

**EVALUATION OF THE STATISTICAL BASIS FOR ESTABLISHING
BACKGROUND LEVELS AND REMEDIATION STANDARDS
AT THE UNITED NUCLEAR CORPORATION CHURCH ROCK
URANIUM MILL TAILINGS DISPOSAL FACILITY
GALLUP, NEW MEXICO**

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10 June, 1996

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EXECUTIVE SUMMARY

The purpose of this review is to delineate an NRC staff position on groundwater constituent background levels established at the United Nuclear Corporation (UNC) Church Rock uranium mill and tailings disposal site near Gallup, New Mexico. The UNC mill and tailings disposal area are under the jurisdiction of NRC regulations; in addition, the tailings disposal area is also on the National Priorities List (EPA, Superfund). Background levels used to establish remediation standards for nitrate, sulfate, and total dissolved solids (TDS) have been contested by the licensee since the signing of EPA's Record of Decision (ROD) for the site in 1988. To date, work by the EPA contractor Jacobs Engineering Group Inc. (Jacobs) and the licensee and its contractor, Canonic Environmental (Canonic), now Smith Environmental Technologies Corporation (Smith), in addition to input from the State of New Mexico and the Navajo Nation has not resolved this issue. Although the constituents in question are not included in the NRC license, under a Memorandum of Understanding (MOU; EPA, August 26, 1988), the NRC is the lead agency in matters concerning surface reclamation and source control. Because the constituents in question are constituents in the tailings liquor, NRC has elected to review the available data in order to help resolve the issue so that appropriate remediation strategies can be developed and implemented.

The ROD delineated two conditions for the establishment of background concentrations of groundwater constituents: 1) premining, pretailing (prior to 1968); 2) postmining, pretailings (1968 to mid-1977). Little data are available for the site prior to 1977; thus, background levels and remediation standards have been established on the basis of data collected during February, March, and April, 1977. UNC has claimed that the background levels established in the ROD are not representative of the site; therefore, the remediation standards were not set appropriately.

Criterion 7 of Appendix A, 10 CFR 40 states that one full year of preoperational monitoring must be conducted to complete baseline data for a milling site and its operations. The monitoring program at the UNC site did not meet this criterion. Milling operations began in the spring of 1977, whereas tailings disposal began in May, 1977. While the February through April data meet the definition of background, they do not meet the temporal variation objective of Criterion 7.

The staff's inspection of the posttailings 1977 data in the South Cell area indicate that no contamination was detected in the summer or late fall sampling periods. Data collected at the north end of the disposal area are considered usable because they were collected upstream from the tailings disposal area during the period at which the mine discharge was nearing the maximum. For these reasons, the NRC staff believes that the entire 1977 data set is a more realistic representation of spatial and temporal conditions at the site *prior to contamination from tailings pile leakage*, and, therefore, meets the intent of the Part 40 requirements.

The staff's analysis demonstrates that the background level concentration determined for sulfate (2025 mg/L) is in good agreement with that presented in the ROD (2160 mg/L). The background level concentrations for nitrate (190 mg/L) and TDS (4900 mg/L) were found to be higher than

those given in the ROD (nitrate, 30 mg/L; TDS, 3120 mg/L). The staff considers that while the proposed background levels are defensible, they should only serve as a basis for determining appropriate remediation levels. The staff has concluded that while nitrate contamination from the tailings piles can be distinguished by location, 1995 well data indicate that nitrate concentrations at the site do not exceed the proposed background levels. The staff has also concluded that it will be very difficult to achieve premining groundwater conditions for the following reasons:

- 1) The background concentrations for the system are based on data collected during the time of near-maximum discharge from the mine. The observed concentrations of dissolved constituents were probably at their lowest, due to dilution.
- 2) The water level has been declining and the aquifer system is drying out. Recharge of the system has not been able to maintain 1977 levels of saturation. Thus, as the system dries out, the waters will become more saline.

Remediation levels should be based upon an understanding of future changes in the water levels and how the overall chemistry of the system affects sulfate solubility. Predicting how the chemistry of the waters will evolve under the transient conditions at the UNC site is difficult and will contain significant uncertainties. Therefore, subsequent attempts to define meaningful remediation levels may not be possible. For this reason the staff recommends that EPA consider dropping remediation standards for these three constituents.

In its review of the background levels for nitrate, sulfate, and TDS, the NRC staff gained considerable insight concerning the chemistry of the UNC site. In addition to those discussed previously, there are other constituents for which potentially unattainable remediation standards have been identified. Specifically, manganese exceeds the remediation standard (2.5 mg/L) by significant amounts and EPA has attempted to address remediation of this constituent. Unfortunately, data on which to base an appropriate remediation strategy for manganese are not available; iron, which often couples with manganese in groundwater and sediments, has not been monitored since 1989.

In summary, the lack of preoperational data, the transient nature of saturation in the sediments at the site, an incomplete suite of monitored constituents has made it difficult in the past to establish defensible background concentrations. However, the staff believes that the background values presented in this report are the most appropriate values achievable with the limited data available because they are representative of site conditions at the beginning of tailings disposal. The staff also considers that the difficulty in establishing background values for the UNC site is symptomatic of a broader and more significant issue related to establishing meaningful and achievable remediation standards for a system that is effectively drying out.

INTRODUCTION

Purpose

This report summarizes the review of documents concerning and analysis of data from the United Nuclear Corporation (UNC) uranium mill and tailings disposal site at Church Rock, New Mexico. The objectives of the review were to 1) respond to UNC's request for a reevaluation of background concentrations for three constituents, nitrate, sulfate, and total dissolved solids (TDS) (UNC, December 16, 1993) and 2) provide comments on the US EPA's Five-Year Review Report (EPA, July, 1995).

Site Regulatory History

Mining of ore began at the UNC Church Rock uranium mill site in 1968 from three mines: Northeast Church Rock, Old Church Rock, and the Kerr-McGee (Quivera) mine. In 1977, the State of New Mexico granted UNC a radioactive materials license. Subsequently, UNC performed milling operations on the ore between 1977 and 1982. Release of tailings from the milling process began in the area now known as the South Cell (Figure 1). In July, 1979, the dam containing the tailings pile breached, releasing approximately 93 million gallons of tailings and pond water to the Rio Puerco (EPA, September 30, 1988). Subsequent to the breach of the tailings pile, several actions were taken by the State of New Mexico and the EPA to establish the extent of contamination due to leakage from the tailings piles. In 1983, the site was formally placed on the National Priorities List in accordance with the 1980 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

In June, 1986, the State of New Mexico returned its authority to regulate uranium mills to the NRC. This action resulted in the development of a Memorandum of Understanding (MOU) between Region VI of EPA and Region IV NRC for remedial action at the UNC site. The MOU (August 26, 1988) establishes the roles and responsibilities of each agency, specifically: the NRC is the lead agency in matters of surface reclamation and source control (mill byproduct materials/tailings); the EPA will address groundwater remediation outside the byproduct materials site (EPA, September 30, 1988).

The Problem: Previous Attempts to Establish Background and ARARs

The EPA issued Applicable or Relevant and Appropriate Requirements (ARARs) for a suite of groundwater constituents in the Record of Decision (ROD) (EPA, September 30, 1988, Table 1). Several of the ARARs given in the ROD were based on "background" levels for the site. Two background conditions were designated in the ROD: 1) premining, pretailings; 2) postmining, pretailings. The ARARs given in the ROD were based upon the postmining, pretailings groundwater quality data. The ROD also stated that: "Should additional information become available that would significantly alter the estimation of background levels, such information would be evaluated in terms of its impact on remedial actions in each aquifer."

UNC has contested the ARARs for the constituents nitrate, sulfate, and TDS, stating that they are too low. In an attempt to demonstrate this point, UNC has sponsored several studies of the mill site (Billings, 1986; Canonic, July, 1988; Canonic, July, 1992; Canonic, April, 1993). In 1993, UNC formally requested that the NRC provide an update regarding discussions with EPA and the state of New Mexico concerning reevaluation of the ARARs for nitrate, sulfate, and TDS (Canonic, October, 1993). The NRC responded to UNC (NRC, October 22, 1993), stating that the agencies "...are currently pursuing the issue of appropriate background water quality in the alluvial materials." As part of the review of the 1993 Corrective Action Plan Annual Report, the NRC recommended that EPA consider establishing background for nitrate, sulfate, and TDS on the basis of data collected at the Church Rock site in 1977 (NRC, January, 1995).

In July, 1995, the NRC agreed to analyze the UNC and other available data for the purpose of discussing possible revisions to the ARARs with EPA (NRC, August 10, 1995).

The EPA has evaluated the UNC Church Rock mill site data in a variety of ways (Jacobs, July 12, 1993; Jacobs, July 13, 1993; Jacobs, August 5, 1993; Jacobs, April 12, 1995; Jacobs, July 26, 1995; Jacobs, December 14, 1995; Jacobs, December 15, 1995; Jacobs, January 4, 1996; Jacobs, February 12, 1996) in an attempt to derive "background" values for the constituents which have become the subject of the contentious debate. In the Five-Year Review Report, EPA presents recommendations for remediation standards for nitrate, sulfate, and TDS in the Southwest Alluvium and Zone 3 of the Gallup Sandstone Formation. One of the conclusions in the Five-Year Review Report is that the present ARARs for sulfate and TDS are too low (EPA, July, 1995).

Review of the data for nitrate, sulfate, and TDS by the NRC staff yields a similar conclusion: the ARARs for the UNC Church Rock site are too low because background levels used for establishing the ARARs do not appear to be based upon all available site-specific data representing spatial and temporal variations. In keeping with the NRC's January 1995 recommendation, the analysis of "background" water quality focuses on the data collected at the Church Rock mill site in 1977. In addition, the chemistry of the site through time was analyzed to establish trends in the concentrations of various constituents for the purpose of evaluating the feasibility of achieving EPA's newly proposed remediation levels (EPA, July, 1995; Jacobs, February 12, 1996).

General Approach and Assumptions

Background water quality can not be established for the UNC site in the same way that it is often done for other sites because the mill and tailings ponds sit on unconsolidated Quaternary alluvial materials and consolidated sands and shales that, according to UNC, were largely unsaturated prior to mining activities. Establishment of premining background groundwater quality was therefore not possible. Discharge of mine water to the alluvium created an artificial, transient groundwater system. The discharge of mine water was at a maximum in 1977; mine water discharge ceased in 1986 (Figure 2). Since that time, because natural recharge to the alluvium is low, the Southwest Alluvium, Zone 3 and Zone 1 have become less saturated (Figures 3, and

4). According to the EPA's Five-Year Review Report (EPA, July, 1995), the total dissolved solids concentrations (TDS) in the Southwest Alluvium and Zone 3, and outside the target areas have generally increased over the 5-year period of 1989 to 1994 (Figure 5 and 6). In some areas of the site, wells have gone dry. It should be noted that even without mobilization of fluids from the tailings piles into the alluvium, or Zones 1 and 3, because natural recharge to the area is low, the observed trends in saturation levels and dissolved salt concentration would still occur. Whereas it is difficult to establish background levels for an unsaturated site, it is also difficult to establish meaningful remediation standards for a site that is effectively drying out.

Staff analysis of the UNC Church Rock site data was based on several assumptions:

1. Because of the unsaturated nature of the Southwest Alluvium prior to mining activities, background concentrations for dissolved constituents will not represent "true" background of the effectively dry condition.
2. The groundwater system at the site is transient. Changes in groundwater chemistry through time need to be considered.
3. All activities at the site, including mining, milling, and grazing, are assumed to have impacted the groundwater chemistry of the site.

This report presents the results of analyses to determine precontaminant background levels for nitrate, sulfate, and TDS at the UNC Church Rock tailings disposal area. The proposed "background" levels are not intended to be considered the same as "remediation standards (ARARs)," except where remediation activities have already achieved "background" for a particular constituent. This analysis demonstrates that proposed background levels, in combination with hydrogeochemical properties of the site should be used to establish appropriate remediation levels. The results of this review indicate that further analysis is required prior to consideration of remediation strategies and establishment of new ARARs for the site.

METHODOLOGY

As part of each Title II license, the NRC establishes site-specific background levels for hazardous constituents deemed to be associated with the waste form or listed in Criterion 13 of Appendix A, 10 CFR 40. Once a constituent has been detected above background at a monitoring well, compliance standards for the constituent are set at the background, the MCL, or an ACL (Criterion 5(B), Appendix A, 10 CFR 40). In the 1988 ROD, the EPA established remediation standards for a variety of constituents not listed in the NRC license in order to minimize the impact of the tailings fluids on this transient groundwater system at the Church Rock site. The ROD states that the ARARs for the UNC mill site were based upon background levels, health-based requirements, MCLs and the New Mexico NMWQA standards (Table 1).

A significant part of the issue addressed by this analysis relates to the question of how to numerically (statistically) establish background levels for dissolved constituents. A variety of techniques have been used by EPA and UNC in an attempt to segregate populations of data, or

estimate the upper tail of the distribution. Some of the techniques include Analysis of Variance (ANOVA), calculation of the 95% tolerance limit for the mean, and Q-Q (quantile-quantile) plots. These techniques require assumptions concerning the distribution of the data, which in the case of the UNC data were often incorrect. This discussion will illustrate some non-parametric techniques and forms of Exploratory Data Analysis (EDA) used to understand the chemistry of the UNC mill site and estimate representative background levels.

Parametric Methods for Establishing Background

Parametric statistical methods require assumptions about the distribution of the data, such as the mean and standard deviation. The UNC data are difficult to classify as specific distributions; moreover, the distributions for the constituents have changed with time.

Mean

New Mexico Solid Waste Management Regulations 20 NMAC 9.1 require using the mean of the distribution for the background (NMED, 1996). While the simplicity of this approach has merit, there are two primary reasons why this method is not effective:

1. not all distributions are normal (Gaussian);
2. even for normal distributions, 50% of the distribution is greater than the mean, which implies that 50% of the distribution would be considered out-of-compliance.

Because the mean calculated from a sample is merely an estimate of the true mean for the population, a common method of setting a background level is to estimate the 95% confidence interval for the mean of the distribution (in NRC language: "mean plus 2 sigma"). The confidence interval specifies the interval in which the parameter of interest (e.g., mean) should fall for a specified probability (Conover, 1980). Tolerance limits provide an interval within which at least a specified proportion of the population lies, with specified probability $1-\alpha$ (Bowen and Bennett, 1988). Tolerance limits have a built in failure rate of α (Gibbons, 1994). The chance of a failure of the upper tolerance limit is $\alpha/2$, or in the case of 95% tolerance, 2.5% chance of failure. Often, when this approach is used, the data exhibit a normal or log-normal distribution. Unfortunately, many groundwater chemical distributions do not exhibit such a characteristic.

Q-Q Plots

Singh, Singh, and Flatman (1994) recently discussed the use of Q-Q plots to distinguish data representing contaminated waters from those representing "background" levels. The Q-Q plot is a plot of the data versus quantiles for the theoretical distribution (e.g., normal). It is very similar to the technique of plotting the data on probability paper. If the Q-Q plot gives a straight line the data exhibit the assumed distribution. Singh, *et. al.* describe an iterative means

of setting a threshold for data representing contaminated waters. By assuming a normal distribution for the background levels, the inflection point ("breakpoint," Figure 7) in the Q-Q plot may be used as the threshold for contaminated concentrations. Because populations of non-contaminated data and contaminated waters will overlap, Singh *et al.* also demonstrate how to derive tolerance limits for the "uncontaminated data."

Nonparametric Methods

The Empirical Density Function

UNC Church Rock site data cannot be classified as parametric; therefore, a nonparametric means of evaluating the upper tails of the distributions was needed. A crude form of the density function is the histogram. However, because of the segmented way in which histograms are constructed, it is difficult to estimate the extent or nature of the tails of the distribution. Empirical estimation of density functions (Silverman, 1986) was done to estimate the 95% tolerance limit for the distributions of the 1977 data. The estimated density function is essentially a smoothing of the histogram, which enables the analyst to better define the nature of the tails of the distribution. Empirical density estimations of the UNC 1977 data were estimated with the nonparametric density function routine available in the interactive statistical analysis package, S-Plus (Statistical Sciences, Inc., 1993). The density functions were estimated in such a way that the area under the curve approximated that of the histogram for the same distribution. The upper 2.5% of the distribution was then estimated graphically. This upper limit corresponds to the 95% tolerance limit for the distribution (the other 2.5% is often assigned the lower tail, assuming symmetry). Sensitivity of the upper 2.5% "cut-off" to the interval over which the smoothing was done if there was difficulty fitting the empirical density function to the histogram. In general, as the width of the smoothing interval increases, the match of the area under the curve to the area under the histogram becomes worse.

Bootstrap estimation of 0.975 quantile

Nonparametric estimation of the 0.975 quantile was done with the quantile function in Splus. The technique known as "bootstrapping" was used to give greater confidence to the analyses in which the 0.975 quantile was estimated. The bootstrap technique (Efron and Tibshirani, 1993; Davidson and Mackinnon, 1993) is essentially a Monte Carlo analysis of the data, whereby the data are resampled (with replacement) to define multiple samples from the same population. Parameters such as the mean can be estimated for each "sample" and the set of values for that particular parameter is used to estimate the confidence interval around the parameter.

In this analysis, the 0.975 quantile, was estimated from the original data set and the empirical density function. The 0.975 quantile was determined for each distribution in a set of 200 "samples" from the original data set. The 0.975 quantile values were then sorted in increasing order and the 95% confidence interval was determined for those values.

Data

The data reviewed in the course of this work include all site data collected in a data base maintained by Smith Environmental Technologies Corporation, Denver, Colorado. The data for the period 1977-1994 was submitted in electronic form to the NRC by the contractor for the EPA, Jacobs Engineering Group, Inc., Albuquerque, New Mexico. The 1995 well monitoring data submitted by UNC (February 12, 1996) was entered by hand as needed.

The analyses of 1977 data used the entire suite of data collected in 1977. Although milling operations began in June, 1977, disposal of tailings at the occurred at the southern end of the present-day South Cell where it could not impact wells upstream (e.g., GW04). The July and October 1977 data for wells GW01, GW02, and GW03 adjacent to the South Cell do not indicate contamination due to leakage from the newly formed tailings pile. Therefore, in order to achieve a more representative sample of space and time and the UNC site, all 1977 data were used in this analysis.

In estimating background, Jacobs and Smith have used only the 1977 premilling data (February through April). The results of analyses using the abbreviated data set are different and less meaningful than those derived from the entire 1977 data set.

STAFF FINDINGS

Tailings Chemistry

In addition to uranium, the tailings liquor contains a number of constituents whose concentrations are environmentally problematic (Table 2; EPA, May 1, 1995). The level of contamination that has occurred as the result of leakage of these contaminants has been quite high. Corrective action at the site since 1989 has brought the levels of contamination down. What remains to be demonstrated is whether the groundwater chemistries can be remediated to pre-tailings disposal quality.

Analysis of background data for the Southwest Alluvium

Nitrate--Groundwater

The ARAR for nitrate at the UNC mill site is 30 mg/L.

The 1977 data for the UNC mill site are presented in Figure 8. The histogram and Q-Q plot indicate that the data are not normally distributed; a coefficient of variation of 1.28 supports this conclusion.

If the data were normally distributed, the upper 95% tolerance limit would be 136.8 mg/L, much less than the upper range of the data. The graphical estimate of the cut-off for the upper 2.5%

of the density function is 205 mg/L (Figure 9). The 0.975 quantile from the data is 167.92 +/- 29.6 mg/L. The 0.975 quantile estimated from the density function with no set width is 179.5 +/- 9.8 mg/L.

Smith Environmental (October 16, 1995) evaluated the 1977 data for the February-April, 1977 time period (Figure 9). Smith reported a maximum value of 95.9 mg/L and an average of 22.98 mg/L.

Jacobs Engineering Group Inc. has made various attempts at estimating the background concentrations for nitrate at the UNC mill site (July 12, 1993, July 13, 1993, August 5, 1993, April 12, 1995; July 26, 1995; December 14 and 15, 1995; January 14, 1996). The 1993 results range from 185-295 mg/L, depending upon the well data used and interpretation of the distributions. The July 1995 results, which are presented in the Five-Year Review Report (EPA, July, 1995), give a range of background values for nitrate between 14.4 and 1816 mg/L NO₃ as N. Although the background values calculated vary with the wells used, these values are clearly questionable because Jacobs' analysis of the 1977 data included only 16 of the 28 observations. Although this approach gave equal weight to each well used in the analysis, it also eliminated spatial and temporal variations in the data.

In its review of UNC's Five-Year Review (Smith, December, 1995), the EPA contractor Jacobs, used Q-Q plots to "calculate the background for nitrate, TDS, and sulfate in ... the Southwest Alluvium and Zone 3 using the method of Singh, et al., 1994" (Jacobs, January 4, 1996). Upper Tolerance Limits (UTL) based upon "breakpoints" of 143 and 205 mg/L were estimated to be 137 and 164 mg/L. In this analysis, Jacobs used all data (1977-1994) rather than the data from 1977 only. It is hard to justify the use of data that is from wells in areas that have undergone change for the last 17 years to set background levels. The staff believes this method is unacceptable for establishing background levels at the UNC Church Rock site for the following reasons:

1. the distributions for the constituents are not normally (or log-normally) distributed;
2. the distributions have changed with time;
3. use of data over such a long time period when the site was exposed to contaminants is clearly not "background;"
4. the length of time for which data are taken from any given well is not the same from well-to-well; therefore unequal weight is given to different areas of the site;
5. decreasing saturation levels at the site will cause a change in the non-contaminated baseline; background data for 1994/1995 will be different from that for 1977, during the time of maximum mine discharge; i.e. the concentrations observed for the system in 1977 were probably at their lowest because of dilution due to the large volumes of water passing through the system. Therefore, the background cannot be considered to be "homogeneous" throughout the site: areas with lower saturation levels will exhibit different background concentrations than areas with higher saturation levels.

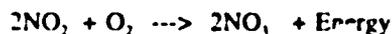
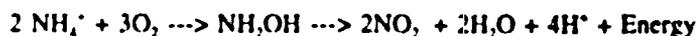
Nitrate Concentrations Through Time

The distribution of nitrate in the Southwest Alluvium has been relatively constant through time (Figure 10). There was a slight increase in the upper tail of the distributions in the mid-to-late 1980's when the bulk of the contaminant plume from tailings pile leakage was moving through the Southwest Alluvium. The constancy of the distribution indicates that the tailings are not the major contributor of nitrates to the groundwater at the UNC Church Rock site.

Nitrate-Soil

The source of nitrate in the soils and alluvial sediments at the UNC Church Rock site has been a major question associated with this project.

Natural concentrations of nitrate in soils is generally 1500-2000 mg/kg N (Pierzynski et al., 1994; Sposito, 1989). The nitrogen is associated with organic matter such as plants or animal wastes. High concentrations of nitrate (NO_3^-) in groundwaters have been observed in agricultural settings, and feedlots (Hubbard and Sheridan, 1994). The nitrate forms by mineralization of amine groups from organic compounds, such as uric acid. The mineralized amine, (ammonium) is then oxidized to nitrite or nitrate because of the oxidation potential (Eh) of the system is high or by bacterial activity:



(Pierzynski et al., 1994)

It should be noted that the conversion of ammonium to nitrate in oxidizing fluids simply requires an increase in pH (Stumm and Morgan, 1981; Figure 11).

In an effort to justify the high nitrate concentrations observed in the Southwest Alluvium groundwater, UNC attempted to demonstrate that the variation in nitrate concentrations in the Southwest Alluvium was due to the presence of "evaporite salts" in the soils. Soil data collected in 1990 by UNC (Canonic, October, 1992) and the state of New Mexico (NMED, 1995) affirm the variability of soil nitrate concentrations at the site (Figure 12). The distributions of leachable nitrate for soils collected near NR-1 and NR-2 and upstream of the UNC mine discharge point are very similar as well as being similar to the 1977 nitrate distribution.

Lysimeter data collected by UNC (Canonic, 1992) indicate a general increase in nitrate concentration with depth in both the leached soil waters and the waters passed through the field lysimeter. Of note are soil water concentrations close to 800 mg/L nitrate as N from the deepest

lysimeter (L-3; -28.1 ft). The staff considers that the high nitrate, chloride, and TDS concentrations in this zone may be related to an undocumented contaminant plume leaking from the former Quivera Pond site. Even though UNC has made a good case for the use of the 600-series wells at the north end of the property for setting background, the staff is of the opinion that these wells might have been contaminated by Quivera activities.

Of note is the lack of a definitive analysis of the soil for nitrate salts. Soil logs describe "evaporites," but no further analysis of these materials was made. The staff believes that analysis of these with a method such as X-ray diffraction would have better defined the "evaporites" as a source term for nitrates in the soil waters.

The soil nitrate distributions and 1977 groundwater data indicate that NO_3^- contributions from the tailings pile may not be readily distinguishable from the background levels. However, the source of nitrate in the soils and alluvial sediments still needs resolution.

The UNC Church Rock site has been a grazing site for domestic livestock (cattle, sheep, and goats) for almost 100 years (Julie Canepa (Navajo Superfund), personal communication; April, 1996). The livestock are a potential source of ammonium at the surface, which can then be oxidized to nitrate. The oxidation of the ammonium species, whether sourced from the tailings liquor or bovine metabolic processes takes place fairly rapidly. Most ammonium will be converted to nitrate within a three week period. (Pierzynski et al., 1994). Many decades of input of organic-based ammonium to the soils at the Church Rock site, in combination with little precipitation in the area, is a potential means of concentrating nitrate in the alluvial soils. For this reason, the staff believes that the proposed background level for nitrate at the UNC site should be used as a baseline for establishing the remediation standard, rather than the NMWQA drinking water standard.

Sulfate

The ARAR for sulfate is 2130 mg/L.

1977 sulfate concentrations in the Southwest Alluvium are given in Figure 13. The histogram and the Q-Q plot indicate two populations, but they cannot be easily segregated on the basis of time or space. Graphical estimation of the upper 2.5% tail for the empirical density function gives 1900 mg/L, whereas the 0.975 quantile for the empirical density function is 2024 mg/l.

Jacobs (July 26, 1995) has calculated background levels for sulfate using 1977 data from wells GW01, GW02, GW03, and GW04. The upper 95% tolerance limit was estimated as 2812 mg/L. The NRC staff had difficulty matching the data used with the data base and calculating the same upper tolerance limit.

In 1993, Canonie (Canonie, December 1993) proposed a sulfate background concentration of 3342 mg/L, based upon data from a series of "upgradient" wells (including the 600 series wells as the northern property boundary). The staff considers that 600 series wells are difficult, at best,

to use for setting background because of the transient nature of the water levels and the suspected contamination from the Quivera ponds.

Sulfate concentrations in the Southwest Alluvium have changed dramatically over the course of 17 years (Figure 14). Sulfate has been the primary component of the dissolved solids, as shown in Figure 15. Historically, sulfate concentrations in the Southwest Alluvium were highest on the north side of the present-day Central cell, in wells 202 and 0015DM. Figure 16 presents plots of sulfate and TDS through time for wells 642 and 202 in the Southwest Alluvium, well 516A in Zone 1. Of note are the passage of contaminant plumes through wells 202 and 516A. Well 642 data indicate increasing sulfate and TDS concentrations. It is not clear whether these latter trends are due to decreasing saturation levels or movement of contamination away from the disposal cells.

Total Dissolved Solids (TDS)

The ARAR for TDS is 3120 mg/L.

As illustrated in Figure 15, the major contributor to the Total Dissolved Solids is dissolved sulfate. Using the ARAR for sulfate set forth in the 1988 ROD, the correct background level of TDS for the site should be at least 4800 mg/L TDS, rather than 3120 mg/L as stated in the ROD. This is supported by the following analysis.

The 1977 Total Dissolved Solids distributions are given in Figure 17. The histogram indicates that the distribution of TDS in the Southwest Alluvium is difficult to define. The mean of the 1977 data is 2179 mg/L. The empirical density function was used to graphically estimate the 0.975 quantile, which is between 4650 and 4800 mg/L, for a smoothing width of $0.5 \cdot \text{interquartile range (IQR)}$ and $0.75 \cdot \text{IQR}$, respectively. The bootstrapped 0.975 quantile for the $0.5 \cdot \text{IQR}$ is 4894 mg/L, with a 95% confidence interval for the 0.975 quantile of 4507-5020 mg/L.

Canonie (April, 1993) proposed a background level for TDS of 8096 mg/L, based upon data from the 600 series wells. Smith (October, 16, 1995) evaluated the February through April 1977 data and reported a mean of 1988 mg/L. Analysis of the same data by NRC staff give an upper (95%) tolerance limit of 4044 mg/L.

Jacobs Engineering attempts (1993) to calculate a background TDS level gave values ranging between 4666 and 5730 mg/L. The estimated background, based on 1977 data (Jacobs Engineering, July 26, 1995), was 7485 mg/L. NRC staff could not reproduce this value.

Mn and Fe

The ARAR for Mn is 2.6 mg/L; the ARAR for Fe is 5.5 mg/L.

In order to evaluate the robustness of the empirical density function technique for estimating the

upper 2.5% of the background population, the 1977 data for iron and manganese were also evaluated. The 1977 data for Mn and the empirical density function for that data are given in Figure 18. The mean + 2 sigma for the Mn data is 2.26, whereas the 97.5% tolerance limit as graphically estimated from the density function is 2.8-2.9 mg/L.

Jacobs Engineering estimated the background level for Mn in the Southwest Alluvium, using premilling data (July 26, 1995). The estimated background levels for Mn ranged between 9.4 and 22 mg/L.

The Fe data (Figure 19) are more difficult to evaluate because of the discontinuous nature of the distribution. The mean + 2 sigma is 6.61, slightly higher than the ARAR. If the 11.6 mg/L Fe is part of the distribution, the 0.975 quantile is 12.0 mg/L.

While the reported concentrations do not indicate the form of the iron species, much of the iron collected in waters with neutral pH may exist in colloidal form (Stumm, 1992). Colloids can be quite mobile through porous media, and iron colloidal material is often associated with Mn in sediments. The background levels for these two constituents may indeed be as low as the ARARs. However, it is difficult to establish this with certainty because of the lack of data distinguishing dissolved from colloidal species.

Analysis of Background Levels in Zones 1 and 3

In 1988, only one set of remediation standards (ARARs) was set for the UNC Church Rock mill tailings disposal site. The data from the Southwest Alluvium were used on the basis that Zones 1 and 3 of the Upper Gallup Sandstone are recharged by waters in the Southwest Alluvium.

In the comments to the EPA concerning UNC's "Groundwater Corrective Action Annual Review, 1993," Jacobs Engineering Group, Inc. (November 11, 1994) recommends that UNC identify unaffected wells down-dip of the tailings pile to use in establishing background. Whereas this may be a noble objective, the staff has identified two concerns associated with this approach:

1. Establishing background for the Zones 1 and 3 at this time does not address the more pertinent and compelling issue of the need to set appropriate ARARs.
2. There are no premilling data for Zones 1 and 3 on which to base background levels.

Several wells have been identified that may be considered in determining background for Zones 1 and 3 (Julie Curtiss, Navajo Superfund, personal communication; UNC, December, 1995); however the earliest times for which data are available for Zone 1 and Zone 3 are 1980 and 1979, respectively. As evident in Figures 20 and 21, Zone 1 was already contaminated at the time of sampling. Sulfates in Zone 1 were analyzed for in 1980, but exhibited concentrations up to 15,550 mg/L. Nitrate was not analyzed for in Zone 1 until 1981 and concentrations greater than 200 mg/L were detected. Because the data suggest that Zone 1 was contaminated by the time data were collected, it is not possible to set a background standard for Zone 1 based upon

Zone 1 data.

Zone 3 1979 sulfate concentrations were in excess of 5000 mg/L and exceeded 17000 mg/L in 1980, indicating early movement of the contaminant plume leaking into Zone 3 (Figure 22). Nitrate data were not collected in Zone 3 until 1981 (Figure 23).

The lack of premilling data and the suspect nature of much of the data collected during the time of milling and tailings disposal indicates that setting "background" for Zones 1 and 3 is difficult to do with confidence.

Analysis of Proposed Remediation Levels (ARARs)

The staff agrees with Jacobs that the ARARs for the UNC Church Rock tailings disposal site are inappropriate in terms of achievable remediation (April 12, 1995). However, the staff is concerned about the proposed remediation levels as described in the Jacobs' February 12, 1996 letter to the EPA. Jacobs used the Q-Q plot to assess all site data for the constituents nitrate, sulfate, and TDS in Zone 3 and the Southwest Alluvium (Figure 7). Zone 1 was not considered in the Jacobs analysis. Although the staff is concerned about how the Q-Q plot was used to define clean-up levels, the following commentary focuses on the achievability of the proposed clean-up levels. The staff considered past trends in the site chemistry, likely future trends, the interactions of various constituents, and the proposed remediation strategies. Tables 3, 4 and 5 present the proposed background levels, the present ARARs, and EPA's proposed ARARs for nitrate, sulfate, TDS, and Mn. Wells indicating exceedance relative to the proposed standards (1995 data) are also listed.

Southwest Alluvium

NO₃. Jacobs analyzed Southwest Alluvium data with the Q-Q plot and determined an upper 95% tolerance limit of 166 mg/L. This is less than the background levels determined by the NRC staff. The 1995 well compliance data for the Southwest Alluvium (UNC, February 12, 1996) indicate that the proposed remediation level of 166 mg/L could be met, perhaps with the exception of well GW04, which is outside of the Target Area. Well GW04 has historically exhibited high nitrate concentrations. Data from 1995 indicate the nitrate concentrations in well GW04 are between 120 and 165 mg/L. The staff believes that the proposed background level (190 mg/L) is an appropriate ARAR for nitrate in the Southwest Alluvium.

SO₄. Jacobs determined a 95% UTL of 3065 mg/L for sulfate in the Southwest Alluvium (Jacobs, February 12, 1996). The 1995 data for sulfate in the Southwest Alluvium (UNC, February 12, 1996) indicate that the proposed remediation level is exceeded in wells 801, 802, and 642. Wells 801 and 802 are in the Southwest Alluvium Target area and appropriately exhibit contamination. Well 642 is outside the target area, and may be drying up. It may also be exhibiting contamination from the Quivera ponds area. The sulfate concentrations in well 801 are greater than the solubility limit for gypsum determined with geochemical modelling by

Jacobs Engineering for almost neutral pH (Jacobs Engineering, April, 1995).

TDS. Jacobs determined a 96% UTL of 5631 mg/L for TDS in the Southwest Alluvium using Q-Q plots. Jacobs did not consider TDS concentrations greater than 10,000 mg/L TDS in its analysis.

Upon inspection of the 1995 monitoring well data (UNC, February 12, 1996) the staff concluded that the proposed remediation level for TDS is exceeded in a number of wells. Of particular interest are the exceedances which are not a function of high sulfate concentrations, but instead, are the result of high concentrations of bicarbonate. Figure 24 is a contour "map" of sulfate, bicarbonate, and TDS response surface for the Southwest Alluvium in 1994. For sulfate concentrations at the proposed remediation standard of 3065 mg/L (Jacobs, February 12, 1996), bicarbonate concentrations in excess of 1000 mg/L will cause exceedance of the proposed TDS standard of 5631 mg/L. The staff believes such a standard is inappropriate because bicarbonate is not considered a hazardous constituent. The staff believes that EPA should consider setting the TDS remediation standard high enough to account for high bicarbonate.

Mn. The staff generally agrees with the background standard of set in the ROD, but does not support its use as a remediation standard. Figure 26 demonstrates the change in Mn concentrations through time, indicating the passage of the plume through the Southwest Alluvium. While neutralization of acidic leakage may help to reduce the Mn concentrations (Figure 27), the standard as set in the ROD is probably not achievable. It should be noted that well 801 exhibits the highest concentrations of Mn and also exhibits a pH of 7 to 7.4. Unfortunately, UNC is no longer monitoring for Fe, which often accompanies Mn in natural water systems. The geochemical modelling for the Zone 3 waters done by Jacobs used a pe of 5.0 (Eh = 0.3). Raising the pH from 3 or 4 to near-neutral will result in the precipitation of iron and manganese oxyhydroxides (Garrels and Christ, 1965). Even with the precipitation of the Fe-Mn oxyhydroxides, the staff cautions the EPA to consider that the Fe-oxyhydroxides are usually in the form of colloids, may still be mobile (Domenico and Schwartz, 1990), and may be detected in significant quantities if filtering is not done in order to remove colloids.

Zone 3

NO₃. Jacobs chose the "middle" breakpoint in the Q-Q plot for the nitrate to be the remediation standard for Zone 3, whereas the upper breakpoints were chosen for sulfate and TDS (Jacobs Engineering, February 12, 1996). The rationale for this change in selection of breakpoints is not clear. Using the "middle" breakpoint, the UTL is 54 mg/L NO₃, whereas the upper breakpoint gives a 95% tolerance limit of 170 mg/L. Although Jacobs proposes that the remediation standard for nitrate in Zone 3 should be 54 mg/L, this latter value is consistent with the other nitrate "background" concentrations determined for the site.

SO₄. The UTL for sulfate in Zone 3 was estimated using Q-Q plots to be 4148 mg/L (Jacobs, February 12, 1996). Comparison of the UNC 1995 monitoring well data indicate that wells EPA13 and 518 exceed this proposed clean-up level. Geochemical modelling of Zone 3 waters

in equilibrium with gypsum, calcite, and gibbsite, suggest equilibrium sulfate concentrations between 3700 mg/L and 4000 mg/L, depending upon the ionic strength and the initial pH (Jacobs, April, 1995). Neutralization of well 518 water by adding lime has been proposed as a possible remediation strategy. The ability to reduce sulfate in well EPA 13 by addition of lime does not appear to be a viable remediation strategy because the pH is presently near-neutral (6.61-6.85). Sulfate concentrations in well EPA13 are 4300 mg/L. Because TDS is highly correlated with sulfate concentration (Figure 18) and the proposed TDS remediation level is 6154 mg/L, the staff recommends setting the remediation level for sulfate approximately 4400 mg/L.

TDS. Jacobs picked an upper breakpoint of 6972 mg/L, which yielded an upper tolerance limit of 6154 mg/L (Jacobs Engineering, February 12, 1996). Comparison with the UNC monitoring well data (UNC February 12, 1996) indicates that wells 518 exceeded this proposed standard in 1995. Well 518 TDS exceeded the proposed standard because the sulfate concentration also exceeded the standard. Remediation of the sulfate levels in this area would reduce the TDS.

DISCUSSION AND RECOMMENDATIONS:

The staff, in principal, supports the EPA's position to set the remediation standards higher than the proposed 1977 background levels for sulfate and TDS. However, the staff recommends that the EPA consider the transitory nature of the UNC site groundwater system in setting nitrate, sulfate, and TDS levels. If the system is effectively "drying out," then as the TDS increases, the solubility of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) will increase. Even though the proposed remediation standards are based upon the present alluvium water chemistry and may be achieved in many of the wells at the site, the standards may become increasingly difficult to achieve with time. Adding fresh water to the system has been considered as a possible remediation strategy (REF). Although fresh water injection may help dilute the salts in the system, the staff is concerned that there will be no time at which this proposed activity could cease.

Other possible remediation strategies that have been considered by EPA include passive reactive barriers for reduction of the nitrate and sulfate (Shawn Ghose (EPA), personal communication; September, 1995). The staff believes that this is only a temporary fix because the exposed-at-the surface alluvium is an oxidizing system. Flushing Zone 3 with fresh water would effectively change the water chemistry, remove sulfate, and raise the pH. Again, this proposed remediation strategy requires further analysis in the context of a potentially changing saturation levels.

In considering remediation strategies and standards, the EPA and UNC need to evaluate 1) the rate at which SO_4 is being released from the tailings pile, 2) how the groundwater chemistry will change once release from the pile has ceased and the system begins to "dry." Consideration of equilibrium with gypsum, calcite, and gibbsite is acceptable; however, the saturation levels need to be considered in the context of changing TDS.

Specific Recommendations

The staff proposes new background levels for the constituents based upon 1977 data. The proposed background levels are given in Table 3.

Staff recommends that background level for nitrate be used as remediation standard in the Southwest Alluvium, and Zone 3 or dropped altogether.

The staff recommends that different remediation standards be set for sulfate and TDS, based upon:

1. present concentrations;
2. relationships between sulfate, TDS, and bicarbonate;
3. changing saturation levels in the Southwest Alluvium, Zones 1 and 3;
4. consideration of saturation levels for minerals with changing water content;
5. possible remediation strategies for sulfate and TDS.

Establishing appropriate remediation standards which account for all of the above factors may be difficult to do because of the large uncertainties associate with future changes in the saturation levels at the site. For these reasons, the staff recommends that EPA consider dropping the standards for these constituents.

The staff recommends that Fe data be collected during groundwater monitoring in an attempt to give a better basis for setting an appropriate ARAR for Mn.

Outstanding Issues

1. The staff did not evaluate the constituents Se, Al, U, or Ra in the context of background levels or the ability of UNC to achieve the ARARs for these constituents.
2. At this writing, the data from leach tests and groundwater analyses are only corroborative, not definitive.

Because nitrate salts are extremely soluble, it is difficult to surmise the presence of these materials in the soils at the Church Rock site. The staff has considered possible sources for nitrate in the Church Rock site soils. Because of the amount of overgrazing by cattle and sheep in the area for up to 100 years (Julie Curtiss, Navajo Superfund; Personal Communication, April 22, 1996), the most likely source of nitrate is the livestock. Mineralization of organic-based nitrogen and oxidation to nitrate can take place during a few weeks (Pierzynski et al., 1994). Soils analysis for a more likely source of nitrogen would have been helpful in bringing this issue to resolution earlier.

3. The staff believes that there may be a contaminant plume to the north, sourced from the Quivera ponds. Potential contamination of groundwater from the mill site needs to be evaluated.

TABLE 1 CONTAMINANT-SPECIFIC GROUNDWATER APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

CONTAMINANT	CONCENTRATION*	SOURCE
Aluminum	5.0	New Mexico Water Quality Act (NMWOA)
Antimony	0.014	Health-based
Arsenic	0.05	Maximum Concentration Limit (MCL)
Barium	1.0	MCL, NMWOA
Beryllium	0.017	Health-based
Cadmium	0.01	MCL, NMWOA
Chromium	0.05	MCL, NMWOA
Cobalt	0.05	NMWOA
Copper	1.0	NMWOA
Iron	5.5	Background Level
Lead	0.05	MCL, NMWOA
Manganese (Mn)	2.6	Background Level
Mercury	0.002	MCL, NMWOA
Molybdenum	1.0	NMWOA
Nickel	0.2	NMWOA
Selenium	0.01	MCL
Silver	0.05	MCL, NMWOA
Thallium	0.014	Health-based
Vanadium	0.7	Health-based
Zinc	10.0	NMWOA
Chloride (Cl)	250.0	NMWOA
Sulfate (SO ₄)	2160.0	Background Level
NO ₃	30.0*	Background Level
Total Dissolved Solids (TDS)	3170.0	Background Level
Radium-226 and .228	5 pCi/l	MCL
Uranium-238	5.0 (1645 pCi/l)	NMWOA
Thorium-230 ^b	15 pCi/l	MCL
Gross Alpha	15 pCi/l	MCL

NOTES: * In mg/L, except as noted. ^a Based on 15 pCi/l gross alpha. ^b Pre-wiring date of 30 mg/l appears reasonable for background.

Table 2
Chemical Characteristics of Tailings Liquid
 (EPA, May 1, 1995)

pH 2-3
 Total dissolved Solids (TDS) >60,000 mg/L
 Sulfate >40,000 mg/L
 Thorium 40,000 pCi/L
 Radium 45 pci/L
 Aluminum: >2000 mg/L
 Ammonia: >5000 mg/L
 Iron: >4000 mg/L

Table 3
Proposed NRC Background Levels and EPA Remediation Standards for the Southwest Alluvium

	Proposed Background/NRC	EPA 1988 ARAR	EPA Proposed ARAR from QQ Plots	Wells exceeding proposed ARAR in 1995
Nitrate	190-205 mg/L	30 mg/L	166 mg/L	
Sulfate	2125 mg/L	2160 mg/L	2065 mg/L	509D, 632, EPA-23, 642, 801, 802, 803, 804
TDS	4800 mg/L	3120 mg/L	5631 mg/L	509D, 632, 642, 801, 802, 803, 804
Mn	2.8-2.9 mg/L	2.5 mg/L	N/A	EPA-23, 801

Table 4
Proposed NRC Background Levels and EPA Remediation Standards for Zone 3

	Proposed Background/NRC	EPA 1988 ARAR	EPA Proposed ARAR from QQ Plots	Wells exceeding proposed ARAR in 1995
Nitrate	190-205 mg/L	30 mg/L	54 mg/L	
Sulfate	2125 mg/L	2160 mg/L	4148 mg/L	517,518,EPA13
TDS	4800 mg/L	3120 mg/L	6154 mg/L	517,518
Mn	2.8-2.9 mg/L	2.5 mg/L	N/A	517,518,411,502B,514B,EPA 1,EPA9,EPA13,EPA15

Table 5
Proposed NRC Background Levels and EPA Remediation Standards for Zone 1

	Proposed Background/NRC	EPA 1988 ARAR	EPA Proposed ARAR from QQ Plots	Wells exceeding proposed Background in 1995
Nitrate	190-205 mg/L	30 mg/L	N/A	
Sulfate	2100 mg/L	2100 mg/L	N/A	516A,604, 614, EPA4,EPA7, 515A, 619, EPAS, EPAS
TDS	4800 mg/L	3120 mg/L	N/A	516A,604,614,EPA7, 515A, EPAS,
Mn	2.8-2.9 mg/L	2.5 mg/L	N/A	604,EPA7, 15A, EPAS

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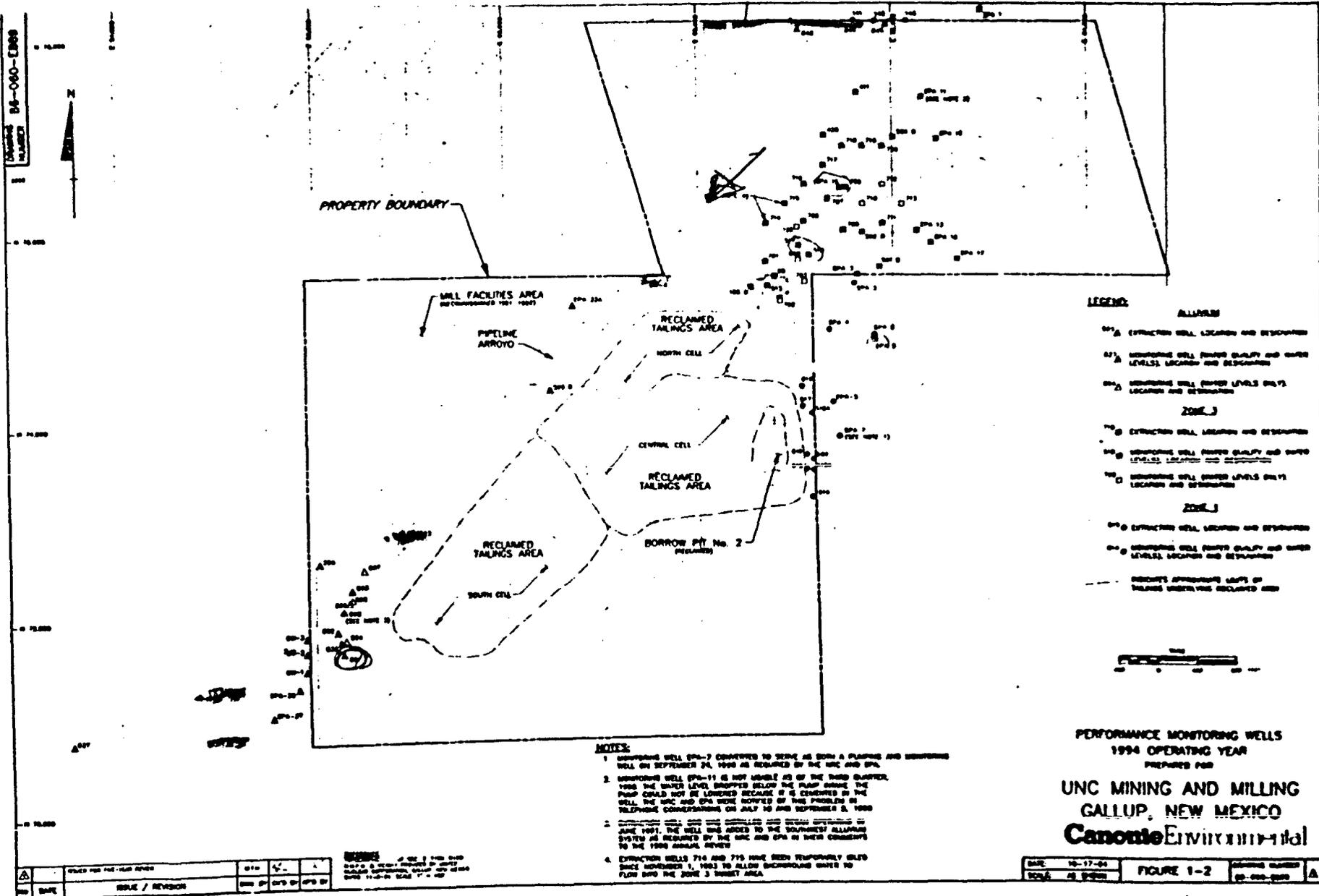
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PERFORMANCE MONITORING WELLS
1994 OPERATING YEAR
PREPARED FOR

UNC MINING AND MILLING
GALLUP, NEW MEXICO
Canon Environmental

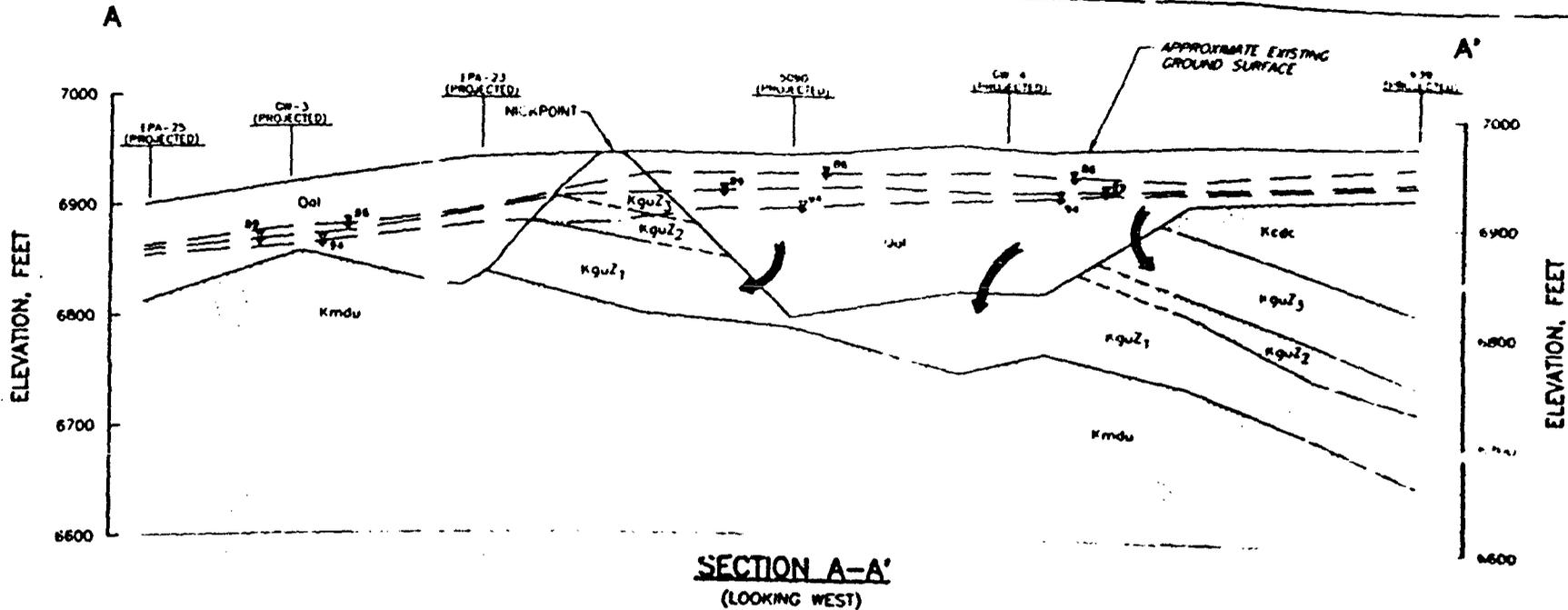
- NOTES:**
- MONITORING WELL SP-7 CONVERTED TO SERVE AS BOTH A PUMP AND MONITORING WELL ON SEPTEMBER 24, 1993 AS REQUESTED BY THE UMC AND EPA.
 - MONITORING WELL SP-11 IS NOT USABLE AS OF THE THIRD QUARTER, 1993. THE WATER LEVEL DROPPED BELOW THE PUMP ABOVE THE PUMP COULD NOT BE LOWERED BECAUSE IT IS COVERED BY THE WELL. THE UMC AND EPA WERE ADVISED OF THIS PROBLEM BY TELEPHONE CORRESPONDENCE ON JULY 10 AND SEPTEMBER 5, 1993.
 - EXTRACTION WELL SP-10 WAS INSTALLED AND BEGAN OPERATING IN JUNE 1991. THE WELL WAS ADDED TO THE SOUTHWEST ALLUVIUM SYSTEM AS REQUESTED BY THE UMC AND EPA IN THEIR COMMENTS TO THE 1990 ANNUAL REPORT.
 - EXTRACTION WELLS 714 AND 715 WERE REPAIRS COMPLETED SINCE NOVEMBER 1, 1993 TO ALLOW DISCHARGING WATER TO FLOW INTO THE ZONE 3 DUNEY AREA.

DATE	10-17-94	FIGURE 1-2	ISSUE NUMBER	00-000-000
SCALE	AS SHOWN			A

DATE	ISSUE / REVISION	DESIGNED BY	CHECKED BY	APPROVED BY

FIGURE 1

DRAWING NUMBER 86-060-8899



NOTES:

1. THE 1986 WATER LEVEL ELEVATION IS BASED ON WATER LEVELS MEASURED IN JANUARY 1986 AT WELLS EPA-25, GW-3, EPA-23, 5090, GW-4, 637 AND 639.
2. THE 1989 WATER LEVEL ELEVATION IS BASED ON WATER LEVELS MEASURED IN OCTOBER 1989 AT WELLS EPA-25, GW-3, EPA-23, 5090, GW-4, AND 639.
3. THE 1994 WATER LEVEL ELEVATION IS BASED ON WATER LEVELS MEASURED IN OCTOBER 1994 AT WELLS EPA-25, GW-3, EPA-23, 5090, GW-4, AND 639.
4. SEE FIGURE 2-2 FOR LOCATION OF CROSS SECTION
5. STIPPLE PATTERN IDENTIFIES LOW PERMEABILITY MATERIAL
6. CROSS SECTION BASED ON DETAIL PRESENTED IN THE BACI GROUND WATER QUALITY REPORT (CANONIE OCTOBER, 1992)

LEGEND:

- 1986 WATER LEVEL ELEVATION
- 1989 WATER LEVEL ELEVATION
- 1994 WATER LEVEL ELEVATION
- ALLUVIUM
- CREVASSE CANYON FORMATION DILCO COAL MEMBER
- UPPER CALLUP SANDSTONE - ZONE 1
- UPPER CALLUP SANDSTONE - ZONE 2
- MANCOS SHALE UPPER D CROSS TONGUE MEMBER
- UPPER CALLUP SANDSTONE - ZONE 3
- DIRECTION OF ALLUVIAL RECHARGE

DECREASE IN ALLUVIAL
WATER LEVELS
1986 - 1994

PREPARED FOR
UNC MINING AND MILLING
GALLUP, NEW MEXICO
Canonie

DATE	BY	REVISION

FIGURE 2-3

FIGURE 3

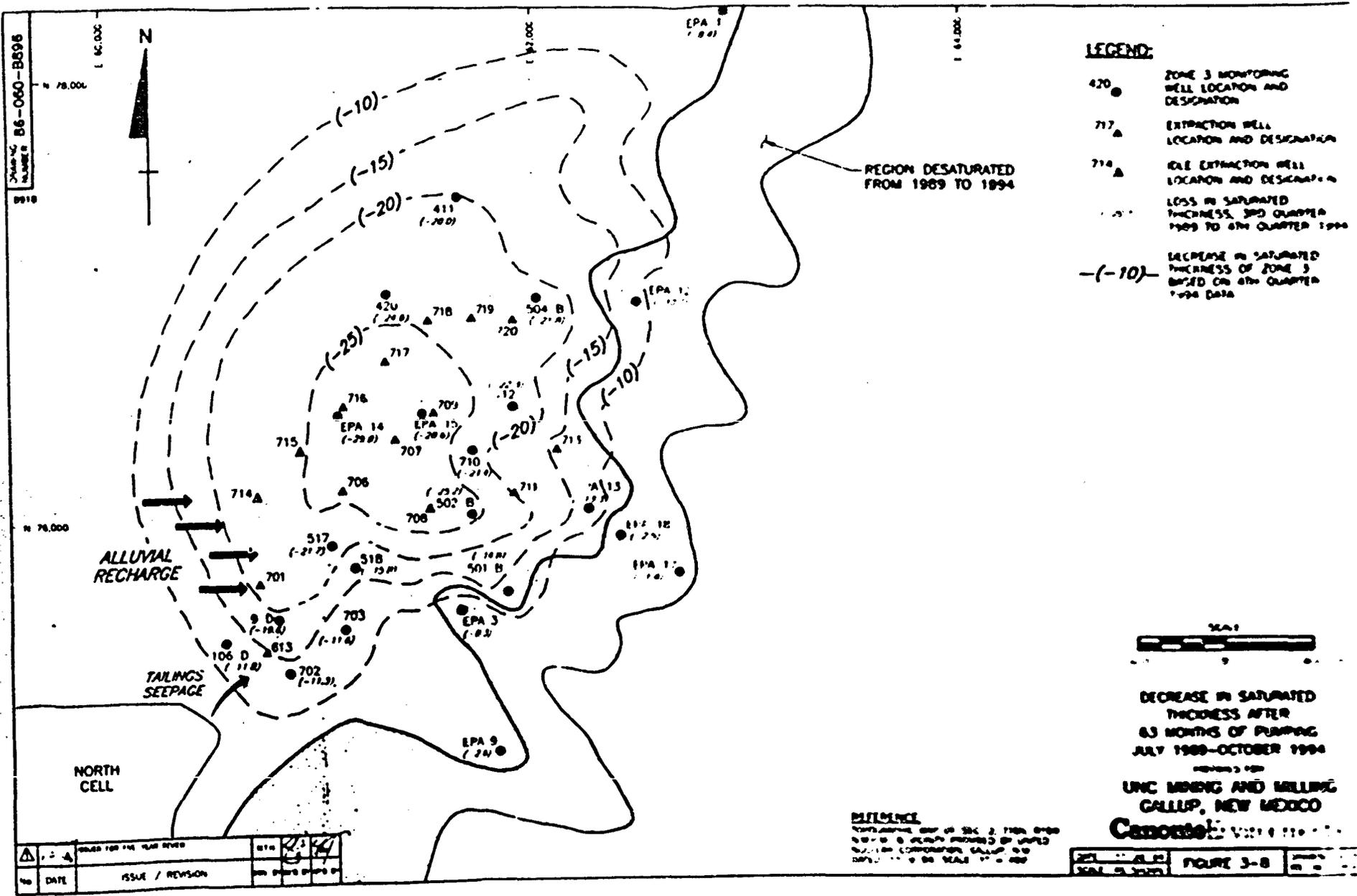
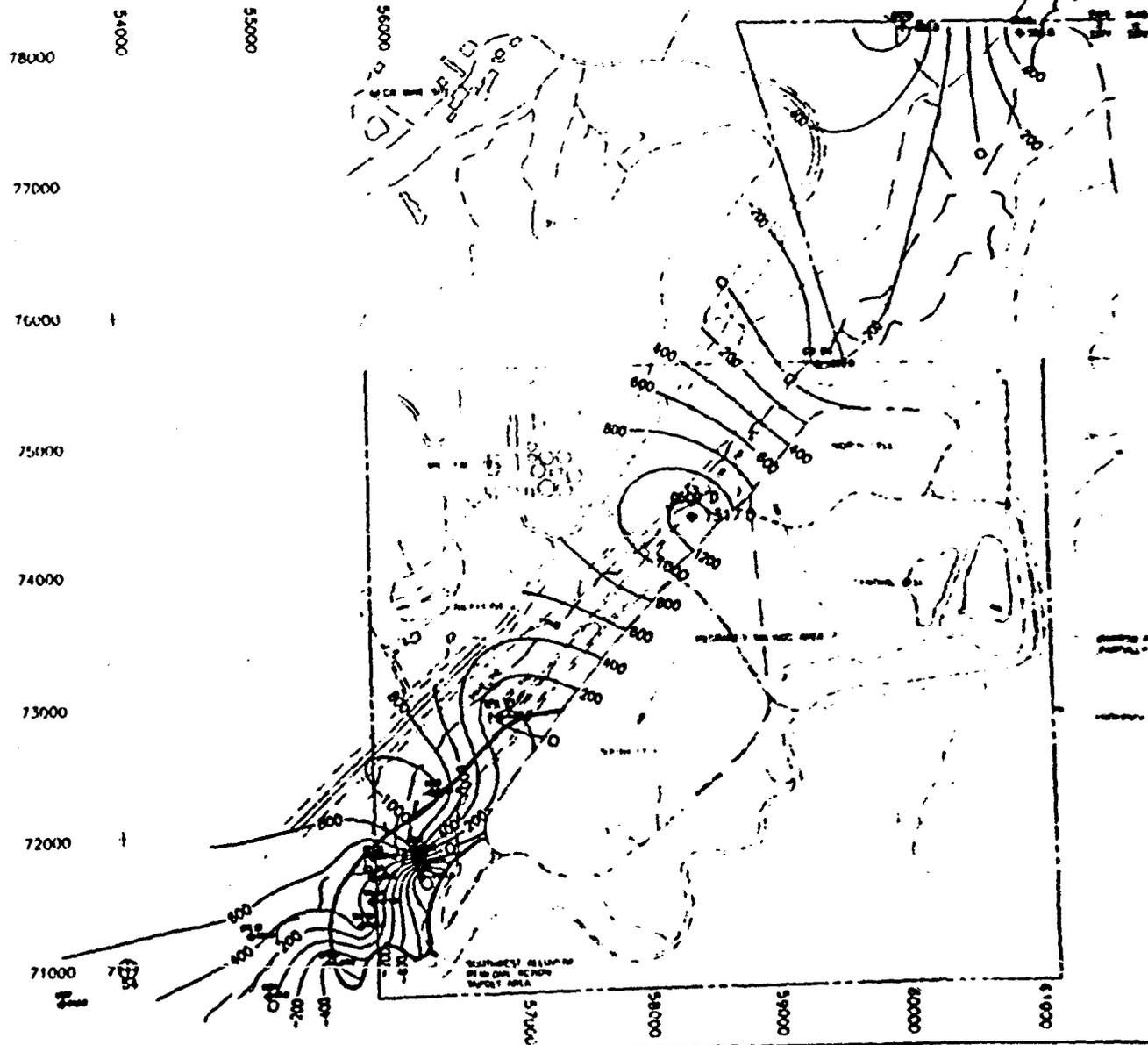


FIGURE 4



- LEGEND**
- BOUNDARY OF SECTION 2
 - BOUNDARY OF TOWNSHIP 14N
 - BOUNDARY OF RANGE 14E
 - ELEVATION POINT

NOTE TOPOGRAPHIC MAP OF SEC. 2, T14N, R14E, NE 1/4 & SW 1/4, PREPARED BY UNITED STATES GEOLOGICAL SURVEY, DATED 10-20-09



DATE	7/15/77	SCALE	2000	SHEET	FIGURE 3 15
<p>JACOB BERENSON GROUP INC. GEOTECHNICAL AND SURVEY AND ENGINEERING GROUP 10000 UNIVERSITY DRIVE SUITE 100 DALLAS, TEXAS 75243 (214) 343-1100 WWW.JBERENSON.COM</p>					

FIGURE 5

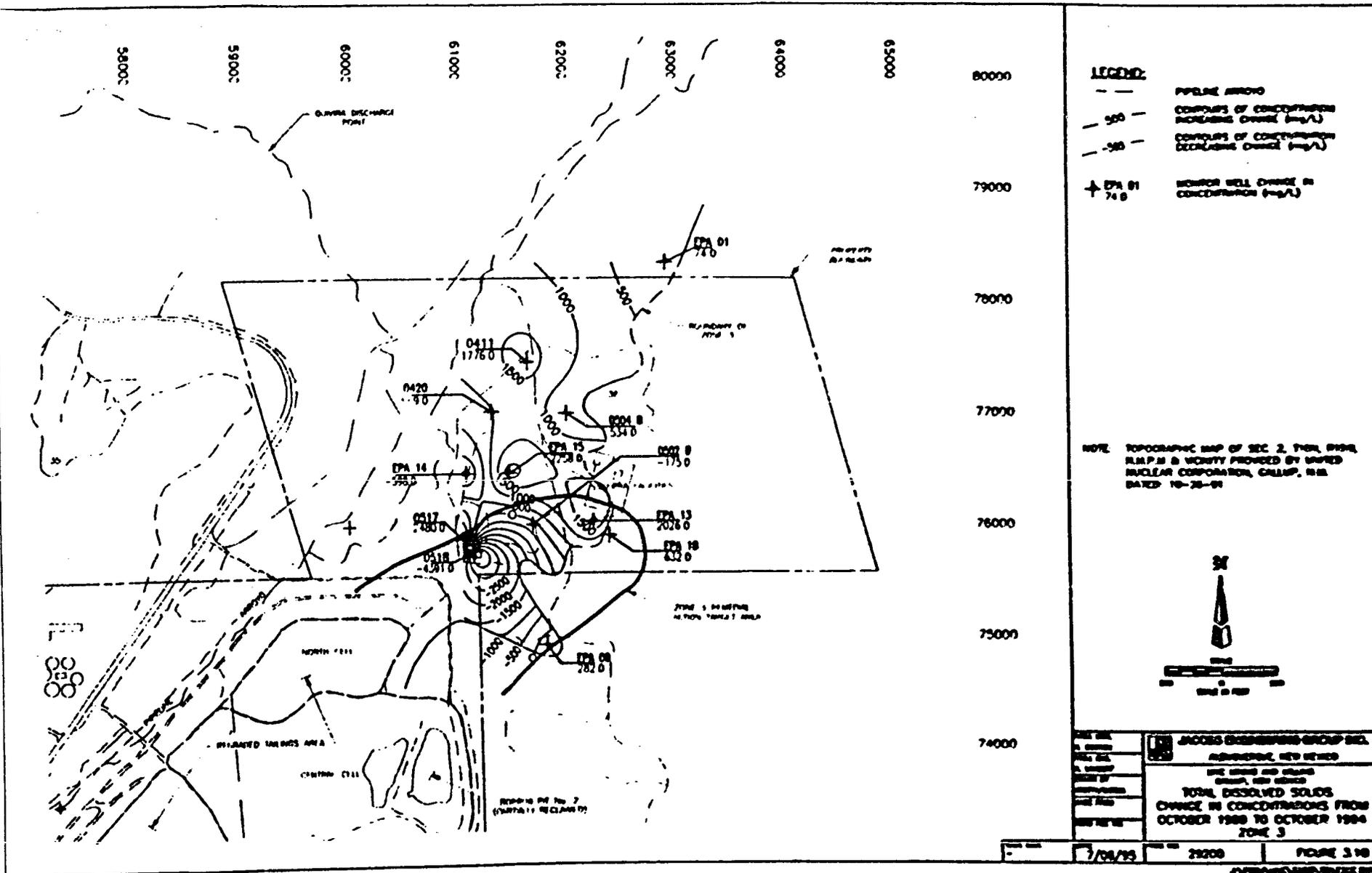
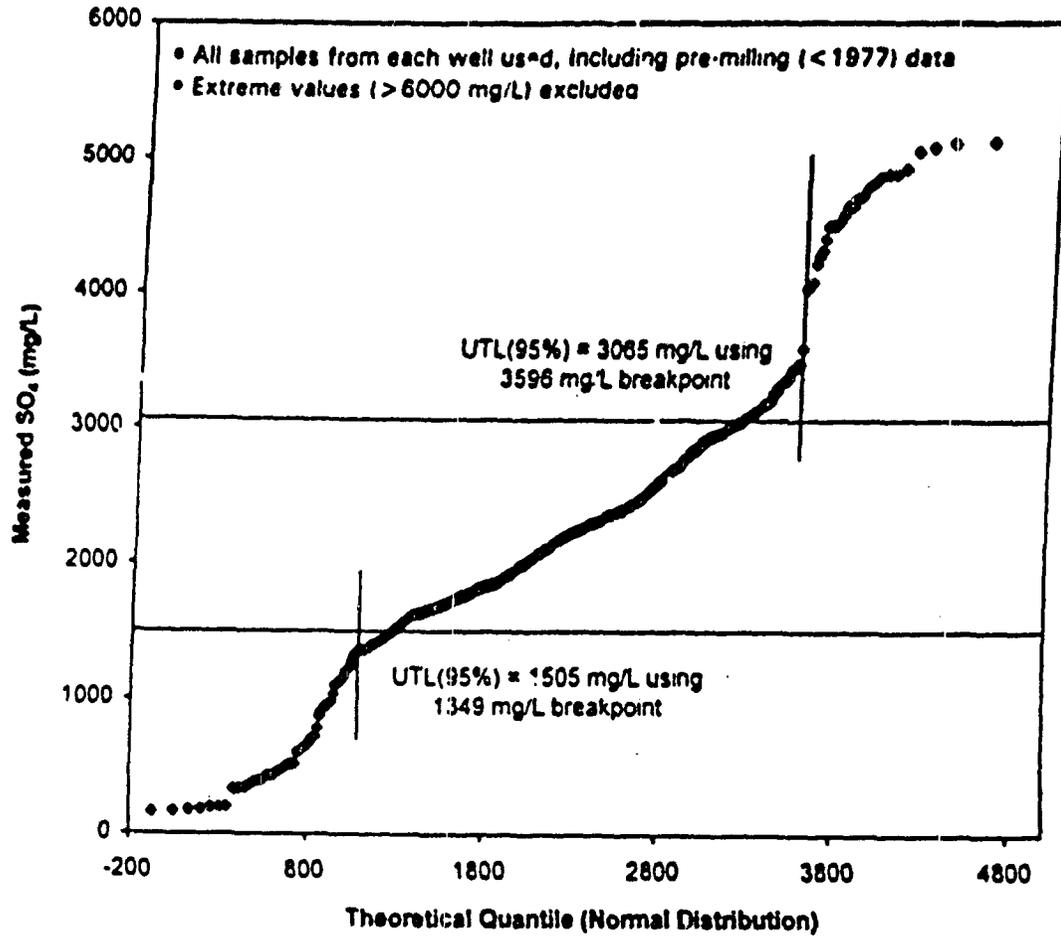


FIGURE 6



Southwest Alluvium: Q-Q Plot for Sulfate

Q-Q Plots of 1977 Southwest Alluvium Nitrate Data

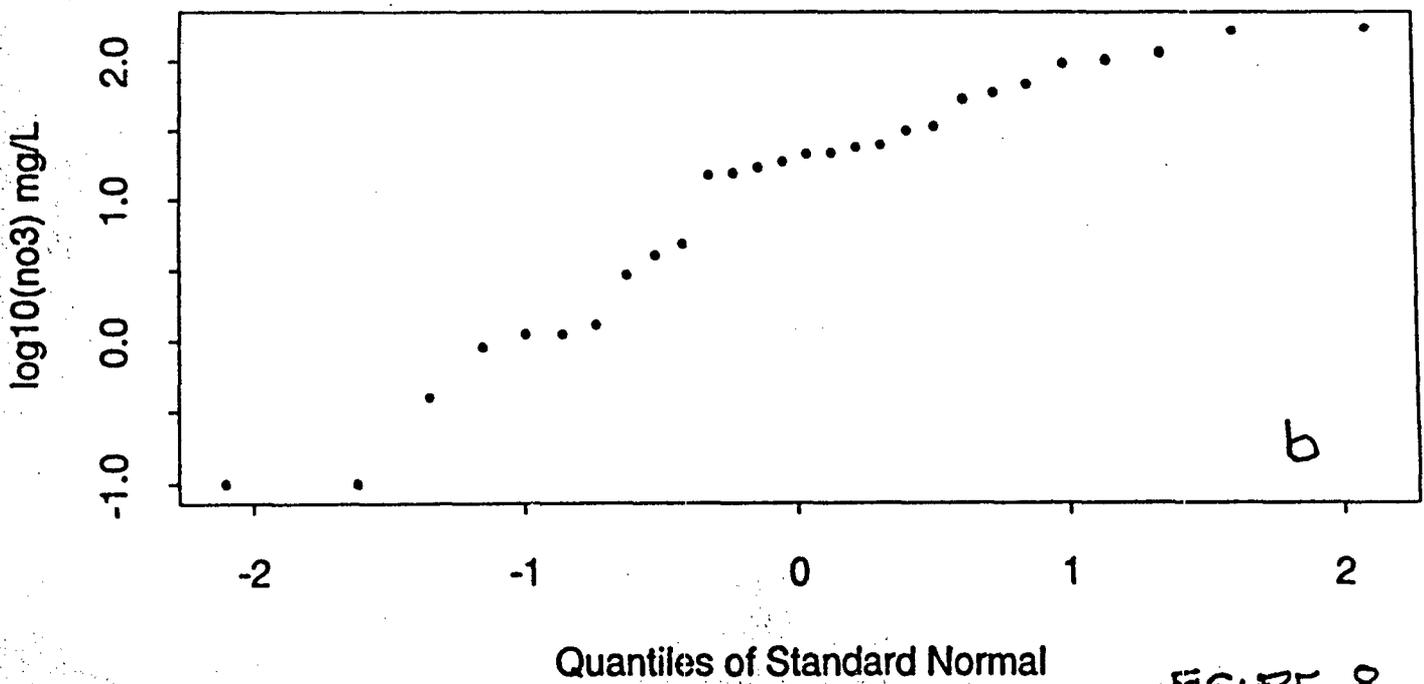
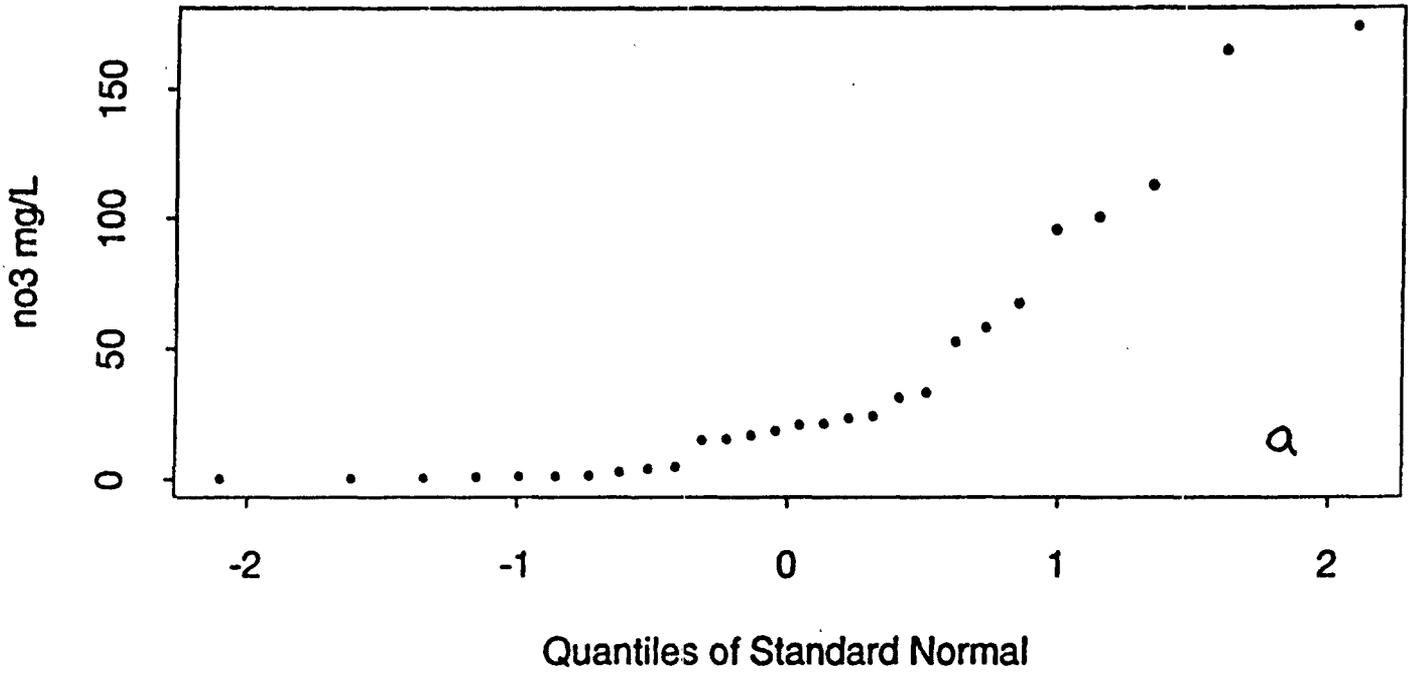
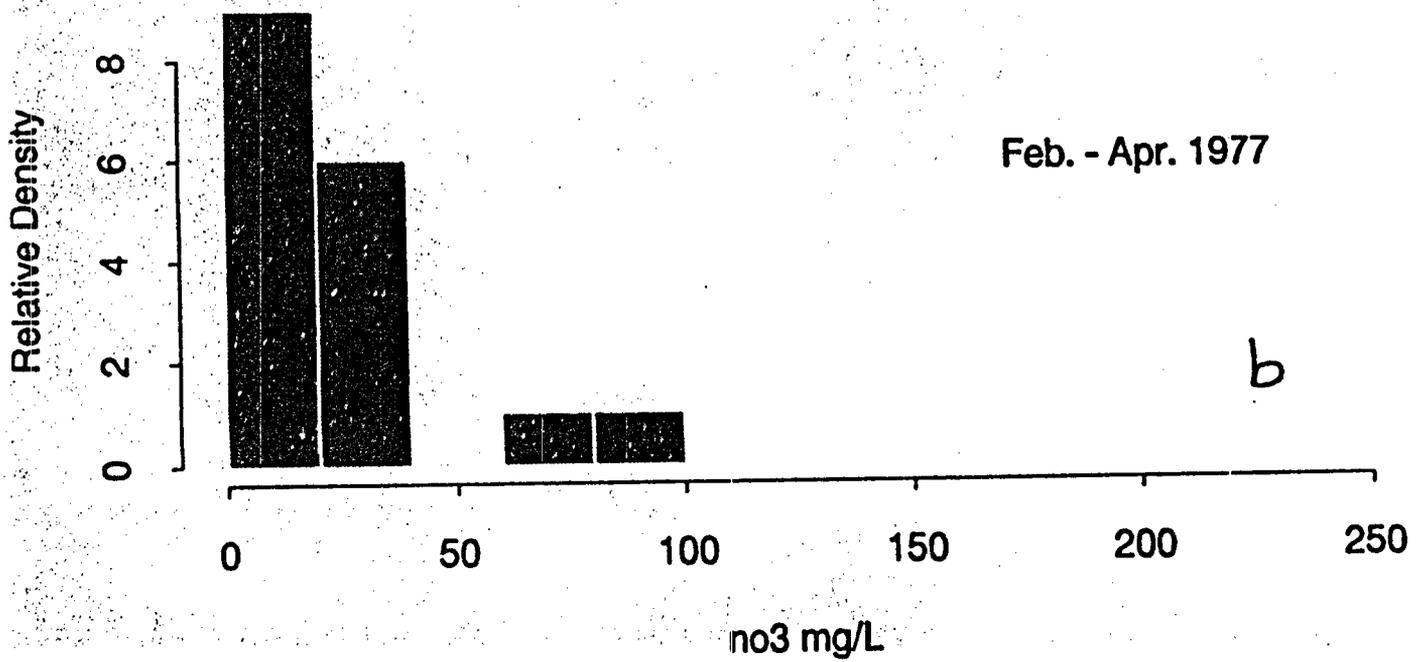
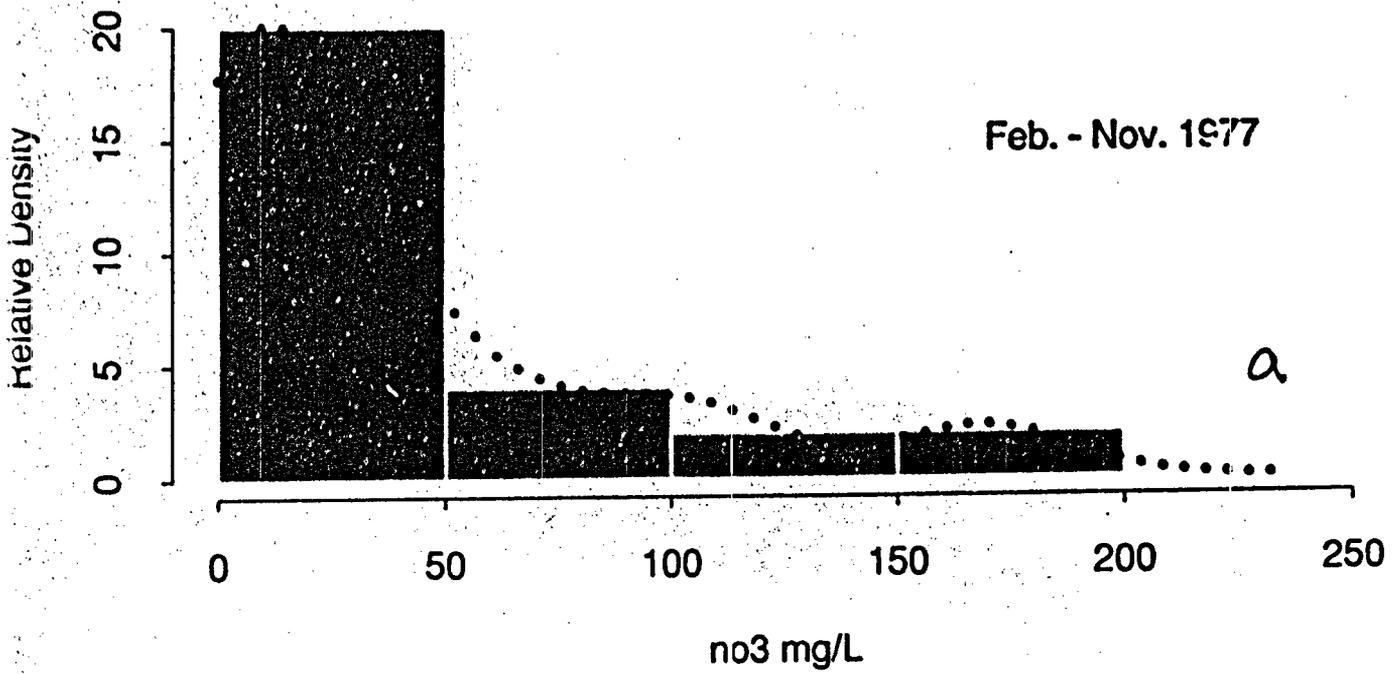
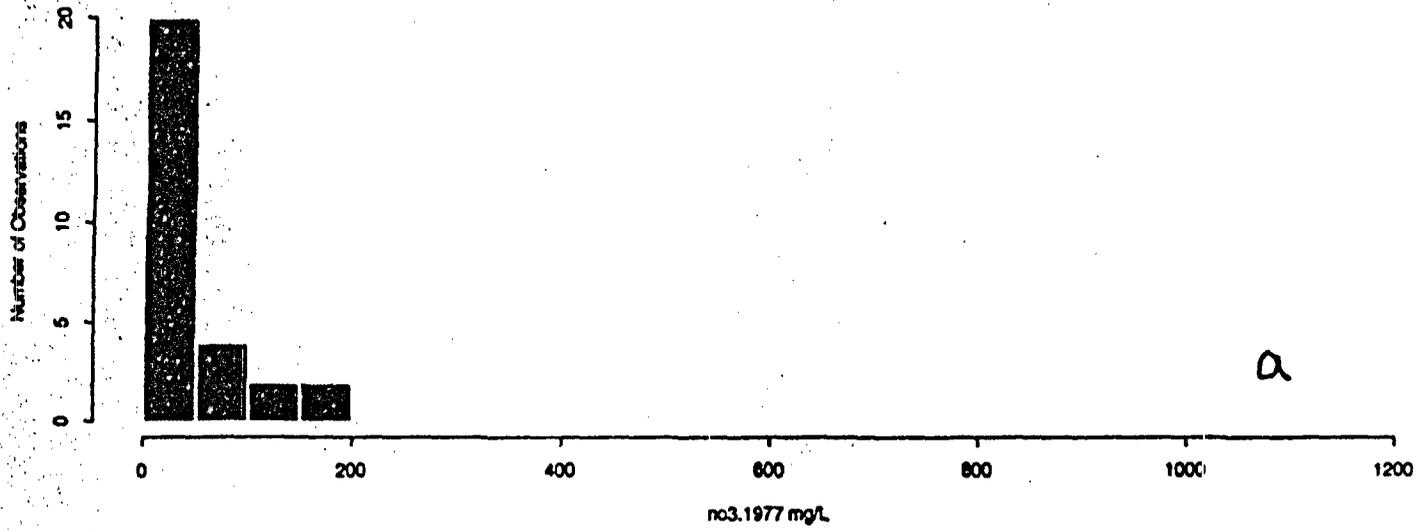


FIGURE 8

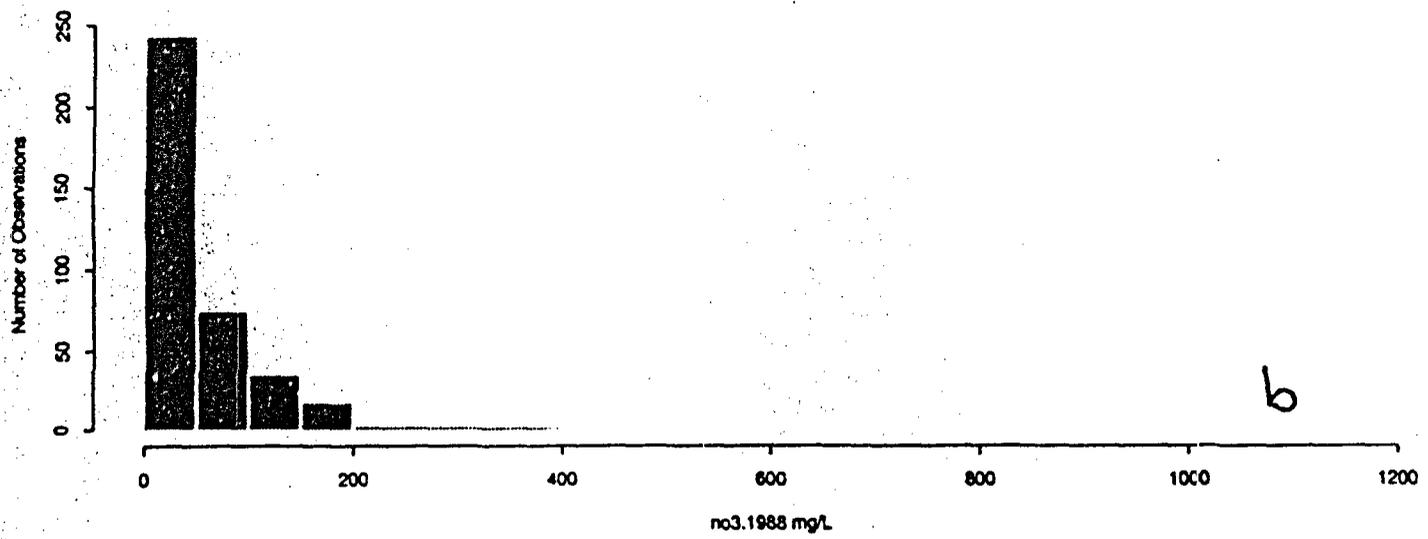
1977 Southwest Alluvium Nitrate Data



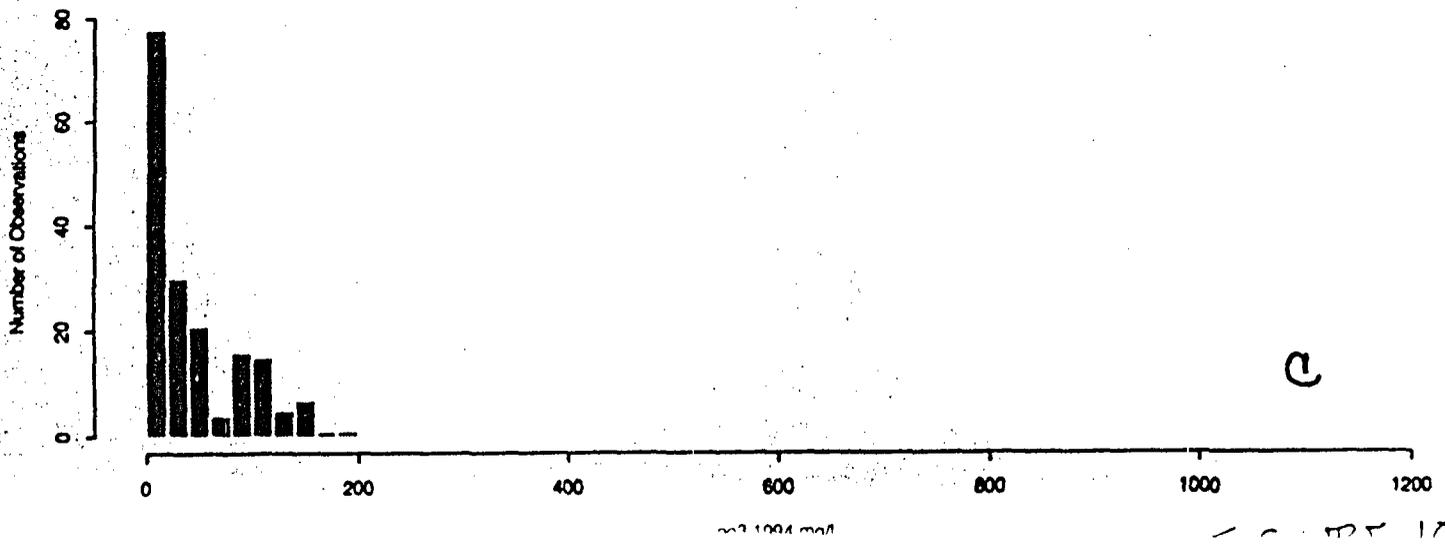
Nitrate Concentrations Through Time/ SW Alluvium



a



b



c

1000000

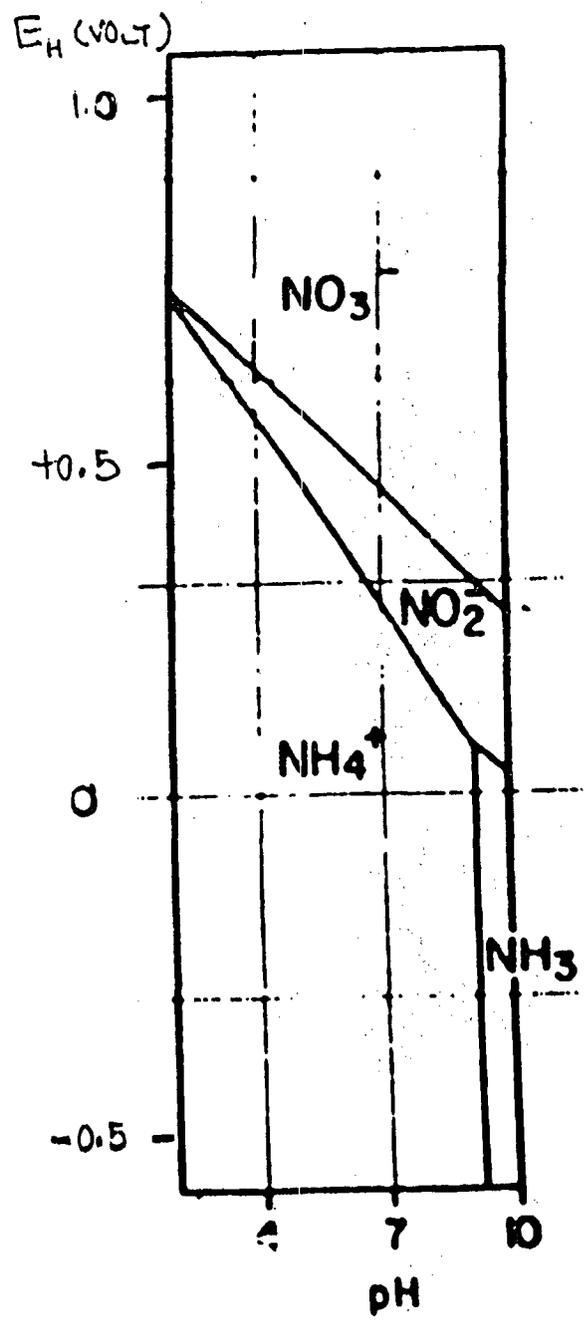
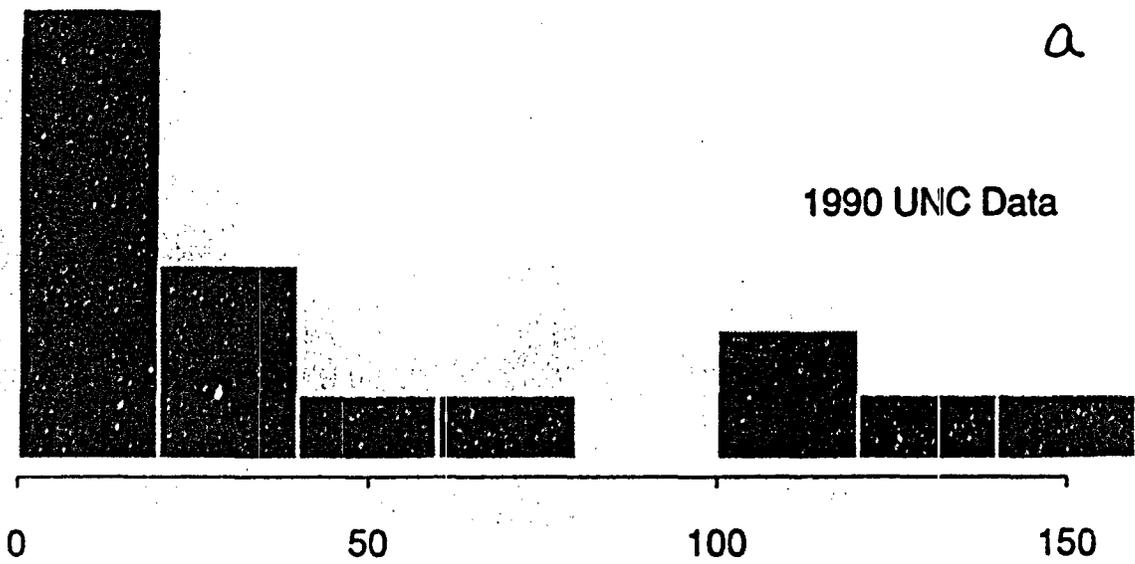


FIGURE 11

Soil Leachable Nitrate Data: 1990, 1995

Number of Observations

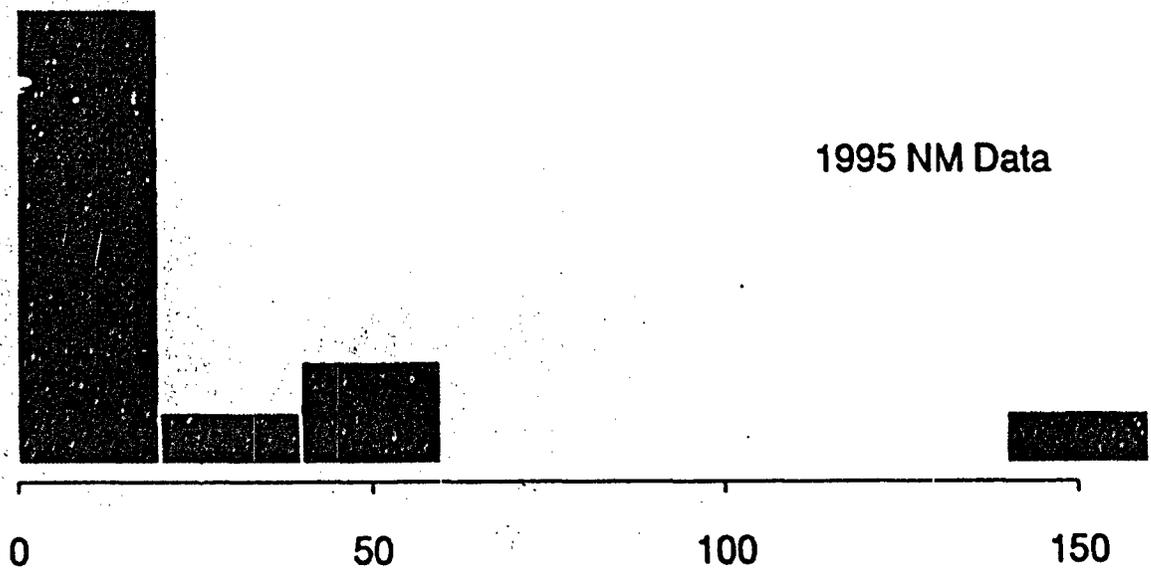
6
4
2
0



a

Number of Observations

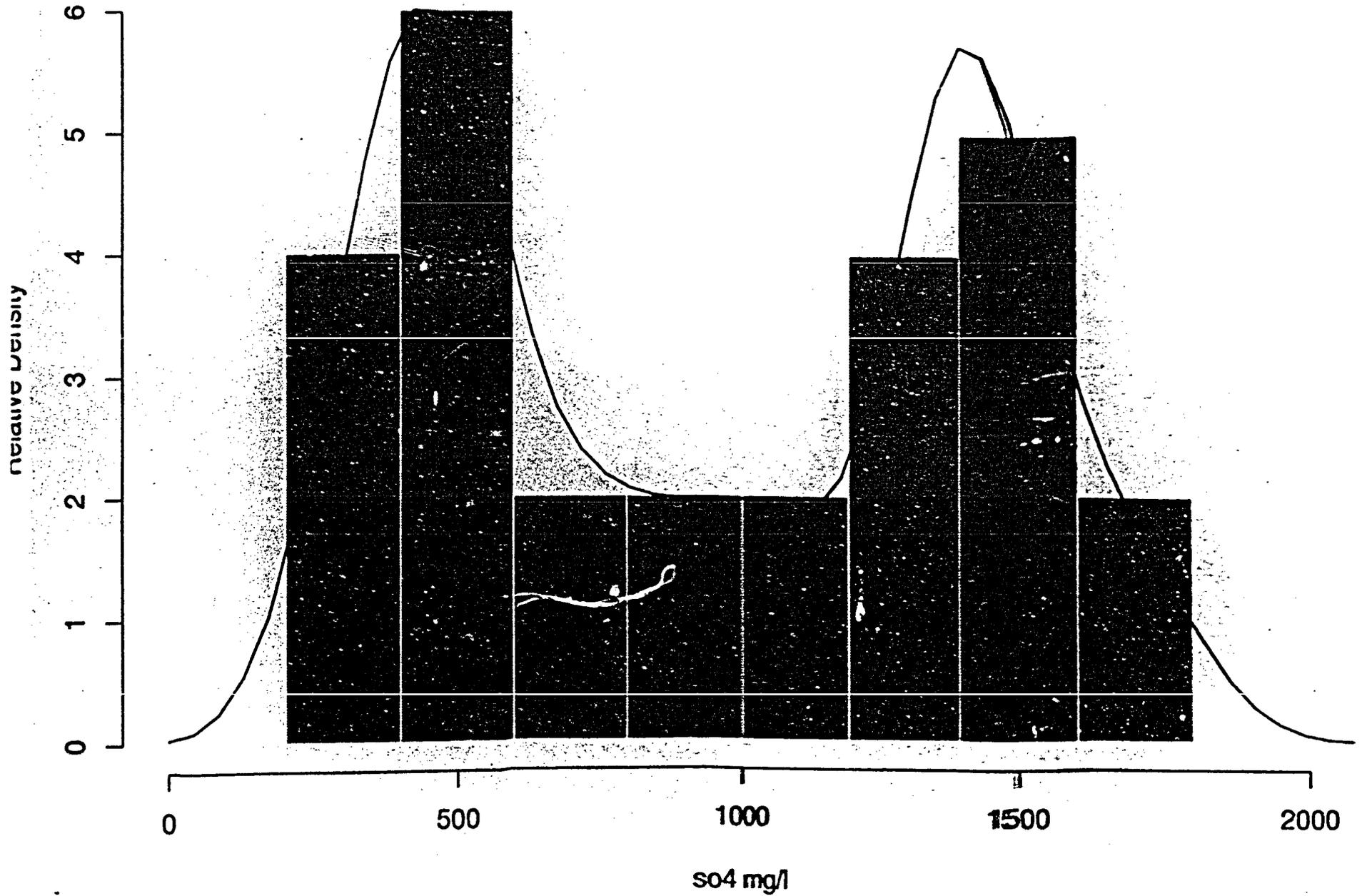
8
6
4
2
0



b

leachable no3 mg/L

1977 SO4 Concentrations



SO4 Distributions in the Southwest Alluvium Through Time

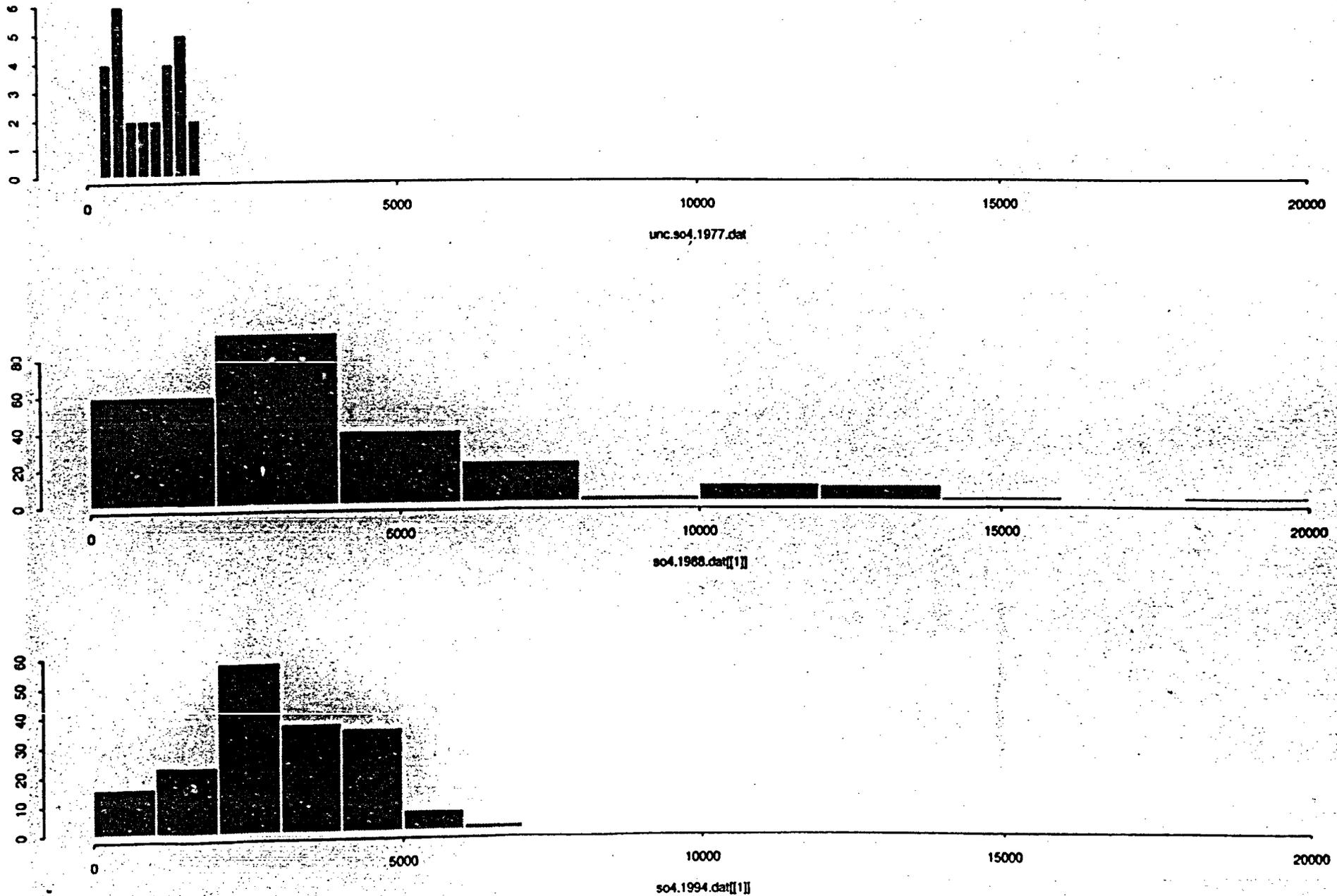
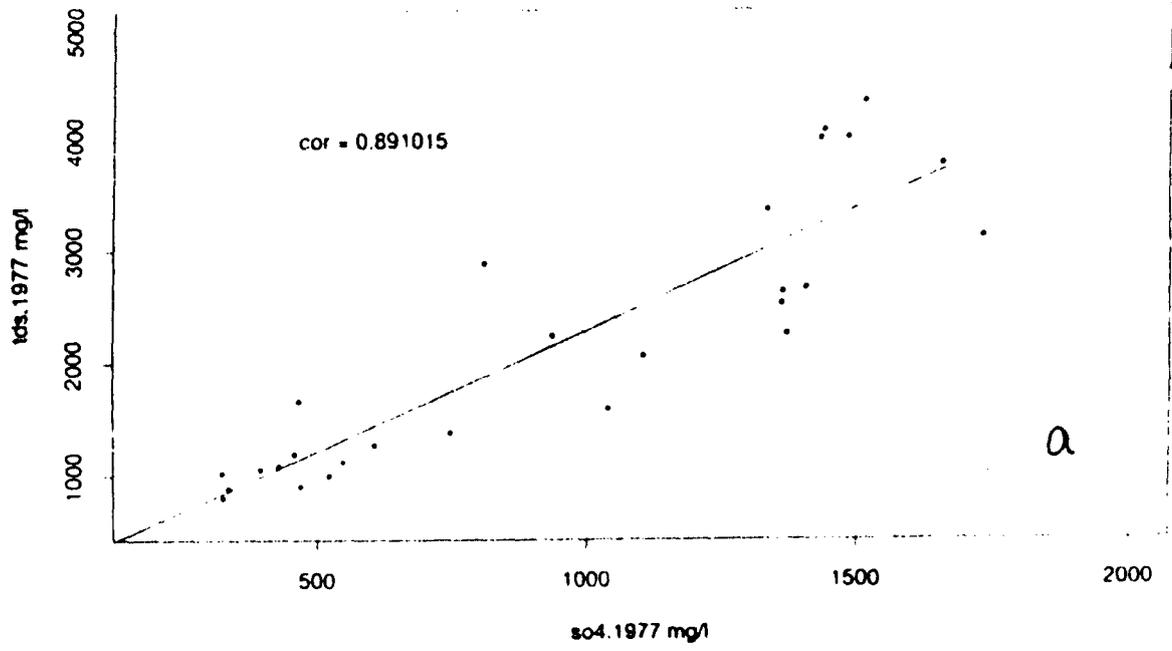
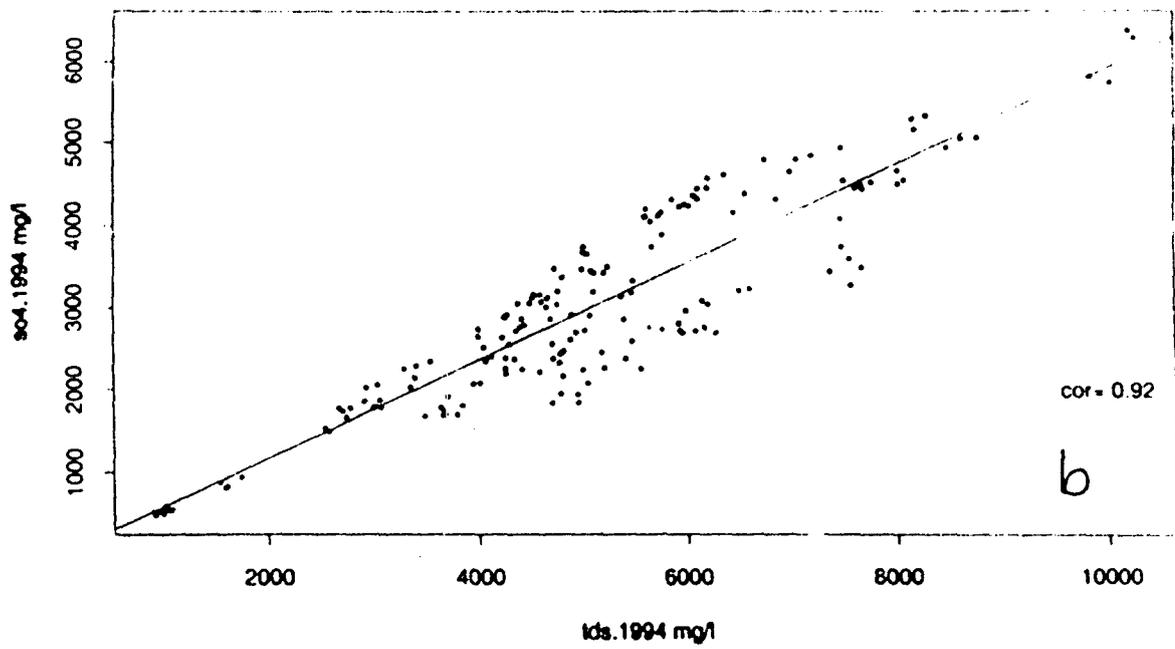


FIGURE 14

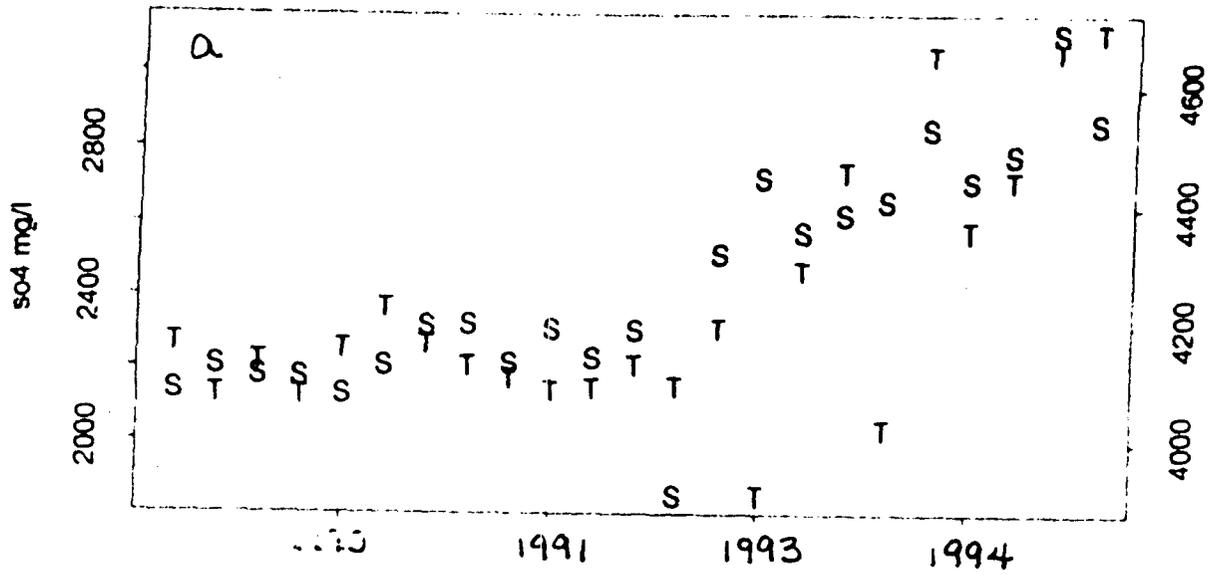
1977 SO4 and TDS Concentrations



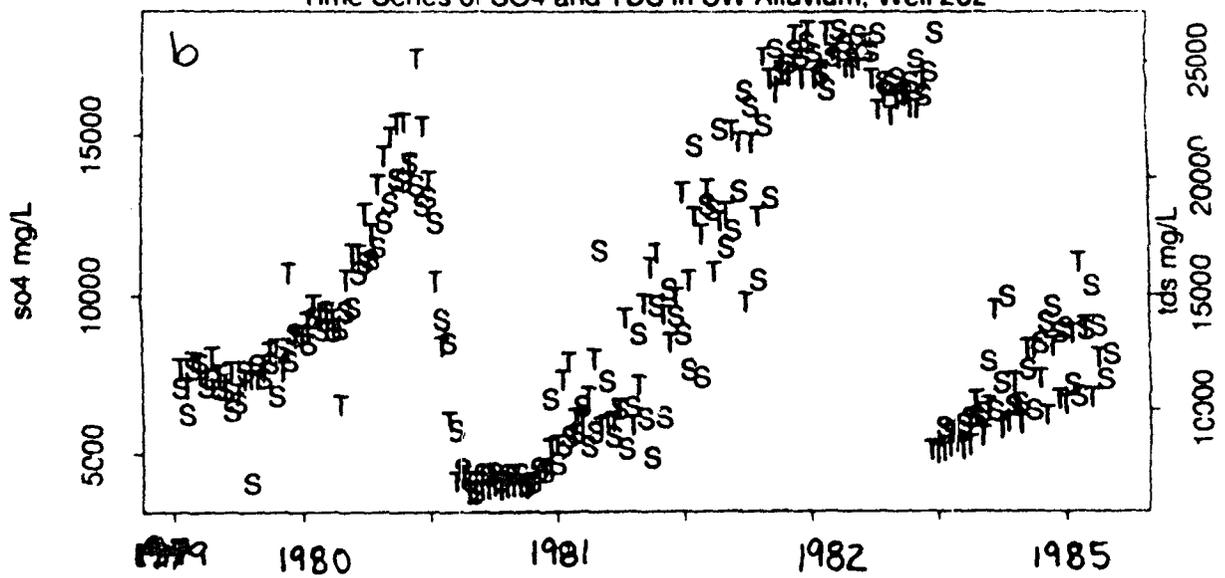
1994 SO4 and TDS Data



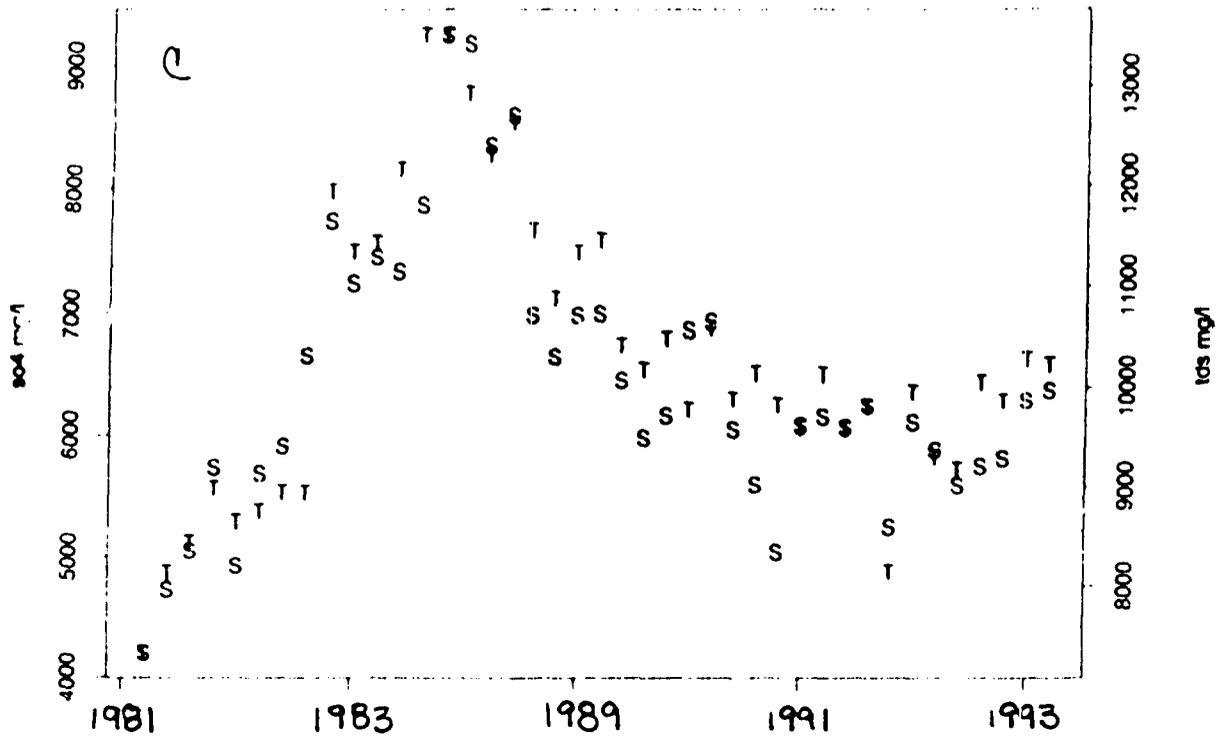
Time Series of SO4 and TDS in Well 642, SW Alluvium



Time Series of SO4 and TDS in SW Alluvium; Well 202



Time Series of SO4 (S) and TDS (T) Well 516A, Zone 1



1977 TDS Concentrations

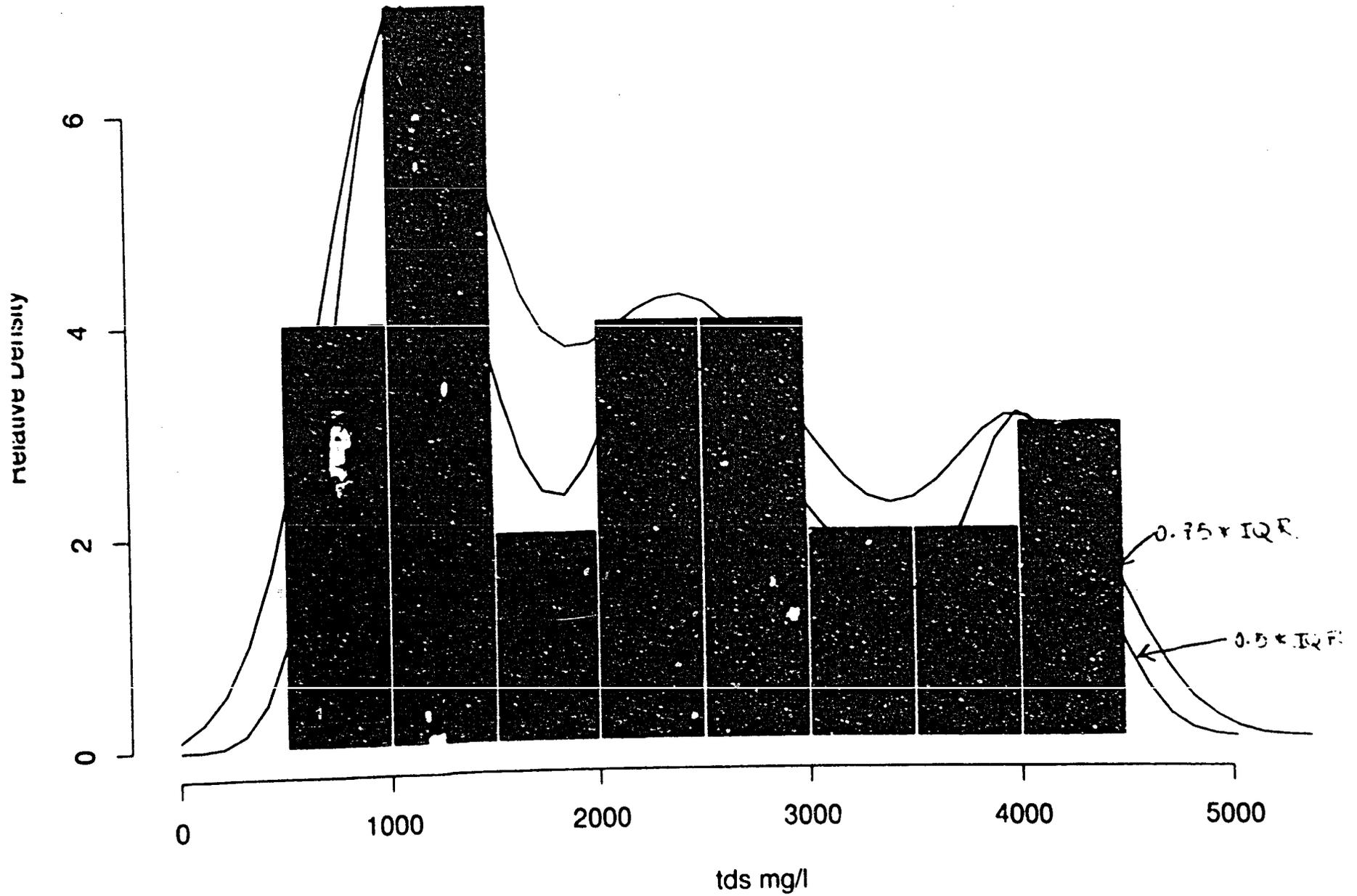


FIGURE 17

Mn and Fe Distributions/ SW Alluvium

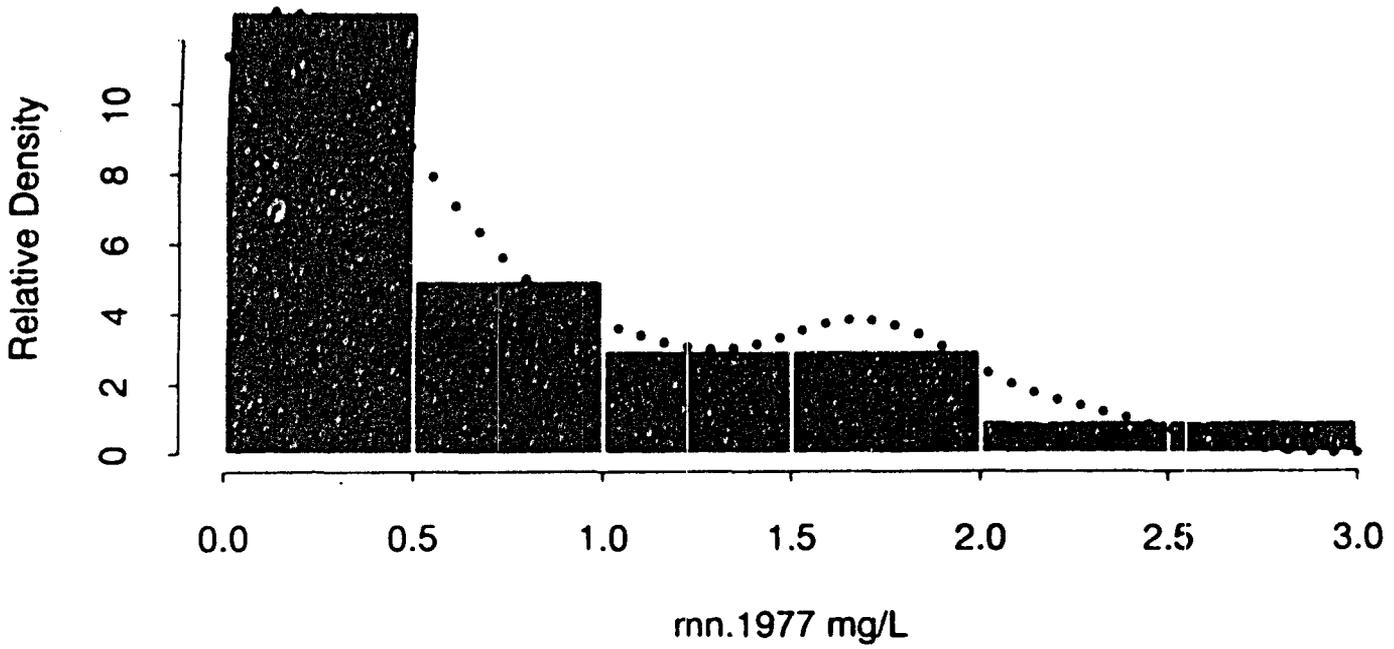


FIGURE 18

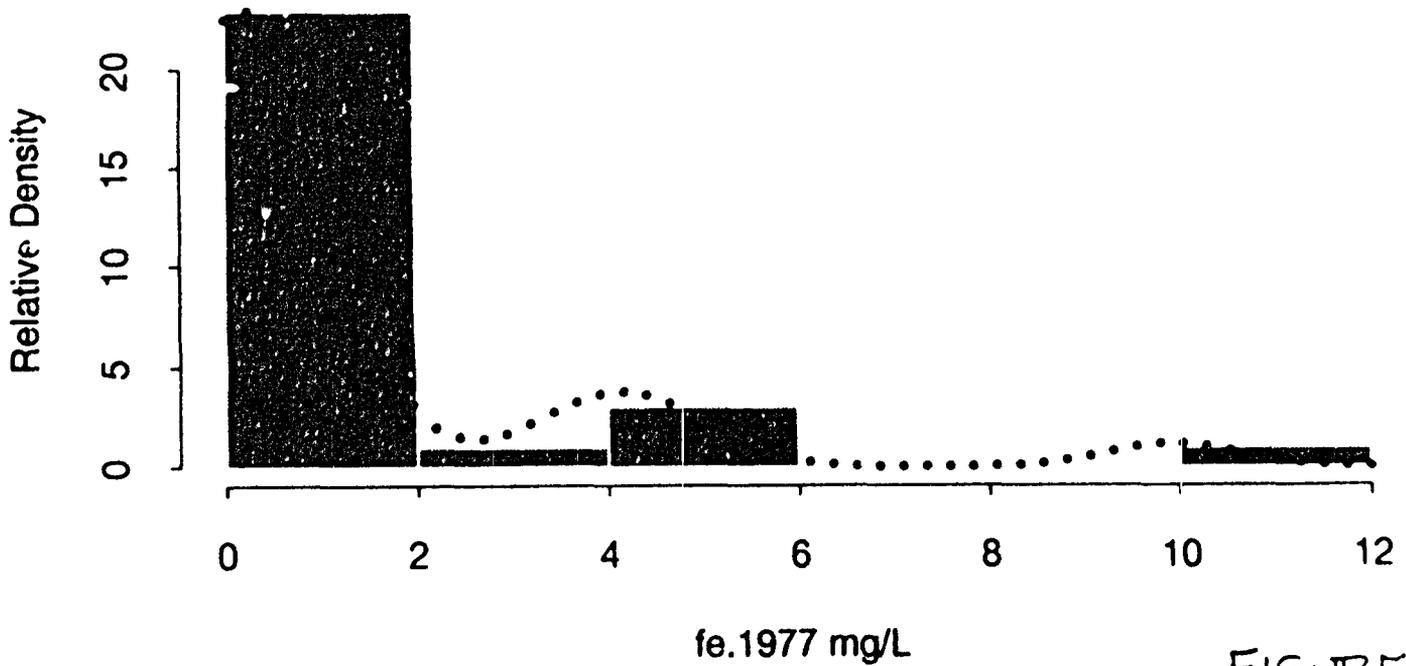
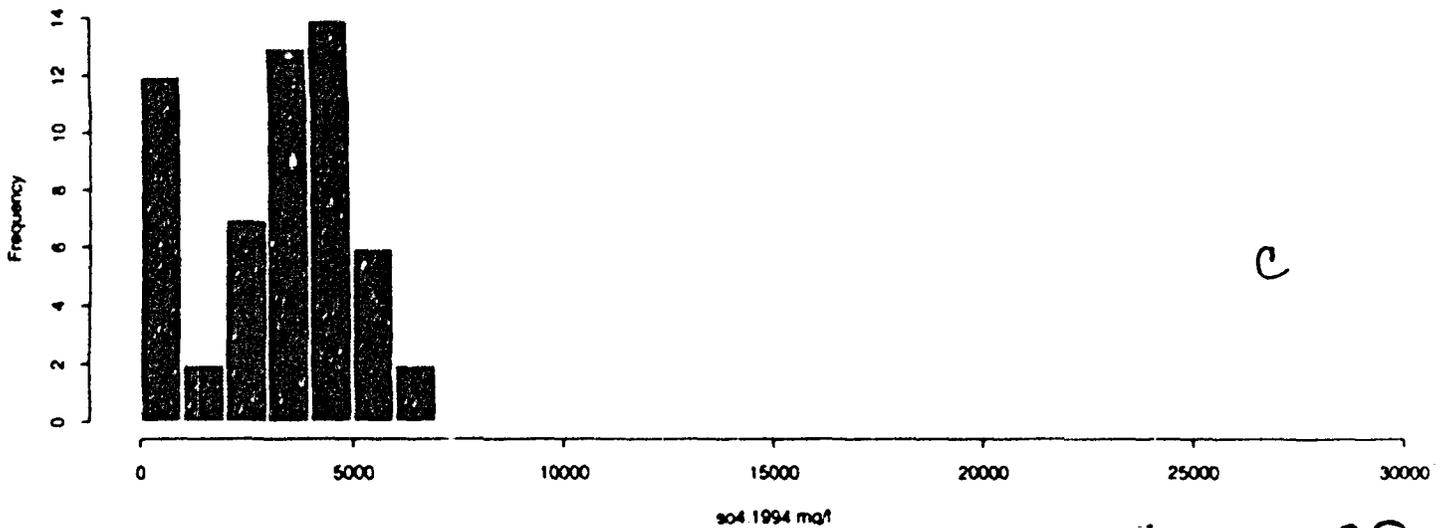
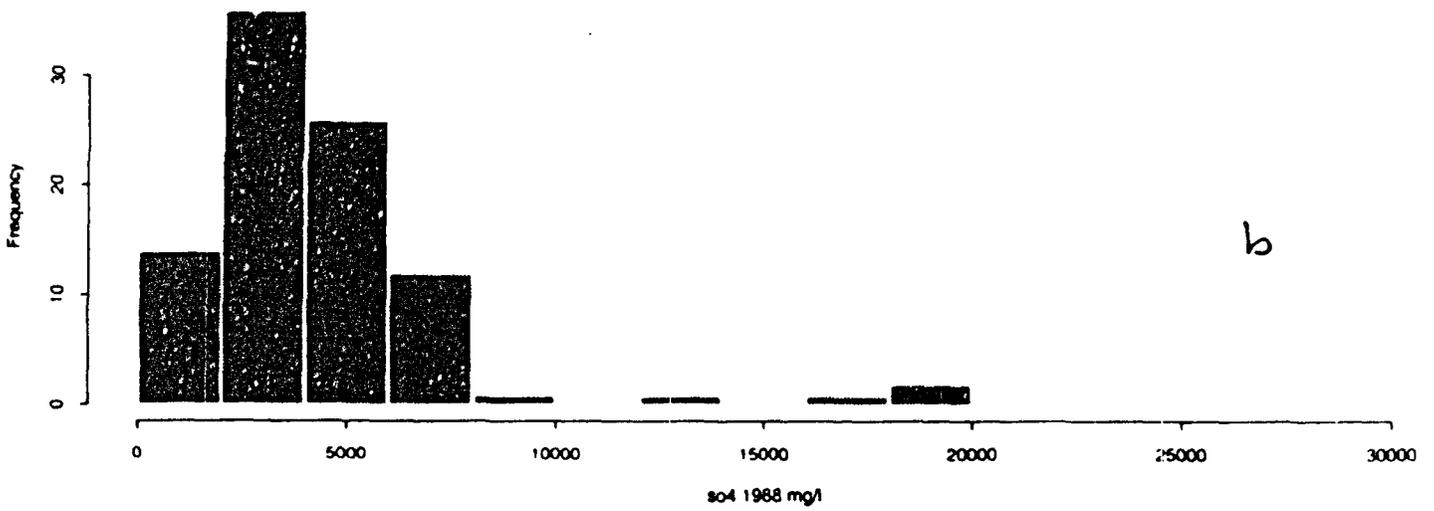
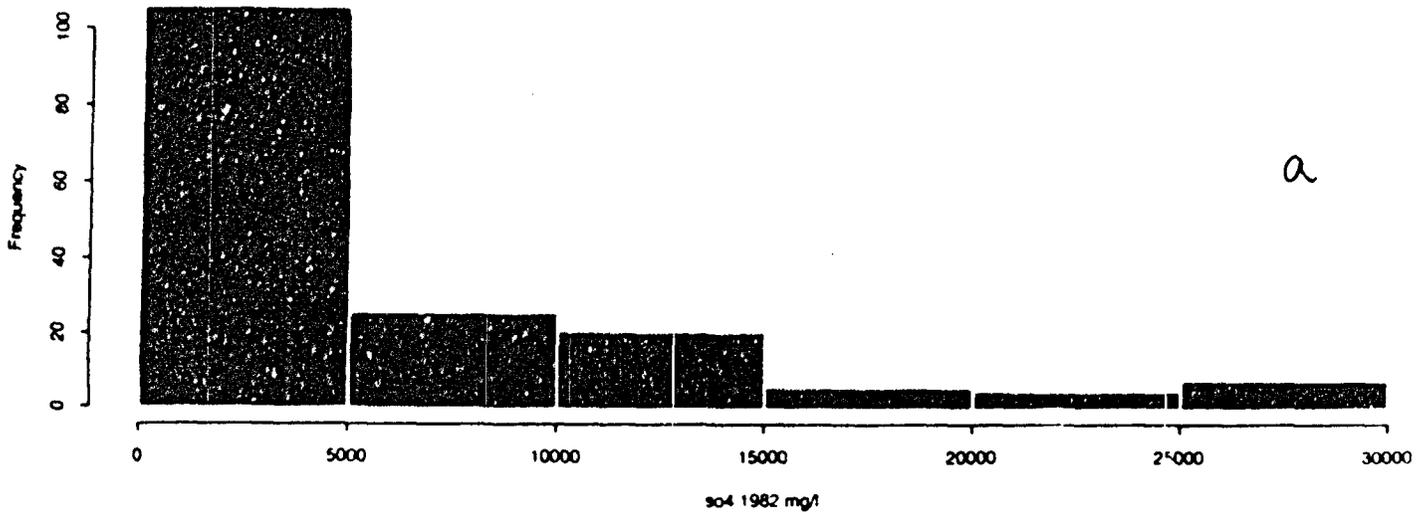
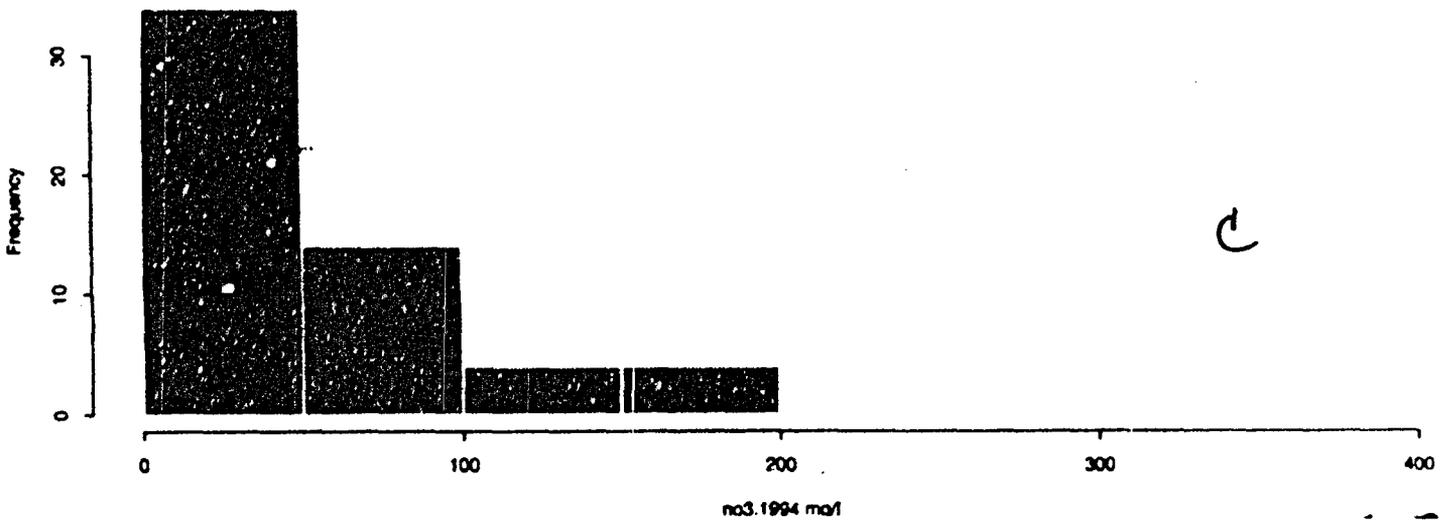
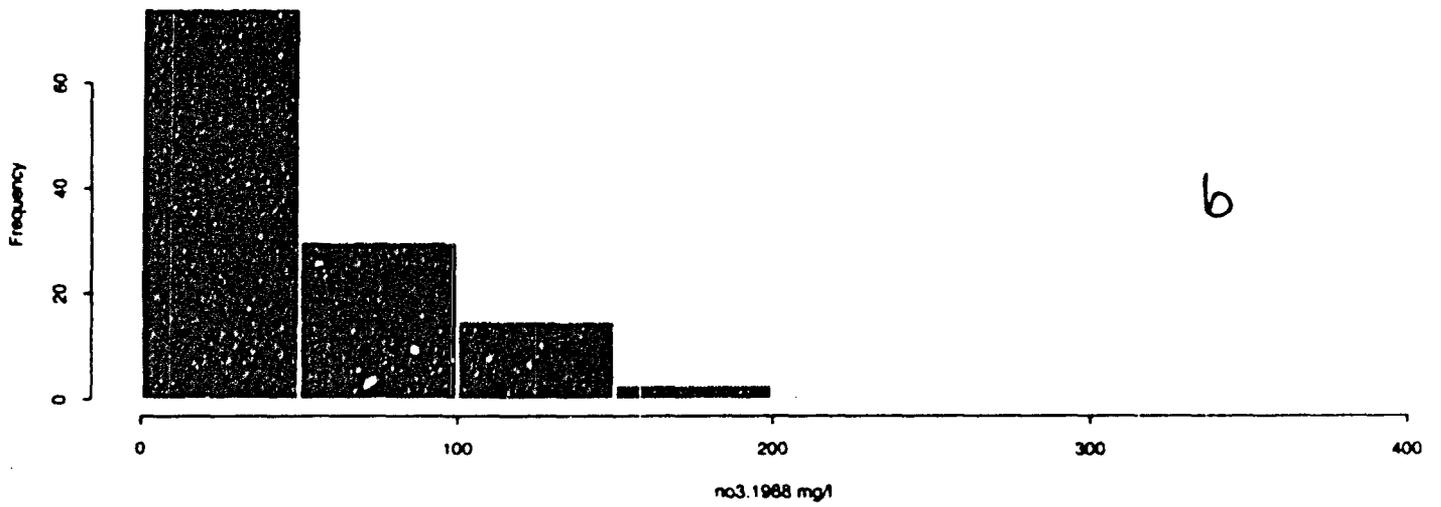
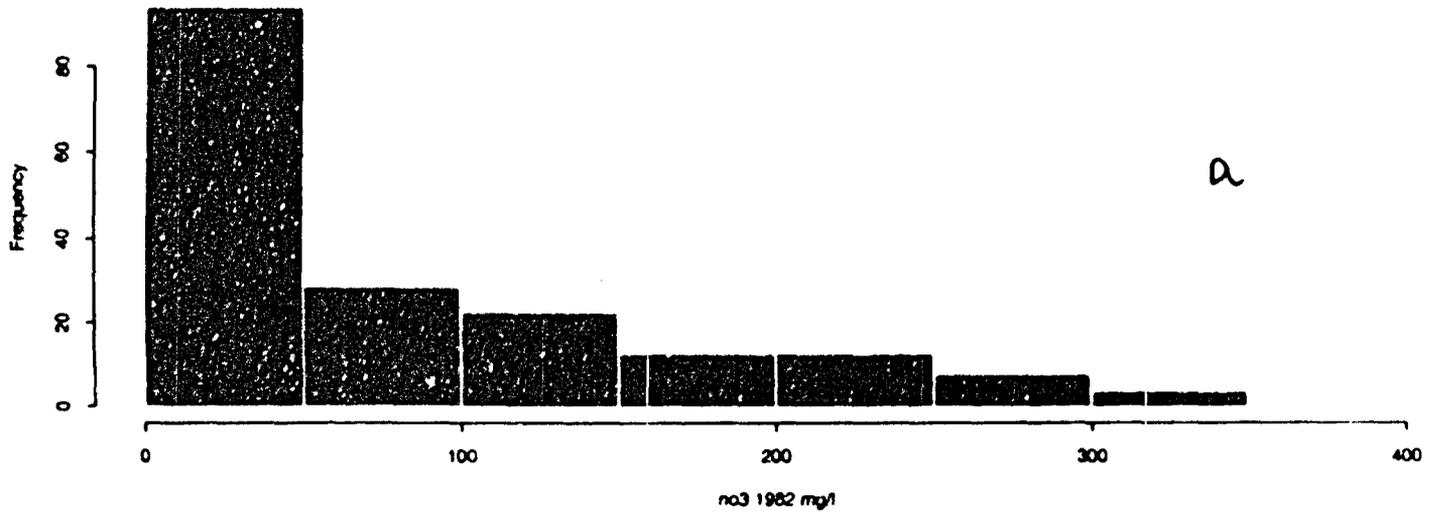


FIGURE 19

ZONE 1 SO4 DISTRIBUTIONS THROUGH TIME



ZONE 1 NO3 DISTRIBUTIONS THROUGH TIME



ZONE 3 NO3 DISTRIBUTIONS THROUGH TIME

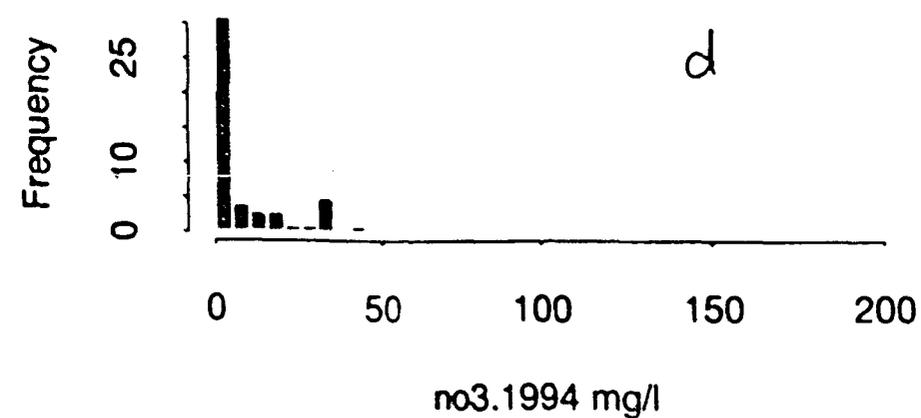
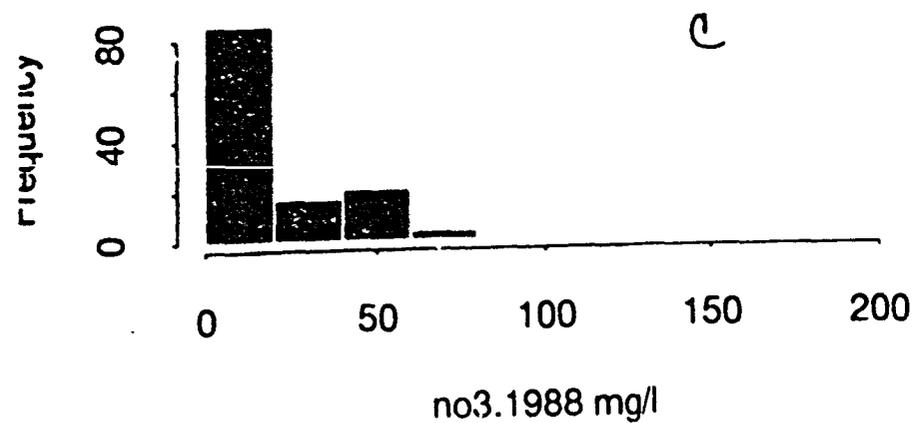
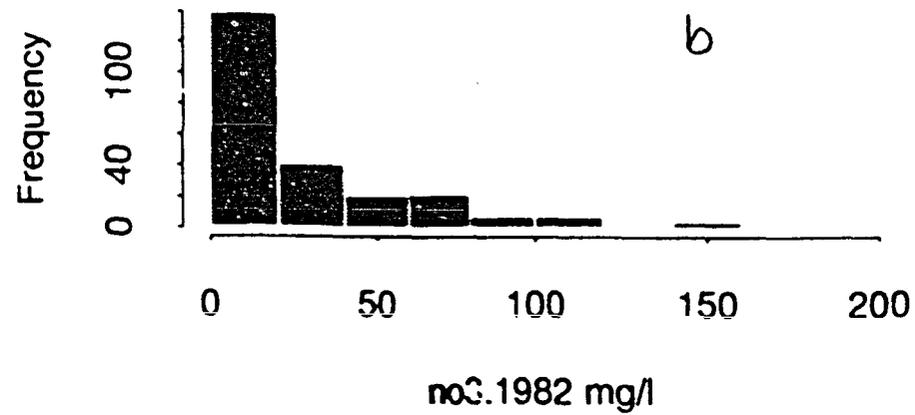
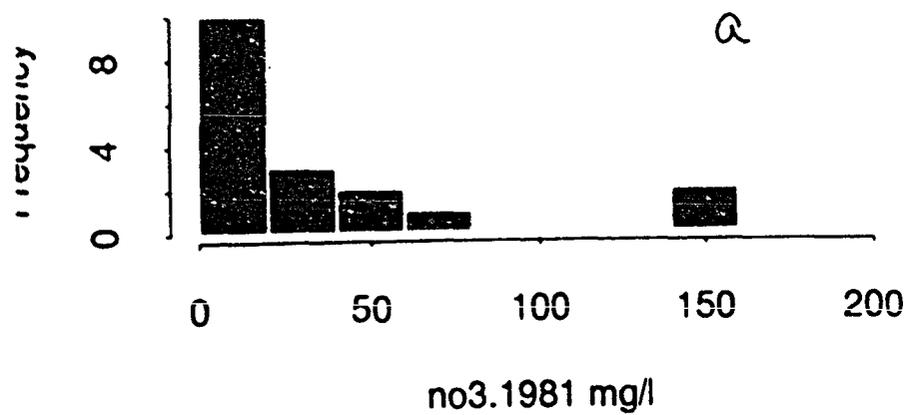


FIGURE 22

ZONE 3 SO4 DISTRIBUTIONS THROUGH TIME

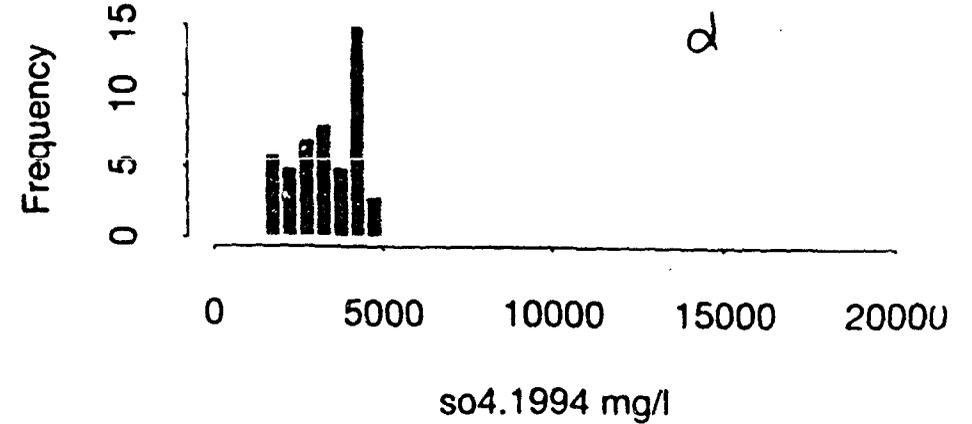
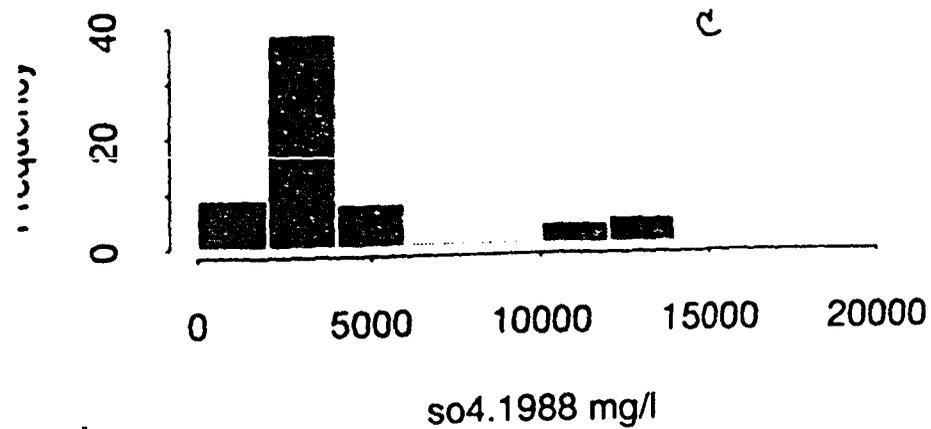
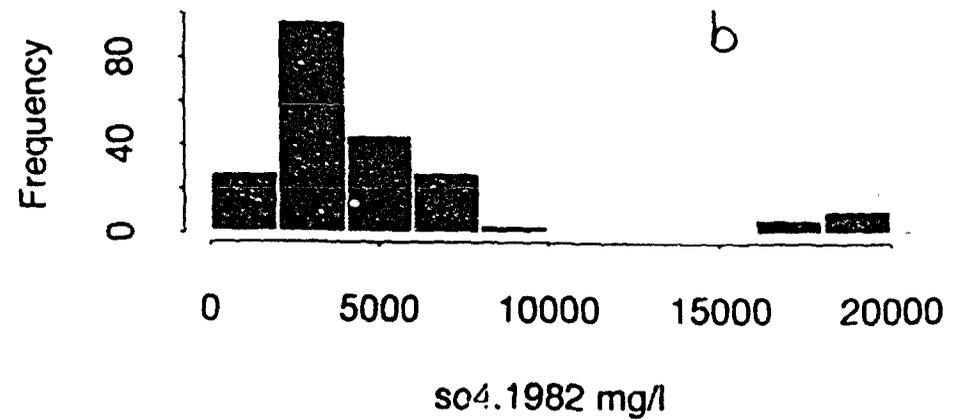
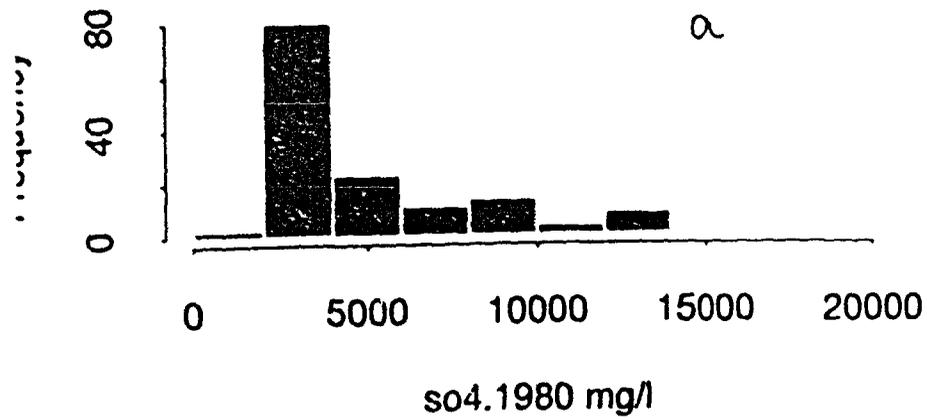
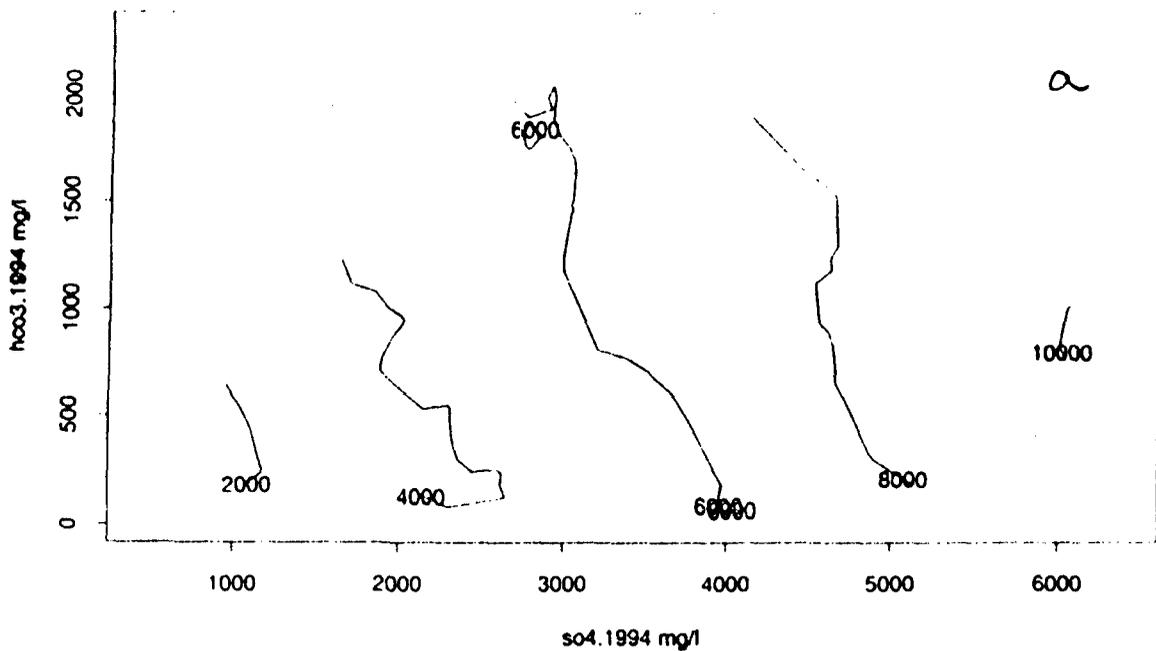
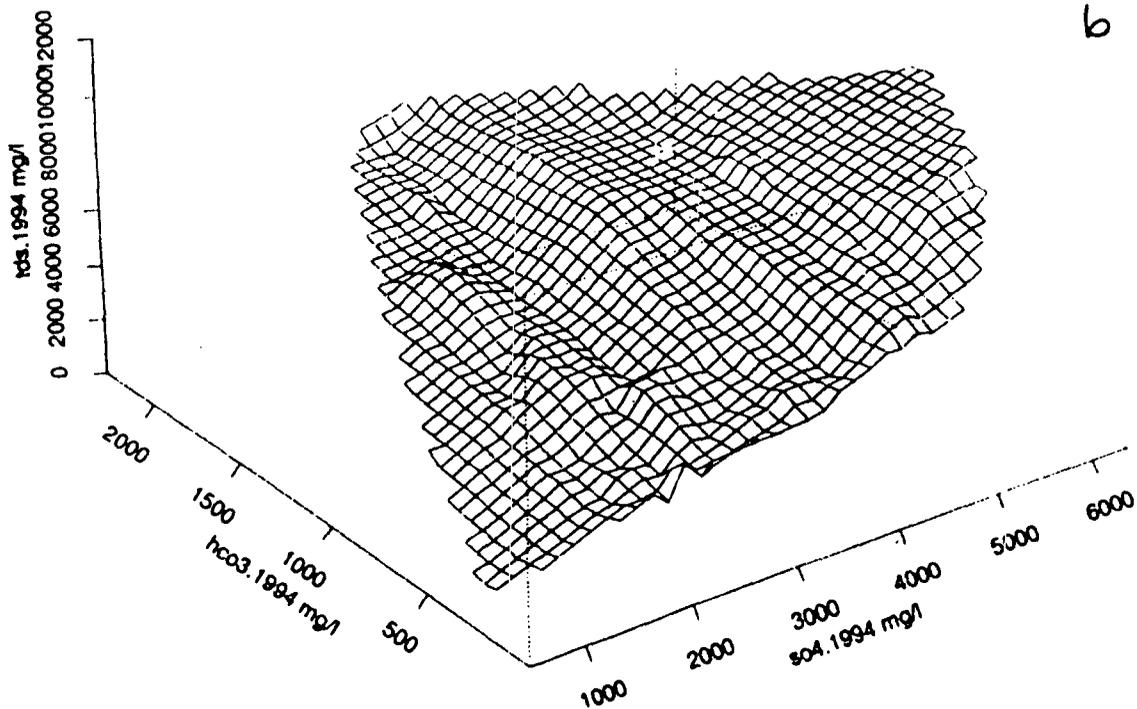


FIGURE 23

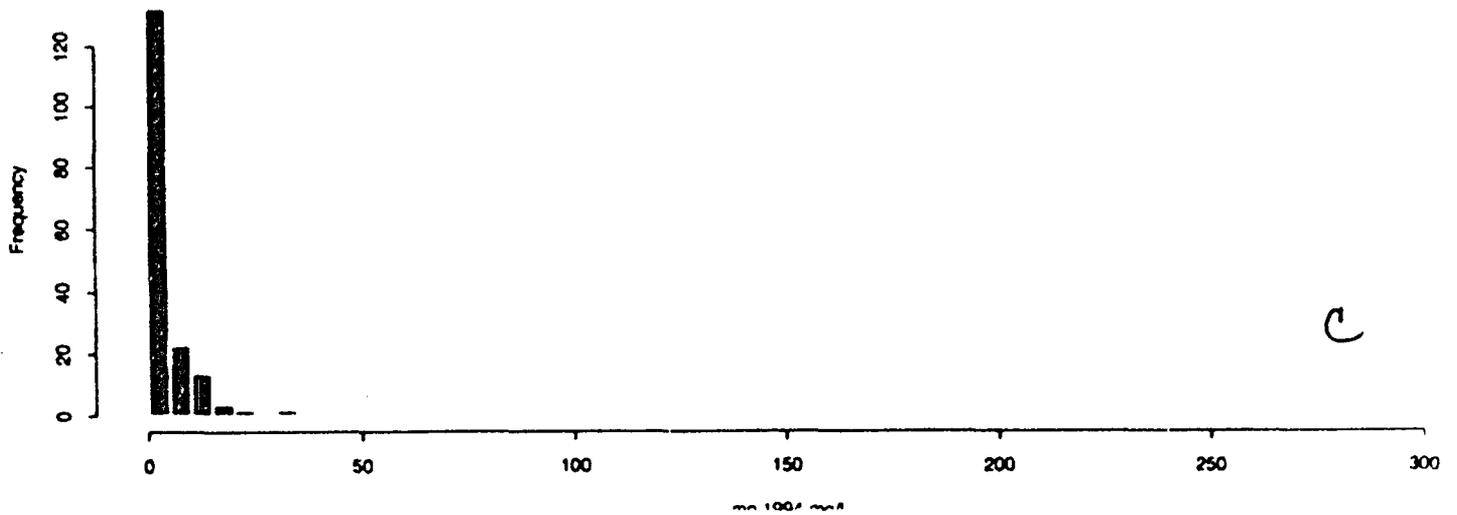
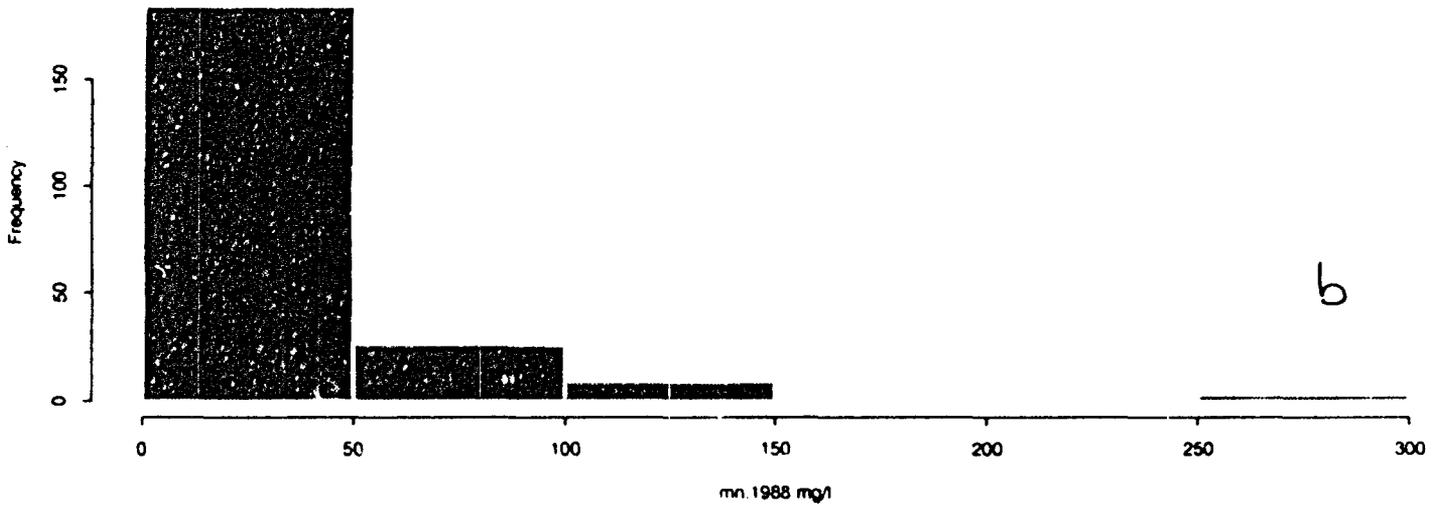
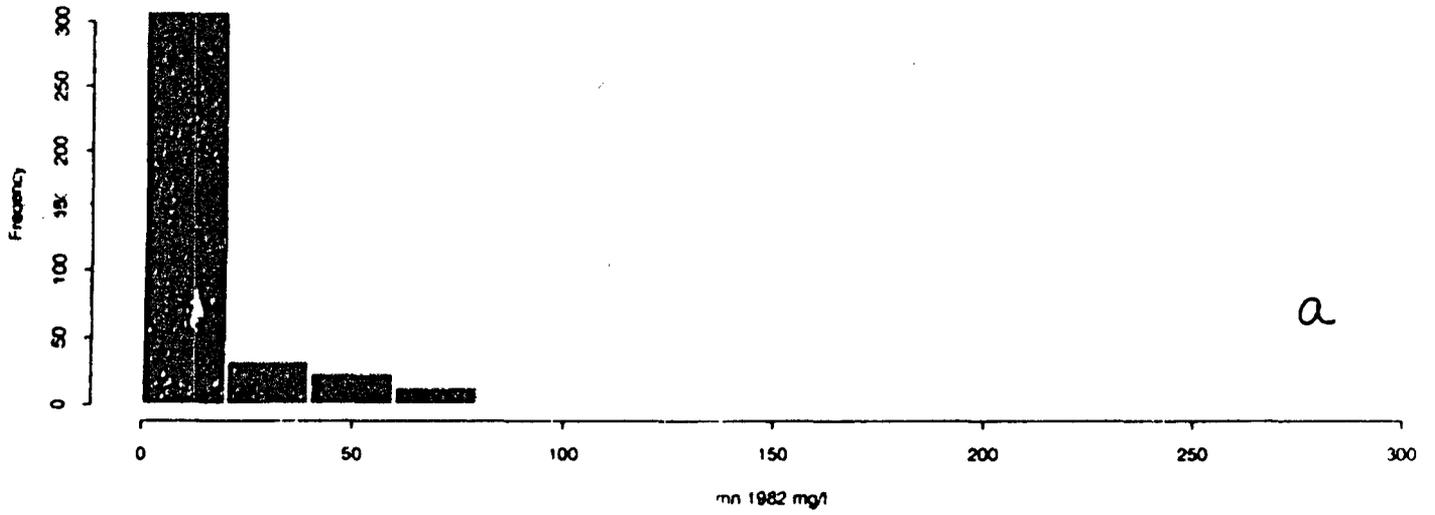
TDS Concentrations in SW Alluvium as Function of SO4 and HCO3



SO4-HCO3-TDS Surface for SW Alluvium: 1994



Mn Concentrations Through Time



Mn versus lab pH/1994

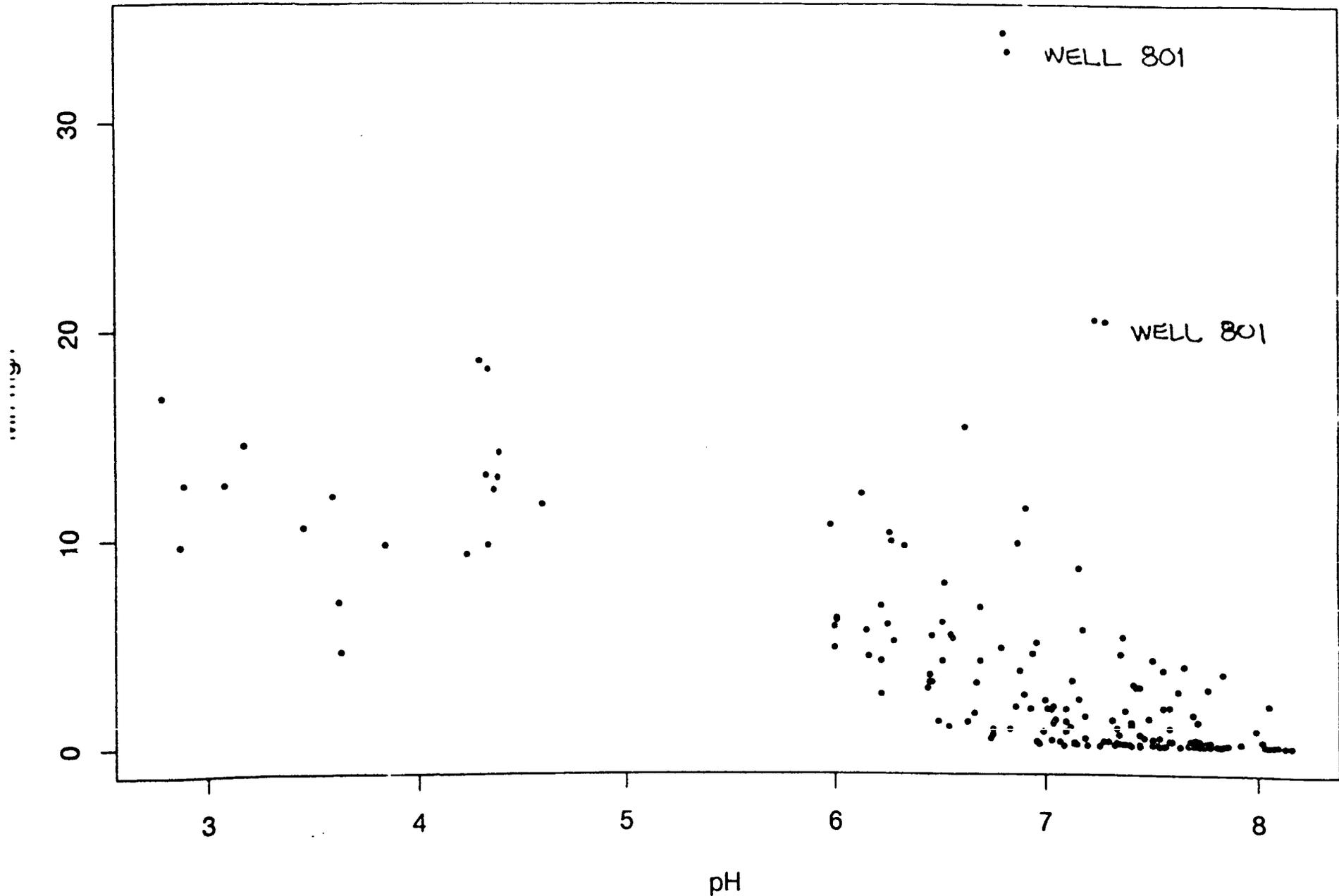


FIGURE 26