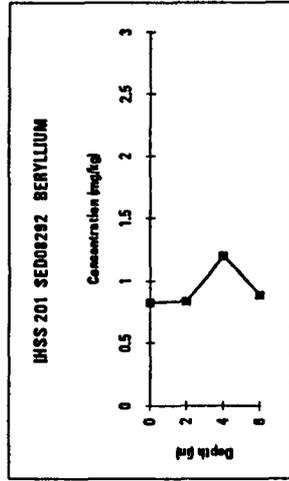
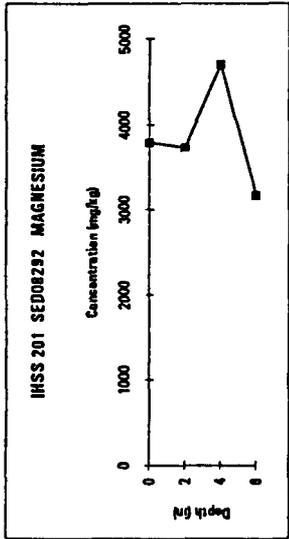
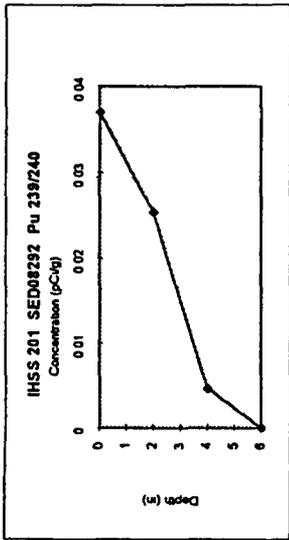
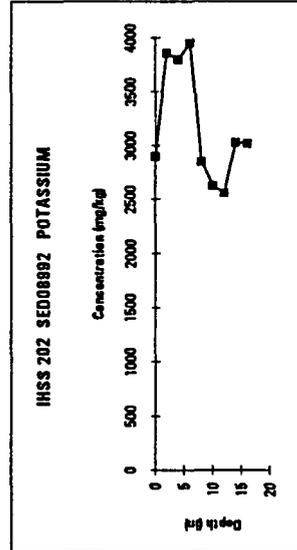
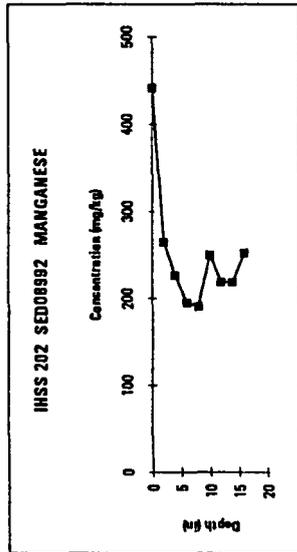
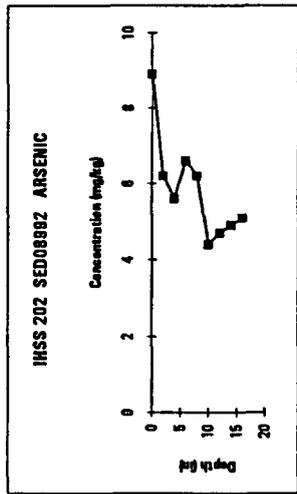
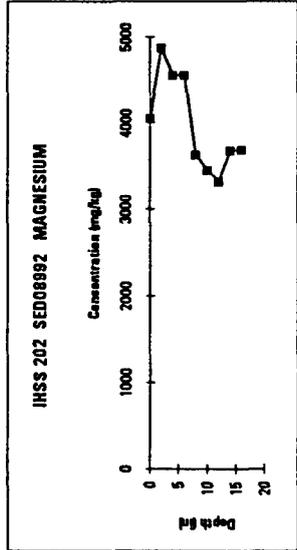
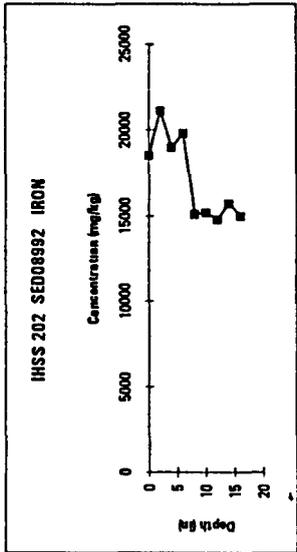
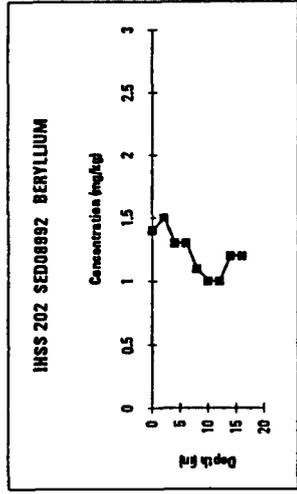
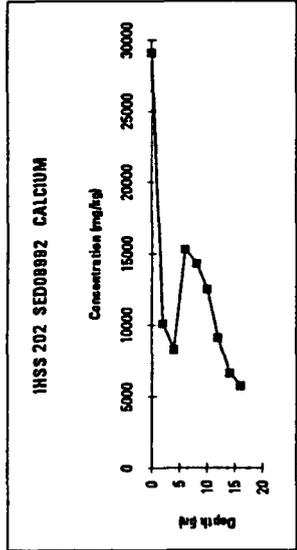
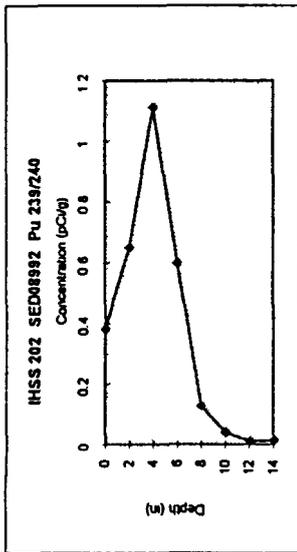


Figure 8 6a Sediment Core Plots



20 22 07
05/08/99

RFP / BU-3

LOGARITHMIC VALUES

VARIABLE = As

UNIT = MG/K

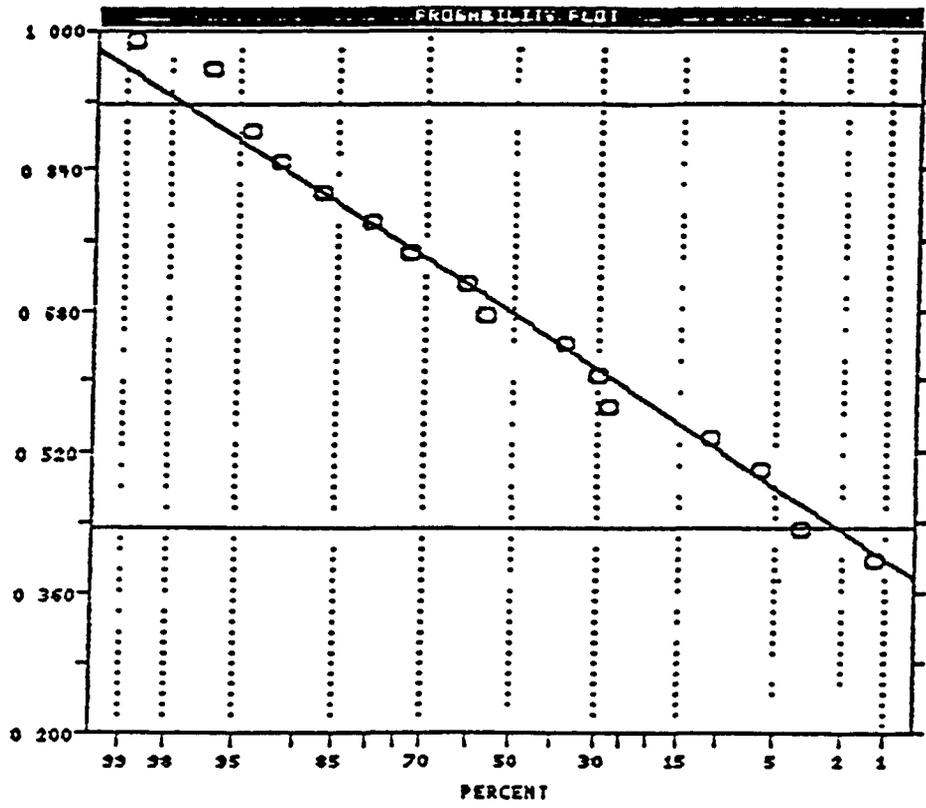
N = 91

M CI = 17

POPULATIONS

Pop	Mean	Std Dev	x
1	0.6749	0.1208	100.0

Pop	THRESHOLDS	
1	0.4334	0.9165



RAW DATA HL
PARAMETER ESTIMATES

Figure 8-7
ARSENIC IN IHSS 200
SURFACE SEDIMENT

42

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15 08 39
05/10/94

RFP / DU-3

LOGARITHMIC VALUES

=====

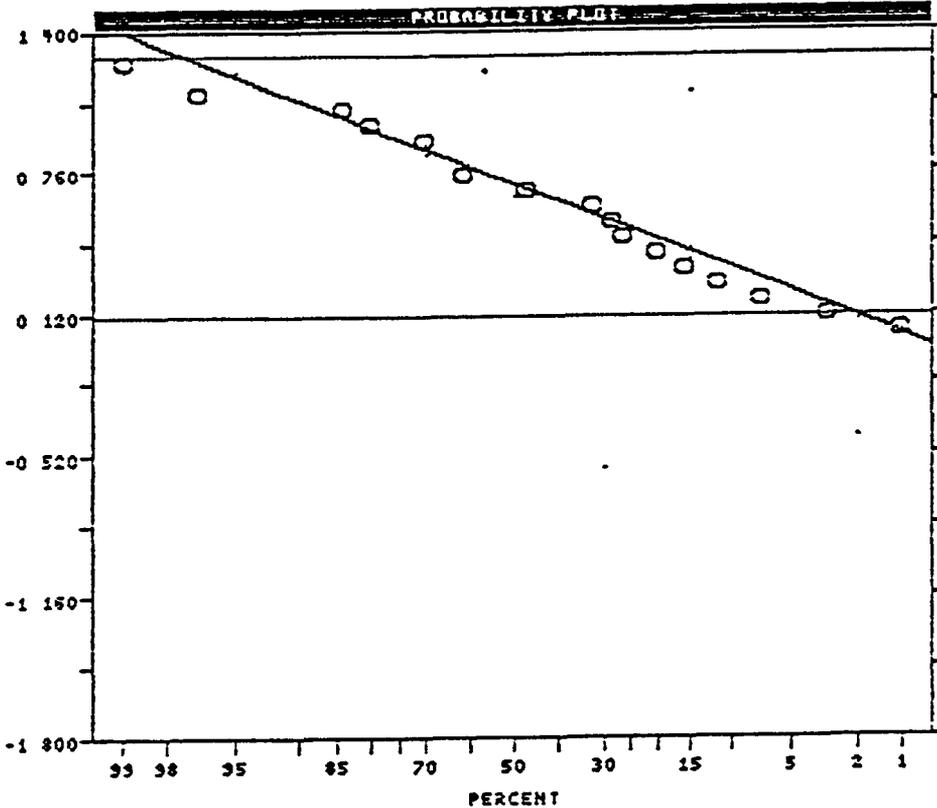
VARIABLE = As
UNIT = MG/K
N = 47
N CI = 17

POPULATIONS

=====

Pop	Mean	Std Dev	Z
1	0.6952	0.2253	100.0

Pop	THRESHOLDS	
1	0.1036	1.2807



RAW DATA ML
PARAMETER ESTIMATES

Figure 8-8
ARSENIC IN IHSS 201
SURFACE SEDIMENT

43

11 11 52
05/03/94

RFP / DU-3 As-S

LOGARITHMIC VALUES

=====

VARIABLE = As
UNIT = NG/K
N = 18
N CI = 13

POPULATIONS

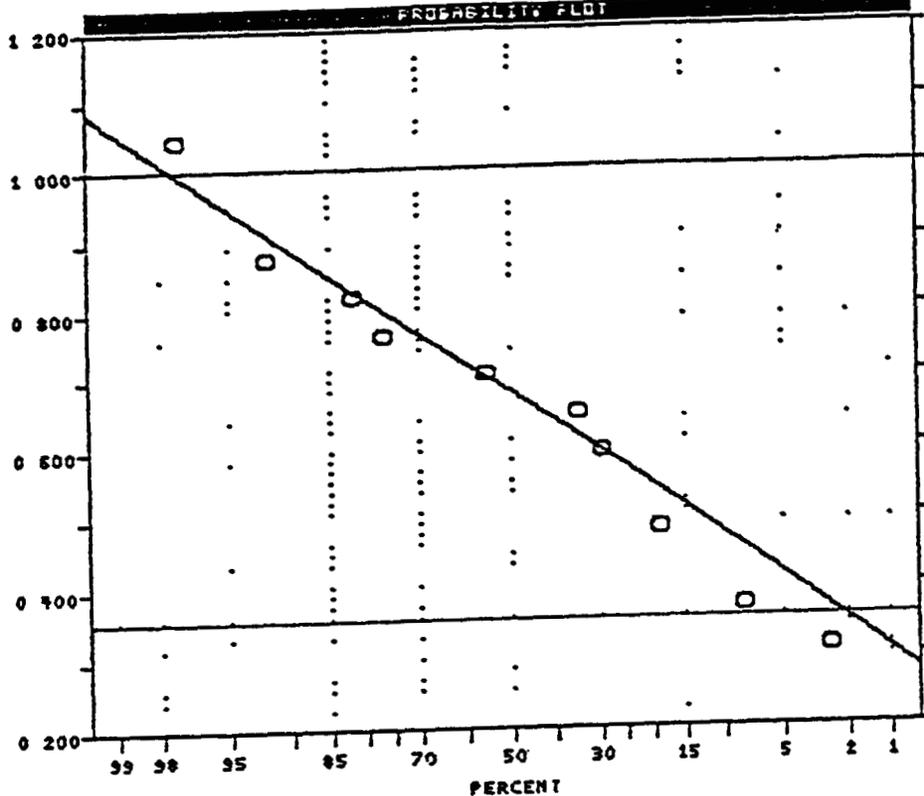
=====

Pop	Mean	Std Dev	x
1	0 6793	0 1619	100 0

THRESHOLDS

=====

1	0 3555	1 0030
---	--------	--------



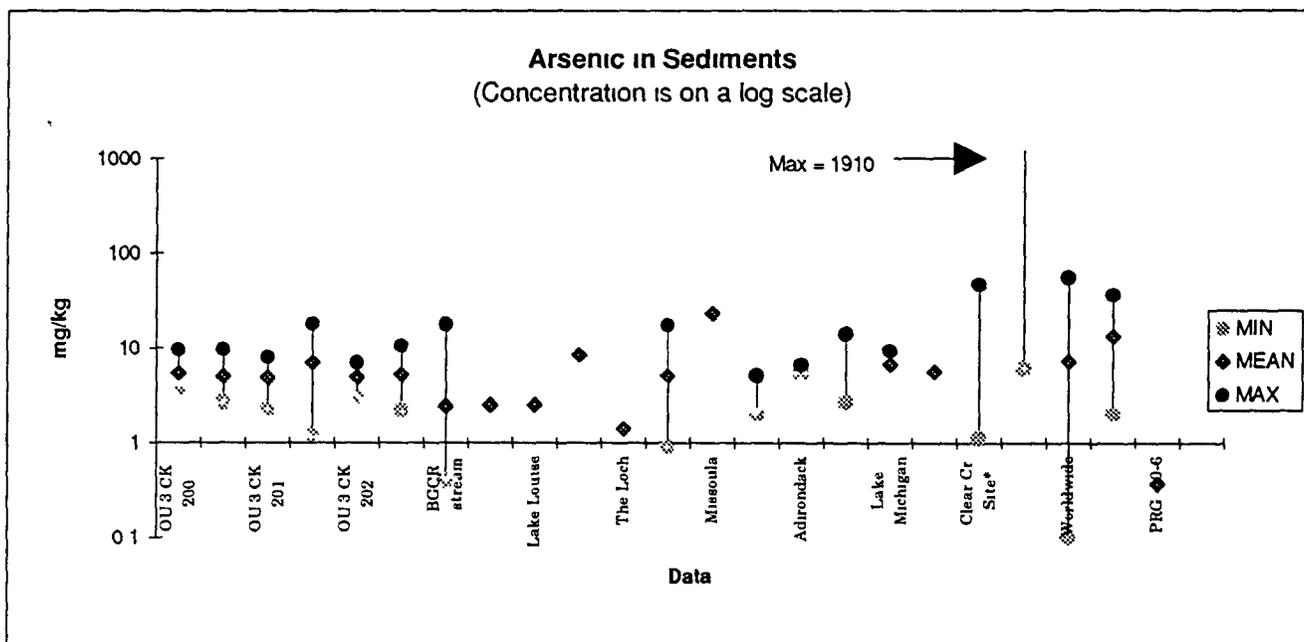
RAW DATA ML
PARAMETER ESTIMATES

Figure 8-9
ARSENIC IN IHSS 202
SURFACE SEDIMENT

44

ARSENIC IN SEDIMENTS
(mg/kg)

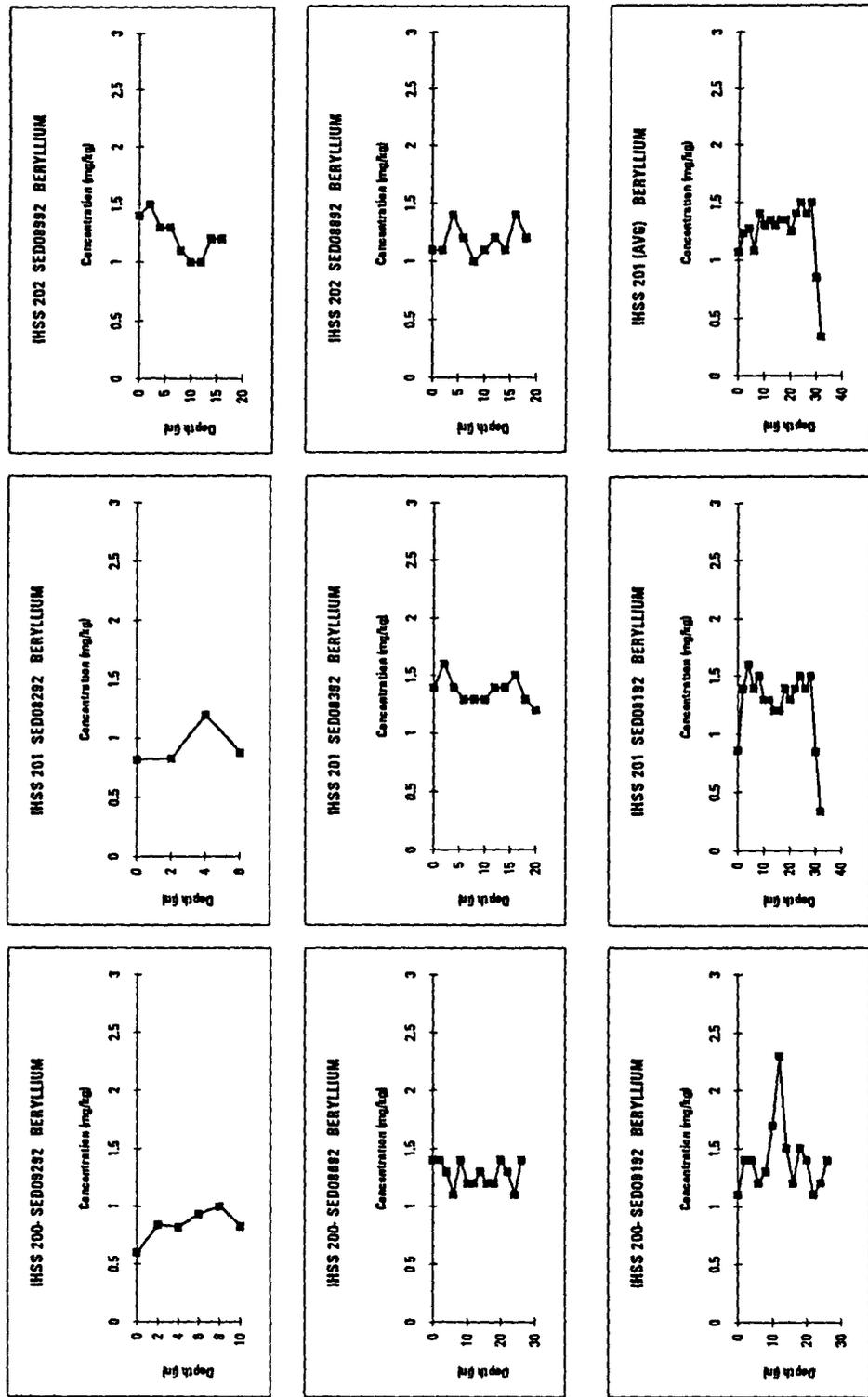
DATA	MIN	MEAN	MAX	STD DEV	COMMENTS/SOURCE
OU 3 CK - 200	3.7	5.31	9.4	1.85	Great Western Reservoir (Creek) (OU 3 Database)
OU 3 LK - 200	2.6	4.91	9.4	1.46	Great Western Reservoir (Lake) (OU 3 Database)
OU 3 CK 201	2.2	4.76	7.8	1.53	Standley Lake (Creek) (OU 3 Database)
OU 3 LK 201	1.2	6.96	17.7	4.34	Standley Lake (Lake) (OU 3 Database)
OU 3 CK 202	3	4.88	6.8	1.56	Mower Reservoir (Creek) (OU 3 Database)
OU 3 LK 202	2.2	5.15	10.4	1.96	Mower Reservoir (Lake) (OU 3 Database)
BGCR stream	0.39	2.4	17.3	2.45	RFP Background Stream Sediments, BGCR (DOE 1993c)
Lake Husted		2.5		0.2	Rocky Mountain National Park Lake Surface Sediment (Hett et al 1984)
Lake Louise		2.5		0.3	Rocky Mountain National Park Lake Surface Sediment (Hett et al 1984)
Lake Haiyaha		8.4		0.2	Rocky Mountain National Park Lake Surface Sediment (Hett et al 1984)
The Loch		1.4		0.2	Rocky Mountain National Park Lake Surface Sediment (Hett et al 1984)
Lowry	0.9	5	17	4	Lowry Landfill Background Stream Sediment OUs 2 5 Baseline Risk Assessment (EPA 1992)
Missoula		23			Missoula Lake Beds Surface Sediment (Moore and Ramamoorthy 1984)
Great Lakes	2		5		Great Lakes Surface Sediment (Fergusson 1990)
Adirondack	5.3		6.5		Lake Adirondack Surface Sediment (Fergusson 1990)
Niagara R	2.7		14		Niagara River Sediment (polluted) (Fergusson 1990)
Lake Michigan		6.6	9.2		Lake Michigan Surface Sediment (Fergusson 1990)
Cherry Creek		5.57			Cherry Creek Reservoir Surface Sediment (CCBA 1994)
Clear Cr Site	1.1		46		Clear Creek Superfund Site (CDPHE 1990)
Warm Springs	6		1910		Warm Springs Pond Superfund Site Pond Bottom Sediments (EPA, 1988)
Worldwide	0.1	7.2	55	7.2	Worldwide Sediment (Boyle & Jonasson 1973)
Peaty Soils	2	13.4	36	9.4	Peaty Soils (Boyle & Jonasson 1973)
PRG-10 ⁶		0.37			10 ⁶ PRG level based on a residential soil scenario (EG&G 1994a)



Notes If blank no data are available
 *Indicates Superfund site
 OU 3 CK 200 = Creek sediment data in IHSS 200
 OU 3 LK 200 = Lake sediment data in IHSS 200

Figure 8-10
ARSENIC IN SEDIMENTS

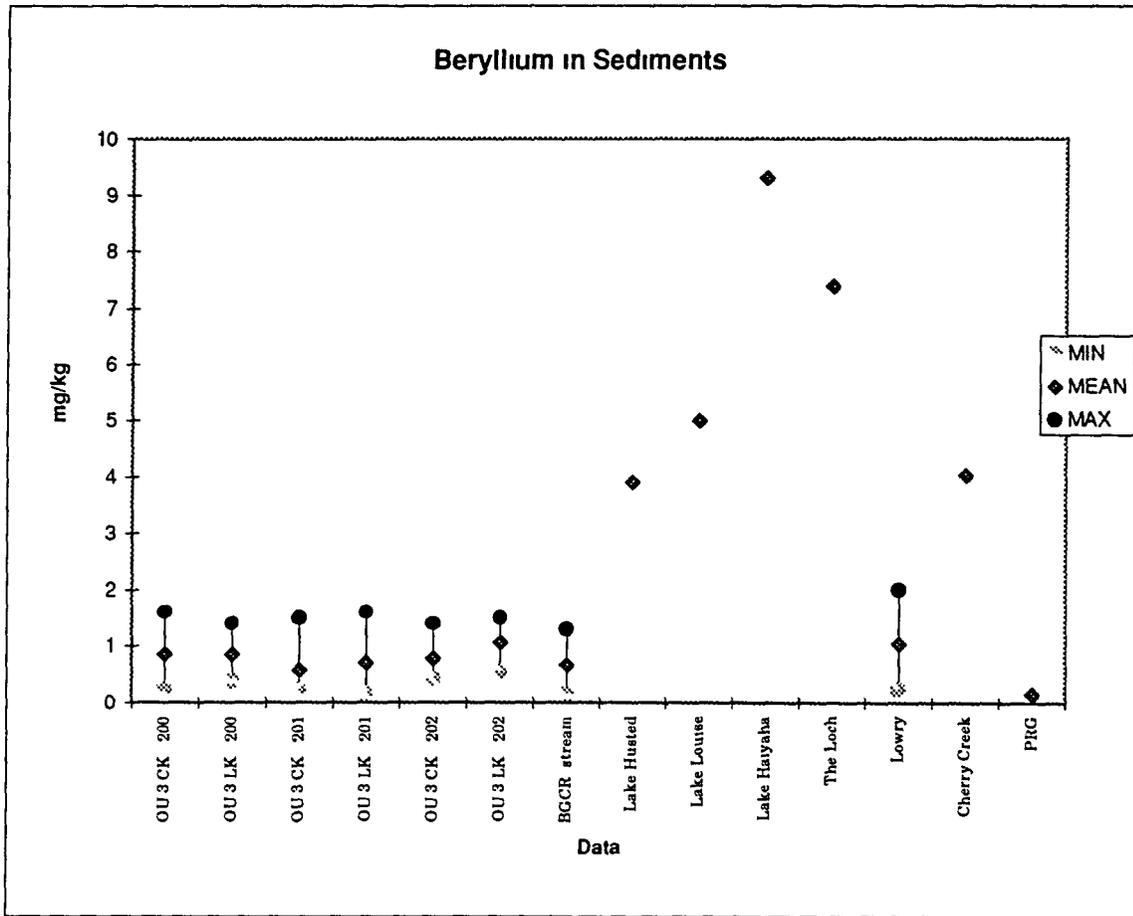
Figure 8-11 Sediment Core Plots Beryllium



BERYLLIUM IN SEDIMENTS

(mg/kg)

DATA	MIN	MEAN	MAX	STD DEV	COMMENTS/SOURCE
OU 3 CK 200	0.24	0.85	1.6	0.38	Great Western Reservoir Surface Sediments (Creek) (OU 3 Database)
OU 3 LK 200	0.37	0.85	1.4	0.27	Great Western Reservoir Surface Sediments (Lake) (OU 3 Database)
OU 3 CK - 201	0.22	0.58	1.5	0.31	Standley Lake Surface Sediments (Creek) (OU 3 Database)
OU 3 LK 201	0.15	0.7	1.6	0.47	Standley Lake Surface Sediments (Lake) (OU 3 Database)
OU 3 CK - 202	0.41	0.78	1.4	0.54	Mower Reservoir Surface Sediments (Creek) (OU 3 Database)
OU 3 LK 202	0.54	1.06	1.5	0.27	Mower Reservoir Surface Sediments (Lake) (OU 3 Database)
BGCR stream	0.15	0.66	1.3	1.69	RFP Background Stream Sediments BGCR (DOE 1993c)
Lake Husted		3.9		1	Rocky Mountain National Park Surface Sediments (Het et al 1984)
Lake Louise		5		3	Rocky Mountain National Park Surface Sediments (Het et al 1984)
Lake Hayaha		9.3		1.1	Rocky Mountain National Park Surface Sediments (Het et al 1984)
The Loch		7.4		1.3	Rocky Mountain National Park Surface Sediments (Het et al 1984)
Lowry	0.23	1.04	2	0.48	Lowry Landfill Background Stream Sediment OUs 2-5 Baseline Risk Assessment (EPA 1992)
Cherry Creek		4.03			Cherry Creek Reservoir (CCBA, 1994)
PRG		0.15			10 ⁻⁶ PRG level based on a residential soil scenario (EG&G 1994a)



Notes: If blank, no data are available

OU 3 CK 200 = Creek sediment data in IHSS 200

OU 3 LK 200 = Lake sediment data in IHSS 200

**Figure 8-12
BERYLLIUM IN SEDIMENTS**

47

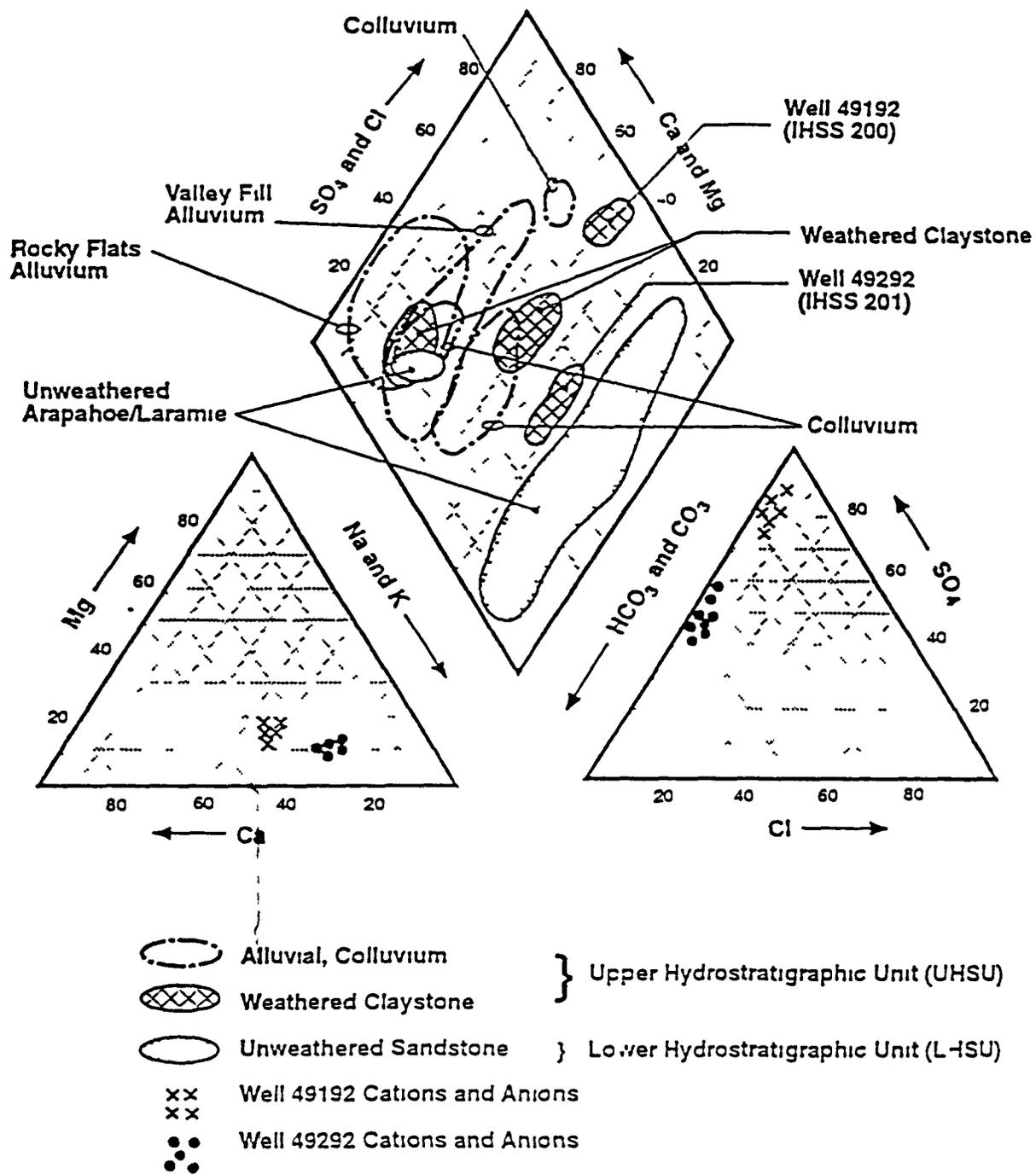
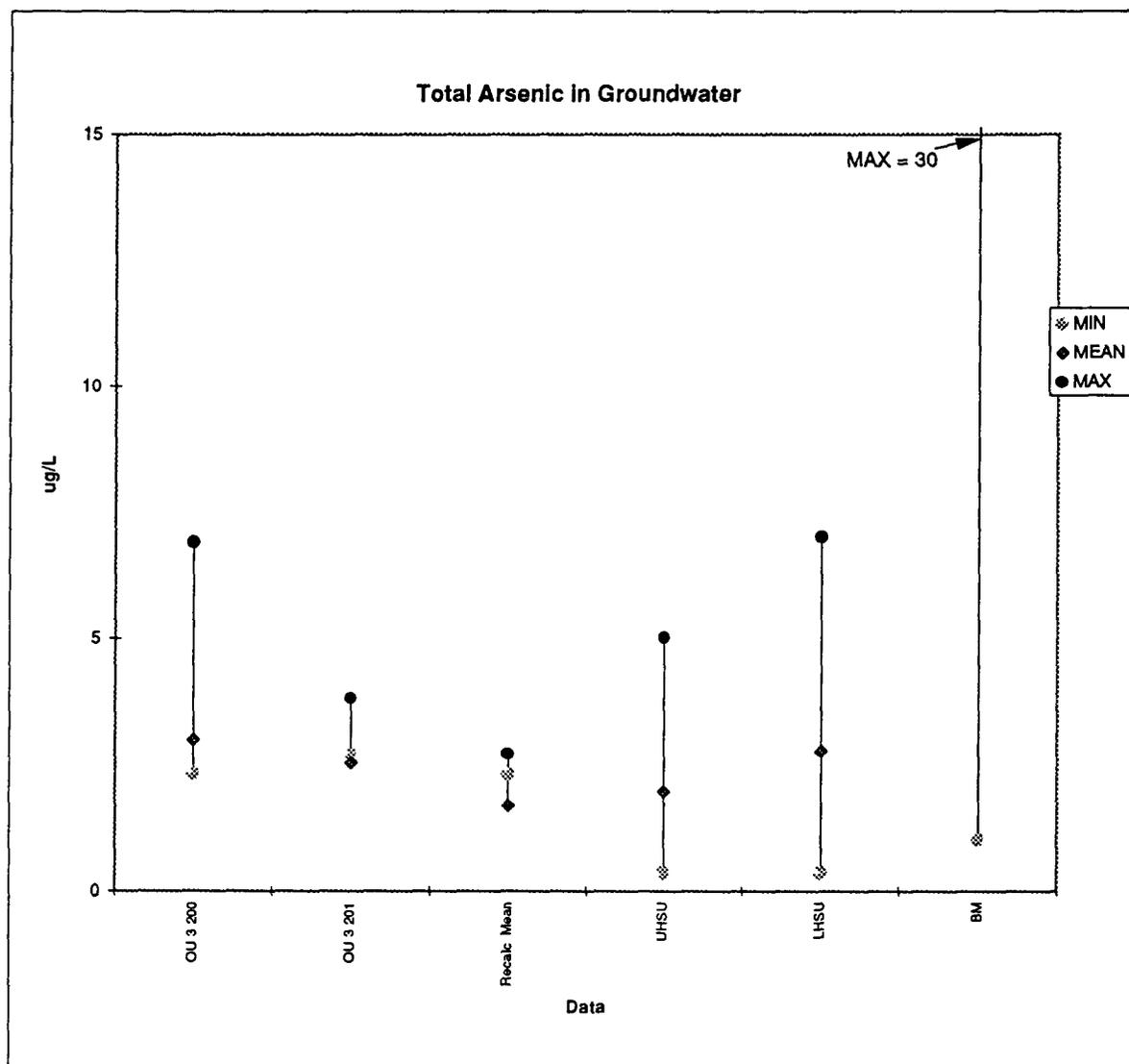


Figure 8-13

PIPER DIAGRAM SHOWING MAJOR ION CHEMISTRY FOR OU 3 WELLS AND BACKGROUND GEOCHEMICAL GROUNDWATER WELLS

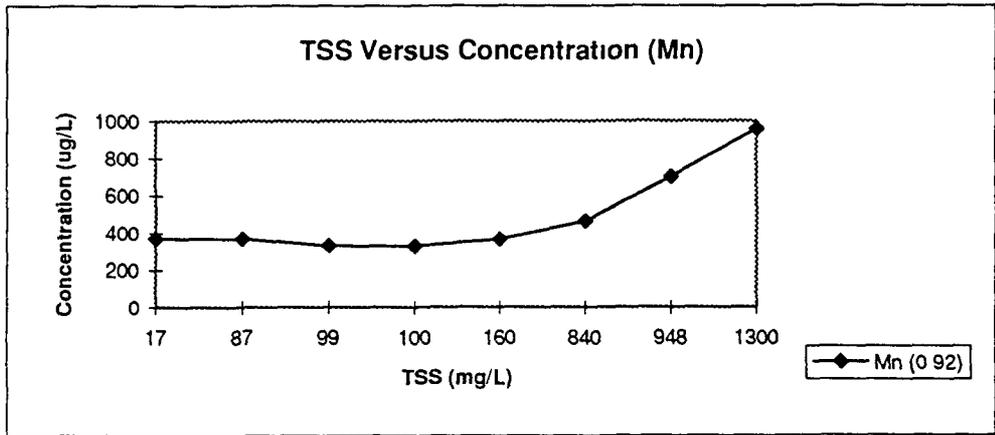
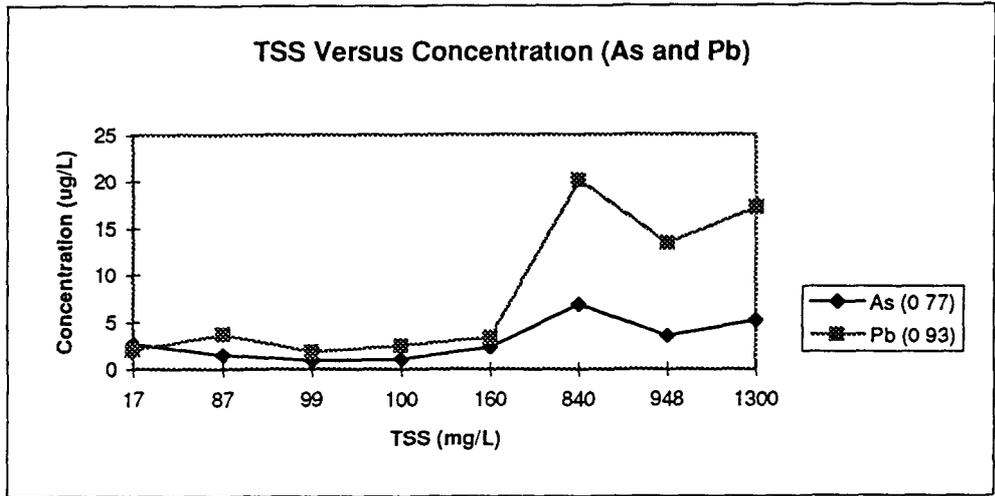
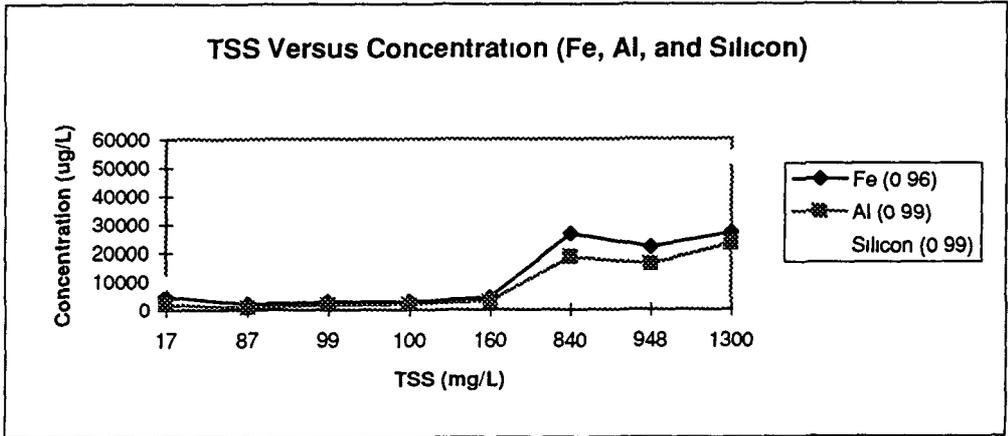
TOTAL ARSENIC IN GROUNDWATER

DATA	(µg/L)				COMMENTS/SOURCE
	MIN	MEAN	MAX	STD DEV	
OU 3-200	2.3	2.99	6.9	0.711	OU 3 Well 49192 (8 sampling events) (OU 3 Database)
OU 3-201	2.7	2.53	3.8	0.424	OU 3 Well 49292 (8 sampling events) (OU 3 Database)
Recalc Mean	2.3	1.67	2.7		OU 3 Well 49192 recalculated without sampling events associated with high TSS
UHSU	0.35	1.95	5	1.71	Weathered Claystone BGCR (DOE 1993c)
LHSU	0.35	2.76	7	2.02	Unweathered Arapahoe and Laramie Formation BGCR (DOE 1993c)
BM	1		30		Benchmark Data (Dragun 1988)



Notes: If blank, no data are available
 OU 3-200 = IHSS 200 in OU 3

Figure 8-14
TOTAL ARSENIC IN GROUNDWATER



Note Values in () are correlation coefficients

Figure 8-15
TSS VERSUS CONCENTRATION FOR WELL 49192

TABLE 8.2
SUMMARY STATISTICS FOR SURFACE SEDIMENTS BY IHSS FOR WEIGHT OF EVIDENCE EVALUATIONS

Chemical Name METALS (mg/kg)	IHSS or Benchmark	Lake or Creek	Area	Number of Detects	Number of Sample	Frequency of Detection	Minimum		Maximum		Mean	Standard Deviation	Coefficient of Variation
							Non-detected Value	Detected Value	Non-detected Value	Detected Value			
ARSENIC	BGCR	CREEK	B	53	59	1.00		0.20	17.30	2.410	2.45	0.35	
ARSENIC	200	CREEK	S	8	8	1.00		3.70	9.40	5.313	1.85	0.32	
ARSENIC	201	CREEK	S	14	14	1.00		2.20	7.80	4.784	1.53	0.32	
ARSENIC	202	CREEK	S	4	4	1.00		3.00	6.80	4.875	1.56	0.32	
ARSENIC	BM	LAKE	B					0.79	8.400	5.57			
ARSENIC	200	LAKE	S	36	36	1.00		2.60	9.40	4.906	1.46	0.30	
ARSENIC	201	LAKE	S	43	43	1.00		1.20	17.70	6.963	4.34	0.62	
ARSENIC	202	LAKE	S	15	15	1.00		2.20	10.40	5.147	1.96	0.38	
ARSENIC	RMNP BM (L Husted)	LAKE	B							2.5	0.2	0.3	
ARSENIC	RMNP BM (L Louise)	LAKE	B							2.5	0.2	0.3	
ARSENIC	RMNP BM (L Hayaha)	LAKE	B							8.4	0.2	0.2	
ARSENIC	RMNP BM (The Loch)	LAKE	B							1.4	0.2	0.2	
ARSENIC	LOWRY	CREEK	B						16.50	4.81	3.95		
BERYLLIUM	BGCR	CREEK	B	27	57	0.47		1.50	1.30	0.680	1.69	0.45	
BERYLLIUM	200	CREEK	S	8	8	1.00		0.24	1.60	0.861	0.38	0.54	
BERYLLIUM	201	CREEK	S	14	14	1.00		0.22	1.50	0.577	0.31	0.69	
BERYLLIUM	202	CREEK	S	3	3	1.00		0.41	1.40	0.783	0.54	0.31	
BERYLLIUM	BM	LAKE	B					3.90	4.03	9.300			
BERYLLIUM	200	LAKE	S	36	36	1.00		0.37	1.40	0.850	0.27	0.31	
BERYLLIUM	201	LAKE	S	39	43	0.91	0.06	0.15	1.60	0.700	0.47	0.67	
BERYLLIUM	202	LAKE	S	13	14	0.93	1.00	0.54	1.50	1.061	0.27	0.25	
BERYLLIUM	RMNP BM (L Husted)	LAKE	B							3.9	1.0	0.30	
BERYLLIUM	RMNP BM (L Louise)	LAKE	B							5.0	3.0	1.1	
BERYLLIUM	RMNP BM (L Hayaha)	LAKE	B							9.3	7.4	1.3	
BERYLLIUM	RMNP BM (The Loch)	LAKE	B							7.4	1.3	0.5	
BERYLLIUM	LOWRY	CREEK	B						2.1	1.0	0.5		

BGCR = Background Geochemical Characterization Report (DOE 1993a)
 CC BM = Cherry Creek Reservoir Surface Sediment (n=1) (CCBA 1994)
 RMNP BM = Rocky Mountain National Park Lakes Surface Sediment Data (Heit, et al 1984)
 LOWRY = Lowry Landfill Site Background Data (Stream Sediment) (EPA 1992)

B = Background
 S = Site

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Table 8-3 Arsenic Concentrations in Surface Sediments			
IHSS	Stream Sediments	Nearshore Sediments	Middle of Reservoir Sediments
	Minimum - Maximum (mg/kg)	Minimum - Maximum (mg/kg)	Minimum - Maximum (mg/kg)
200	4.5 to 4.6	2.8 to 9.4	3.6 to 9.4
201	2.2 to 5.4	1.2 to 8.7	5.7 to 17.7
202	3.0 to 5.1	2.2 to 6.8	2.7 to 10.4

Table 8-4 Arsenic Concentrations Subsurface Sediments (Cores)			
IHSS	Minimum (mg/kg)	Mean (mg/kg)	Maximum (mg/kg)
200	3.6	6.5	10.4 at 2 to 4 in
201	5.7	12.3	36.2 at 20-22 in
202	2.6	4.7	8.9 at 0 to 2 in

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APPENDIX A PROBABILITY PLOT ANALYSIS

A probability plot analysis was performed on selected chemicals in surface sediments and surface water to assess whether a chemical concentration/activity data set (i.e., population) represents either a background (natural or anthropogenic in the case of global fallout of radionuclides) or contaminated population. A contaminated population may indicate the chemical is a chemical of concern (COC). This analysis was performed using a statistical software program called PROBLOT. PROBLOT was used to define the number of populations present and the concentration/activity range for each population. A description of the results and methods of the probability plot analysis are presented in this appendix.

The analysis indicated the presence of one statistically normal population for each of the metals and radionuclides in each of the IHSS with the exception of aluminum, chromium, manganese, and ^{239/240}Pu in Mower Reservoir (IHSS 202) and chromium in Great Western Reservoir (IHSS 200) (Table G-1). In these cases where two populations were identified, the concentration/activity variations represent subpopulations within the population and are attributed to geochemical (complexation, adsorption, dissolution, precipitation), organic (aquatic organisms, plants, and detritus), and physical processes (transport and deposition) that collectively cause natural variability. The final decision whether a chemical is a COC will be made after reviewing the other weight-of-evidence evaluation results.

A more detailed description of the results and methods employed in the evaluation is included in this appendix, which is divided into the following sections:

- PROBLOT Procedure (Section A 2)
- Data Input (Section A 3)
- Data Interpretation for Sediments (Section A 4)
- Data Interpretation for Surface Water (Section A 5)
- PROBLOT Output (Section A 6)
- References

A 2 PROBLOT PROCEDURE

PROBLOT is an interactive software tool (Stanley, 1987) that allows a user to statistically evaluate cumulative frequency distributions for a given data set. The PROBLOT analysis determines the number of populations and statistical boundaries present. The software program was used to

Table A-1

**RESULTS OF PROBABILITY PLOT ANALYSIS
NUMBER OF DATA POPULATIONS**

Chemical	Surface Sediments IHSS			Surface Water
	200	201	202	IHSSs Combined
Aluminum	1	1	2 ^N	--
Arsenic	1	1	1	1
Beryllium	1	1	1	--
Cadmium	1	1	1	--
Chromium	2 ^N	1	2 ^N	--
Cobalt	1	1	1	--
Iron	1	1	1	1
Lead	1	1	1	1
Lithium	1	1	1	--
Manganese	1	1	2 ^N	1
Mercury	1	1	1	--
Nickel	1	1	1	--
Silicon	1	1	1	1
Zinc	1	1	1	--
^{238/240} Pu	1	1	2 ^N	--
^{233/234} U	1	1	1	--
²³⁴ U	1	1	1	--

Notes

- = Analysis not performed

One population may indicate chemical is not a COC Population represents background conditions

Two or more populations may indicate chemical is a COC

N = Second population is attributed to natural background processes

Chemical does not appear to be a COC

evaluate the concentration/activity distributions of specific metals and radionuclides contained in sediment and surface water samples at OU 3. The distribution information was used to define the number of populations present and the concentration range for each population and each metal/radionuclide data set. PROBPLOT has been used at the Operating Industries, Inc. (OII) Superfund site (EPA, 1994), the Lawrence Livermore National Laboratory (DOE, 1994), and has been used extensively by the mining industry for over 20 years to identify geochemical anomalies for exploration (Sinclair, 1986, Sinclair, 1976, Stanley, 1987).

The computer analysis in PROBPLOT compares the actual cumulative frequency distribution for given data sets with that of a normally distributed population. In a cumulative frequency distribution, the concentration frequencies of a distribution are cumulated from low to high values. Cumulating from low to high produces a "less than" distribution where each cumulative frequency includes all concentrations/activities that are less than a given value. The model is flexible, it is capable of representing numerous forms of frequency distributions consisting of combinations of normal or lognormal component populations.

PROBPLOT generates a probability plot that presents the distribution for each population identified within a data set. The mean plus two standard deviations (i.e., threshold) value is also summarized for each population.

A 3 DATA INPUT

Metal and radionuclide concentrations/activities from the surface-sediment and surface-water samples collected from Great Western Reservoir (IHSS 200), Standley Lake (IHSS 201), and Mower Reservoir (IHSS 202) for the RFI/RI for OU 3 were analyzed using PROBPLOT. Surface-sediment samples, collected in each reservoir and in the adjoining creeks for each of the IHSSs, were used in the PROBPLOT analyses. Only concentration data reported above the detection limit (i.e., detects) were used in the PROBPLOT analysis. The concentration/activity data were logtransformed before being input into PROBPLOT because natural environments are typically lognormally distributed (Rose, 1979). If multiple samples were collected at a given location, the data values for the additional samples were averaged prior to analysis. However, for Mower Reservoir, if a given location was sampled more than once, the samples were treated as individual samples and not averaged. This was done in order to have a sufficient number of data points for the PROBPLOT analysis. (A minimum of 15 points is required by the PROBPLOT program to define populations [Stanley, 1987].) The following metals and radionuclides for sediments at each IHSS were evaluated:

- Aluminum
- Arsenic
- Beryllium
- Cadmium
- Chromium
- Cobalt
- Iron
- Lead
- Lithium
- Manganese
- Mercury
- Nickel
- Silicon
- Zinc
- $^{233/234}\text{U}$
- ^{235}U
- $^{239/240}\text{Pu}$

A probability plot for every metal is not included in this appendix. A subset was selected based on their potential toxicity. Additional metals were selected to provide information on the potential geochemical association with other metals or processes. For example, cobalt and nickel are similar in chemical behavior. Therefore, information on each of these metals can be used to confirm the conclusions made.

Surface-water samples were collected in the streams upgradient to RFP to establish background levels. The background data sets were collected from areas considered unimpacted by RFP activities and are described in the Background Geochemical Characterization Report (DOE, 1993). If more than one sample was collected at a given location for either the background or the OU 3 data, each value was used as part of the data set. No averaging of the data was performed. Only detected data were used in the analysis. Surface-water data collected (creek and reservoir data) for the three IHSSs (Great Western Reservoir-200, Standley Lake-201, and Mower Reservoir-202) were combined with background data to determine if more than one population was present. The background and OU 3 surface-water data were combined to have a sufficient number of samples (i.e., 15 or greater) because some of the metals had low detection frequencies. Probability plots were generated for arsenic, lead, manganese, iron, and silicon. These metals were selected based on their toxicity factors and potential association with other metals and geochemical processes.

A 4 DATA INTERPRETATION FOR SEDIMENTS

This section presents the interpretation of the probability plots for the surface-sediment data. Based on the PROBLOT analysis, the chemicals in the OU 3 surface sediment exhibit low concentrations/activities of naturally occurring metals and radionuclides and appear to represent a single, background population (see Table G-1). This subsection provides an example of a chemical exhibiting a population that appears to represent contamination, brief descriptions of the processes

that cause variability within a natural background population, and the results for each metal/radionuclide evaluated

For OU 3 sediments, the metal/radionuclide analytical results for samples from each of the three reservoirs were evaluated separately. However, the creek sediment data associated with each reservoir were included with reservoir sediments in the data sets. This was done in order to evaluate the complete physical system of the reservoir.

Geochemical evaluations (of all the metals/radionuclides in total), the low concentrations present, geologic setting, and available background and benchmark data indicate the population identified in PROBLOT represents a statistically normal background population.

Where more than one population is identified in PROBLOT, the two populations can either represent background and contamination (depending on the magnitude of differences for each population) or represent natural physical processes within the background population that result in a concentration/activity slightly elevated above the upper limit background concentration/activity.

To illustrate a scenario where a probability plot shows two populations that represent one background population and one contamination population, the OU 3 $^{239/240}\text{Pu}$ data from surface-soil samples were evaluated. Based on the Gilbert statistical analysis (see Subsection 4.3), some of the soil sample activity values were above background, however, most were below background. Therefore, the OU 3 soil sample results represent two populations (one background and one with elevated $^{239/240}\text{Pu}$ activities). The data set used for the PROBLOT analysis included the OU 3 RFI/RI soil plots plus the Jefferson County Remedy Acres samples.

The histogram and probability plot for the soil data clearly show two separate populations (see Figures G-1 and G-2a). The statistically defined threshold level (defined as the mean plus two standard deviations) is the activity at which background is exceeded in the cumulative frequency distribution and is 0.07 pCi/g for this data set. This value compares favorably with the background mean plus two standard deviations of 0.09 pCi/g that was calculated using the surface-soil background data.

In reviewing the soil probability plot (Figure G-2a), it is important to note that the two population distributions *diverge* with increasing plutonium activities rather than *converge*. In the OU 3 sediment data sets where two populations are identified (for example, aluminum for IHSS 202), the populations *converge* at higher concentrations/activities (Figure G-2b). The convergence of the upper and lower populations indicates that, unlike the diverging populations, these represent two

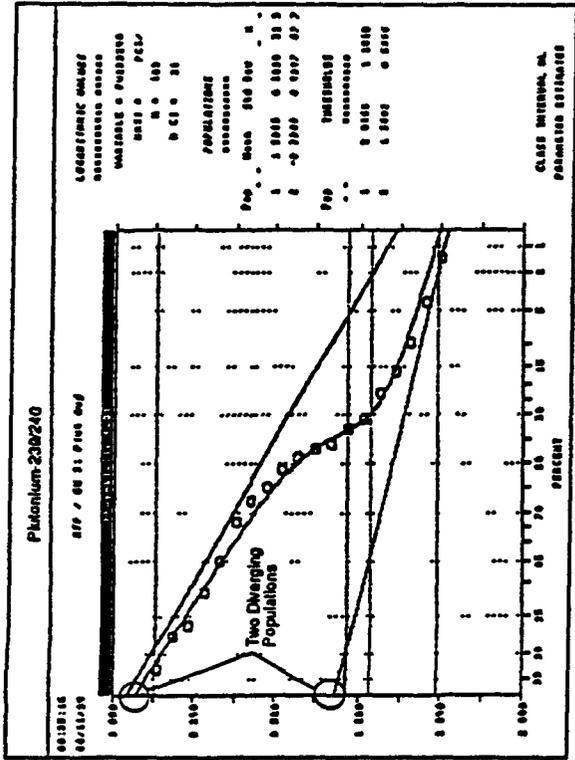


Figure A-2a
 TWO DIVERGING POPULATIONS
 PLUTONIUM IN SURFACE SOIL
 IHSS 199

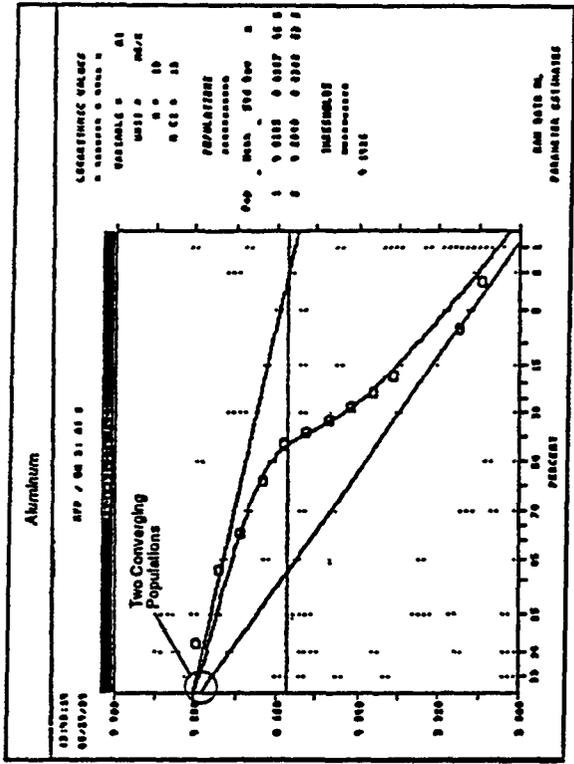


Figure A-2b
 TWO CONVERGING POPULATIONS
 ALUMINUM IN SURFACE SEDIMENTS
 MOWER RESERVOIR (IHSS 202)

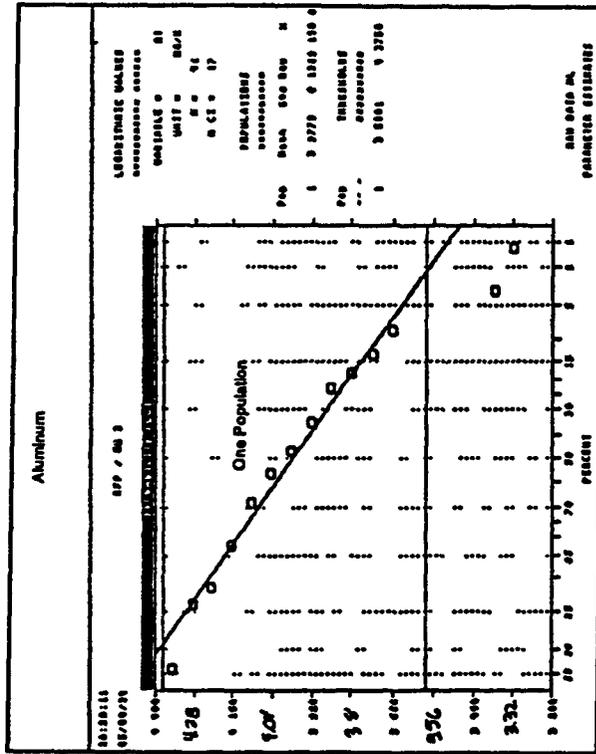


Figure A-2c
 ONE POPULATION
 ALUMINUM IN SURFACE SEDIMENTS
 GREAT WESTERN RESERVOIR (IHSS 200)

subpopulations of a single (background) population. The upper subpopulation represents a concentration/activity range of values resulting from precipitation or adsorption of the individual metal/radionuclide. As a comparison, aluminum in Great Western Reservoir (IHSS 202) represents a single, background population (Figure G-2c).

In the sediment PROBLOT results, most of the plots for a given metal/radionuclide show all the data for an IHSS to be below the threshold value (clearly indicating one population). In the cases where more than one population is identified, the threshold values for the two populations are similar (indicating the second population is due to natural processes and not contamination).

The overall OU 3 data sets exhibit a range of concentrations/activities within expected natural ranges for sediment data, as seen in the benchmark comparison described in previous sections of TM 4. The logarithmic values for the metals and the radionuclides evaluated range from approximately -0.4 to almost 5, yet the logarithmic values of the standard deviations range from only 0.1 to 0.4 with an average of approximately 0.25. In other words, there is little variation from the mean concentrations/activities, regardless of the value of the mean metal or radionuclide concentration/activity for the OU 3 sediments. If concentration levels were the result of contamination, there would be higher standard deviations for the contaminating constituents (Rose et al., 1979). These small, similar standard deviations suggest that the sediments probably represent background conditions and are within naturally expected variability.

A 4.1 Reasons for Naturally Occurring Variability

Several physiochemical processes cause variability in sediments in nature, depending on geologic setting. The predominant processes causing variability within OU 3 sediments are described in the following paragraphs.

Geochemical Processes

The sediment grab samples were collected from both the streams draining into the reservoir and the reservoir itself. Within the reservoir, sediment samples were collected from both peripheral (inlets, shoreline, and adjacent to the dam) and central parts of the reservoir. Each of the individual sediment sample locations represent unique local environments with differing microbiota, physicochemical conditions, water depth, and flow regimes. Each environment results in spatially variable concentrations of metals and/or radionuclides. For example, streams have significantly higher flow velocities than reservoirs, this generally results in coarser-grained sediment, oxygenated water (i.e., oxidizing oxidation-reduction (Eh) conditions), near-neutral pH, and a highly variable

aerobic microbiotic and aquatic population (Rose et al , 1979) Coarse-grained sediments typically have lower metal concentrations in comparison to finer-grained sediments because of the lower surface area for a given volume of sediment, this results in a lower number of sorption sites (Davis and Kent, 1990) Oxidizing conditions with near-neutral pH minimizes the dissolved metals concentrations because metals are least soluble in these environmental conditions (Rose et al , 1979) Compared to the reservoir sediments, the stream sediments have a very low total organic carbon (TOC) and nutrient load, thus, less chemical reactions with organics occur As a result, lower metal concentrations are expected

Physical Processes

Shoreline peripheral sediments primarily reflect the local land use, soils, and bedrock composition The sediment composition can be highly variable because of surface-water runoff, such as irrigation return flow, industrial outfalls, return rills, and sheetflow into the reservoir Reservoir sediments in the nearshore area (littoral) are generally finer-grained than stream sediments, but much coarser than either the central reservoir or in the area adjacent to the dam

The central area of the reservoir and the area adjacent to the dam receive the finest-grained material As a stream enters a reservoir, a deltaic environment at the inlet of the reservoir is created wherein the coarser-grained sediments settle near the inlet as the flow velocity decreases Finer-grained sediments are transported farther into the reservoir The finer-grained sediments are a mixture of clay minerals, natural organic acids (humic and fulvic), and iron, manganese, and aluminum oxyhydroxide flocculants (Davis and Kent, 1990) Both the organic acids and the oxyhydroxide flocculants contain variable concentrations of complexed and adsorbed metals (Rose et al , 1979) Generally, only the finest-grained material reaches the reservoir area nearest the dam (the deepest portion of the reservoir)

Organic Processes

In addition, algal growth in the reservoir can change the pH (and to an extent, the Eh) of the reservoir water on not only a seasonal, but also a diurnal, cycle The pH of reservoir water can change from a near-neutral pH of 7 during darker hours to a more alkaline pH of 8.5 to 9 during the daylight hours (Hem, 1985) This cycle can cause a change in dissolved (at near-neutral pH) versus precipitated (more alkaline pH) metal concentrations Carbonate minerals (calcium, iron, and, potentially, magnesium and manganese) can be precipitated and become part of the sediments on both diurnal and seasonal cycles, thus causing temporal variations in concentrations (Hem, 1985)

Variability in concentrations/activity can also be caused by how the sample is collected and what materials compose the sample. For example, the more organic-enriched and fine-grained materials in the sample, the greater the concentration of metals (Rose et al , 1979)

As the above discussion illustrates, the variability in stream and reservoir sediment environmental conditions (i.e., sample locations) can result in a concentration/activity range of values within a statistically normal background population, that is, these processes cause natural variability within a population without any contribution from a potential contaminant. When statistically evaluated using cumulative frequency distributions, one population or several subpopulations that are a result of these physiochemical processes may be identified. Two populations may also be identified with one population representing background and one population representing contamination, as seen in the soil plot example in Figures G-1 and G-2. As described in the following paragraphs, most of the metals and radionuclides are defined by a single (low concentration range, similar to benchmark ranges) population that defines background concentration/activity ranges. Each reservoir also has environmental characteristics that cause some differences in concentration and characteristics. These result from natural variation attributable to the physiochemical factors described above.

The PROBLOT results for each metal and radionuclide that was evaluated are discussed in the following paragraphs. PROBLOT output for each metal and radionuclide for each IHSS is included in Subsection A.6

A.4.2 Aluminum

Aluminum is the third most abundant element in the earth's crust (Hem, 1985). Based on the probability plots, one population was identified for Great Western Reservoir and one for Standley Lake. In Mower Reservoir, two populations were identified. The two populations in Mower Reservoir are most likely the result of organic processes occurring in the reservoir and represent subpopulations within a background population, as described in the following paragraphs.

Mower Reservoir sediments have the highest mean and median concentrations (13,300 and 14,600 mg/kg, respectively) but the lowest maximum concentration (18,300 mg/kg) of the three reservoirs. The small range of aluminum concentrations (less than an order of magnitude) between the mean, median, and maximum values indicates physiochemical processes are occurring in Mower Reservoir, thus causing two subpopulations. If contamination were present, a larger difference in the mean, median, and maximum would be expected. This small range in aluminum concentrations and similarity in threshold values for each population is shown on the probability plot by the subpopulations converging at higher concentrations.

In Mower Reservoir, pH fluctuations and algal growth have been observed. The higher pH generated by algae in Mower Reservoir results in clay minerals precipitating out of solution more readily than in the other two reservoirs. Therefore, algal activity increases aluminum concentrations. The kinetics of clay-mineral precipitation increase with pHs above 8 (Stumm, 1990). The clay precipitation also enhances the potential for coprecipitation of metals (calcium, magnesium, sodium, iron, and lithium) into the Mower Reservoir sediments (Deer et al., 1971).

Based on the varying pH in Mower Reservoir, the similarity of the two populations within Mower Reservoir, and the similarity of Great Western Reservoir and Standley Lake, it is most probable that the aluminum in Mower Reservoir sediments represents natural variability within background (two subpopulations within background), and is not representative of a contamination source.

A 4 3 Arsenic

One population was identified for arsenic in each of the three reservoirs, with little difference in arsenic concentrations in Great Western Reservoir and Mower Reservoir, their respective means were 4.7 and 4.8 mg/kg and their respective maximums were 9.4 and 10 mg/kg. Standley Lake has essentially the same mean (5.0 mg/kg) but almost twice the maximum concentration (19 mg/kg) compared to Great Western Reservoir and Mower Reservoir. However, Standley Lake also receives sediments from the highly mineralized Clear Creek drainage, which may account for the higher maximum concentration. The similar mean concentrations of arsenic for the three reservoirs, coupled with the single population defined by the PROBLOT analysis for all three reservoirs, indicates a common background population.

A 4 4 Beryllium

Beryllium in sediments shows no difference in mean (0.78, 0.59, and 0.95 mg/kg for IHSSs 200, 201, and 202, respectively), standard deviation (1.45, 1.84, and 1.47 mg/kg for IHSSs 200, 201, and 202, respectively), and median (0.83, 0.6, 1.1 mg/kg for IHSSs 200, 201, and 202, respectively) concentrations between the three reservoirs. The probability plots for each reservoir also indicate only one population. Because only one population was identified and the concentrations are low (less than 2.1 mg/kg and similar to benchmark data), the beryllium concentrations in sediment represent a background population.

A 4 5 Cadmium

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In Great Western Reservoir and Standley Lake, only one population was identified for cadmium, based on the probability analysis. PROBPLOT was not performed for Mower Reservoir because cadmium was not detected in any of the samples. The PROBPLOT results also show all the data for a given IHSS were below the threshold value defined from the cumulative frequency distribution. Cadmium occurs naturally in the surrounding mineralized areas (Sheridan et al, 1967)

A 4 6 Chromium

The PROBPLOT analysis indicates two subpopulations of chromium were identified for Mower Reservoir and Great Western Reservoir but only one population for Standley Lake. In February 1989, a waste chromic acid spill occurred at the RFP. An estimated 750 gallons of chromic acid were discharged into a drain system that flowed to the plant's sewage treatment plant. The chromic acid went through the treatment plant and was discharged to retention pond B-3 (CDPHE, 1994). According to the Phase 1 Health Studies on RFP, "No documentation of off-site contamination was located for the event" (CDPHE, 1994). If releases did occur offsite, Great Western Reservoir would have been the receiving reservoir and its sediments should have the highest chromium concentrations. However, chromium was detected in the highest concentrations in Standley Lake (31.9 mg/kg), and Mower Reservoir (14 mg/kg) had the highest mean concentration. In Great Western Reservoir, the mean and maximum concentrations of chromium were 9.1 mg/kg and 17.9 mg/kg, respectively.

Two subpopulations representing background have been identified in Great Western Reservoir and Mower Reservoir. The two subpopulations (the lower and upper subpopulation distributions) have essentially the same 95th percentile chromium concentration (24.9 and 21.7 mg/kg, respectively, for Great Western Reservoir and 17.6 and 17.6 mg/kg, respectively, for Mower Reservoir). Furthermore, the higher concentration population for each has a lower slope than the lower population (the population distributions converge at the 95-percentile concentration). The upper subpopulation is likely caused by physiochemical processes such as adsorption or precipitation, organic absorption, or algal or microbial bioaccumulation.

The high algal content in Mower Reservoir suggests that organic complexing and absorption, coupled with pH and Eh conditions imposed by the organics, are probably responsible for the two chromium subpopulations. Chromium has a tendency to be cycled by the diurnally changing pH and Eh conditions imposed by the algal organisms. This cycle can cause a change in dissolved versus precipitated metal concentrations.

The micas derived from the pegmatites in the adjacent drainages are the most likely source of chromium-rich micas (Deer et al , 1971)

A comparison of the three reservoir means and medians and probability plots indicates that each reservoir is a normal background population

A 4 7 Cobalt

Based on the probability plots, one population was identified for each of the three reservoirs Cobalt concentrations in sediments are essentially the same as the nickel concentrations divided by a value of approximately 2 in all three sediment areas This close association between cobalt and nickel is common in sediments, regardless of source, because of the similarity in the chemical behavior of the two metals (Deer et al , 1971) This relationship in all three reservoirs indicates that the population represents a background population

A 4 8 Iron

One population was identified in each reservoir for iron, based on the PROBPLOT analysis Iron has the second highest metal concentration range in the sediments Relatively high iron concentrations are typical for sediments from lacustrine environments because the reservoirs collect the iron oxyhydroxide precipitates, and the lacustrine organisms, particularly algae, utilize iron in their metabolic processes This promotes and retains iron concentrations in the reservoir (Davis and Kent, 1990) There is a seasonal die-off of aquatic organisms, which incorporates a major part of the retained iron into the sediments The means (16,400, 13,120, and 18,600 mg/kg for IHSSs 200, 201, and 202, respectively) and medians (16,400, 14,150, and 18,300 mg/kg for IHSSs 200, 201, and 202, respectively) for the three reservoirs are similar

A 4 9 Lead

In each of the three reservoirs, only one population was identified for lead, based on the PROBPLOT analysis The similarity of the means and medians for the three reservoirs indicates that the background mean and median for lead is between 20 and 30 mg/kg, a narrow range considering the diverse source areas for the three reservoirs

The maximum concentration of lead occurs in Standley Lake The Standley Lake maximum is approximately twice the maximum concentration for Great Western Reservoir and six times the maximum in Mower Reservoir Although Mower Reservoir receives 100 percent of its water from

the RFP drainage, Mower Reservoir sediments have approximately half the lead concentration of Great Western Reservoir sediments and only 20 percent of the Standley Lake maximum sediment concentration. The likely source area for the lead in Standley Lake sediments is from the mining wastes being transported in Clear Creek. Only one sample (SED012792) from the 41 Great Western Reservoir samples exceeds the 95th percentile concentration (70 mg/kg) of the PROBLOT-defined background population with a concentration of 80.3 mg/kg. This sample is located in the deepest portion of the reservoir. As described previously, the fine-grained sediments are transported to the deepest portion of the reservoir, this is probably why the concentration is higher. Contamination is not indicated because metals adsorb more readily to the finer-grained material (Davis and Kent, 1990, and Pankow, 1991).

A 4 10 Lithium

Based on probability plots, there is one population for lithium in all three reservoirs. Mean and median concentrations are highest in Mower, intermediate in Great Western, and lowest in Standley Lake. In all three, the median is higher than the mean lithium concentration, this indicates a dominance of lower lithium concentrations in all three populations. Similar to other metals, the maximum lithium concentration is highest in Standley Lake sediments. The maximum concentrations of lithium for Standley Lake, Great Western Reservoir, and Mower Reservoir are 34.6, 17.6 and 16.2 mg/kg, respectively. Lithium is a common constituent in micas, which are released by acid attack (mine waste areas) and, to a much lesser extent, natural weathering processes, ultimately, they are incorporated in the clay minerals (Deer et al., 1971). The maximum concentration occurring in Standley Lake is likely due to the contribution from the highly mineralized sediments from Clear Creek.

A 4 11 Manganese

One population for manganese was identified in Great Western Reservoir and Standley Lake from PROBLOT for manganese. In Mower Reservoir, two similar populations were identified. The mean and medians for Great Western Reservoir (378.6 and 441.4 mg/kg, respectively) and Standley Lake (449.7 and 350.8 mg/kg, respectively) sediments are similar, but the maximum manganese concentration in Standley Lake (4450.4 mg/kg) sediments is three times higher than the maximum concentration in Great Western Reservoir (1549.9 mg/kg). This probably reflects the contribution from the highly mineralized Clear Creek sediments to Standley Lake. The mean, median, and maximum concentrations of manganese (294, 250.8, and 1170 mg/kg, respectively) are the lowest in Mower Reservoir.

The two subpopulation distributions in Mower Reservoir converge near the upper threshold concentration. The two subpopulations are likely due to fluctuations in pH within the reservoir. Of the three reservoirs, Mower Reservoir is the most strongly influenced by algal growth, which causes a diurnal (and seasonal) increase in pH to values above 9. Manganese precipitates much more rapidly with increasing pH, precipitating in minutes to hours at pH values higher than 8 (Stumm, 1990, and Pankow, 1991). This process increases the amount of oxidized manganese deposited in the reservoir sediments and causes variability in concentrations, depending on when the sampling occurred. In the other two reservoirs, manganese is also oxidized and precipitated, but the algal population is not sufficient to enhance the precipitation process. The two populations in Mower Reservoir are likely due to physical processes. The two subpopulations are similar to Standley Lake and Great Western Reservoir.

A 4 12 Mercury

Probability plots were only developed for Standley Lake. There was an insufficient number of detects to perform a PROBPLOT analysis for Great Western Reservoir and Mower Reservoir. One population was observed in Standley Lake based on the probability plot. The maximum mercury concentration in Standley Lake sediment is only 0.6 mg/kg. Considering the potential strong complexing characteristics (organics, microbiota, and chloride) of mercury and the placering (historical use of elemental mercury to recover gold) that has taken place along Clear Creek, these sediment concentrations of mercury are low.

A 4 13 Nickel

Based on the probability plots, one population for nickel was identified for each of the three reservoirs. The mean and median nickel concentrations in both Great Western Reservoir and Mower Reservoir are essentially the same values (16 to 17.5 mg/kg) and higher than Standley Lake sediment mean and median. The nickel is slightly higher in Mower Reservoir than in Great Western Reservoir, this difference may be due to the presence of aquatic microbiota.

Only one of the 41 Great Western sediment samples (SED00692) exceeds the 95th percentile concentration from PROBPLOT, the sample is located along Broomfield Ditch. This is the same location that has the highest concentrations for cobalt, manganese, and one of the highest concentrations for iron. This is the result of iron/manganese oxyhydroxide adsorption, which elevates the nickel and cobalt concentrations through the adsorption process (Davis and Kent, 1990, Pankow, 1991). This enhancement is most likely a natural phenomenon rather than an anthropogenic impact.

A 4 14 Silicon (Silica)

In Great Western Reservoir and Standley Lake, one population for silicon was identified, based on probability plots. In Mower Reservoir, only one sample was analyzed for silicon, so no PROBPLOT analysis was performed. The laboratory reports silica (SiO_2) in terms of Silicon, Si. Considering the abundance of silica in quartz and other minerals contained in sediments, the silica concentration is surprisingly low. The maximum concentrations of silica are less than 1 percent (10,000 mg/kg) compared to an average crustal abundance of approximately 28 percent (280,000 mg/kg) (Taylor, 1964). Standley Lake sediments have higher silica concentrations than Great Western, which probably reflects the higher quartz relative to mica in Standley Lake sediments. Quartz is readily available in the placer and mine waste areas of the Clear Creek drainage.

A 4 15 Zinc

One population for zinc was identified in each reservoir based on PROBPLOT. Zinc is one of the most mobile metals. The zinc mean, median, and maximum concentrations are all highest in Standley Lake (181.9, 184.4, and 1170 mg/kg, respectively) sediments, intermediate in Great Western Reservoir (137.8, 120.5, and 496 mg/kg, respectively), and lowest in Mower Reservoir (69.5, 68.6, and 193 mg/kg, respectively) sediments. These relationships support and enforce the relative importance of historic and current mining waste and discharge sources in the Clear Creek drainage to the site-specific background of Standley Lake sediments.

A 4 16 $^{239/240}\text{Pu}$

One population for $^{239/240}\text{Pu}$ was identified for Standley Lake and Great Western Reservoir. Two subpopulations were identified in Mower Reservoir. All activities in both Mower Reservoir and Standley Lake sediments are less than 1 pCi/g. Median activities and 95th percentile activity values from PROBPLOT indicate that Standley Lake sediments have the lowest activity, Mower Reservoir has intermediate activities, and Great Western Reservoir has the highest activities in sediments. In fact, three Great Western sediment samples (GWR-EG 46, 47, and 48) have the only activities that exceed 1 pCi/g across all three sediment reservoirs (3.1, 3.2, and 3.3 pCi/g, respectively). These three samples were collected in 1983 investigations. Given the two subpopulations in Mower Reservoir are similar to the values to the single populations in the other two IHSSs, it appears the activities represent background conditions. Further, the two subpopulations are converging, which indicates natural processes affecting one natural-background population.

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A 4 17 ^{233/234}U

Based on PROBPLOT, ^{233/234}U is remarkably consistent in all three reservoirs and shows only one population. The median activities for all three reservoirs are similar, ranging from 1.20 to 1.24 pCi/g. The 95th percentile activity values for Great Western and Mower are similar (2.79 and 2.61 pCi/g, respectively) but lower than Standley Lake sediment (3.71 pCi/g). The highest activity is in Great Western Reservoir (SED06692).

A 4 18 ²³⁵U

Based on the PROBPLOT analysis, one population for ²³⁵U was identified in each of the reservoirs. With the exception of a single exceedance from a sample in Great Western Reservoir (SED06692), described in the ^{233/234}U discussion, the ²³⁵U activities are a background population. This single population is indicated by means, medians, and PROBPLOT 95th percentile activities. The suite of radioactivity present at SED06692 is likely due to natural uranium mineralization and not anthropogenic contamination.

A 4 19 Summary for Sediments

Most of the metals and radionuclides reviewed indicate the presence of only one population in a given reservoir. Where two subpopulations were identified, a review of the natural physical processes and associated physicochemical conditions indicates that the differences are due to natural environmental variability and not to contamination. As shown in Figure G-2, these chemicals exhibit two converging populations, unlike the diverging populations of the ^{239/240}Pu surface soil data.

REFERENCES

CDPHE, 1994 Colorado Department of Public Health and Environment Health Studies on Rocky Flats Phase I Historical Public Exposures Project Task 5 Report Estimating Historical Emission from Rocky Flats 1952-1989 March 1994

Davis and Kent, 1990 J A Davis and D B Kent Surface Complexation Modeling in Aqueous Geochemistry In Mineral-Water Interface Geochemistry M F Hochella, Jr , and A F White, eds Mineralogical Society of America, *Reviews in Mineralogy*, Volume 23, pp 177-260

Deer et al , 1971 W A Deer, R A Howie, and V Zussman Rock Forming Minerals Volume 3- Sheet Silicates London Longman, W Clowes and Sons Limited

DOE, 1994 United States Department of Energy Lawrence Livermore National Laboratory Site 300 Remedial Investigation Report 1994

DOE, 1993 United States Department of Energy Background Geochemical Characterization Report September 30, 1993

EPA, 1994 United States Environmental Protection Agency Preliminary Draft Operating Industries, Inc Landfill Superfund Site Monterey Park, California May 1994

Fletcher, 1986 W K Fletcher Analysis of Soil Samples In Exploration Geochemistry Design and Interpretation of Soil Surveys Society of Economic Geologists, El Paso TX, pp 79-96

Hem, 1985 John D Hem Study and Interpretation of the Chemical Characteristics of Natural Water U S Geological Survey Water Supply Paper No 2254

Pankow, 1991 J F Pankow Aquatic Chemistry Concepts Chelsea, Michigan Lewis Publishers

Rose et al , 1979 A W Rose, H E Hawkins, and J S Webb Geochemistry in Mineral Exploration Second Edition New York Academic Press

Schwoerbel, 1987 J Schwoerbel Handbook of Limnology New York John Wiley & Sons

Sheridan et al , 1967 D M Sheridan, C H Maxwell, and A L Albee Geology and Uranium Deposits of the Ralston Buttes District Jefferson County, Colorado Geological Survey Professional Paper 520

Sinclair, 1986 A J Sinclair Statistical Interpretation of Soil Geochemical Data In Exploration Geochemistry Design and Interpretation of Soil Surveys Society of Economic Geologists, El Paso, TX, pp 97-116

Sinclair, 1976 A J Sinclair Applications of Probability Graphs in Mineral Exploration Association of Exploration Geochemists Special Volume No 4

Stanley, 1987 C R Stanley PROBPLOT An Interactive Computer Program to Fit Mixtures of Normal (or Lognormal) Distributions with Maximum Likelihood Optimization Procedures Association of Exploration Geochemists, Special Volume No 14

Stumm, 1990 Werner Stumm Aquatic Chemical Kinetics, Reaction Rates of Processes in Natural Waters New York John Wiley & Sons, Inc

Taylor, 1964 S R Taylor Abundance of Chemical Elements in the Continental Crust A New Table *Geochimica et Cosmochimica Acta*, Vol 28

ARSENIC

IHSS 200, Great Western Reservoir

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 SUMMARY STATISTICS and HISTOGRAM LOGARITHMIC VALUES

Variable = As Unit = MG/K N = 41

Mean = 0.6749 Min = 0.4150 1st Quartile = 0.5682
 Std. Dev. = 0.1208 Max = 0.9731 Median = 0.6628
 CV % = 17.8955 Skewness = 0.2745 3rd Quartile = 0.7442

Anti-Log Mean = 4.731 Anti-Log Std. Dev. : (-) 3.582
 (+) 6.247

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%	cum %	antilog	cls int	(# of bins = 17 - bin size = 0.0349,
0.00	1.19	2.498	0.3975	
2.44	3.57	2.707	0.4324	*
0.00	3.57	2.933	0.4673	
2.44	5.95	3.178	0.5022	*
4.88	10.71	3.444	0.5371	**
17.07	27.38	3.732	0.5720	*****
2.44	29.76	4.044	0.6068	*
7.32	36.90	4.383	0.6417	***
19.51	55.95	4.749	0.6766	*****
4.88	60.71	5.146	0.7115	**
12.20	72.62	5.577	0.7464	****
7.32	79.76	6.043	0.7813	***
7.32	86.90	6.549	0.8161	***
4.88	91.67	7.096	0.8510	**
2.44	94.05	7.690	0.8859	*
0.00	94.05	8.333	0.9208	
2.44	96.43	9.030	0.9557	*
2.44	98.81	9.785	0.9906	*

 0 1 2 3 4

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RFP / BU-3

LOGARITHMIC VALUES

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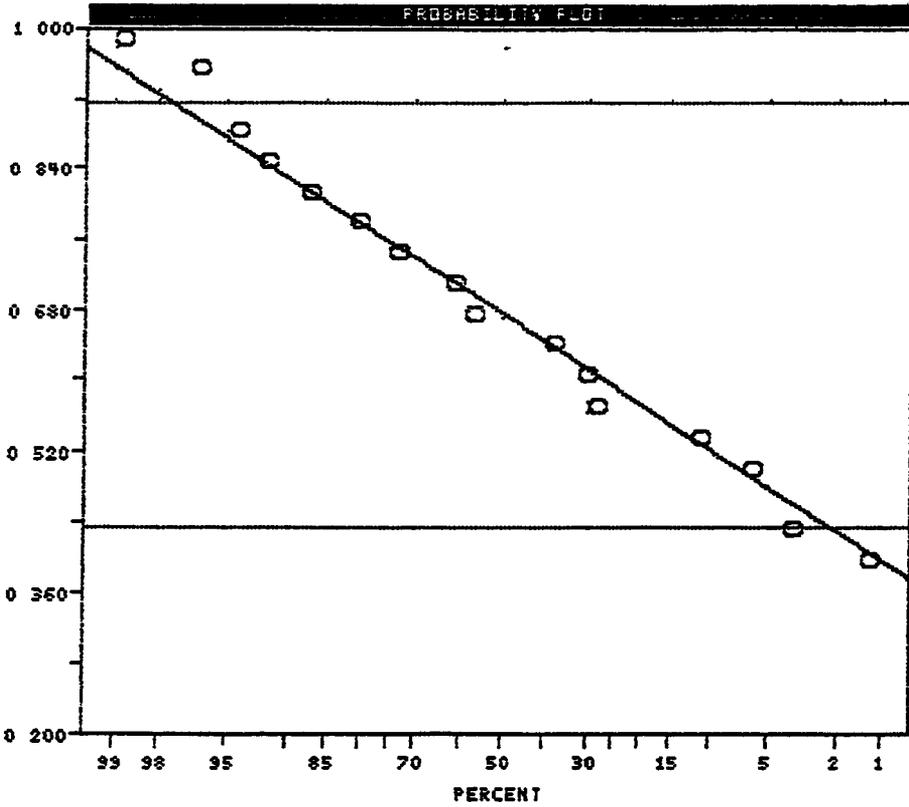
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UNIT = MG/K
N = 41
N CI = 17

POPULATIONS

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Pop	Mean	Std Dev	x
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Pop	THRESHOLDS	
1	0 4334	0 9165



RAW DATA HL
PARAMETER ESTIMATES

20:23:14

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PARAMETER SUMMARY STATISTICS FOR PROBABILITY PLOT ANALYSIS

Data File Name = AS-OD.DAT

Variable = As Unit = MG/K N = 41
N CI = 17

Transform = Logarithmic Number of Populations = 1

of Missing Observations = 0

=====

Raw Data Maximum Likelihood Parameter Estimates

Maximum LN Likelihood Value = 28.989

Parameterized Degrees of Freedom = 1

Population	Mean	Std Dev	Percentage
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74

25

15

10

4



ARSENIC

IHSS 201, Standley Lake

DEN1001645A DEN/5

80

15:08:02

FFF / QU-3

05/10/94

SUMMARY STATISTICS and HISTOGRAM LOGARITHMIC VALUES

Variable = As Unit = MG/k N = 47
Mean = 0.6962 Min = 0.0792 1st Quartile = 0.4191
Std. Dev. = 0.2963 Max = 1.2253 Median = 0.7201
CV % = 42.5597 Skewness = -0.3356 3rd Quartile = 0.9457
Anti-Log Mean = 4.968 Anti-Log Std. Dev. : (-) 2.511
(+) 9.828

%	cum %	antilog	cls int	(* of bins = 17 - bin size = 0.0716)
0.00	1.04	1.105	0.0434	
2.13	3.13	1.303	0.1150	*
4.26	7.29	1.537	0.1866	**
4.26	11.46	1.812	0.2583	**
4.26	15.63	2.137	0.3299	**
4.26	19.79	2.521	0.4015	**
6.38	26.04	2.973	0.4732	***
2.13	28.13	3.506	0.5448	*
4.26	32.29	4.135	0.6164	**
14.89	46.88	4.876	0.6881	*****
14.89	61.46	5.750	0.7597	*****
0.00	61.46	6.782	0.8313	
8.51	69.79	7.998	0.9030	****
10.64	80.21	9.432	0.9746	*****
4.26	84.37	11.123	1.0462	**
12.77	96.87	13.118	1.1179	*A*****
0.00	96.87	15.470	1.1893	
2.13	98.96	18.244	1.2611	*

0 1 2 3 4

#####

81

15 08 39
05/10/94

RFP / DU-3

LOGARITHMIC VALUES

=====

VARIABLE = As
UNIT = MG/K
N = 47
N CI = 17

POPULATIONS

=====

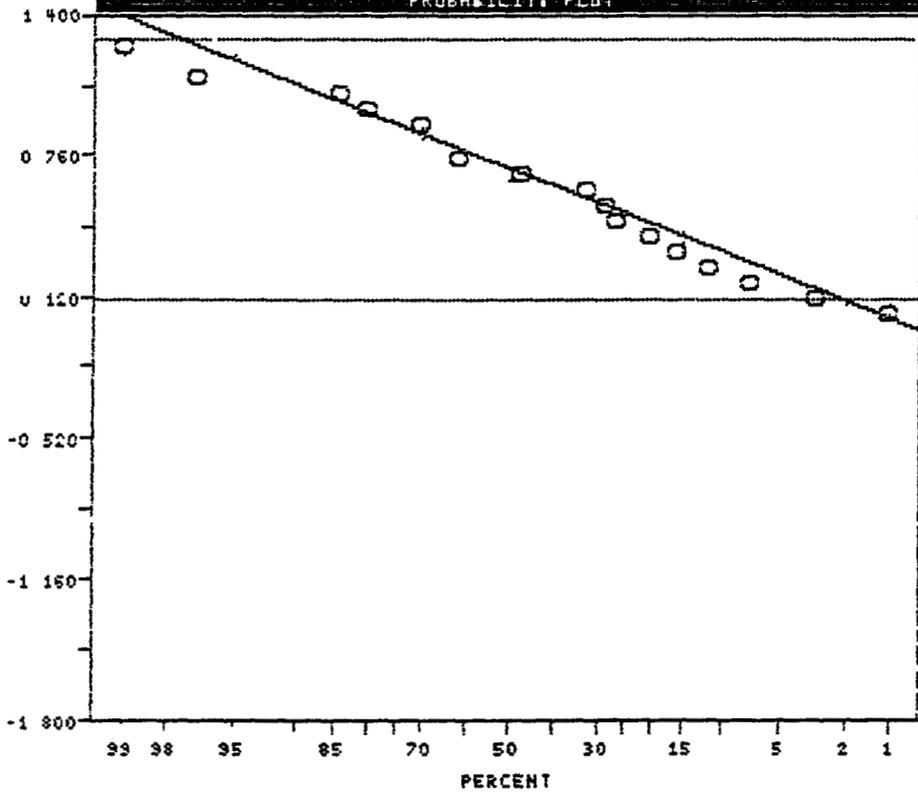
Pop	Mean	Std Dev	/
1	0.6962	0.2963	100.0

Pop	THRESHOLDS	
1	0.1036	1.2887

RAW DATA HL

PARAMETER ESTIMATES

PROBABILITY PLOT



82

15:11:37

RFF / OU-3

05/10/94

PARAMETER SUMMARY STATISTICS FOR PROBABILITY FLOT ANALYSIS

Data File Name = AS-ID DAT

Variable = As Unit = MG/K N = 47
N CI = 17

Transform = Logarithmic Number of Populations = 1

of Missing Observations = 0.

=====

Raw Data Maximum Likelihood Parameter Estimates

Maximum LN Likelihood Value = -9.018

Parameterized Degrees of Freedom = 1

Population	Mean	Std Dev	Percentage
1	4.968	- 2.511 + 9.828	100.00

ARSENIC
IHSS 202, Mower Reservoir

DEN1001645A.DEN/6

84

 SUMMARY STATISTICS and HISTOGRAM LOGARITHMIC VALUE

Variable =	As	Unit =	MG/K	N =	18
Mean =	0.6793	Min =	0.3424	1st Quartile =	0.5623
Std. Dev. =	0.1619	Ma =	1.0170	Median =	0.7076
CV % =	23.8314	Skewness =	-0.2023	3rd Quartile =	0.7443
Anti-Log Mean =	4.778	Anti-Log Std. Dev. :	(-)	3.292	
			(+)	6.937	

%	cum %	antilog	cls int	(# of bins = 13 - bin size = 0.0562)
0.00	2.63	2.062	0.3143	
5.56	7.89	2.347	0.3705	*
0.00	7.89	2.671	0.4267	
11.11	18.42	3.041	0.4830	**
0.00	18.42	3.461	0.5392	
11.11	28.95	3.939	0.5954	**
5.56	34.21	4.484	0.6516	*
22.22	55.26	5.103	0.7078	****
22.22	76.32	5.808	0.7641	****
5.56	81.58	6.611	0.8203	*
11.11	92.11	7.525	0.8765	**
0.00	92.11	8.565	0.9327	
0.00	92.11	9.748	0.9889	
5.56	97.37	11.095	1.0451	*

0 1 2 3

#####

85

11 11 52
05/03/94

RFP / BU-3 AS-5

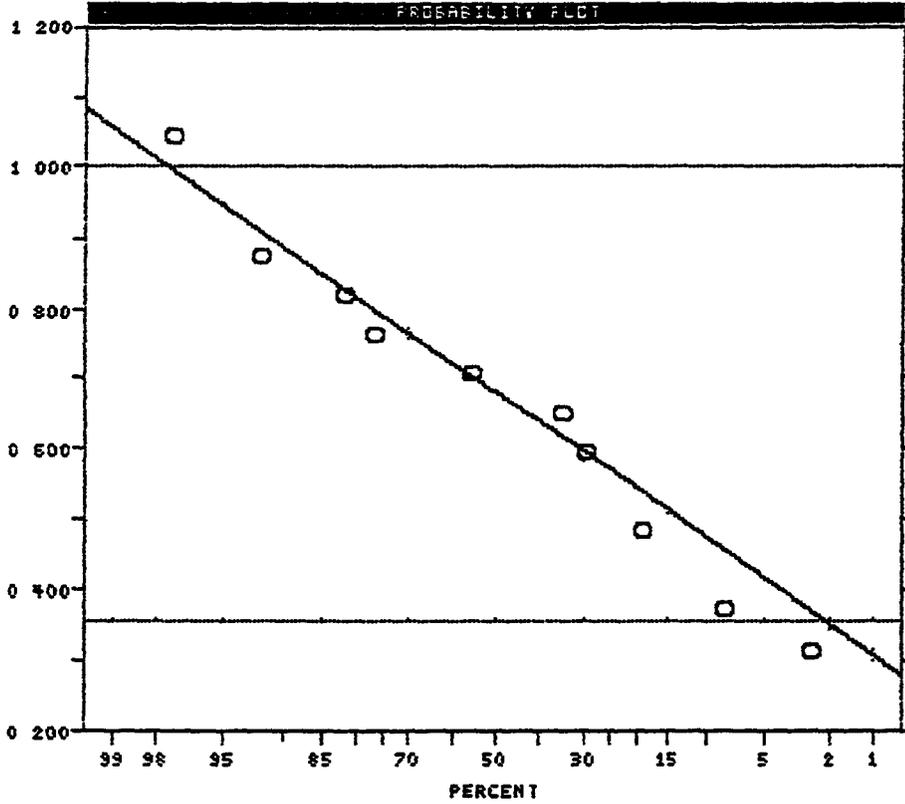
LOGARITHMIC VALUES

VARIABLE = AS
UNIT = MG/K
N = 16
N CI = 10

POPULATIONS

Pop	Mean	Std Dev	/
1	0.6793	0.1619	100.0

Pop	THRESHOLDS	
1	0.3555	1.0030



RAW DATA NL
PARAMETER ESTIMATES

#####

PARAMETER SUMMARY STATISTICS FOR PROBABILITY PLOT ANALYSIS

Data File Name = A:AS-S.DAT

Variable = As Unit = MG/K N = 18
N CI = 13

Transform = Logarithmic Number of Populations = 1

of Missing Observations = 0.

=====

Raw Data Maximum Likelihood Parameter Estimates

Maximum LN Likelihood Value = 7.735

Parameterized Degrees of Freedom = 1

<u>Population</u>	<u>Mean</u>	<u>Std Dev</u>	<u>Percentage</u>
1	4.778	- 3.292 + 6.937	100.00

=====

Default Thresholds.

Standard Deviation Multiplier = 2.0

<u>Pop.</u>	<u>Thresholds</u>
1	2.267 10.070

#####

BERYLLIUM
IHSS 200, Great Western Reservoir

DEN100164SA DEN/7

19:13:26

FFF / DU-3

05/08/94

 SUMMARY STATISTICS and HISTOGRAM LOGARITHMIC VALUES

Variable = Be Unit = MG/K N = 41

Mean = -0.1044 Min = -0.6198 1st Quartile = -0.1973
 Std Dev. = 0.1636 Max = 0.2041 Median = -0.0784
 CV % = 156.7277 Skewness = -0.8475 3rd Quartile = 0.0000

Anti-Log Mean = 0.786 Anti-Log Std. Dev. : (-) 0.540
 (+) 1.146

%	cum %	antilog	cls int	(# of bins = 17 - bin size = 0.0515)
0.00	1.19	0.226	-0.6455	
2.44	3.57	0.255	-0.5940	*
0.00	3.57	0.267	-0.5425	
0.00	3.57	0.323	-0.4911	
0.00	3.57	0.363	-0.4396	
2.44	5.95	0.409	-0.3881	*
7.32	13.10	0.461	-0.3366	***
2.44	15.48	0.519	-0.2851	*
4.88	20.24	0.584	-0.2336	**
7.32	27.38	0.658	-0.1821	***
12.20	39.29	0.740	-0.1306	*****
9.76	48.81	0.833	-0.0791	****
9.76	58.33	0.938	-0.0276	****
26.83	84.52	1.057	0.0239	*****
2.44	86.90	1.190	0.0754	*
7.32	94.05	1.339	0.1269	**
2.44	96.43	1.508	0.1784	*
2.44	93.91	1.698	0.2299	*

0 1 2 3 4

#####

22 15 55
05 08/94

RFP / DU-3

LOGARITHMIC VALUES

=====

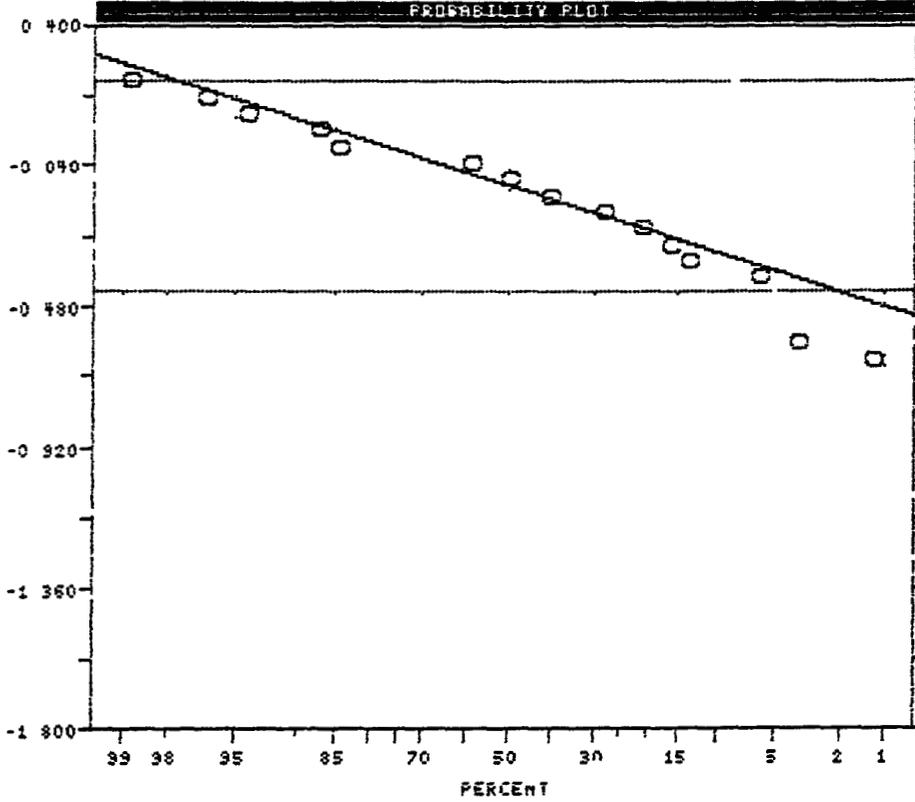
VARIABLE = Be
UNIT = MG/K
N = 41
N CI = 17

POPULATIONS

=====

Pop	Mean	Std Dev	/
1	-0.1044	0.1634	100.0

Pop	THRESHOLDS	
1	-0.4316	0.2228



RAW DATA ML
PARAMETER ESTIMATES

BERYLLIUM

IHSS 201, Standley Lake

DEN1001645A DEN/8

92

14 14 21
05 10/94

RFP / DU-3

LOGARITHMIC VALUES

=====

VARIABLE = Be
UNIT = MG/K
N = 43
N CI = 17

POPULATIONS

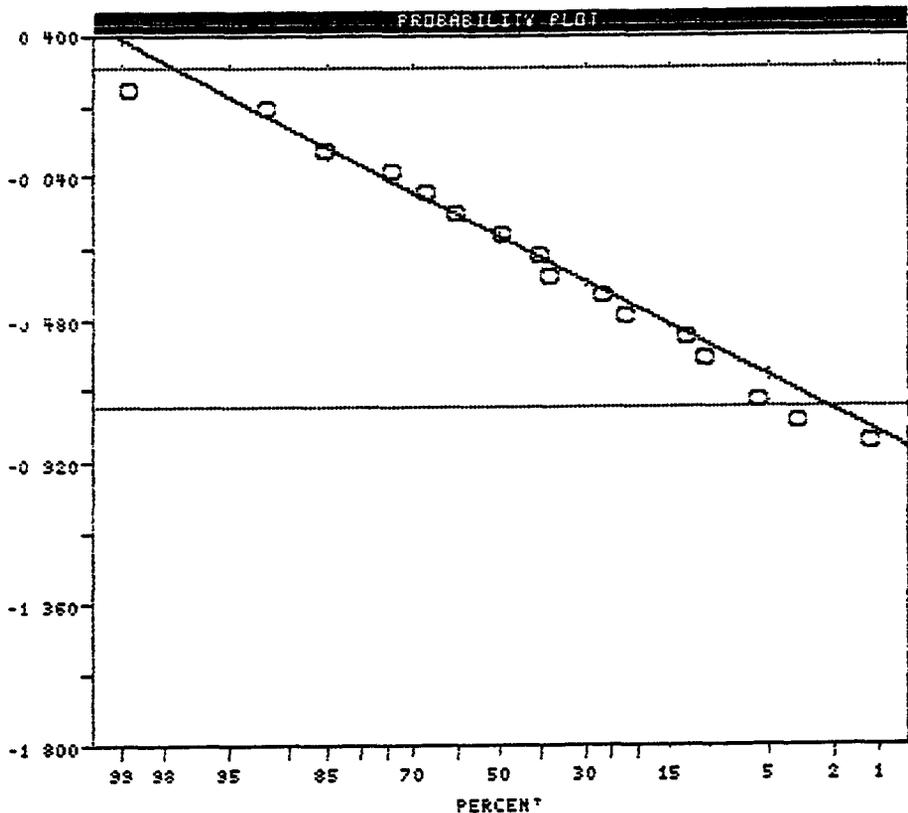
=====

Pop	Mean	Std Dev	/
1	-0.2271	0.2637	100.0

THRESHOLDS

Pop	Mean	Std Dev
1	-0.7546	0.3004

RAW DATA ML
PARAMETER ESTIMATES



94

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14:15:31

FFF / DU-3

05/10/94

PARAMETER SUMMARY STATISTICS FOR PROBABILITY PLOT ANALYSIS

Data File Name = BE-1D.DAT

Variable = Be Unit = MG/K N = 43
N C J = 17

Transform = Logarithmic Number of Populations = 1

of Missing Observations = 0.

=====

Raw Data Maximum Likelihood Parameter Estimates

Maximum LN Likelihood Value = -3.205

Parameterized Degrees of Freedom = 1

Population	Mean	Std Dev	Percentage
1	0.593	- 0.323 + 1.088	100.00

95

BERYLLIUM
IHSS 202, Mower Reservoir

DEN1001645A.DEN/9

96

13:44:09

RFP / DU-3: Be-S

06/24/94

 SUMMARY STATISTICS and HISTOGRAM LOGARITHMIC VALUES

Variable = Be Unit = MG/K N = 16

Mean = -0.0217 Min = -0.3872 1st Quartile = -0.0802
 Std. Dev. = 0.1683 Ma. = 0.1761 Median = 0.0414
 CV % = 773.9253 Skewness = -0.7923 3rd Quartile = 0.1139

Anti-Log Mean = 0.951 Anti-Log Std. Dev. : (-) 0.646
 (+) 1.401

%	cum %	antilog	cls int	(# of bins = 13 - bin size = 0.0469)
0.00	2.94	0.388	-0.4107	
6.25	8.82	0.433	-0.3637	*
0.00	8.82	0.482	-0.3168	
0.00	8.82	0.537	-0.2699	
12.50	20.59	0.599	-0.2229	**
0.00	20.59	0.667	-0.1760	
6.25	26.47	0.743	-0.1290	*
6.25	32.35	0.828	-0.0821	*
0.00	32.35	0.922	-0.0351	
18.75	50.00	1.028	0.0118	***
18.75	67.65	1.145	0.0587	***
6.25	73.53	1.275	0.1057	*
12.50	85.29	1.421	0.1526	**
12.50	97.06	1.583	0.1996	**

0 1 2 3

#####

91

13:45:32

RFP / DU-3: Be-S

06/24/94

#####

PARAMETER SUMMARY STATISTICS FOR PROBABILITY PLOT ANALYSIS

Data File Name = A:BE-S.DAT

Variable = Be Unit = MG/K N = 16
N CI = 13

Transform = Logarithmic Number of Populations = 1

of Missing Observations = 0.

=====

Raw Data Maximum Likelihood Parameter Estimates

Maximum LN Likelihood Value = 6.311

Parameterized Degrees of Freedom = 1

Population	Mean	Std Dev	Percentage
1	0.951	- 0.646 + 1.401	100.00

=====

Default Thresholds.

Standard Deviation Multiplier = 2.0

Pop.	Thresholds
1	0.438 - 2.065

#####

98

13 46 10
05/24/94

RFP / DU-3 Be-S

LOGARITHMIC VALUES

=====

VARIABLE = Be
UNIT = MG/K
N = 16
N CI = 13

POPULATIONS

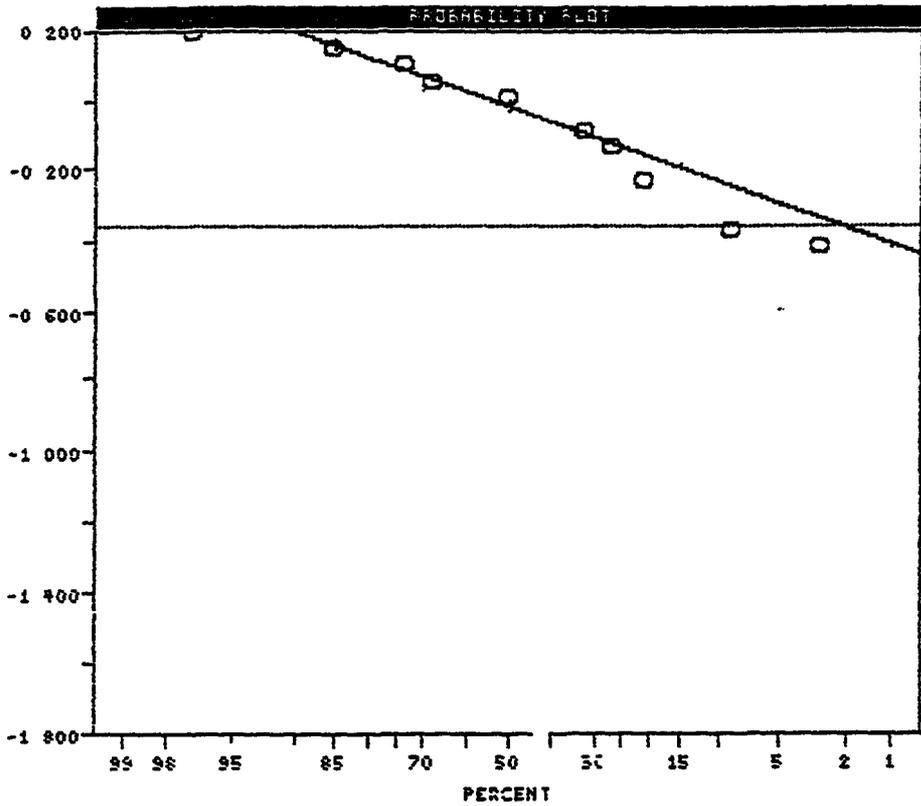
=====

Pop	Mean	Std Dev	/
1	-0 0217	0 1683	100 0

Pop THRESHOLDS

=====

1	-0 3583	0 3198
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RAW DATA ML
PARAMETER ESTIMATES

99/99

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Figure 8 4

Analytical Results of Selected Metals for Sediment Samples

OPERABLE UNIT 3
IHSS 202 Mower Reservoir
ROCKY FLATS
ENVIRONMENTAL TECHNOLOGY SITE
U.S. Department of Energy

Analyte Symbols:
As Arsenic
Ba Beryllium
Ca Calcium
Cr Chromium
Fe Iron
Mn Manganese
Zn Zinc

Units are mg/kg.

1992 Sediment grab sample

Mapping Sources:
Jefferson County Mapping Dept.
EG&G Rocky Flats
U.S. Geological Survey

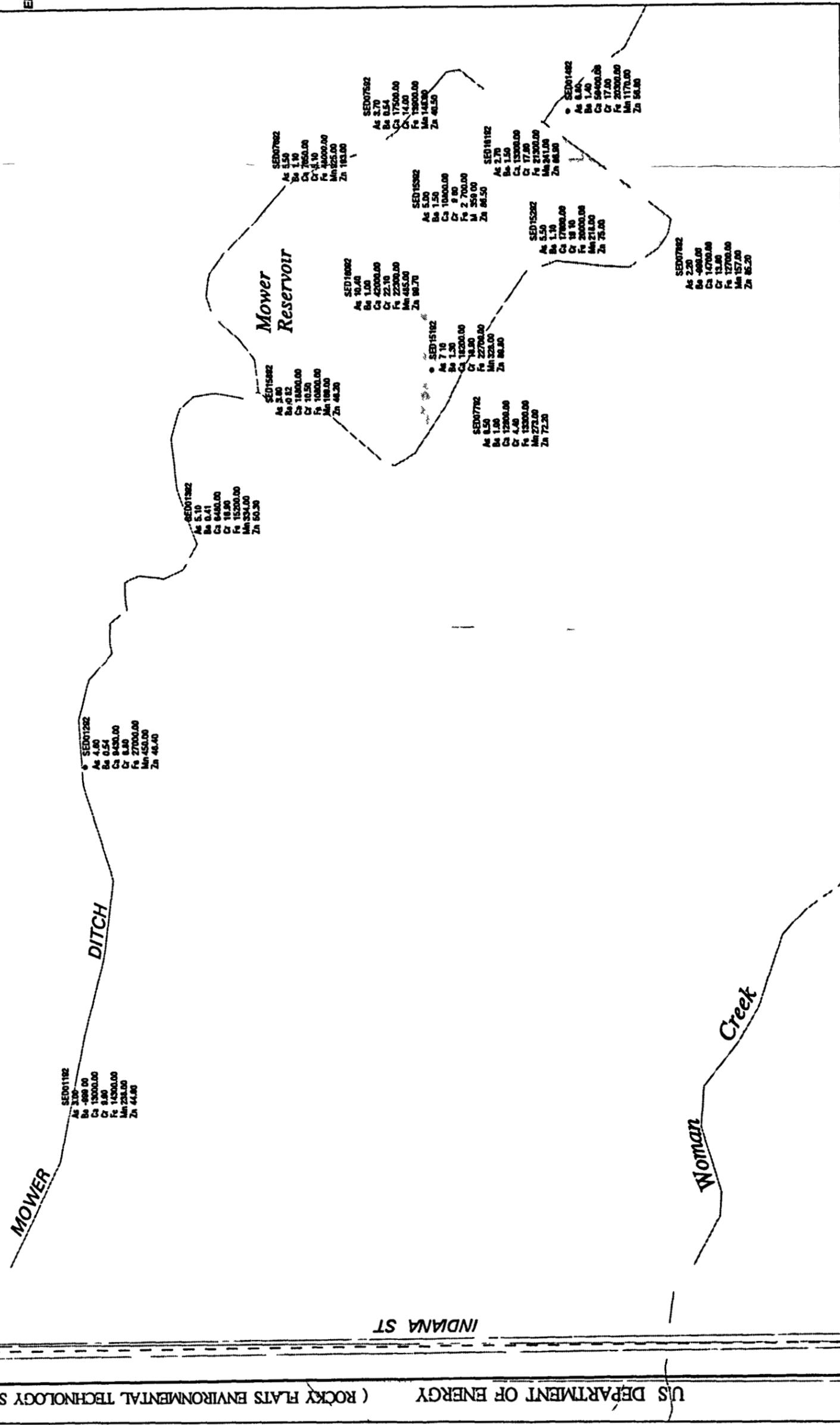


Scale 1 2400
1 inch = 200 ft



SCALE IN FEET

Polyconic projection, 1927 North American datum, Colorado central zone state plane coordinate system.



U.S. DEPARTMENT OF ENERGY (ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE)