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STATISTICAL AND GEOCHEMICAL ANALYSIS OF MANGANESE AND ANTIMONY IN GROUNDWATER AT OPERABLE UNIT NO. 1

In support of the

Phase III
RCRA Facility Investigation/Remedial Investigation
Report

U.S. Department of Energy
Rocky Flats Plant
Golden, Colorado

ENVIRONMENTAL RESTORATION PROGRAM

April 15, 1994

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CRDL	contract-required detection limit
EPA	U.S. Environmental Protection Agency
HSU	hydrostratigraphic unit
ICP	inductively coupled plasma
Kd	coefficients
Mn	manganese
OU1	Operable Unit No. 1
ppm	parts per million
RFI/RI	RCRA Facility Investigation/Remedial Investigation
RFP	Rocky Flats Plant
Sb	antimony
μg/L	micrograms per liter
VOC	volatile organic compound

EXECUTIVE SUMMARY

At the request of the U.S. Environmental Protection Agency (EPA), the method described in Gilbert (1993) for determining site contaminants was applied to the Rocky Flats Plant (RFP) Operable Unit No. 1 (OU1) RCRA Facility Investigation/Remedial Investigation (RFI/RI) groundwater data for manganese (Mn) and antimony (Sb). The Gilbert Method specifies that the data be statistically compared to background, and further evaluated using professional judgement to determine if these elements are contaminants. The results of this assessment indicate that neither manganese nor antimony are groundwater contaminants at OU1.

The statistical tests used to compare OU1 manganese concentrations with background generally demonstrate that a statistically significant difference exists between these two populations. Although the slippage test results were a notable exception to this broad conclusion, examination of the data distributions and the overall statistical results suggest the OU1 manganese concentrations are higher than background. However, review of the spatial distribution of the concentration data indicates no strong horizontal gradients indicative of a source and plume, and no strong vertical gradients. The elevated manganese in the deep bedrock groundwater cannot be explained by vertical migration rates if manganese were a contaminant originating from a near surface source impacting the shallow groundwater. This is in contrast to the volatile organic compound concentrations in the groundwater which have notable horizontal and vertical gradients, and have clearly arisen from a discrete source. Also, the large temporal changes in manganese concentrations in OU1 groundwater at many of the wells is not characteristic of contamination. Lastly, the highest concentrations of manganese occur in groundwater samples from a well that consistently produces cloudy water, i.e., the samples may not be representative of groundwater at that location. Manganese is an abundant element in soil, and manganese oxide has been noted to occur in bedrock fractures throughout the RFP site. It is concluded that the manganese concentrations in OU1 groundwater is a natural small scale geochemical feature not represented by the background data.

The statistical tests used to compare OU1 antimony concentrations with background did not demonstrate, as convincingly as for manganese, that a statistically significant difference exists between these two populations. This uncertainty is largely due to the high percentage of non-detects and the influence of replacement values on the statistical results. Like manganese, a review of the spatial distribution of the concentration data indicates no strong horizontal gradients indicative of a source and plume, and no strong vertical gradients. Also, like manganese, the highest antimony concentration is from a well producing cloudy water that may be unrepresentative of groundwater at that location. Furthermore, most of the detected antimony concentrations are estimated values only, either due to the presence of antimony in laboratory blanks or as a result of interference from aluminum in the inductively coupled plasma (ICP) analysis of antimony. The highest concentration of antimony in OU1 groundwater (210 $\mu g/\ell$), which is generally greater than three times the other observed concentrations, is estimated value because of aluminum interference. Even if a real difference between background and OU1 antimony concentrations exists, the overall evidence suggest the difference is a result of differing geochemical environments.

It is worthy of note that the OU1 RFI/RI report shows that the concentrations of more than 50% of the major and trace elements analyzed are elevated above background in OU1 groundwater. This observation is indicative of a natural difference in the geochemistry at OU1 and background. Concentrations of major and trace elements in groundwater can be expected to vary on both small and large scales as a result of:

1) Differences in the mineralogy of the host rock as a result of provenance in the case of sedimentary rocks;

2) Local variation in Eh/pH conditions of the groundwater;

3) Variation in the degree of hydrothermal mineralization;

4) The source of groundwater currently in the hydrogeologic system (i.e., recharge by surface waters traversing geologic terrain of differing mineralogy); and,

5) Groundwater residence time.

A computer simulation was performed to determine the likelihood that an area the size of the geochemical feature at OU1 would be intercepted by the background wells. The simulation shows there is only a 7% chance that the southern area background configuration of wells would intercept this feature. There is a 21% chance that the northern area background wells would intercept this feature. In consideration of all the information presented above, it is concluded that the site-wide background data should not be considered, a priori, representative of all smaller-scale geochemical conditions at the RFP.

SECTION 1
INTRODUCTION

At the request of the U.S. Environmental Protection Agency (EPA), the method described in Gilbert (1993) for determining site contaminants was applied to the Rocky Flats Plant (RFP) Operable Unit No. 1 (OU1) RCRA Facility Investigation/Remedial Investigation (RFI/RI) groundwater data for manganese (Mn) and antimony (Sb).

The Gilbert methodology is used to screen a list of chemical detections for potential site contaminants. The method involves non-parametric and parametric statistical tests coupled with professional judgement. Specifically, statistical comparisons have been made between OU1 and background data, and the OU1 data have been further subjected to a conceptual analysis to determine if manganese and antimony are OU1 contaminants.

Two background data sets were used: cumulative data through the end of 1992, and cumulative data through the end of 1993. Prior to performing the statistical tests, the background and OU1 data sets were subdivided by hydrostratigraphic unit (HSU) (Upper and Lower) so that comparisons could be made between groundwater in similar formations. A detailed description of the UHSU and LHSU is presented in (DOE, 1993). In general, the UHSU is defined as unconsolidated water-bearing materials and the LHSU is comprised of water-bearing bedrock. Locally, the UHSU can also include shallow sandstone or weathered claystone bedrock containing unconfined groundwater. Details of the methodology and results are presented and discussed in this report.

SECTION 2
METHODOLOGY

A flow chart showing the Gilbert method for comparing site data to background is presented as Figure 2-1. The following discussion pertains to the formal statistical tests recommended by Gilbert. The initial steps leading to the statistical tests had been evaluated prior to the preparation of this report and resulted in the conclusion that manganese and antimony should be subjected to formal statistical tests.

Gehan Test

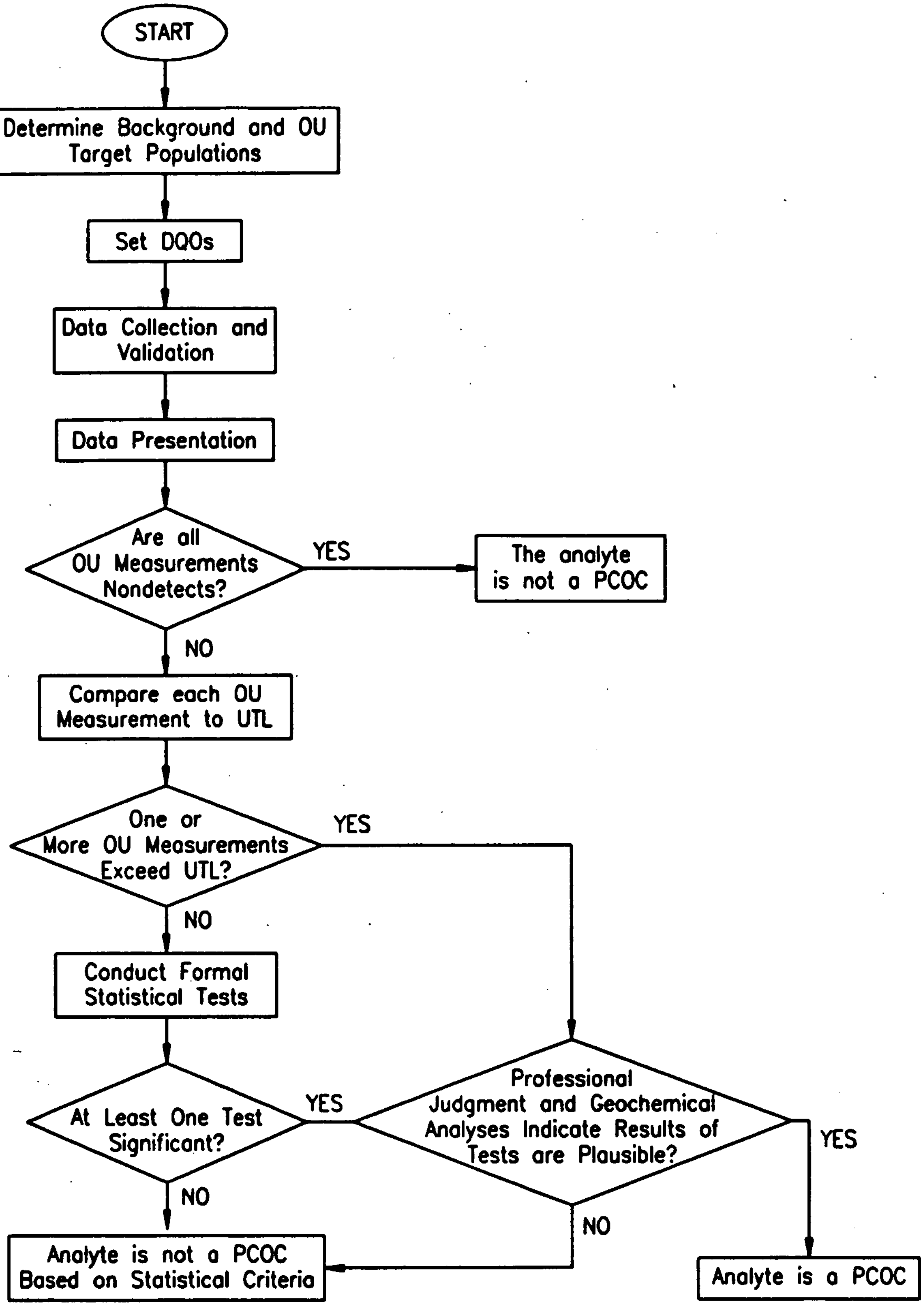
The Gehan test is a nonparametric test used to compare site analyte concentrations with those of the background area when there are censored data and multiple detection limits. The general procedure is to first list the combined background and site measurements (from smallest to largest) and then determine the ranks for these ordered values. The ranks are then converted by a simple equation into scores which are used to obtain the statistic Z. If the Z value is greater than or equal to the appropriate critical value from the standard normal distribution, the site analyte concentrations are considered higher than background.

Slippage Test

The Slippage test is a nonparametric test used to rapidly identify analytes that may require more rigorous statistical evaluation. The test consists of simply counting the number of site measurements (K) that exceed the maximum background value. If K exceeds a critical value obtained from tables in Rosenbaum (1954), the site analyte concentrations are considered higher than background.

Quantile Test

The quantile test is a rapid nonparametric screening test. It is performed by first listing the combined background and site measurements from smallest to largest. Then one counts the number of measurements (n) from the site data set that are among the largest measurements (r)



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Golden, Colorado

FLOW CHART FOR COMPARING SITE DATA TO BACKGROUND

FIGURE 2-1

of the combined data sets. If n is larger than a predetermined value (k), then the site analyte concentrations are considered higher than background. The values of r and k are determined from tables in Gilbert and Simpson (1992).

T-Test

The Student t-test is a parametric test to determine whether the mean of one distribution is different from another distribution at a specified significance level.

P-values are calculated for all the statistical tests. The resulting p-value is the significance level associated with the null hypothesis that the means are similar. The null hypothesis is rejected for p-values less than or equal to 0.05.

The Gilbert Method requires that if at least one test shows there is a significant difference between site analyte concentrations and background, then the analyte must be evaluated further before being considered a site contaminant (Figure 2-1). The additional evaluation methods suggested by Gilbert include, but are not limited to, identification of concentration patterns or concentration gradients, and historical information pertaining to the potential for the substance to be present (use and/or disposal history). These steps are particularly important in the evaluation of naturally occurring compounds and elements.

SECTION 3
MANGANESE

3.1 GEOCHEMISTRY AND GEOLOGY OF MANGANESE

Manganese is "...one of the more abundant metallic elements..." (Hem, 1992), and is the 12^{th} most abundant element in the crust of the earth. Manganese can substitute for iron, magnesium, or calcium in silicate minerals. Manganese is "...a significant constituent of basalt and many olivines and of pyroxene and amphibole. Small amounts commonly are present in dolomite and limestone, substituting for calcium" (Hem, 1992). Typically, basalts contain 1,700 parts per million (ppm) manganese, whereas the crustal average is 1,000 ppm manganese.

Manganese is

> ...an undesirable impurity in water supplies, mainly owing to a tendency to deposit black oxide stains. The recommended upper limit for manganese in public water supplies in the Unites States is 0.05 mg/L (50 μg/L). No mandatory limit is specified for this element by the EPA. It is an essential element for both plant and animal life forms (Hem, 1992).

In addition, data collected from United States' streams since 1970 indicate "...that concentrations up to a few hundred micrograms per liter occur in many streams at times" (Hem, 1992).

The RFP lies along the trend of the Colorado Mineral Belt, with numerous mines and prospects to the west of the RFP. At the RFP, geologists have noted, from the study of lithologic cores, the common occurrence of iron- and manganese-oxides along fractures in these cores. The areal and vertical extent of stained fracture zones in bedrock at the RFP is currently under investigation by geologists.

3.2 STATISTICAL TESTS RESULTS

3.2.1 Results of Statistical Comparisons for Total Manganese in UHSU Groundwater

Although the range of total manganese concentrations in UHSU groundwater for OU1 and background is virtually identical, there is more clustering toward low-end values in the background population (Figure 3-1). Results of the statistical tests are shown below.

STATISTICS FOR TOTAL MANGANESE IN UHSU GROUNDWATER

	N	%det	Gehan p-value	Slippage p-value	Quantile p-value	T-test p-value	$UTL_{99/99}$ ($\mu g/L$)	> UTL
OU1	68	98.5%						
1992 BKG	50	94.0%	0.0001	0.5763	0.0001	0.0002	977	7
1993 BKG	149	90.6%	0.0001	0.3134	0.0001	0.0001	606	13

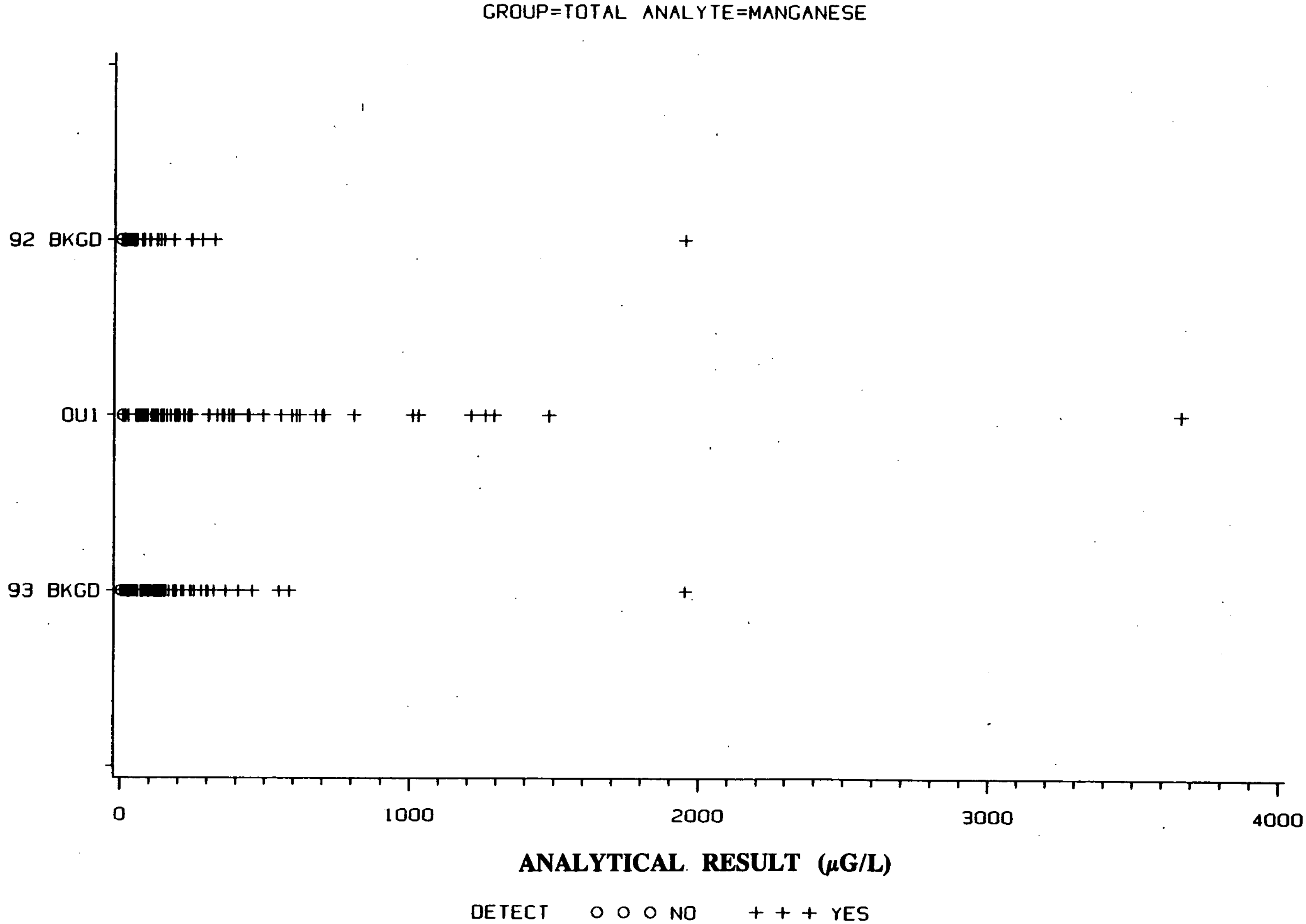
The p-values for the Gehan, quantile, and t-test indicate the total manganese concentration in UHSU groundwater is significantly higher than background (comparisons to both 1992 and 1993 background). However, the p-values for the slippage test indicates no statistically significant difference in the total manganese concentration between OU1 and the background data sets.

The OU1 total manganese data were compared with the 1992 and 1993 calculated background upper tolerance limits [99 percent of the population with 99 percent confidence ($UTL_{99/99}$)]. Seven out of 50 results from OU1 exceed the $UTL_{99/99}$ for the 1992 data set. This indicates, with 99 percent confidence, that 86 percent of the OU1 results for total manganese in UHSU groundwater fall within background values. For the 1993 background data, the UTL value is smaller due to the larger sample size (NOTE: the tolerance factor is directly related to sample size, N). Using the 1993 UTL, 72 percent of the OU1 data fall within background values.

Histograms of the data for total manganese (Figures 3-2a, 3-2b, and 3-2c) show the relative proportions of detects and non-detects in each data set for the UHSU.

Figure 3-1

OU1 UPPER HSU DATA COMPARED TO 92 & 93 BACKGROUND DATA



TOTAL MANGANESE FOR OU1 UPPER HSU AND 92 & 93 BACKGROUNDS

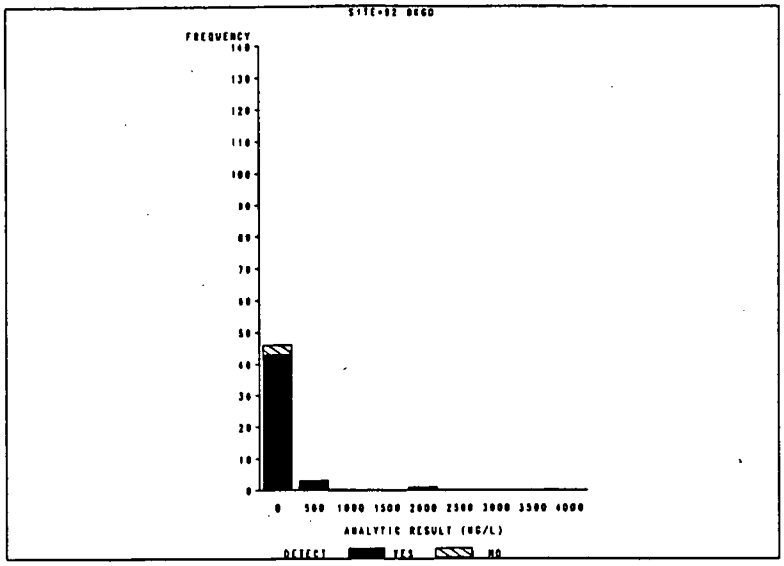


Figure 3-2a

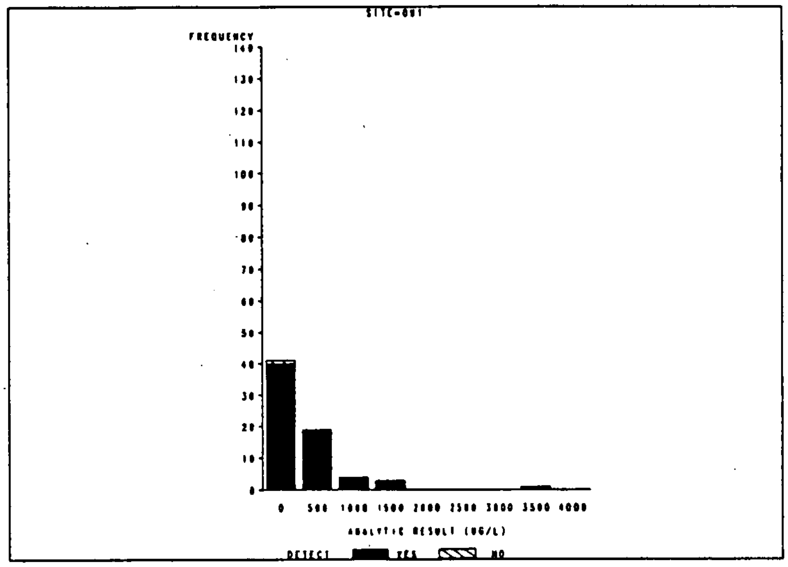


Figure 3-2b

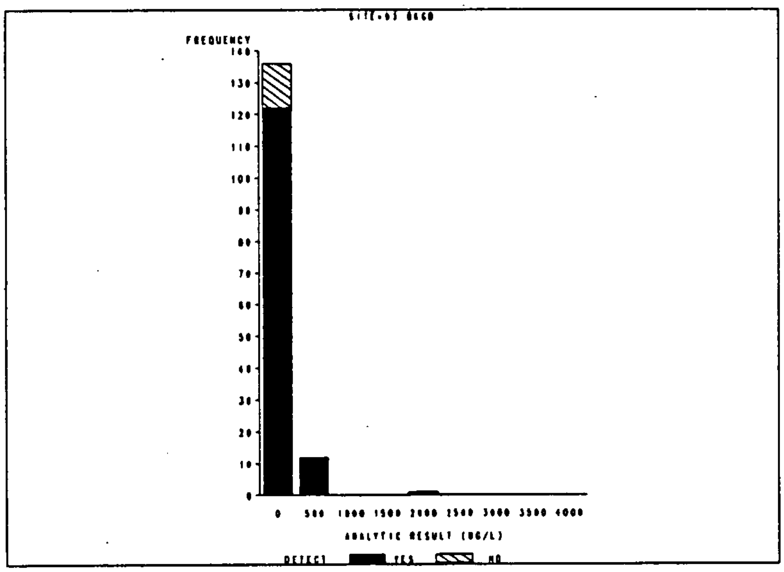


Figure 3-2c

3.2.2 Results of Statistical Comparisons for Total Manganese in LHSU Groundwater

Although the range of concentrations for total manganese concentrations in LHSU groundwater is similar for background and OU1, there is more clustering toward low-end values in the background population (Figure 3-3). Results of the statistical tests are shown below.

STATISTICS FOR TOTAL MANGANESE IN LHSU GROUNDWATER

	N	%det	Gehan p-value	Slippage p-value	Quantile p-value	T-test p-value	$UTL_{99/99}$ (µg/L)	# > UTL
OU1	11	100%						
1992 BKG	13	86.5%	0.0111	1.0000	0.1118	0.0109	974	0
1993 BKG	37	100%	0.0008	1.0000	0.0004	0.0011	475	1

The p-values for the Gehan, quantile, and t-test indicate the total manganese concentration in UHSU groundwater is significantly higher than background considering the 1993 background data, and with the exception of the quantile test, also the 1992 background data. However, the p-values for the slippage test indicate no statistically significant difference in total manganese concentrations between OU1 and background.

Comparison of each OU result with the 1992 and 1993 background $UTL_{99/99}$ (974 and 475 µg/L, respectively) shows that only one result from OU1 exceeds the $UTL_{99/99}$. This indicates, with 99 percent confidence, that 92 percent of the OU1 results for dissolved manganese in LHSU groundwater fall within background values.

Histograms of the data for total manganese concentrations (Figures 3-4a, 3-4b, and 3-4c) show the relative proportions of detects and non-detects in each data set.

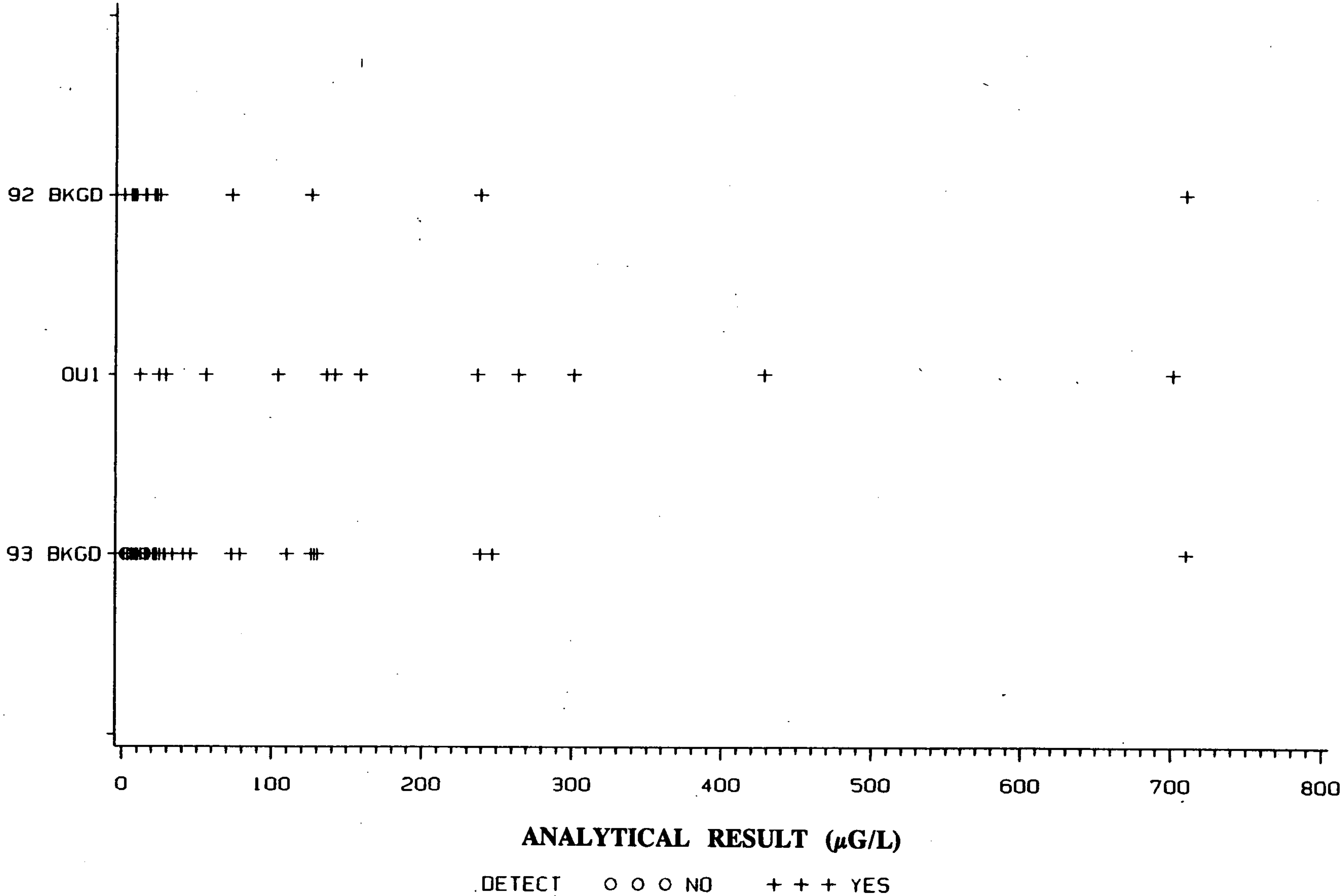
3.2.3 Results of Statistical Comparisons for Dissolved Manganese in UHSU Groundwater

The range of values for OU1 and background data is dissimilar (Figure 3-5). Results of the statistical tests are shown below.

Figure 3-3

OU1 LOWER HSU DATA COMPARED TO 92 & 93 BACKGROUND DATA

GROUP=TOTAL ANALYTE=MANGANESE



TOTAL MANGANESE FOR OU1 LOWER HSU AND 92 & 93 BACKGROUNDS

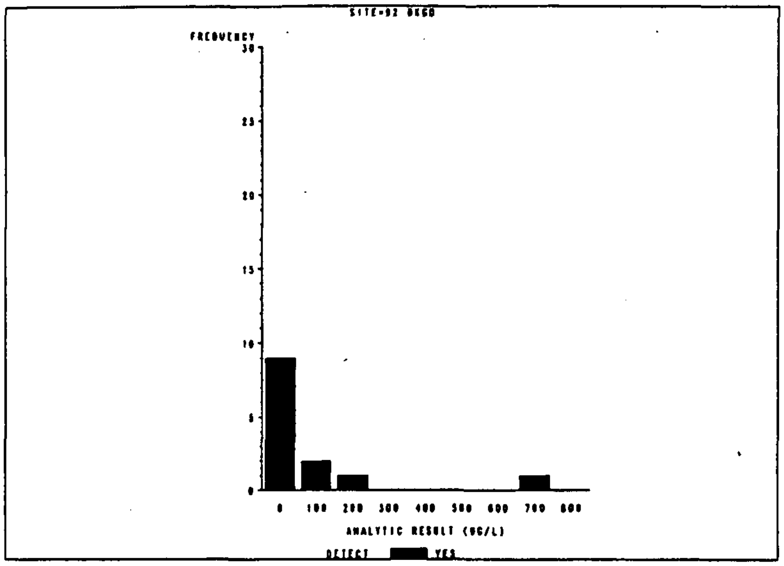


Figure 3-4a

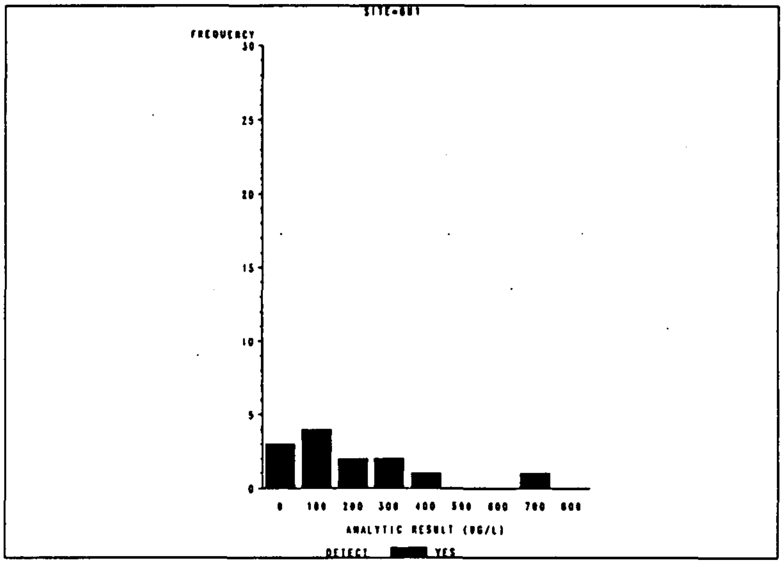


Figure 3-4b

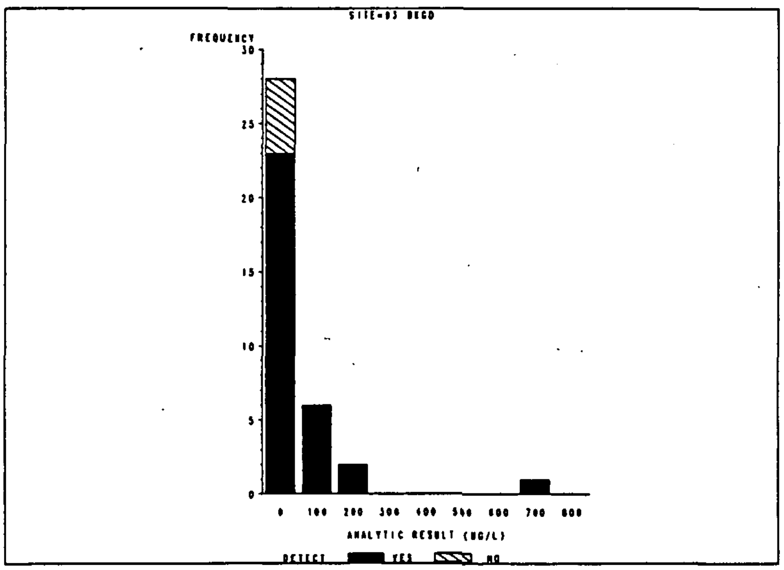
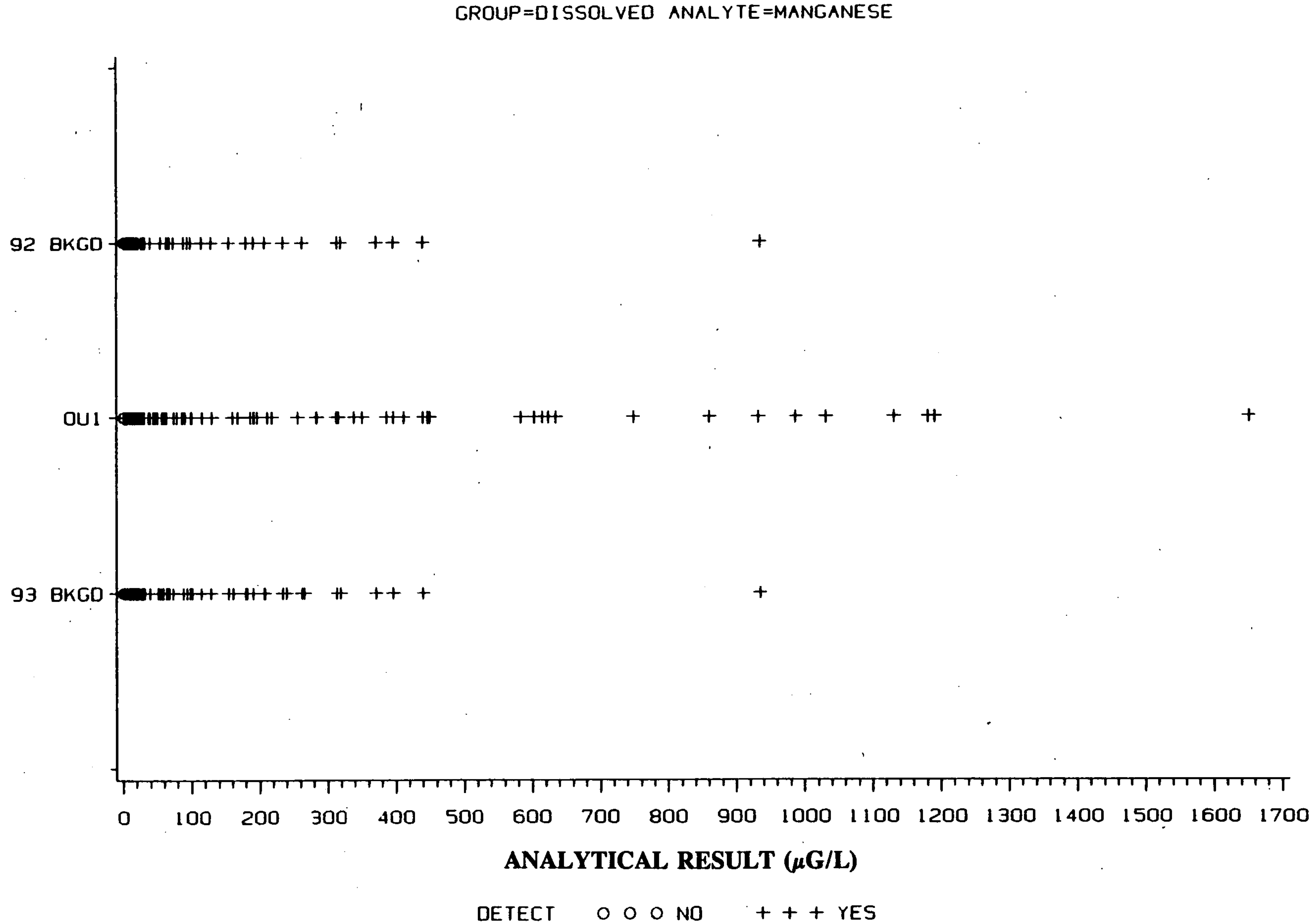


Figure 3-4c

Figure 3-5

OU1 UPPER HSU DATA COMPARED TO 92 & 93 BACKGROUND DATA



STATISTICS FOR DISSOLVED MANGANESE IN UHSU GROUNDWATER

	N	%det	Gehan p-value	Slippage p-value	Quantile p-value	T-test p-value	$UTL_{99/99}$ ($\mu g/L$)	# > UTL
OU1	122	86.1%						
1992 BKG	157	74.5%	0.0065	0.0001	0.0001	NA	323	22
1993 BKG	256	60.2%	0.0001	0.0010	0.0001	NA	263	26

The p-values for the Gehan, slippage, and quantile tests indicate that the total concentration of dissolved manganese in OU1 groundwater is significantly higher than background. The t-test was not applicable due to the non-detect rate greater than 20 percent.

Comparison of each OU result with the 1992 and 1993 background $UTL_{99/99}$ (323 and 263 $\mu g/L$, respectively) shows that 22 out of 157 results from OU1 exceed the $UTL_{99/99}$ for the 1992 data set. This indicates, with 99 percent confidence, that 86 percent of the OU1 results for dissolved manganese in UHSU groundwater fall within background values. For the 1993 background data, the UTL value is smaller due to the larger sample size. Using the 1993 UTL, 90 percent of the OU1 data fall within background values.

Histograms of the data for dissolved manganese (Figures 3-6a, 3-6b, and 3-6c) show the relative proportions of detects and non-detects in each data set for the UHSU.

3.2.4 Results of Statistical Comparisons for Dissolved Manganese in LHSU Groundwater

The range of concentrations for dissolved manganese in LHSU groundwater at RFP is dissimilar for the background and OU1 data (Figure 3-7). Results of the statistical tests are shown below.

STATISTICS FOR DISSOLVED MANGANESE IN LHSU GROUNDWATER

	N	%det	Gehan p-value	Slippage p-value	Quantile p-value	T-test p-value	$UTL_{99/99}$ ($\mu g/L$)	# > UTL
OU1	28	96.4%						
1992 BKG	43	83.7%	0.0001	0.0001	0.0001	0.0005	34.5	16
1993 BKG	67	71.6%	0.0001	0.0001	0.0001	0.0001	31	18

DISSOLVED MANGANESE FOR OU1 UPPER HSU AND 92 & 93 BACKGROUNDS

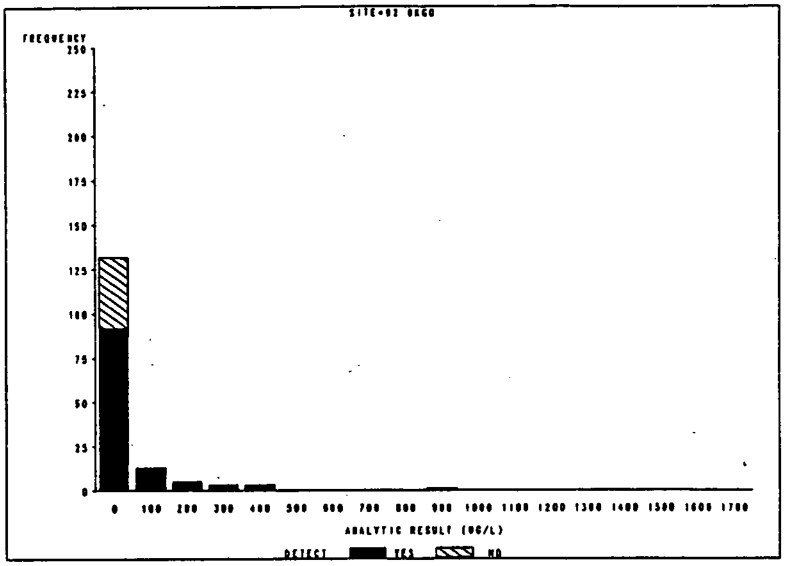


Figure 3-6a

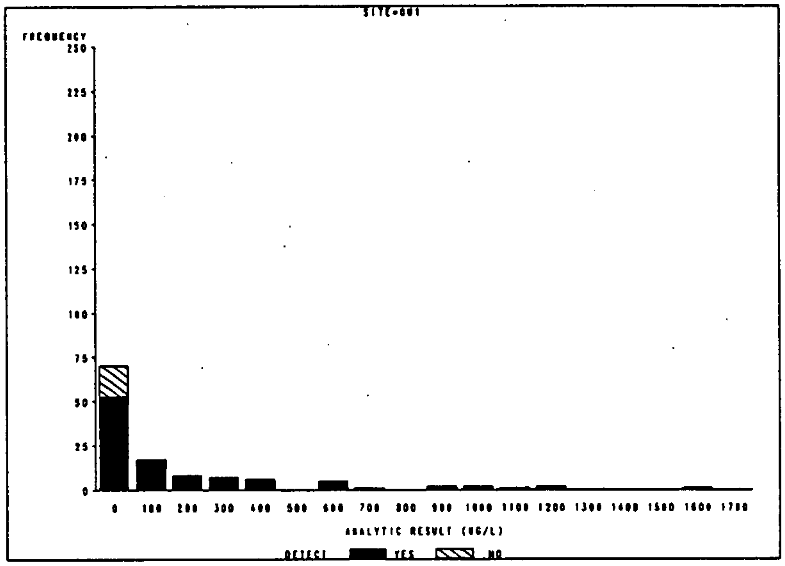


Figure 3-6b

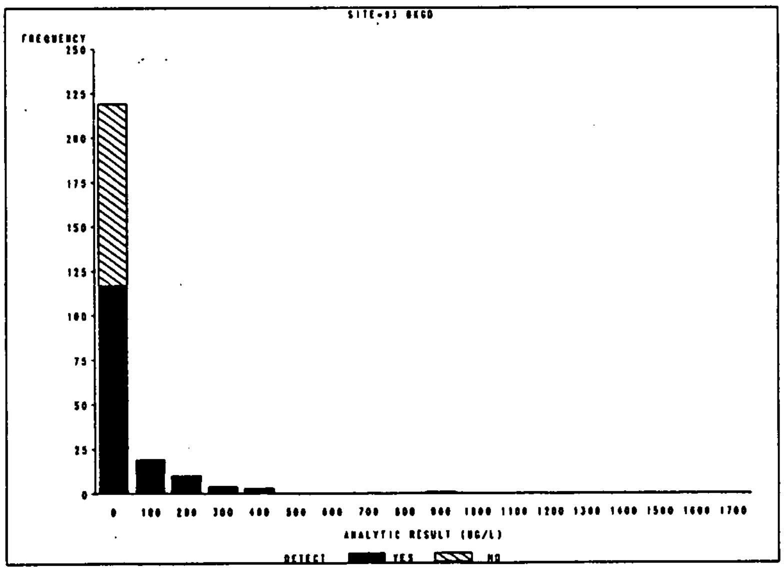
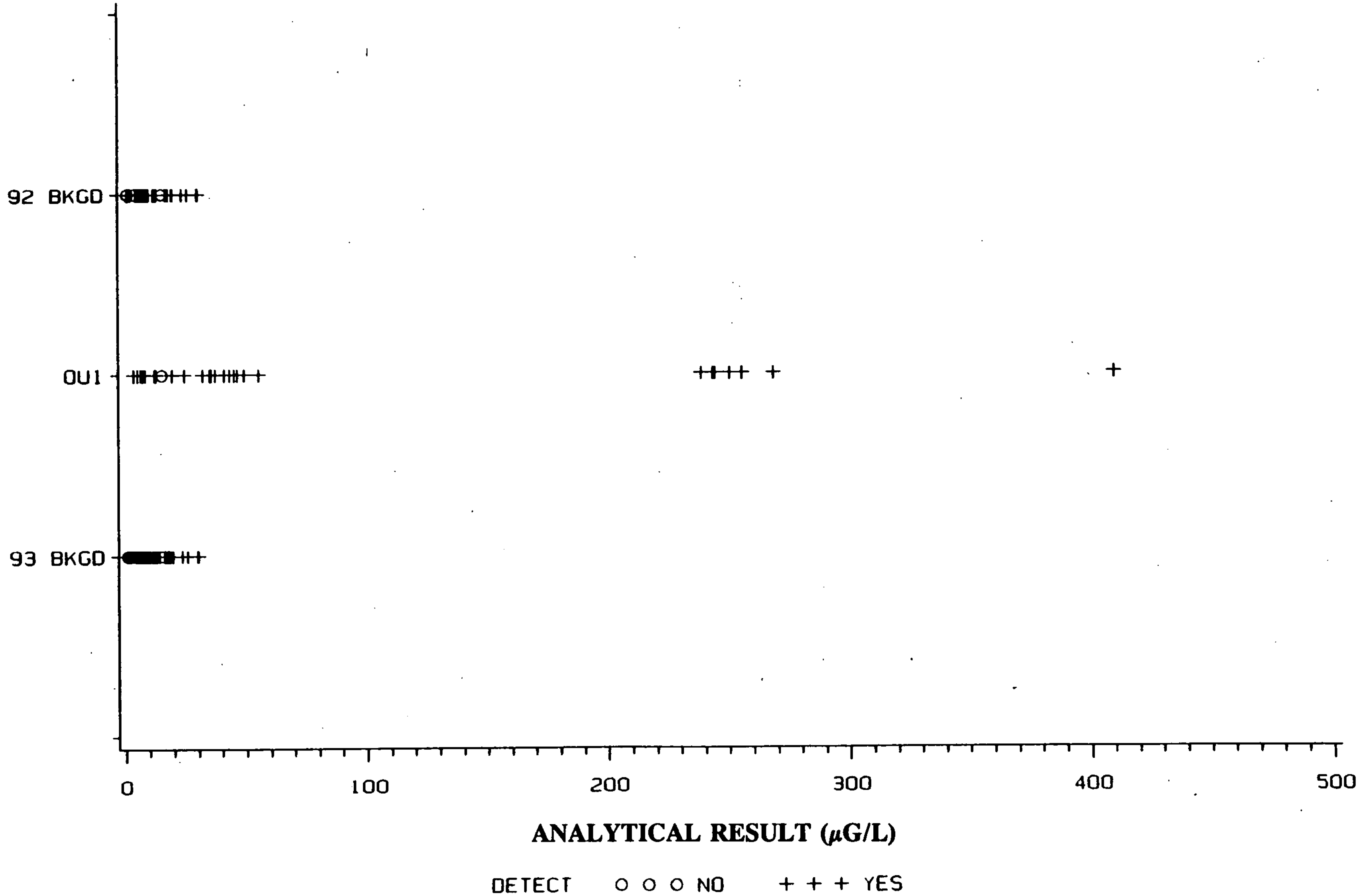


Figure 3-6c

Figure 3-7

OU1 LOWER HSU DATA COMPARED TO 92 & 93 BACKGROUND DATA

GROUP=DISSOLVED ANALYTE=MANGANESE



The p-values for the Gehan, slippage, quantile, and t-test indicate that the concentration of dissolved manganese in OU1 LHSU groundwater is significantly greater than background.

Comparison of each OU1 result with the 1992 and 1993 background $UTL_{99/99}$ (34.5 and 31 μg/L, respectively) shows that 16 results from OU1 exceed the 1992 $UTL_{99/99}$ and 18 results from OU1 exceed the 1993 $UTL_{99/99}$. This indicates, with 99 percent confidence, that 63 percent of the OU1 results for dissolved manganese in LHSU groundwater are within the 1992 background values and that 73 percent fall within 1993 background values.

Histograms of the data for dissolved manganese (Figures 3-8a, 3-8b, and 3-8c) show the relative proportions of detects and non-detects in each data set.

3.2.5 Conclusions

In general, the statistical test results indicate the manganese concentration in OU1 UHSU and LHSU groundwater is significantly different from background even though the slippage test results often did not support this conclusion and most of the OU1 manganese concentrations were below the UTLs.

3.3 PROFESSIONAL JUDGMENT

If one statistical test suggests a difference between the data sets, Gilbert (1993) requires that other factors be considered before identifying the analyte as a site contaminant. In the case of manganese these other considerations include:

- Historical use and/or disposal of manganese at RFP.
- Horizontal, vertical, and temporal patterns of manganese concentrations in OU1 groundwater.
- Evidence of natural differences in geochemistry of water-bearing materials between OU1 and background.
- Effects due to well construction and sampling procedures.

DISSOLVED MANGANESE FOR OU1 LOWER HSU AND 92 & 93 BACKGROUNDS

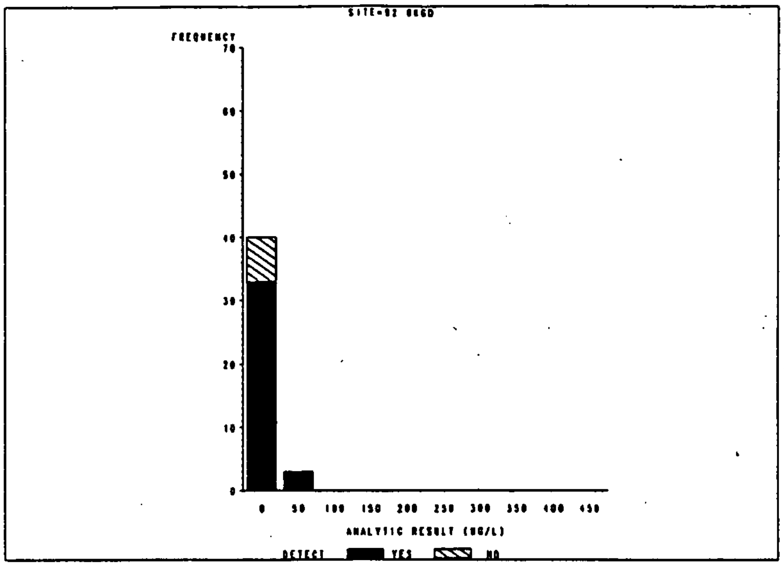


Figure 3-8a

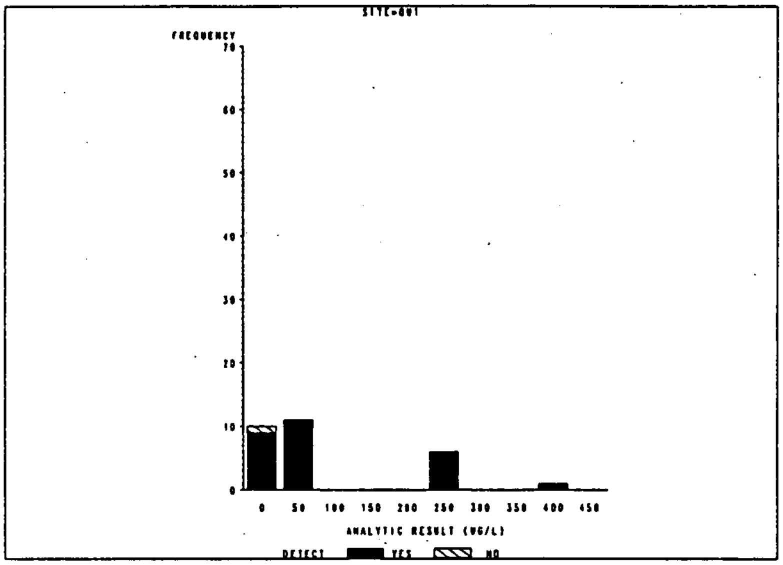


Figure 3-8b

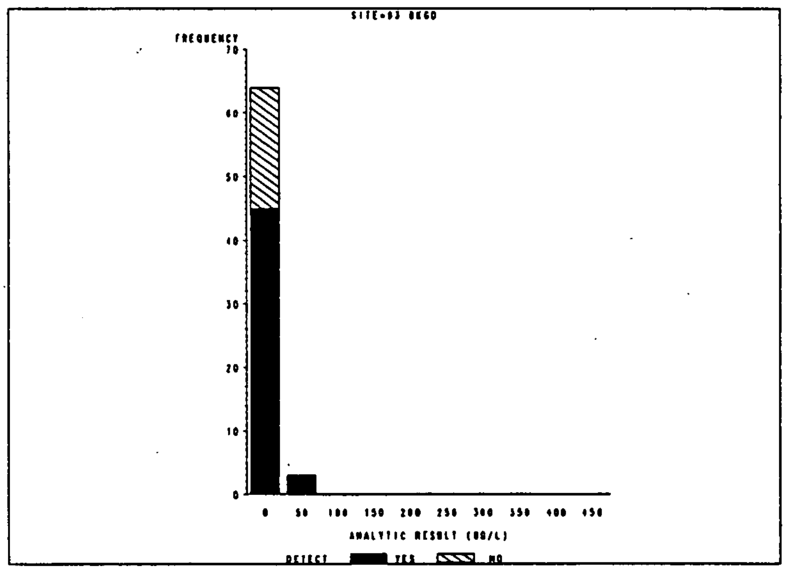


Figure 3-8c

3.3.1 Historical Use of Manganese at RFP

Based on the Historical Release Report (DOE, 1992), there are no records of manganese use in any RFP processes, or of its disposal or storage at OU1.

3.3.2 Pattern Recognition

The concentration of manganese in the UHSU and LHSU groundwater at OU1 has been found to be statistically significantly higher than in the background area. If the "elevated" manganese is the result of man-made contamination, some concentration gradients should be apparent in either the horizontal or vertical direction. Even if the source for the manganese in OU1 groundwater is diffuse, wind-blown manganese containing dust with no apparent horizontal concentration gradient or point source, a vertical gradient resulting from attenuation during migration from shallow to deeper groundwater should still be apparent.

Figure 3-9 illustrates the distribution of manganese in UHSU and LHSU groundwater. Examination of the spatial distribution of the manganese results indicates that there are no well-defined horizontal concentration gradients indicative of a "source." Exceedances of the background UTL (as calculated in the Phase III RFI/RI report [DOE, 1993]) occur in five UHSU wells within OU1. Three of these wells (36391, 37991, and 37191) are located within IHSS boundaries; however, these wells contained little or no organic contamination (DOE, 1993) Co-occurrence of high manganese values with high volatile organic contamination would be partial evidence that manganese is a site contaminant. Additionally, the maximum concentrations of manganese in the two off-site wells are of similar magnitude to the concentrations at the IHSS.

With respect to vertical concentration gradients, the arithmetic mean concentration of manganese in groundwater was calculated for alluvial/colluvial groundwater monitoring wells (shallow) and for bedrock wells (deep). The mean manganese concentrations for shallow and deep wells are 377 ug/ℓ and 258 ug/ℓ, respectively. These values are similar and do not demonstrate a clear concentration gradient between the shallow and deep water-bearing zones. It is more likely that the observed differences in average manganese concentrations represent natural differences between the two water bearing zones.

An estimate of vertical migration rate was made to further investigate the potential for vertical manganese migration from a near-surface source. The calculation method is presented in Appendix B. Using aquifer parameters specific to the IHSS 119.1 area of OU1 (vertical hydraulic conductivity and gradient, porosity etc.) coupled with literature values of distribution coefficients (Kd) for manganese, a range of vertical travel distance has been estimated. This range assumes a 25 year travel time and incorporates the full range of vertical permeabilities measured in the bedrock formations. Distribution coefficients for manganese range from 0.2 to 10,000 depending on soil types. Based on the high clay content of the claystone bedrock, and the tendency for metal cations to sorb to clays, a Kd in the upper half of the range was considered to be reasonable. As a conservative measure, the midpoint of the range (5,000) was used. The resulting estimates of travel distance (0.78 feet to 4.3 E-5 feet) suggest that manganese could not naturally migrate vertically over any appreciable distance. This further supports the occurrence of manganese in the LHSU is most likely due to natural conditions.

Concentration versus time graphs were prepared for those stations where the UTL for total manganese (932 $\mu g/\ell$) was exceeded (Figures 3-10 through 3-13). (The UTL is as reported in the OU1 RFI/RI report [DOE, 1993]). None of these stations showed consistently elevated (above the UTL) concentrations of manganese. Only one well (37191) contained manganese at a concentrations more than 2 times the UTL (3,660 $\mu g/\ell$). This high detection was a one-time occurrence, and the data from successive quarters show a steep decline in manganese concentrations. The most recent manganese concentration was below the UTL. The large disparity in concentration values from one sampling period to the next is inconsistent with "contamination."

3.3.3 Natural Differences Between OU1 and Background

In general, spatial variations in the geochemistry of water-bearing formations and groundwater is the expected condition rather than the exception. Appendix D of the RFI/RI Report for OU1 (DOE, 1993) indicates that greater than 50 percent of the major and trace elements are at

FIGURE 3-10

Total Manganese in Well 37191

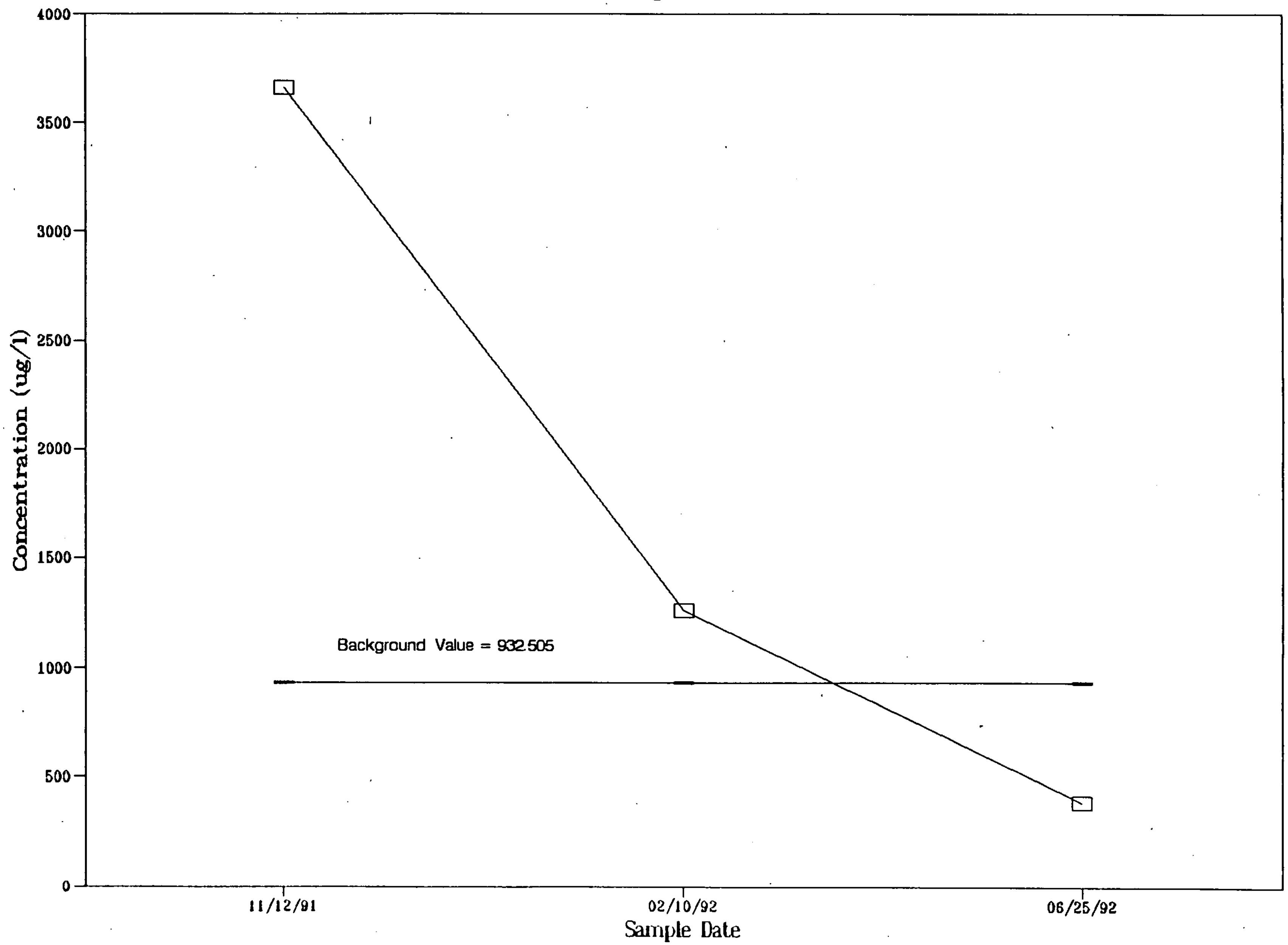


FIGURE 3-11

Total Manganese in Well 37991

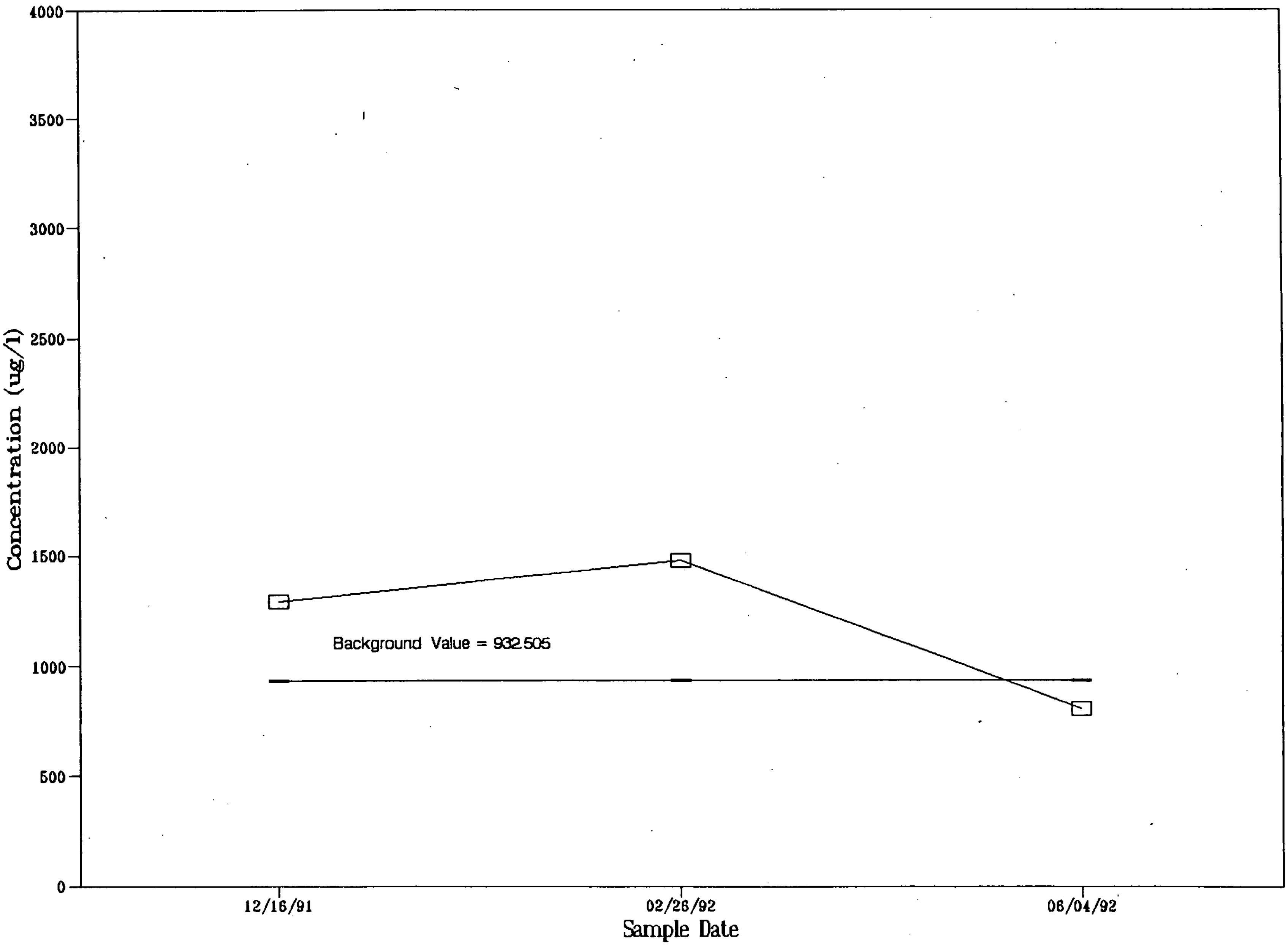


FIGURE 3-12

Total Manganese in Well 38591

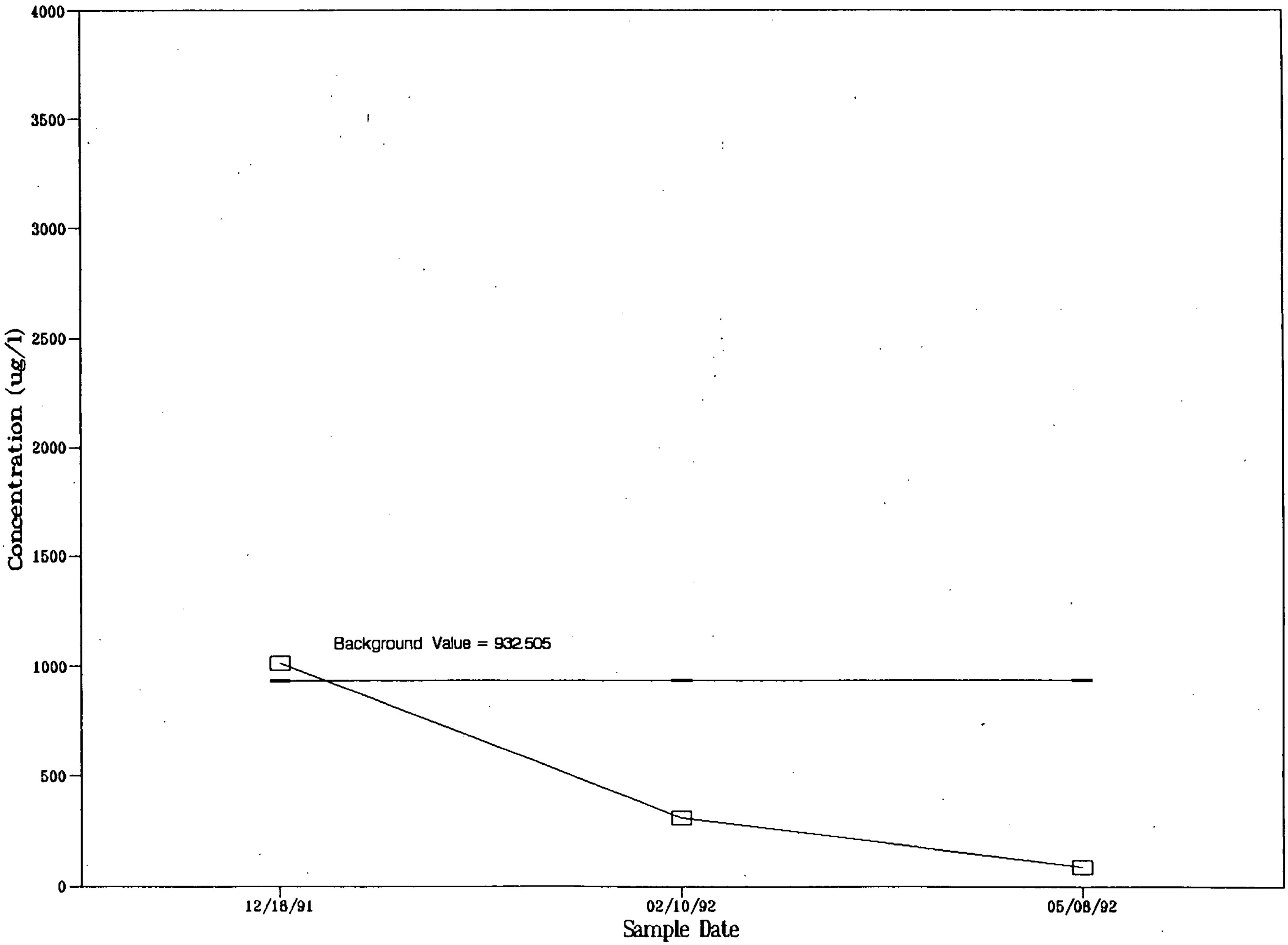
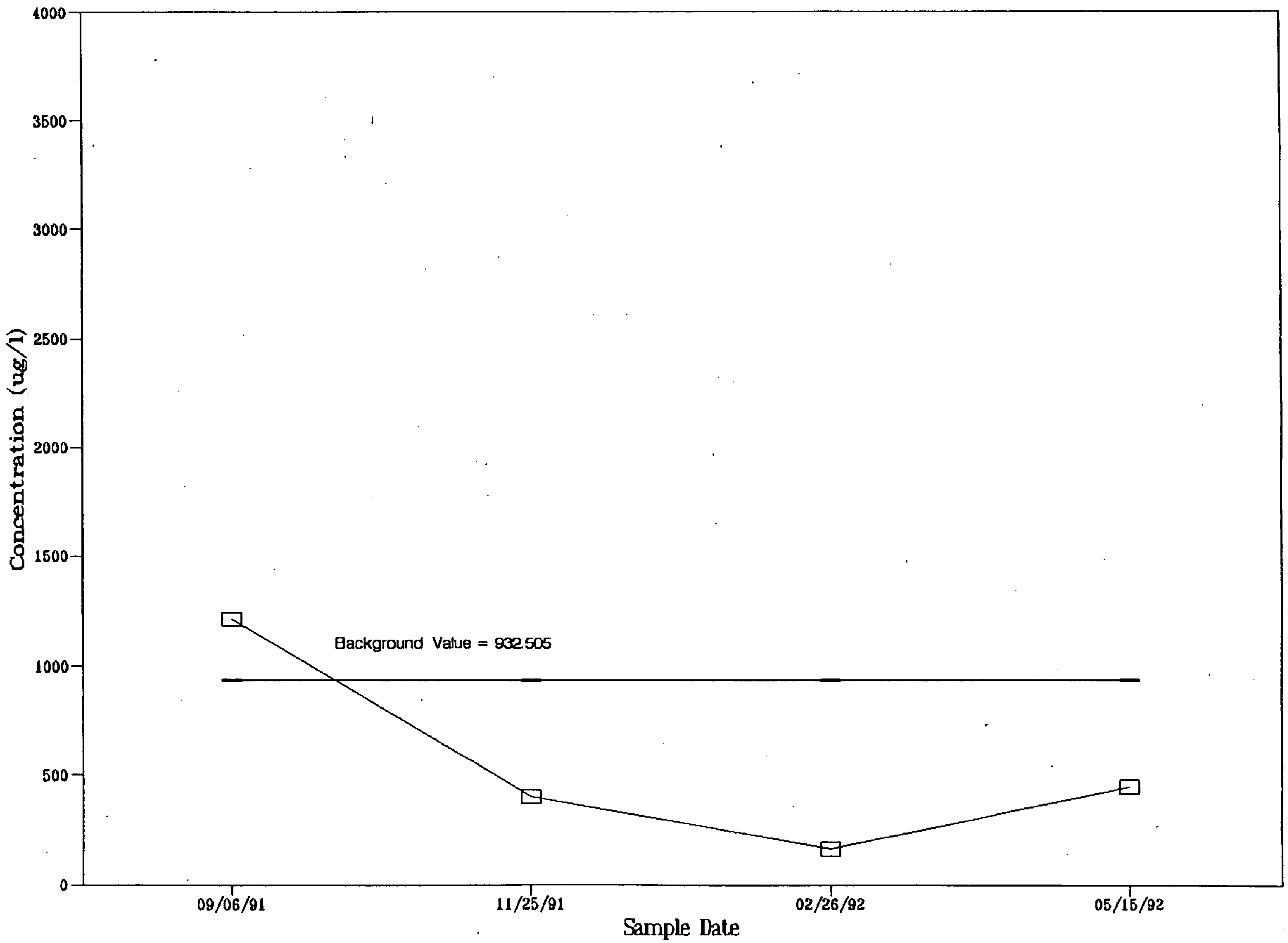


FIGURE 3-13

Total Manganese in Well 6886



statistically significantly higher concentrations in OU1 groundwater relative to background. As it is very unlikely that all these elements are site contaminants (with the exception of selenium and vanadium, each has been dismissed as a site contaminant in Appendix D [DOE, 1993]), it appears there are natural differences between the geochemistry of OU1 and the background area, i.e., the site-wide background data are not representative of all smaller-scale, natural geochemical conditions at the RFP.

In order to further support that a small-scale, natural geochemical condition could be undetected by the RFP background wells, a computer simulation was performed to determine the likelihood that an area the size of the geochemical feature at OU1 would be intercepted by the background wells. The simulation shows there is only a 7 percent chance that the background configuration of wells would intercept this area (a circle approximately 300 feet in radius). Therefore, the site-wide background data should not necessarily be considered representative of all smaller-scale geochemical conditions at the RFP. southern area 21% for northern area

3.3.4 Well Construction/Sampling Effects

The groundwater sample collected from well 37191 on 12 November 1991 contained the highest manganese concentration in the OU1 data set. A review of well development and sampling forms for well 37191 reveals an apparent development problem. The development water from this well is consistently described as cloudy or brown (i.e., the well could not be developed to produce low turbidity water). The well purge records for subsequent sampling events also show that cloudy water is present. Although there is no data to indicate a decrease in turbidity with the decline in manganese concentration over time, the presence of consistently high turbidity suggests the total (and dissolved) manganese concentrations in samples from this well may be unrepresentative of the manganese concentrations in groundwater at this location.

3.3.5 Conclusions

Although there is higher manganese concentrations at OU1 relative to background, the lack of concentration gradients, the high variability of manganese concentrations over time, and the presence of many other elements at concentrations higher than background (showing similar concentration distribution patterns) indicate manganese is not a contaminant of groundwater at OU1.

SECTION 4
ANTIMONY

4.1 GEOLOGY AND GEOCHEMISTRY OF ANTIMONY

The concentrations of antimony in natural waters are expected to be low in most areas (thermal areas constitute a notable exception). Some geochemical characteristics of antimony are similar to those of arsenic (i.e., forms oxyanions in aqueous solutions, etc.), but antimony is only about one-tenth as abundant in crustal rocks, averaging about 0.2 ppm (Hem, 1992; Krauskopf, 1979).

4.2 STATISTICAL TESTS RESULTS

4.2.1 Results of Statistical Comparisons for Total Antimony in UHSU Groundwater

Although the range of concentrations of total antimony in UHSU groundwater is similar for the OU1 and background data sets (Figure 4-1), there is more clustering of low-end values in the background data set. Results of the statistical tests are shown below.

STATISTICS FOR TOTAL ANTIMONY IN UHSU GROUNDWATER

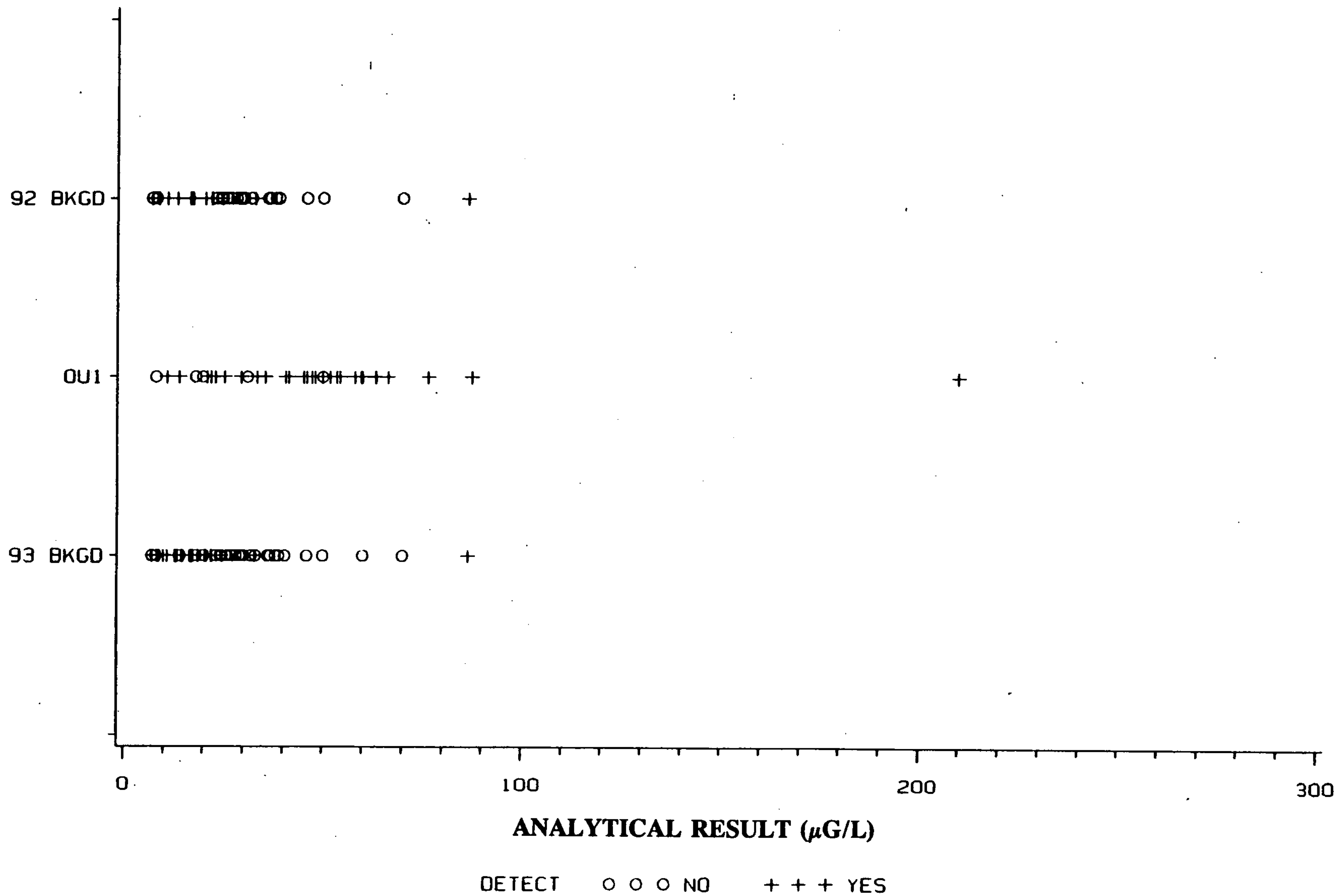
	N	%det	Gehan p-value	Slippage p-value	Quantile p-value	T-test p-value	$UTL_{99/99}$ (μg/L)	# > UTL
OU1	65	43.1%						
1992 BKG	4	34.1%	0.0052	0.3534	NA	NA	60	8
1993 BKG	140	16.4%	0.0001	0.0995	NA	NA	NA	NA

The p-values for the Gehan test indicate that the concentration of total antimony in OU1 groundwater is significantly greater than background. However, the p-values for the slippage test indicate no statistically significant differences in the total antimony concentration between OU1 and the background data sets. It should be noted that the non-detect rate greater than 60 percent makes the use of any inferential statistical test suspect because the result is greatly dependent on the replacement values substituted for the non-detects. This impact in further discussed in Section 4.3.

Figure 4-1

OU1 UPPER HSU DATA COMPARED TO 92 & 93 BACKGROUND DATA

GROUP=TOTAL ANALYTE=ANTIMONY



The quantile and t-tests were not applicable due to the high percentage of non-detects in the background data sets.

Comparison of each OU result with the 1992 background $UTL_{99/99}$ (60 μg/L) shows that eight results from OU1 exceed the $UTL_{99/99}$. This indicates, with 99 percent confidence, that greater than 87 percent of the OU1 data for total antimony in UHSU groundwater fall within background. No UTL was calculated for the 1993 background data set due to the high rate of non-detects. Histograms show the distribution of detects and non-detects in the three data sets (Figures 4-2a, 4-2b, and 4-2c).

4.2.2 Results of Statistical Comparisons for Total Antimony in LHSU Groundwater

The range of total antimony concentrations in LHSU groundwater are similar to the range in background groundwater, with the exception of one high value in the background data set. The high value (1,610 $\mu g/\ell$) in background exceeds all values in the OU1 data set (compare Figures 4-3 and 4-4). Additionally, the occurrence of multiple detection limits reduces the power of the statistical tests to discern a difference between the OU1 and background sample populations. Results of the statistical tests are shown below.

STATISTICS FOR TOTAL ANTIMONY IN LHSU GROUNDWATER

	N	%det	Gehan p-value	Slippage p-value	Quantile p-value	T-test p-value	$UTL_{99/99}$ (μg/L)	# > UTL
OU1	12	75.0%						
1992 BKG	13	23.1%	0.0090	1.0000	0.1360	NA	2118	0
1993 BKG	36	8.3%	0.0001	1.0000	NA	NA	NA	NA

The p-values for the Gehan test indicate that the concentration of total antimony in OU1 groundwater is statistically significantly greater than background. However, the p-values for the slippage test indicate no statistically significant differences in the total antimony concentration between OU1 and the background data sets. For the quantile test, the p-value (0.1360), derived by using 1992 background data, indicates no significant difference between OU1 and background. This test was not conducted for the 1993 background data due to the high rate of

TOTAL ANTIMONY FOR OU1 UPPER HSU AND 92 & 93 BACKGROUNDS

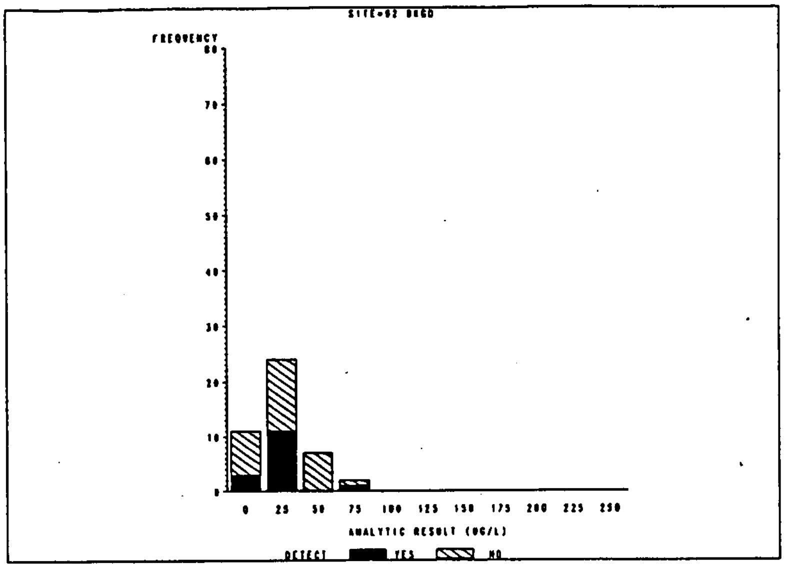


Figure 4-2a

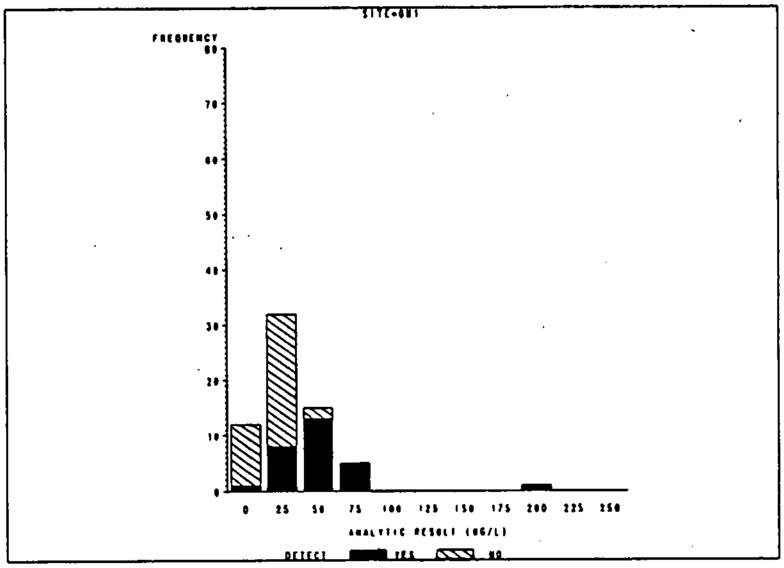


Figure 4-2b

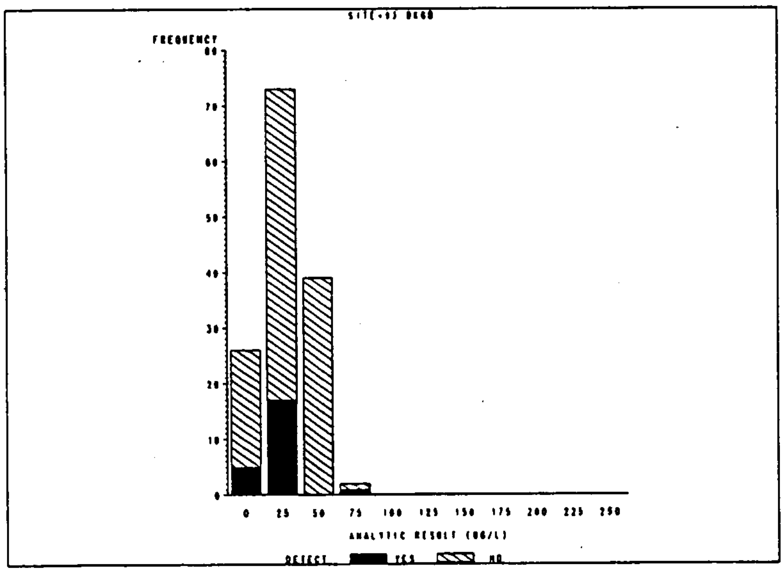


Figure 4-2c

Figure 4-3

OU1 LOWER HSU DATA COMPARED TO 92 & 93 BACKGROUND DATA

GROUP=TOTAL ANALYTE=ANTIMONY

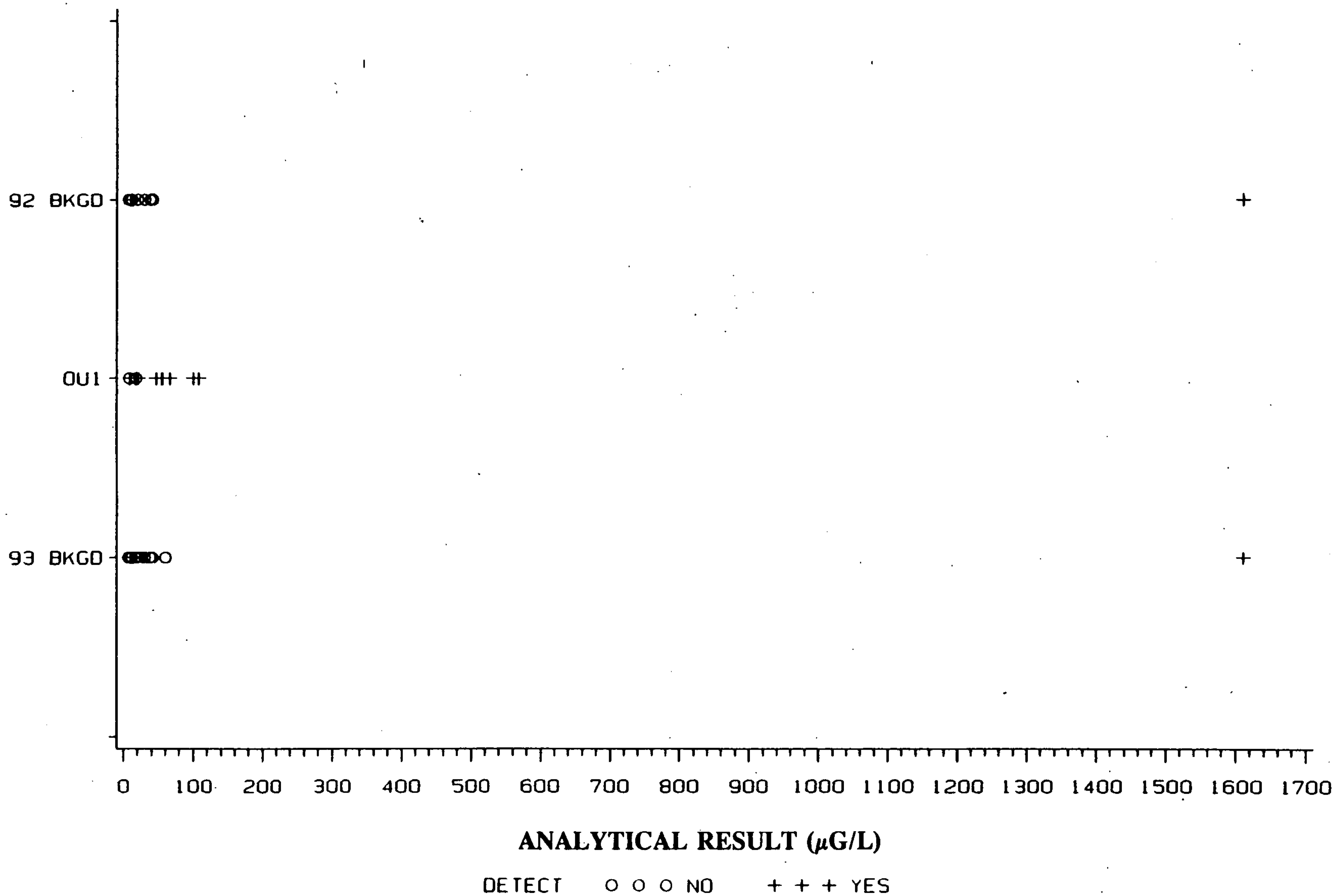
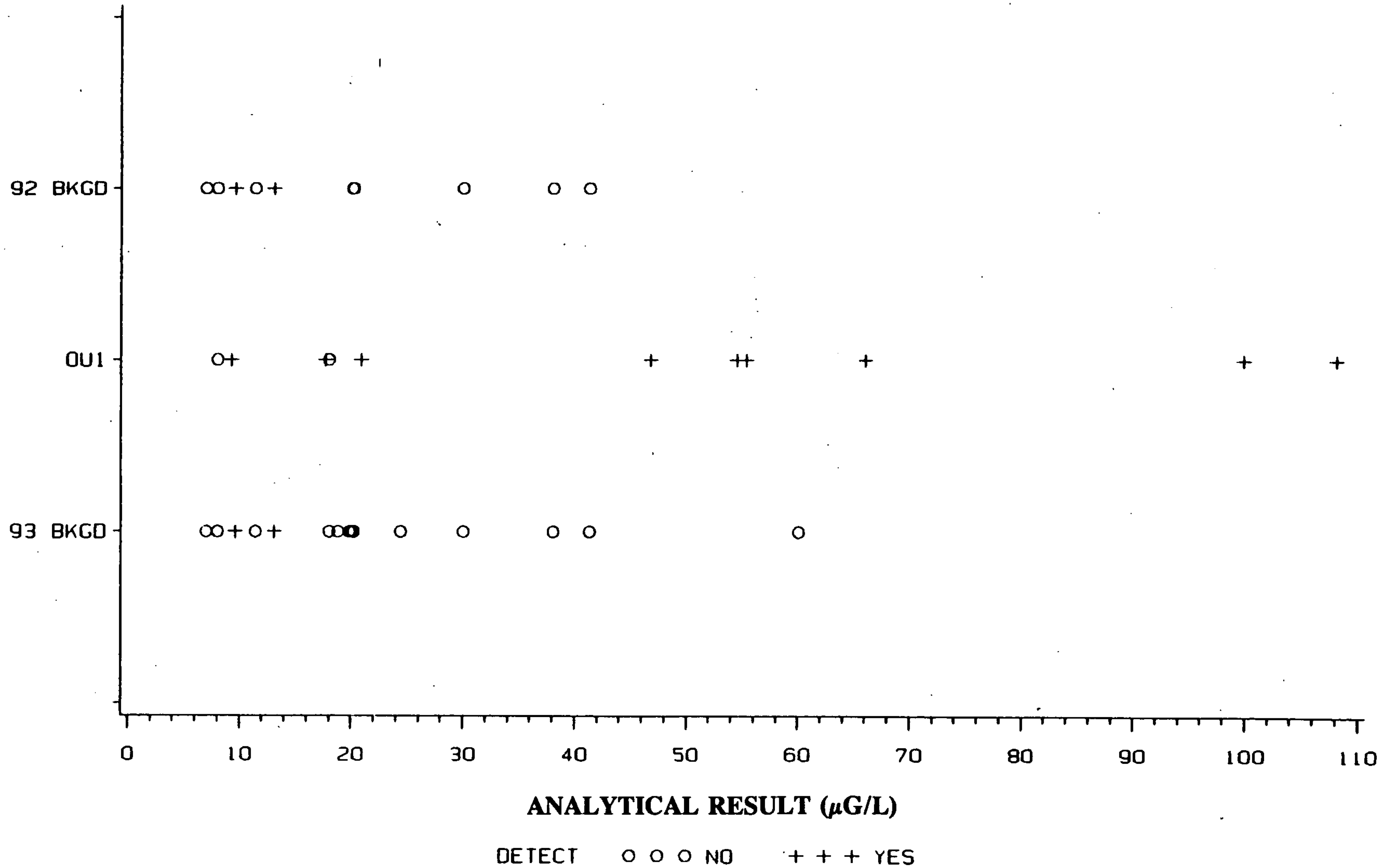


Figure 4-4

OU1 LOWER HSU DATA COMPARED TO 92 & 93 BACKGROUND DATA

GROUP=TOTAL ANALYTE=ANTIMONY



SAMPLE NUMBER GW017561T WAS DELETED FROM BACKGROUND DATA non-detects. The t-test was also not applicable due to the high rate of non-detects in the background data sets. Again, the extremely high percentage of non-detects renders conclusions drawn from this inferential statistical test uncertain.

Comparison of each OU result with the 1992 background $UTL_{99/99}$ (2,118 μg/L) shows that no result from OU1 exceeds the $UTL_{99/99}$. This indicates with 99 percent confidence, that none of the OU1 results for total antimony in LHSU groundwater fall outside of background values. No UTL was computed for the 1993 background data sets due to the high rate of non-detects Histograms show the distribution of detects and non-detects in the three data sets (Figure 4-5a, 4-5b, 4-5c).

4.2.3 Results of Statistical Comparisons for Dissolved Antimony in UHSU Groundwater

Although the range of concentrations of dissolved antimony in UHSU groundwater is similar for OU1 and background data sets (Figure 4-6), there is more clustering of low-end values in the background data set. Results of the statistical tests are shown below.

STATISTICS FOR DISSOLVED ANTIMONY IN UHSU GROUNDWATER

	N	%det	Gehan p-value	Slippage p-value	Quantile p-value	T-test p-value	$UTL_{99/99}$ (μg/L)	# > UTL
OU1	121	48.8%						
1992 BKG	149	38.3%	0.0001	0.1999	NA	NA	41.3	21
1993 BKG	248	28.2%	0.0001	0.1069	NA	NA	41.3	21

The p-values for the Gehan test indicate that the concentration of dissolved antimony in OU1 groundwater is significantly greater than background. However, the p-values for the slippage test indicate no statistically significant differences in the dissolved antimony concentration between UHSU groundwater and background. The quantile and t-tests were not applicable due to the high rate of non-detects in the background data sets.

Comparison of each OU result with the 1992 background $UTL_{99/99}$ (41.3 μg/L) shows that 21 results from OU1 exceed the $UTL_{99/99}$. This indicates, with 99 percent confidence, that 86 percent of the OU1 data for dissolved antimony in UHSU groundwater fall within

TOTAL ANTIMONY FOR OU1 LOWER HSU AND 92 & 93 BACKGROUNDS

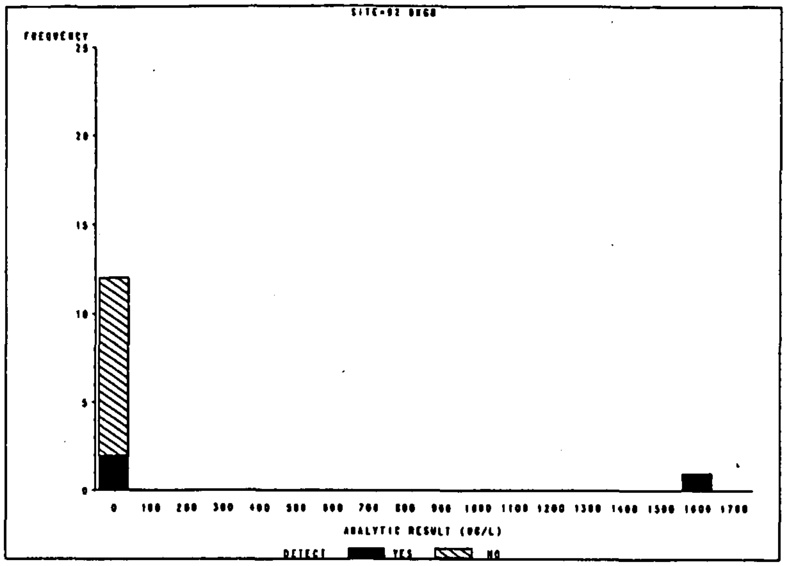


Figure 4-5a

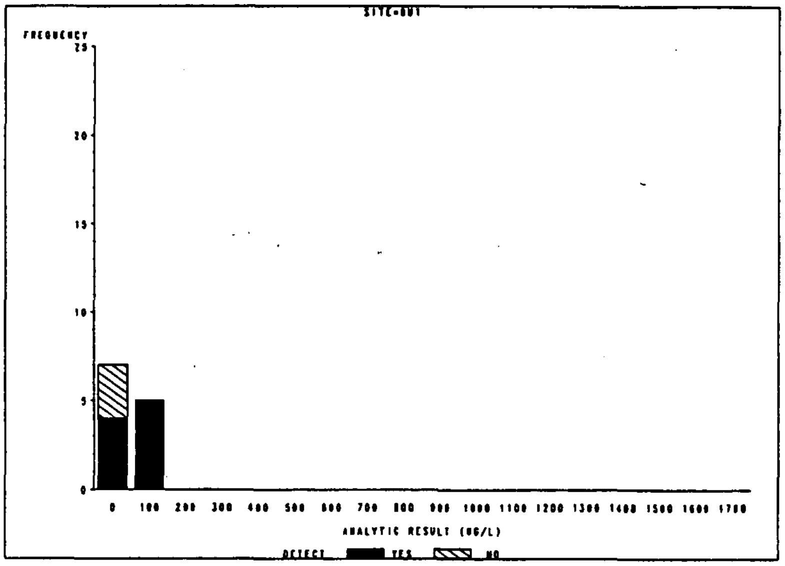


Figure 4-5b

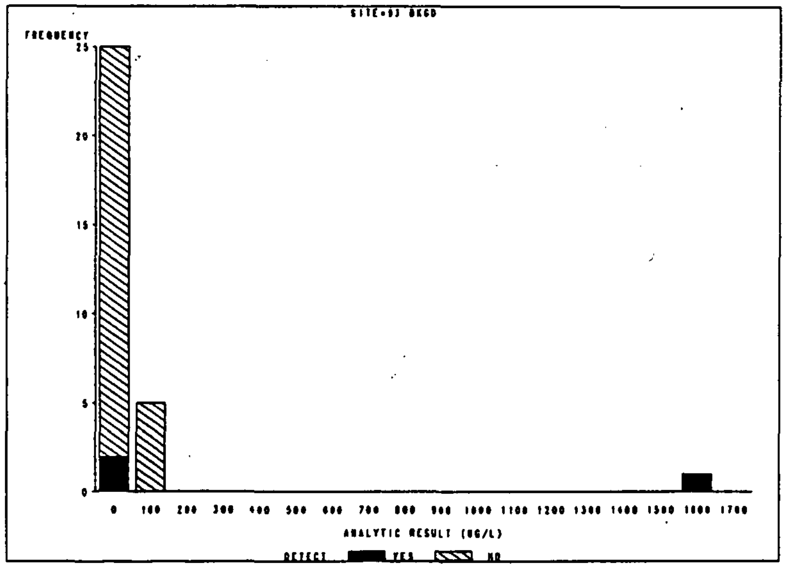
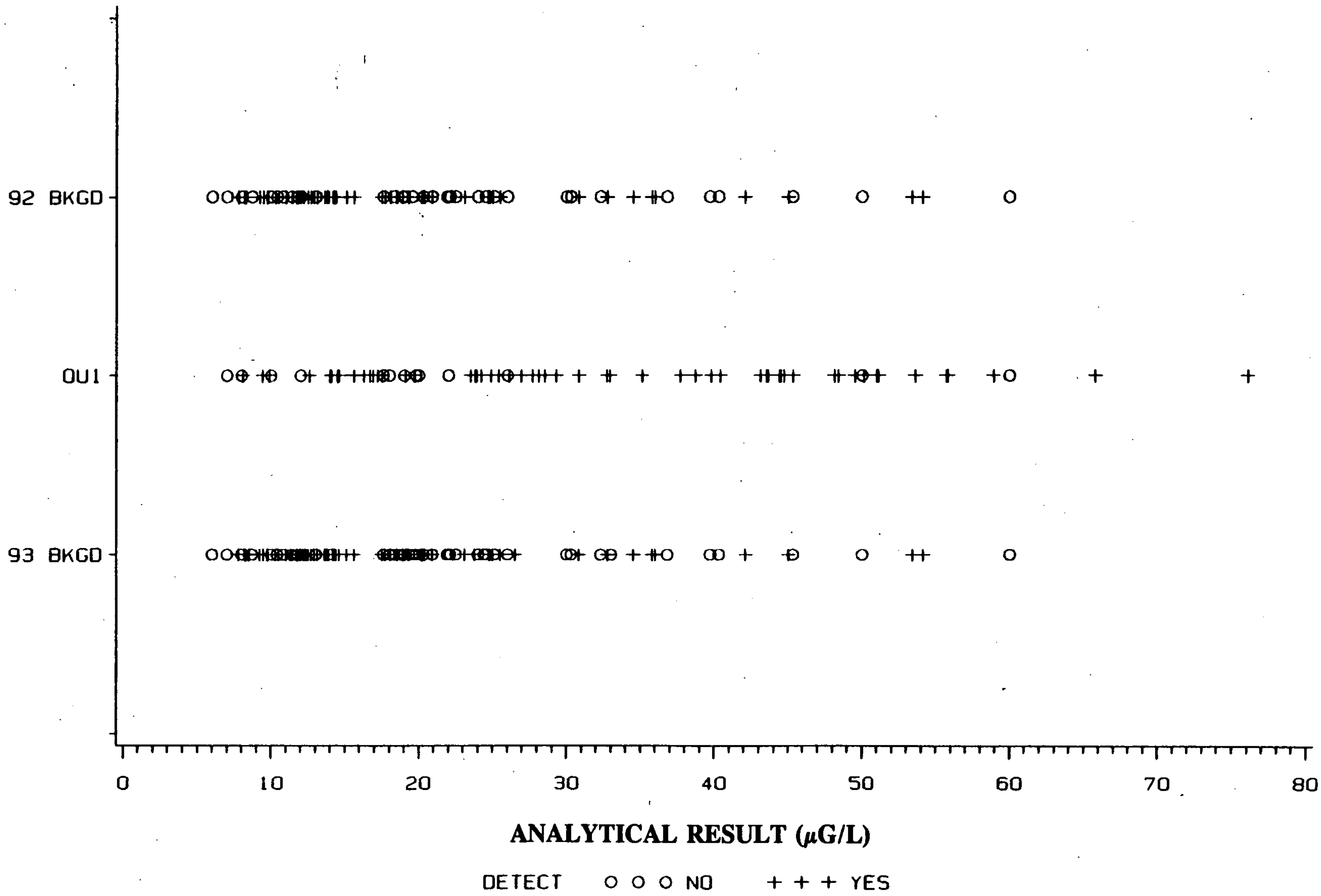


Figure 4-5c

Figure 4-6

OU1 UPPER HSU DATA COMPARED TO 92 & 93 BACKGROUND DATA

GROUP=DISSOLVED ANALYTE=ANTIMONY



background. For the 1993 background data set (UTL = 41.3 μg/L), the same result is obtained. Histograms show the distribution of detects and non-detects (lined bars) in the three data sets (Figures 4-7a, 4-7b, and 4-7c).

4.2.4 Results of Statistical Comparisons for Dissolved Antimony in LHSU Groundwater

The range of concentrations of dissolved antimony in LHSU groundwater is dissimilar for OU1 and background data sets (Figure 4-8). Results of the statistical tests are shown below.

STATISTICS FOR DISSOLVED ANTIMONY IN LHSU GROUNDWATER

	N	%det	Gehan p-value	Slippage p-value	Quantile p-value	T-test p-value	$UTL_{99/99}$ (μg/L)	# > UTL
OU1	28	57.1%						
1992 BKG	39	30.8%	0.0008	0.0683	NA	NA	39.4	7
1993 BKG	63	23.8%	0.0001	0.0270	NA	NA	39.8	6

The p-values for the Gehan test indicate that the concentration of dissolved antimony in OU1 groundwater is statistically significantly greater than background. The p-value for the slippage test using the 1992 background data indicate no statistically significant differences in the dissolved antimony concentration between LHSU groundwater at OU1 and background. However, the slippage p-value using the 1993 background data does indicate a statistically significant difference. The quantile and t-tests were not applicable due to the high percentage of non-detects.

Comparison of each OU result with the 1992 and 1993 background $UTL_{99/99}$ values (39.4 and 39.8 μg/L, respectively) indicates that six to seven results from OU1 exceed the $UTL_{99/99}$ values. Therefore, with 99 percent confidence, less than 10 percent of the OU1 results for dissolved antimony in LHSU groundwater fall outside the background values. Histograms show the distribution of detects and non-detects in the three data sets (Figures 4-9a, 4-9b, 4-9c).

DISSOLVED ANTIMONY FOR OU1 UPPER HSU AND 92 & 93 BACKGROUNDS

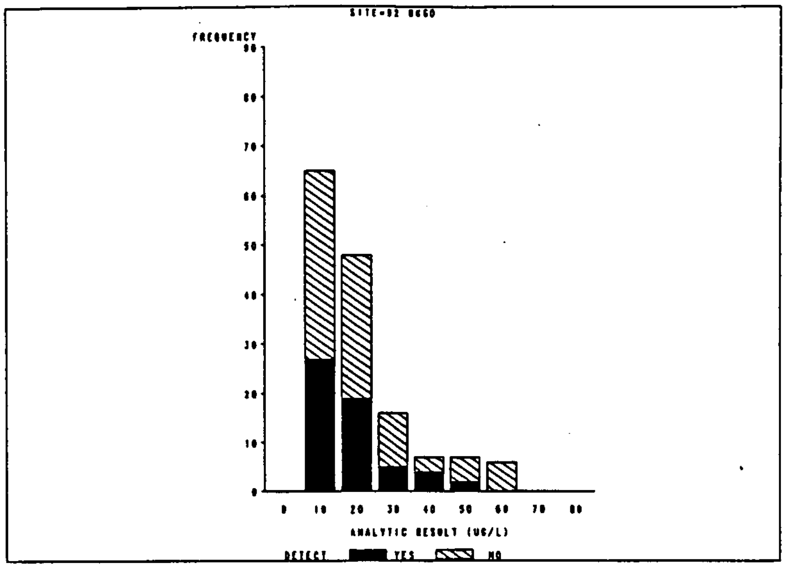


Figure 4-7a

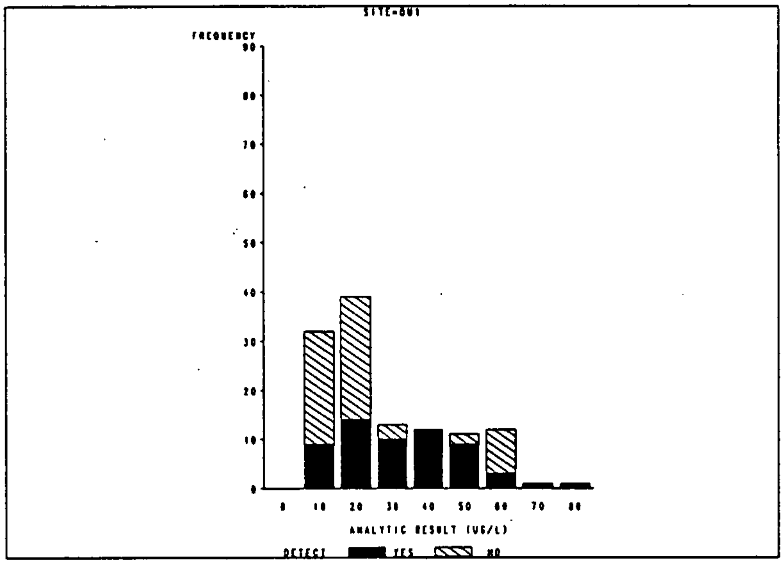


Figure 4-7b

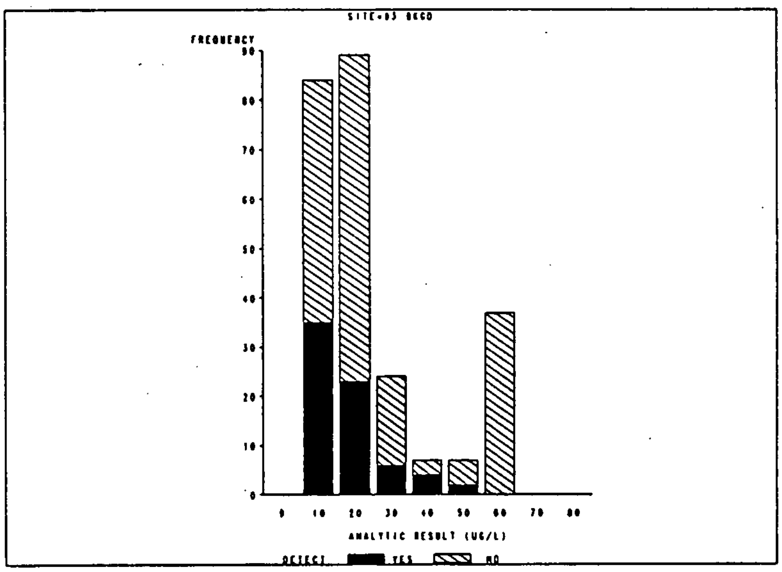
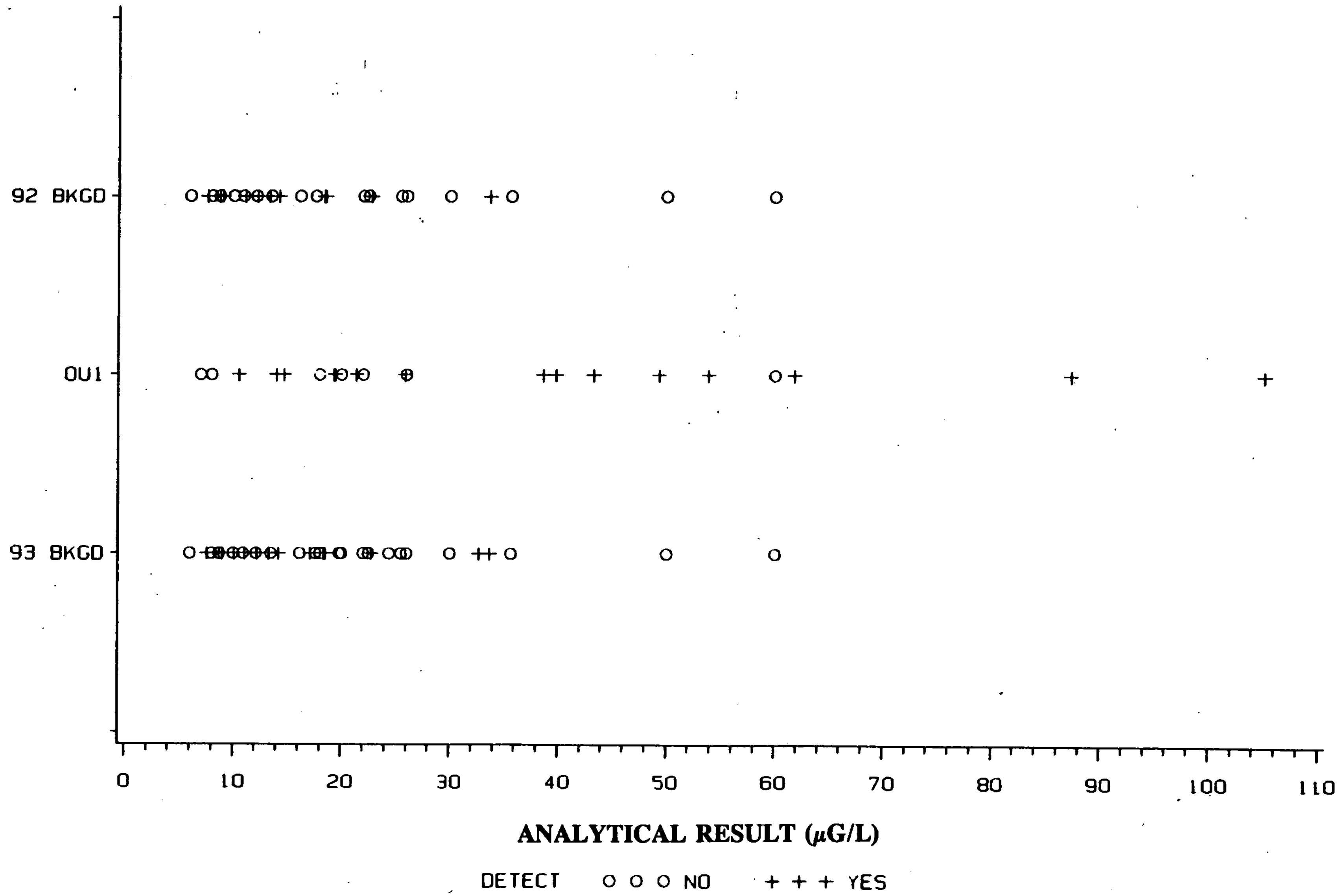


Figure 4-7c

Figure 4-8

OU1 LOWER HSU DATA COMPARED TO 92 & 93 BACKGROUND DATA

GROUP=DISSOLVED ANALYTE=ANTIMONY



DISSOLVED ANTIMONY FOR OU1 LOWER HSU AND 92 & 93 BACKGROUNDS

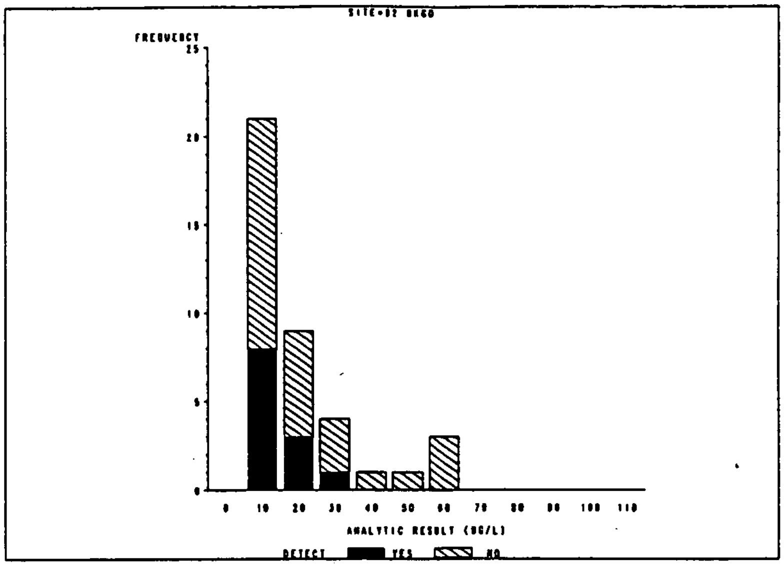


Figure 4-9a

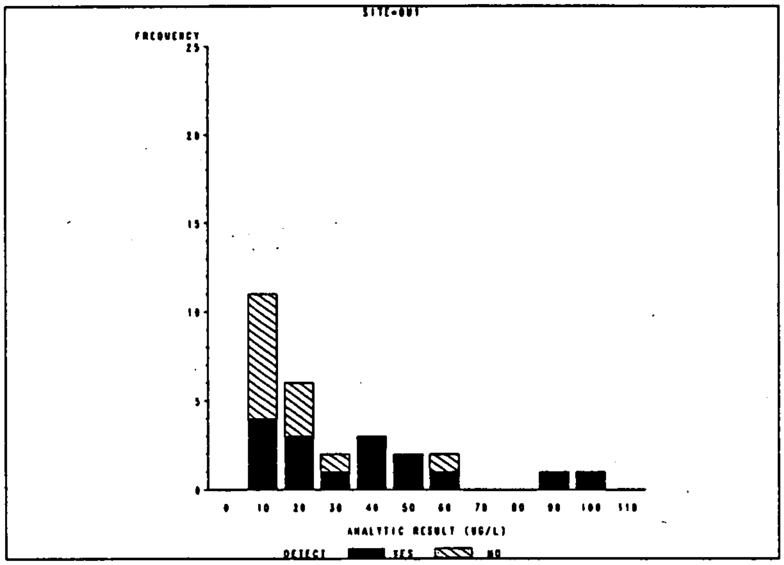


Figure 4-9b

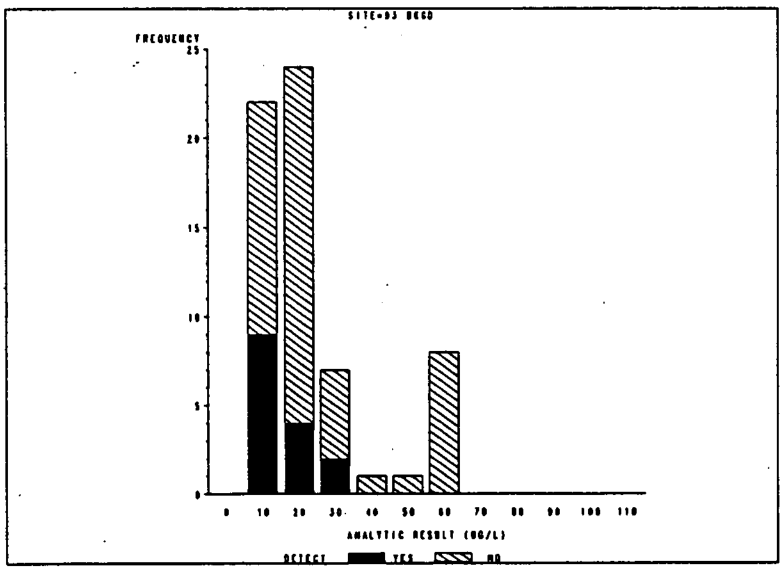


Figure 4-9c

4.2.5 Conclusions

The Gehan test results indicate that antimony concentrations in OU1 groundwater are significantly higher than background; however, this conclusions was often not supported by the slippage test results. Generally, there were too few detects to conduct the quantile and t-test. The detection rate for antimony in background is generally less than 20 to 30 percent; therefore, applying inferential statistics, such as the Gehan test, to such highly censored data sets is inappropriate and misleading. As noted by Helsel (1990), for highly censored data sets, the outcome of the statistical tests is "...strongly dependent on the value substituted!" Helsel (1990) goes on to state that "...fabrication of data followed by a t-test must be considered too arbitrary for use, especially for legal or management decision purposes, and should be avoided." Therefore, there is considerable uncertainty as to whether antimony in groundwater at OU1 is higher than background.

4.3 PROFESSIONAL JUDGMENT

In accordance with the Gilbert method, the OU1 data have been reviewed to determine if antimony is actually a contaminant of OU1 groundwater. Consideration of other information is particularly important for antimony because the use of inferential statistics may be inappropriate and misleading due to the low rate of detections. These other considerations include:

- Historical use and/or disposal of antimony at RFP.
- Horizontal, vertical, and temporal patterns of antimony concentrations in OU1 groundwater.
- Evidence of natural differences in geochemistry of water bearing materials between OU1 and background.
- Effects due to well construction and sampling procedures.
- Potential for false positive or high bias in antimony analytical results due to interference by aluminum.

4.3.1 Historical Use of Antimony at RFP

Based on the Historical Release Report for the Rocky Flats Plant (DOE, 1992), there are no records of antimony use in any RFP processes, or of its disposal or storage at OU1.

4.3.2 Pattern Recognition

Figure 4-10 illustrates the distribution of antimony in UHSU and LHSU groundwater. Examination of the spatial distribution of the antimony results does not indicate the presence of concentration gradients indicative of a "source." Exceedances of the background UTL (calculated from the OU1 RFI/RI report [DOE, 1993]) occurs in four wells (UHSU and LHSU) within OU1. Three of these wells are located within IHSS 119.1; however, there is no discernable concentration gradient either vertically or horizontally. One sample of groundwater collected from well 1074 yielded an elevated antimony concentration (77 $\mu g/\ell$ on 22 August 1991). This well has also yielded groundwater with relatively high levels of volatile organic compounds (VOCs). Although the co-occurrence of elevated antimony with VOCs may be an indication of antimony contamination, the exceedance of the antimony UTL was marginal, and antimony was not detected in a subsequent sample collected from this well (18U $\mu g/\ell$).

Concentration versus time graphs were prepared for those stations where the UTL was exceeded (Figures 4-11 through 4-14). None of these stations showed consistently high concentrations of antimony. Only one well (37191) contained antimony at a concentration more than 2 times the UTL (70U $\mu g/\ell$). This high detection (210 $\mu g/\ell$) was a one-time occurrence, and the data from successive quarters show antimony was undetected. The large disparity in concentration values from one sampling period to the next is inconsistent with the presence of contamination.

4.3.3 Natural Differences Between OU1 and Background

See Section 3.3.3 for this discussion.

FIGURE 4-11

Total Antimony in Well 37191

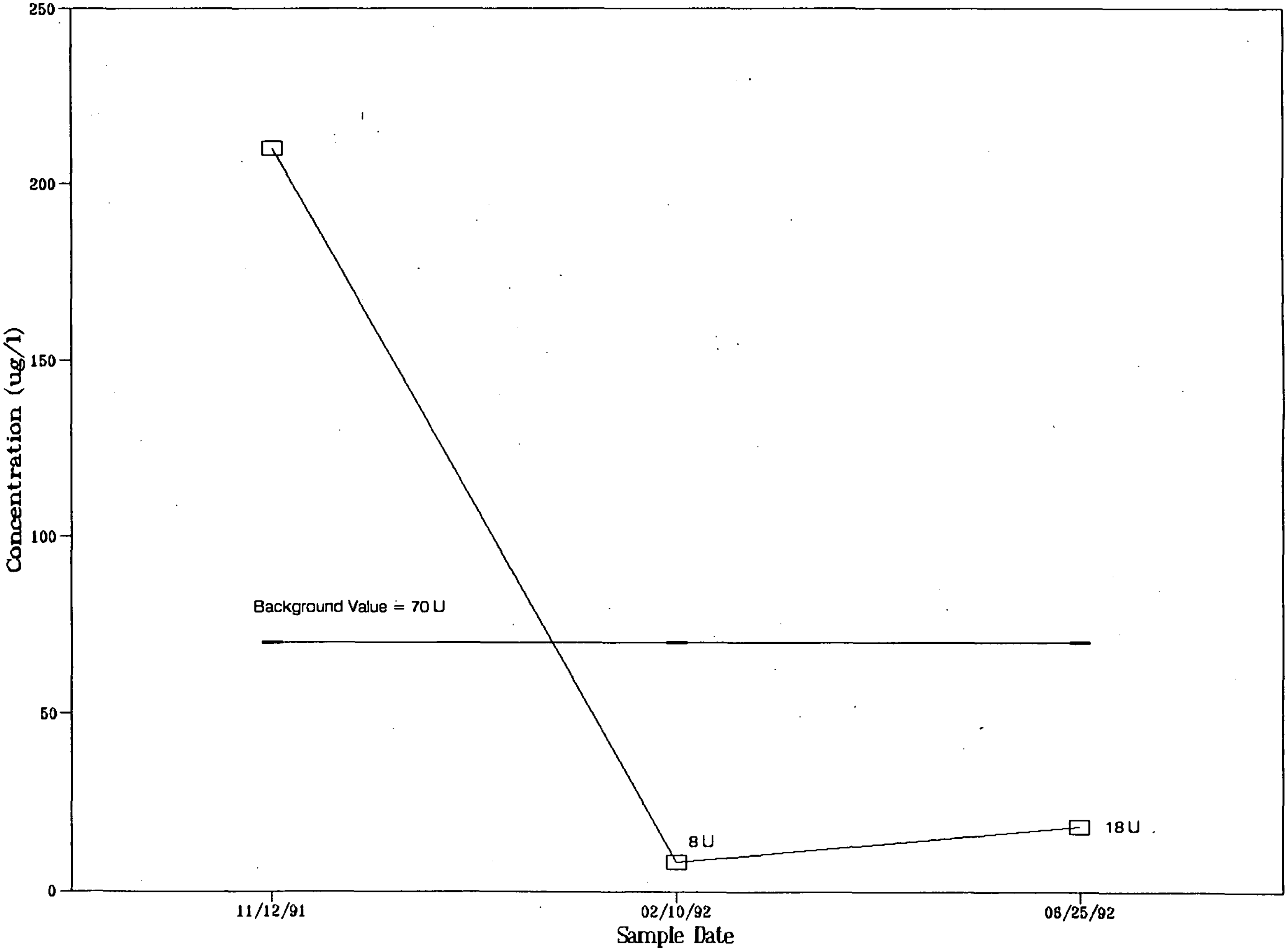


FIGURE 4-12

Total Antimony in Well 37991

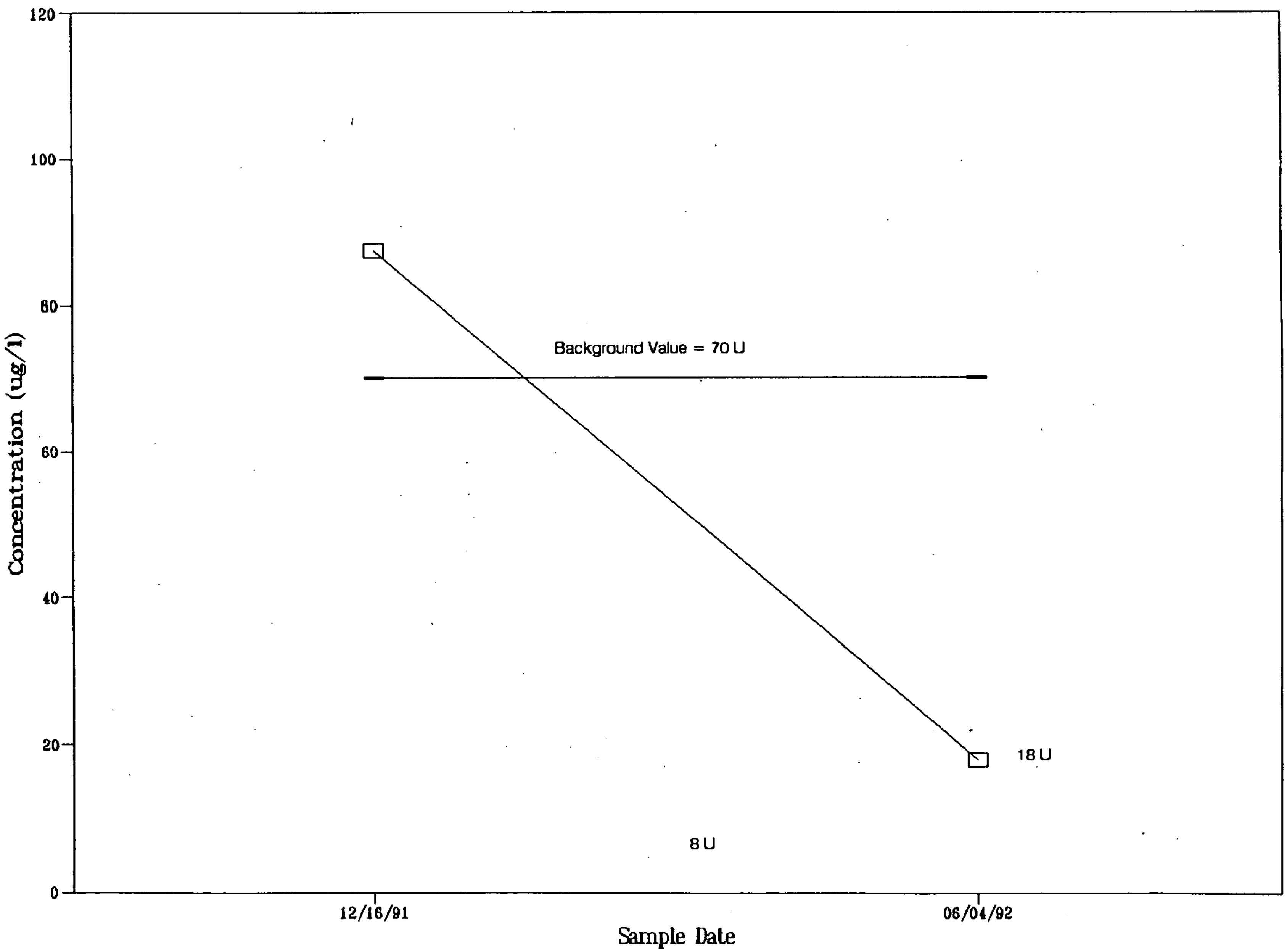


FIGURE 4-13

Total Antimony in Well 0587

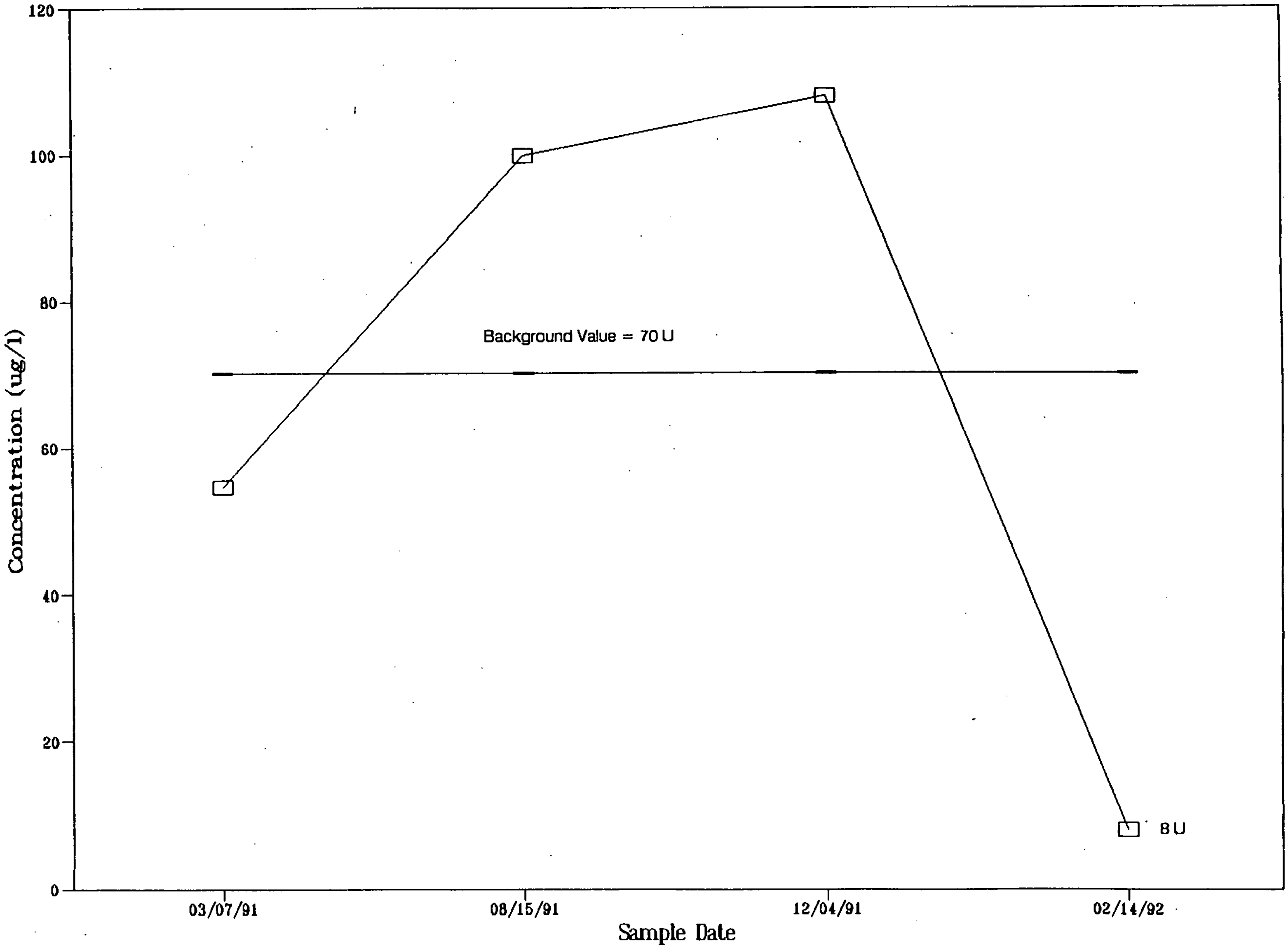
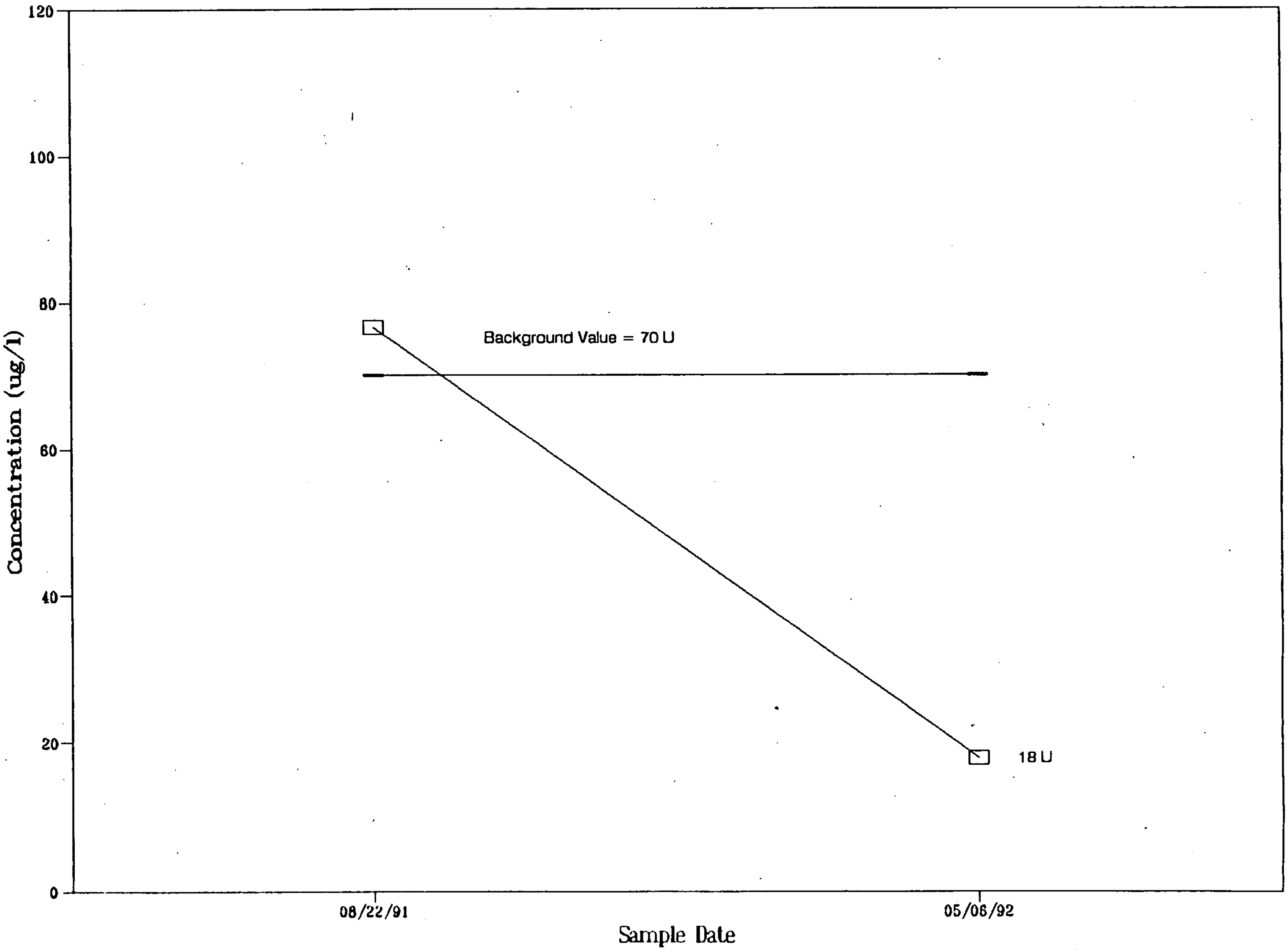


FIGURE 4-14

Total Antimony in Well 1074



4.3.4 Well Construction/Sampling Effects

See discussion in Section 3.3.4, which is applicable to antimony.

4.3.5 Potential for False Positive Analytical Results

Based on information provided by QUANALEX, the independent data validator for RFP-generated data, the potential exists for false positive inductively coupled plasma (ICP) analytical results for antimony in the presence of several potential interferents. As can be seen on Table 4-1, aluminum, chromium, titanium, and vanadium can acts as interferents to varying degrees. Of these elements, only aluminum is present in OU1 and background groundwaters at high enough concentrations to have an appreciable effect on antimony analytical results. According to Table 4-1, the presence of 100 mg/ℓ of aluminum can result in an antimony value of 0.47 mg/ℓ when no antimony is present. For those OU1 wells where antimony exceeds the background UTL, the aluminum concentrations are as high as 200 mg/ℓ. Therefore, according to Table 4-1, the potential exists for antimony results to be biased high by as much as 0.940 mg/ℓ. QUANTATEX has qualified most of the detected antimony results as "estimated" either due to this interference or as a result of detectable concentrations of antimony in the laboratory blanks. The antimony concentration in the 12 November 1991 sample from well 37191 (highest antimony concentration in OU1 data set) is qualified as "estimated" because of the aluminum interference. Figure 4-15 and 4-16 show that antimony and aluminum concentrations are somewhat correlated, and also indicate the qualified data points.

4.3.6 Conclusion

The low rate of UTL exceedances, the lack of concentration gradients, and the high temporal variations in concentrations argues against classification of antimony as an OU1 groundwater contaminant. In particular, the detections of antimony in the UHSU are, with very few exceptions, consistently less than the contract-required detection limit (CRDL) of 60 μg/ℓ. Additionally, the presence of antimony in the water is uncertain because of analytical interference in its measurement.

NOTICE:

The following page has been misnumbered when originally printed. No pages are missing from this document.

The Administrative Record Staff

Table 4-1

Example of Analyte Concentration Equivalents (mg/ℓ) Arising from Interferents at the 100 mg/ℓ Level

Analyte	Wavelength, nm	Interferent									
		Al	Ca	Cr	Cu	Fe	Mg	Mn	Ni	Ti	V
Aluminum	308.215	—	—	—	—	—	—	0.21	—	—	1.4
Antimony	206.833	0.47	—	2.9	—	0.08	—	—	—	.25	0.45
Arsenic	193.696	1.3	—	0.44	—	—	—	—	—	—	1.1
Barium	455.403	—	—	—	—	—	—	—	—	—	—
Beryllium	313.042	—	—	—	—	—	—	—	—	0.04	0.05
Boron	249-773	0.04	—	—	—	0.32	—	—	—	—	—
Cadmium	226.502	—	—	—	—	0.03	—	—	0.02	—	—
Calcium	317.933	—	—	0.08	—	0.01	0.01	0.04	—	0.03	0.03
Chromium	267.716	—	—	—	—	0.003	—	0.04	—	—	0.04
Cobalt	228.616	—	—	0.03	—	0.005	—	—	0.03	0.15	—
Copper	324.754	—	—	—	—	0.003	—	—	—	0.05	0.02
Iron	259.940	—	—	—	—	—	—	0.12	—	—	—
Lead	220.353	0.17	—	—	—	—	—	—	—	—	—
Magnesium	279.079	—	0.02	0.11	—	0.13	—	0.25	—	0.07	0.12
Manganese	257.610	0.005	—	0.01	—	0.002	0.002	—	—	—	—
Molybdenum	202.030	0.05	—	—	—	0.03	—	—	—	—	—
Nickel	231.604	—	—	—	—	—	—	—	—	—	—
Selenium	196.026	0.23	—	—	—	0.09	—	—	—	—	—
Silicon	288.158	—	—	0.07	—	—	—	—	—	—	0.01
Sodium	588.995	—	—	—	—	—	—	—	—	0.08	—
Thallium	190.864	0.30	—	—	—	—	—	—	—	—	—
Vanadium	292.402	—	—	0.05	—	0.005	—	—	—	0.02	—
Zinc	213.856	—	—	—	0.14	—	—	—	0.29	—	—

FIGURE 4-15

Antimony vs. Aluminum Concentrations
Total Metals in Groundwater

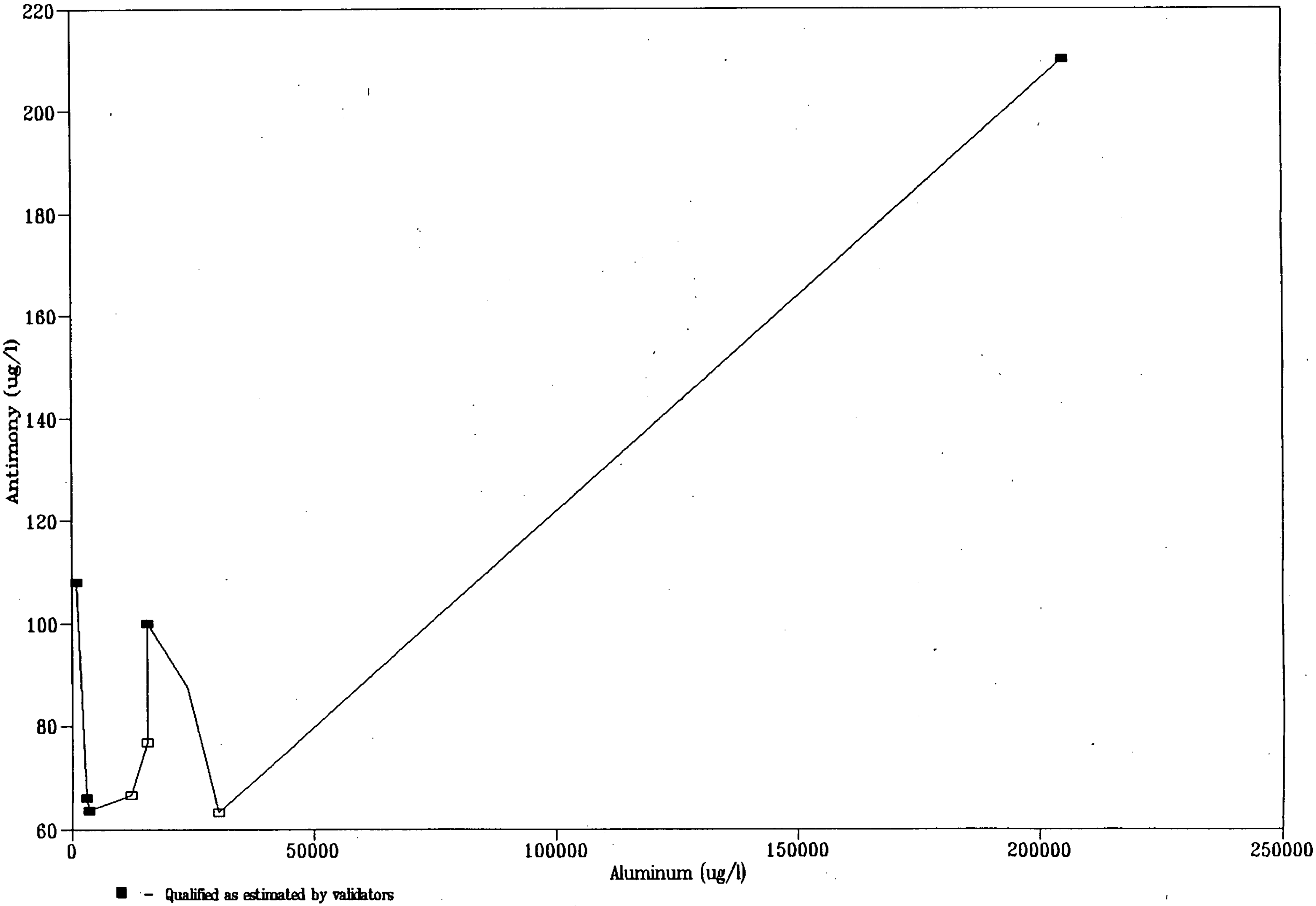
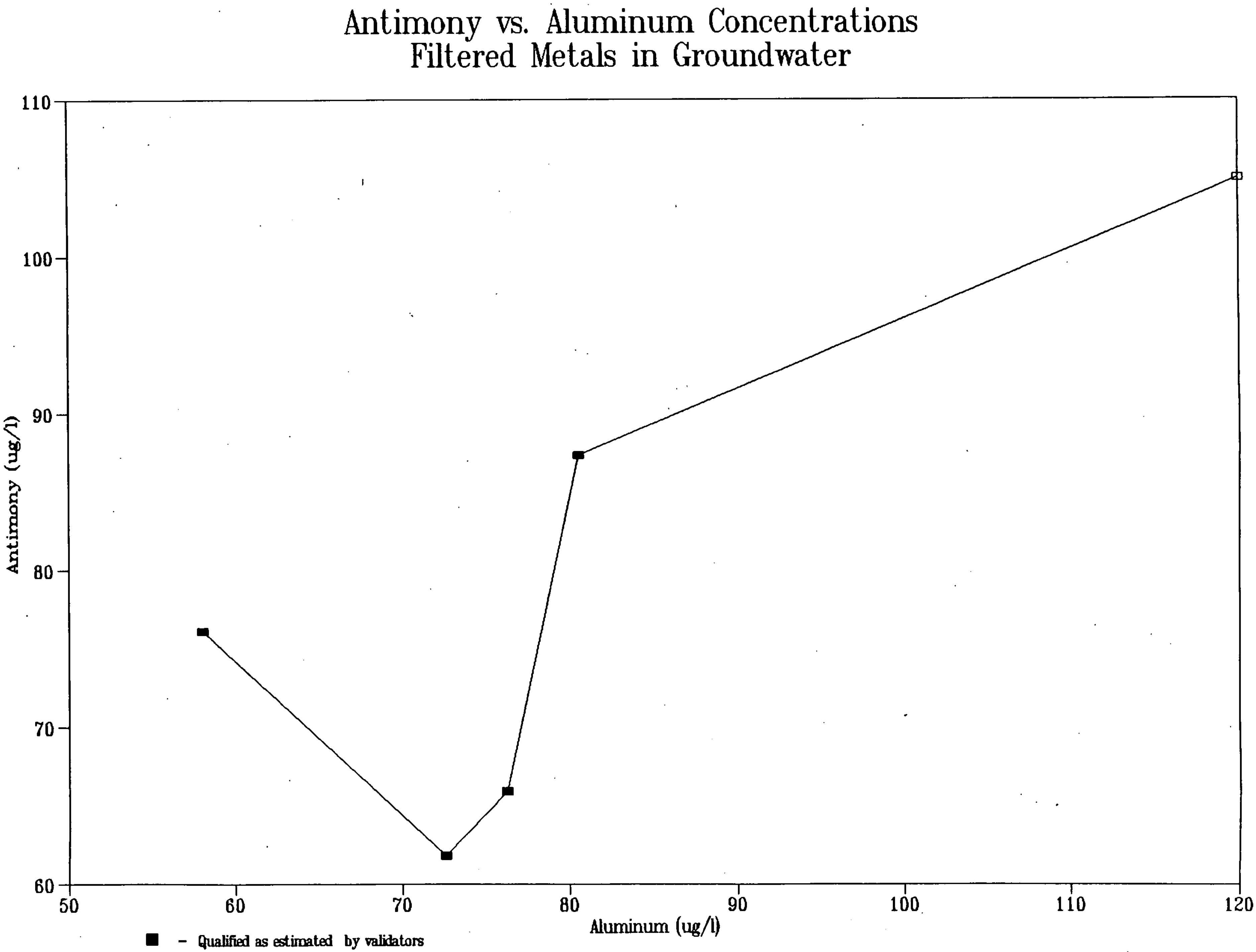


FIGURE 4-16


Antimony vs. Aluminum Concentrations
Filtered Metals in Groundwater
110
100
90
80
70
60
Antimony (ug/l)
50
60
70
80
90
100
110
120
Aluminum (ug/l)
■ - Qualified as estimated by validators

Based on hydrogeology, geochemistry, geology, and chemical analysis considerations, as well as the spatial and temporal distribution of antimony in OU1 groundwater, antimony is not considered a contaminant of groundwater at OU1.

SECTION 5

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APPENDIX A

MANGANESE AND ANTIMONY DATA

Appendix A contains a printout of the OU1 data for manganese and antimony. The data are sorted by location ("LOCATION") and by analyte ("CHEMICAL"). The date of sample collection ("SAMP_DAT"), analytical result or concentration ("RESULT"), unit measure ("UNIT"), reported detection limit ("DETLIMIT"), lab qualifier ("QUALIFIE"), and validation code ("VFLAG") are also presented in this printout.

A lab qualifier containing "U" designates a concentration that was below the instrumental detection limit (i.e., a non-detect). A qualifier containing a "B" designates a concentration that was above the instrumental detection limit, but below the contract-required detection limit, and is therefore considered an estimated concentration. The qualifier "E" indicates a sample concentration that exceeded the linear working range of the analytical instrument; this necessitates a dilution and reanalysis of the sample.

The validation code is assigned by an independent, third-party subcontractor. Acceptable data are coded "A," "JA," or "V." Unsuitable or rejected data are coded with an "R." No rejected data were used in the statistical or graphical analyses for this report.

APPENDIX B

SPATIAL ANALYSIS OF BACKGROUND GROUNDWATER WELL LOCATIONS

APPENDIX B

SPATIAL ANALYSIS OF BACKGROUND GROUNDWATER WELL LOCATIONS

B.1 STATEMENT OF PROBLEM

It is entirely possible that the alleged "plumes" of groundwater at OU1 with elevated metals content (manganese [Mn] and antimony [Sb] in this case) is a naturally occurring geochemical feature. There are two possible reasons for this phenomenon:

1. The background data area is not extensive enough to include this geochemical feature.

2. The background well spacing is so distant that the geochemical feature would not be detected, even if present.

Addressing the fist limitation would require determining the areal frequency of this feature in an area considerably larger than the Rocky Flats Plant (RFP) background area. This would require an extensive well installation and monitoring program, and thus is far beyond the scope of the OU1 RFI/RI report.

However, an assessment of the second issue can be provided without initiating field sampling programs. This analysis is based soley on the spacing of the RFP background wells and involves a simple numerical simulation.

B.2 METHODOLOGY

The numerical simulation was conducted as follows:

1. A random location (X,Y) was selected within the background area. This random location represents the center of a hypothetical mineralized water feature.

2. The distance from this random location X,Y to the nearest background well was determined. This distance is therefore the radius of the smallest possible mineralize water feature that could be centered at X,Y and still be detected by one of the background wells.

3. This radius (the result for one individual trial) is recorded.

4. Steps 1 through 3 were repeated numerous times. In this analysis, 1,000 trials were used. A table was then created of distributions of the radii of hypothetical circular features, centered at random locations, that could be detected by any background well.

5. By simply sorting this table by radius and assigning cumulative frequencies to each trial, a table of the frequency of detection (in percent) of hypothetical circular features of increasing sizes was derived. To illustrate:

   The smallest radius encountered is the first trial in the table after sorting. This trial is assigned a probability of 0.001, or 0.10% (1 out of 1,000). The second-smallest radius is the second trial in the table, and is assigned a cumulative probability of 0.002 or 0.20% (2 out of 1,000). The 500th trial is assigned 50% and the last trial (having the greatest distance to a neighboring well) is assigned a cumulative probability of 100%.

   Therefore, this table quantifies for a hypothetical circular feature of a given radius the probability of detecting that feature by a background well.

B.3 ASSUMPTIONS

The following assumptions were made in performing these calculations:

1. One background well must intersect the mineralized water feature in order to detect the feature. Realistically, it might have been better to require that two or three adjacent wells penetrate the feature to be sure that it is identified as such. However, to avoid being overly restrictive and causing the numerical simulation to score "hits" only rarely, it is assumed that one well hitting the feature is sufficient.

2. The mineralized water feature found at OU1 is roughly circular and approximately 300 feet in radius. We are primarily interested in quantifying our ability to detect and identify a circular feature with a 300 foot radius.

3. The randomly selected locations for hypothetical deposits of mineralized water were required to be within the background areas shown in Figures B-1 and B-2.

4. No effort was made to separate the background wells by UHSU or LHSU. Even though it would be appropriate to differentiate the background wells by flow system, removing wells from the data set would only serve to reduce the number of detections and thereby strengthen the argument that the wells are too far apart to reliably identify deposits of mineralized water.

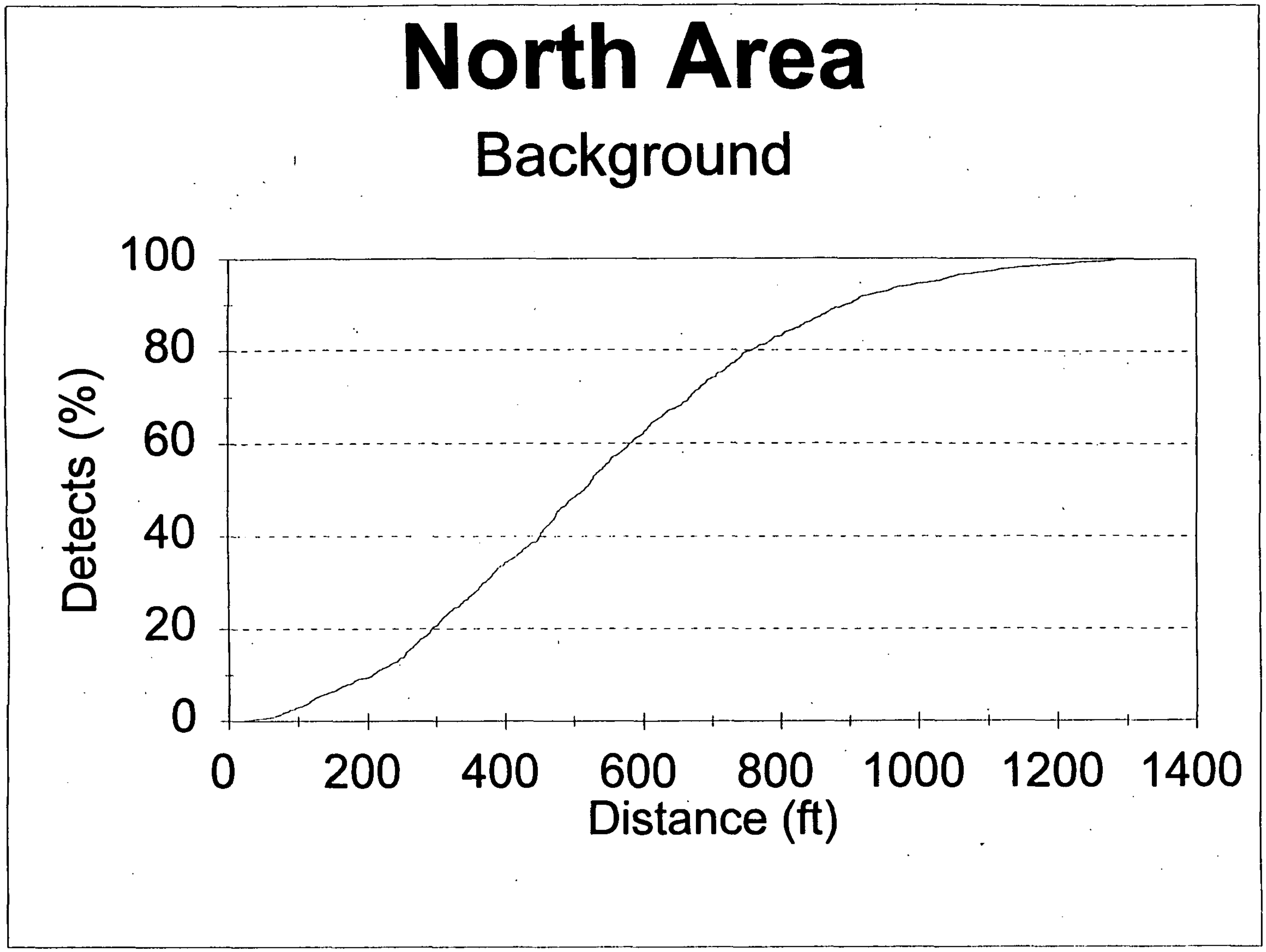
5. One thousand trials should be a sufficient number of trials to assess the probability of detecting geochemical features of various sizes.

B.4 RESULTS OF SIMULATION

Figure B-3 through B-6 display the results of the 1,000 trial simulation for both the north and south background areas. The radius of hypothetical mineralized water deposits are plotted along the X-axis. The Y-axis represents the percentage of trials in which deposits of radius X are detected by a background well. These graphs are presented for the frequency of detection range of 0 to 100%, and also for the radius of deposit range 0 to 500 feet. The results are also presented numerically in the summary table below.

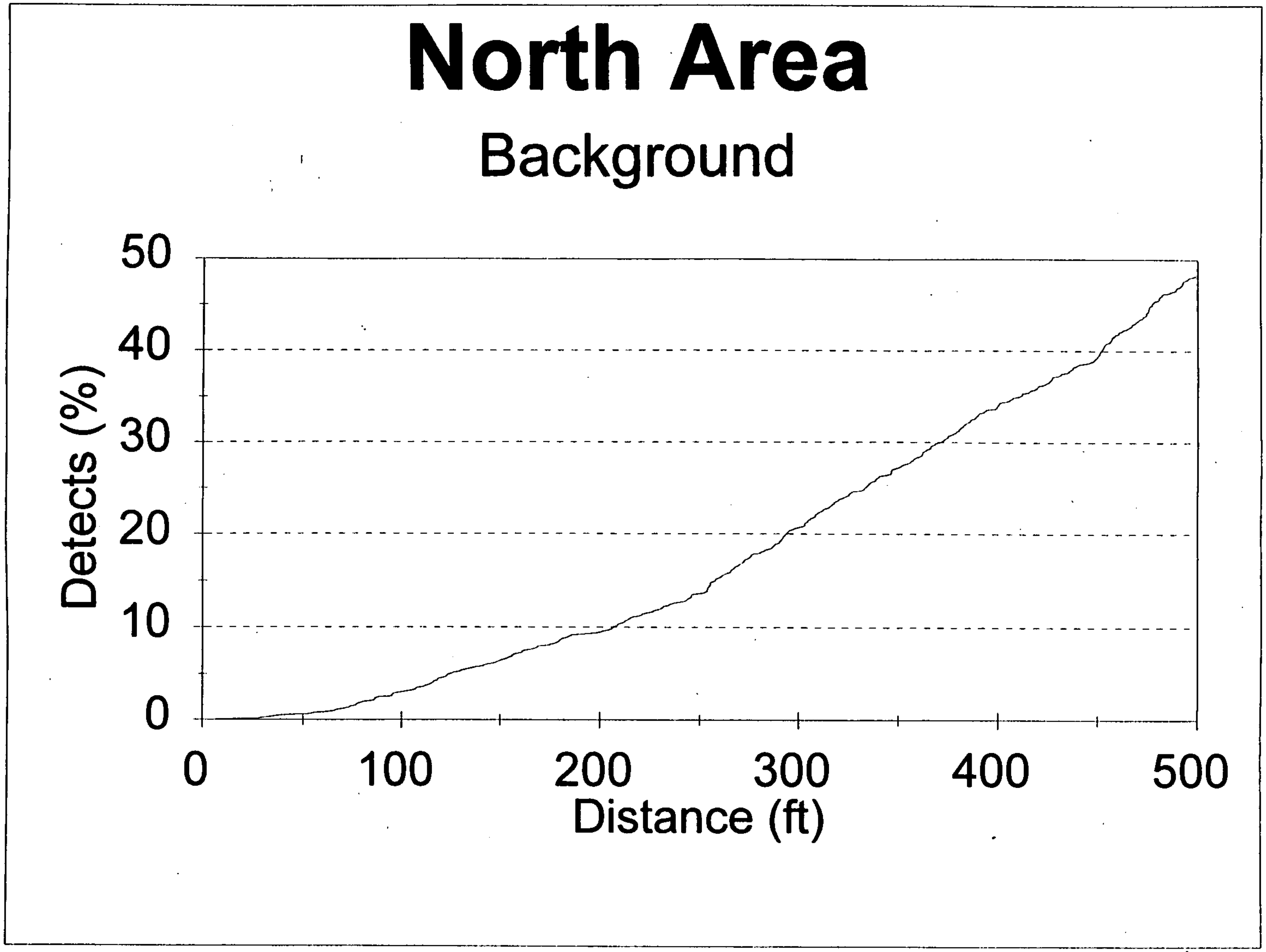
Radius	Percent Detected	
	North	South
100	3.0	1.0
200	9.5	3.6
300	20.8	7.0
400	34.1	11.3
500	48.4	16.2
600	62.0	22.8
700	73.9	27.1
800	83.1	32.9
900	90.2	38.6
1,000	94.5	44.5
1,100	97.2	50.8
1,200	98.9	56.2
1,300		65.2
1,400		73.3
1,500		78.2
1,600		84.4
1,700		88.5
1,800		91.6
1,900		93.7
2,000		95.7
2,100		96.7
2,200		97.6
2,300		98.7
2,400		99.3
2,500		99.6

B2029B4



U.S. DEPARTMENT OF ENERGY Rocky Flats Plant Golden, Colorado	SIMULATION RESULTS FOR NORTH AREA Scale: 0 to 1400 Feet	FIGURE B-3

B2029B4



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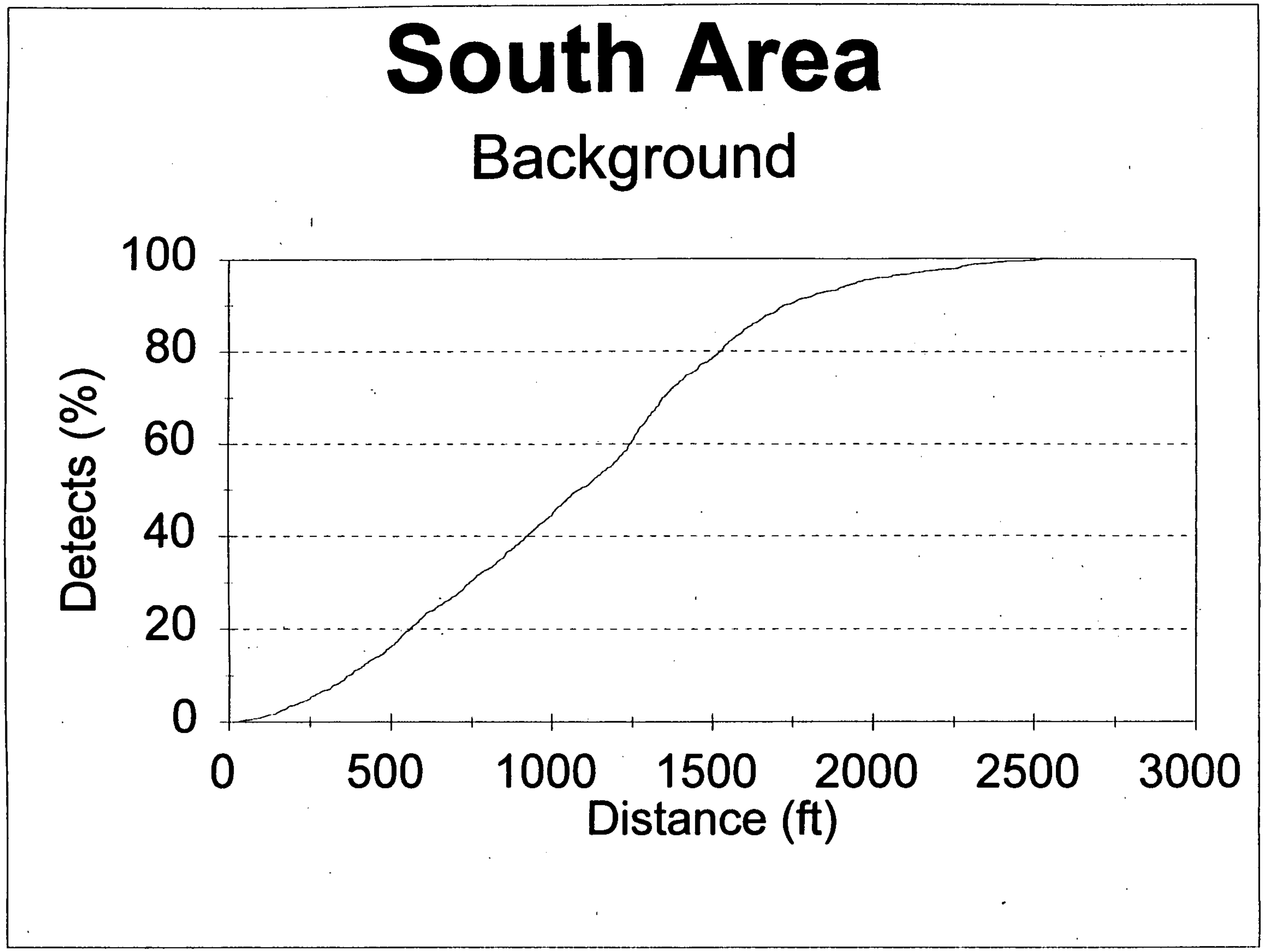
Rocky Flats Plant
Golden, Colorado

SIMULATION RESULTS FOR NORTH AREA
Scale: 0 to 500 Feet

FIGURE B-4

B2029B4



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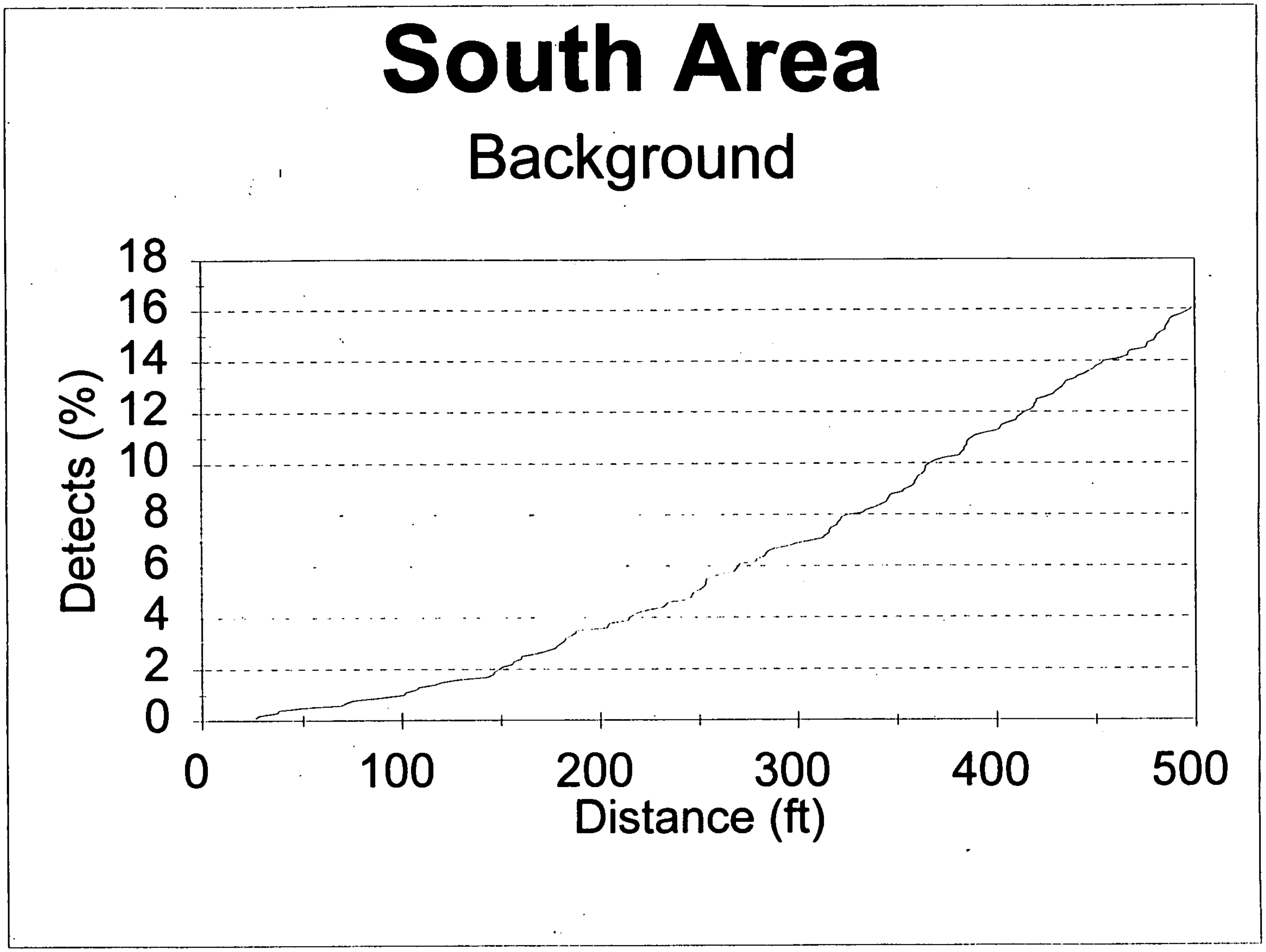
Golden, Colorado

SIMULATION RESULTS FOR SOUTH AREA
Scale: 0 to 3000 Feet

FIGURE
B-5

B2029B4



U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant
Golden, Colorado

SIMULATION RESULTS FOR SOUTH AREA
Scale: 0 to 500 Feet

FIGURE B-6

B.5 CONCLUSIONS

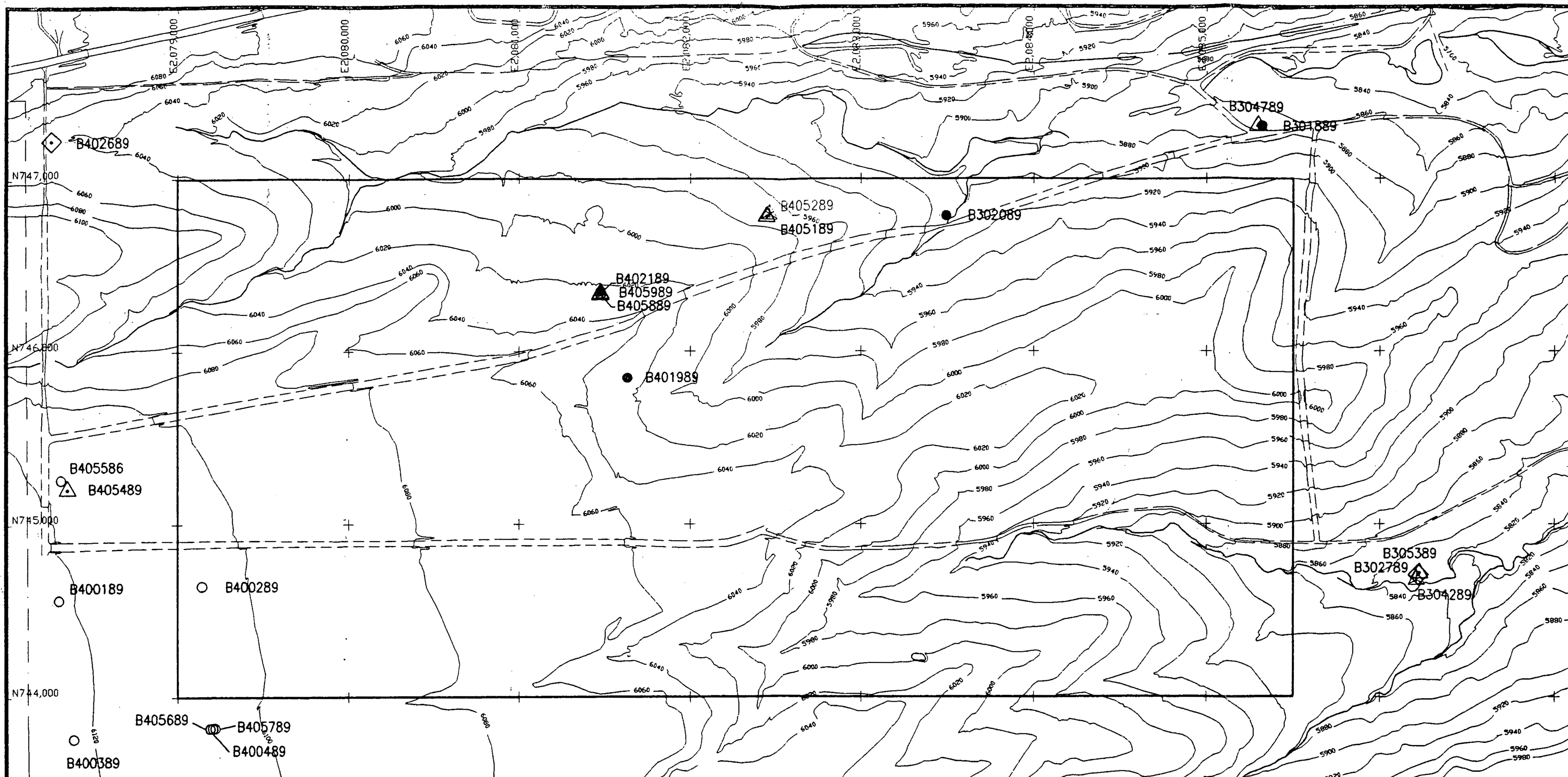
At OU1, there ia a 300-foot radius feature of groundwater with elevated metals content. There is a low probability that a hydrologic feature of this size would be detected by the background wells. The probability of detecting this feature with the northern background wells is only 21 percent. In the south area, which can be considered more representative of OU1 background, the probability of detecting such a feature is only 7 percent.

North Area Background Chart

North Area Background Chart

South Area Background Chart

South Area Background Chart



EXPLANATIONS

B405586 ○ BACKGROUND ROCKY FLATS ALLUVIAL MONITORING WELL

B201089 ● BACKGROUND COLLUVIAL MONITORING WELL

B402689 ◇ VALLEY FILL ALLUVIAL MONITORING WELL

B405189 △ WEATHERED CLAYSTONE BACKGROUND BEDROCK MONITORING WELL

B402189 △ WEATHERED NON-SUBCROPPING SANDSTONE BACKGROUND BEDROCK MONITORING WELL

B405289 △ UNWEATHERED SANDSTONE BACKGROUND BEDROCK MONITORING WELL

N

0 600' 1200'

SCALE: 1 INCH = 600 FEET
CONTOUR INTERVAL = 20 FEET

R74300.MB041494/600

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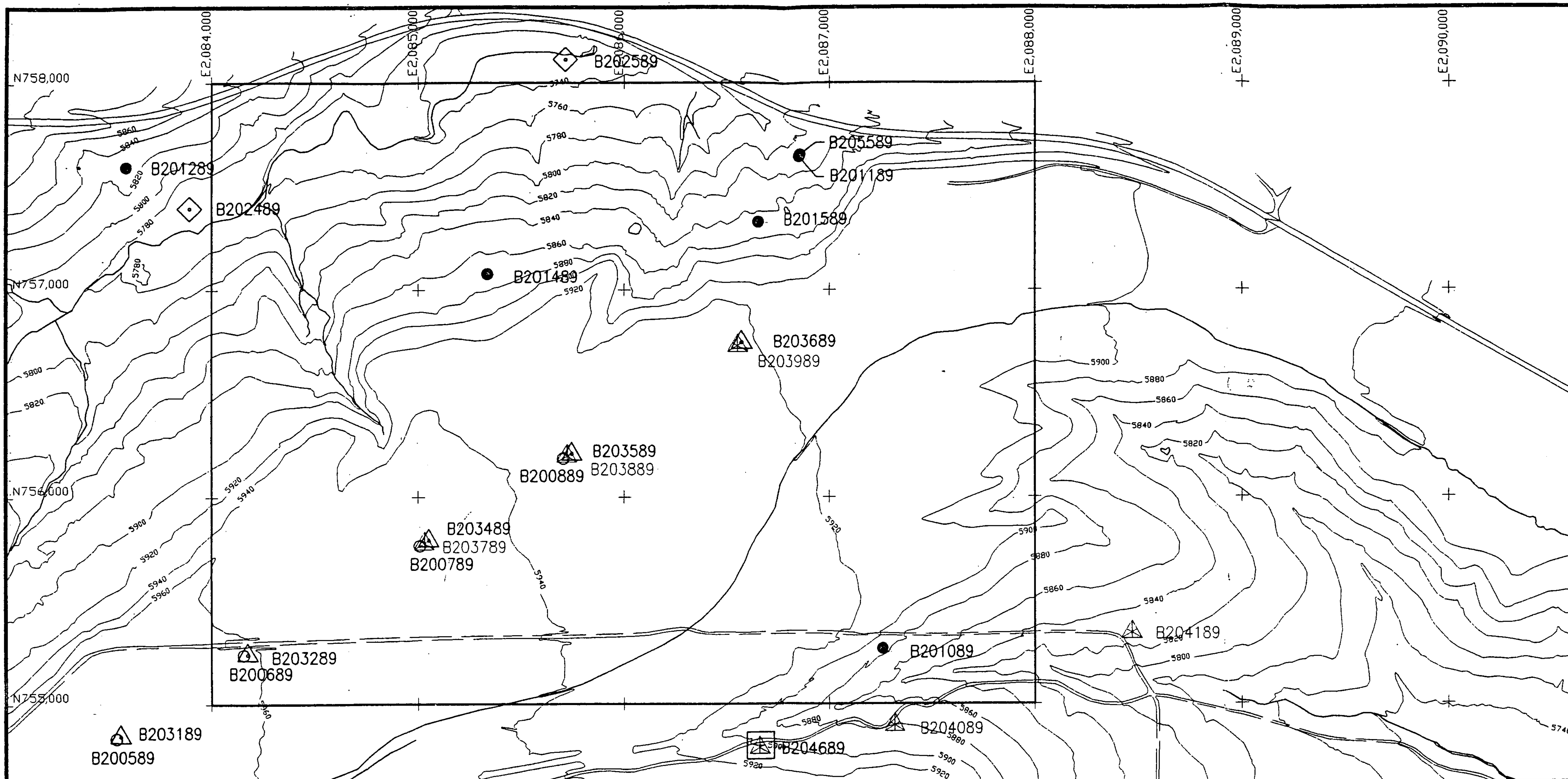
FIGURE B-2

SOUTH BACKGROUND AREA AND WELLS USED IN SIMULATION

April 1994



EXPLANATIONS

B405586 ○ BACKGROUND ROCKY FLATS ALLUVIAL MONITORING WELL

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B405189 △ WEATHERED CLAYSTONE BACKGROUND BEDROCK MONITORING WELL

B402189 △ WEATHERED NON-SUBCROPPING SANDSTONE BACKGROUND BEDROCK MONITORING WELL

B405289 △ UNWEATHERED SANDSTONE BACKGROUND BEDROCK MONITORING WELL

B204689 △ INACTIVE BEDROCK MONITORING WELL

N

0 500' 1000'

SCALE: 1 INCH = 500 FEET
CONTOUR INTERVAL = 20 FEET

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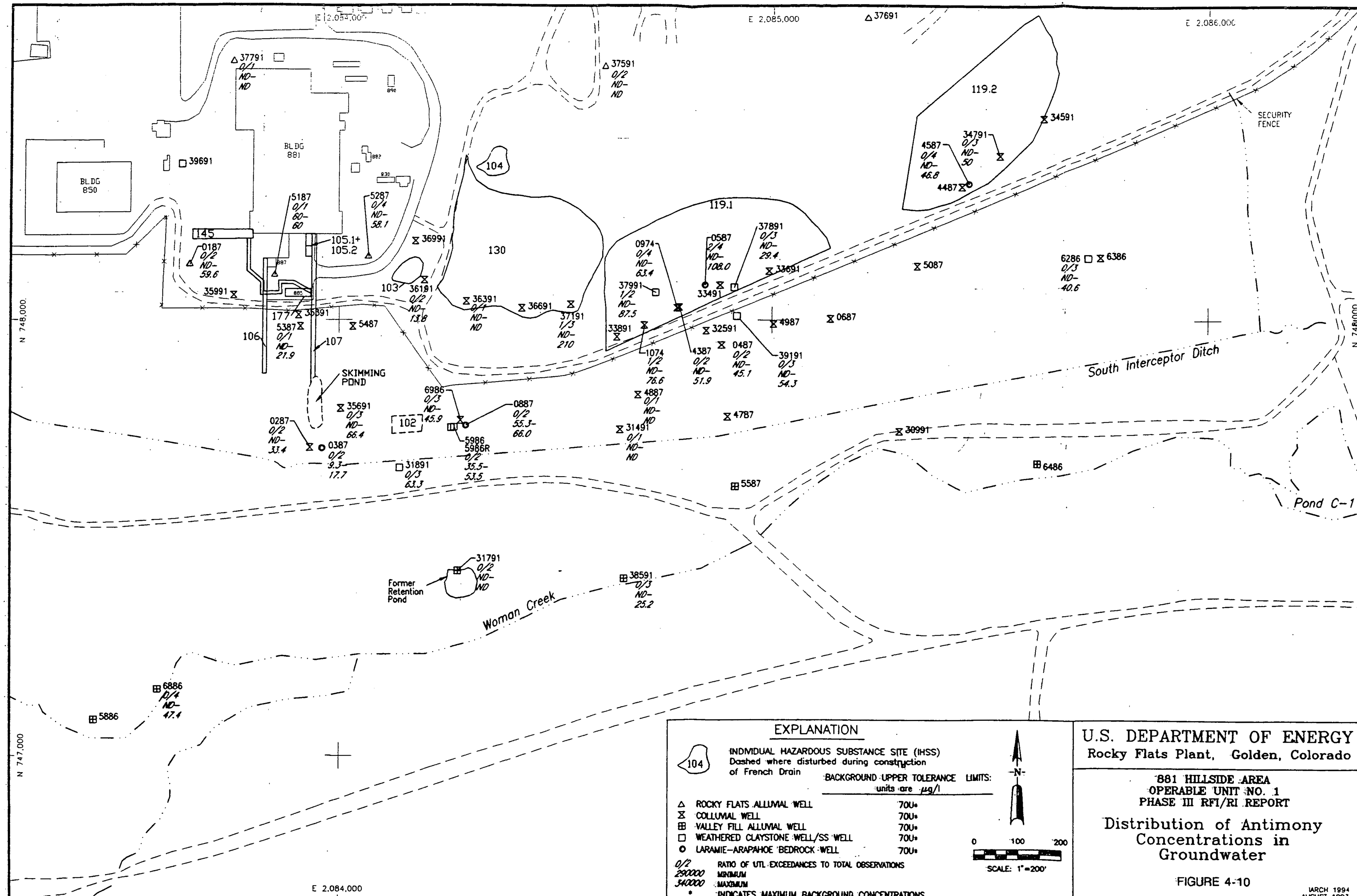
Golden, Colorado

FIGURE B-1

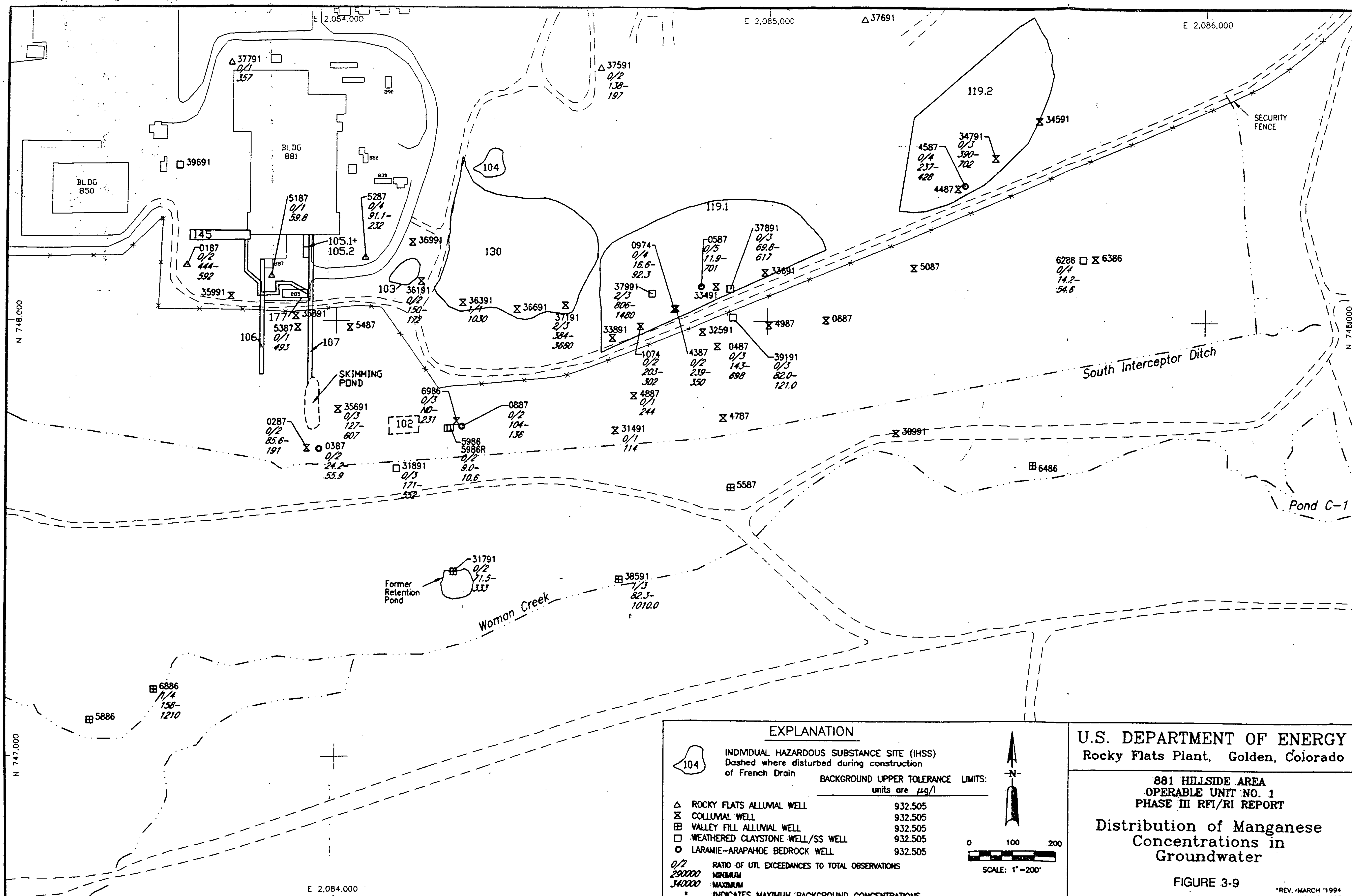
NORTH BACKGROUND AREA AND WELLS USED IN SIMULATION

April 1994

R74301.MB041594/500



R74137.CWMB030494/200



EXPLANATION

104 — INDIVIDUAL HAZARDOUS SUBSTANCE SITE (IHSS) Dashed where disturbed during construction of French Drain

	BACKGROUND UPPER TOLERANCE LIMITS: units are µg/l
△ ROCKY FLATS ALLUVIAL WELL	932.505
⧗ COLLUVIAL WELL	932.505
⊞ VALLEY FILL ALLUVIAL WELL	932.505
□ WEATHERED CLAYSTONE WELL/SS WELL	932.505
○ LARAMIE-ARAPAHOE BEDROCK WELL	932.505

0/2 — RATIO OF UTL EXCEEDANCES TO TOTAL OBSERVATIONS
290000 — MINIMUM
340000 — MAXIMUM
* — INDICATES MAXIMUM BACKGROUND CONCENTRATIONS

N

0 100 200

SCALE: 1" = 200'

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Rocky Flats Plant, Golden, Colorado

881 HILLSIDE AREA
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PHASE III RFI/RI REPORT

Distribution of Manganese Concentrations in Groundwater

FIGURE 3-9

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AUGUST 1993

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