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This document provides the United Nuclear Corporation (UNC) response to the U.S. Nuclear Regulatory Commission's (NRC's) June 4, 2013, Request for Additional Information (RAI) on the Report Entitled "Technical Analysis Report in Support of License Amendment Request for Revised Groundwater Protection Standards Based on Updated Background Concentrations, Source Materials License SUA-1475, Groundwater Corrective Action Program, United Nuclear Corporation Church Rock Mill and Tailings Site, New Mexico April 2012". NRC comments are shown in blue text and UNC responses are shown in black text.

1) Comment: In Section 2, Identification of Samples Representative of Background Water Quality, Page 2; the establishment of monitoring wells having samples representative of background water quality in the 2008 N.A. Water Systems report [Agencywide Document Access and Management System (ADAMs) Accession Number ML083530220] was not formally reviewed or approved by the U.S. Nuclear Regulatory Commission (NRC). The NRC staff believes that this section, as drafted, incorrectly implies that the 2008 N.A. Water Systems report was submitted and approved by the NRC staff.

Technical Basis: The current amendment request has chosen to utilize the same monitoring well network in the Southwest Alluvium and Zone 1 that was previously assessed during NRC review of Amendment No. 37 for the Technical Analysis Report revised in 2006 [ML006073004]. However, a key difference in the current submittal is that the time interval from the background wells includes two additional years of data than that was not previously assessed and includes data from Zone 3 background wells. Therefore, the monitoring wells associated with the current licensing request were reevaluated to determine if they are representative of background conditions for the newly proposed time interval.

Path Forward: United Nuclear Corporation (UNC) should revise this section to clearly state that the 2008 N.A. Water Systems report was reviewed and approved only by the U.S. Environmental Protection Agency (EPA). The NRC will be reviewing the selected background wells to ensure they are representative of background water quality.

UNC RESPONSE

UNC will make the requested modification to the text.

2) Comment: The Technical Analysis Report – April 2012 does not discuss the algorithmic method (if only dependent on higher order statistics and the value of k samples) used or the mathematical method used to determine the Upper Predictable Limit (UPL) 95 for the nonparametric background statistic.

Technical Basis: The report is deficient in documenting how the ProUCL software calculates the nonparametric UPL 95.

Path Forward: Provide a detailed explanation of how the nonparametric UPL 95 is determined.

UNC RESPONSE

Summary

Potential background threshold values (BTVs) were calculated for the License Amendment Request using the EPA's software package ProUCL (Singh et al., 2010). The statistic selected to estimate BTVs is the upper prediction limit at 95 percent confidence (UPL95) of an anticipated number of future samples. Most background constituent of concern (COC) sample sets are left-censored (i.e., contain non-detected results in the lower part of the analytical range) and do not follow frequency distributions (e.g., normal or log-normal) for which parametric estimation methods are applicable. Because it is difficult to reliably perform goodness-of-fit tests for data distributions on left-censored sample sets, the ProUCL software technical guidance (Singh et al., 2010) emphasizes the use of distribution-free non-parametric methods including the Kaplan-Meier Method (KM), and others, for the estimation of UPL95 statistics. Specification of the future number of samples is required for the calculation of UPL95 statistics. The appropriate number of future samples was based on the anticipated number of sampling locations in each hydrostratigraphic unit and anticipated future sampling frequencies and durations.

The Kaplan-Meier method is a non-parametric statistical method used to estimate the mean and standard deviation of populations with censored data; these estimates are then used by ProUCL in a parametric UPL95 calculation. The number of future samples (k) is used to adjust the exceedance probability (based upon the Bonferroni inequality) to select the appropriate critical value (i.e., t-statistic or z-statistic) for the UPL95 calculation. Detailed calculation methods and reference citations are provided in the following discussion.

Discussion

Kaplan-Meier Method

The Kaplan-Meier estimation method, also known as the product limit estimate (PLE), is a recommended statistical method to analyze environmental data containing non-detected values (Singh, 2011). According to EPA statistical guidance (Unified Guidance, EPA, 2009), the Kaplan-Meier estimator was originally devised to estimate survival probabilities for right-censored samples (Kaplan and Meier, 1958), such as in medical studies of cancer treatments. Because it is non-parametric, there is no requirement that the underlying population be normal or transformable to normality. EPA also incorporates the Kaplan-Meier procedure to calculate a UPL for left-censored data without a discernible distribution within its ProUCL software (Singh et al., 2010).

The Kaplan-Meier method is applied by ordering and assigning ranks to each of the detected values and accounting for non-detected values to create a cumulative distribution function (CDF). Starting at the largest detected value, the proportion of concentrations below each detected value (the estimator) is calculated. The estimator for left-censored data thus depends on a series of conditional probabilities, where the frequency of lower concentrations depends on how many larger concentrations have already been observed (EPA, 2009).

The equations used to calculate the Kaplan-Meier estimator in the EPA Unified Guidance (EPA, 2009) are excerpted below. Equations are also presented in Singh et al. (2010; see Section 4.6) and Singh (2011), using a slightly different notation.

In mathematical notation, suppose there are m distinct values in the sample (out of a total of n measurements), including distinct reporting limits. Order these values from least to greatest and denote them as $x_{(1)}, x_{(2)}, \ldots, x_{(m)}$. Let n_i for i = 1 to m denote the 'risk set' associated with value $x_{(i)}$. The risk set represents the total number of measurements — both detects and non-detects — no greater than $x_{(i)}$. Since a non-detect with a RL larger than $x_{(i)}$ is potentially (but not necessarily) larger than $x_{(i)}$, nondetects with RL > $x_{(i)}$ are not included in n_i. A further term di identifies the number of detected measurements exactly equal to $x_{(i)}$.

With these definitions in place and letting X denote a random variable concentration from the true underlying distribution, the Kaplan-Meier estimator is constructed from the pair of probabilities:

$$\Pr\left(X \le x_{(m)}\right) = 1 \qquad [15.1]$$

$$\Pr\left(X \le x_{(i)} \middle| X \le x_{(i+1)}\right) = 1 - \frac{d_{i+1}}{n_{i+1}} \quad for\ i = 1\ to\ m \qquad [15.2]$$

where $x_{(m+1)} = +\infty$, $d_{m+1} = 0$, and $n_{m+1} = n$ all by definition. Equation [15.2] represents the conditional probability that the concentration does not exceed $x_{(i)}$ given that it does not exceed $x_{(i+1)}$. The final Kaplan-Meier CDF estimate (F_{KM}) for each i = 1 to m−1 (each distinct detected value) is given by a product of these conditional probabilities and can be expressed as:

$$F_{KM}\left(x_{(i)}\right) = \Pr\left(X \le x_{(i)}\right) = \left(1 - \frac{d_{i+1}}{n_{i+1}}\right) \times \left(1 - \frac{d_{i+2}}{n_{i+2}}\right) \times \ldots \times \left(1 - \frac{d_m}{n_m}\right) = \prod_{k=i}^{m-1}\left(1 - \frac{d_{k+1}}{n_{k+1}}\right) \qquad [15.3]$$

The mean and standard deviation estimates are calculated using the following equations excerpted from the Unified Guidance (EPA, 2009).

$$\hat{\mu}_{KM} = \sum_{i=1}^{m} x_{(i)} \cdot \left[F_{KM}\left(x_{(i)}\right) - F_{KM}\left(x_{(i-1)}\right)\right] \quad [15.4]$$

$$\hat{\sigma}_{KM} = \sqrt{\sum_{i=1}^{m} \left(x_{(i)} - \hat{\mu}_{KM}\right)^2 \cdot \left[F_{KM}\left(x_{(i)}\right) - F_{KM}\left(x_{(i-1)}\right)\right]} \quad [15.5]$$

where $x_{(0)} = 0$, and $F_{KM}(x_{(0)}) = F_{KM}(0) = 0$ by definition.

Example spreadsheet calculations for the Kaplan-Meier CDF, mean, and standard deviation using the Church Rock Site Zone 3 background arsenic data are provided in Table 1. The resulting mean and standard deviation estimates are then used as the sample mean and standard deviation in parametric equations for the UPL, as demonstrated in the following section.

UPL95 and UPL$_k$95

UPLs are often used as background threshold values (BTVs) for point-by-point individual site observation comparisons. A UPL95 calculated for a background data population represents an upper limit for which a single independently obtained observation from that population will be below, or equal to, with a confidence level 95%. Accordingly, there is a 5% probability that a single sample drawn from the population would be above the UPL95.

ProUCL contains parametric and non-parametric methods to calculate UPLs and other BTVs. A parametric UPL that can be used to compare a single future sample comparison based on the Kaplan-Meier estimates of mean and population standard deviation can be calculated using following equation (excerpted from Singh, 2011):

> **Upper Prediction Limit (UPL):** For small samples (e.g., fewer than 30 samples), UPL can be computed using the critical value from the Student's t-distribution; and for large datasets, UPL can be computed using the critical values from normal distribution.
>
> $$UPL = \hat{\mu}_{KM} + t_{((1-\alpha),(n-1))} * \hat{\sigma}_{KM}\sqrt{1+\frac{1}{n}}$$
>
> $$UPL = \hat{\mu}_{KM} + z_{\alpha} * \hat{\sigma}_{KM}\sqrt{1+\frac{1}{n}}$$
>
> $\hat{\mu}_{KM}$ = Kaplan Meier estimate of mean based upon data x_i, $i = 1, 2, \ldots, n$;
>
> $\hat{\sigma}_{KM}$ = Kaplan Meier estimate of population standard deviation;
>
> $t_{((1-\alpha),(n-1))} = (1-\alpha)^{th}$ critical value from t-distribution with degrees of freedom of $(n-1)$;
>
> $z_{\alpha} = \alpha^{th}$ critical value from standard normal distribution

However, should k future observations be compared against a UPL designed for one future comparison, the overall probability of exceeding the UPL (i.e., the false positive rate) increases in accordance with the following equation (Singh, 2011):

$$\alpha_{\text{actual}} = 1\text{-}(1\text{-}\ \alpha)^k$$

Singh (2011) summarizes an adjustment that can be made to a UPL95 equation (based upon the Bonferroni inequality) to account for one or more future observations and uses the notation UPL_k95 to represent a 95% UPL for k (>=1) future observations. In the adjusted equation, the exceedance probability α is divided by the number of k future samples and used to generate the appropriate critical value (i.e., t-statistic or z-statistic) for the UPL95 calculation:

$$UPL_k 95 = \left(\overline{x} \div t_{((1-0.05/k),n-1)} s \sqrt{1 + \frac{1}{n}} \right)$$

The preceding equation shows a normal-distribution based UPL95 calculation with the population mean and standard deviation, rather than Kaplan-Meier estimates of the population mean and standard deviation. The use of the analogous equation for the UPL_k95 based on the Kaplan-Meier estimates of the population mean and standard deviation is not explicitly described in the ProUCL technical guidance manual, but referred to in Section 5.4.1.1 (Singh et al., 2010). The calculation is made in ProUCL when performing non-parametric background statistics for censored datasets (i.e., with NDs) and more than one "different or future k values" has been entered as an option. The results of this analysis are identified in the ProUCL output (for a selected 95% confidence level) as the "95% KM UPL for Next k Observations".

It should also be noted that ProUCL does not appear to provide an option to use the z-statistic from the standard normal distribution (i.e., rather than the t-statistic from Student's t-test) to calculate the Kaplan-Meier UPL95 for multiple future k values from a large background dataset (i.e., greater than 30 samples). However, the use of the t-statistic is considered acceptable because the t-statistic approaches the z-statistic as the number of samples (i.e., degrees of freedom in the Student's t-test) increase, and the Church Rock site background datasets for the three hydrostratigraphic units are relatively large (i.e., a minimum of 185 to a maximum of 429 samples).

Example spreadsheet calculations for the Church Rock Zone 3 arsenic UPL95 for 216 future samples are provided in Table 2. The resulting UPL95 estimate (0.757 mg/l) is identical to that provided in Table 6 and Appendix C in the License Amendment request.

3) Comment: Remedial action of Zone 3 is reported in numerous documents to have begun in 1983 at the Northeast Pump-Back wells. However, a December 7, 1981, quarterly report [ADAMs No. ML101050277] from UNC to the New Mexico Natural Resources Department indicates that ten 400 series seepage extraction pumps in Section 36 and three 300 Series pumps around the tailings area were being utilized prior to 1981. While the document does not identify each of the 13 wells, early cross-sections and monitoring well maps indicate that many of the 400 and 300 series wells were screened within Zone 3.

Technical Basis: Information on seepage extraction prior to commencement of remedial action activities would provide accurate information necessary for the NRC staff to determine those influences that may have affected the transport of seepage from the tailings cells and burrow pits.

Path Forward: Provide further detailed information about the wells used for seepage extraction prior to commencement of remedial actions for each of the hydrostratigraphic units.

UNC RESPONSE

Summary

The referenced text from the December 7, 1981, quarterly report (UNC, 1981c) reads as follows:

> *The ten 400-Series seepage extraction pumps on Section 36 were turned off on September 14, 1981, and so were the three 300-Series pumps around the tailings area on November 30, 1981. Therefore, no seepage extraction water is being returned to the borrow pits now.*

The United States Nuclear Regulatory Commission (NRC) has suggested that the use of the terminology "seepage extraction pumps" in the referenced quarterly report implies that these wells were pumping what was previously determined to be seepage-impacted water from Zone 3. During the July 11, 2013, teleconference, NRC indicated the following additional concerns related to historical pumping of the 300- and 400-series wells: (1) due to the downgradient position of the 400-series wells, this pumping may have temporarily expanded the seepage-impacted area into background (i.e., non-impacted) areas; and (2) subsequent to the cessation of 400-series well pumping, background groundwater may have become re-established in the temporarily impacted areas, such that the evidence of impact was lessened and previously impacted monitoring wells might be included improperly in the statistical evaluations of background concentrations.

Our review of the available historical information indicates that three 300-series wells screened in multiple hydrostratigraphic units were pumped for approximately 11 months. Based on their proximity to the Central Tailings Cell, these wells likely extracted seepage-impacted water. The ten 400-series wells were pumped for approximately five months prior to September 1981 and it is unlikely that the 400-series wells were pumping seepage-impacted water during this period. Historical investigations were not able to clearly distinguish between seepage impacted and background waters in Zone 3; therefore, historical seepage-impact delineations are not as reliable as comparisons made via our current capabilities, which use the evolution of bicarbonate concentrations as the best geochemical indicator of differentiating seepage-impacted from other water types. Additionally, variations in monitoring well construction may have affected the historical interpretations of seepage impact. We will address each of these topics below in support of a conclusion that the 1981 pumping of the 300- and 400-series wells was inconsequential with respect to the extent of seepage impacts.

Discussion

UNC has reviewed available historical documents related to pumping of the 300-series and 400-series wells conducted prior to the initiation of Zone 3 remedial action in 1983. A March 6, 1981, UNC letter report (UNC, 1981a) indicates that UNC operated the Central Cell seepage interception system, comprising four 300-series wells (340, 304, 323A, and 335) in early 1981 (see Figures 1 and 2). Three of these wells (340, 304, and 323A) appear to be the 300-series wells referenced in the December 1981 quarterly report (UNC, 1981c). The March 1981 letter report (UNC, 1981a) contains daily pumping records for these wells for February 1 through March 6, 1981, and indicates that 1,075,000 gallons were pumped during February 1981. The March 1981 letter report (UNC, 1981a) also provides pH and conductivity measurements collected from January 5 to March 6, 1981. These data suggest that well 340 replaced well 335 as a pumping well because pH and conductivity measurements ceased for well 335 in mid-January and are subsequently initiated for well 340.

Based on this information it appears that the three 300-series wells operated for approximately 11 months until they were shut down in November 1981. However, the location and construction of these wells indicate that the pumping would not have significantly affected the Zone 3 seepage-impact area. The well locations near the Central Cell (see Figures 1 and 2) are too distant from the Zone 3 downgradient background areas and well construction records indicate that these wells are open to multiple hydrostratigraphic units. The screened interval for each of the wells extends from the lower part of Zone 3, through Zones 2 and Zone 1 and into the top of Mancos Shale; the sandpack for each well extends from the bottom of the well to (or near) the ground surface.

It appears that the 400-series wells described in the December 1981 quarterly report (UNC, 1981c) were pumped for a period of approximately five to seven months, prior to being turned off in September 1981. According to the UNC database and master wells table, the 400-series wells were installed between February 1981 and April 1981. The March 1981 letter report (UNC, 1981a), which summarizes plans to install the 400-series wells between wells TWQ-115D and TWQ-148, further constrains the 400-series wells operating period. The report indicates that only three of the wells (401, 402, and 403, see Figures 1 and 3) had been installed at the time of the report and that pumping had been initiated at one well (402), at a rate of approximately 8 gpm, on February 27, 1981. Wells 401 and 403 were not being pumped because they were being redeveloped and redrilled, respectively.

UNC files contain a partial copy of a report related to the 400-series well installation and pumping (UNC, 1981b; titled Report 2, Northern Collection System; dated May 20, 1981; no author listed) which indicates that pumps were installed in ten 400-series wells (401, 402, 403A, 422, 424, 433, 435, 438, 444, and 446) in early 1981. This report summarizes the results of pumping tests conducted at wells 402 and 438 at rates of approximately 5 gpm prior to the initiation of "extractive pumpage" on April 29, 1981, from all extraction wells. Therefore, the combined pumping of the ten 400-series wells was limited to approximately five months ending September 14, 1981. The aggregate pumping rate for the ten well system is not documented.

There is additional information indicating that the ten 400-series wells were pumped together for only five months. Billings & Associates (1982) references a five-month operation period for the 400-series wells in a report providing recommendations for the future Zone 3 seepage control system. Water level hydrographs for wells 411 and 420 prepared by Billings & Associates (1984, attached) show a response to pumping corresponding to that described Northern Collection System report. The hydrographs also show that the wells recovered fully and that the Zone 3 water level continued to rise in response to the continuing mine dewatering discharge (i.e., background water). Billings & Associates (1984) also indicates that neither of these wells appeared to be contaminated when they were last sampled.

It is unlikely that the 400-series wells were pumping seepage-impacted water during this period. Billings & Associates (1982) notes that several feet of drawdown were documented in the Well 126/127 area (south of the 400-series wells) after five months of pumping and that water quality "worsened" in the eastern half of the 400 Series wells during the pumping, but there is no evidence presented that the 400-series wells were pumping seepage-impacted water. As was typical in the early part of the site investigation, Billings & Associates (1982) was not able to clearly distinguish geochemical differences between seepage-impacted and background waters and stated that "Without clear and undebatable background water quality data existing at the UNC site, the determination of the degree of contamination is based on professional judgment and opinion". Billings & Associates (1982) indicated that the general shape of the seepage-impacted water could be discerned using total dissolved solids (TDS) and sulfate concentrations, and suggested a TDS concentration of 4,000 mg/l as a general criterion for seepage impacts. These historical determinations were likely limited by inconsistent well construction. For example, the March 6, 1981, letter report (UNC, 1981a) provides well chemistry data for wells 402 and 401, which have quite different construction. Well 402 is screened across Zone 3 and the top of Zone 2 (although the sandpack extends into the Dilco Coal Member), while well 401 is screened across multiple hydrostratigraphic zones (i.e., Dilco, Zone 3, Zone 2, Zone 1, and the Mancos Shale). The May 20, 1981, Northern Collection System report (UNC, 1981b) suggests that wells completed in the Dilco or at the Dilco/Zone 3 interface have inferior water quality to those completed only in Zone 3 or Zone 1 of the Upper Gallup sandstone. It is further suggested that elevated concentrations of TDS, sulfate, manganese, molybdenum, and uranium may be correlatable to localized carbonaceous deposits in the Dilco shale and sandy shale.

The 400-series well area was not seepage-impacted in the mid- to late 1980s. Canonie (1987) used pH as the primary indicator of seepage impact and stated that all other indicators, such as TDS, thorium-230, heavy metals, and ammonia follow the trend set by pH. This seepage impact delineation shows that the 400-series well area was not seepage-impacted as of May 1986. EPA subsequently utilized TDS as the primary indicator in the Remedial Investigation (EPA, 1988), which also showed that the 400-series well area was not seepage-impacted.

The current seepage-impact delineation methodology has been used to track the seepage-impact progression for approximately ten years and is more reliable than previous single parameter delineations because the current method more fully considers the geochemical response to the acid seepage front by considering the following (N.A. Water Systems, 2008a):

- The key indicators of seepage impact are pH and bicarbonate; the analysis considers empirically derived concentration ranges and time-series of these two indicator parameters.
- Time trends in the concentration of major ions; in particular, decreasing ratios of Ca:Mg are associated with degrading groundwater quality.
- Time trends in the concentrations of many metals and radionuclides will usually increase as the buffering capacity degrades in Zone 3.

UNC considers the five-month pumping of the 400-series wells to be volumetrically minor in comparison to the combination of the remediation pumping initiated at the northeast corner of the impoundment in October 1983 and the subsequent Zone 3 pumping, initiated in 1989 and 2005. Assuming a pumping rate of 5 gpm per well (i.e., equal to pumping rates used for pumping tests of wells 402 and 438) during the five month period, the 400-series would have pumped approximately 11,000,000 gallons. In comparison, Earth Tech (2002) shows that the total volume pumped from the Zone 3 wells from 1989 to 2000 was approximately 160,000,000 gallons. Additionally, approximately 14,100,000 gallons were extracted from the current Zone 3 pumping system pumping from January 2005 to June 2012 (Chester Engineers, 2013). Any slight, short-term shifts in the distribution of background and seepage-impacted waters that might have occurred due to the 400-series pumping in 1981 would likely have been substantially reversed due to the continued mine dewatering discharge and recharge into Zone 3 over the several intervening years. UNC concludes that the small proportion of water removed in the early 1980s was volumetrically insignificant and of too short duration to adversely influence the current methodology used to discriminate between background and seepage-impacted groundwater. Finally, we should point out that the underlying premise of this comment as expressed during the July 11, 2013, teleconference is perhaps misplaced. The procedure to discriminate background from seepage-impacted is via a statistical analysis of chemical attributes and is not influenced or confounded by pumping history which only influences the location and timing of seepage-impacts. UNC has in fact solved the background determination problem that was previously inhibitive – rather than using a well's location or sampling time to establish background, the water chemistry is the only variable that should be considered.

4) Comment: Molybdenum concentrations have been observed in far downgradient Zone 3 wells at concentrations greater than expected for being impacted by mining alone. The origin of the high molybdenum concentrations is unclear due to the lack of groundwater data available prior to 1989.

Technical Basis: It would be unlikely that the concentrations were a result of mining effluents discharged to the Southwest Alluvium or seepage from the drying pads at the Quivira facilities which contained a minimum amount of water. The Upper Gallup Sandstone is known to be fractured in the vicinity of the site. The NRC staff is concerned that fracture controlled flow could account for the unusually high concentrations observed at distant downgradient wells including the tendency of the plume to migrate toward the north-northeast instead of in the down dip direction to the northwest. Molybdenum concentrations obtained from a limited number of sampling events for the North Pond and Burrow Pits 1 and 2 ranged from 0.001 mg/l to 18.7 mg/l.

Path Forward: Provide further explanation of the high concentrations of molybdenum found downgradient in Zone 3 and historic sampling results from the tailings ponds and burrow pits during operations.

UNC RESPONSE

Summary

Elevated molybdenum concentrations observed in samples from Zone 3 wells outside the tailings seepage plume have historically been considered to be representative of background conditions. The United States Nuclear Regulatory Commission (NRC) comment contemplates instead that molybdenum is an indicator of seepage impacts and could be preferentially transported from the tailings ponds via fracture-controlled flow pathways to locations beyond the geochemically-established extent of seepage impacts. This alternative interpretation of the historical data is considered to be implausible for the following reasons:

1. The geochemical interaction of tailings seepage with aquifer materials is well known and the distribution of tailings seepage-impacted waters is reliably indicated by key parameters pH and bicarbonate (HCO_3^-). Elevated molybdenum concentrations were present at background locations in the absence of known indicators of tailings seepage.
2. It is highly implausible that molybdenum would migrate completely independently of all other well-known seepage-impact parameters. Even if there were fracture zones with enhanced permeability extending from the tailings cells to the northern part of Section 36 and molybdenum was more highly concentrated in seepage-impacted water, then the comment purports that the fractures transmit molybdenum preferentially more than any other dissolved constituent. We can identify no possible physical or chemical mechanism that would bring this about.
3. The observed distribution of molybdenum concentrations in the three site hydrostratigraphic units demonstrates that molybdenum is not a suitable indicator of tailings seepage at the Church Rock site. Molybdenum has a high natural variance in both seepage-impacted and

background water in Zone 3, and as a consequence the water types are not amenable to differentiation on the basis of molybdenum data.

More plausible explanations for the observed site molybdenum concentration distributions are related to its complex environmental geochemistry and the presence of potential natural geologic sources of molybdenum such as coal beds and carbonaceous shales in the Zone 3 and Zone 2 bedrock and the overlying Dilco Member of the Crevasse Canyon Formation. Molybdenum concentrations in water are also complicated by inconsistent well construction in Zone 3; certain wells have screened or sandpacked intervals that coincide with, or adjoin, the Zone 2 coal, while other wells have screened or sandpacked intervals that extend from the Dilco or Zone 3 to the Mancos Shale underlying Zone 1. Additional details regarding these issues are provided in the following section.

Discussion

Historical molybdenum concentrations detected in samples from several Zone 3 wells near the northern Section 36 boundary (e.g., wells EPA-1, EPA-11, and 0504 B) frequently exceeded 5 mg/l and have a maximum of 75 mg/l. Many of these detected concentrations are among the highest measured at any location on the site (including samples collected directly from the tailings ponds and borrow pits) and, in previous analyses, have been considered representative of background conditions prior to impact by tailings seepage.

A portion of the dewatering fluids discharged from the Northeast Church Rock (NECR) Mine and Kerr-McGee Church Rock I Mine into Pipeline Arroyo infiltrated the previously unsaturated alluvium and bedrock to form the current background groundwater at the Church Rock Mill Site. This mine dewatering discharge was a source of some molybdenum to the Zone 3 background groundwater; however, historical discharge monitoring data indicate that molybdenum concentrations in these mine-related waters were typically lower than those reported in Zone 3 background groundwater. NPDES monitoring data show that the treated NECR Mine discharge had molybdenum concentrations were in the range of <0.010 to 0.2 mg/l (1975-1982) and the Kerr-McGee Church Rock I Mine discharge (1980-1984) had a mean concentration of approximately 0.5 mg/l (Wirt et al., 1991). Blickwedel (2006) shows that a NECR mine vent shaft sample and several Pipeline Arroyo surface water samples had molybdenum concentrations similar to the NECR mine discharge results. These analyses do not encompass the entire operating period of the mines and therefore may not account for all of the variability in concentrations discharged to the Arroyo.

Zone 3 is fractured sandstone in which groundwater flows both through the pores in the rock (i.e., primary porosity) and through a network of interconnected fractures (i.e., secondary porosity). The geochemical interaction of acidic tailings seepage with aquifer materials is well known and the distribution of tailings seepage-impacted waters is reliably indicated by the key parameters pH and bicarbonate (HCO_3^-). The aquifer materials neutralize the acidic seepage, causing a relatively gradual increase of the bicarbonate concentration indicative of carbonate mineral dissolution, followed by a rapid decrease in bicarbonate and pH as the buffering capacity of the formation is exhausted (BBL, 2006). Historical Zone 3 groundwater quality data (see Chester Engineers, 2013, Appendix B) from fully seepage-impacted wells indicate that it takes from one to three years, from the onset of geochemical changes associated with the arrival of seepage-impacted groundwater, for full seepage impact to develop (unless the constituent transport is affected by pumping). Once the buffering capacity of the formation is exhausted, acidic conditions will remain indefinitely. The use of pH and bicarbonate as plume indicators, and to distinguish background from seepage-impacted water quality, is well documented (N. A. Water Systems, 2008a and 2008b) and has been accepted for various uses (including an NRC License Amendment, the site Human Health Risk Assessment, and the site Five Year Review) by NRC, the United States Environmental Protection Agency (EPA), and New Mexico Environment Department (NMED).

NRC has expressed concern that the source of elevated molybdenum concentrations observed in the northern Zone 3 wells is tailings seepage that migrated through hypothetical fracture zones (i.e., enhanced permeability zones or conduits) from the tailings disposal cells to the well locations. Similarly EPA, in the Remedial Investigation Report (1988), speculates (without supporting evidence) that higher downgradient molybdenum concentrations could result from a single discrete introduction of contamination into the groundwater system. However, historical data show that elevated molybdenum concentrations were present at background locations in the absence of other known indicators of tailings seepage. It is implausible that the chemical signature of acidic seepage-impacted water traveling in an enhanced fracture system would be limited to elevated molybdenum concentrations, independent of the other more typical seepage indicator parameters (i.e., low pH and bicarbonate concentrations). There are no identified physical or geochemical mechanisms under which these conditions would occur and no means for elevated concentrations to be sustained over time such as in samples from well EPA-1 or exhibit variability over time such as in samples from well 0504B.

UNC also considers this potential migration pathway to be unlikely based on the distribution of molybdenum concentrations in the three site hydrostratigraphic units, which demonstrates that the molybdenum is not a suitable indicator of tailings seepage at the Church Rock site. Although there are a few historical examples of significantly elevated molybdenum concentrations in the North Pond and Borrow Pit 2, these are likely to be related to very low pH conditions (i.e., pH <2.0) which do not persist for substantial distances in the areas outside the tailings ponds.

The following tables summarize the results of the molybdenum analyses from the background and exposure point concentration (EPC) statistical evaluations (N.A. Water Systems, 2008a and 2008b) for each of the three hydrostratigraphic units.

Summary Statistics for Molybdenum (mg/L) in Background Water (N.A. Water Systems, 2008a)

Zone	Total Data	Percent Nondetect	Minimum Detected	Maximum Detected	Mean of Detected	Median of Detected	UCL95 of Mean
Z3	184	14.13%	0.02	75	11.88	3.76	17.43
Z1	234	97.9%	0.03	0.27	0.12	0.13	0.132
SWA	391	99.5%	0.03	0.03	N/A	N/A	N/A

Summary Statistics for Molybdenum (mg/L) in Impacted Groundwater (N.A. Water Systems, 2008b)

Zone	Total Data	Percent Nondetect	Minimum Detected	Maximum Detected	Mean of Detected	Median of Detected	UCL95 of Mean
Z3	70	54.3%	0.1	5	1.084	0.3	0.739
Z1	16	100.0%	N/A	N/A	N/A	N/A	N/A
SWA	96	100.0%	N/A	N/A	N/A	N/A	N/A

Two observations regarding these summary data demonstrate that molybdenum should not be considered a viable indicator of tailings seepage impacts. First, there is a wide, overlapping range of molybdenum concentrations observed in the Zone 3 background and impacted wells; however, significantly higher concentrations and greater variance are found in background data. Molybdenum was detected in approximately 86% of the background samples and in only approximately 46% of the impacted samples. During the two-year EPC statistical evaluation period (July 2006 through April 2008 inclusive), only two of the 10 seepage-impacted wells (0504 B and NBL-01) had molybdenum concentrations exceeding 0.4 mg/l, including the maximum detected concentration at NBL-01 (5 mg/L). Both of these wells also had elevated molybdenum concentrations prior to observing other geochemical evidence of seepage impact (i.e., changes in pH and bicarbonate). These data show that molybdenum is a poor indicator to distinguish background from seepage-impacted water. Second, molybdenum was not detected in any sample of seepage-impacted water from Zone 1 and the Southwest Alluvium (SWA) during the two-year EPC evaluation period and was detected only infrequently at low concentration in the background water sample data. If molybdenum were a significant component of the tailings seepage and that seepage was the source of highly elevated downgradient molybdenum concentrations in Zone 3, it should also be detected in impacted water in the other hydrostratigraphic units as well. These conclusions are supported by a review of the annual report data (Chester Engineers, 2013).

More plausible explanations for the observed site molybdenum concentration distributions are related to its complex environmental geochemistry and the potential presence of natural geologic sources of molybdenum. Hem (1985) indicates that the dominant molybdenum species change at pH values of 2 and 5 and that above pH 5 the molybdate ion (MoO_4^{-2}) is dominant. Hem (1985) further indicates that many of the metallic elements have molybdates of low solubility and that ferrous molybdate specifically limits solubility in relatively iron-rich waters below pH 5. This suggests a sensitivity to pH and effects related to the availability of other dissolved metals that would favor higher molybdenum solubility at higher pH (i.e., under background conditions existing after the influx of mine discharge water) than at lower pH (i.e., impacted conditions).

Hem (1985) notes that molybdenum is also present in fossil fuels and it is well known that molybdenum is often present in coal combustion products (i.e., fly ash). This is of interest because coal beds and carbonaceous shales are locally present in the Dilco Coal Member of the Crevasse Canyon Formation (which overlies Zone 3), the lower part of Zone 3, and Zone 2 (which underlies Zone 3 and is considered a shale and coal unit). These coals and carbonaceous shales may be a significant source background molybdenum concentrations and many plausible geochemical reactions related to the other metals present. Well construction, particularly the position of screened and/or sandpacked intervals with respect to these coal beds and carbonaceous shales, varies among the Zone 3 wells. For example, a review of construction information for four northern Section 36 wells indicates that they either penetrated Zone 2 or were completed near the base of Zone 3:

- EPA-1 – Total drilled depth 250 ft bgs, screened from 215 to 240 ft bgs, with a sandpack from 210 to 251 ft bgs. The Zone 2 contact is indicated to be within the sandpack at 244 ft bgs. Therefore the well sandpack is approximately 6 to 7 feet into Zone 2.
- EPA-10 – Total drilled depth 206 ft bgs, screened from 155 to 195 ft bgs, with a sandpack from 151 to 205 ft bgs. The Zone 2 contact is indicated to be within the screened interval at 194 ft bgs and the entire thickness of Zone 2 (10 ft) is within the drilled depth of the well.
- EPA-11 – Total drilled depth 180 ft bgs, screened from 136 to 171 ft bgs, with a sandpack from 133 to 180 ft bgs. The Zone 2 contact is indicated to be within the sandpack at 175 ft bgs. Therefore the well is approximately 5 feet into Zone 2.
- 0504 B – Total drilled depth 172 ft bgs, screened from 120 to 170 ft bgs, with a sandpack from 120 to 170 ft bgs. The bottom of Zone 3 is indicated to be just below the sandpack at 172 ft bgs.

Regarding the Dilco coal, UNC files contain a partial copy of a report related to the 400-series well installation and pumping in Section 36 (UNC, 1981b; titled Report 2, Northern Collection System; dated May 20, 1981; no author listed), which suggests that wells completed in the Dilco or at the Dilco/Zone 3 interface have inferior water quality to those completed only in Zone 3 or Zone 1 of the Upper Gallup sandstone. It is further suggested that elevated concentrations of TDS, sulfate, manganese, molybdenum, and uranium may be correlatable to localized carbonaceous deposits in the Dilco shale and sandy shale.

The Mancos Shale, which underlies Zone 1, is another possible source of molybdenum at certain well locations. Canonie (1987) considered the Mancos Shale to be the likely source of anomalously high TDS, elevated magnesium, and acidic pH found in several alluvium wells. Bush and Morrison (2012) have also determined that the Mancos Shale can be the source of elevated background concentrations of certain parameters (e.g., uranium, nitrate, selenium, sulfate). Certain wells constructed in the early 1980s (e.g., wells 147 and 401) have screened intervals and/or sandpacked intervals that extend from Zone 3 through Zone 2 and Zone 1 into the Mancos Shale.

In conclusion, there are no identified physical or chemical mechanisms that could result in the transport of molybdenum from the tailings ponds in the absence of other geochemical evidence of seepage impacts. More plausible explanations for the observed site molybdenum concentration distributions are related to its complex environmental geochemistry and the presence of potential natural geologic sources of molybdenum such as coal beds and carbonaceous shales in the Dilco Coal, Zone 3, and Zone 2, as well as the Mancos Shale.

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TABLES

11	0.011	2	91	0.489247312	0.00011828	6.4673E-05
12	0.012	2	93	0.5	0.000129032	6.30159E-05
13	0.013	3	96	0.516129032	0.000209677	9.20705E-05
14	0.014	3	99	0.532258065	0.000225806	8.96494E-05
15	0.015	1	100	0.537634409	8.06452E-05	2.90869E-05
16	0.016	2	102	0.548387097	0.000172043	5.66027E-05
17	0.017	4	106	0.569892473	0.000365591	0.000110106
18	0.018	3	109	0.586021505	0.000290323	8.02876E-05
19	0.019	2	111	0.596774194	0.000204301	5.20186E-05
20	0.02	1	112	0.602150538	0.000107527	2.52668E-05
21	0.021	1	113	0.607526882	0.000112903	2.4535E-05
22	0.022	4	117	0.629032258	0.000473118	9.5256E-05
23	0.023	1	118	0.634408602	0.000123656	2.31037E-05
24	0.024	1	119	0.639784946	0.000129032	2.24042E-05
25	0.025	1	120	0.64516129	0.000134409	2.17155E-05
26	0.026	1	121	0.650537634	0.000139785	2.10375E-05
27	0.029	2	123	0.661290323	0.000311828	3.8136E-05
28	0.031	1	124	0.666666667	0.000166667	1.78088E-05
29	0.035	2	126	0.677419355	0.000376344	3.08388E-05
30	0.036	2	128	0.688172043	0.000387097	2.96978E-05
31	0.037	1	129	0.693548387	0.000198925	1.42892E-05
32	0.043	1	130	0.698924731	0.000231183	1.11567E-05
33	0.044	1	131	0.704301075	0.000236559	1.06722E-05
34	0.047	1	132	0.709677419	0.000252688	9.28342E-06
35	0.05	2	134	0.720430108	0.000537634	1.59827E-05
36	0.054	3	137	0.73655914	0.000870968	1.92575E-05
37	0.055	2	139	0.747311828	0.000591398	1.2106E-05
38	0.059	1	140	0.752688172	0.000317204	4.69583E-06
39	0.06	1	141	0.758064516	0.000322581	4.38343E-06
40	0.062	1	142	0.76344086	0.000333333	3.79087E-06
41	0.066	1	143	0.768817204	0.000354839	2.7348E-06
42	0.069	1	144	0.774193548	0.000370968	2.05564E-06
43	0.071	1	145	0.779569892	0.00038172	1.65664E-06
44	0.084	1	146	0.784946237	0.000451613	1.11488E-07
45	0.087	1	147	0.790322581	0.000467742	1.29795E-08
46	0.088	1	148	0.795698925	0.000473118	1.64868E-09
47	0.095	1	149	0.801075269	0.000510753	2.23408E-07
48	0.107	1	150	0.806451613	0.000575269	1.82937E-06
49	0.113	1	151	0.811827957	0.000607527	3.213E-06
50	0.133	1	152	0.817204301	0.000715054	1.06208E-05
51	0.137	1	153	0.822580645	0.000736559	1.26185E-05
52	0.14	1	154	0.827956989	0.000752688	1.42297E-05
53	0.142	1	155	0.833333333	0.000763441	1.53575E-05
54	0.149	1	156	0.838709677	0.000801075	1.96438E-05
55	0.156	1	157	0.844086022	0.00083871	2.4457E-05
56	0.175	1	158	0.849462366	0.00094086	4.01772E-05
57	0.176	1	159	0.85483871	0.000946237	4.11121E-05
58	0.181	1	160	0.860215054	0.000973118	4.59479E-05
59	0.183	1	161	0.865591398	0.000983871	4.79575E-05
60	0.19	1	162	0.870967742	0.001021505	5.53298E-05
61	0.193	1	163	0.876344086	0.001037634	5.86506E-05
62	0.195	1	164	0.88172043	0.001048387	6.09183E-05
63	0.21	1	165	0.887096774	0.001129032	7.92967E-05
64	0.224	1	166	0.892473118	0.001204301	9.86327E-05
65	0.242	1	167	0.897849462	0.001301075	0.00012659
66	0.253	1	168	0.903225806	0.001360215	0.00014539
67	0.303	1	169	0.908602151	0.001629032	0.000247243
68	0.318	1	170	0.913978495	0.001709677	0.000283041
69	0.34	1	171	0.919354839	0.001827957	0.00033992
70	0.357	1	172	0.924731183	0.001919355	0.000387438
71	0.481	1	173	0.930107527	0.002586022	0.000828033
72	0.523	1	174	0.935483871	0.002811828	0.00101475
73	0.538	1	175	0.940860215	0.002892473	0.001086032
74	0.57	1	176	0.946236559	0.003064516	0.001246185
75	0.573	1	177	0.951612903	0.003080645	0.001261764
76	0.604	1	178	0.956989247	0.003247312	0.001428413
77	0.613	1	179	0.962365591	0.003295699	0.00147873
78	0.688	1	180	0.967741935	0.003698925	0.001931913
79	0.714	1	181	0.97311828	0.00383871	0.002103134
80	0.728	1	182	0.978494624	0.003913978	0.002198341
81	0.768	1	183	0.983870968	0.004129032	0.002481974
82	0.776	1	184	0.989247312	0.004172043	0.002540765
83	0.955	1	185	0.994623656	0.005134409	0.004036178
84	1.01	1	186	1	0.005430108	0.004564856
					0.088553763	**0.187067608**

Cumulative Probability Distribution Function

$$F_{KM}\left(x_{(i)}\right)=\Pr\left(X\le x_{(i)}\right)=\left(1-\frac{d_{i+1}}{n_{i+1}}\right)\times\left(1-\frac{d_{i+2}}{n_{i+2}}\right)\times\ldots\times\left(1-\frac{d_m}{n_m}\right)=\prod_{k=i}^{m-1}\left(1-\frac{d_{k+1}}{n_{k+1}}\right)$$

TABLE 2

UPLk95 Calculations Showing Difference Between Use of Z-Statistic and T-Statistic

UNC Church Rock Site, Church Rock, New Mexico

COPC	n	k	KM Mean	KM SD	α	Probability α/k	1-α/k	Critical Value Normal Dist. (z)	Calculated UPL Using z-statistic	t-statistic	Calculated UPL Using t-statistic	ProUCL UPL
As	186	1	0.0886	0.187	0.05	0.050000	0.950000	1.645	0.397	1.653	0.399	0.399
As	186	4	0.0886	0.187	0.05	0.012500	0.987500	2.241	0.509	2.260	0.512	0.512
As	186	16	0.0886	0.187	0.05	0.003125	0.996875	2.734	0.601	2.766	0.607	0.607
As	186	40	0.0886	0.187	0.05	0.001250	0.998750	3.023	0.656	3.065	0.6635	0.6635
As	186	136	0.0886	0.187	0.05	0.000368	0.999632	3.376	0.722	3.433	0.733	0.733
As	186	216	0.0886	0.187	0.05	0.000231	0.999769	3.501	0.745	3.565	0.757	0.757
As	186	544	0.0886	0.187	0.05	0.000092	0.999908	3.740	0.790	3.817	0.805	0.805

Note: the actual k value for Zone 3 = 216

Equation for t-statistic based calculation

$$UPL_k 95 = \left(\bar{x} + t_{((1-0.05/k),n-1)} s \sqrt{1 + \frac{1}{n}} \right)$$

Note: The Kaplan-Meier estimates of the population mean and standard deviation are substituted into the preceding equation to make the UPL calculation (Singh, 2011).

FIGURES

FIGURE 1
Composite (Multiple Formation) Wells in the 300-400 Series
United Nuclear Corporation Church Rock Site,
Church Rock, New Mexico

CHESTER ENGINEERS

FIGURE 2
Zone 1 Wells in the 300-400 Series
United Nuclear Corporation Church Rock Site,
Church Rock, New Mexico

CHESTER ENGINEERS

FIGURE 3
Zone 3 Wells in the 300-400 Series
United Nuclear Corporation Church Rock Site,
Church Rock, New Mexico

CHESTER ENGINEERS

Attachments

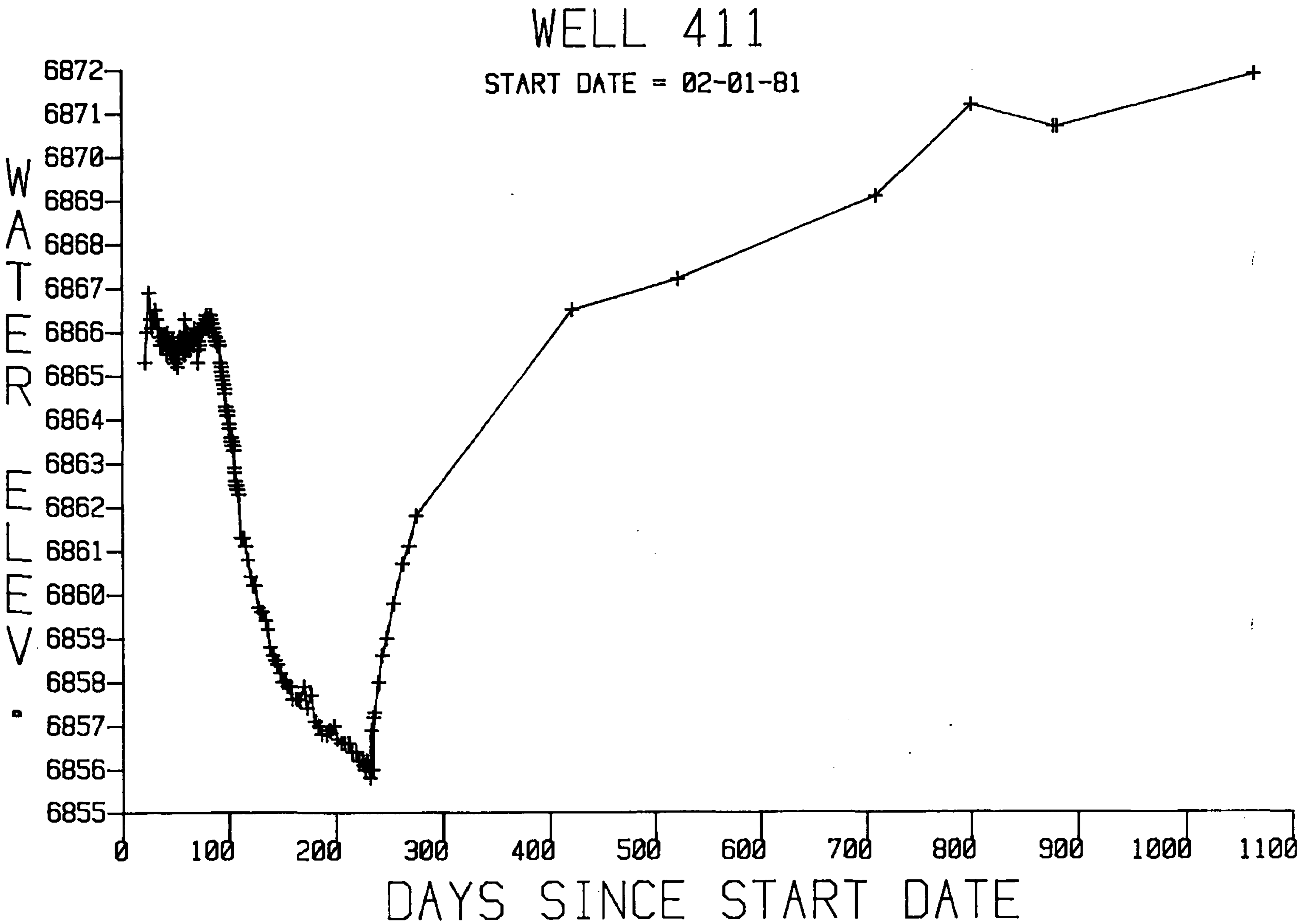
Well Hydrographs

BILLINGS & ASSOCIATES, INC.
Rt. 3, Box 739
Kimberling City, MO 65686
(417) 739-4492

DATABASE MANAGEMENT INTERPRETIVE COMMENTS

WELL: 411

Well 411 is a Zone 3 well north of the 400 Series at the same location as the KMEID well. The water level shows good response to the pumping of the 400 Series and is an excellent long distance observation well for analysis. The well does not appear to be contaminated.


WELL 411
START DATE = 02-01-81
WATER ELEV.
6872
6871
6870
6869
6868
6867
6866
6865
6864
6863
6862
6861
6860
6859
6858
6857
6856
6855
0
100
200
300
400
500
600
700
800
900
1000
1100
DAYS SINCE START DATE

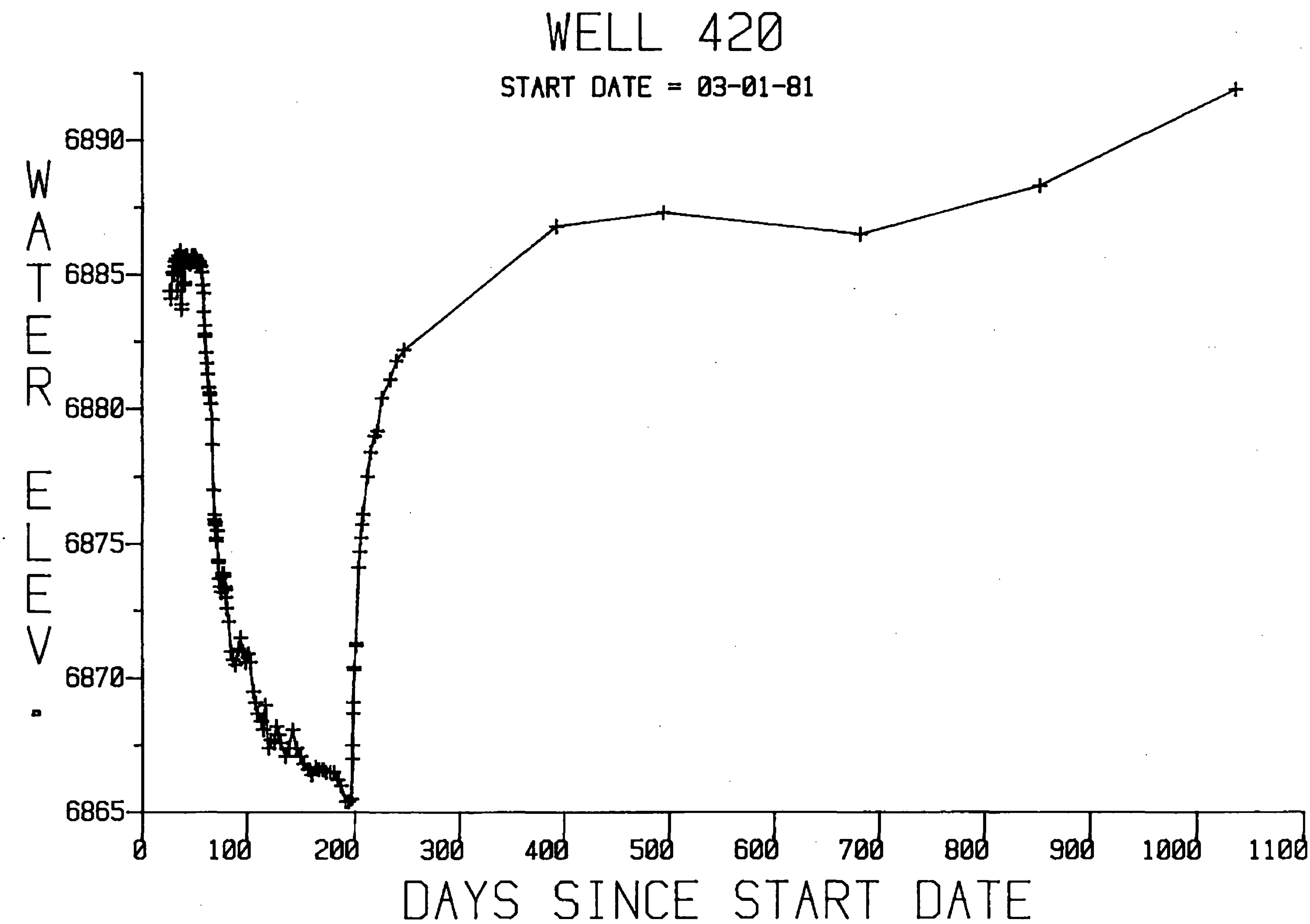
BILLINGS & ASSOCIATES, INC.
Rt. 3, Box 739
Kimberling City, MO 65686
(417) 739-4492

WELL: 420

DATE: 11-11-84

SUBJECT: Interpretive Comments

Well 420 is a Zone 3 observation well in the 400 Series pumping system. The well was probably not contaminated at the last sampling (1982). The well demonstrates response to pumping and the later, general rise in Zone 3 water level.


WELL 420
START DATE = 03-01-81
WATER ELEV.
6890
6885
6880
6875
6870
6865
0
100
200
300
400
500
600
700
800
900
1000
1100
DAYS SINCE START DATE

xerox

freeflow3

Document Name:	DESIGN OF A SEEPAGE CONTROL SYSTEM FOR ZONE 3 (UPPER GALLUP) NORTHEAST OF THE NORTH POND
Printing Time:	02/12/14 09:12:27
Copies Requested:	1
Account:	
Virtual Printer:	j75/j75_slipsheet
Printed For:	freeflow3

freeflow3

Design of a Seepage Control System

for Zone 3 (Upper Gallup) Northeast

of the North Pond

)0025887

BILLINGS & ASSOCIATES, INC.

Design of a Seepage Control System for Zone 3 (Upper Gallup) Northeast of the North Pond

For

United Nuclear Corporation

Church Rock Operations

Church Rock, New Mexico

By

Billings & Associates, Inc.

Kimberling City, Missouri

December, 1982

Jeffery F. Billings

Hydrologist

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Plate	Description
1	Northeast Zone 3 Aquifer Parameter Distribution
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List of Appendices

Appendix	Description
A	Drilling and Well Construction Specifications
B	Well Development Procedures
C	Material Specifications
D	System Materials
E	Necessary Personnel

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CONCLUSIONS

A trend in increasing transmissivity is noted in a northeast direction in Zone 3 (northeast of the North Pond). This trend parrallels trends in grain size. Such a trend affects travel time computations, extent of contamination, and correlates well with the rate of change in TDS along flow lines.

002593

Ground water flow lines are northeasterly and indicate contamination should not be expected in the western half of the 400 Series Wells. Ground water flow lines indicate the 400 Series will be useful in seepage control but insufficient for total control.

Contours of TDS concentration indicate a narrow zone of very high concentration northeast of the North Pond and continued contamination of decreasing level at least to the area of well 504. The shape of the plume indicated control by premeability, fractures and/or recharge head from the west coupled with decreasing saturation to the east.

Decreasing saturation in Zone 3 towards the east suggests a physical control on the extent of eastward migration of contamination and warrants further evaluation because of its' possible effect on pumping efficiency and possible need for injection to the east of the currently drilled area.

Elevation of changes of water quality with time in the area of well 505 and 517 indicate a worsening situation.

Consideration of the geohydrologic setting indicate that the proposed collection system, including the 400 Series, should: a) stop further release of major contamination from the well 124 area north-eastward; b) control radionuclide contamination in the well 124 area; c) collect known contamination in the presently drilled area.

002594

RECOMMENDATION

The proposed collection system should be installed immediately (including activation of the 400 Series).

A waste-water treatment facility should be evaluated.

1.0 Introduction

Previous investigations (Billings & Associates, Inc., 1982. Reference 1) have identified tailings related contamination existing in the Upper Gallup (Zone 3) aquifer northeast of the United Nuclear Corporation's (UNC) Northeast Church Rock Mill Site. The full extent of this contamination has not been established pending a final definition of background water quality. It is therefore one of the purposes of this report to present in more detail the known extent of contamination in terms of the water quality parameters TDS (total dissolved solids) and sulfate. It is also the purpose of this report to present an extraction system that will prevent further release of additional contamination to the northeast and provide a partial framework for decontamination within the area of known contamination based on present drilling. The local geohydrology involved with the particular design of this system, as well as design specifications, will also be presented.

002595

The most efficient way to demonstrate the system is accomplishing its objectives is by means of monitoring water quality and water level in selected wells. Thus a monitoring program is presented. If indicated by monitoring, modifications can be made in the future in order to ensure the objectives of the system are met.

2.0 Geohydrology

The depositional pattern of Zone 3 in the northeast area yields a grain size distribution that ranges predominantly from fine at well 517 to coarse at well 504-B. A trend in the depositional pattern may be the cause of variation in hydraulic conductivity values, represented as transmissivity, for various locations in the northeast area (See Plate 1). The values of transmissivity and storativity on Plate 1 were obtained from pump and slug tests performed by Science Applications, Inc. (Reference 2) and from pump tests performed by Billings & Associates, Inc. (Reference 3). The results of the slug tests performed by Science Applications, Inc. were reanalyzed as errors in the analysis procedure were noted by Billings and Associates, Inc. during preparation of this report.

002596

The values of transmissivity on Plate 1 are grouped in three categories in order to represent three areas of differing aquifer characteristics. Where enough data were available, geometric means of the transmissivity and storage coefficient were computed for each area. The mean values of area A were used in the design calculations of the extraction system.

As observed from Plate 1, an increasing trend in the transmissivity (i.e., the ability to transmit water) occurs with increasing distance from the tailings. This type of trending heterogeneity is common in sedimentation processes that create depositional environments (Freeze and Cherry, 1979. Reference

4);similar to the depositional environment of Zone 3 (Science Applications Inc., 1980. Reference 5).

Geologic investigations (Science Applications Inc., 1980. Reference 5) have shown the presence of fractures existing on the outcrops of certain zones in the Upper Gallup Formation. It is probable these fractures continue further into the formation from their surface exposure.

The possibility of fractures in Zone 3 in the well 600 area is evidenced by the pump test conducted at well 600 (Billings & Associates, Inc., 1982. Reference 3). During this test, recharge and discharge barriers were encountered. These barriers are indicated by the water level response of the observation well 517 and by the response of the pumping well 600.

The direction of groundwater movement is primarily controlled by the piezometric surface. The determination of the piezometric gradient is essential in estimating the direction of movement of a contamination plume and in indicating directions in which contamination is unlikely to move. The piezometric gradient is also important in the design of the spacing and location of extraction wells. Plate 2 shows the water levels of all northeast Zone 3 wells measured during July, 1982 except for 501-B, 502-B, and 503-B which, were measured on October 1, 1982. The water levels were obtained from the Environmental Improvement Divisions' and UNC's files. The top of pipe elevations needed to convert to water elevations were taken from UNC files. The contours on Plate

2 indicate a northeast-east gradient of groundwater flow in Zone 3 in this area.

Zone 3 has been recharged for several years by the alluvial system. This recharging process has resulted in a wetting front occuring in Zone 3 as is evidenced by comparing the aquifer percent saturation of geophysically logged Northeast Zone 3 wells. The percent saturation of these wells is shown on Plate 3. Calculations of percent saturation in a recharge situation change with time. Not all available data are shown on Plate 3 to avoid clutter on the map.

3.0 Water Quality

Without clear and undebatable background water quality data existing at the UNC site, the determination of the degree of contamination is based on professional judgement and opinion. The background question does not relate to the area being considered by this collection system design. We suggest that a water quality value of less than 4,000 mg/l total dissolved solids be the design criteria for this system. By this statement, we are not suggesting that contamination from tailings does not occur unless a total dissolved solids value of 4,000 mg/l or greater is present. Rather, we suggest that 4,000 mg/l TDS or greater represents undebatable influence of tailings unless it can be shown that tailings liquid cannot be present. In our opinion, installation of the design presented will control the area of known 4,000 mg/l TDS concentrations and much of the known area of 2,000 - 4,000 mg/l TDS water.

The general shape of the contamination plume in this area can definitely be tracked by the parameters total dissolved solids and sulfate. The values of these parameters have been plotted for Zone 3 and are shown on Plate 4. The values along with the date the sample was taken are shown in Table 1.

002599

Table 1 - Northeast - Zone 3 Water Quality

Well No.	Date	TDS	SO4	Remarks
12D	820421	13,512	7,884	
11D	-------	-------	-------	No Data (TDS & SO4)
10D	820506	8,146	5,900	
121	820506	6,171	4,373	
106D	810409	4,447	2,859	
9D	810419	6.900	4,387	
125	820505	5,435	3,934	
449	820316	6,890	4,158	
450B	820505	7,081	4.959	
505B	820921	16,294	12,117	
517	820921	13,320	9,709	
518	820921	8,442	6,609	
600	820610	8,423	5,959	
501B	820217	5,130	2,185	
502B	820217	4,348	1,998	
503B	820217	4,380	2,094	
126	820512	4,752	3,203	
127	820217	4,988	2,180	
118	810818	2,981	1,619	
114	820316	3,948	1,996	
404	------	-----	-----	No Data
432	------	-----	-----	No Data
433	810921	3,672	2,124	
434	------	-----	-----	No Data
424	810921	3,595	2,124	
421	------	-----	-----	No Data
422	820316	2,524	1,435	
425	------	-----	-----	No Data
426	820316	3,820	1,899	
427	------	-----	-----	No Data
428	------	-----	-----	No Data
429	820316	4,112	2,006	
430	------	-----	-----	No Data
431	------	-----	-----	No Data
432	------	-----	-----	No Data
420	------	-----	-----	No Data
423	------	-----	-----	No Data
414	------	-----	-----	No Data
436	------	-----	-----	No Data
437	------	-----	-----	No Data
438	820316	3,380	1,903	
439	------	-----	-----	No Data
440	------	-----	-----	No Data
441	------	-----	-----	No Data
442	------	-----	-----	No Data
443	810918	3,705	1,998	
444	------	-----	-----	No Data
445	------	-----	-----	No Data
446	820506	4,140	2,165	

Table 1 - Northeast - Zone 3 Water Quality (Continued)

Well No.	Date	TDS	SO4	Remarks
447	------	-----	-----	No Data
403A	820421	3,135	1,580	
406	820701	2,644	1,486	
407	820316	2,819	1,598	
408	------	-----	-----	No Data
403A	820421	3,135	1,580	
411	820316	3,588	1,977	
413	------	-----	-----	No Data
415	820316	3,895	1,020	
416	------	-----	-----	No Data
504B	820217	4,434	2,114	
435	810918	3,417	2,072	
124	820505	29,213	19,655	

002601

It appears from Plate 4 that high concentrations of contamination (i.e., TDS greater than 10,000 mg/l) exist in a narrow northeasterly path as far as the Well 505-B and 517 area. However, from this point the concentrations appear to decrease rapidly to the north and east. The piezometric gradient prohibits the movement of any major contamination further to the west. The shape of the contours could be interpreted to indicate fracture control and/or control by piezometric gradient coupled with a recharge front to the east.

002602

Evaluation of historical water quality data for wells 505-B and 517 indicate the water quality is worsening in this area. Evaluation of historical water quality data in the 400 Series wells indicates that in at least the eastern half, water quality worsened as pumping continued.

As previously stated, the presently proposed extraction design is concerned with that water with a known total dissolved solids concentration of 4,000 mg/l or greater. The 4,000 mg/l contour appears to extend in a northeasterly fashion to a point at least as far as 504-B. Our design therefore exists to the area of 504-B. It is not known at this time whether or not concentrations of total dissolved solids greater than or equal to 4,000 mg/l exist further to the north and/or east of 504-B. The proposed system should collect water from several hundred feet north and east of 504-B.

4.0 Design

The physical setting of Zone 3 in the northeast area has been discussed in previous sections. The setting of Zone 3 for purposes of design can be summarized as follows.

A contamination plume exists in Zone 3 in the northeast area of the UNC site. The plume is traveling in a northeast path with a lessor concentration vector in the eastern direction. The extent of contamination is dependent upon many variables. First, a northeast to east piezometric gradient prohibits any large scale movement of contamination to the west. Second, the known areas of high contamination are localized and spatially variable in the well 517/124 area. Probable reasons for the localization and spatial variability of contamination in this area are fractures and/or the relatively low permeability (see Plate 1). Total dissolved solids concentrations of less than 5,000 mg/l but greater than 4,000 mg/l exist from slightly south (less than 100 feet) of the 126/127 area to at least as far as the 504 area. In the 501/502 area, contamination is probably bounded at an unknown limit on the east due to the wetting front. The eastern and northern bounds of the 4,000 mg/l contour are not known in the 504 area.

The northeast extraction system will prevent any additional migration of contamination from the North Pond in this area as well as provide a framework for the decontamination of Zone 3 in the area of known contamination based on current drilling. When water quality data to the north and east of well 504 become available modifications to this pumping system, if necessary, can be made.

The northeast extraction design consists of two separate areas of pumping wells. The first area lies on a northwest-southeast line near the well 600 area (see Plate 5). The wells in this area provide a means of cutting off any further northeast to east migration of high contamination (i.e., TDS greater than 10,000 mg/1).

002604

Calculations to determine the spacing of the pumping wells were made using the aquifer parameters of area A on Plate 1. These calculations were based on the Theis (Reference 6) non-equilibrium equation for homogeneous, confined aquifers. The calculations indicate a design radius of 300 feet for four months of pumping (one foot drawdown) at one gallon per minute. It is the opinion of BAI this spacing is too large because the calculated results do not agree with the observed field data. Therefore, the spacing of the pumping wells in this area is based on observed field data obtained from the well 600 pump test (Billings & Associates, Inc., 1982. Reference 3). The data indicated drawdown at a distance of 54 feet from the pumping source after approximately 12 days of pumping. However, no drawdown was observed at a distance of approximately 105 feet. Therefore, a distance between pumping wells of 175 feet (i.e., radii of 88 feet) was chosen for the design. This distance is expected to provide drawdown in 5 months of pumping at the proposed observation wells (see Plate 5). If not, modifications to the system can be made.

These wells serve to decontaminate the most highly contaminated portion of the aquifer. It is also recommended pumping wells be placed in the vicinity of 450B and 504B. Well 124 will be redrilled and converted to pumping wells to serve as part of this system.

The second area of pumping wells consists of installing pumps in Wells 402, 433, 424, 422, 435, 403-A, 438, 443, 446, and in a well to be drilled due east of well 504. It has been demonstrated pumping wells in the 400 Series (Billing & Associates, Inc., 1982. Reference 7) caused several feet of drawdown in the well 126/127 area after 5 months of pumping. Therefore, this arrangement of pumping wells should change the northeast to east piezometric gradient to a northerly gradient. This change, in conjunction with the stress being applied to Zone 3 in the well 600 area should result in interlocking cones of depression between the two areas of pumping wells. Once achieved, the driving force necessary to push water further to the east from the area of the North Pond is removed. There is another advantage to utilizing this system. Once the eastward driving hydraulic head is removed, contamination in the 127/128 area should move dowwndip (Billings & Associates, Inc., 1982. Reference 8) (i.e., to the north) and be captured by the 400 Series system. Note that the system does not address any presumed or real contamination east or northeast of currently drilled areas. It is our opinion that the system should

002605

be installed prior to any continued exploration of plume boundaries as further delay will increase risk, contaminant extent and cost.

The above approach and rationale results in the design of the extraction system shown on Plate 5. The observation wells necessary to monitor the effectiveness of the system are also shown on Plate 5.

002606

5.0 Pumping System

The pumping system should be constructed in such a way so as to allow for the measurement of the pump discharge as well as the water level of both the pumping and observation wells. Each well should pump to one or more central holding tanks where the water is further pumped to the tailings area. Each of the pumping wells should be installed as shown in Figure 1. No special apparatus is needed for the observation wells as their water level can be measured by a steel tape.

002607

Table 2 presents the purpose of each well to be used in the system as well as the estimated discharge of each pumping well.

Drilling and well construction specifications are given in Appendix A. Well development procedures and material specifications are in Appendices B and C respectively. The materials needed for the system are listed in Appendix D.

BAI staff should establish a pumping rate for each pumping well prior to the initialization of the extraction system. BAI staff should also be responsible for supervising the construction of all wells.

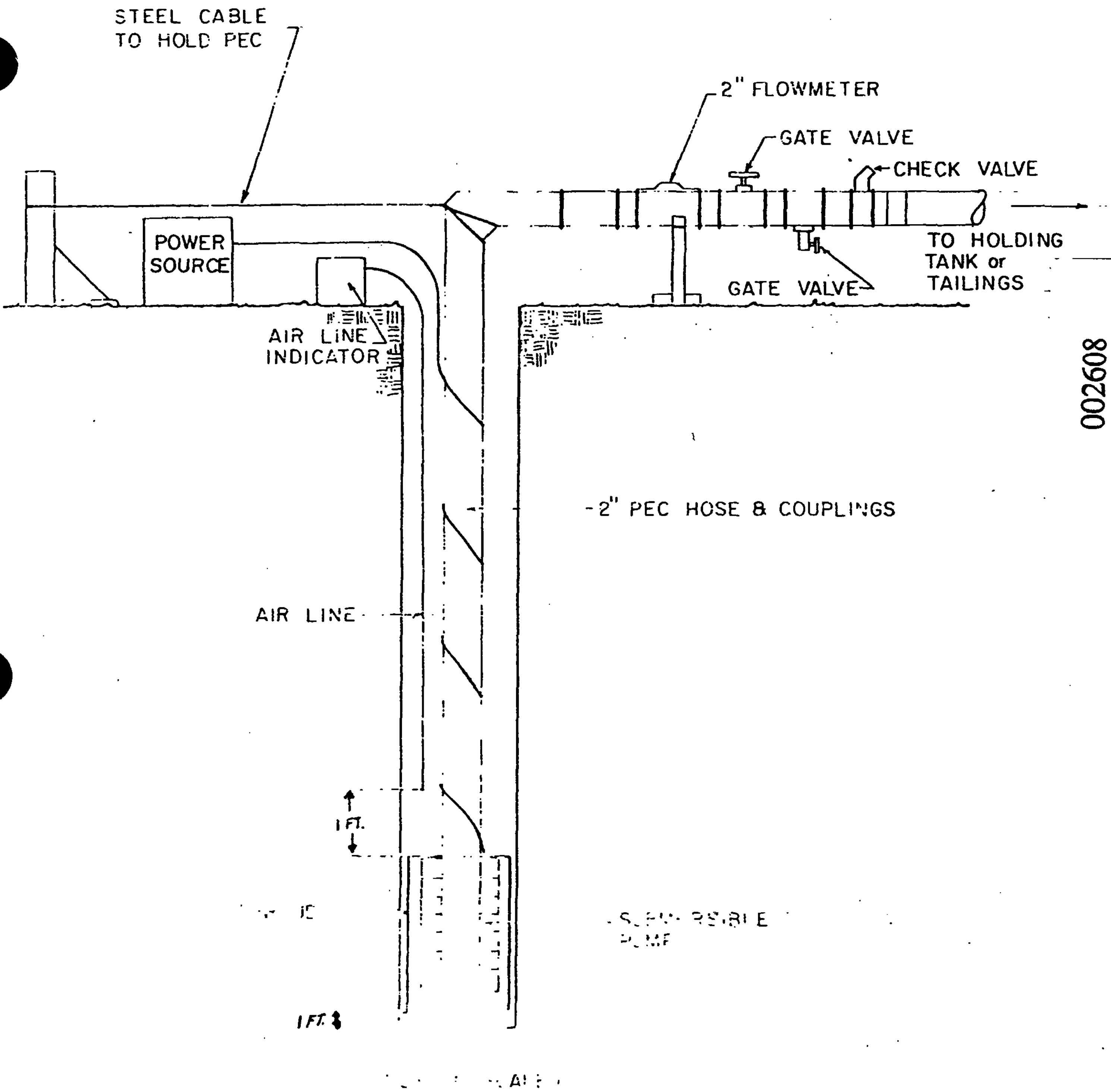

Figure 1 Pumping Well Installation

002608

Table 2 - Extraction System Wells

Well No.	Purpose	Estimated Discharge (gallons/day)
606	Pumping	1,440
607	"	1,440
608	"	1,440
609	"	1,440
610	"	1,440
611	"	1,440
612	"	1,440
613	"	1,440
600	"	1,440
124	"	1,440
9	Observation	--
450B	"	--
505B	"	--
517	"	--
518	"	--
526	"	--
527	"	--
528	"	--
529	"	--
530	"	--
531	"	--
532	"	--
533	"	--
534	"	--
125	"	--
126	"	--
127	"	--
118	"	--
503B	"	--
504B	"	--
411	"	--
415	"	--
424	"	--
605	Pumping	4,320
446	"	4,320
443	"	4,320
438	"	4,320
403A	"	4,320
435	"	4,320
422	"	4,320
424	"	4,320
433	"	4,320
402	"	4,320

Prior to the setting of the pumps, static water levels and total depths should be measured in all wells. The length of the shroud (see Figure 1) should be measured and the pump set so that the bottom of the shroud is one foot above the bottom of the hole and the bottom of the airline set one foot above the top of the pump according to the dimensions shown on Figure 1. After the pump is set, the water level should have time to stabilize (approximately 2 hours) and the static air line pressure should be measured sufficiently often to demonstrate static conditions. Should it become necessary to pull the pump, the length of the shroud and the total depth of the well should be remeasured and the pump reset according to the dimensions on Figure 1.

002610

6.0 Monitoring

The monitoring for the first month of pumping should proceed according to the following schedule.

- The discharge and air line pressure of all pumping wells should be measured daily.
- The water level of all observation wells should be measured weekly.
- A water sample should be taken from the pumping wells once a month and analyzed for pH, SO4, N-NO3, N-NH3, and TDS.
- Prior to pumping, a water sample will be taken from all wells and analyzed for the above list.

After the first six months of pumping, the data should be analyzed and modifications to the monitoring schedule and/or pumping system may be necessary.

002611

7.0 Treatment of Discharge from the Collection System

At present, for reasons of time, it is planned that discharge from the collection system be taken to Borrow Pit #2 where at is subsequently neutralized and placed in the North Pond. As the mill is currently shut-down, it is recognized that such a discharge procedure is inefficient and prolongs cleanup. Therefore, we recommend that an engineering study be initiated to evaluate the cost and feasibility of a waste-water treatment facility with subsequent surface or subsurface discharge. A subsurface discharge would not require an NPDES permit, would avoid water rights problems, and would accelerate the decontamination process.

Appendix A

Drilling and Well Construction Specifications

Pumping Wells

The pumping wells should be rotary drilled, using Revert as the drilling fluid, to a diameter of 12 and 1/4 inches. Cuttings should be obtained and recorded at 5 ft. intervals. The total depth of drilling will be determined in the field, dependent upon the cuttings obtained. The wells should then be geophysically logged in order to verify the correct depth of the target formation (Zone 3) If necessary, modifications to the well depth may be made. The following parameters will be obtained from the geophysical log:

002614

- Resistance
- Gamma
- Spontaneous Potential

Once the target formation has been identified, the construction of the wells will proceed according to the guidelines described in the UNC letter of September 8, 1982 (Reference 9) to the New Mexico Environmental Improvement Division (EID) and according to the following procedure (See Figure 2):

- The borehole will, if necessary, be backfilled with bentonite pellets until a seal is obtained below the bottom of the target formation.

- The casing and screen will then be lowered into the well until the screen is opposite the formation.

- The sand pack will then be placed in the annulus opposite the screen.

- A bentonite seal of approximately 15 feet will then be placed on top of the sand pack.

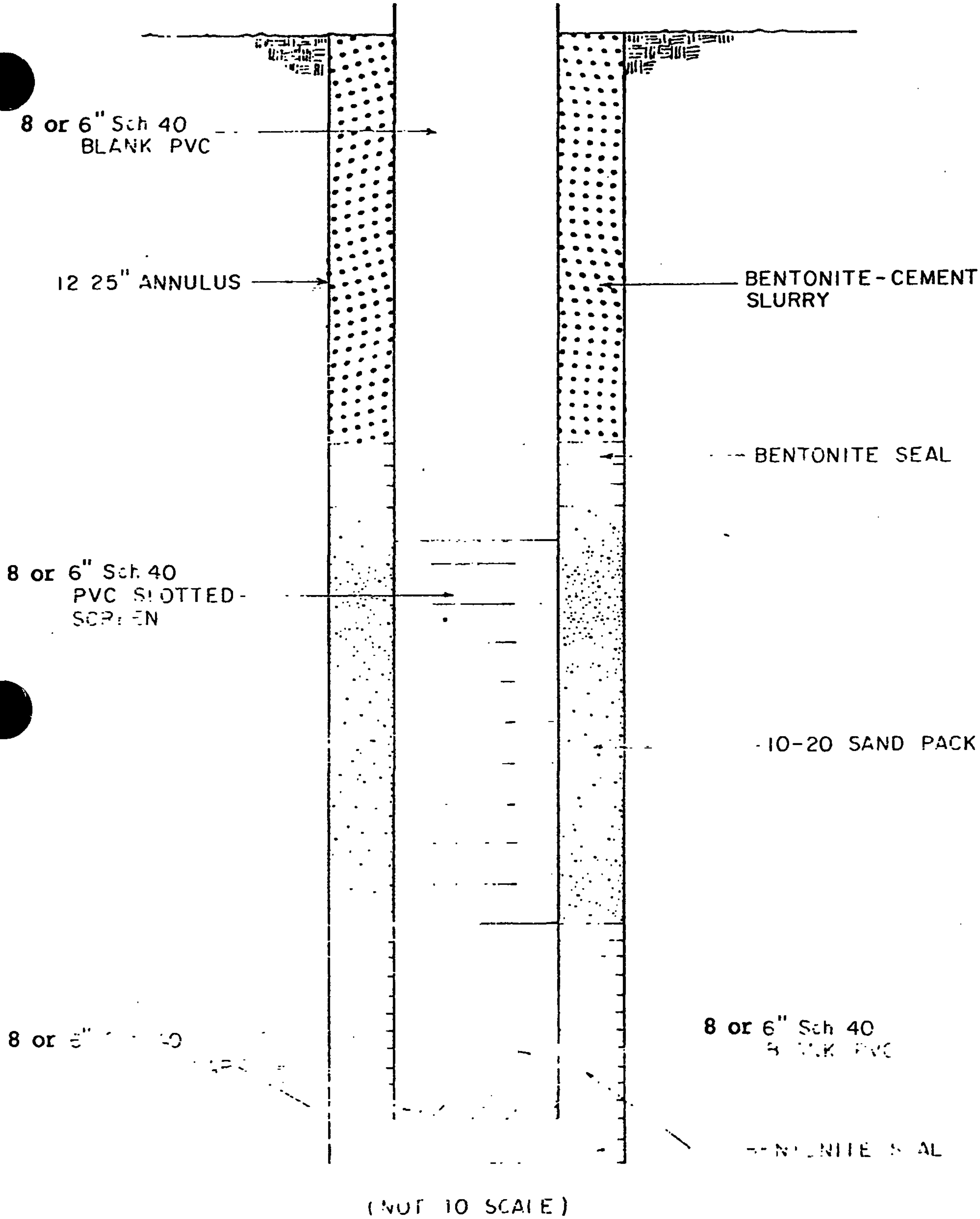

Figure 2 Cross Section of Typical Pumping Well

002615

- A bentonite cement slurry will then be injected into the annulus from the top bentonite seal up to the ground surface.

As is discussed in the UNC letter to the EID, these wells and their gravel pack specifications' are designed based on guidelines given by Johnson (Johnson Division, UOP Inc., 1975. Reference 10).

In order to obtain maximum drawdown in Zone 3, the well will be drilled eight feet into Zone 2. The casing will be capped and blank in this drilled extension. The pack outside the casing will be bentonite. The pump will be set below the bottom of Zone 3, in this extension. The pump should be shrouded or equivalent as is necessary due to lowering the pump into the nonproductive Zone 2. Shrouding may require use of 8 inch ID casing.

Observation Wells:

The observation wells will be rotary drilled, using Revert as the drilling fluid, to a diameter of 5 inches. The target formation will be identified by cuttings from the well and by geophysical logs of wells in the vicinity.

The construction of the observation wells will proceed in the same manner as the pumping wells except for the diameter of the well (See Figure 3) and the drilled extension into Zone 2.

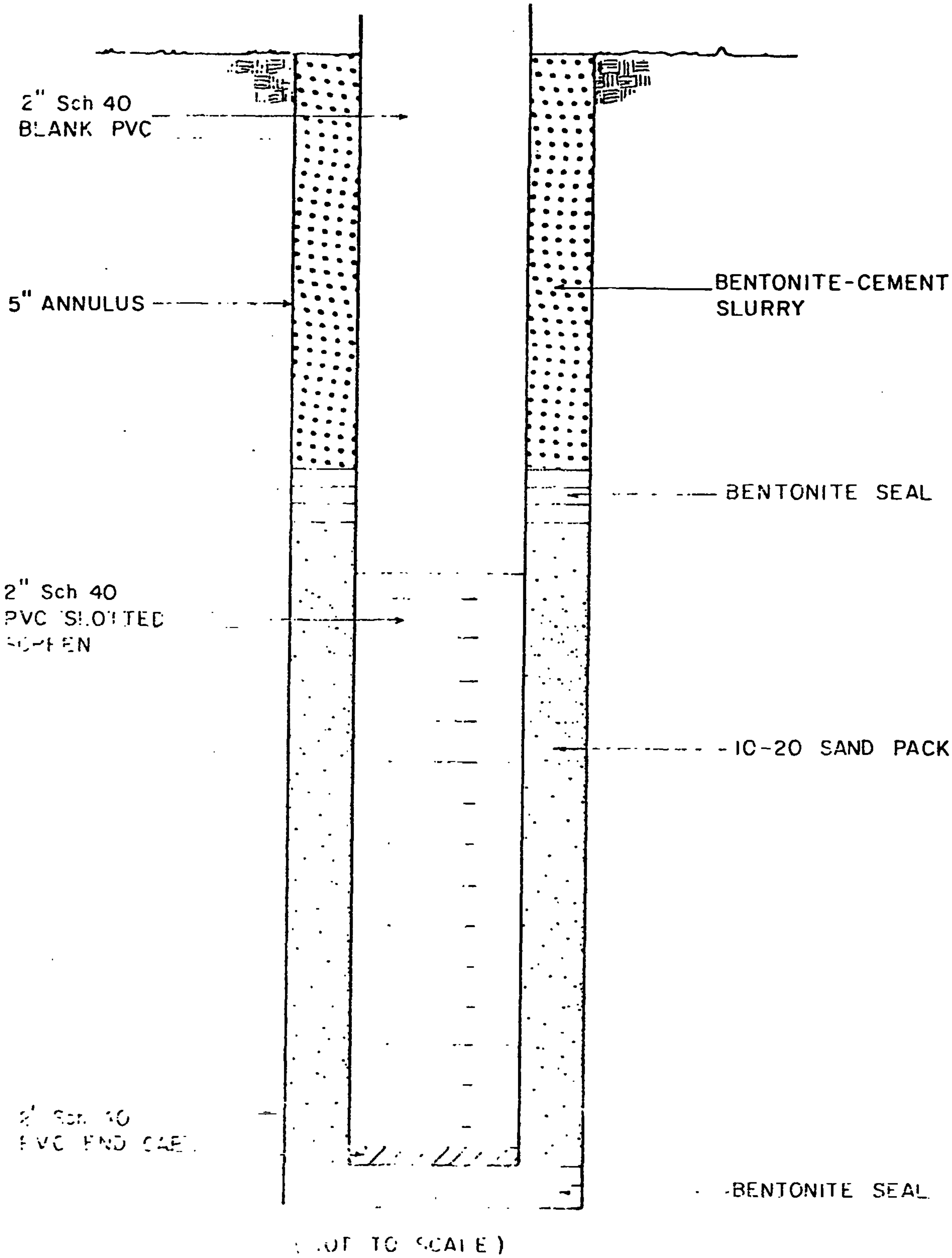

Figure 3 Cross Section of Typical Observation Well

002617

Appendix B

Well Development Procedures

002618

The purpose of well development is to clean the well bore and the immediate area of drilling mud and fluid, fine grained sediment and any other foreign material. One of the best methods is to pump or otherwise produce water from the water bearing zone to flush the foreign fluid and sediments.

All of the pumping wells should be developed by:

1. Circulating for appproximately one-half hour with new, clean pit water before setting the casing.
2. Blowing the well dry by air-lifting, using a drill stem inside the well casing. In this procedure, the bottom of the drill stem will be periodically raised at 5 ft. intervals until the entire thickness of the formation has been blown. The procedure will be repeated until the water is clear.

When the well development process is completed, a water sample should be taken and analyzed. The water level in the well will then be allowed to stabilize. Periodic water levels should then be measured until a decision is reached concerning the static water level.

The observation wells should be developed by:

1. Circulating for approximately one-half hour with used pit water before setting the casing.
2. Hand bailing or air-jet blowing of the well after the casing is set until the water is clear.

A water sample should then be taken and analyzed. The well should then be allowed to stabilize while periodic water levels are obtained until a decision is reached as to static water level.

002620

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Title: Design of a Seepage Control System for Zone 3 (Upper Gallop) Northeast of the North Pond

Date: December 01, 1982

Comment: Cover Page for Appendix C "Material Specification"

Bates Number: 002620.001

Materials	Quantity
2" PVC Screen (Sch 40, 0.035 in. slot)	720 feet
2" PVC-Solid (Sch 40, bell end)	1620 feet
Bentonite Pellets (1/2" diameter, 50# buckets)	225 buckets
Sand (10-20 grade)	560 cu. ft.
Cement (1 bag & 6 gal. H_2O =1 cu. ft., Type II)	1700 bags
Bentonite (loose bagged)	255 cu. ft.
2" PVC End Caps (Sch 40 solid)	18
2" PVC slip coupings (Sch 40, long type)	108
PVC primer (Purple HiEtch)	20 cans
PVC Brushes	40
PVC Glue (Clear Fastset, 1 qt. cans)	20 cans
6" or 8" (ID) PVC Screen (Sch 40, 0.035 in. slot)	520 ft.
6" or 8" (ID) PVC Slip Couplings (Sch 40, long type)	65
6" or 8" (ID) PVC-Solid (Sch 40, Bell end)	880 ft.
6" or 8" (ID) PVC End Caps (Sch 40, solid)	10
2" Check Valves	19

002621

APPENDIX D

System Materials

002622

Materials	Quantity
Submersible Pumps with Shrouds or Equivalent	
- 1 to 10 gal./min. at 220 ft. head	8
- 0.4 to 3 gal./min. at 175 ft. head	10
2" PEC Tubing and Necessary Couplings	3000 feet
1/4" Steel Cable	3000 feet
Gate Valves	
- 2"	20
90-degree Elbows	
- 2"	17
Nipples	
- 2" diameter x 6" length	78
Flowmeter	
- 2" Intake and Outake	
- Instantaneous and Totalizer	
- 0.4-3 gal./min.	12
- 1-20 gal./min	5
Hose Clamps (stainless)	290

002623

Appendix E

Necessary Personnel

002624

UNC Participation:

1. Drill Rig and crew.
2. Well Construction Crew (2 technicians).
3. Pump setter.
4. Electrician (Start-Up).
5. Geophysical truck and crew.

002625

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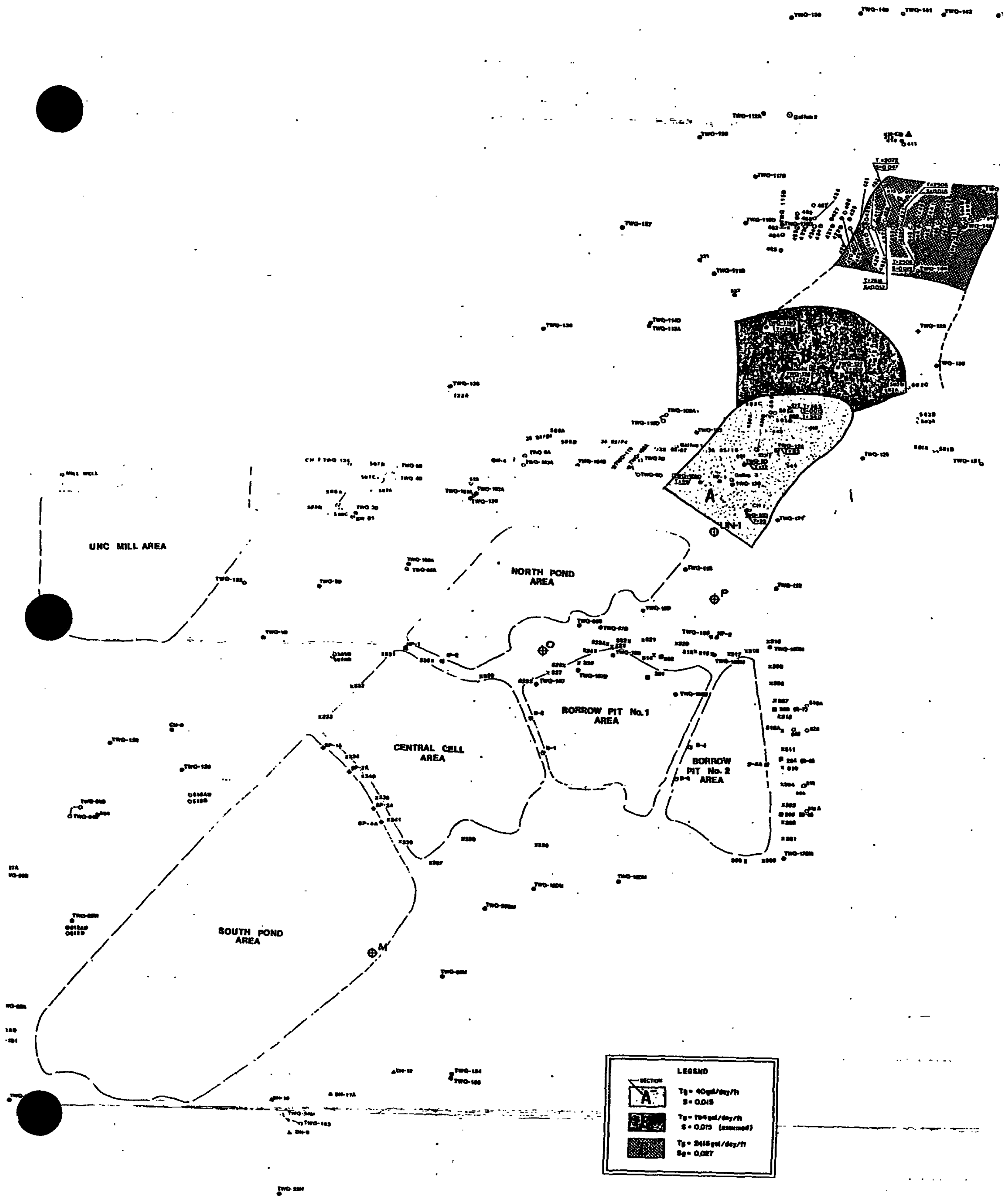
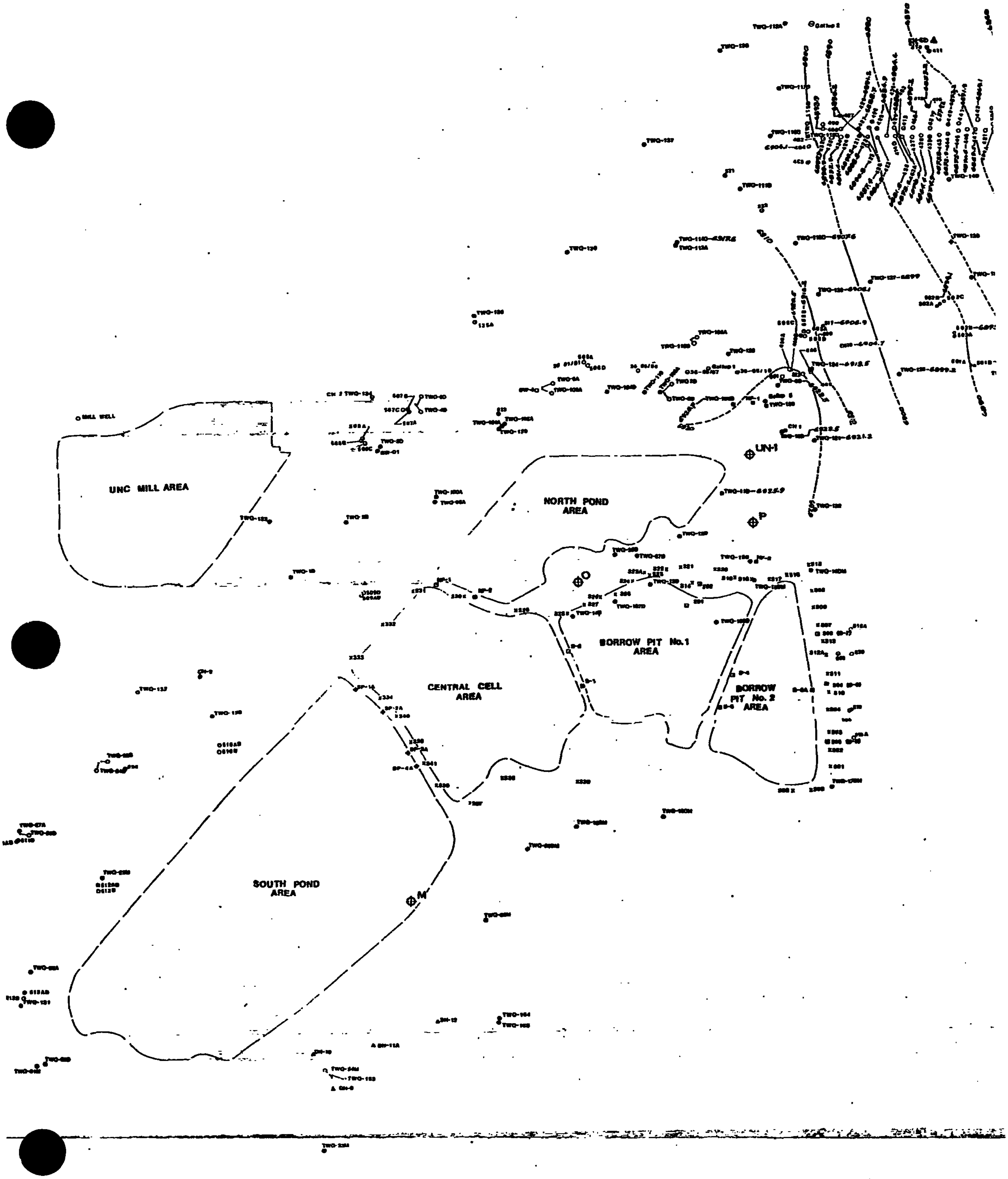


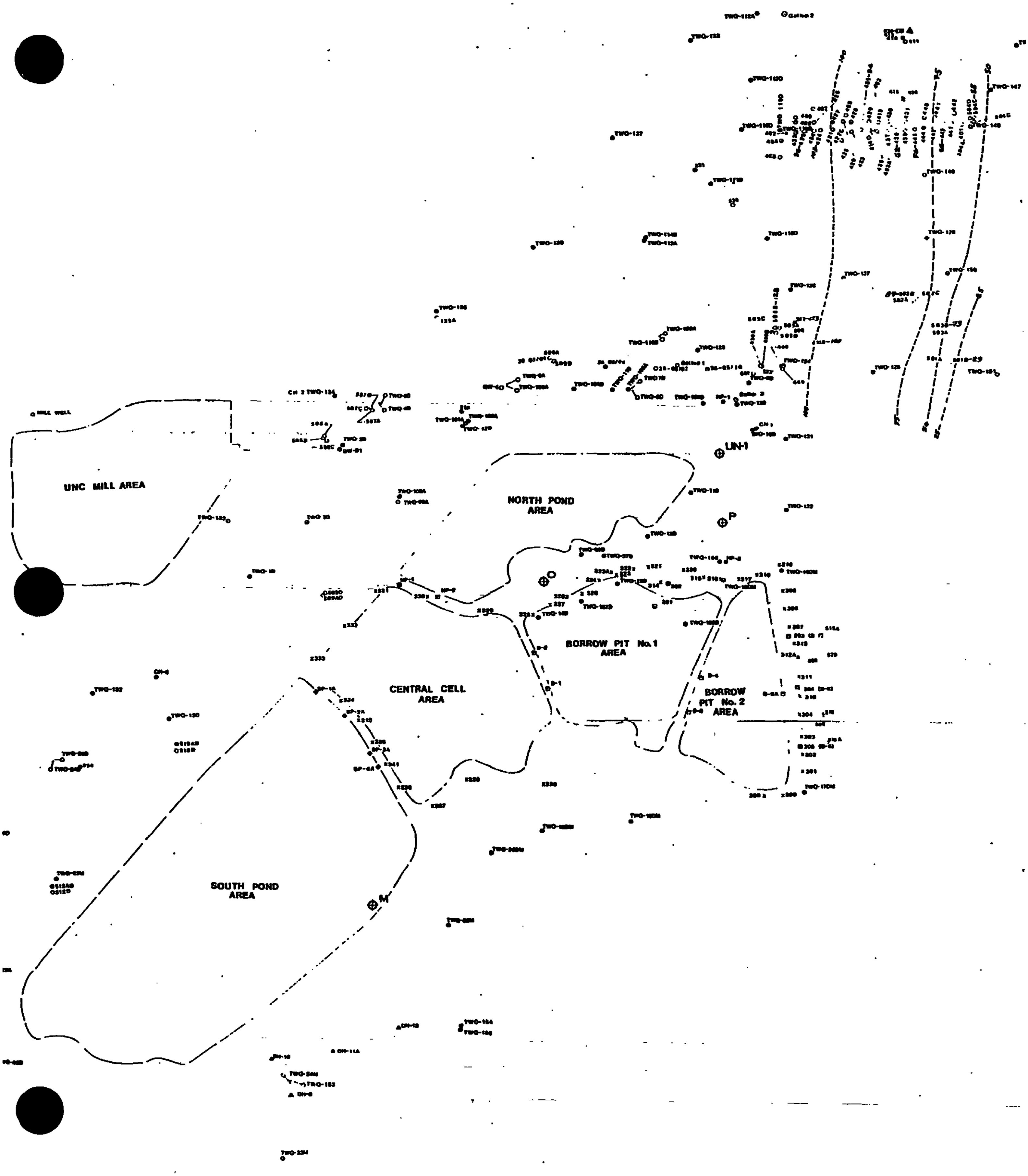
UNC MILL AREA
NORTH POND AREA
BORROW PIT No. 1 AREA
BORROW PIT No. 2 AREA
CENTRAL CELL AREA
SOUTH POND AREA
LEGEND
SECTION
A
Tg = 40gal/day/ft
S = 0.015
Tg = 194gal/day/ft
S = 0.015 (assumed)
Tg = 2416gal/day/ft
Sg = 0.027



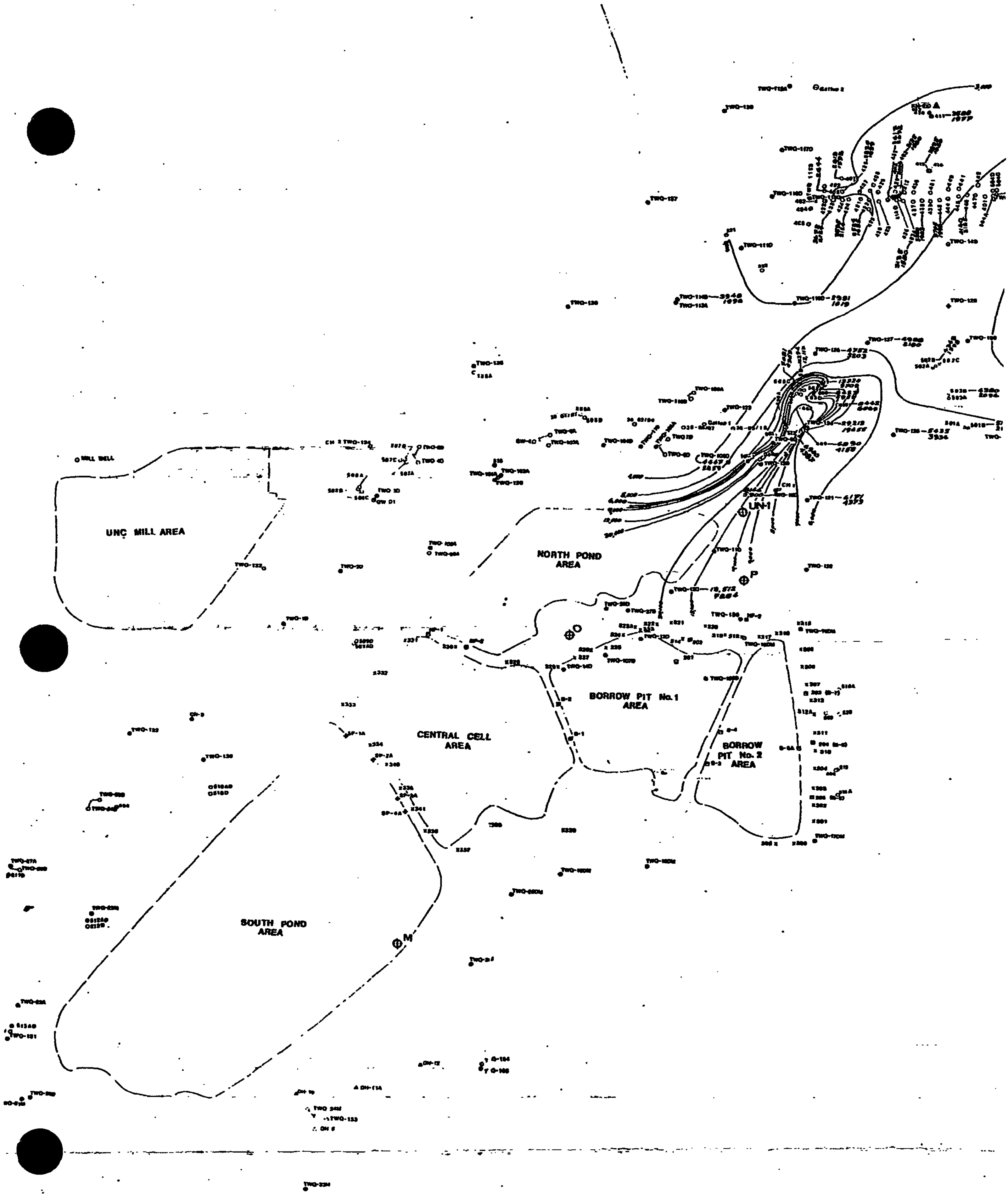
NORTHEAST ZONE 3 PIEZOMETRIC SURFACE

——— CONTOUR INTERVAL

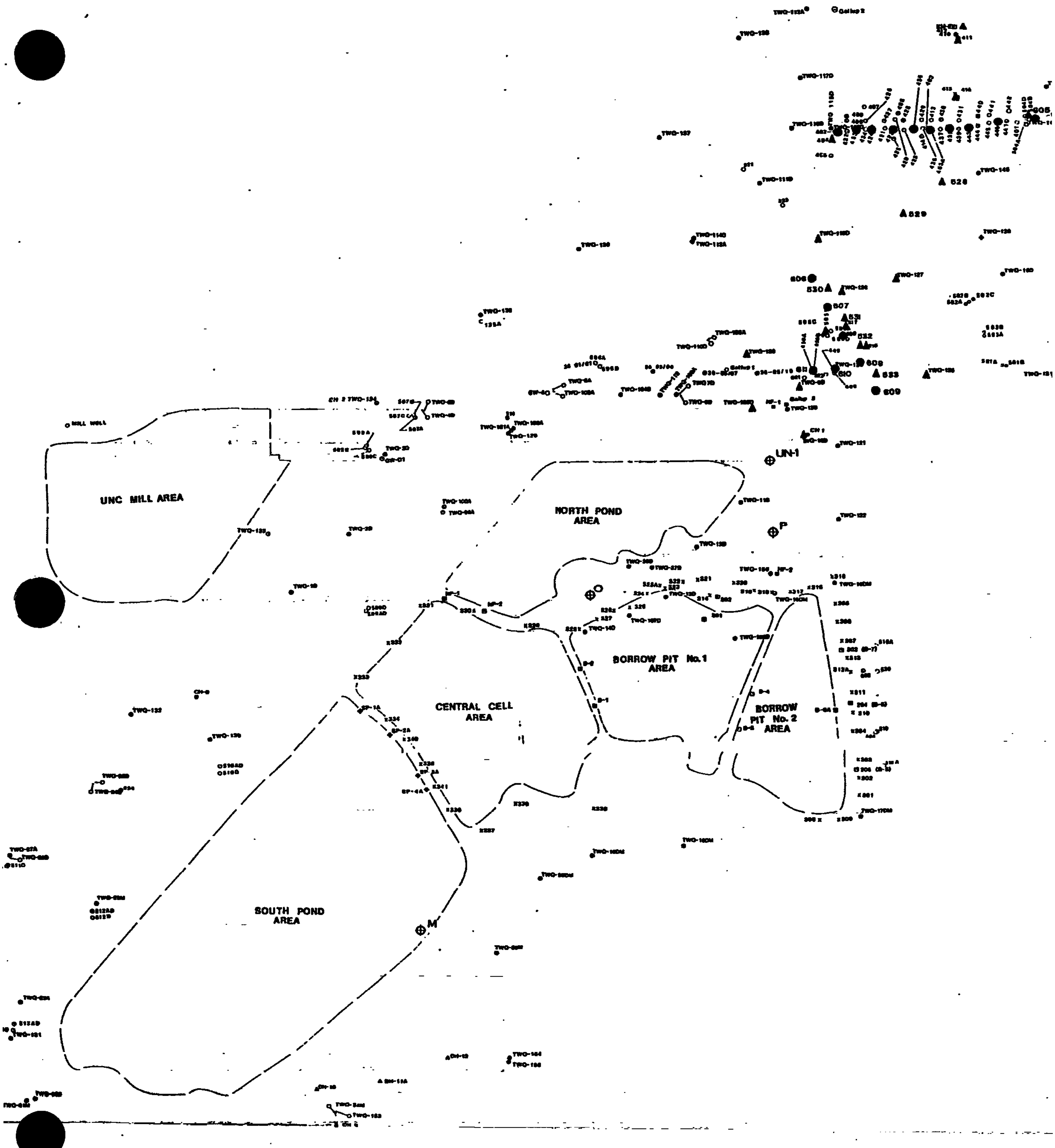
– – – – APPROXIMATED



NORTHEAST ZONE 3 PERCENT SATURATION



NORTHEAST ZONE 3
T.D.S. AND SULFATE



PROPOSED NORTHEAST ZONE 3 EXTRACTION SYSTEM

● – PUMPING WELL

▲ – MONITORING WELL

Evaluation of Background Concentrations of Contaminants in an Unusual Desert Arroyo Near a Uranium Mill Tailings Disposal Cell - 12260

Richard P. Bush* and Stan J. Morrison**
*U.S. Department of Energy Office of Legacy Management
**S.M. Stoller Corporation

ABSTRACT

The U.S. Department of Energy (DOE) Office of Legacy Management (LM) manages 27 sites that have groundwater containing uranium concentrations above background levels. The distal portions of the plumes merge into background groundwater that can have 50 µg/L or more uranium. Distinguishing background from site-related uranium is often problematic, but it is critical to determining if remediation is warranted, establishing appropriate remediation goals, and evaluating disposal cell performance. In particular, groundwater at disposal cells located on the upper Cretaceous Mancos Shale may have relatively high background concentrations of uranium. Elevated concentrations of nitrate, selenium, and sulfate accompany the uranium. LM used geologic analogs and uranium isotopic signatures to distinguish background groundwater from groundwater contaminated by a former uranium processing site.

INTRODUCTION

Restoring contaminated groundwater to background concentrations is often a goal of groundwater remediation efforts. Inaccurate determination of background concentrations can result in unrealistic cleanup goals and regulations. The determination of background can be complicated by release of contaminants from geologic media. An interesting example of the difficulty in determining background concentrations is found at former uranium processing sites located on bedrock of the upper Cretaceous Mancos Shale. The Mancos Shale releases the same suite of contaminants via natural processes as those found in uranium mill tailings.

Field investigations over the last several decades by personnel from the U.S. Geological Survey [1,2,3,4], the University of California Davis [5,6,7], Colorado State University [8,9,10], and others [11] have shown that high concentrations of selenium are typical in surface water resulting from irrigated land in Mancos Shale terrain. The selenium is derived from shale beds in the Mancos. Because selenium concentrations are elevated sufficiently to affect aqueous species in lakes and streams, its occurrence, magnitude, and control measures have been widely researched. Although most of the published material relates to the impact of selenium on surface water, high concentrations of nitrate, selenium, sulfate, and uranium have also been observed in Mancos groundwater. In a recent LM study, groundwater samples were collected from the Mancos Shale at locations covering much of its depositional basin and found to contain high concentrations of these same contaminants [12]. The same suite of contaminants (nitrate, selenium, sulfate, and uranium) is found in groundwater associated with uranium mill tailings disposal cells.

Contaminants (and their concentrations) observed in Mancos Shale groundwater from natural sources are similar to those at a uranium mill tailings site at Shiprock, New Mexico. Two arroyos (Salt Creek Wash and Upper Eagles Nest) located about 8 to 11 km northeast of the disposal cell were studied as representing natural analogs to Many Devils Wash. Isotopic ratios of uranium-234 to uranium-238 are also being investigated as a tool to better define the sources of the uranium in groundwater.

NATURAL CONTAMINATION FROM MANCOS SHALE

The Mancos Shale outcrops over an area of about 3237 km^2 in Arizona, Colorado, New Mexico, and Utah. It has long been known that the Mancos Shale contributes high levels of sulfate and selenium to groundwater and surface water in irrigated terrain. Less well known is that the Mancos also contributes elevated concentrations of nitrate [13] and uranium [12] to groundwater. Uranium and nitrate concentrations found in natural seeps emanating from Mancos groundwater commonly exceed 100 µg/L and 400 mg/L, respectively. Locations with high concentrations of natural contaminants are widely distributed, suggesting that the phenomenon is common. There was no apparent correlation of high concentrations with particular geologic members of the Mancos; however, only seeps emanating from shale and siltstone were contaminated, and those from Mancos sandstone had much lower concentrations.

ANALOGS TO MANY DEVILS WASH AT SHIPROCK

A particularly enigmatic example of the uncertainty in determining background concentrations is found near a former uranium processing site at Shiprock (Figure 1). DOE stabilized tailings and mill residues in a disposal cell, and LM now administers the site. A line of seeps, located about 0.8 km from the disposal cell, contributes about 4 liters per minute (Lpm) to surface water in an arroyo named Many Devils Wash (Figure 2). Because Many Devils Wash is close to the disposal cell, and because it and the disposal cell have similar suites of contaminants, DOE assumed responsibility for Many Devils Wash as part of the mill site remediation. If contaminants in the wash are derived from natural processes rather than from the mill site, then remediation efforts would be futile.

Figure 1. Areas of investigation near the former uranium milling processing site at Shiprock, New Mexico.

Figure 2. Seeps (marked by arrows) in the Many Devils Wash arroyo.

The seeps in Many Devils Wash are contaminated with nitrate, selenium, sulfate, and uranium, the same contaminants found in the uranium mill tailings and groundwater immediately adjacent to the disposal cell. Concentrations of these contaminants are similar to naturally occurring seeps at two analog sites, the arroyos named Salt Creek Wash and Upper Eagles Nest, located about 8 to 11 km northeast of the disposal cell (Figure 1). Contamination from the former mill site did not influence the analog sites; besides being far removed from the mill site, the analog sites are in different drainages on the opposite side of the San Juan River, and are at higher elevations. Groundwater flowing from the seeps in Many Devils Wash forms yellow to deep-red pools in the arroyo (Figure 3). The color is from dissolved, not particulate, constituents and is not due to iron or manganese, as indicated by the low concentrations of these elements. The same yellow and red coloration is present in seep pools in Salt Creek Wash (Figure 4) and is present at numerous other locations across the Colorado Plateau where groundwater forms natural seeps emanating from Mancos Shale [12]. In Salt Creek Wash, the color of the water, as measured by light absorbance at 465 nanometers normalized to a platinum-cobalt standard method, correlates with dissolved organic carbon (DOC).

Figure 3. Red pool fed by seeps in the Many Devils Wash arroyo.

Figure 4. Red pool fed by seeps emanating from the Mancos Shale in the Salt Creek Wash arroyo.

Figure 5 compares concentrations from several wells located near the uranium disposal cell, and from seeps in Many Devils Wash, Salt Creek Wash, and Upper Eagles Nest. The concentrations of all four constituents are much higher than drinking water standards at all four locations. The tailings groundwater has lower selenium and higher uranium concentrations than

Many Devils Wash or the analog sites. The graphs depict similar chemical signatures for Many Devils Wash, Salt Creek Wash, and Upper Eagles Nest, but a different signature for the tailings.

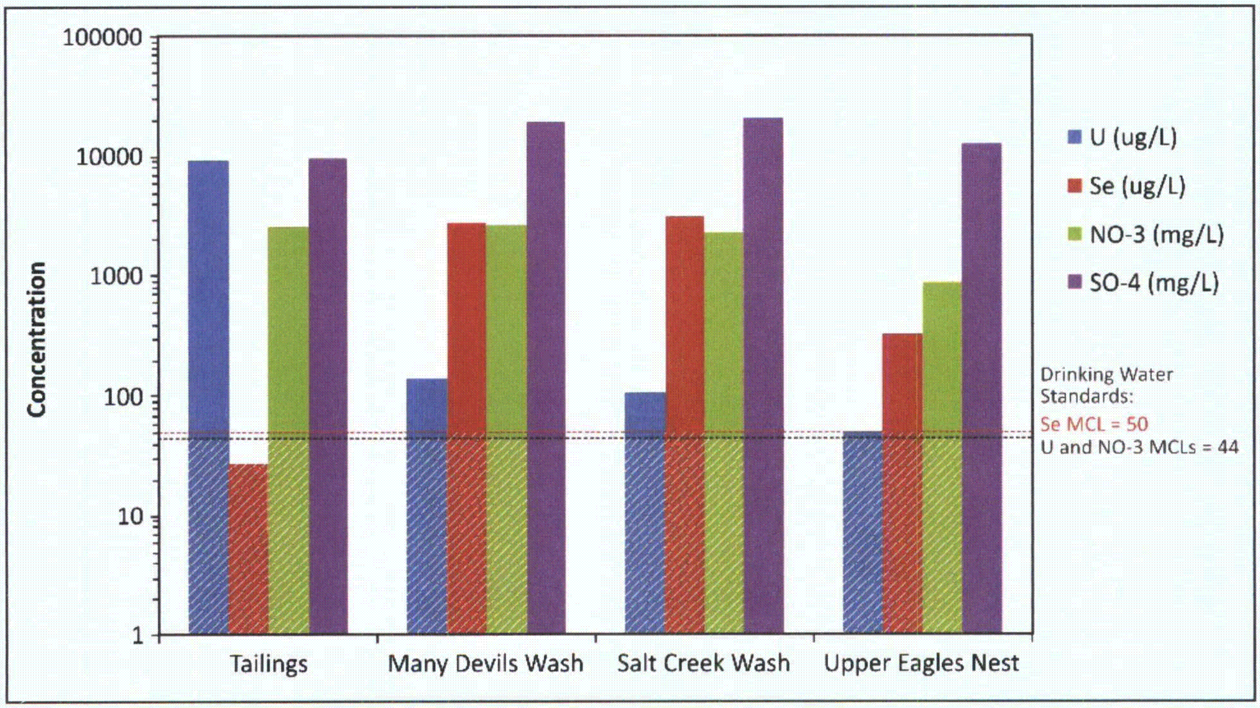


Figure 5. Concentrations of nitrate, selenium, sulfate, and uranium in selected wells near the Shiprock tailings disposal cell, and from seeps in the Many Devils Wash, Salt Creek Wash, and Upper Eagles Nest arroyos. Drinking water standards are indicated (40 CFR 141) [14].

URANIUM ISOTOPIC SIGNATURES

Activity ratio (AR) values of uranium-234 to uranium-238 provide information that can help determine the source of uranium in groundwater. Colorado Plateau uranium ores were deposited for more than 1 million years, a sufficient time to reach secular equilibrium. Thus, AR values in the ores are near 1.0. Aggressive digestion of the ores during milling preserves the AR values near 1.0. Values of AR in groundwater near the Shiprock disposal cell are often close to 1.0, consistent with secular equilibrium; however, some variations exist. Because uranium in most groundwater not associated with uranium processing has higher AR values., Zielinski et al. [15] were able to use AR values to help distinguish natural uranium from that added from a uranium mill near Cañon City, Colorado.

AR values increase in groundwater by alpha recoil [16] whereby the energy released by alpha decay of uranium-238 causes the daughter atom of uranium-234 to be ejected out of the mineral grain and into the pore water. Various other chemical and physical processes (particularly oxidation and mineral damage) that can affect the rate at which uranium-234 concentrates in the groundwater during alpha decay occur [17].

Mancos seeps typically have AR values that are much higher than 1.0 and often exceed 2.0. The seeps in Many Devils Wash and at the analog sites at Salt Creek Wash and Upper Eagles Nest have AR values between 2.0 and 3.0, whereas tailings-derived groundwater has an AR value of about 1.0 (Figure 6). Thus, higher AR values help distinguish uranium in natural Mancos groundwater from uranium contributed by milling processes.

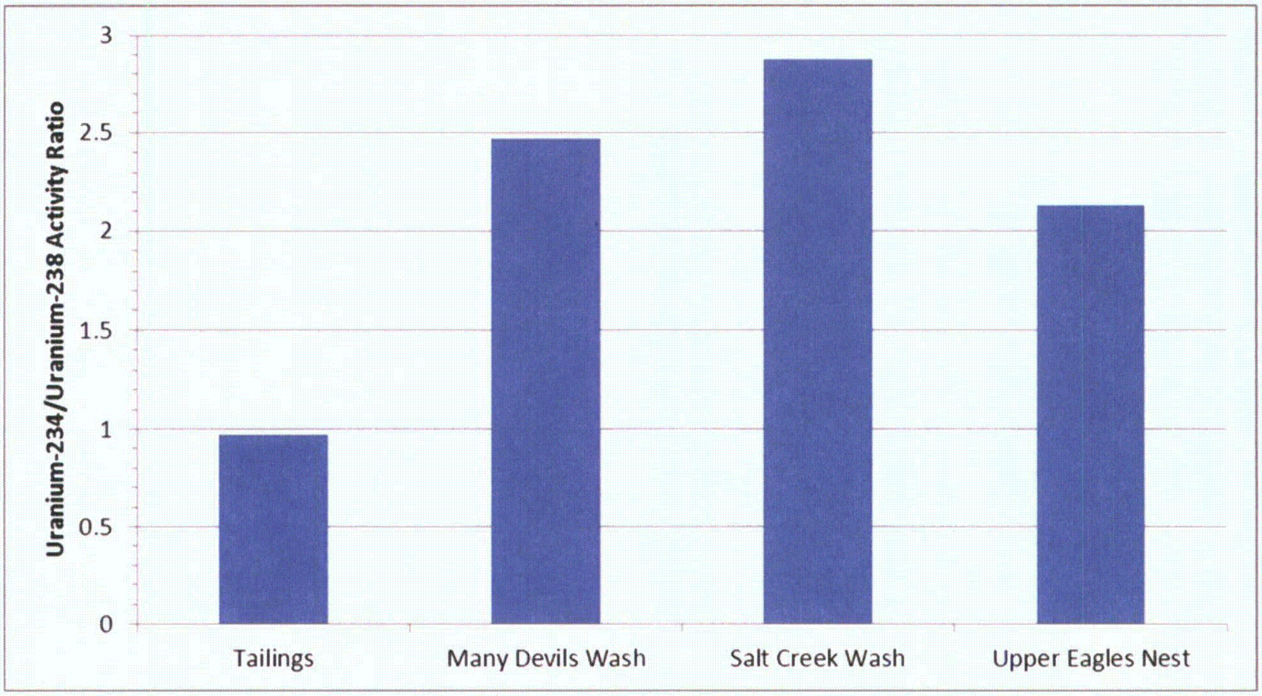


Figure 6. AR values of (1) groundwater wells contaminated by uranium mill tailings and (2) groundwater seeps in Many Devils Wash, Salt Creek Wash, and Upper Eagles Nest arroyos.

SUMMARY AND CONCLUSIONS

The same suite of contaminants is present in groundwater near former uranium processing sites and in groundwater seeps emanating from the Mancos Shale over a broad area. The concentrations of these contaminants in Many Devils Wash, located near LM's Shiprock disposal cell, are similar to those in samples collected from many Mancos seeps, including two analog sites that are 8 to 11 km from the disposal cell. Samples collected from Many Devils Wash and the analog sites have high AR values (about 2.0)—in contrast, groundwater samples collected near the tailings disposal cell have AR values near 1.0. These chemical signatures raise questions about the origin of the contamination seeping into Many Devils Wash.

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STATISTICAL METHODS USED TO

ESTABLISH BACKGROUND DATASETS USING SAMPLED DATA COLLECTED FROM DTLS, AND SURFACE AND SUBSURFACE SOILS OF THREE RBRAS OF THE TWO FORMATIONS

AND

COMPUTE ESTIMATES OF BACKGROUND THRESHOLD VALUES BASED UPON ESTABLISHED BACKGROUND DATASETS (WITH AND WITHOUT NONDETECT OBSERVATIONS)

FOR THE SANTA SUSANA FIELD LABORATORY INVESTIGATION

Prepared by

Anita Singh

October 2011

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1.0 INTRODUCTION

This appendix provides a brief description of the statistical and graphical methods that were used to: 1) establish background datasets using the surface and subsurface soils data collected from three radiological background reference areas (RBRA) from the Santa Susana (Bridle Path RBRA) and Chatsworth (Rocky Peak and Lang Ranch RBRAs) formations; and 2) compute estimates of the background level concentrations/background threshold values (BTV) based upon the established background datasets thus obtained. This appendix will also describe the process and methods used to establish defensible background datasets free of outliers (Section 2.0). Sectoion 3.0 describes the methods used (in this Background Study Report) to compute BTV estimates for datasets with nondetects (ND) and without NDs. Section 4.0 discusses an alternative approach to compute statistics of interest including BTV estimates based upon radionuclide datasets consisting of ND observations. The alternative approach uses ND values as detected observations.

Statistical software packages ProUCL 4.1 (U. S. Environmental Protection Agency [EPA], 2011) and Scout 1.1 have been used to perform statistical analyses as summarized in the various radionuclide evaluations (Appendix A) of this Draft Background Study Report for the Santa Susana Field Laboratory (SSFL).

In the present study, univariate BTVs have been computed for more than 50 radionuclides. For each radionuclide, many onsite observations will be compared with its respective BTV estimate. On-site observations exceeding BTVs may require re-sampling (including step-out sampling) and/or cleanup activities. Since on-site observations versus BTV comparisons will be performed for multiple contaminants, the use of multivariate statistical methods is better suited to provide a balance between false positive and false negative error rates (Singh and Nocerino, 1995). However, theory and methods associated with multivariate and robust statistical methods are quite complex; and therefore are beyond the scope of the current SSFL Background Evaluation Report. Using the multivariate methods on multiple contaminants perhaps divided into sub-groups of highly correlated radionuclides (e.g., all uranium, all thorium), one will be computing multivariate BTV estimates represented by multivariate simultaneous ellipsoids. An onsite vector observation (e.g., for thorium) lying within the ellipsoid can be considered as coming from the same background population; and vector observations lying outside the BTV ellipsoid potentially represent impacted locations requiring further investigations. A much lesser number of comparisons will be made when using multivariate methods; additionally multivariate methods take correlations among the various analytes into consideration. These multivariate methods are available in the EPA software package, Scout 2008 (EPA 2009). Statistical details of the robust univariate and multivariate methods are summarized in the Scout 2008 User Guide (EPA, 2009) and in Singh and Nocerino (1995).

To keep the document simple and understandable by all interested readers, the Project Team and the stakeholders decided to use well-known and well- adopted univariate methods as described in the existing environmental literature (e.g., EPA Guidance Documents, 1992, 2000, 2002, 2006, 2009). The advantage of using univariate methods is that these methods are described in most of the environmental text books (e.g., Gilbert 1987) and various guidance documents; and environmental scientists are familiar with these univariate methods.

As noted in the appendices summarizing statistical analyses and BTV computations for the various radionuclides, all background datasets collected from the three RBRAs are fairly consistent with low variability; and not many outliers were identified in those background datasets. Keeping these observations in mind, the Project Team recommends the use of the Bonferroni inequality based upper simultaneous limits (Section 3.0) as estimates of BTVs for the various radionuclides included in this Background Study Report for the SSFL.

2.0 STATISTICAL METHODS USED TO ESTABLISH BACKGROUND DATASETS BASED UPON THE SURFACE AND SUBSURFACE SOILS DATA COLLECTED FROM THE THREE RBRAS OF THE TWO FORMATIONS

For each radionuclide, the objective is to establish a defensible background data set represented by a "single" population free of outliers potentially representing impacted observations. There is some concern among the stakeholders that some of the chosen RBRA locations might have been impacted by the site activities; therefore all identified outliers will be excluded from the background data set. When data from the various strata could not be merged, separate BTV estimates were computed for each stratum.

This section describes statistical methods that have been used to establish background datasets based upon the data collected from the surface and subsurface soils of the three RBRAs. The established background datasets thus obtained have been used to compute estimates of the BTVs for the various radionuclides considered in this SSFL Background Study Report. Several steps were followed to assure that the datasets collected from the three RBRAs were representative of the site-specific background free of impacted locations (e.g., with elevated activities). A brief discussion of the step-by-step procedure used is described below.

In order to compute reliable and defensible estimates of BTVs, it is necessary that the background dataset represents a single statistical population; and the dataset does not consist of observations potentially representing the impacted locations (outliers). A well-established background dataset represents a single statistical population consisting of observations collected from unimpacted locations. For background datasets representing mixture populations, separate BTVs are computed for each individual population (e.g., RBRA). Observations representing potential outliers are not included in the computation of BTV estimates. It should be noted that various upper limits used to estimate BTVs are meant to provide coverage for population observations and not for any of the parameters (e.g., mean) of the sampled population. It is not appropriate to use upper confidence limit (UCL) of the mean as estimates of BTVs.

Whenever possible, statistical results are supplemented with formalized graphical displays. Graphical displays provide added insight (e.g., presence of outliers, data distributions and patterns, mixture populations, visual comparison of two or more groups) into datasets that is not possible to visualize and understand by reviewing the estimates and test statistics such as Dixon and Rosner outlier test statistics, WMW and ANOVA test statistics, and upper limits used to estimate BTVs.

Proper Identification of Outliers

Dixon and Rosner outlier tests require that the data set follows a normal distribution. However, it should be pointed out that the presence of moderate to extreme outliers (e.g., lying farther away from the tails of the normal distribution) destroys the normality of the data set. Therefore, one may not use Dixon and Rosner test to identify moderate to extreme outliers (lying outside the tails of a normal distribution) which are inevitable in environmental applications. Dixon (1953) and Rosner (1975) tests were developed when computing power that we have today was not available. These outlier tests are not meant to process complex environmental data sets as considered in this SSFL Radiological Background Report. Moreover, due to masking, these classical tests often fail to identify all outliers present in a data set. The Dixon test can be used on data sets of size ≤ 25 and the Rosner test can be used on data sets of size ≥ 25. The Rosner test requires the user to know the number of outliers that may be present in a data set. If an incorrect number of outliers are specified, the Rosner test may not be able to correctly identify all outliers present in a data set.

The use of modern computer intensive robust methods and graphical displays is recommended to properly identify all potential outliers present in environmental data sets. The use of Q-Q plots to assess data distributions and to identify outliers is quite common (Gnanadesikan, 1977; Hoaglin, Mosteller, and Tukey, 1983; Singh and Nocerino, 1995; Johnson and Wichern, 2002) in the statistical literature. As with all other tests used in this Report, Dixon and Rosner test results are also supplemented by graphical displays (e.g., Box plots and formal Q-Q plots). Graphical methods do not suffer from masking effects. Scout software equipped with robust outlier identification methods was used to verify the proper identification of outliers. However, due to the complexity of robust methods, results obtained using those robust methods are not included in this Report.

An example illustrating the issues associated with Dixon and Rosner tests is considered next. Advantages of using graphical and robust outlier identification methods are also discussed using the same data set.

Example. Consider a normally distributed data of size 20. The formal Q-Q plot (with Shapiro-Wilk test statistic) assessing the normality of the data set is shown in Figure 1 below. Next an outlier was added to this normally distributed data of size 20. Figure 2 has the normal Q-Q plot based upon the data set with the outlier. It is noted that the presence of even a single outlier causes the data set to be non-normally distributed. However, the Dixon test when used on the data set of size 21 identified the single outlier present in the data set. As mentioned earlier, the Dixon test suffers from masking and often fails to identify multiple outliers present in a data set. Next, a couple of more outliers are included in the data set. The Q-Q plot based upon 23 data points is shown in Figure 3. It is obvious from Figure 3 that there are 3 values which are well-separated from the rest of the data set and can be considered outlying with respect to the main dominant population represented by the original data set of size 20.

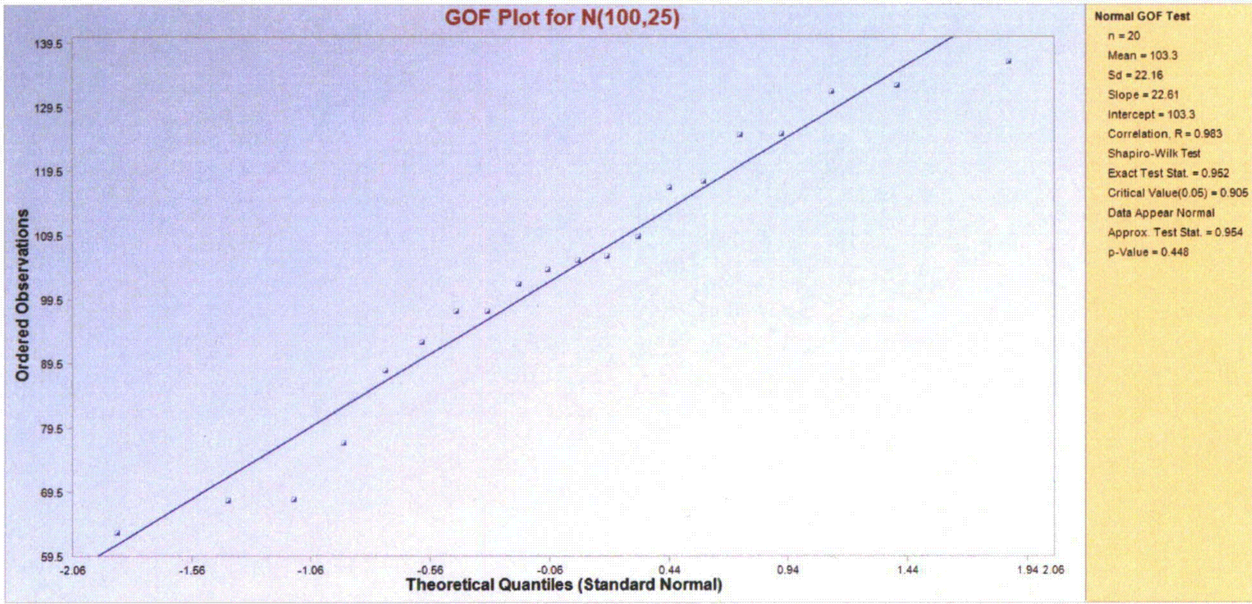

Figure 1. Formal Q-Q plot with Shapiro-Wilk Test Results - Assessing Normality of the Data Set.

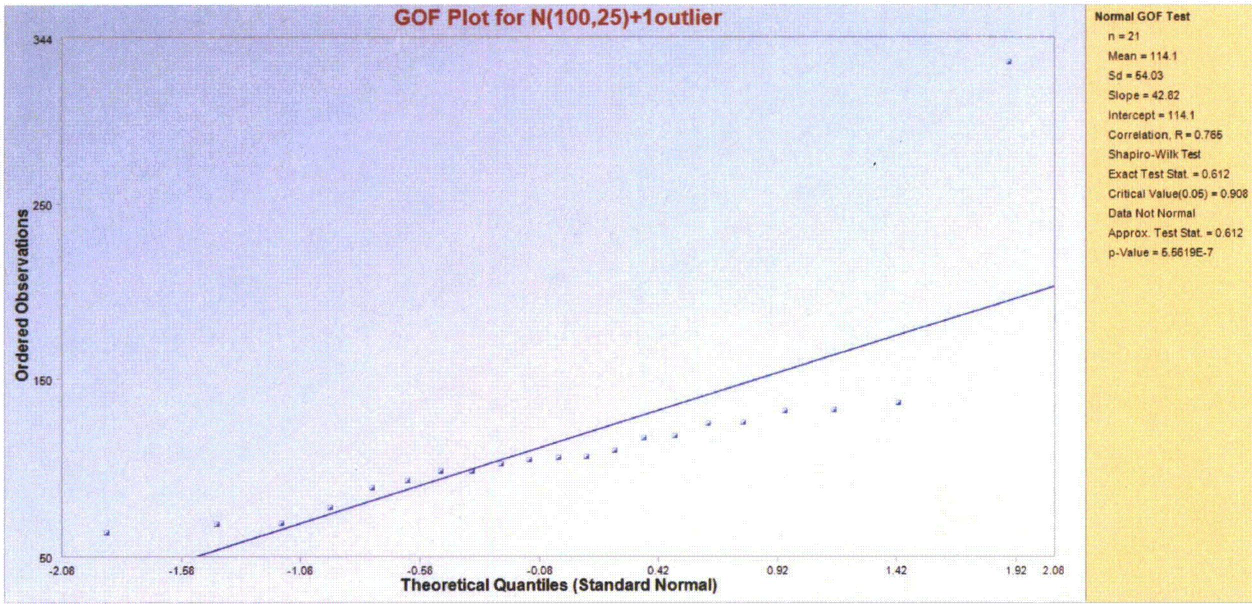

Figure 2. Formal Q-Q plot with Shapiro-Wilk Test Statistic and Indentifying Outliers Present in the Data Set.

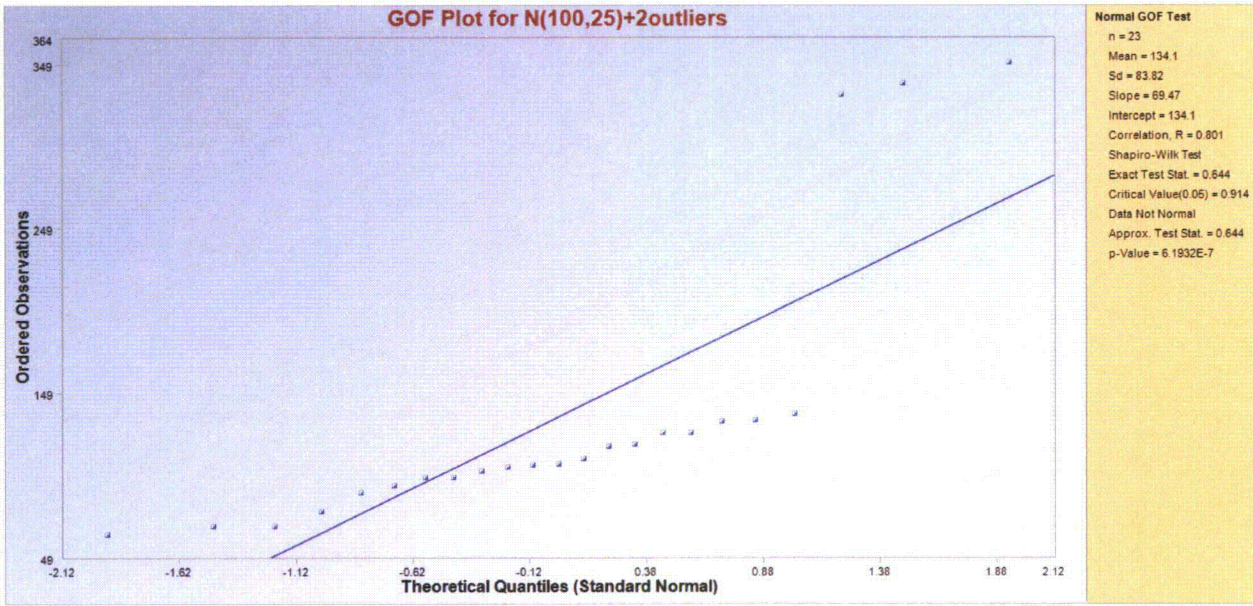

Figure 3. Formal Q-Q plot with Shapiro-Wilk Test Statistic and Indentifying Outliers Present in the Data Set.

Dixon Test Results on Data Set Used in Figure 3

Dixon's Outlier Test for N(100,25)+3outliers

Mean 134.1
Standard Deviation 83.82

Number of data = 23
10% critical value: 0.374
5% critical value: 0.421
1% critical value: 0.505

1. 349.8921 is a Potential Outlier (Upper Tail)

Test Statistic: 0.070

For 10% significance level, 349.8921 is not an outlier.
For 5% significance level, 349.8921 is not an outlier.
For 1% significance level, 349.8921 is not an outlier.

2. 63.1259374598842 is a Potential Outlier (Lower Tail)

Test Statistic: 0.019

For 10% significance level, 63.1259374598842 is not an outlier.
For 5% significance level, 63.1259374598842 is not an outlier.
For 1% significance level, 63.1259374598842 is not an outlier.

Due to masking, the Dixon test failed to identify the 3 outliers present in the data set. The Rosner test cannot be used on this data set as the number of observations in this data set is less than 25. The graphical Q-Q plot shown in Figure 3 successfully identifies the 3 outliers (well-separated from the main dominant data set) present in the data set. Today, modern robust statistical methods (e.g., Rousseeuw and Leroy, 1987; Rousseeuw and van Zomeren, 1990; Singh and Nocerino, 1995; Rousseeuw and van Driessen, 1999; Maronna, Marin and Yohai, 2006) are used to identify multiple outliers. Several commercial software packages (e.g., SAS, SPSS) are equipped with the robust estimation and outlier identification methods. Several of the robust methods are available in the EPA software package Scout 2008 (EPA 2009). Using the PROP influence function method of the Outlier Module of the Scout 2008 software (Singh, 1993), the three outliers present in the data set are identified. The formal Index Plot identifying all of the outliers present in the data set is shown in Figure 4. The details of these methods can be found in the User Guide for Scout 2008 (EPA 2009).

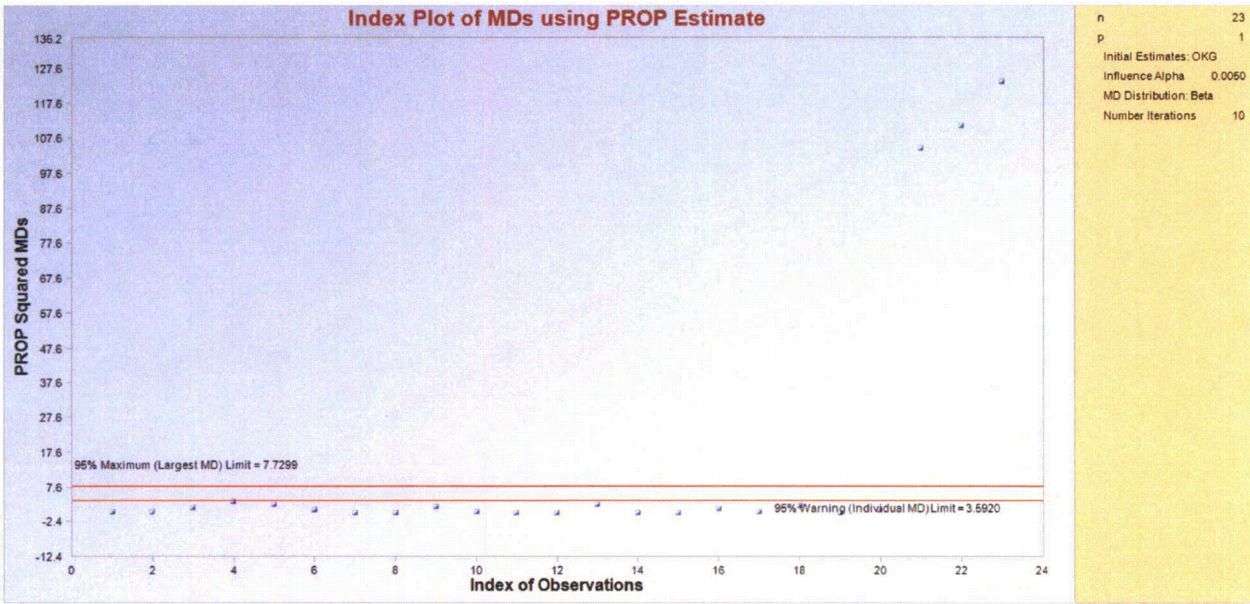

Figure 4. Formal Index Plot with Critical Value of the Test Statistic (Largest Mahalanobis Distance = Largest MD) Identifying the 3 Outliers Present in the Data Set

Use of Log-transformation was avoided

Statistical analysis including outlier tests and hypothesis testing approaches were performed on datasets in the original raw scale (non-transformed dataset) as the remediation and cleanup decisions need to be made using data and statistics (e.g., tolerance limits, prediction limits) in the original scale. Often, the use of a log-transformation tends to hide contamination by accommodating outlying observations (Singh et al., 1997; EPA, 2010b) as part of the dataset. For an example, an outlier in the raw scale may not appear to be an outlier in the transformed space (e.g., log-scale). This does not imply that the outlier (e.g., an elevated RBRA concentration in the original scale) identified in the original scale represents a clean unimpacted location and can be included in the computation of a BTV, estimated by upper prediction limit (UPL)/upper tolerance limit (UTL). Furthermore, since environmental decisions need be made based upon the values of statistics (e.g., UPL, t-test, Wilcoxon Rank Sum [WRS] test statistic) in the original scale, all transformed test statistics computed using log-transformation need to be back-transformed in the original scale. The transformation and back-transformation process yields statistics which suffer from an unknown amount of transformation bias.

Comparing DTL Data with Data Collected from the Three RBRAs
For select radionuclides (cobalt-60, cesium-137, plutonium-238, plutonium-239/240, strontium-90), surface soil datasets were collected from the 20 distant test locations (DTL). One of the objectives of this effort was to determine if the selected RBRAs represent unimpacted background locations. Specifically, surface soils data collected from the DTLs were compared with the surface soils data collected from the three RBRAs to determine if the sampling locations of the three RBRAs represent unimpacted background locations.

In this process, the first step was to identify high outlying observations potentially present in the combined surface soil dataset from the DTLs and the two formations/three RBRAs. Outliers (if any) were removed before comparing concentrations of DTLs and the three RBRAs. In addition to graphical Quantile-Quantile (Q-Q) plot, Rosner and Dixon outlier tests were used to identify high outliers potentially representing impacted locations. The details of these graphical and outlier tests can be found in ProUCL 4.00.05 Technical Guide (EPA, 2010b), *Data Quality Assessment: Statistical Methods for Practitioners* (EPA, 2006), and *Statistical Methods for Environmental Pollution Monitoring* (Gilbert, 1987).

In order to compare radionuclide activities of the three regions, DTLs and two formations, both graphical and statistical methods were used. Graphical methods used include side-by-side box plots and multiple Q-Q plots (details in the ProUCL 4.00.05 Technical Guide, 2010b), and statistical methods used include two-sample hypothesis tests and Oneway Analysis of Variance (ANOVA) test (EPA, 2000; EPA, 2002; EPA, 2006; EPA, 2009). Before computing BTV estimates based upon the established background data sets, Goodness-of-fit (GOF) tests were used to determine data distributions of the established background data sets. Depending upon the data distribution, appropriate parametric or nonparametric methods were used to compute estimates of BTVs. GOF tests as incorporated in ProUCL 4.1 (EPA, 2011) were used to determine distributions (normal, gamma, and lognormal) of the various datasets collected from the DTLs and three RBRAs. All GOF test statistics are supplemented with Q-Q plots which are commonly used to assess data distributions. The detailed description of the GOF tests, two-sample hypothesis tests, and Oneway ANOVA test used in this Background Evaluation Report are given in the ProUCL 4.00.05 Technical Guide (EPA 2010b).

Specifically, the two sample parametric t-tests (when applicable), nonparametric WRS or Wilcoxon Mann-Whitney (WMW) tests, Quantile tests, and Gehan tests were used to compare radionuclide concentrations of the: two formations, two RBRAs of the Chatsworth formation, and surface and subsurface soils of the three RBRAs and two formations. In some cases, for the verification of results and conclusions, more than one statistical method was used on the same dataset. Depending upon the data distribution, parametric and nonparametric methods were used to compare concentrations of two or more populations. Appropriate parametric (e.g., Student's t-test) or nonparametric (e.g., WMW) two-sample hypothesis tests were used to compare activities of two populations (e.g., DTLs versus Santa Susana, Santa Susana versus Chatsworth). For datasets with NDs, the Gehan test was used to compare concentrations of two populations. Appropriate parametric or nonparametric (e.g., Kruskal-Wallis test) Oneway ANOVA tests were used to compare concentrations of three (e.g., DTLs, Santa Susana, and Chatsworth) or more (e.g., DTLs versus three RBRAs) groups. Once it was determined that the concentrations of the selected RBRAs are comparable to those of DTLs, it is concluded that the selected RBRAs (without outlying locations) indeed represent defensible site-specific unimpacted background locations.

Comparing Concentrations/Activities of Six Individual Datasets: Surface and Subsurface Soils of the Three RBRAs

Defensible background datasets free of outliers (potentially representing impacted locations) were established for the various radionuclides using the surface and subsurface soil data collected from the three RBRAs. Datasets collected from the various areas (e.g., surface and subsurface soils of three RBRAs) were compared to establish statistically/numerically different background populations. Separate BTV estimates were computed for each population (e.g., two different populations represented by surface and subsurface soils).

- Using the ProUCL 1.1 software, outliers were identified first in the combined dataset collected from the surface and subsurface soils of the three RBRAs. All identified outliers (if any) were removed from the combined dataset. It is noted that for most of the radionuclides, the datasets from the three RBRAs are fairly consistent and tight (with small variations) and do not consist of any outliers. These observations guided the Project Team to use more appropriate upper simultaneous limits (USL) to estimate BTVs (see Section 3.0 for details).

- To determine how many BTVs would need to be computed for each radionuclide, data from the six datasets (surface and subsurface soils of each of the three RBRAs) were compared using the hypothesis and ANOVA tests as described in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (EPA, 2000) and EPA guidance documents (2002; 2006; 2010b).

- Surface and subsurface activities of the two formations were compared first.

    - Graphical and two sample hypothesis tests (t-test, WMW test, and Gehan test) were used to perform these comparisons.

    - If surface and subsurface activities are determined to be comparable, the Project Team may decide to use a single BTV estimate based upon the combined surface and subsurface dataset. The details of the methods used to compute estimates of BTVs are summarized in Section 3.0 of this appendix.

- If radionuclide activities in surface and subsurface soils of the two formations are determined to be different, concentrations of the three RBRAs were compared separately for surface and subsurface soils.

    - Graphical displays (box plots and Q-Q plots) and Oneway ANOVA tests were used to perform these comparisons.

    - If radionuclide activities in surface/subsurface soils of the three RBRAs are determined to be not comparable, radionuclide activities in surface/subsurface soils of Lang Ranch and Rocky Peak RBRAs of Chatsworth were compared.

- o If radionuclide activities in surface/subsurface soils of Lang Ranch and Rocky Peak are comparable, then one BTV estimate may be used for the surface/subsurface soils of the Chatsworth Formation (combined Lang Ranch and Rocky Peak data), and one BTV estimate may be used for the surface/subsurface soils of the Santa Susana Formation (Bridle Path).

- o In case radionuclide activities in the six datasets are not comparable, six BTV estimates may be used, one for each dataset.

3.0 STATISTICAL METHODS USED TO ESTIMATE BACKGROUND THRESHOLD VALUES BASED UPON ESTABLISHED BACKGROUND DATASETS WITH AND WITHOUT NONDETECT OBSERVATIONS

This section details the statistical methods and limits that have been used to estimate BTVs for the various radionuclides based upon well-established background datasets collected from the three background reference areas (Bridle Path, Lang Ranch, and Rocky Peak) of the two formations: Santa Susana and Chatsworth. Methods used to establish background datasets were described in Section 2.0.

Typically, in background evaluation and comparison studies, site-specific background level contaminant concentrations (data) are used to compare on-site concentrations with background level contaminant concentrations. These BTVs are estimated based upon well-established background datasets. Methods used to establish background datasets are summarized in Section 2.0 of this appendix. An onsite observation exceeding a BTV may be viewed as potentially coming from an impacted site area not belonging to the background population.

Let $x_1, x_2, \ldots, x_n$ represent a well-established background dataset of size n for a contaminant (e.g., cesium-137) collected randomly from some site-specific background/reference area. The objective is to estimate a BTV based upon this dataset. It should be pointed out that BTV estimates based upon parametric methods (e.g., normal, gamma distribution based) account for the variability present in the dataset; whereas nonparametric limits are based upon order statistics and, therefore, do not take data variability into consideration. It is also noted that nonparametric estimates of BTVs based upon order statistics (e.g., largest value, second largest value) tend to under estimate the background statistics, especially when the sample size is small (e.g., less than 60 samples). For an example, a nonparametric UTL95-95 or USL95 may not provide desired/specified confidence coefficient 0.95.

The sample mean and sample standard deviation are given as follows:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

The sample values are arranged in ascending order. The resulting ordered sample (called ordered statistics) is denoted by $x_{(1)} \leq x_{(2)} \leq \ldots \leq x_{(n)}$. The ordered statistics are used as nonparametric estimates of upper percentiles, UPLs, UTLs, and USLs. Let y_i = ln (x_i); i = 1, 2, ... , n, then $\bar{y}$ and s_y represent the mean and standard deviation (*sd*) of the log-transformed data. Once the data distribution of a background dataset has been determined, one can use parametric or nonparametric statistical methods to compute estimates of BTVs based upon the background dataset. Depending upon the sample size, data distribution and data variability, one of the following upper limits (EPA, 2011 [ProUCL 4.1]; Scout, 2008 [Version 1.0]; Singh and Nocerino, 1997) can be used to estimate BTVs.

Based upon well-established datasets collected from the three RBRAs of the two formations, the following limits have been computed:

- Upper percentiles
- UPLs
- UTLs
- USLs

Choosing a Confidence Coefficient (CC)

- Higher statistical limits are associated with higher levels of the confidence coefficient (CC). For an example, a 95% UPL is larger than a 90% UPL.

- Higher values of CC (e.g., 99%) tend to decrease the power of a test resulting in higher number of false negatives - dismissing contamination when present.
  Therefore, CC should not be set higher than necessary.

- Smaller values of CC (e.g., 0.80) tend to result in higher number of false positives (e.g., declaring contamination when not present).

- In most practical applications, choice of 95% CC provides a good compromise between confidence and power.

Sample Size

- Smaller sample sizes (e.g., fewer than 30 samples) tend to yield estimates with higher variabilities; which in turn result in higher values of USLs, UTLs and UPLs.

- Higher level of uncertainty in a background dataset (e.g., due to a smaller background dataset) tends to dismiss contamination as representing background conditions (results in more false negatives, i.e., identifying a location that may be dirty as background).

Parametric and Nonparametric Statistical Limits used to Estimate BTVs Based Upon Data without Nondetect Observations

In this background study report, 95% CC has been used to compute various upper limits to estimate BTVs, also, UTLs have been computed for the 95th percentile (coverage coefficient = 0.95). Depending upon the data distribution, both parametric and nonparametric methods have been used to estimate BTVs. For parametric methods, BTV estimates have been computed for normal, lognormal, and gamma distributions.

Upper Percentiles to Estimate BTV: Based upon an established background (e.g., RBRA) dataset, the 95th percentile ($x_{0.95}$) represents an estimate of the 95th percentile of the background population. It is expected that 95% of values coming from the background population will be less than or equal to $x_{0.95}$. By definition, about 5% of observations from the background dataset will exceed $x_{0.95}$.

If the distributions of the site data and the background data are comparable, then an observation coming from a population (e.g., site) comparable to that of the background population should lie at or below the p*100% percentile, with probability p.

Normal distribution based p*100th sample percentile is given by the following statement:

$$\hat{x}_p = \bar{x} + s z_p$$

Here z_p is the p*100th percentile of a standard normal, N (0, 1) distribution, which means that the area (under the standard normal curve) to the left of z_p is p.

Interpreting 95% Percentile

- If one uses 95% percentile to estimate BTV, at least 5% of the on-site observations with concentrations comparble to background will be determined as not belonging to the background population even when they actually come from the background population.

- If an on-site value (x_{onsite}) exceeds background $x_{0.95}$, it may be concluded that x_{onsite} does not belong to the background population.

- The use of 95% percentile to estimate BTV potentially may lead to a higher number of false positives resulting in unnecessary cleanup (i.e., determining a clean on-site location comparable to background as dirty).

Upper Prediction Limits and Upper Tolerance Limits to Estimate BTV
Unlike upper percentiles, UPLs and UTLs provide predictive setup for future observations.

Upper Prediction Limits
UPLs can be computed for 1 or more future observations (e.g., future on-site values). Let UPL_k 95 represent a 95% UPL for k *(≥1)* future observations. A UPL_k 95 is designed to provide coverage for k future observations with CC 0.95.

95% Upper Prediction Limit ($UPL_1$95): The $UPL_1$95 is based upon a background dataset is designed to compare a *single future* observation with $UPL_1$95. We are 95% sure that a *"single"* future value from the background population will be less than or equal to $UPL_1$95 with a CC of 0.95. If an on-site value, $x_{onsite} < UPL_1$95, it is interpreted that x_{onsite} (=future value) comes from the background population with a CC of 0.95. A $UPL_1$95 is not meant to perform more than 1 future comparison.

Normal distribution: A normal distribution based $UPL_l(1-\alpha)100\%$ for a *single future* observation is given by the following probability statement:

$$P\left(x_0 \le \bar{x} + t_{((1-\alpha),(n-1))} s\sqrt{1+\frac{1}{n}}\right) = 1-\alpha \text{, with } UPL_l 95 = \left(\bar{x} + t_{((1-0.05),n-1)} s\sqrt{1+\frac{1}{n}}\right)$$

Here $t_{((1-\alpha),(n-1))}$ is a critical value from Student's t-distribution with (n–1) degrees of freedom.

Interpreting UPL_l95

- An on-site value (x_{onsite}) exceeding UPL_l95 potentially represents a value not belonging to the background population.
- UPLs are useful when a background dataset is of smaller size (e.g., fewer than 20 to 30 samples); and/or a few and known number of future observations are to be compared with a UPL.

Improper Use of UPL_l95 to Perform Many Future Comparisons
In practice, users tend to use UPL_l95 for many future comparisons which results in a higher number of false postives (observations declared contaminated when in fact they are clean). When k future comparisons are made with a UPL_l, some of those future observations will exceed UPL_l just by chance, each with probability 0.05. For proper comparison, UPLs need to be computed according to the number of comparisons that will be performed.

In order to achieve the specified false rejection rate of 0.05, we need to take the number of future comparisons into account; for a false positive error rate, α, UPL_k for k future observations should be used to estimate the BTV when k comparisons are to be performed with the BTV.

If many (as is the case in the present study) independent onsite comparisons (e.g., plutonium-238 activity from 30 on-site locations) are made with the same UPL_l, each on-site value may exceed that UPL_l with probability 0.05 just by chance. The overall probability of at least one of those 30 comparisons being significant (exceeding BTV) just by chance is:

$\alpha_{actual} = 1-(1-\alpha)^k = 1 - 0.95^{30} \sim 1-0.21 = 0.79$ (false positive rate).

This means that the probability (overall false positive rate) is 0.79 that at least one of the 30 on-site locations will be considered contaminated even when they are comparable to background.

Similar arguments hold when multiple ($=m$) contaminants are analyzed, and status (clean or impacted) of an on-site location is determined based upon m comparisons (one for each analyte).

UPL_k for k Future Comparisons

95% Upper Prediction Limit (UPL_k95) with k≥1 is designed to compare *k future* observations with UPL_k95. We are 95% sure that *"k"* future values from the background population will be less than or equal to UPL_k95 with a CC of 0.95. A UPL_k95 is meant to perform k future comparisons. A UPL_k uses an appropriate critical value (based upon Bonferroni inequality) to accommodate k future observations/comparisons. These UPLs statisfy the relationship: $UPL_1 \leq UPL_2 \leq UPL_3 \leq \ldots \leq UPL_k \ldots$

Normal distribution based UPL_3 for three future observations: x_{01}, x_{02}, x_{03} is given by:

$$P\left(x_{01}, x_{02}, x_{03} \leq \bar{x} + t_{((1-\alpha/3),n-1)} s\sqrt{1+\frac{1}{n}}\right) = 1-\alpha \text{ With } UPL_3 95 = \left(\bar{x} + t_{((1-0.05/3),n-1)} s\sqrt{1+\frac{1}{n}}\right)$$

Normal distribution based UPL_k for k future observations is given by:

$$P\left(x_{01}, x_{02}, \ldots, x_{0k} \leq \bar{x} + t_{((1-\alpha/k),n-1)} s\sqrt{1+\frac{1}{n}}\right) = 1-\alpha \text{ With } UPL_k 95 = \left(\bar{x} + t_{((1-0.05/k),n-1)} s\sqrt{1+\frac{1}{n}}\right)$$

Upper Tolerance Limit (UTL): A UTL *(1-α)-p* (e.g., UTL95-95) based upon an established background dataset represents that limit such that *p%* of the sampled data will be less than or equal to UTL with a CC of (1-α). It is expected that p% of the observations belonging to the background population will be less than or equal to UTL with CC of (1-α). A UTL *(1-α)-p* represents a *(1-α) 100%* upper confidence limit for the p^{th} percentile of the underlying background population.

A UTL95-95 represents that statistic such that 95% observations from the target population (e.g., background) will be less than or equal to UTL95-95 with a CC of 0.95. UTL95-95 is designed to simultaneously provide coverage for 95% of all potential observations (current and future) from the background population with a CC of 0.95. UTL95-95 can be used to perform many on-site comparisons.

Normal Distribution Based UTLs: For normally distributed datasets, an upper *(1-α)*100%* tolerance limit with tolerance or coverage coefficient = p (that is providing coverage to at least p100% proportion of observations) is given by the following statement:

$$UTL = \bar{x} + K * s$$

Here, $K = K(n, \alpha, p)$ is the tolerance factor and depends upon the sample size, n, confidence coefficient = $(1-\alpha)$, and the coverage proportion = p. The values of the tolerance factor, K, have been tabulated extensively in the various statistical books (Hahn and Meeker, 1991). Those K values are based upon non-central t-distributions. Also, some large sample approximations (Natrella, 1963) are available to compute the K values for one-sided tolerance intervals (same for both UTLs and lower tolerance limit). The approximate value of K is also a function of the sample size, n, coverage coefficient, p, and the CC $(1-\alpha)$. In the ProUCL 4.1 software package, the values of K for samples of sizes ≤ 30, as given in Hahn and Meeker (1991) have been directly programmed. For sample sizes larger than 30, the large sample approximations, as given in Natrella (1963), have been used to compute the K values.

Interpreting UTL95-95

- UTL95-95 based upon a background dataset is that value which will be exceeded by all values potentially coming from the background population less than 5% of the time with confidence coefficient 0.95.

- For a UTL95-95, five exceedances per 100 comparisons (of background values) can result just by chance for an overall CC of 0.95; or 5% exceedances (in any number of comparisons) can occur just by chance with an overall CC of 0.95. Similarly, for UTL95-99, 1 exceedance per 100 comparisons can result just by chance for an overall CC of 0.95.

- Just like UPLs, a parametric UTL takes variability into account.

- When sample size is large (e.g., 500), UTL95-95 approaches the upper 95th percentile; UTL90-90 will approach the upper 90th percentile.

- Use of UTL95-95 is preferred to $UPL_1 95$ when the number of future comparisons is large and/or unknown.

Upper Simultanenous Limit (USL): A $(1-\alpha)100\%$ USL based upon an "established" background dataset is meant to provide coverage for all observations, x_i, $i = 1, 2, n$ simultaneously in the background dataset. A USL95 represents that statistic such that all observations from the "established" background dataset will be less than or equal to USL95 with a CC of 0.95. It is expected that observations coming from the background population will be less than or equal to USL95 with 95% CC. A USL95 can be used to perform many on-site comparisons.

Normal distribution based the two-sided $(1-\alpha)100\%$ simultaneous interval based upon the first order Bonferroni inequality (Singh and Nocerino, 1995; Singh and Nocerino, 1997) is given as follows:

$$P\left(\bar{x} - sd_\alpha^b \le x_i \le \bar{x} + sd_\alpha^b; i := 1,2,...,n\right) = 1 - \alpha .$$

Here, $(d_\alpha^b)^2$ represents the critical value (obtained using the Bonferroni inequality) of the maximum Mahalanobis distance (Max MD) for α level of significance (Singh and Nocerino, 1995; Singh, 1996).

In order to maintain proper balance between false positives and false negatives, the use of USL95 was proposed to estimate BTVs based upon well-established background data sets free of outliers. It should be noted that a USL95 has a built-in outlier identification test (Wilks, 1963; Gnanadesikan, 1977; Barnett and Lewis, 1994; Singh and Nocerino, 1997). This means that observations lying above a USL95 potentially represent outliers not belonging to the main background population.

Inclusion of outliers in background data sets will yield inflated estimates of BTVs including USL95 values. The use of USL95 already addresses the issue of increased number of false positives. To control the number of false negatives, it is recommended not to include moderate to extreme outliers in the computation of USL95. USL95 should be computed based upon a data set representing the main dominant background population; it is not desirable to accommodate a few outliers in the computation of USL95 resulting in inflated USL95.

Normal distribution based one-sided $(1-\alpha)100\%$ USL is given by:

$$P\left(x_i \leq \bar{x} + sd_{2\alpha}^{b}; i := 1,2,...,n\right) = 1-\alpha \ ;$$

$$\text{USL} = \bar{x} + d_{2\alpha}^{b} * s_x$$

Here $(d_{2\alpha}^{b})^2$ is the critical value of the Max MD for $2*\alpha$ level of significance.

Interpreting USL95

In layman's terminology, a USL95 provides coverage to all observations (current and future) coming from the same background population with probability 0.95. Depending upon the data variability, some observations (current and future) will exceed USL95 with probability 0.05. The computation of USL95 depends upon the sample size, data mean and variability, and the critical value of the test statistic used. Sample values (e.g., maximum value) exceeding USL95 potentially represent extreme values and may not be considered as coming from the background population.

- A USL95 based upon an established background dataset represents that estimate of BTV such that *all* observations in the background dataset are less than or equal to USL95 with 95% CC.

- It is expected that observations coming from that background population will be less than or equal to USL95 with a 95% CC.

- A USL can be used when many (and/or unknown) future on-site observations need to be compared with BTV.

- For an analyte, the false positive error rate does not change with the number of comparisons, as USL95 is meant to perform many comparisons simultaneously. The use of USL95 is preferred when many comparisons need to be performed.

If BTVs are to be computed based upon the background data sets incorporating data variability, it is suggested to use USL95 as computed based upon the data set without using biased judgment about the data set and the computed statistics.

Other parametric (e.g., lognormal and gamma) and nonparametric limits used to estimate BTVs are described as follows.

Lognormal Distribution Based Upper Limits

Lognormal Percentiles: Lognormal $p*100^{th}$ percentile is given by the following statement:

$$\hat{x}_p = \exp(\bar{y} + s_y z_p)$$

Where, z_p is the upper $p*100^{th}$ percentile of a standard normal, N(0,1), distribution.

Lognormal UPLs: An upper (1 – α)*100% lognormal UPL is given as follows:

$$\text{UPL} = \exp(\bar{y} + t_{((1-\alpha),(n-1))} * s_y * \sqrt{(1+1/n)})$$

As before, $t_{((1-\alpha),(n-1))}$ represent the critical value from Student's t-distribution with (n–1) degrees of freedom.

Lognormal UTLs: The procedure to compute UTLs for lognormally distributed datasets is similar to that for normally distributed datasets. The sample mean, $\bar{y}$, and standard deviation (sd), s_y, of the log-transformed data are computed using a defensible unique background dataset without outliers. An upper (1 – α)*100% tolerance limit with tolerance or coverage coefficient = p (that is, providing coverage to at least p100% proportion of observations) is given by the following statement:

$$\text{UTL} = \exp(\bar{y} + K * s_y)$$

Just like the normal distribution, the UTL given above represents a (1-α)*100% confidence interval for the p^{th} percentile of the lognormal distribution. The critical value, K used to compute the UTL is the same as the one used to compute the normal UTL.

Lognormal USL: An upper (1 – α)*100% lognormal USL is given by the following equation:

$$\text{USL} = \exp(\bar{y} + d_{2\alpha}^{b} * s_y)$$

Here $(d_{2\alpha}^{b})^2$ is the critical value of the Max MD for $2*\alpha$ level of significance as described earlier.

Gamma Distribution Based Upper Limits

Positively skewed environmental data can often be modeled by a gamma distribution (Singh et al., 2002). ProUCL 4.1 software has two goodness-of-fit tests (Anderson-Darling test and Kolmogorov-Smirnov test) to test for gamma distribution. UPLs and UTLs obtained using normal approximation to the gamma distribution (Krishnamoorthy et al., 2008) have been incorporated in ProUCL 4.1. Those approximations are based upon Wilson-Hilferty - WH (1931) and Hawkins-Wixley - HW (1986) approximations.

- According to WH approximation, the transformation, $Y = X^{1/3}$ follows an approximate normal distribution.

- According to HW approximation, the transformation, $Y = X^{1/4}$ follows an approximate normal distribution

In the following, $\bar{y}$ and s_y are the mean and standard deviation of the observations in the transformed scale (Y) defined above.

Gamma Distribution Percentiles: The details of computing percentiles of a gamma distribution, $G(k, \theta)$ can be found in the ProUCL 4.00.05 Technical Guide (2010b). Let $y_{(\alpha\ 2k)}$ represent the α*100th percentile of the chi-square distribution with $2k$ degrees of freedom. The α*100% percentile for a gamma distribution can be obtained by using the equation:

$$x_\alpha = y_\alpha * \theta / 2$$

Gamma Distribution Based UPLs: Given a sample, $x_1, x_2, \ldots, x_n$ of size n from a gamma, G(k, θ) distribution, approximate (based upon WH and HW approximations) $(1-\alpha)*100\%$ upper prediction limits for a future observation from the same gamma distribution are given by:

$$\text{Wilson-Hilferty (WH) UPL} = \max\left(0, \left(\bar{y} + t_{((1-\alpha),(n-1))} * s_y * \sqrt{1 + \tfrac{1}{n}}\right)^3\right)$$

$$\text{Hawkins-Wixley (HW) UPL} = \left(\bar{y} + t_{((1-\alpha),(n-1))} * s_y * \sqrt{1 + \tfrac{1}{n}}\right)^4$$

$t_{((1-\alpha),(n-1))}$ is the critical value from Student's t-distribution with $(n-1)$ degrees of freedom. The UPLs for the next k>1 (k future observation) can be obtained similarly and have been incorporated in ProUCL 4.1.

Gamma Distribution Based UTLs: Using the WH approximation, the gamma UTL based upon a sample of size n (in original scale, X), is given by:

$$UTL = \max\left(0, \left(\bar{y} + K * s_y\right)^3\right)$$

Similarly, using the HW approximation, the gamma UTL in original scale is given by:

$$UTL = \left(\bar{y} + K * s_y\right)^4$$

Here K represents the same cutoff value as used for normal and lognormal distributions.

Gamma Distribution Based USLs: Given a sample, $x_1, x_2, \ldots, x_n$ of size n from a gamma, G(k, θ) distribution, approximate (based upon WH and HW approximations) $(1-\alpha)*100\%$ upper simultaneous limit is given by:

$$\text{Wilson-Hilferty (WH) USL} = \max\left(0, \left(\bar{y} + d_{2\alpha}^{b} * s_y\right)^3\right)$$

Hawkins-Wixley (HW) USL = $\left(\bar{y} + d_{2\alpha}^{b} * s_y\right)^4$

Here $(d_{2\alpha}^{b})^2$ is the critical value of the Max MD for $2*\alpha$ level of significance.

Nonparametric Upper Limits

When the background dataset does not follow a discernable distribution, nonparametric methods have been used to estimate BTVs as described below.

Upper Percentile: Details can be found in the ProUCL Technical Guide (EPA, 2010b). It is noted that the nonparametric 95% percentile ($x_{0.95}$) does not take variabilities of future observations coming from the background population into account.

Nonparametric Upper Prediction Limits: A one-sided nonparametric UPL is simple to compute and is given by the following mth order statistic. One can use linear interpolation if the resulting number, m, given below does not represent a whole number (a positive integer).

$$\text{UPL} = X_{(m)}, \text{ where } m = (n + 1) * (1 - \alpha).$$

For example, for a nonparametric dataset of size 25, a 90% UPL is desired. Then m = (26*0.90) = 23.4. Thus, a 90% nonparametric UPL can be obtained by using the 23rd and the 24th ordered statistics and is given by the following equation:

$$\text{UPL} = X_{(23)} + 0.4 * (X_{(24)} - X_{(23)})$$

Nonparametric Upper Tolerance Limits: The computation of nonparametric UTLs is somewhat messy as it is based upon binomial cumulative probabilities and order statistics. Just like parametric UTLs, a nonparametric UTL is supposed to provide coverage to p*100% observations from the target population with a specified CC. It is noted that nonparametric UTLs (computed by order statistics) cannot exactly achieve the specified confidence coefficient (1-α). In most cases, only an approximate CC can be achieved by nonparametric UTLs. One has to be satisfied with the achievable CC, which is as close as possible to the specified CC of (1-α). Thus, an appropriate UTL is chosen which provides coverage for the p^{th} percentile as close as possible to the specified CC of (1-α). The details about the computation of nonparametric UTLs can be found in ProUCL 4.00.05 Technical Guide (2010b), Conover (1999), Gogolak et al. (1998), David and Nagaraja (2003), and Hahn and Meeker (1991).

Nonparametric Upper Simultaneous Limit: A nonparametric USL is estimated by the largest value of the dataset.

Statistical Limits used to Estimate BTVs Based Upon Dataset Consisting of Nondetect / Below Detection Limit Observations

For datasets consisting of NDs with multiple detection limits or minimum detectable concentrations (MDC), several estimation methods including the maximum likelihood (MLE) method, Kaplan-Meier (KM) method, bootstrap methods, regression on order statistics (ROS) methods, and substitution methods are available in ProUCL 4.1 (EPA, 2011) and Scout 2008 Version 1.0 (EPA, 2009) software packages. In this study, the preferred KM method (Helsel, 2005; Singh et al., 2006; Kaplan and Meier, 1958) has been used to compute estimates of BTVs.

The details of the various estimation methods including the KM method can be found in the ProUCL 4.00.05 Technical Guide (EPA, 2010b), Singh et al. (2006), and Helsel (2005). A brief description of the KM method and various limits used to estimate BTVs based upon the KM method is given as follows. ProUCL 4.1 and Scout software packages have been used to generate graphical displays and compute the various BTV estimates based upon datasets consisting of ND observations.

Nonparametric Kaplan-Meier (KM) Estimation Method

Practitioners (Helsel, 2005; Singh et al., 2006) and EPA guidance documents (2009) recommend the use of KM method when dealing with environmental datasets consisting of ND (values reported with U flags; values less than respective MDC) observations. For datasets with ND observations with multiple detection limits, the KM estimation method has been incorporated in ProUCL 4.1. A brief description of the KM method to estimate the population mean and standard deviation, and standard error (SE) of the mean is given as follows.

Let $x_1, x_2, \ldots, x_n$ (reported ND values or actual measurement) represent n data values obtained from samples collected from an area of concern (AOC), and let $x_1' < x_2', \ldots < x_n'$ denote the n' distinct values at which detects are observed. That is, n' ($\leq n$) represents distinct observed values in the collected dataset of size n. For $j = 1, \ldots, n'$, let m_j denote the number of detects at x_j' and let n_j denote the number of $xi \leq x_j'$. Also, let $x(1)$ denote the smallest x_i. Then:

$$\widetilde{F}(x) = 1, \qquad x \leq x_{n'}'$$

$$\widetilde{F}(x) = \prod_{j \text{ such that } x_j' > x} \frac{n_j - m_j}{n_j}, \qquad x_1' \leq x \leq x_{n'}'$$

$$\widetilde{F}(x) = \widetilde{F}(x_1'), \qquad x(1) \leq x \leq x_1'$$

$$\widetilde{F}(x) = 0 \text{ or undefined}, \qquad 0 \leq x \leq x(1)$$

Note that in the last equality statement of $\widetilde{F}(x)$ above, $\widetilde{F}(x) = 0$ when $x(1)$ is a detect, and is undefined when $x(1)$ is a ND. The estimation of the population mean using the KM method is described as follows.

$$\hat{\mu} = \sum_{i=1}^{n'} x_i' [\widetilde{F}(x_i') - \widetilde{F}(x_{i-1}')], \text{ with } x_0 = 0$$

An estimate of the SE of the mean is given by the following equation:

$$\hat{\sigma}_{SE}^2 = \frac{n-k}{n-k-1} \sum_{i=1}^{n'-1} a_i^2 \frac{m_{i+1}}{n_{i+1}(n_{i+1} - m_{i+1})},$$

Where k = number of observation below the detection limit and

$$a_i = \sum_{j=1}^{i}(x'_{j+1} - x'_j)\widetilde{F}(x'_j),\ i: =1, 2, \ldots, n'\text{-}1.$$

The KM method based mean is also denoted by $\hat{\mu} = \hat{\mu}_{KM}$. The KM method based estimate of the population variance is computed by using the following equation:

$$\hat{\sigma}^2_{KM} = \hat{\mu}_{(x^2)-KM} - \left(\hat{\mu}_{(x)-KM}\right)^2,\ \text{where } \hat{\mu}_{(x)-KM} = \text{KM mean of the data}$$

$\hat{\mu}_{(x^2)-KM}$ = KM mean of the square of the data (second raw moment)

The literature referenced above suggests using the following equation to compute the UCL95 of the mean.

$$\text{UCL95} = \hat{\mu} + t_{0.95,(n-1)}\sqrt{\hat{\sigma}^2_{SE}}$$

Computation of KM Method Based Estimates of BTVs

The following limits (Helsel, 2005; Singh, Maichle, and Lee, 2006; EPA, 2010b; EPA, 2009) have been used to compute BTV estimates for datasets consisting of below detection limit (e.g., MDC) observations.

Percentiles: The p^{th} percentile based upon KM estimates (as incorporated in ProUCL 4.1) is given as follows.

$$\hat{x}_p = \hat{\mu}_{KM} + z_p\sqrt{\hat{\sigma}^2_{KM}}$$

$\hat{\mu}_{KM}$ = KM method based estimate of mean;

$\hat{\sigma}_{KM}$ = KM method based estimate of the population standard deviation; and

z_p is the p*100th percentile of a standard normal, N (0, 1) distribution, which means that the area (under the standard normal curve) to the left of z_p is p.

If the distributions of the site data and the background data are comparable/similar, then an observation coming from a population (e.g., site) similar to that of the background population should lie at or below the p*100% percentile, with probability p.

Upper Prediction Limit (UPL): For small samples (e.g., fewer than 30 samples), UPL can be computed using the critical value from the Student's t-distribution; and for large datasets, UPL can be computed using the critical values from normal distribution.

$$UPL = \hat{\mu}_{KM} + t_{((1-\alpha),(n-1))} * \hat{\sigma}_{KM}\sqrt{1+\frac{1}{n}}$$

$$UPL = \hat{\mu}_{KM} + z_{\alpha} * \hat{\sigma}_{KM}\sqrt{1+\frac{1}{n}}$$

$\hat{\mu}_{KM}$ = Kaplan Meier estimate of mean based upon data x_i, $i = 1, 2, ..., n$;

$\hat{\sigma}_{KM}$ = Kaplan Meier estimate of population standard deviation;

$t_{((1-\alpha),(n-1))} = (1-\alpha)^{th}$ critical value from t-distribution with degrees of freedom of $(n-1)$;

$z_{\alpha} = \alpha^{th}$ critical value from standard normal distribution

Upper Tolerance Limit (UTL): Just like Student's t-statistic-based UPL, the use of the following equation has been used to compute upper (1-α)*100% tolerance limits with tolerance or coverage coefficient = p (that is providing coverage to at least p*100% of observations):

$$\text{UTL} = \hat{\mu}_{KM} + K * \sqrt{\hat{\sigma}^2_{KM}}$$

As before, K = K (n, α, p) is the tolerance factor and depends upon the sample size, n, *CC* = (1-α), and the coverage proportion = p. The K critical values are based upon non-central t-distribution, and have been tabulated extensively in the statistical literature (Hahn and Meeker, 1991).

Upper Simultaneous Limit (USL): An upper (1-α)*100% KM method based USL is given by the following equation:

$$\text{USL} = \hat{\mu}_{KM} + d^b_{2\alpha} * \hat{\sigma}_{KM}$$

Where $(d^b_{2\alpha})^2$ is the critical value of the Max (MDs) for $2*\alpha$ level of significance.

4.0 ALTERNATIVE METHODS TO COMPUTE STATISTICS OF INTEREST: MEAN, STANDARD DEVIATION, UCLS, UTLS, USLS, UPLS BASED UPON RADIONUCLIDE DATASETS CONSISTING OF NONDETECTS

In the absence of the well-established statistical literature and theoretical guidance on how to compute various statistics of interest based upon radionuclide datasets consisting of NDs (U-flagged values), the available established statistical methods as described in the previous sections were used to compute BTV estimates for the SSFL Background Study. Historically, due to the complexity of statistical methods and lack of computer programs to compute decision making statistics (e.g., UPLs, UTLs, USLs) based upon datasets consisting of NDs (e.g., represented by negative radionuclide results), the use of some rule-of-thumb methods (without theoretical backup and detailed thought process) have been suggested based upon professional judgement/opinion in the various environmental documents (EPA, 2000). Those suggestions/statements have been made due to the lack of the availability of computer programs (at the time) to properly analyze radionulcide datasets with NDs represented by positive or negative results.

Team Decision to Compute BTV Estimates Based upon Dataset with Nondetects (U Flag)
At the start of the SSFL Background Study Project, the members of the Project Team including: Nicole Moutoux, Gregg Dempsey, Daniel Stralka, Jeffrey Bigelow, and Anita Singh decided to treat NDs as NDs, and use the available well-established statistical methods (Helsel, 2005; Singh

et al., 2006) to statistically analyse datasets consisting of ND observations. A considerable amount of effort was spent by the data validators to properly report NDs with U flags. In order to compute accurate and reliable estimates of BTVs, it is important to take this information (ND status with U flags) into account in the computation of various decision making statistics (e.g., UTLs, USLs). The statistical methods used to compute estimates of BTVs for the various radionuclides (and summarized above) properly account for the ND status of the reported radionuclide concentrations. If one has to ignore the non-detect status of concentrations reported with U flag, then there is no point in spending so much time during the data validation process to tag concentrations with U flag.

It was also decided by the Project Team that for radionuclides with no detected values or only a few detects (less than 5), BTVs will be estimated by their respective largest ND values. The largest ND still represents a ND, therefore its use as an estimate of BTV should not be considered as an overestimate of the BTV potentially resulting in false negatives.

Alternative Approach to Handle Datasets With NDs

Some technical stakeholders believe that radionuclide data consisting of NDs (positive as well as negative results) should be treated as detected data. They seem to suggest that one should ignore the ND status of radionuclide concentrations and their detection limits/MDCs. All detected as well as ND values should be treated equally in the computation of various statistics of interest including BTV estimates. They do not acknowledge the fact that in practice concentrations cannot be negative.

It is noted that radionuclides are reported as negative values due to background noise and limitation of the instruments. Some technical stakeholders argue that the bias in radionuclide concentrations cancels out as the uncertainty is associated with each result; sometime positive and sometime negative. However, the background noise (uncertainty in activity of a specific sample) cancels out for a specific single sample when the same sample is analyzed many times but not for all samples combined together. It is noted that the intensity of background noise (uncertainty in a result) depends upon activity/concentration of the samples that are being analyzed.

Note: The appropriateness of the approach proposed by these technical stakeholders is not clear and well-established. Specifically, it is not clear if the BTV estimates based upon the proposed approach provide the desired confidence associated with the various limits (e.g., UTL95-95, USL95) used to estimate BTVs. The proposed approach requires further investigation perhaps via monte carlo simulation experiments.

The Project Team for the SSFL Background Study believes that the altermative technical stakeholder approach results in biased estimates of BTVs and other statistics of interest. In the absence of the published literature illustrating the proposed approach, the author of this report and other members of the Project Team prefer to use the documented and well-researched statistical methods to deal with radionuclide datasets with ND observations.

The Project Team believes and recommends that instead of computing distorted BTV estimates by including NDs directly in the computation of upper limits, the status of ND observations should be taken into consideration by using appropriate statistical methods designed to deal with datasets with NDs.

Some Observations

- It needs to be emphasized that if all or most (e.g., greater than 95%-99%) of results in a dataset are reported as NDs (uncensored or censored), then decision statistics (e.g., UCL, UPL, UTL, USL) based upon such a dataset may also be considered as NDs.

    - The approach which ignores the status of results reported as NDs tends to yield BTV estimates higher than what they should have been, especially when the majority of results are reported as NDs (see examples below).
    - By treating NDs as detects, the valueable information about NDs (U flagged data) is lost and the resulting statistics (e.g., USL, UTL) used to estimate BTVs and UCL95 used to estimate the exposure point concentration (EPC) term may be misleading and/or incorrect.

- Negative NDs when treated as detects increase the dataset variability; which in turn may result in inflated estimates of BTVs and EPC term; this is especially true when % of NDs is high.

    - Treating negative NDs as detects may result in a dataset without a discernable distribution. BTV estimates for such datasets are typically estimated by the higher order statistics (e.g., the largest, the second largest,..) which do not take the data variability into consideration. Depending upon sample size, nonprametric upper limits may overestimate the BTV estimate (e.g., for larger sample sizes greater than 100); or may not provide the specified (e.g., 95%) coverage (that is the BTV estimates are lower than what they should have been), especially when dataset is of smaller size (e.g., less than 60).

- By treating NDs as detects – the resulting statistics (e.g., estimates of BTVs) may become larger than the largest ND (examples below); and it is not clear how to interpret such a decision statistic - a detect or a ND.

Examples Illustrating the Issues Listed Above

Some issues associated with the technical stakeholders approach to compute decision statistics (e.g., UCLs, UTLs, USLs) are discussed in the following examples. For comparison sake, statistics of interest are computed using the two approaches: 1) treating NDs as detects as suggested by technical stakeholders; and 2) KM method which treats NDs as NDs. Real data sets collected from DOE sites considered in Examples 2-4 were provided by Dr. Beal of SAIC (a colleague of Dr. Rucker).

Example 1. Consider a small cobalt-60 (Co-60) dataset of size 14 from a real site. About 29% results of Co-60 are reported as NDs, and all NDs are positive. The dataset of size 14 obtained by treating all NDs as detects follows a normal (and also lognormal, gamma) distribution. Data are: 0.796 (U), 0.6 (U), 4.3, 1.1, 3.1, 2.5 (U), 0.1, 1.6, 1.2, 4, 3.9, 0.2, 1.04 (U), and 1.7.

	C-60
Number of Observations	14
Number of Missing Values	0
Number of Detects	10
Number of Non-Detects	4
Percentage of Non-Detects	28.57%
Minimum Non-Detect Value	0.6
Maximum Non-Detect Value	2.5
Minimum Observed Detected Value	0.1
Maximum Observed Detected Value	4.3
Mean of Detected Values	2.12
Median of Detected Values	1.65

Normal distribution based BTV estimates (treating NDs as detects) are shown in Figure 5 and the KM method based BTV estimates (treating NDs as NDs) are shown in Figure 6.

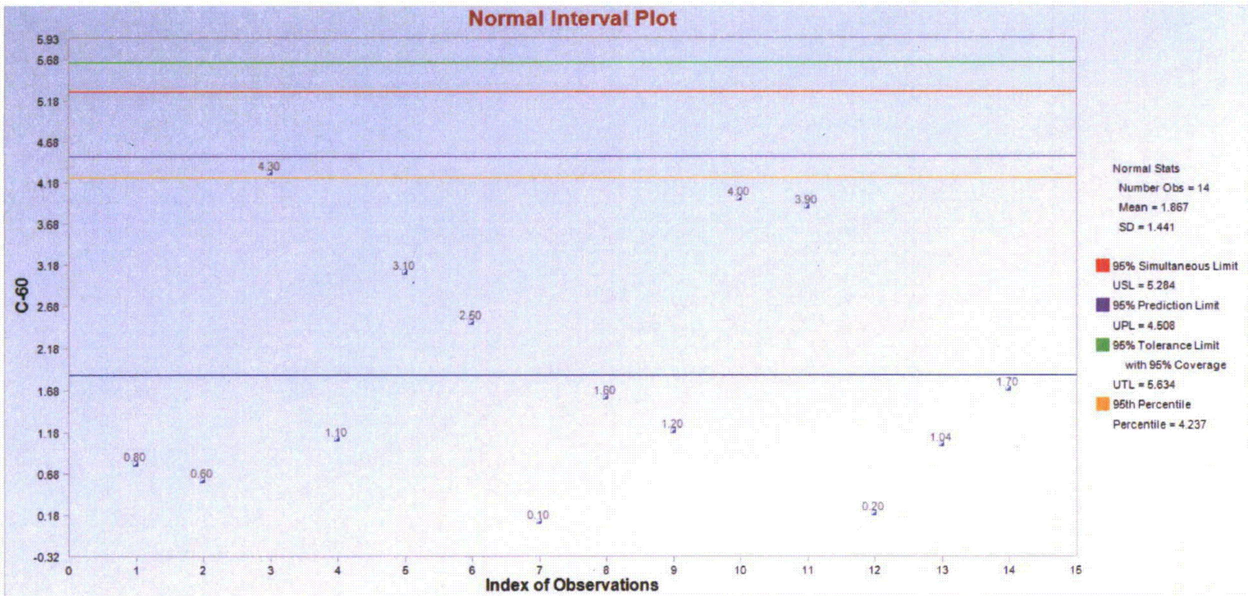

Figure 5 - Normal Distribution Based BTV Estimates for Co-60 in Site 1

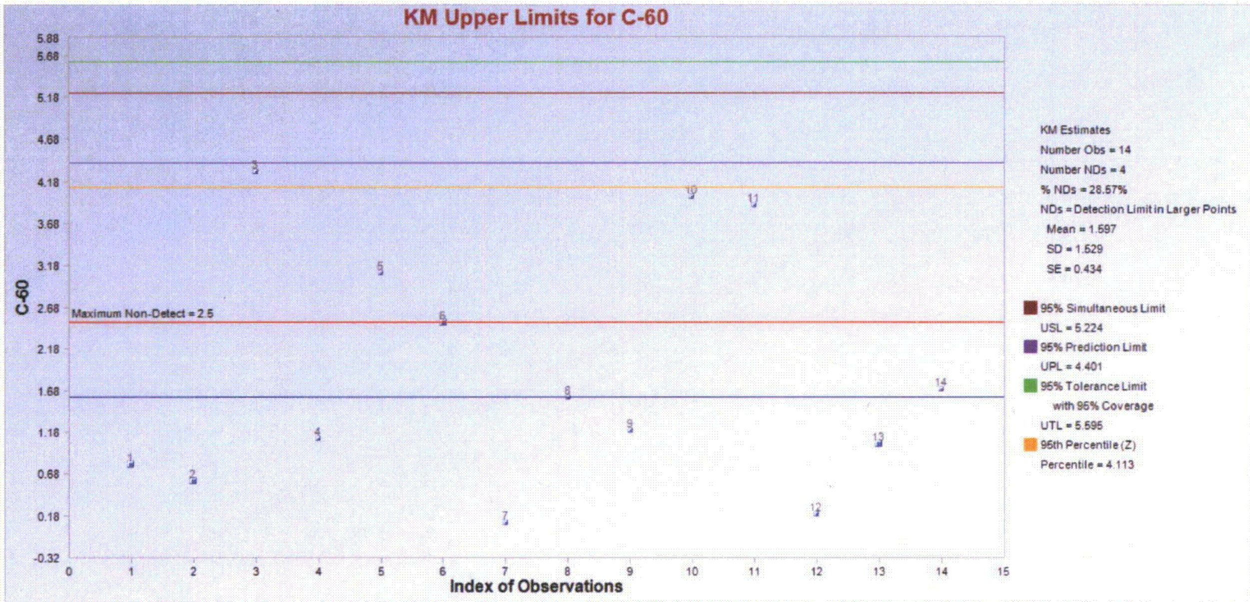

Figure 6 - KM Method Based BTV Estimates for Co-60 from Site 1

For this small dataset of size 14 with all positive NDs, the differences in BTV estimates obtained using the two approaches are not significantly large.

Example 3. Consider the cesium-137 (Cs-137) dataset of size 14 from a real site. All activity results are reported as NDs (some positive and some negative). Since all results are NDs - mean, UCL, UTL, USL should also be considered as NDs. When treating NDs as detects, the presence of negative and positive values increases the data variability, which in turn will result in higher estimates of BTVs.

	Cs-137
Number of Observations	14
Number of Missing Values	0
Number of Detects	0
Number of Non-Detects	14
Percentage of Non-Detects	100%
Minimum Non-Detect Value	-3.47
Maximum Non-Detect Value	6.36

Using the approach suggested by some technical stakeholders, treating ND Cs-137 results as detects, the Cs-137 dataset follows a normal distribution and normal distribution BTV estimates are shown below:

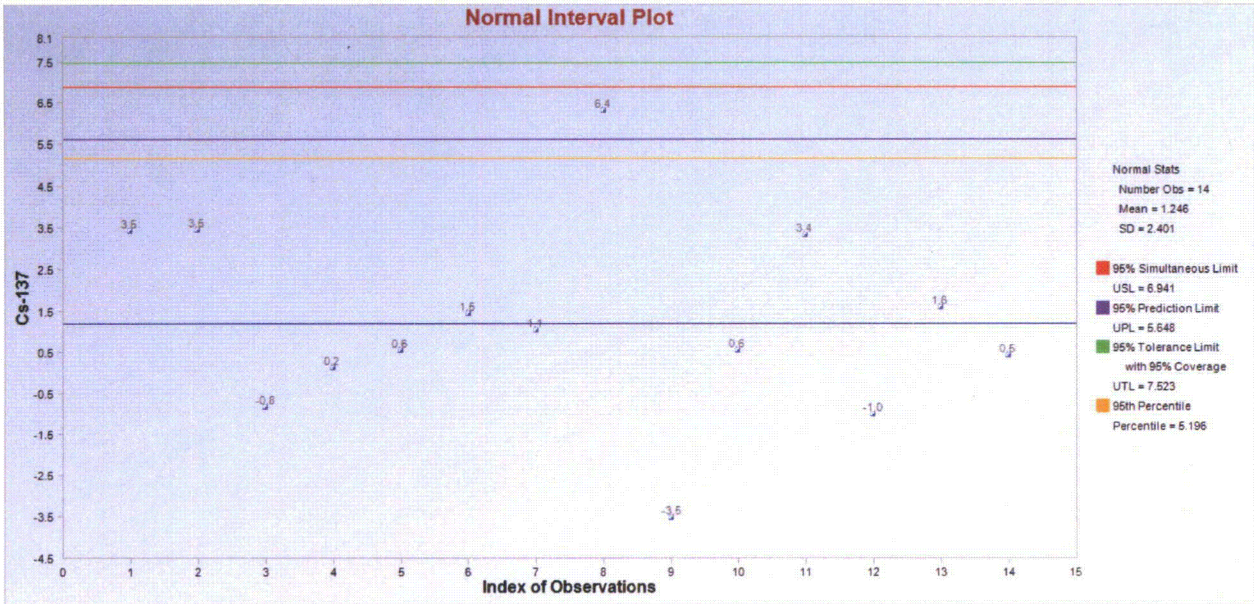

Figure 7 - Cs-137 Dataset of Size 14 with All Results Reported as NDs

Normal distribution based USL95= 6.941, and UTL95-95 = 7.52. Both of these values exceed the largest ND of 6.36.

It is not clear whether USL95 and UTL95-95 represent nondetects or detects.

Example 4. Just like Cs-137, all Co-60 results from this site are reported as NDs. Since all results are NDs, mean, UCL, UTL, USL should also be considered as NDs. Perhaps the BTV estimate may be considered as the largest non-detect value of 4.34.

	C-60
Number of Observations	14
Number of Missing Values	0
Number of Detects	0
Number of Non-Detects	14
Percentage of Non-Detects	100%
Minimum Non-Detect Value	-3.6
Maximum Non-Detect Value	4.34

Treating ND Co-60 results as detects, the Co-60 dataset follows a normal distribution. Presence of negative results increased the dataset variability, which resulted in inflated estimates of BTVs. Normal distribution based BTV estimates are shown below in Figure 8.

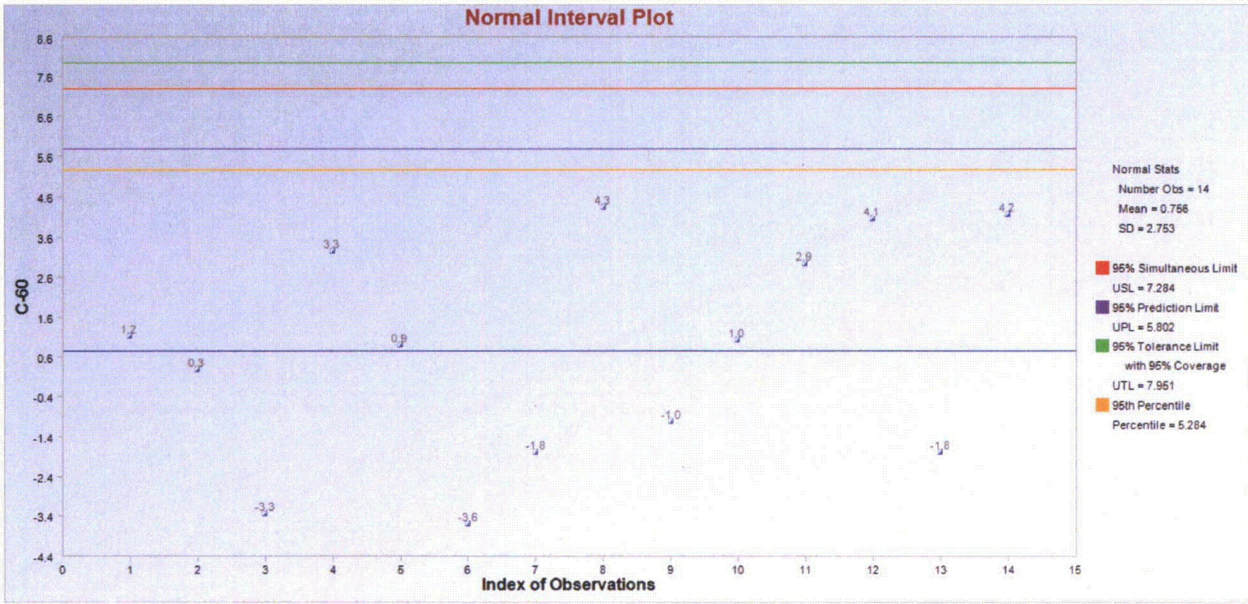

Figure 8 – C0-60 Dataset of Size 14 with All Results Reported as NDs

Normal distribution based USL95= 7.28, and UTL95-95 = 7.95. Both of these values exceed the largest ND of 4.34. The use of inflated USL95 to estimate BTV may result in a larger number of false negatives.

Also, it is not clear whether USL95 and UTL95-95 represent NDs or detects.

Example 5. Consider the uranium-232 (U-232) dataset collected from the reference areas of the two formations selected for the SSFL Background Study.

The datasets consists of only 1 (out of 149) detect = 0.417. Therefore, an estimate of BTV is also considered a ND.

Now if one treats NDs as detects – the detected value 0.417 represents an outlier as shown in Figure 9 below. The outlier is removed; the resulting dataset follows a normal distribution (Figure 10). Normal distribution based BTV estimates (without outlier) are shown in Figure 11.

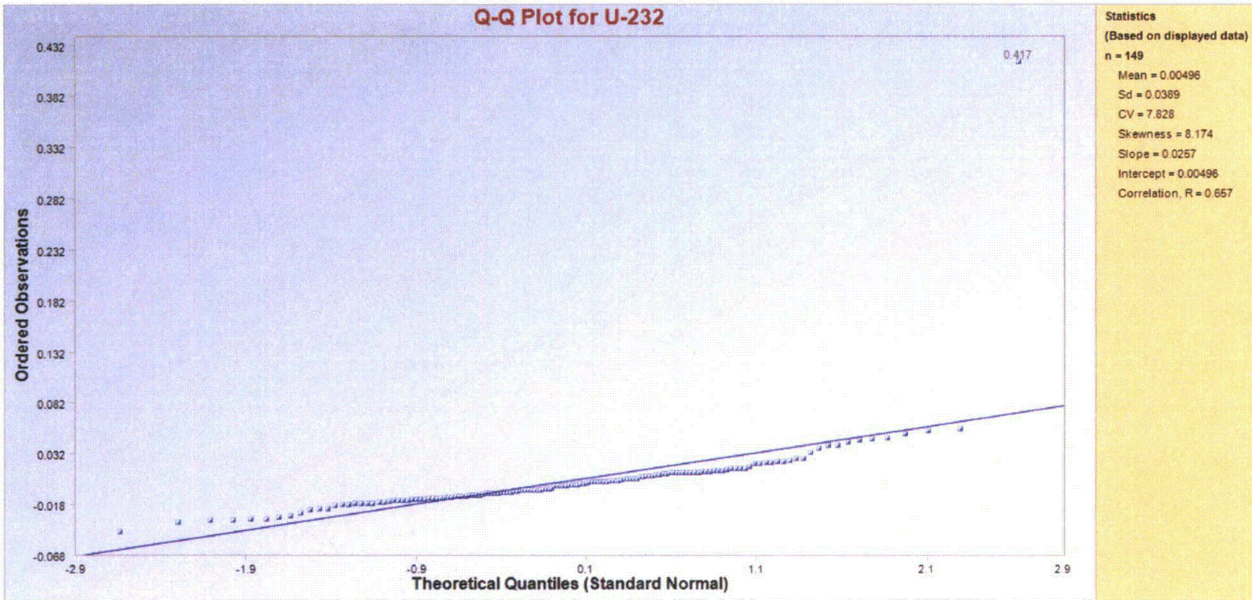

Figure 9 - Q-Q Plot Showing Observation 0.417 as Outlying

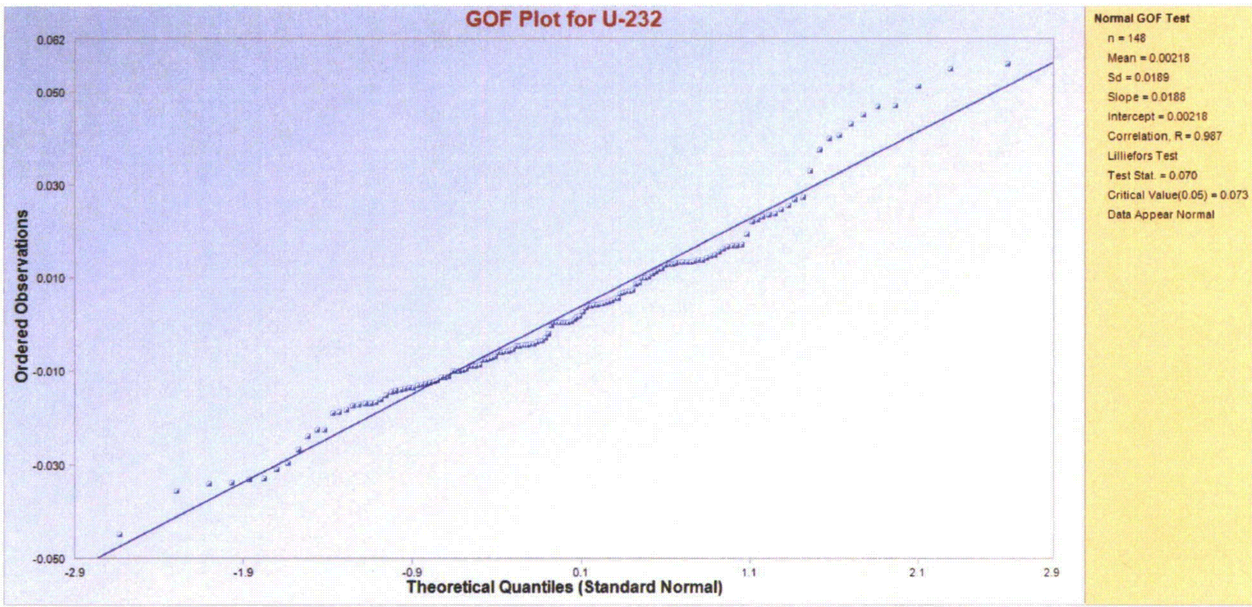

Figure 10 - U-232 Follows a Normal Distribution (without outlier) Treating NDs as Detects

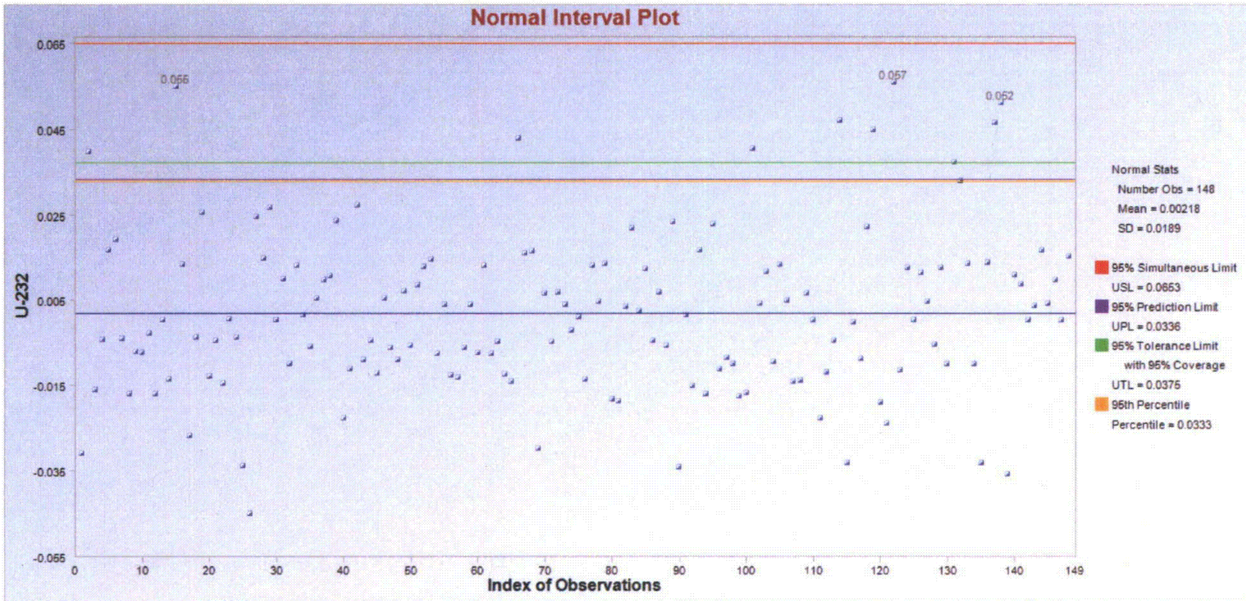

Figure 11 - Normal Distribution Based BTV Estimates for U-232

USL 95 = 0.0653 > largest ND = 0.057

How to treat USL95 as a detected value or a nondetect?

Example 6. Consider a plutonium-241 (Pu-241) dataset collected from the three RBRAs. All but one observation are reported as NDs. The detected observation comes from surface soil sample BP-8-SUR. The detected of BP-8-SUR value = 0.437. Therefore, for Pu-241 an estimate of BTV may be considered as a ND. Based upon the available data, BTV for Pu-241 is estimated by the largest ND value = 0.349.

If one treats all NDs as detects and computes BTV estimates treating all Pu-241 activity as detects, another level of uncertainty/noise is added to the BTV estimate. It is not clear whether the BTV estimate represents a ND or a detected measurement. Treating all Pu-241 data as detects, the resulting dataset follows a normal distribution, and normal distribution based BTV estimates are shown in Figure 12 as follows. The USL95 = 0.514.

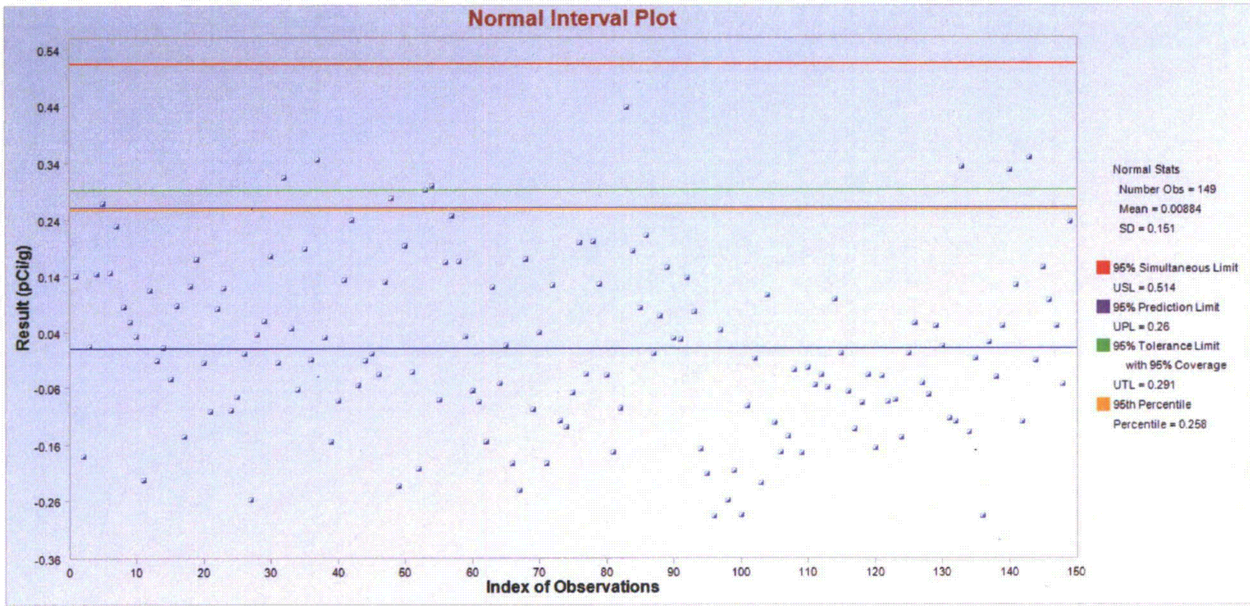

Figure 12 - Normal Distribution Based BTV Estimates for Pu-241 Activity

Example 7. Consider the americium-241 (Am-241) background dataset collected from the three RBRAs of the two formations selected for the SSFL Background Study. The dataset consists of five detects. Accounting for the ND observations, the KM method based BTV estimates are shown in Figure 13 below.

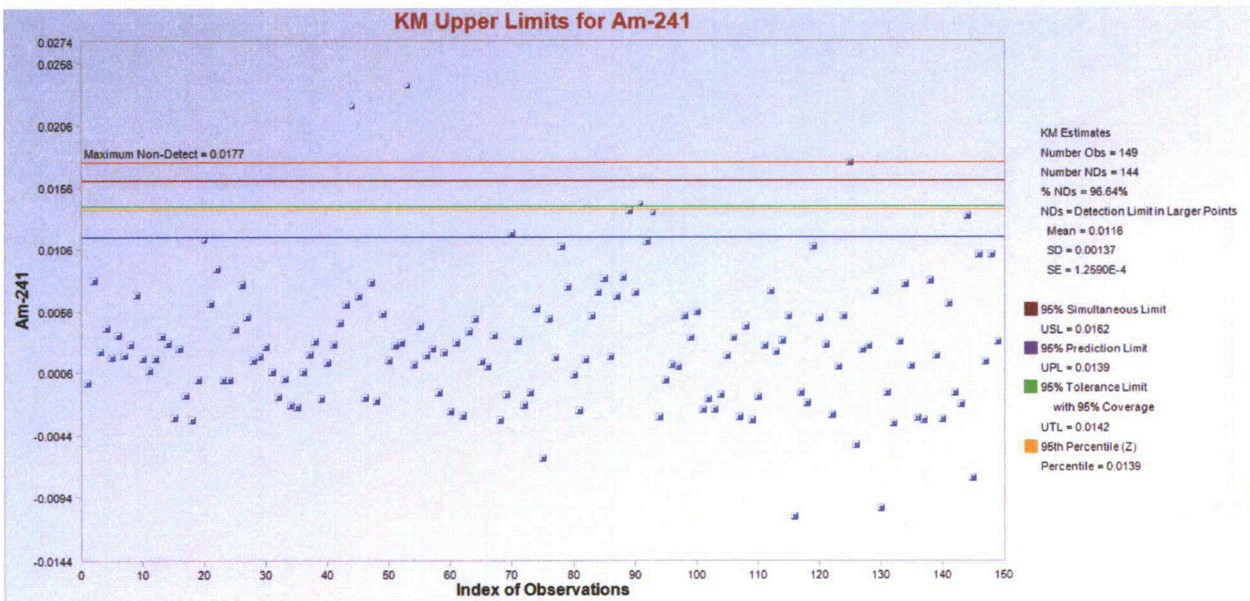

Figure 13 - KM Method Based BTV Estimates

Largest ND = 0.0177 ; and Largest Detect = 0.0239, and USL95 = 0.0162

Treating all NDs as detects, the normal distribution based and nonparametric BTV estimates are shown in Figures 14 and 15 below.

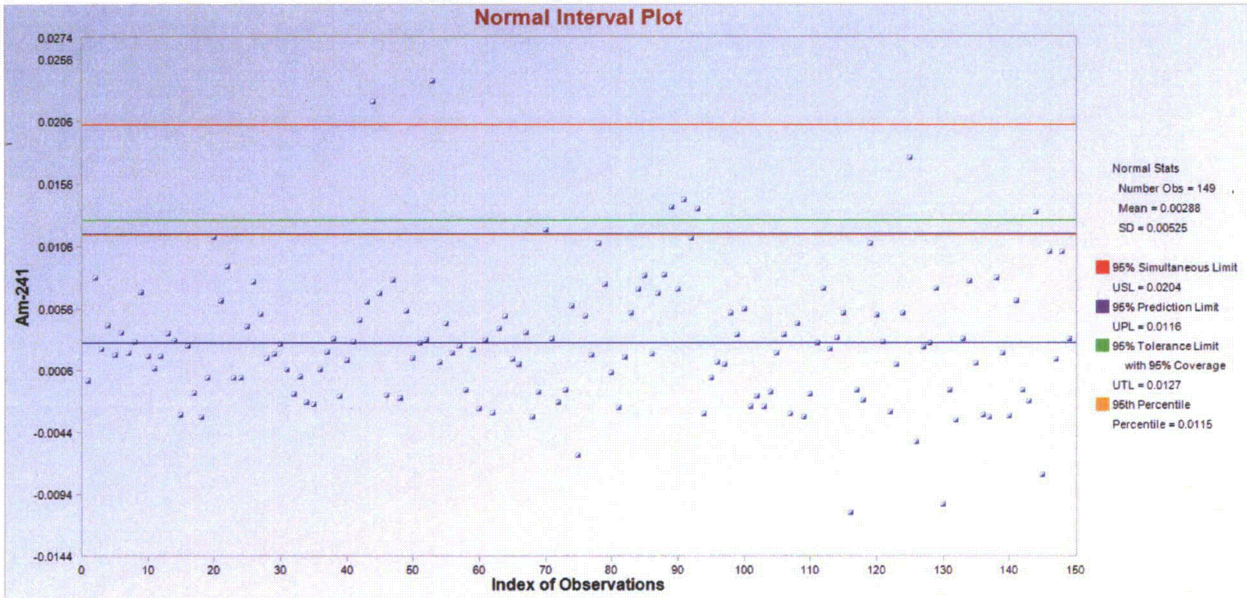

Figure 14 - Normal Distribution Based BTV Estimates (treating NDs as detects), USL=0.0204

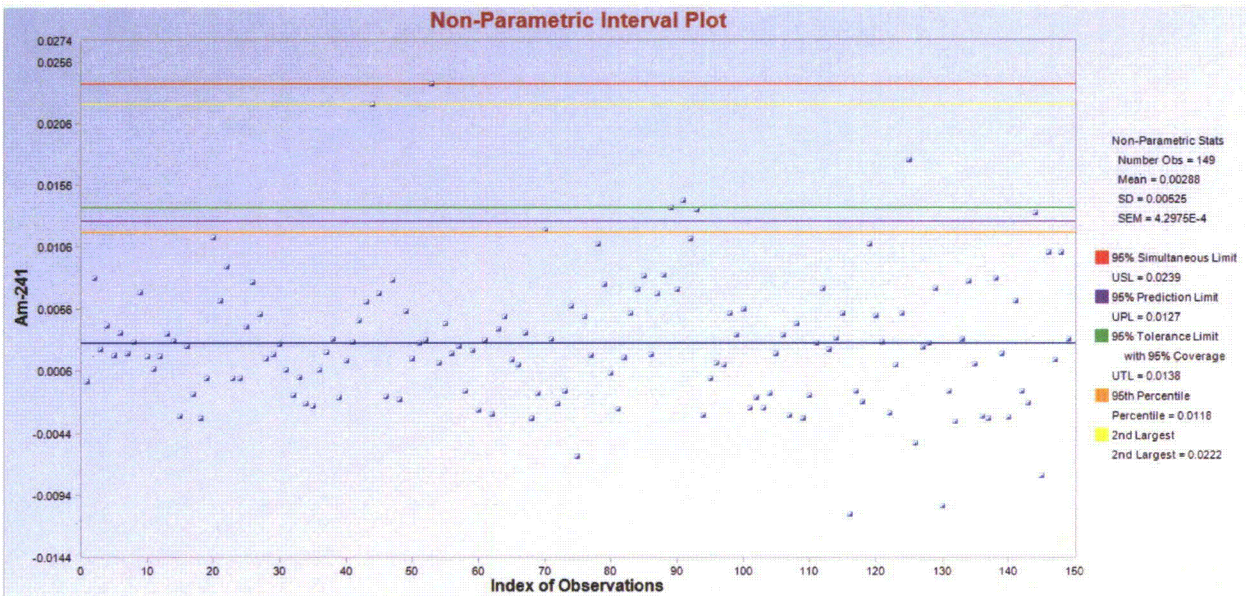

Figure 15 - Nonparametric BTV Estimates (treating NDs as detects), USL = 0.0239

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Job # 292

Division of United Nuclear Corporation
A UNC RESOURCES Company

Church Rock Operations
P.O. Drawer QQ

Gallup, New Mexico 87301
Telephone 505/722-6651

March 6, 1981

Mr. Thomas Baca, Director
Environmental Improvement Division
Post Office Box 968
Santa Fe, New Mexico 87501

Dear Mr. Baca:

The purpose of this letter is to outline the measures taken by UNC to control seepage at its Churchrock facility. UNC believes that the substantial accomplishment made to date supports a finding of good cause to allow continued discharges from the Company's Churchrock mill facility. Accordingly, UNC requests an extension of time to continue operating without an approved discharge plan.

On January 22, 1981 UNC and EID personnel met to discuss the field measures feasible by March 11. UNC outlined its committment to commence drilling of wells to create a chain of wells that ultimately will form the interlocking cones of depression necessary to effectively intercept seepage, some of which could be completed by March 11. In addition, the problems posed by the geological formations at the site were identified and field visits planned. Well drilling has commenced and field visits have been conducted.

DRILLING AND PUMP DATA
SINCE JANUARY 9, 1981

The plan implemented was to establish the interlocking well chain and to drill new wells between existing northern wells TWQ-115D and TWQ-148. To date, three new wells have been drilled and as of this date a fourth well is being drilled. In addition, fourteen monitoring wells have been drilled and apparatus has been installed which permits the pumping of intercepted seepage back to the tailings area. The results of this drilling and the pump data generated thus far are encouraging and indicate the present ability of UNC to intercept seepage by an outreaching cone of depression.

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The most complete data to date for the recent wells are from Well 402 near well TWQ-115. Well 402 is installed near the heart of the northern reaches of the existing plume, and currently pumps about 8 g.p.m. The observation to date since pumping commenced on February 27 indicates drawdown effects to monitoring wells as much as 125 feet from Well 402. The drawdown curves and other technical data on this well are included within data submitted to the Division herewith.

UNC has drilled two other wells adjacent to Well 402. These are identified as Wells 401 and 403. These wells were drilled during the same time as Well 402. The purpose of this simultaneous drilling has been to increase the likelihood of having in place a well such as Well 402 by March 11. That is, UNC undertook to drill more than one well during the extension period to avoid the risk that the drilling of one well alone might not tap a producing horizon or, as was the case with Well 403, not show results owing to equipment failure. Although Well 401 did not result in significant yields, efforts are continuing in an attempt to further develop this well. UNC proposes to pump this well at a lower rate to adjust to the low level of flow encountered at this location. Well 403 is currently being redrilled as a result of equipment difficulties encountered during the start up of pumping. As these are corrected, it will be pumped and the results reported.

UNC now has Well 402 with a demonstrable drawdown of 125 feet which is currently pumping intercepted seepage back to the tailings area at a rate which approaches 12,500 gallons per day. The location of the next wells, with respect to the creation of the interlocking chain of wells can now be more accurately determined.

In addition to the northern plume wells, UNC, as stated in its January 20 outline, has continued operation of the Central Cell seepage interception system. Specifically, Wells 304, 323A, 335 and 340 have been pumped and extensive chemical and drawdown data are available and being submitted to the Director and his staff. In sum, this data shows as expected, drawdown as a result of pumping which, combined with a decrease in seepage (to be addressed below) has combined to significantly reduce the outflow of unsatisfactory water. The Central Cell system supports the proposition that considered by UNC to be sufficient to demonstrate that seepage is being effectively controlled. When combined with

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the pumping and drawdown of the northern wells, as well as the reduction in seepage from the disposal area itself, the Central Cell seepage interception system is a significant contribution to the overall operation. Pumping of the Central Cell wells alone during the month of February has amounted to approximately 1,075,000 captured gallons returned to the disposal area. In addition, as explained in UNC's submittal to the Director dated March 5, 1981 UNC has accomplished extensive refinement and improvement of the estimation of the amount of seepage and the amount being pumped back to the disposal areas. Consequently, UNC is able to state that there has been at least a twofold reduction in the amount of seepage captured. Moreover, UNC is intercepting unsatisfactory water from its central cell wells at a rate which exceeds the amount of seepage from the borrow pits in the mill tailings area. There is indication that the disposal area (Borrow Pit 1) now substantially lined with slimes, is able to retain more liquids. During the extension period, there has been an increase in the fluid levels being retained in the disposal area.

The demonstrable field results to date then show:

(1) There has been a twofold reduction in the amounts seeping from the disposal area. UNC is intercepting more seepage than is lost from the borrow pit.

(2) There has been an increase in the amount of liquid being retained in the disposal area such that the two foot elevation increase granted on January 21 has proven necessary.

(3) The pumping of the existing central cell wells has continued uninterrupted and drawdown configurations can be defined.

(4) The northern plume now contains a seepage interception well currently pumping as much as 11 g.p.m. Drawdown has been observed in a monitoring well 125 feet away from the seepage collection well.

It is submitted these results show improvement and progress during the extension period. By these results it is evident that the difficulties posed by the seepage problem can be and are being brought under control.

In addition to these actual results there is an additional measure taken by UNC. On March 6, 1981 it submitted to the Director its committment to not permit use of water wells for domestic purposes on that portion of Section 36 governed by its business lease. Furthermore, UNC has unequivocally committed to cleaning up and restoring the aquifers affected by its operations.

There is, additionally, the matter of wells not controlled by UNC. To date, there has been no cause known to believe that any well within a twenty-five mile radius used for domestic or stock or agricultural purposes has been the location of a withdrawal of contaminated water.

In the Churchrock area the following wells are located in the Gallup formation:

NAME and OWNERSHIP: 15T-303; The Navajo Tribe
LOCATION: Section 31, T17N, R15W; 1.75 miles Northeast of tailings area
COMPLETION: Depth - 614 feet; steel casing to 537 feet; perforation through 134' of Kg
AQUIFER: Gallup, development test 23 gpm; pump rate 2-3 gpm
USE: Domestic stock

NAME & OWNERSHIP: Training School Well; Kerr-McGee
LOCATION: Section 36, T17N, R16W; 2,000 feet Northeast of tailings area
COMPLETION: Depth - 455 feet; steel casing to 250 feet; perforations from 200-250 annulus gravel packed from bottom to near surface.
AQUIFER: Lower Gallup; development pump rate - 2 gpm
USE: None

NAME & OWNERSHIP: Friendship 1; the Navajo Tribe
LOCATION: Section 35, T17N, R16W; 1.25 miles Northwest of tailings area
COMPLETION: Depth - 747 feet; steel casing to 747 feet; perforations last 40 feet; annulus gravel packed from bottom to near surface;
AQUIFER: Upper and lower Gallup; development pump rate - 50 gpm; pump rate - 7 gpm
USE: Domestic/stock

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By identifying the location of these wells UNC does not intend to underestimate the seriousness of the problem it is committed to control and remedy. However, UNC believes that the unlikelihood of withdrawal of unsatisfactory water from nearby wells is a factor to be weighed by the Director.

Based upon the progress made by UNC in the operation of its seepage interception program to date, UNC requests an extension of time to continue operations during review of its discharge plan. UNC's seepage interception program can best be properly evaluated and improved on a continuing basis if the Company is allowed to operate.

In your letter of January 21, 1981, you requested submission of: (1) water quality data obtained during the operation of UNC's seepage control system; (2) total gallons pumped per day by each collection well; (3) water levels of specified wells.

Accordingly, we are transmitting preliminary water quality data for the parameters requested for the North Area Monitoring Wells, the North Area Pumping Wells, and the Central Cell Wells. Data showing daily samples for Ph and electrical conductivity from the Central Cell Pumping Wells is also included.

UNC also submits the Daily Pumping Record for the Seepage Collection Wells 304, 323A and 340 during the entire month of February and early March.

Finally, graphs of water levels in specified wells are submitted.

Mr. Baca, United Nuclear is very pleased with the results to date at Well 402, which indicates that a cone of depression is being created in the heart of the plume area to the north. We would like to bring into production wells flanking 402 and drill and complete any additional wells indicated by the drawdown data. This should complete the intercept system across the north plume. United Nuclear has also discussed with your staff the possible need for a pumping well north of well 304. Well 304 is on the east side of borrow pit 2. A pumping well north of Well 304 would decrease the possibility of seepage going into Section 1. United Nuclear has several wells drilled north of Well 304, but pumps have not yet been installed. While there may be little flow in this area, United Nuclear proposes pump installation and pumping at one of the wells north of Well 304.

Very truly yours,

Thomas F. Bailey

TFB/mjc
Attachments

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Well: Date:	136 2-19-81	136 2-19-81	137 2-19-81	138 2-20-81	138 2-20-81	139 2-20-81	140 2-20-81	141 2-21-81	141 2-21-81
Aluminum	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cobalt	0.007	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Iron	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Manganese	1.45	1.53	0.67	0.50	0.53	0.87	0.73	0.82	0.79
Molybdenum	0.004	0.005	0.142	0.1	<0.1	0.2	0.3	<0.1	0.1
Uranium	0.17	0.06	0.10	0.04	0.05	0.12	0.21	0.14	0.14
Sulfate	1,804.6	1,805.6	775.4	1,887.9	1,875.1	1,913.6	607.6	591.8	604.2
Tot. Dis. Solids	3,404.3	3,436.0	1,632.0	3,274.3	3,258.3	3,087.5	1,129.0	992.5	978.8
pH	7.65	7.88	7.16	8.04	7.99	7.84	8.04	8.14	8.05
Conductivity	2,700	2,950	1,500	2,600	2,830	2,600	1,200	1,120	1,120

Well: Date:	142 2-21-81	142 2-21-81	143 2-21-81	143 2-21-81	144 2-21-81	145 2-21-81	147 2-20-81	148 2-20-81	149 2-18-81
Aluminum	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1
Cobalt	<0.001	0.003	0.001	<0.001	<0.001	<0.001	<0.001	0.138	0.182
Iron	<0.01	0.01	<0.01	0.03	0.13	0.03	<0.01	0.01	0.01
Manganese	0.01	<0.01	0.09	0.10	0.08	0.98	0.09	3.00	3.60
Molybdenum	<0.1	<0.1	0.2	0.2	0.1	10.3	2.7	8.1	16.500
Uranium	0.03	0.04	0.14	0.16	0.11	0.28	0.09	0.53	0.86
Sulfate	738.1	630.3	612.5	491.8	488.0	2,703.3	564.8	3,105.3	2,333.1
Tot. Dis. Solids	995.8	1,006.8	953.0	953.5	1,097.8	4,255.5	1,026.8	5,189.5	4,465.0
pH	8.20	8.28	8.14	8.11	7.68	7.36	8.27	6.56	6.65
Conductivity	1,180	930	1,150	1,200	1,250	2,930	1,080	3,800	3,490

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Well:	149	150	151
Date:	2-18-81	2-22-81	2-22-81
Aluminum	<0.1	0.2	<0.1
Cobalt	0.186	0.080	<0.001
Iron	<0.01	10.00	0.01
Manganese	3.30	5.30	1.33
Molybdenum	17.600	5.7	<0.1
Uranium	0.86	0.14	0.07
Sulfate	2,292.9	2,941.3	1,130.3
Tot. Dis. Solids	4,454.3	5,296.8	1,724.3
pH	6.84	6.26	7.58
Conductivity	3,780	3,780	1,580

Well:
Date:
Aluminum
Cobalt
Iron
Manganese
Molybdenum
Uranium
Sulfate
Tot. Dis. Solids
pH
Conductivity

Well:	401	401	402	402	402	402	402	402
Date:	2-18-81	2/27/81	2-9-81	2-27-81	2-28-81	3-1-81	3-2-81	3-3-81
Aluminum	<0.1	0.1	0.01	<0.1	<0.1	<0.1	<0.1	<0.1
Cobalt	0.157	0.12	<0.001	<0.01	<0.01	<0.01	<0.01	< 0.01
Iron	<0.01	0.79	0.04	0.06	1.07	1.71	0.85	1.77
Manganese	2.90	3.10	0.368	0.42	0.92	1.03	0.97	1.17
Molybdenum	13.900	17.300	0.075	0.149	0.197	0.224	0.204	0.224
Uranium	1.10	1.08	0.10	0.10	0.11	0.10	0.10	0.10
Sulfate	2,297.9	2,535.6	1,449.9	1,470.0	1,455.9	1,498.7	1,474.2	1,530.6
Tot. Dis. Solids	4,210.3	4,633.5	2,493.3	4,019.3	2,580.3	2,630.8	2,581.5	2,620.3
pH	7.81	6.50	7.80	7.04	6.76	6.75	6.67	6.71
Conductivity	3,310	3,830	2,440	2,510	2,380	2,450	2,320	2,440

Well:	
Date:	
Aluminum	
Cobalt	
Iron	
Manganese	
Molybdenum	
Uranium	
Sulfate	
Tot. Dis. Solids	
pH	
Conductivity	

NORTH AREA MONITOR WELLS

Well: Date:	103A 2-17-81	104D 2-17-81	110D 2-22-81	110D 2-22-81	111D 2-19-81	114 2-13-81	115 2-13-81	116D 2-19-81	116D 2-19-81
Aluminum	<0.1	<0.1	0.2	0.2	<0.1	<0.01	54.30	<0.1	0.1
Cobalt	<0.001	<0.001	0.011	0.012	0.007	<0.001	0.023	0.015	0.071
Iron	0.03	<0.01	0.53	0.55	<0.01	2.16	4.34	0.20	0.09
Manganese	0.90	0.57	0.96	0.97	0.54	6.400	13.200	1.45	1.54
Molybdenum	0.001	0.002	<0.1	<0.1	0.006	0.002	<0.001	0.010	0.008
Uranium	0.10	0.11	0.40	0.40	0.13	<0.01	0.42	0.20	0.09
Sulfate	1,047.8	1,120.4	2,085.2	2,089.9	1,862.7	2,419.3	3,475.9	1,765.8	1,766.4
Tot. Dis. Solids	2,456.0	2,330.0	3,683.0	3,630.3	3,255.8	3,980.8	5,583.5	3,115.8	3,233.0
pH	7.32	7.33	6.43	6.37	7.56	6.88	4.26	6.81	6.69
Conductivity	2,530	2,280	2,750	2,530	2,600	3,580	4,670	2,320	2,490

Well: Date:	117D 2-18-81	117D 2-18-81	118 2-13-81	123 2-23-81	123 2-23-81	124 2-22-81	124 2-22-81	126 2-13-81	127 2-14-81
Aluminum	<0.1	<0.1	0.01	3.1	3.3	1,590.0	1,580.0	1.03	0.18
Cobalt	<0.001	<0.001	0.001	0.242	0.230	3.151	3.217	0.003	0.001
Iron	<0.01	<0.01	0.05	0.41	0.33	2,300.0	2,100.00	0.19	0.21
Manganese	4.20	4.00	1.128	3.00	3.00	102.00	101.00	1.450	1.833
Molybdenum	0.050	0.003	0.093	<0.1	<0.1	0.8	0.8	0.028	0.019
Uranium	0.04	0.05	0.11	0.06	0.06	8.12	7.88	0.04	0.09
Sulfate	1,984.3	2,008.4	1,785.9	2,587.8	2,622.6	23,447.3	22,486.8	2,920.5	2,783.3
Tot. Dis. Solids	3,289.8	3,330.3	3,244.0	4,144.5	4,188.0	33,710.0	33,403.0	4,851.5	4,993.0
pH	7.45	7.11	6.75	5.04	5.11	1.97	1.95	5.40	6.11
Conductivity	2,630	2,620	3,110	3,700	3,700	15,000	15,000	4,260	4,090

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Well:	13-D	304	313	317	323-A	340	341
Date:		3-3-81	3-3-81	3-4-81	3-3-81	3-3-81	
Aluminum	46.1	0.6	290.0	1,720.0	1,540.0	940.0	2,530.0
Cobalt	0.03	0.15	1.50	2.35	3.24	4.03	7.10
Iron	1.85	0.54	2.09	710.00	880.00	645.00	482.00
Manganese	7.10	35.00	31.00	90.00	126.00	142.00	675.00
Molybdenum	<0.001	<0.001	0.002	0.019	0.018	0.014	0.016
Uranium	0.03	0.11	0.11	2.46	4.12	4.12	7.48
Sulfate	2,877.9	3,848.1	4,991.9	15,916.8	16,059.2	4,926.1	6,780.5
Tot. Dis. Solids	4,230.5	7,610.3	11,049.5	25,693.5	23,946.3	16,478.5	36,506.5
pH	4.27	6.20	4.15	2.88	2.19	3.73	3.55
Conductivity	3,320	6,500	8,100	13,000	13,000	8,900	14,000

Well:	
Date:	
Aluminum	
Cobalt	
Iron	
Manganese	
Molybdenum	
Uranium	
Sulfate	
Tot. Dis. Solids	
pH	
Conductivity	

	Well 304		Well 323A		Well 335		Well 340	
	pH	Conductivity	pH	Conduc	pH	Cond	pH	Cond
-81	6.31	4900	2.20	11,500	2.00	12,600		
1-6-81	6.44	5,200	2.26	12,300	2.04	13,200		
1-7-81	6.26	5,400	2.21	12,700	2.00	13,700		
1-8-	6.23	5,500	2.31	12,200	2.13	13,600		
1-9	6.28	5500	2.35	12,900	2.15	13,800		
1-12	6.22	5800	2.30	13,000	2.13	13,500		
1-12	6.27	5100						
1-13	6.40	5000	2.31	12,700	2.14	13,000		
1-13	6.22	5000						
1-14	6.39	6,100	2.37	13,500	2.20	14,000		
1-14	6.39	5,600						
1-15	6.37	5,800	2.34	12,300	2.16	13,100		
1-15	6.33	5,800						
1-19	6.21	6,200	2.39	13,700	2.17	13,800		
1-19	6.22	5,300						
1-20	6.31	6,300	2.34	13000				
1-20	6.26	6,000	2.30	12,800				
1-21	6.37	5,600						
1-21	6.29	6000						
1-22	6.29	6,200	2.36	13,100				
-3	6.23	6,200					3.84	12,100
3	6.33	6,000	2.37	12,800			3.82	12,000
26	6.32	6,200	2.35	12,900			3.76	8,400
-26	6.24	6,300						
1-27	6.30	6,300	2.37	12,900			3.84	8,900
	6.30	5,900						
1-28	6.28	6,800	2.40	13,500			3.72	8,300
	6.28	6,700						
1-29	6.26	6,500	2.37	7,900			3.77	7,900
	6.28	5,500						
1-30	6.53	6,200	2.39	12,300			3.80	7500
2-2	6.46	6,800	3.78	8000			3.78	8,000
2-3	6.29	6,700	2.37	13,700			3.76	8,200
2-4	6.29	6,200	2.33	12,900			3.79	7,600
2-5	6.34	6,300	2.34	12,200			3.77	7,400
2-6	6.31	6,000	2.34	12,400			3.76	7,500
2-9	6.33	5,600	2.25	10,500			3.88	7,000
2-10	6.33	6,500	2.38	13,200			3.75	8,100
2-11	6.42	7,000	2.35	13,200			3.75	8,600
2-12	6.34	7,000	2.35	13,600			3.73	8,500
-13	6.23	6,400	2.37	13,500			3.79	8,100
-16	6.38	6,200	2.29	12,400			3.74	8,000
7	6.35	6,600	2.30	13,200			3.71	8,600
8	6.36	6,600	2.27	13,000			3.72	8,400
2-17	6.31	6,300	2.26	13,000			3.73	8,100
-20	6.16	5,800	2.33	12,000			3.81	7,500

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2-5	6.50	6,200	2.37	12,100	3.76	8,200
2-6	6.49	6,200	2.35	12,000	3.76	8,300
2-7	6.42	6,200	2.30	12,500	3.74	8,500
3-2	6.26	6,300	2.23	12,200	3.69	7,300
3-3	6.19	5,700	2.19	12,100	3.72	8,000
3-3	6.29	6,500	2.19	13,000	3.73	8,900
-4	6.42	6,600	2.23	13,000	3.72	7,000
-5	6.35	6,600	2.24	12,900	3.72	7,000
-6	6.28	4,800	2.11	10,800	3.82	5,500

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DAILY PUMPING RECORD
FOR THE SEEPAGE COLLECTION WELLS

1981 Date	Well No.	Hours Pumped	Avg. G.P.M.	Total Gallons	Well No.	Hours Pumped	Avg. G.P.M.	Total Gallons	Well No.	Hours Pumped	Avg. G.P.M.	Total Gallons
2/1	340	24	4.10	5908	304	22	20.02	26430	323A	8	3.01	1447
2/2	340	24	3.80	5466	304	24	15.48	22296	323A	2.5	16.13	2420
2/3	340	24	3.83	5515	304	24	14.94	21516	323A	15	14.54	13086
2/4	340	24	3.87	5576	304	24	14.43	20782	323A	24	9.92	14290
2/5	340	24	4.09	5895	304	24	13.33	19197	323A	24	9.24	13304
2/6	340	24	3.98	5725	304	24	12.88	18543	323A	24	8.49	12219
2/7	340	24	3.99	5750	304	24	12.89	18568	323A	24	8.32	11980
2/8	340	24	4.05	5838	304	24	13.43	19340	323A	23	8.31	11467
2/9	340	24	4.01	5781	304	24	13.41	19312	323A	23	14.56	20090
2/10	340	24	3.91	5627	304	24	12.81	18450	323A	24	7.20	10362
2/11	340	24	4.00	5768	304	24	12.87	18529	323A	24	6.63	9550
2/12	340	24	3.80	5468	304	24	12.73	18337	323A	24	8.49	12221
2/13	340	24	3.83	5517	304	24	12.16	17516	323A	8	2.98	1431
2/14	340	24	4.18	6025	304	24	17.51	25217	323A	20	9.27	11127
2/15	340	24	3.56	5130	304	24	13.32	19183	323A	24	7.88	11352
2/16	340	24	3.85	5550	304	24	14.44	20797	323A	24	7.58	10918
2/17	340	24	3.90	5614	304	22	15.08	19900	323A	24	6.65	9576
2/18	340	24	3.83	5516	304	24	14.58	20999	323A	24	4.82	6942
2/19	340	24	3.86	5562	304	24	14.13	20353	323A	22	4.75	6269
2/20	340	24	4.00	5760	304	24	12.00	17280	323A	24	12.0	17280
2/21	340	24	4.00	5760	304	24	12.00	17280	323A	24	12.0	17280
2/22	340	24	5.00	7200	304	16	12.50	12000	323A	24	12.0	17280
2/23	340	24	5.00	7200	304	24	15.00	21600	323A	24	15.0	21600
2/24	340	24	5.00	7200	304	24	14.00	20160	323A	24	15.0	21600
2/25	340	24	5.00	7200	304	24	14.00	20160	323A	24	15.0	21600
2/26	340	24	5.26	7572	304	24	12.00	17280	323A	24	15.0	21600
2/27	340	24	5.20	7488	304	24	10.71	15422	323A	22	11.37	15003
2/28	340	24	5.00	7200	304	24	10.34	14890	323A	24	15.79	22738
FEB. TOTAL	340			169,811	304			541,337	323A			366,032

G 46818

1981 Date	Well No.	Hours Pumped	Avg. G.P.M.	Total Gallons	Well No.	Hours Pumped	Avg. G.P.M.	Total Gallons	Well No.	Hours Pumped	Avg. G.P.M.	Total Gallons
/1	340	24	5.17	7445	304	24	12	17280	323A	24	13.64	19642
3/2	340	24	5.17	7445	304	24	12.5	18000	323A	24	15.00	21600
3/3	340	24	4.94	7114	304	24	12.63	18187	323A	24	14.46	20822
3/4	340	24	5.50	7920	304	24	11.65	16776	323A	24	13.33	19195
3/5	340	24	5.48	7891	304	24	11.65	16776	323A	24	12.90	18576
3/6	340	24	5.22	7517	304	24	11.65	16776	323A	24	13.19	18994

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Discharge Plan
Addendum I

REPORT 2

NORTHERN COLLECTION SYSTEM
400 Series Wells

May 20, 1981

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SECTION 1.0 INTRODUCTION

1.1 BACKGROUND

Since submission of the Discharge Plan on December 1, 1980, a great deal of discussion has taken place regarding the location and interception of seepage in Section 36 north of the present tailings disposal area. The EID has requested interception and control of contamination by installation and operation of a system of wells that demonstrate intersecting cones of depression and the creation of a hydraulic barrier to further northerly spread of the contamination.

A plan was developed on January 30, 1981 and implemented. The initial phase of the plan was satisfactory and an additional extension was provided to May 25, 1981 by the EID to continue the implementation of the plan.

The work prior to March 11, 1981 was provided the EID in a report entitled "An Initial Report of the Drilling Program in Section 36, UNC Church Rock Mill" dated March 10, 1981. The deadline extension to May 26, 1981 permitted the continued execution of the plan and the results of this effort are contained in this Report.

SECTION 2.0 GEOLOGY

2.1 AREAL EXTENT

The geology of United Nuclear Corporation (UNC) Church Rock Tailings Disposal Site and its vicinity has been described in detail in previous reports (SAI-Bearpaw, August 1980; SAI Seepage Study, August 1980; Ground Water Discharge Plan, December 1980; An Initial Report of the Drilling Program in Section 36, UNC Church Rock Mill, March, 1981). This section of the present report deals only with the site geology of Section 36, T17N, R16W. The following descriptions are based upon the results of previous investigations and the recent drilling program to the north of the disposal area. The drilling program was conducted approximately 1500 feet north of UNC's property line, in the central portion of Section 36, T17N, R16W. Additional drilling was conducted near the NE corner of the existing tailings containment area (near TWQ-124, see Plate 2-1).

2.2 STRATIGRAPHY AND STRUCTURE

The strata encountered during the recent drilling program ranges in age from mid-Cretaceous to Recent. See Appendix A. The formations include Pleistocene to Recent Alluvium, the Dilco Coal member of the Crevasse Canyon Formation (upper Cretaceous), the Upper Gallup Sandstone and the D-Cross Tongue of the Mancos Shale (mid-Cretaceous).

The alluvium in the study area ranges in age from Pleistocene to Recent. It consists of yellow-brown to gray, fine- to medium-grained clayey sand with local gravel/cobble zones and clay stringers. The alluvium in the north part of the drilled area varies in thickness from 80' in hole 447 to 0' in hole 430. In the southern portion of Section 36 the alluvium ranges from 30' to 45' thick.

In Section 36, the alluvium unconformably overlies the Dilco Coal Member of the Crevasse Canyon Formation (Cretaceous). The Dilco Coal Member consists of sandy to silty, gray shales interbedded with yellowish to grey, fine-grained sandstones. Drilling also shows two relatively continuous, shaley coal seams, each about 1'-2' thick and a petroliferous zone that varies in quality, thickness and stratigraphic position. The petroliferous zone occasionally produces cuttings that seep oil and at times covers the mud pits and PVC with a film of oil.

Plates 2-2 and 2-4 indicate that the Dilco Coal Member crops out at the bottom of the north pond.

The base of the Dilco Coal Member is marked by a shale coal bed that conformably overlies the Upper Gallup Sandstone (Cretaceous). The Upper Gallup Sandstone is divided into three (3) zones which are, in descending order, Zone 3 (predominantly coarse-grained sandstone), Zone 2 (coal/shale zone) and Zone 1 (fine-grained sandstone).

Zone 3 - The unit consists of predominantly medium- to coarse-grained, light gray sandstone with occasional thin beds of brownish gray to dark gray thin bedded shale. The unit is commonly cross-bedded, poorly cemented, and arkosic. The lower part of the unit is often fine-grained with medium- to coarse-grained sandstone zones. Paper thin coaly interbeds are often found in this part of Zone 3. The thickness of Zone 3 increases to the northeast to a maximum of 61 feet in Well 401. In Zone 3 the grain size decreases in an easterly direction between Wells 443 and 447. The contact between Zones 3 and 2 is a sharp pronounced change to an interbedded coal and dark gray shale sequence.

Zone 2 - The unit consists of shale, coal and underclay. In the northern part of Section 36, the sharp contact between Zones 3 and 2 is used to verify stratigraphic position and to determine the total depth drilled. The top coal seam is underlain by an underclay unit that changes gradually downward into dark gray shale. The underclay is gray to dark gray in color. The thickness of Zone 2 ranges from 15' to 20'. In the southern area of Section 36 the coals are thinner and this zone becomes predominantly shale with thin interbeds of fine-grained, gray sandstone. The basal contact between Zones 2 and 1 is gradational over about 5 feet.

Zone 1 - The unit consists of very fine- to fine-grained, light gray to gray sandstone and argillaceous sandstone. In general, the sandstones are associated with thin beds or stringers of carbonaceous shale or coaly materials. Geophysical logs and cuttings logs show increasing clay/shale percentages over the last 45' as this unit grades into the D-Cross Tongue of the Mancos Shale. See Appendix A and Plate 2-6. The thickness of Zone 1 varies between 40' and 75'.

The D-Cross Tongue of the Mancos Shale is conformably overlain by Zone 1 of the Upper Gallup Sandstone. In the current drilling program two holes were drilled to the D-Cross and are located in the vicinity of hole TWQ-124 (holes 448 and 450A, Appendix A of this report). The D-Cross is a thin bedded medium- to dark-gray shale with traces of silt. Drilling was terminated about 2 feet into the D-Cross Tongue of the Mancos Shale. Readers are referred to previous studies for additional details (SAI/Bearpaw, August 1980; SAI, December 1980 and March 1981).

2.3 STRUCTURE

As a result of the closely spaced drill holes, the structural geologic details of the site have been significantly improved upon.

Detailed cross-sections (Plates 2-2, 2-3, and 2-5) show a moderate flexure and local thinning of the Upper Gallup Sandstone. The flexure that is shown to lie on the projection of the Pipeline Canyon lineament. The reader should refer to SAI-Bearpaw report, August 1980.

The implications of this flexure with respect to groundwater movement should be investigated further.

SECTION 3.0 PUMPING SYSTEM DESCRIPTION

3.1 RATIONALE FOR DRILLING

The second phase of drilling began after the March 11 report was submitted and a discharge extension was granted. Thirty new wells were proposed as a continuation of the 400 series pumping well line located between wells TWQ-115D and TWQ-14S (Plate 2-1).

During the first phase of drilling, (prior to March 11), pumping well 401' was screened in several hydrologic units. Packer tests and pump tests were performed to define aquifer properties and water availability. The packer test results were inconclusive and pump tests failed due to low water yield or borehole plugging. Also, water quality analysis indicated a composite water quality, not the quality of each screened hydrologic unit. A pump test was also performed in well 402 which gave unsatisfactory results due to a variable pumping (Q) rate. For these reasons it was decided that single screened intervals, sealed by bentonite, would yield a more accurate test of aquifer pumping capabilities and water quality analyses.

The initial phase of this drilling program and the background information that lead to its execution and the results obtained through March 11, 1981 were presented in a report entitled "An Initial Report of the

Drilling Program in Section 36, UNC Church Rock Mill," dated March 10, 1981. Approximately thirty new wells were placed between wells 402 and 401 to ensure an effective hydrologic barrier against possible contaminant migration. In order to achieve uniform completion, the wells were drilled to the contact between the coarse grained Upper Gallup Sandstone, Zone 3 (a zone of relatively high permeability), and the shale/coal Zone 2 of the Upper Gallup formation (a zone of low permeability). Monitoring the progress and effectiveness of the draw-down barrier is aided by the observation wells.

The observation wells serve two purposes: (1) to monitor drawdown and intersecting cones of depression between the pumping wells, and (2) to observe the possibility of leakage to the north through the pumping line barrier. Observation wells monitoring drawdown are positioned between the pumping wells. As pumping continues, drawdown cones of depression spreading laterally eventually meet and intersect with each other. The second type of observation wells are located 50' or more north of the pumping line.

3.2 WELL DRILLING AND COMPLETION TECHNIQUES USED

Two Gardner-Denver Model 15-W Drill Rigs were used to drill all extraction and observation wells. The objectives were to place the screened interval opposite Zone 3 of the Upper Gallup Sandstone and the lowest sandstone interval of the Dilco Coal Member. For exact depths and screened intervals see Table 3-1, Summary of Well Completion Specifications.

All extraction wells with the exception of Well 422 were drilled to 12 1/4" diameter. Well 422 was drilled to 9 7/8" diameter. The wells were drilled using compressed air as the drilling fluid until water was encountered, then Revert mud drilling fluid additive and water were used to complete the wells.

The extraction wells were completed in the following manner: a bentonite seal was placed at the bottom of each extraction well to prevent communication between Zone 3 and Zones 1 and 2 of the Upper Gallup Sandstone. The casing and well screen were connected using these specifications: a 10' to 20', 6" schedule 40 PVC blank followed by a 50' to 60' interval of 6" Johnson 35 slot PVC wound screen set opposite the Upper Gallup Zone 3 followed by 5" schedule 40 PVC to approximately 2 feet above the ground surface. A 10-20 size sand pack was placed above the bottom seal to the first sandstone in the Dilco formation then 2 to 3 feet of bentonite was placed on top of the sand pack to isolate the sanded interval, followed by cuttings to within 1 to 2 feet of the ground surface. Bentonite was placed on top of the cuttings to the ground surface to provide a seal against downward surface water infiltration. (See Figure 3-2).

SUMMARY OF WELL COMPLETION SPECIFICATIONS

Well Number	Ground Elevation (ft)	Total Depth (ft)	Top of Pipe Elevation	Screen or Slotted Interval	Drill Diameter (inch)	Casing Diameter (inch)	Formation Tested
401	6993.79	282	7000.22	70-80 160-170 182-192 200-230	8-3/4	6	Kcd Kguc Kguf Kguf
402	6965.77	154	6968.99	117-147	8-3/4	6	Kguc
403A	6994.10	283	6996.31	130-175 195-230	8-3/4	6	Kguc Kguf
404	6965.16	159	6968.96	125-155	5	2	Kguc
405	6964.11	157	6967.72	119-149	5	2	Kguc
406	6968.45	156	6971.82	119-149	5	2	Kguc
407	6971.61	162	6974.96	124-154	5	2	Kguc
408	6978.74	285	6982.05	120-165 175-230	6-1/4	2	Kguc Kguf
409	6968.72	260	6971.71	187-250	6-1/4	2	Kguf
410	6977.65	270	6980.65	90-110 130-180 190-240	6-3/4	2	Kcd Kguc Kguf
411	6977.83	180	6981.16	140-175	6-3/4	2	Kguc
412	6977.46	280	6980.17	200-270	6-3/4	2	Kguc-Kguf
413	6991.95	293	6995.63	128-168 198-238	6-1/4	2	Kguc Kguf
414	6991.59	280	6994.88	130-170 200-240	6-3/4	2	Kguc Kguf
415	6988.80	185	6991.76	178-183	6-3/4	2	Kguc
416	6989.12	285	6992.12	135-165 205-275	6-3/4	2	Kguc Kguf
420	6981.72	170	6982.48	116-156	6-1/4	2	Kcd, Kguc
421	6980.64	163	6982.38	95-155	6-1/4	2	Kcd, Kguc
422	6985.09	165	6986.55	95-156	9-7/8	6	Kcd, Kguc
423	6987.94	175	6989.59	108-158	6-1/4	2	Kcd, Kguc
424	6972.22	155	6973.08	89-149	6-1/4	2	Kcd, Kguc
425	6984.81	160	6986.65	94-154	6-3/4	2	Kcd, Kguc
426	6971.37	153	6973.06	91-141	6-3/4	2	Kcd, Kguc
427	6977.27	156	6978.81	94-144	6-3/4	2	Kcd, Kguc
428	6994.54	168	6996.36	103-153	6-3/4	2	Kcd, Kguc
429	6988.88	173	6990.69	113-163	6-3/4	2	Kcd, Kguc
430	6996.19	179	6997.98	116-166	6-3/4	2	Kcd, Kguc
431	6997.94	180	6999.05	116-166	6-3/4	2	Kcd, Kguc
432	6968.00	150	6969.78	84-134	6-3/4	2	Kcd, Kguc
433	6979.26	155	6970.19	84-144	12-1/4	6	Kcd, Kguc
434	6970.36	151	6972.16	89-139	6-3/4	2	Kcd, Kguc
435	6989.65	176	6990.87	103-153	12-1/4	6	Kcd, Kguc
436	6993.42	173	6995.08	114-164	6-3/4	2	Kcd, Kguc
437	6997.36	178	6998.91	104-154	6-3/4	2	Kcd, Kguc
438	6998.02	175	6999.47	109-159	6-3/4	2	Kcd, Kguc
439	6999.57	175	7000.75	101-151	6-3/4	2	Kcd, Kguc
440	6994.75	175	6995.50	110-160	6-3/4	2	Kcd, Kguc
441	6995.82	173	6996.99	109-159	6-1/4	2	Kcd, Kguc
442	6996.71	174	6998.22	111-161	6-1/4	2	Kcd, Kguc
443	6999.73	175	7001.14	109-159	6-3/4	2	Kcd, Kguc
444	6996.17	178	6997.46	112-162	6-3/4	2	Kcd, Kguc
445	6997.36	173	6998.59	109-159	6-1/4	2	Kcd, Kguc
446	6997.60	174	6998.31	108-158	12-1/4	6	Kcd, Kguc
447	6997.63	175	6998.97	111-161	6-1/4	2	Kcd, Kguc
448	6968.31	210	6969.93	150-190	6-1/4	2	Kguf
449	6967.87	75	6969.36	44-64	6-1/4	2	Kcd
450A	6962.85	210	6964.30	150-190	12-1/4	2	Kguf
450B	6962.75	72	6965.18	47-67	12-1/4	2	Kcd

Table 3-1

TYPICAL PUMPING WELL COMPLETION

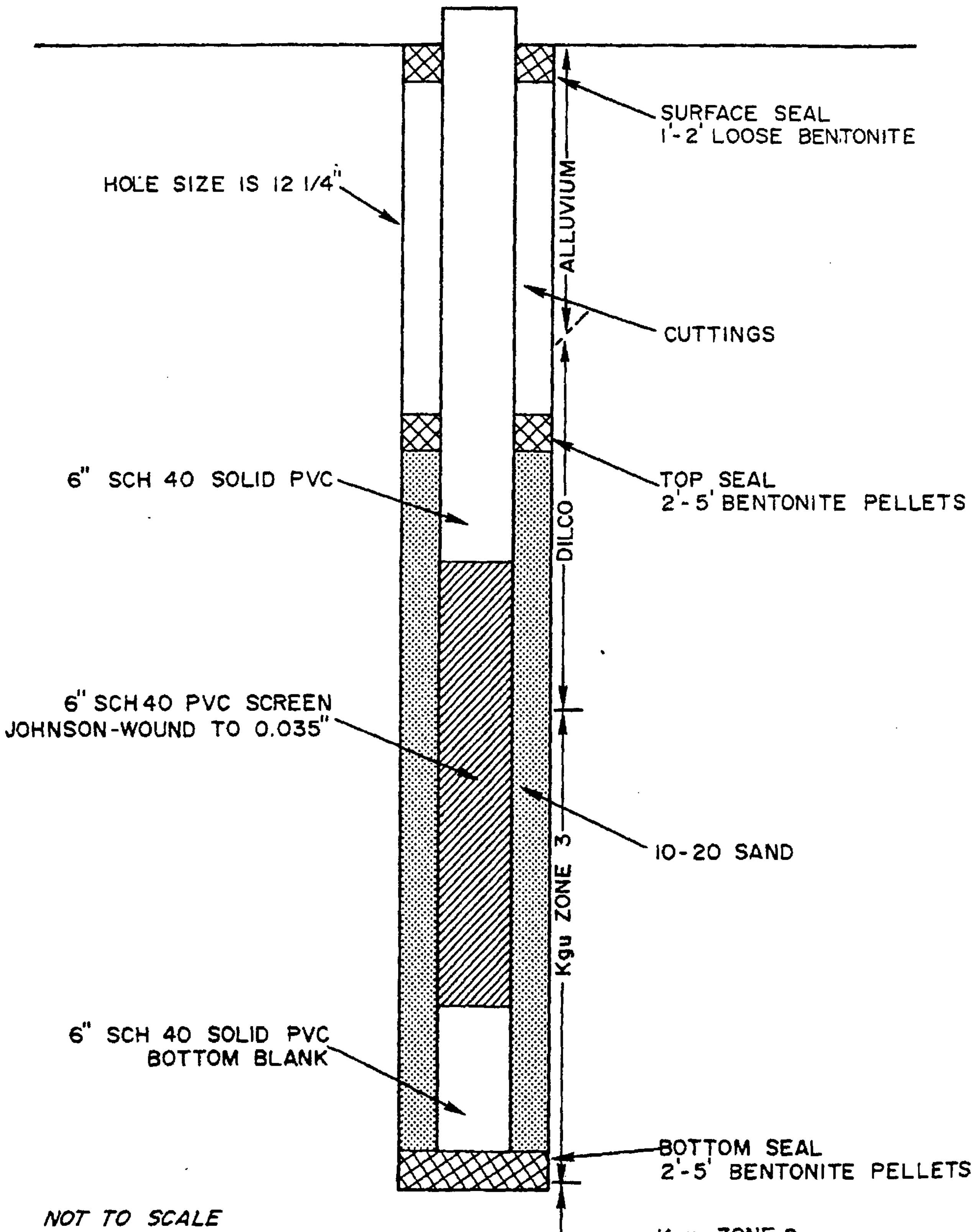


Figure 3-2

The extraction wells were then developed for approximately 24 hours by jetting with compressed air at 10 foot intervals opposite the screened interval to remove the mudcake and any undersized sand which may have been in the sandpack.

Pumps were set in the wells approximately 5 feet above the base of the bottom section of screen.

OBSERVATION WELLS

The observation wells were typically drilled to a 6 1/4" diameter and completed in the same manner as the extraction wells using a 2" diameter schedule 40 PVC and 2" Johnson 35 slot wound PVC screen. The target zones are identical to those of the extraction wells.

3.3 PUMPING SYSTEM

The pumping materials for wells 401, 402, 403A, 422, 424, 433, 435, 438, 444, and 446 were assembled in the following manner: (see Figure 3-3 for a schematic diagram of the assembly). Grundfos SP-10-9 SP 4-14 and SP 2-10 submersible pumps were lowered to the appropriate target zones (230 feet in 401, 130 feet in 402, 200 feet in 403A and 5 feet above the bottom of the lowest screen) with 3/16" stainless steel cable. The discharge line from the pump to the surface consisted of

50' lengths of 1 1/2" to 2" hose joined with steel nipples and hose clamps.

The discharge line was then connected to a flow metering and control system. This system consists of a 2" gate valve (to control the discharge rate), a Conrad totalizing flowmeter (1"), a swedge or check valve (to eliminate backflow in the event of pump stoppage), a 2" "T" to a water sampling system (Figure 3-3). From this point the pumping discharges are channeled to a closed collection system constructed by UNC for conveying the waters to the pond area (Plate 3-1). This collection system consists of 2" feeder lines leading to a 3000 gallon collection tank with two 150 gpm Worthington pumps to convey the water to the Borrow Pit area. The pumps are cycled on and off by water level probes in the collection tank.

The dynamic water level in the pumping well was monitored by an air manometer system. This system consisted of a 1/4" nylon tube taped to the discharge line from 1" above the shoulder of the pump to the surface. The nylon tube was then attached to a 1-200 PSI air gauge. The air pressure source is a 100 PSI capacity air tank and nitrogen tank that discharged through an air gauge and venturi bowl to create a readable back pressure.

Water levels in the observation wells were monitored using a steel tape measure.

GENERALIZED PUMPING ASSEMBLY

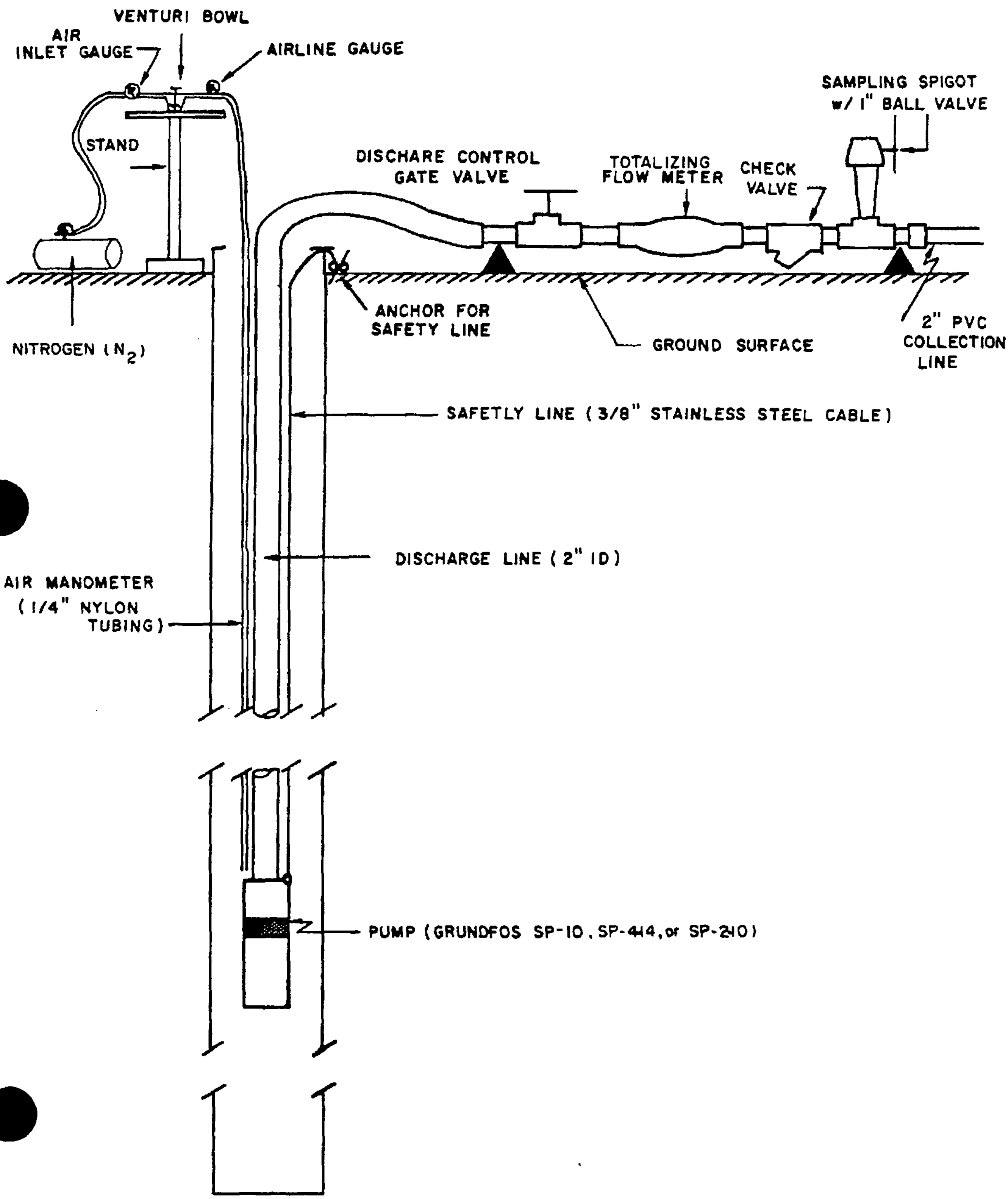


Figure 3-3

Power for lighting and pump operation was provided by a diesel generator near the collection tank.

SECTION 4.0 HYDROLOGY

4.1 AQUIFER TEST RESULTS

4.1.1 PUMPING WELL 402

BACKGROUND

The first pump test was conducted at well 402, using wells 404, 405, 406, 407, 432, 433, TWQ-115, and 409 as observation wells. The aquifer material tested here consists of fine to coarse grained sandstone comprising most of the upper portion of the Upper Gallup Sandstone (Zone 3); this unit is overlain by the Dilco Coal Member and underlain by Zone 2 (an SAI designation), which consists of a 10 to 20 foot sequence of coal and shale within the Upper Gallup (see Section 2 and Appendix A for a complete description). Water level observations made during this pump test in well TWQ-115 for the overlying Dilco and in well 409 below the lower shale-coal sequence and into Zone 1 suggest little or no vertical hydraulic communication between these three units. Table 4-1 summarizes pumping and observation well data pertinent to this test; several well location maps are located in the plate section of this Report (see Plates 4-1 through 4-5).

PUMP TEST WELL COMPLETION SUMMARY

(all depths below ground surface)

WELL NO.	TOTAL PVC DEPTH (ft)	SCREENED INTERVAL (ft)	DEPTH TO WATER WHILE DRILLING (ft)	APPROX. STATIC DEPTH TO WATER (ft)	DEPTH TO BOTTOM OF UPPER CONFINING LAYER (ft)	DEPTH TO TOP OF LOWER CONFINING LAYER (ft)	DISTANCE FROM PUMP WELL (ft)	REMARKS
402	154	117-147	80	65	121	154	0.0	402 E-log
404	159	125-155	Unknown	65	121	154	50.7	402 E-log
406	156	119-149	Unknown	76	121	154	75.6	402 E-log
432	144	84-134	73	73	124	154	52.4	402 & 433 E-logs
433	149	84-144	70	76	124	154	96.9	403 E-log
438	169	109-159	130	124	128	158	0.0	438 E-log
430	176	116-166	130	121	128	160	65.4	403 & 438 E-logs
437	174	104-154	130	121	128	160	50.8	403 & 438 E-logs
439	171	101-151	50	126	127	159	50.2	438 & 443 E-logs
431	176	116-166	115	126	127	159	68.6	438 & 433 E-logs
411	180	140-175	Unknown	113	130	180	811.6 (402) 495.0 (438)	410 & 412 E-logs

Table 4-1

The pumping well is screened within the depth interval of 117 to 147 feet below ground surface and has a sand pack diameter of 8.5 inches. The confined zone which was tested occurs between 121 and 154 feet below ground surface; it showed a static water level approximately 65 feet below ground surface. The duration of the pumping test was 72 hours 33 minutes at a rate ranging between 3.1 gallons per minute (gpm) and 5.0 gpm, and averaging 4.47 gpm over the 72 hours. However, during the first 51 minutes, the flow averaged 3.2 gpm; whereas, during the next 23 hours, it averaged 4.7 gpm (see Figure 4-1). During the analysis these fluctuations in discharge (Q) were approximated by a step function for Q (see Figure 4-1). This function assumes that $Q = 3.18$ gpm for $0 \le t \le 51$ minutes, and $Q = 4.47$ gpm for $t > 51$ minutes. Extractive pumpage at 402 continues. After 260 hours extractive pumpage at adjacent wells commenced; hence, no recovery test was performed nor planned in conjunction with this well. It had not been planned to operate the pump test for more than 72 hours. Additional frequent water level monitoring in all surrounding wells continues to the present, as does extractive pumpage from all pumping wells. For this test, drawdowns were measured with steel tapes in wells 404, 405, 406, 407, 409, 432, 433, and TWQ-115 and with an air line and pressure gauge in well 402. Drawdowns sufficient for subsequent analysis were observed in wells 404, 406, 432, and 433 (see Appendix C). The flow rate from 402 was controlled with an in-line automatic flow rate orifice type control valve; however, silting problems prevented its proper functioning. The flow was metered with a three-quarter inch totalizer type meter reading in gallons.

?

According to Table 4-1, only well 404 completely penetrates the tested coarse sandstone zone. The screened portions of wells 402, 406, 432, and 433 penetrate the upper 79%, 85%, 33%, and 67%, respectively. The sand packs surrounding wells 402 and 406 do fully penetrate the tested horizon, however. This same table also indicates that the coarse zone which was tested was initially under confined aquifer conditions at all observation wells and at the pumping well; furthermore, the aquifer remained confined at all of these well locations throughout the test period.

In the following analysis, owing to the relatively large percentage of screen penetration of wells 402, 406, and 433, and complete penetration by well 404, the effects of partial penetration was neglected. As will be seen below, the results of the analysis appear to be mixed. However, it is felt the major contributing cause to this behavior was not the influence of partial penetration, but rather erratic pumpage rates combined with a dynamic non-equilibrium within the tested horizon.

SEMILOGARITHMIC METHOD

Because of the erratic pumping rates from 402, especially during the first 24 hours of testing, a type curve method of aquifer formation evaluation was considered inadequate, even though log-log drawdown plots appear to follow a Theis type curve very well. Instead, a semilogarithmic procedure was selected because some account of erratic pumpage could be more easily incorporated into the analysis.

The solution to the two-dimensional partial differential equation governing radial confined flow to a fully penetrating well is given by (Theis, 1935):

$$s = \frac{Q_1}{4\pi T}\left[-0.577 - \ln u + u - \frac{u^2}{2\cdot 2!} + \frac{u^3}{3\cdot 3!} - \cdot \cdot \cdot\right] \tag{1}$$

where s is drawdown, Q is some constant discharge, T is aquifer transmissivity, and u is given by

$$u = \frac{r^2 S}{4Tt} \tag{2}$$

The function between brackets in equation (1) is called the well function, $W(u)$. For $u \leq 0.01$, the first two terms in brackets approximate $W(u)$ with an error of less than 1%. In equation (2) r is the radial distance from the pumping well to the observation well, S is the aquifer storage coefficient, and t is time since the beginning of pumpage. Equation (1) is valid only for a constant discharge, Q. However, if a step change in Q is assumed such that

$$\begin{aligned} Q &= Q_1 \text{ for } 0 \leq t \leq \Delta t \\ &= Q_2 \text{ for } t > \Delta t \end{aligned} \tag{3}$$

where Δt is some specified time interval, then by the superposition principle equation (1) becomes for $u \leq = 0.01$

$$s = \frac{Q_1}{4\pi T}\left[-0.577 - \ln\left(\frac{r^2 S}{4Tt}\right)\right] + \frac{\Delta Q}{4\pi t}\left[-0.577 - \ln\frac{r^2 S}{4T(t - \Delta t)}\right] \tag{4}$$

where ΔQ is the change in pumping rate at some time Δt (see Figure

4-1). The superposition principle applies because the system is linear. Equation (4) may be simplified to

$$\frac{4\pi Ts}{Q_1} = \left(1 + \frac{\Delta Q}{Q_1}\right)\ln\left(\frac{2.25T}{r^2 S}\right) + \ln\left[t(t - \Delta t)^{\Delta Q/Q_1}\right] \qquad (5)$$

which becomes

$$s = \frac{Q_1}{4\pi T} \ln\left[\left(\frac{2.25T}{r^2 S}\right)^{\gamma} \tau\right] \qquad (6)$$

where $\gamma = 1 + \Delta Q/Q_1$ and $\tau = t(t - \Delta t)^{\Delta Q/Q_1}$. On a semilogarithmic plot of s versus $\log \tau$, a best visual linear fit of the data is made. This linear fit projects to τ_0 at $s = 0$; hence,

$$\log\left[\left(\frac{2.25T}{r^2 S}\right)^{\gamma} \tau_0\right] = 0 \qquad (7)$$

and

$$S = \frac{2.25T\tau_0^{\,1/\gamma}}{r^2} \qquad (8)$$

At $\tau = 10\tau_0$ (or over one complete log cycle), $s = \Delta s$; hence,

$$\log \frac{2.25T}{r^2 S}^{\gamma}{}_{\tau} = 1 \qquad (9)$$

and

$$T = \frac{2.30Q_1}{4\pi \Delta s} \qquad (10)$$

Equations (8) and (10) are then utilized as in the traditional Cooper-Jacob (1946) technique.

One should recall that all terms in the well function of equation (1) beyond the second one are neglected in the Cooper-Jacob approach

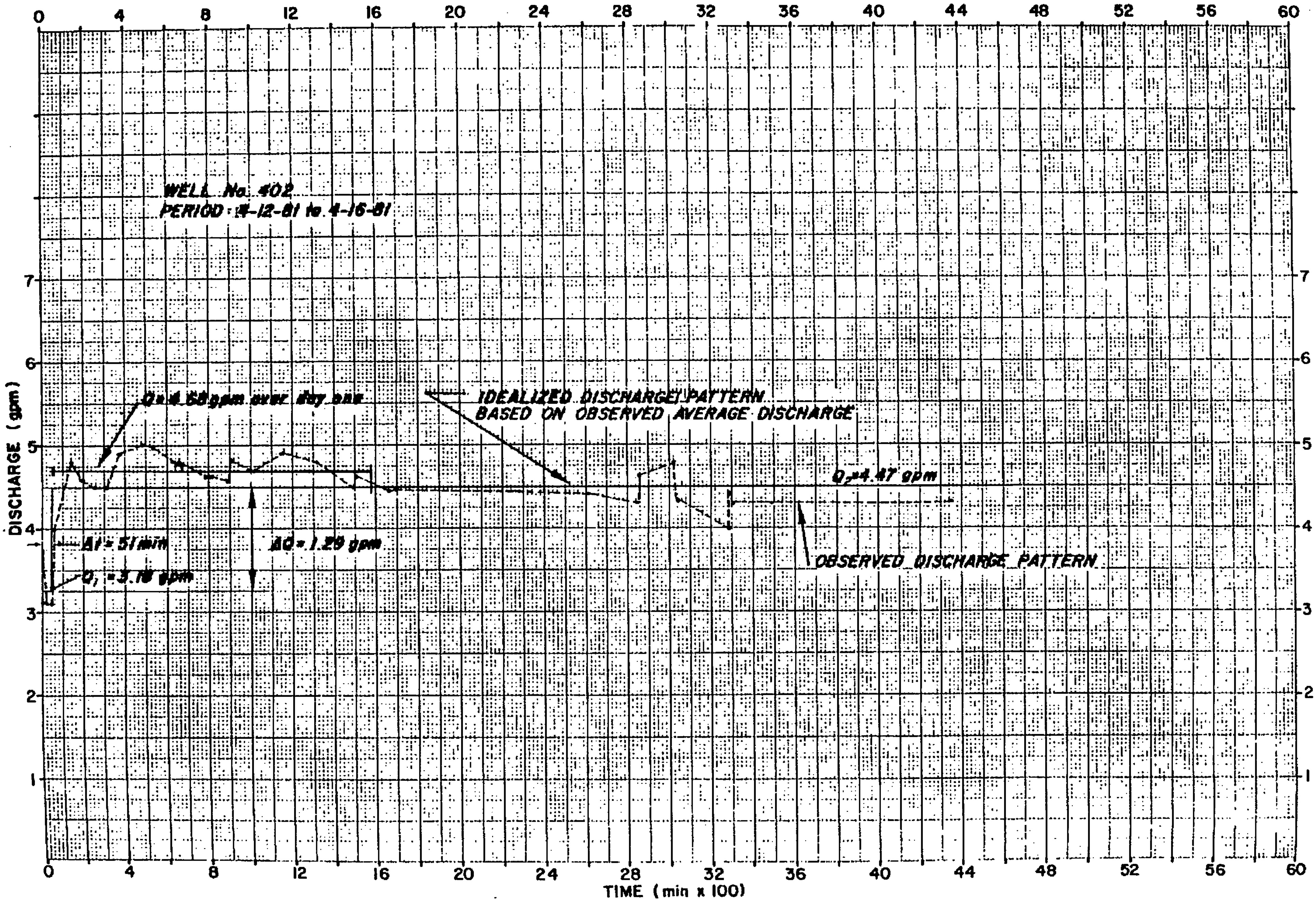


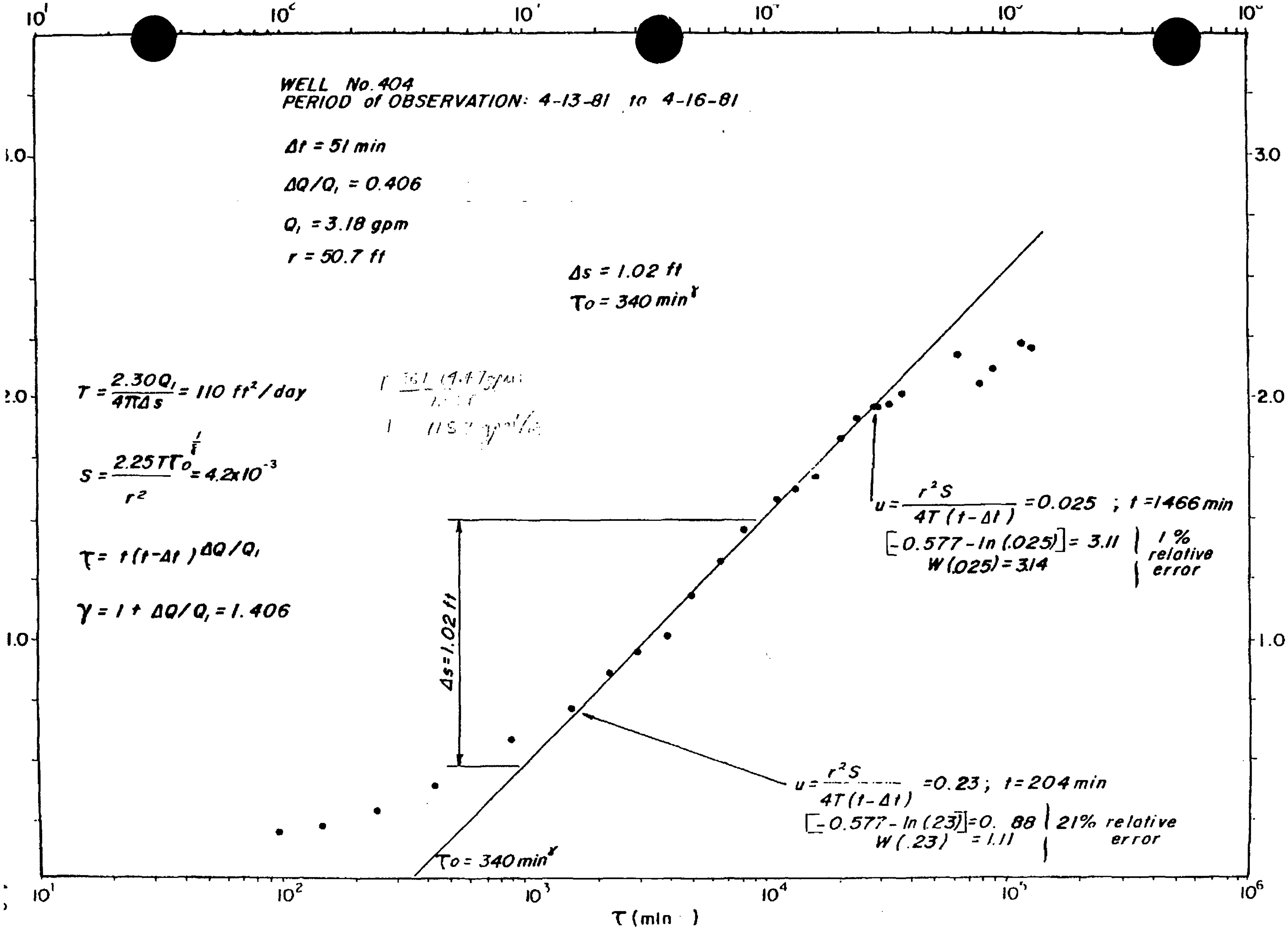
Figure 4-1. Pumping History in Well 402

(i.e., the bracket terms are truncated beyond the second term). This truncation procedure is valid only when u, given by equation (2), is less than 0.01 (i.e., at large values of time, t). In our modified solution, equation (2) is also modified to

$$u = \frac{r^2 S}{4T(t - \Delta t)} \tag{11}$$

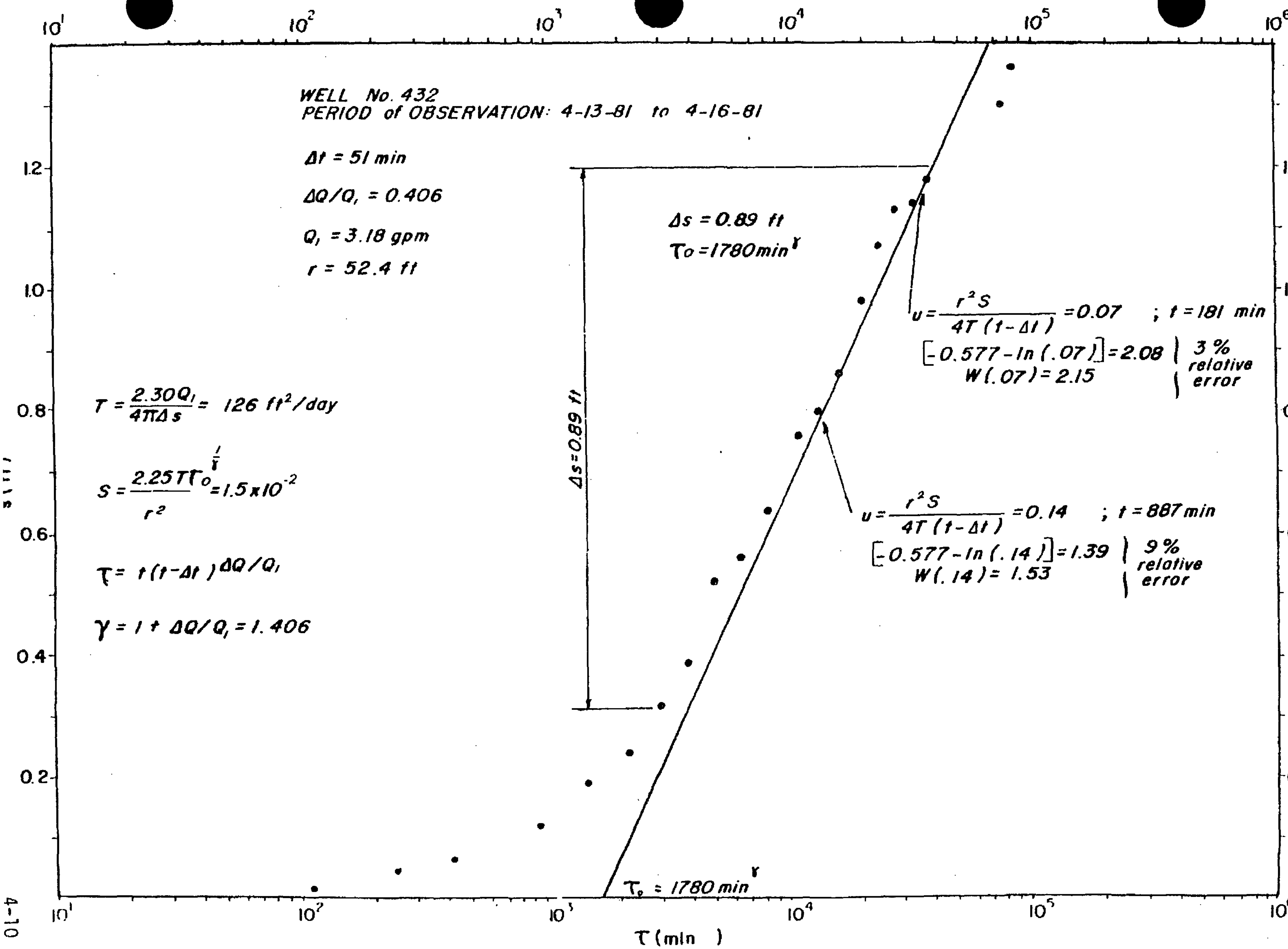
where Δt is the time interval over which the well produces water at a rate of Q_1. At $t > t$, this Q_1 rate is changed by some ΔQ in a stepwise fashion.

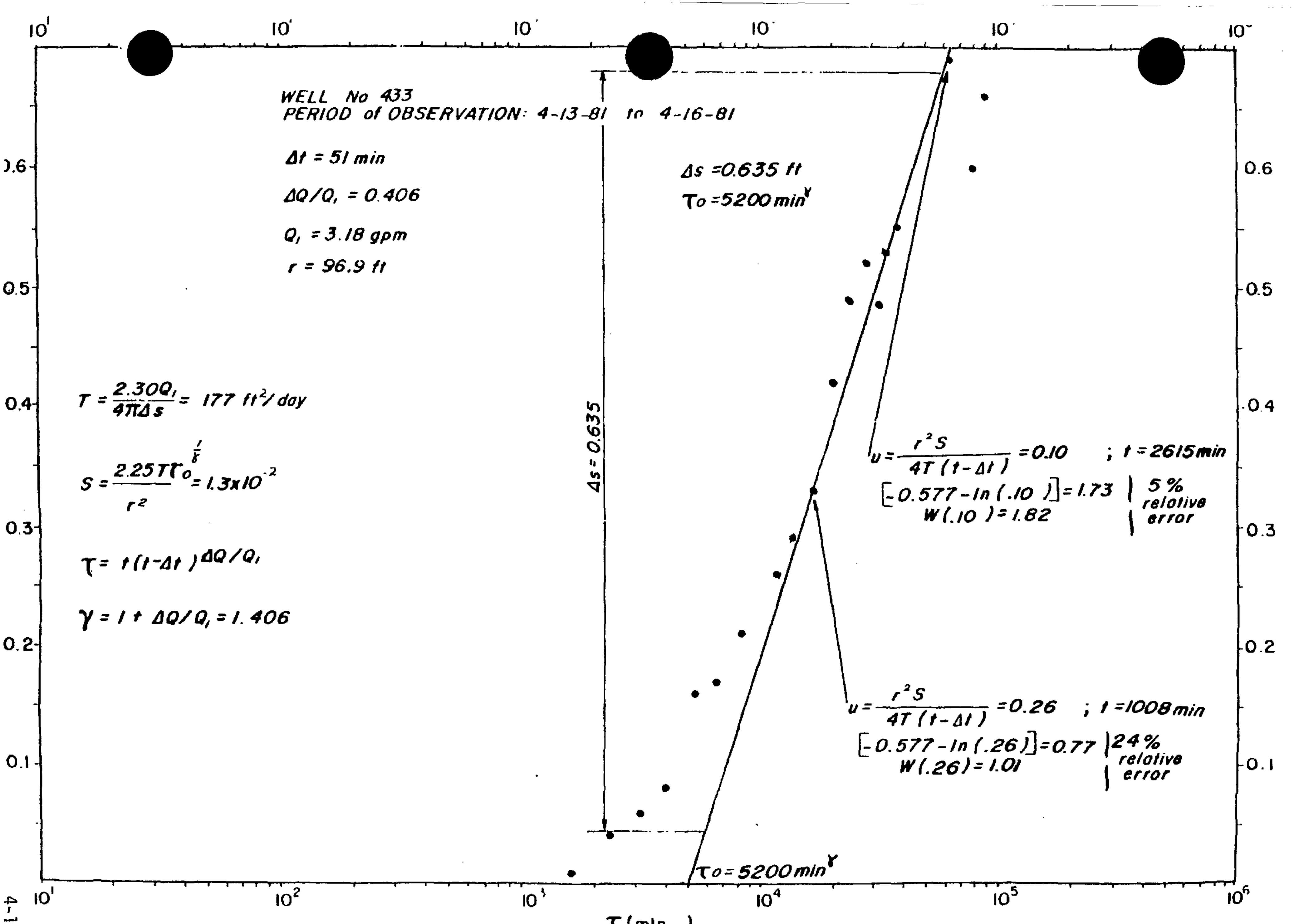
The variation of drawdown with time in observation wells 404, 432, and 433 are shown by small circles in Figures 4-2 through 4-4. The solid lines on each figure are traces of the best visual linear fit of the data. The data from each well are contained in Tables 4-2 through 4-5; actual field data are contained in Appendix B. The coordinates of the τ_o intercept and Δs value over one log cycle corresponding to each observation well are contained on the appropriate figure, as well as computed aquifer parameters for T and S. The results obtained from the drawdown data from well 406 are not presented herein because of the noticeable decline in water level trends before pumping (see Figure 4-5 and Appendix C).



WELL No. 404
PERIOD of OBSERVATION: 4-13-81 to 4-16-81
$\Delta t = 51$ min
$\Delta Q/Q_1 = 0.406$
$Q_1 = 3.18$ gpm
$r = 50.7$ ft
$\Delta s = 1.02$ ft
$\tau_o = 340\ min^{\gamma}$
$T = \frac{2.30 Q_1}{4\pi \Delta s} = 110\ ft^2/day$
$S = \frac{2.25 T \tau_o^{\frac{1}{\gamma}}}{r^2} = 4.2 \times 10^{-3}$
$\tau = t(t-\Delta t)^{\Delta Q/Q_1}$
$\gamma = 1 + \Delta Q/Q_1 = 1.406$
$\Delta s = 1.02$ ft
$u = \frac{r^2 S}{4T(t-\Delta t)} = 0.025$; $t = 1466$ min
$[-0.577 - \ln(.025)] = 3.11$
$W(.025) = 3.14$
1% relative error
$u = \frac{r^2 S}{4T(t-\Delta t)} = 0.23$; $t = 204$ min
$[-0.577 - \ln(.23)] = 0.88$
$W(.23) = 1.11$
21% relative error
$\tau_o = 340\ min^{\gamma}$
τ (min)
1.0
2.0
3.0
10^1
10^2
10^3
10^4
10^5
10^6

Figure 4.2


WELL No. 432
PERIOD of OBSERVATION: 4-13-81 to 4-16-81
Δt = 51 min
ΔQ/Q₁ = 0.406
Q₁ = 3.18 gpm
r = 52.4 ft
Δs = 0.89 ft
τo = 1780 min^γ
T = 2.30Q₁/4πΔs = 126 ft²/day
S = 2.25Tτo^(1/γ)/r² = 1.5 x 10⁻²
τ = t(t-Δt)^(ΔQ/Q₁)
γ = 1 + ΔQ/Q₁ = 1.406
Δs = 0.89 ft
u = r²S/4T(t-Δt) = 0.07 ; t = 181 min
[-0.577 - ln(.07)] = 2.08
W(.07) = 2.15
3% relative error
u = r²S/4T(t-Δt) = 0.14 ; t = 887 min
[-0.577 - ln(.14)] = 1.39
W(.14) = 1.53
9% relative error
τ₀ = 1780 min^γ
τ (min)



WELL No 433
PERIOD of OBSERVATION: 4-13-81 to 4-16-81
Δt = 51 min
ΔQ/Q, = 0.406
Q, = 3.18 gpm
r = 96.9 ft
Δs =0.635 ft
τo =5200 min^γ
T = 2.30Q,/4πΔs = 177 ft²/day
S = 2.25Tτo^(1/γ)/r² = 1.3x10^-2
τ = t(t-Δt)^(ΔQ/Q,)
γ = 1 + ΔQ/Q, = 1.406
Δs = 0.635
u = r²S/4T(t-Δt) = 0.10 ; t = 2615 min
[-0.577 - ln(.10)] = 1.73
W(.10) = 1.82
5% relative error
u = r²S/4T(t-Δt) = 0.26 ; t = 1008 min
[-0.577 - ln(.26)] = 0.77
W(.26) = 1.01
24% relative error
τo = 5200 min^γ
τ (min)

Figure 4-4

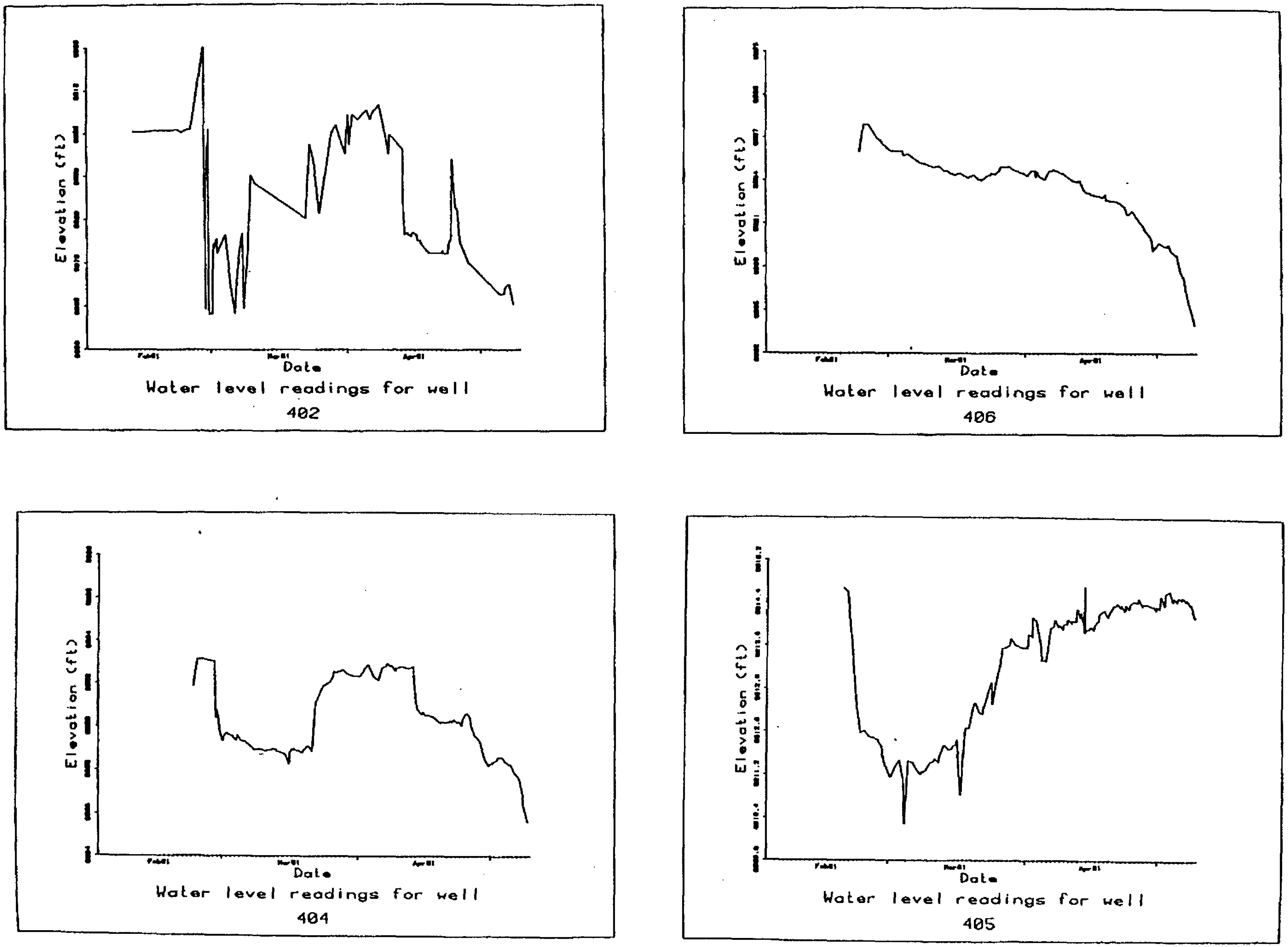


Figure 4-5 Water Level Histories for Selected Wells Near 402; see Appendix C.

OBSERVATION WELL NO. 404 (PUMPING WELL NO. 402)

Period of Observation: 4-13-81 to 4-16-81

Static Depth to Water = 66.23 ft.

r = 50.7 ft

Time (min)	τ^* $(\min^\gamma)$	Steel Tape Drawdown (ft)	Time (min)	τ^* $(\min^\gamma)$	Steel Tape Drawdown (ft)
0.5		0.01	72	248	0.29
1		0.01	93	424	0.39
2		0.02	143	895	0.58
3		0.02	204	1570	0.72
4		0.00	257	2231	0.86
5		0.02	313	2996	0.95
6		0.01	374	3897	1.01
7		0.02	433	4830	1.18
8		0.02	526	6409	1.32
9		0.02	618	8091	1.45
10		0.01	779	11,287	1.57
11		0.01	876	13,354	1.62
13		0.04	1004	16,227	1.67
14		0.02	1166	20,084	1.82
16		0.06	1312	23,756	1.91
18		0.06	1466	27,815	1.95
21		0.07	1505	28,871	1.95
23		0.07	1650	32,897	1.97
27		0.09	1809	37,481	2.01
32		0.11	2609	62,940	2.17
39		0.15	3053	78,591	2.05
50		0.19	3285	87,156	2.11
55	96.5	0.20	4079	118,303	2.22
60	146.3	0.23	4338	129,036	2.20

*See text for explanation

Table 4-2

OBSERVATION WELL #432 (PUMPING WELL #402 and 433)

Period of Observation: 4-13-81 to 4-24-81
Static Depth to Water = 74.26 ft.
r = 52.4 ft.

Time (min)	τ* (min^{γ})	Steel Tape Drawdown (ft)	Time (min)	τ* (min^{γ})	Steel Tape Drawdown (ft)
1		0.00	1811	37,635	1.18
1.75		0.00	2612	63,210	1.37
4		0.00	3041	78,368	1.30
5		-0.01	3275	87,020	1.36
6.25		-0.01	4083	118,801	1.48
8		0.00	4333	129,192	1.46
9.5		-0.01	4588	140,046	1.44
11		0.00	5611	186,012	1.55
13		-0.01	5967	202,861	1.47
15		-0.01	7017	254,919	1.57
19		0.00	7478	278,828	1.59
24		0.00	8419	329,492	1.64
39		0.00	8669	343,356	1.74
57	118	0.01	8869	354,564	1.73
73	256	0.04	10,309	438,236	1.73
95	442	0.06	11,550	514,292	1.72
151	979	0.12	11,693	523,279	1.68
202	1,549	0.19	12,728	589,637	1.77
260	2,275	0.24	13,034	609,688	1.78
318	3,073	0.32	14,142	683,882	1.89
378	3,966	0.39	14,160	685,108	1.89
444	5,020	0.52	14,175	686,129	1.90
528	6,458	0.56	14,242	690,698	2.02
624	8,222	0.64	14,573	713,398	2.14
780	11,333	0.76	14,598	715,121	2.18
887	13,625	0.80	14,617	716,431	2.21
1005	16,288	0.86	14,642	718,156	2.27
1171	20,255	0.98	14,699	722,094	2.36
1314	23,865	1.07	14,756	726,038	2.45
1474	28,100	1.13	14,814	730,058	2.54
1654	33,093	1.14	15,607	785,652	2.93

*See text for details

Table 4-3

OBSERVATION WELL #433 (PUMP WELL NO. 402)

Period of observation: 4-13-81 to 4-16-81

Static Depth to Water: 77.64 ft.

r = 96.9 ft.

Time (min)	τ* (minᵞ)	Steel Tape Drawdown (ft)
76	281	0.00
149	959	-0.01
208	1,620	0.01
264	2,328	0.04
321	3,116	0.06
381	4,013	0.08
457	5,236	0.16
532	6,529	0.17
621	8,165	0.21
786	11,459	0.26
885	13,581	0.29
1008	16,357	0.33
1173	20,305	0.42
1318	23,969	0.49
1475	28,127	0.52
1664	33,377	0.53
1813	37,694	0.55
2615	63,313	0.69
3048	78,623	0.60
3277	87,095	0.66
4086	118,924	0.77
4335	129,277	0.76

*See text for details

Table 4-4

PUMPING WELL NO. 402

Period of Observation: 4-13-81 to 4-16-81

Static Airline Reading = 20.5 psi

Time (min)	Q (gpm)	Airline Drawdown (ft)	Time (min)	Q (gpm)	Airline Drawdown (ft)
0	0.00	0.00	793	4.63	19.84
2	3.10	3.46	809	4.64	-
5	3.70	6.00	899	4.58	19.61
8	3.20	6.92	916	4.81	-
11	3.20	8.07	1017	4.70	19.38
14	3.20	8.07	1162	4.90	19.38
17	3.20	8.07	1306	-	19.61
20	3.20	8.07	1317	4.80	19.61
23	3.00	8.07	1492	4.50	19.38
26	3.10	8.07	1502	4.62	19.61
29	3.10	8.07	1666	4.45	19.61
56	3.90	12.96	1696	4.49	19.84
72	-	14.76	1806	4.47	19.84
99	-	14.99	2619	4.41	20.30
142	4.80	14.99	2862	4.32	19.61
196	4.60	16.15	2884	4.64	-
258	4.50	16.61	3034	4.78	-
315	4.50	16.84	3039	4.33	19.61
375	4.90	17.07	3059	4.34	19.61
436	-	19.61	3284	3.97	19.38
499	5.00	19.61	3299	4.43	-
537	4.97	19.61	3304	4.32	19.38
634	4.82	19.84	4089	4.29	19.84
645	4.78	-	4353	4.32	19.84
650	4.83	19.84			

NOTES:

(1) The ave. Q $(0 \leq t \leq 51$ min.) based on total volume pumpage was 3.18 gpm (i.e., 123.9 gal/31 min.)

(2) At $t \geq 51$ min., Q was increased to an average of 4.47 gpm (i.e., 18,837 gal./4210 min.)

Table 4-5

The results of the 402 pump test are summarized below:

Well No.	T(ft^{-2}/day)	S(dimensionless)
404	110	4.2×10^{-3}
432	126	1.5×10^{-2}
433	177	1.3×10^{-2}

We believe the results from observation wells 404 and 432 are most representative of the coarse aquifer surrounding well 402. The transmissivity estimates from data at these two wells are based on well defined straight lines on the respective semilogarithmic plots. In addition the u values for points on the 404 straight line range from 0.21 for small times to 0.01 for large times. These values of u indicate that a straight line is probably forming in the data at large time. The u values for 432 range from 0.09 for small times to 0.03 for large times, another indication that a straight line is forming in the data. The transmissivity estimate from the well 433 data is higher than that obtained from either the 404 or 432 data. The straight line data on the semilogarithmic plot of 433 is not as well defined as the others; furthermore, the u values are slightly higher, indicating that the straight line is not quite formed yet.

The storage coefficient value is higher at 432 than at 404 by a factor of 3.6; this may result from the anisotropy of the tested medium. The storage coefficients determined from these tests are very high for what the drilling logs and water levels indicate is a confined aquifer.

A review of the T and S values obtained from the data illustrate the apparent inconsistent nature of the system. A combination of factors has in all likelihood produced this behavior. These are: (1) erratic pumpage in well 402, especially during the first 24 hours of testing, (2) the dynamic nonequilibrium of the aquifer surrounding well 402, as seen in Figure 4-5, (3) the potential effects of partial penetration of pumping and observation wells, (4) barometric effects on water level fluctuations, and (5) the apparent anisotropic nature of the aquifer itself, as suggested by the second pump test at 438. The analysis made herein has attempted to address and incorporate the effects of the first factor only. The other factors mentioned above were not taken into account in this analysis. While each factor separately would appear to be small, a combination of all factors apparently is not. Hence, results from this test should be viewed as approximate only.

4.1.2 PUMPING WELL 438

BACKGROUND

A second pump test was conducted at well 438, utilizing wells 430, 431, 437 and 439 as observation wells. The aquifer material tested here consists of fine to coarse grained sandstone comprising most of the upper portion of the Upper Gallup Sandstone (Zone 3); this unit is overlain by the Dilco Coal Member and underlain by Zone 2 (an SAI designation), which consists of a 10 to 20 foot sequence of coal and shale within the Upper Gallup (see Section 2 and Appendix A for a complete description). The tested zone surrounding well 438 is a lateral extension of the same geological horizon tested near well 402, although some aquifer thinning toward the west is evident. Water level observations separately made in the upper Dilco (i.e., at well TWQ-115) and below the lower shale-coal sequence (i.e., at well 400) during the pump test at 402 suggest little or no vertical hydraulic communication between these units; furthermore, Plates 4-1 through 4-3 appear to confirm the areal extent of this observation. Drilling and geophysical logs indicate a continuous lateral extent of all major geological units or zones between wells 401, 438, and 402 (an east-west line); and between wells 412, 438, and 448 (a north-south line). Table 4-1 briefly summarizes pumping and observation well data pertinent to this test; several well location maps are contained in the plate section of this report. (See plates 4-1 to 4-5).

The pumping well is screened within the depth interval of 109 to 159 feet below ground surface and has a sand pack diameter of 12 inches. The confined zone which was tested occurs between 128 and 158 feet below ground surface; it showed a static water level approximately 124 feet below ground surface at well 438. The duration of the pumping test was 91 hours, 3 minutes at a rate that oscillated between 4.1 and 5.9 gallons per minute (gpm), and averaged 5.25 gpm over the 91 hours; however, the majority of these oscillations were confined between 5.0 and 5.6 gpm (see Figure 4-6). After about 91 hours, 15 minutes of

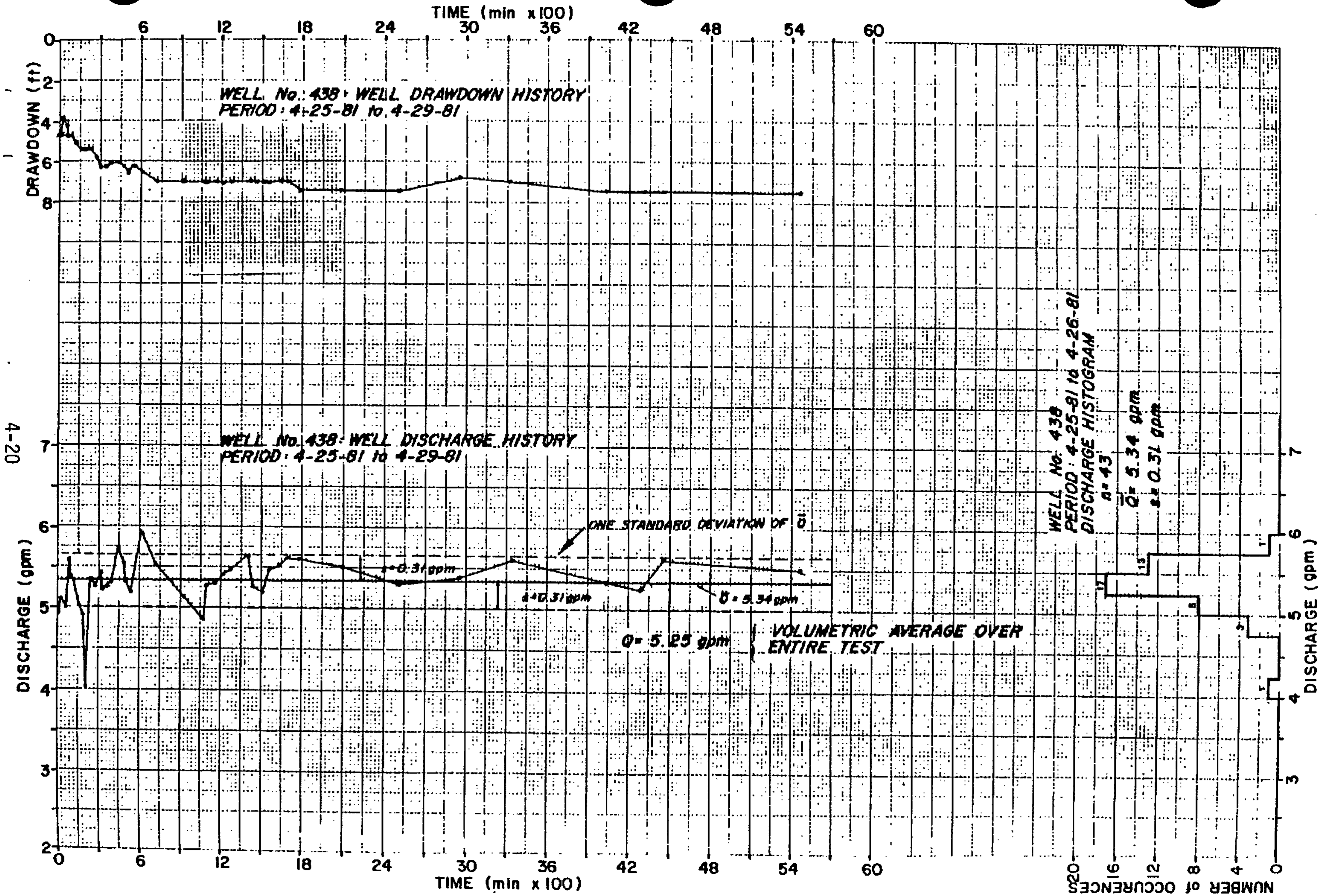


Figure 4-6. Drawdown and Pumping History in Well 438

pumping at 438, adjacent extractive wells commenced pumping operations; hence, no recovery test was performed in conjunction with this well. Additional frequent water level monitoring in all surrounding wells continues to the present, as does extractive pumpage. For this test, drawdowns were monitored in wells 430, 431, 437, and 439 with steel tapes and pressure transducers (wells 437 and 439 only), and in well 438 with an air line and pressure gauge; only steel tape measurements and air line pressures are utilized in the analyses presented herein. The flow rate from well 438 was controlled with an in-line two inch gate valve; the flow was metered with a three-quarter inch totalizer type meter reading in gallons.

According to Table 4-1, wells 438, 430, and 431 completely penetrate the tested coarse sandstone zone, while the screened portions of wells 437 and 439 penetrate the upper 81% and 75% of this same horizon, respectively, although the sand pack of these later wells do fully penetrate the tested zone. This same table also indicates that the coarse zone which was tested was initially under slight confined conditions at all four observation wells and at the pumping well. Furthermore, earlier water level measurements from the 400 series wells indicate that the coarse zone was confined everywhere between wells 401 and 402, except in the immediate vicinity of wells 403 and 403A, (composite wells into the Dilco and Zones 3 and 1), where initial phreatic conditions prevailed. Drawdown data collected over the test interval indicate that at wells 430 and 437 the tested aquifer remained slightly confined, (i.e., water levels only a foot or two above the bottom of the upper confining layer), while at wells 438, 439 and 431 this formation began a transition towards a phreatic condition.

In the following analysis it was assumed that, owing to the relatively large percentage of screen penetration of wells 437 and 439, and complete screen penetration of wells 438, 430, and 431, the effects of partial penetration of observation wells was neglected. As will be seen below, the results of the analysis appear to be quite consistent, an indication that the influence of partial penetration of these observation wells on the data is sufficiently small to be neglected.

Because earlier water level monitoring of the 400 series wells and aquifer testing near well 402 indicated only relatively small drawdowns would be achieved at low pumping rates, it was felt that barometric influences during aquifer testing would be significant. However, the project schedule required a demonstration of intersecting cones of depression between pumping wells along the line between 401 and 402; this procedure precluded any evaluation of formation barometric efficiency in observation wells here. Well 411 was selected for this evaluation because: (1) it was felt that this well was sufficiently removed from the effects of any ongoing pumping, and (2) it was completed only into the coarse sandstone unit where formation testing was already underway at wells 402 and 438. Barometric pressure was continuously recorded from April 22, 1981, through May 19, 1981, with a strip-chart type B-201 barograph (Weather Measure Corporation, Sacramento, California). Water level measurements were frequently recorded in well 411 over a 31 hour period from April 27 to April 28, 1981. This information is summarized in Table 4-6. A plot of water level fluctuations and atmospheric pressure over time (see Figure 4-7) clearly suggests a relationship between these parameters. The definition of barometric efficiency (BE) is given by (Bear, 1972):

$$BE = -\frac{dH}{dP_a} = -\frac{\Delta H}{\Delta Pa} = \frac{H_1 - H_2}{Pa_1 - Pa_2} \qquad (12)$$

where ΔH (units of length) is the change in water level resulting from a change in atmospheric pressure, ΔPa, (units of length). Equation (12) contains a negative sign convention to indicate that an increase in atmospheric pressure results in a corresponding decrease in aquifer water level. This relationship applies to confined and semi-confined aquifers. Theoretically, the dimensionless BE varies between 0 and 1, but typical values of 0.60 to 0.80 are commonly reported in the literature. Equation (12) says that ΔPa and ΔH are linearly related. That is:

$$\Delta H = a + b(\Delta Pa) \qquad (13)$$

where a and b are constants; furthermore, a is ideally equal to zero and b equals BE. A linear plot of the ΔH and ΔPa data from Table 4-6 is given in Figure 4-8. A least squares linear regression of this data yields:

$$\Delta H = 0.02 + 1.13(\Delta Pa) \qquad (14)$$

WELL NO. 411: BAROMETRIC EFFICIENCY

Period of Observation: 4-27-81 to 4-28-81

Time (min)	Atmospheric Pressure (Pa) (in Hg)	(ft)	Depth-to-Water (ft)	Head*(H) (ft MSL)
0	28.67	32.42	114.29	6866.87
108	28.64	32.39	114.27	6866.89
186	28.61	32.35	114.24	6866.92
268	28.60	32.34	114.23	6866.93
308	28.59	32.33	114.21	6866.95
353	28.59	32.33	114.23	6866.93
368	28.60	32.34	114.25	6866.91
428	28.63	32.37	114.28	6866.88
488	28.62	32.36	114.27	6866.89
548	28.63	32.37	114.26	6866.90
620	28.65	32.40	114.29	6866.87
675	28.65	32.40	114.29	6866.87
736	28.65	32.40	114.29	6866.87
828	28.65	32.40	114.29	6866.87
953	28.66	32.41	114.33	6866.83
1058	28.69	32.44	114.35	6866.81
1248	28.70	32.45	114.36	6866.80
1325	28.70	32.45	114.37	6866.79
1395	28.70	32.45	114.37	6866.79
1518	28.68	32.43	114.35	6866.81
1548	28.67	32.42	114.34	6866.82
1665	28.65	32.40	114.33	6866.83
1737	28.63	32.37	114.32	6866.84

*Top of pipe elevation is 6981.16 ft MSL

Table 4-6

WELL NO. 411: BAROMETRIC EFFICIENCY

$\Delta Pa^{(1)}$ (ft)	Δt (min)	$\Delta H^{(2)}$ (ft)	$\Delta\hat{H}_1^{(3)}$ (ft)	$\Delta H-\Delta\hat{H}_1$ (ft)	$\Delta\hat{H}_2^{(4)}$ (ft)	$\Delta H-\Delta\hat{H}_2$ (ft)
0.09	0	0.08	0.118	-0.038	0.080	+0.000
-0.06	108	0.06	0.084	-0.024	0.059	+0.001
0.02	186	0.03	0.038	-0.008	0.028	+0.002
0.01	268	0.02	0.027	-0.007	0.023	-0.003
0.00	308	0.00	0.016	-0.016	0.016	-0.016
0.00	353	0.02	0.016	+0.004	0.018	+0.002
0.01	368	0.04	0.027	+0.013	0.027	+0.013
0.04	428	0.07	0.061	+0.009	0.054	+0.016
0.03	488	0.06	0.050	+0.010	0.048	+0.012
0.04	548	0.05	0.061	-0.011	0.058	-0.008
0.07	620	0.08	0.095	-0.015	0.086	-0.006
0.07	675	0.08	0.095	-0.015	0.088	-0.008
0.07	736	0.08	0.095	-0.015	0.090	-0.010
0.07	828	0.08	0.095	-0.015	0.094	-0.014
0.08	953	0.12	0.106	+0.014	0.107	+0.013
0.11	1058	0.14	0.140	+0.000	0.135	+0.005
0.12	1248	0.15	0.152	-0.002	0.151	-0.001
0.12	1325	0.16	0.152	+0.008	0.153	+0.007
0.12	1395	0.16	0.152	+0.008	0.156	+0.007
0.10	1518	0.14	0.129	+0.011	0.144	-0.004
0.09	1548	0.13	0.118	+0.012	0.137	-0.007
0.07	1665	0.12	0.095	+0.025	0.125	-0.005
0.04	1737	0.11	0.061	+0.049	0.102	+0.008

(1) ΔPa = Pa - datum, where datum = 32.33 ft of water

(2) ΔH = H - datum, where datum = 6866.95 ft MSL

(3) Computed from a least squares linear regression of the form $\Delta\hat{H}_1 = a_1 + b_1(\Delta Pa)$, where $a_1 = 0.0157$, $b_1 = 1.1319$, and correlation coefficient = 0.853.

(4) Computed from a least squares multiple linear regression of the form $\Delta\hat{H}_2 = a_2 + b_2(\Delta Pa) + c(\Delta t)$, where $a_2 = 0.0051$, $b_2 = 0.8275$, $c = 3.70*10^{-5}$, and the square of the multiple correlation coefficient = 0.966.

Table 4-6 (con'd)

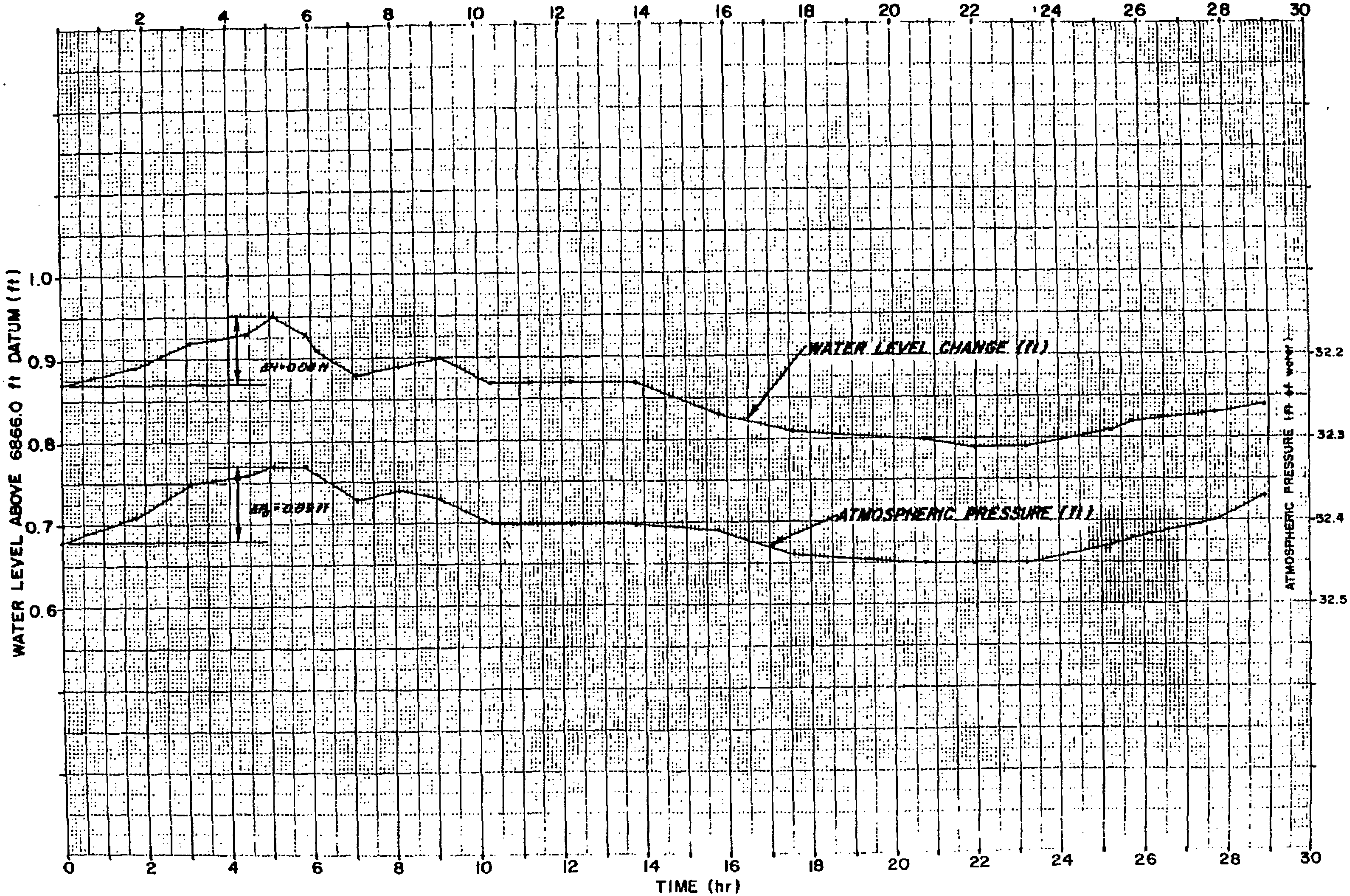

WATER LEVEL ABOVE 6866.0 ft DATUM (ft)
1.0
0.9
0.8
0.7
0.6
WATER LEVEL CHANGE (ft)
ATMOSPHERIC PRESSURE (ft)
ATMOSPHERIC PRESSURE (ft of water)
32.2
32.3
32.4
32.5
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
TIME (hr)

Figure 4-7

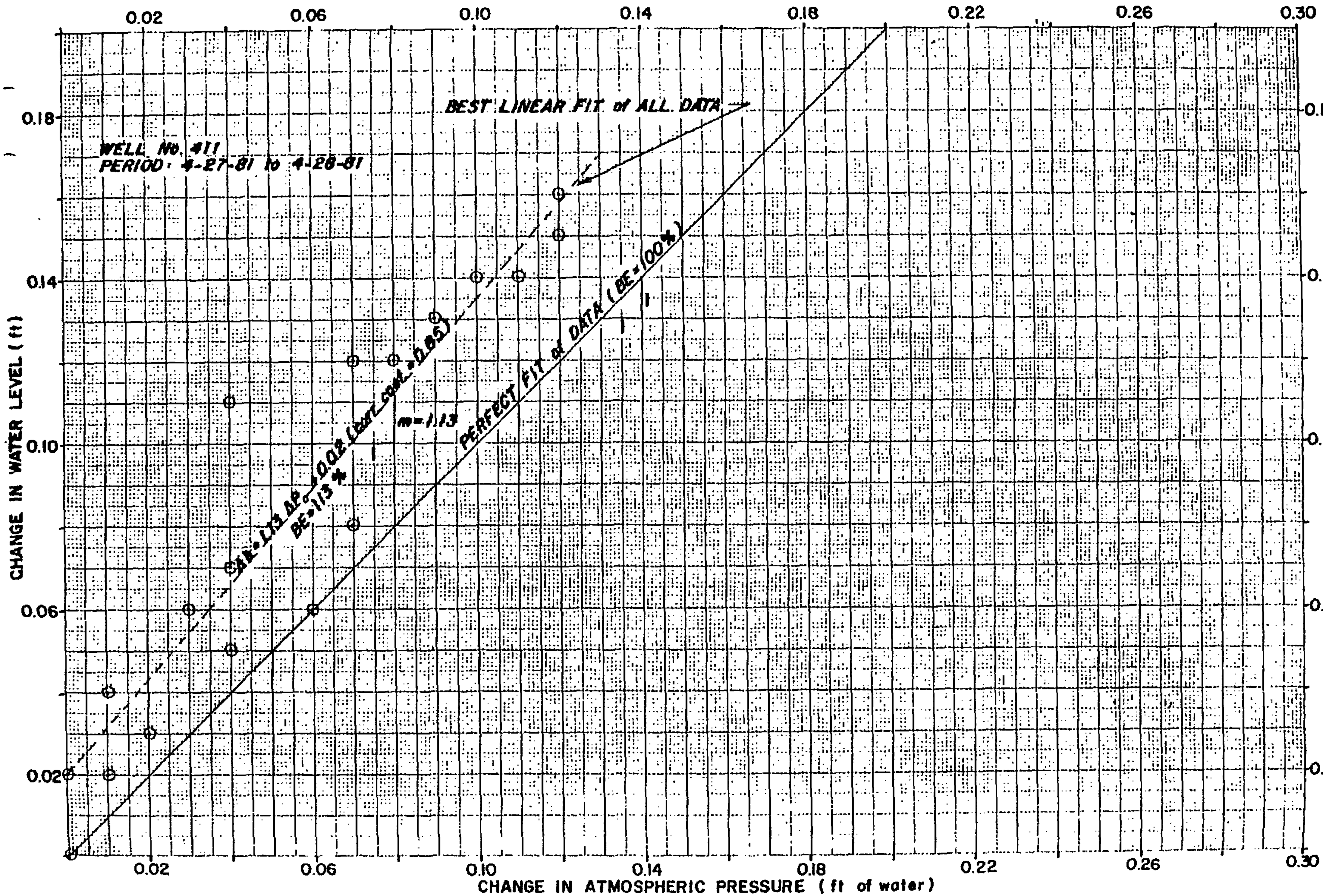


Figure 4-8. Least Squares Linear Regression of ΔPa versus ΔH for Well 411.

This last expression says BE = 113% which is physically impossible. Table 4-6 also contains the estimated $\Delta\hat{H}$ values computed from equation (14) for observed ΔPa values. The residual change in water levels are simply the difference between observed ΔH and computed $\Delta\hat{H}$ values, and are plotted with respect to time in Figure 4-9. An increasing trend in the residuals is clearly evident, suggesting that a relationship of the form given by equation (13) is inadequate for the data from well 411. An apparent reason for this discrepancy between equations (12) and (14) might lie in measurement errors or the short duration of the test. However, if a long-term upward or downward water level trend in well 411 (see the time history plot of water levels in 411, Appendix C) were simultaneously occurring during the test (as is indicated by the residual plot), one would not expect a good correlation between ΔH and ΔPa. Actually a slight downward trend followed by an upward one is present (see Appendix C) over the 31 hour test interval. If we assume that this trend is completely linear in time, then equation (13) should be modified to the form:

$$\Delta H = a + b(\Delta Pa) + C(\Delta t) \tag{15}$$

where a, b, and c are different constants, and where Δt represents time since the start of water level observations. In this form b still represents BE and is compatible with equation (12). A multiple linear regression of these data (see Table 4-6) yields:

$$\Delta H = 0.0051 + 0.8275(\Delta Pa) + 3.70 \cdot 10^{-5}(\Delta t) \tag{16}$$

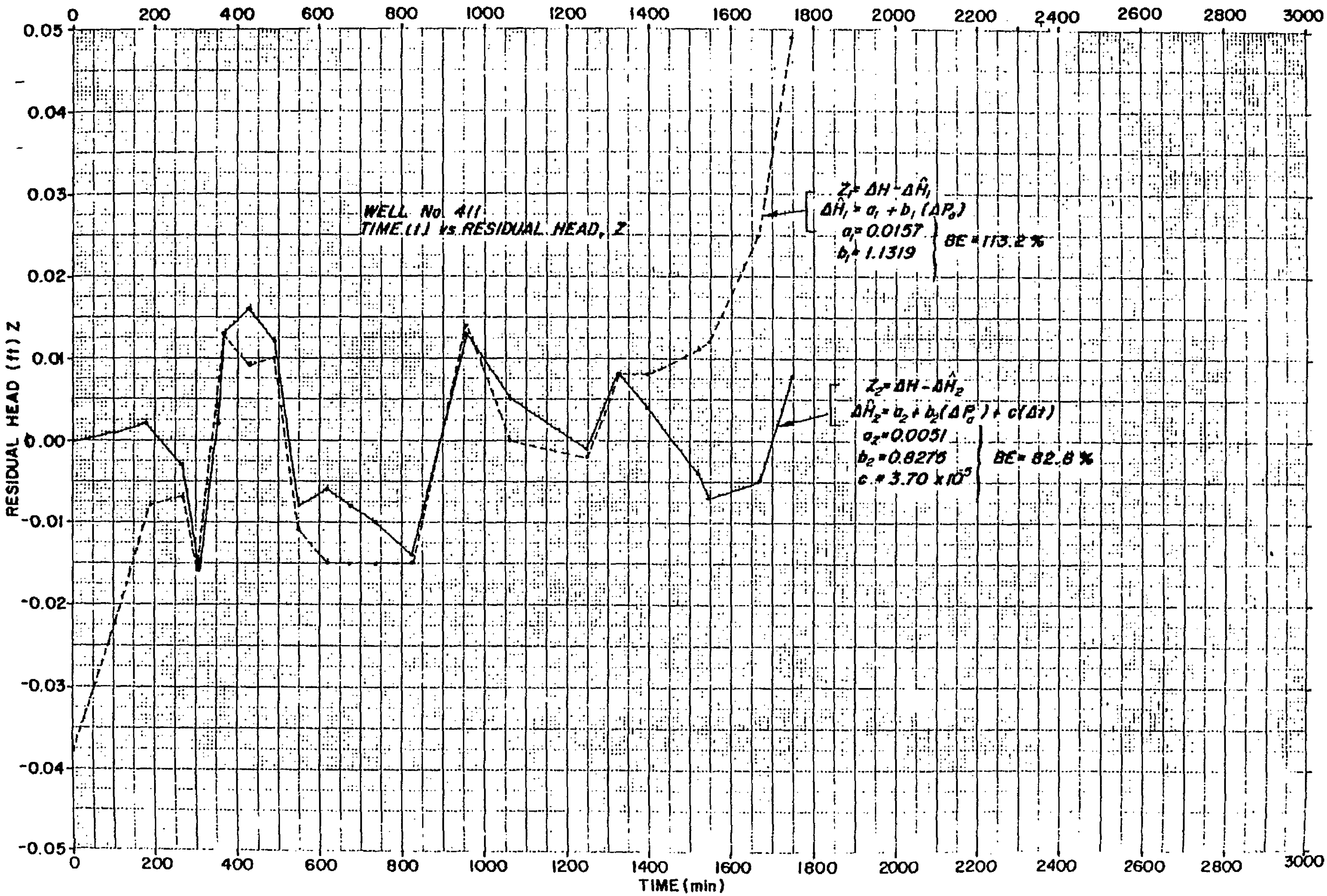


Figure 4-9. Residual heads versus time

The computed residuals utilizing equation (16) are also shown in Figure 4-9. Equation (16) indicates a BE = 82.75%; the value for the parameter c indicates a very slight average ($+3.7*10^{-5}$ ft/min) upward water level trend over the 31 hour test period superimposed on barometric fluctuations. The observed overall downward water level trend, which contains a small observed upward blip in water level during the test, reflects a very early hydraulic disturbance caused by extractive pumpage in wells 402 and/or 438 (see plot 411, Appendix C). Despite this interference effect, equation (16) still yields a reasonable estimate for BE, hence, a value of 82.75% was used to correct all drawdown data from wells 430, 431, 437, and 439 before any type curve analysis. This procedure assumes that the coarse zone BE does not change between wells 411 and those near 438.

TYPE CURVE METHOD

The variation of barometrically corrected drawdown with time in observation wells 437, 430, 439 and 431 are shown by small solid circles in Figures 4-10 through 4-13. The solid lines on each figure are traces of the Theis type curve that appear to give the best visual fit with the data. The data from each observation well are contained in Tables 4-7 through 4-11; actual field data are contained in Appendix B. The coordinates of the match point corresponding to each observation well are contained on the appropriate figure, as well as the computed aquifer parameters for transmissivity (T) and storage coefficient (S).

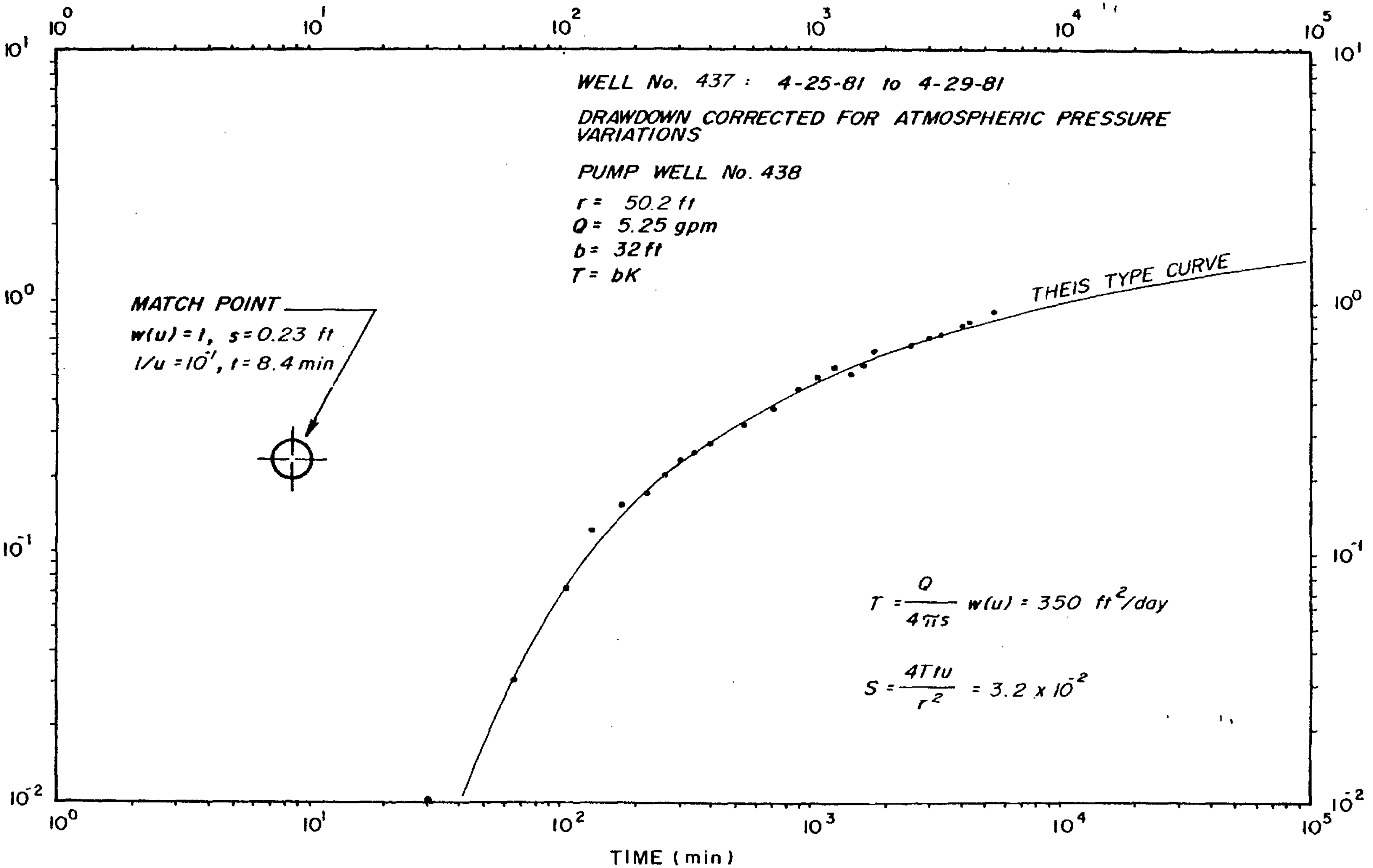


Figure 4-10. Well 437 Drawdown Plot

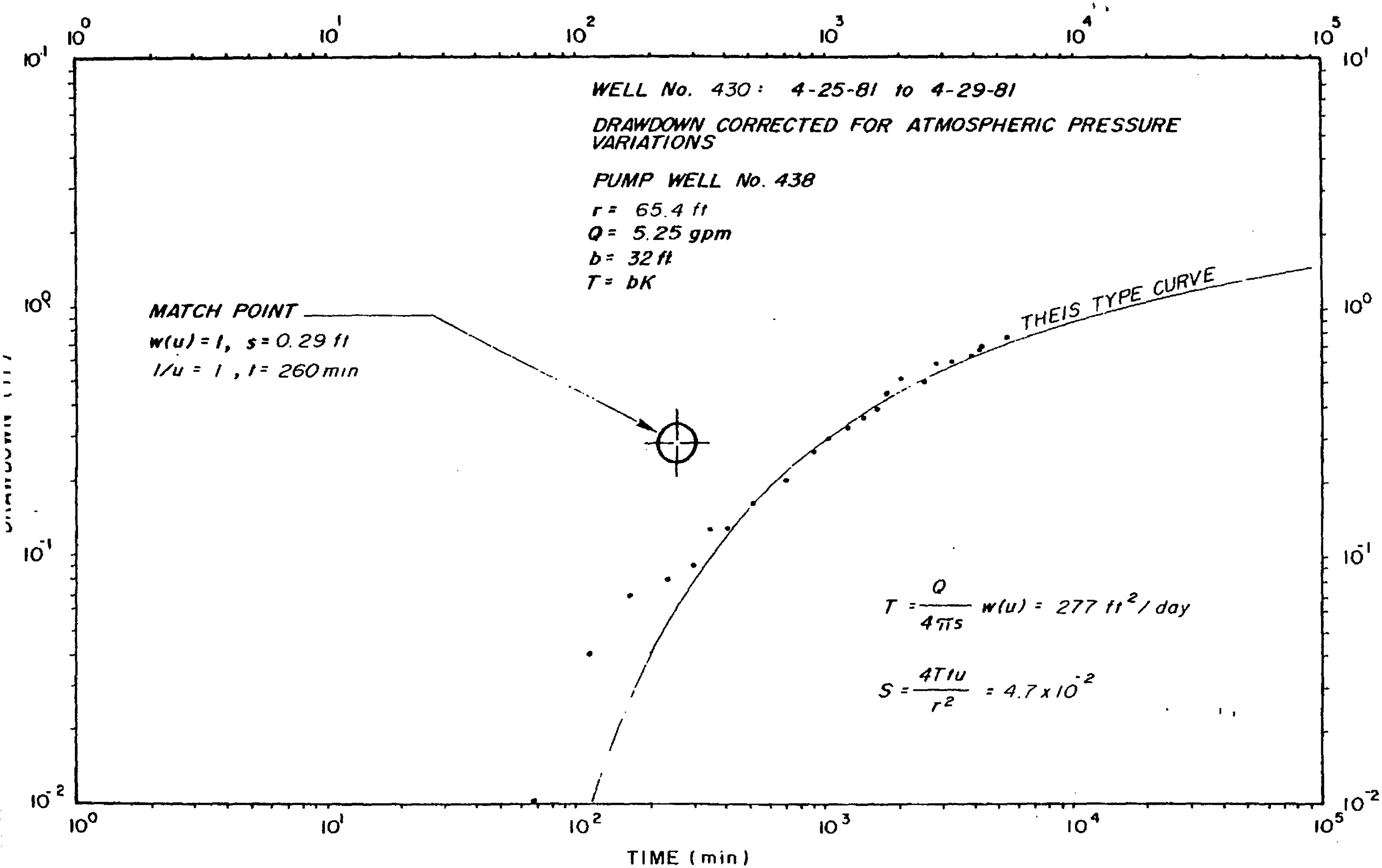


Figure 4-11. Well 430 Drawdown Plot

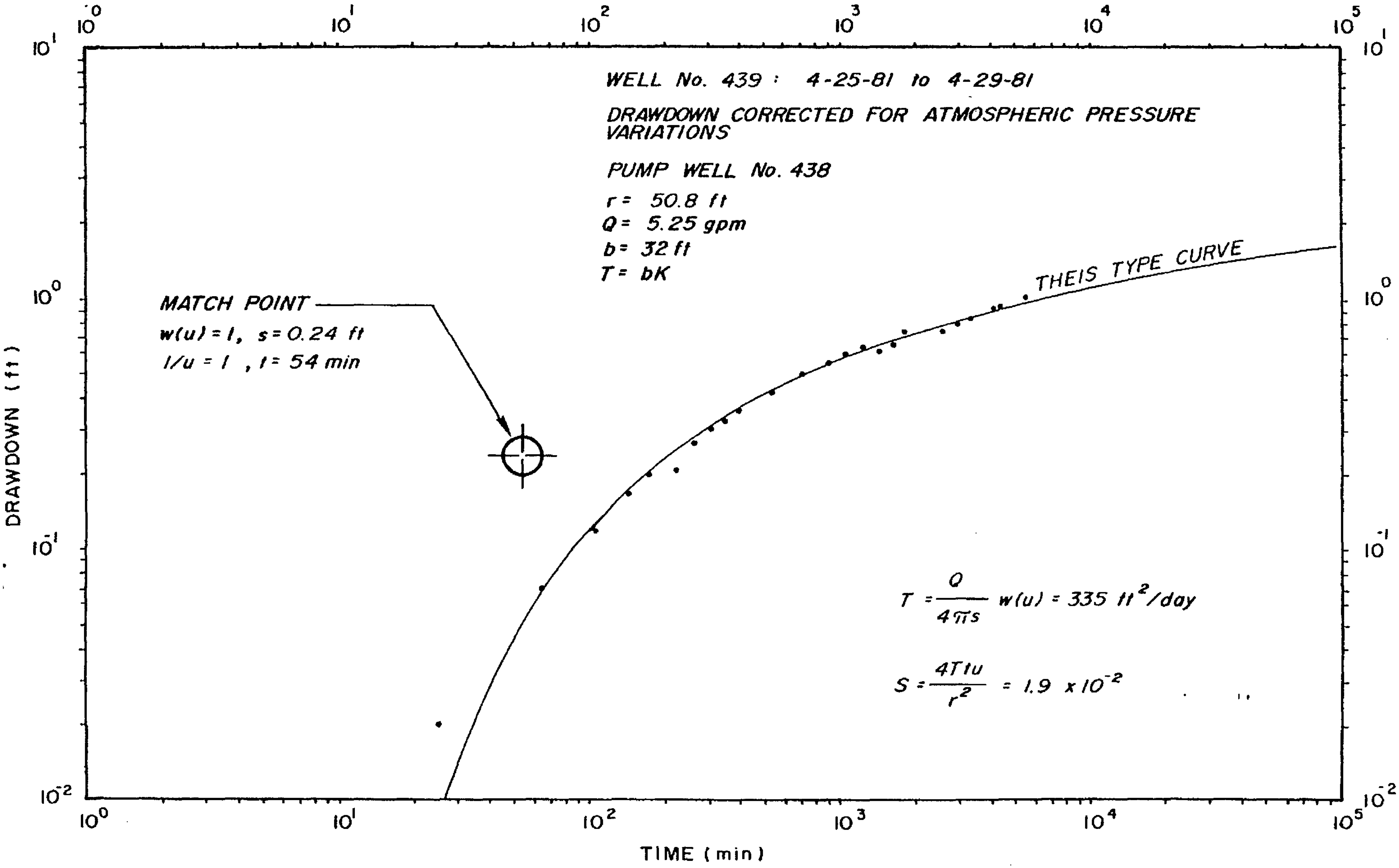


Figure 4-12. Well 439 Drawdown Plot

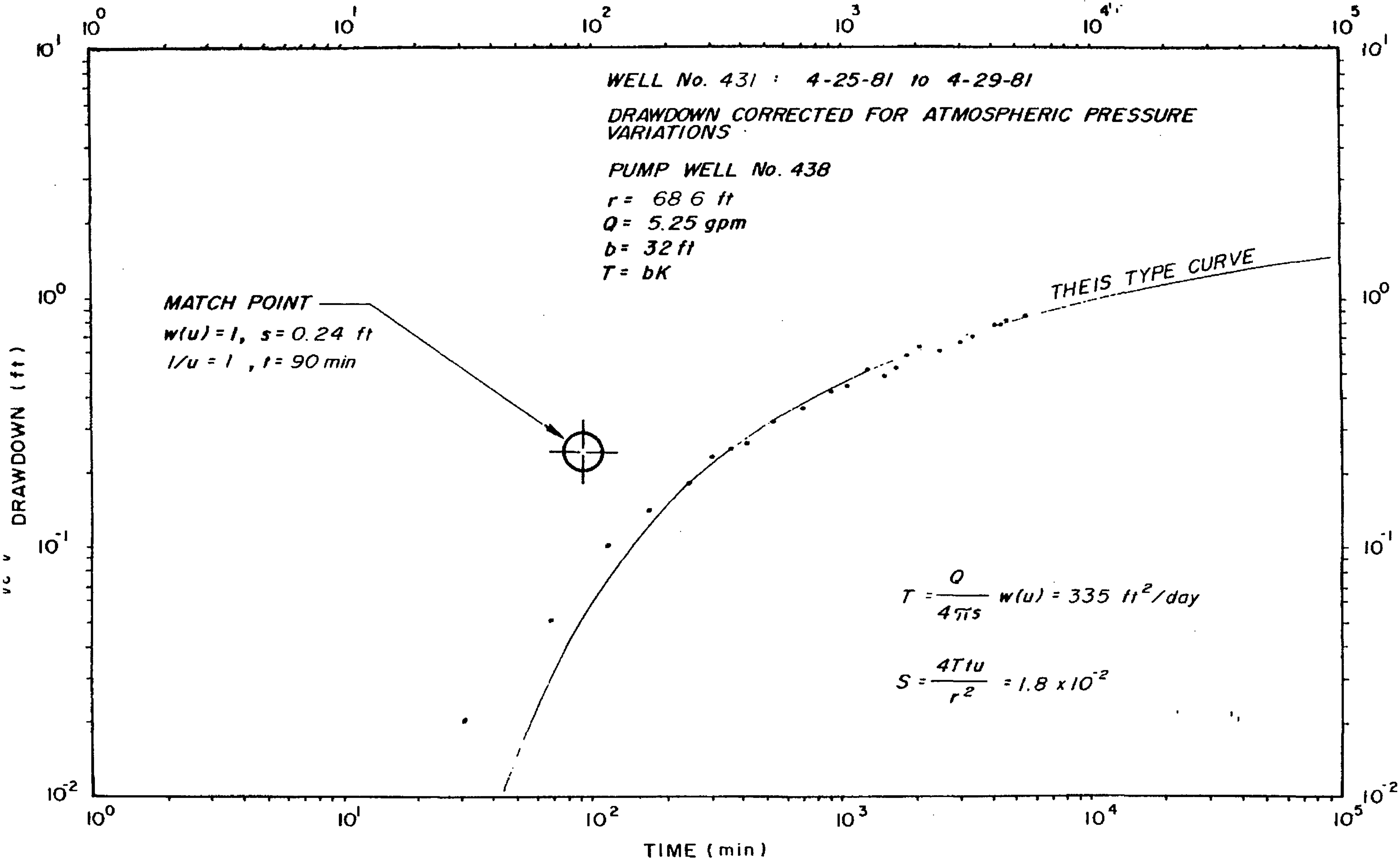


Figure 4-13. Well 431 Drawdown Plot

WELL #437 (PUMPING WELL #438)
r = 50.8 ft.
Q = 5.25 gpm

STATIC DEPTH TO WATER = 122.53 ft.
STATIC ATM. PRESS. = 28.61 in. Hg
B.E. = 82.75%

Time (min)	Drawdown (ft)	Atmospheric Pressure (in. Hg)	Barometrically Corrected Drawdown (ft)	Jacob Corrected Drawdown (ft)
25	0.01	28.60	0.02	0.02
65	0.05	28.59	0.07	0.07
105	0.09	28.58	0.12	0.12
135	0.12	28.56	0.17	0.17
173	0.14	28.55	0.20	0.20
223	0.15	28.55	0.21	0.21
263	0.21	28.55	0.27	0.27
305	0.24	28.55	0.30	0.29
350	0.27	28.55	0.33	0.32
393	0.30	28.55	0.36	0.35
536	0.41	28.59	0.43	0.43
714	0.50	28.61	0.50	0.50
911	0.56	28.61	0.56	0.55
1072	0.63	28.64	0.60	0.60
1250	0.68	28.65	0.64	0.64
1430	0.67	28.66	0.62	0.62
1612	0.67	28.61	0.67	0.66
1795	0.69	28.55	0.75	0.74
2543	0.83	28.69	0.76	0.75
2962	0.80	28.61	0.80	0.79
3329	0.88	28.64	0.85	0.84
4015	1.02	28.71	0.93	0.91
4286	1.02	28.68	0.95	0.94
4433	1.00	28.65	0.96	0.95
5463	1.18	28.75	1.05	1.03

Table 4-7

WELL #430 (PUMPING WELL #438)
r = 65.4 ft.
Q = 5.25 gpm

STATIC DEPTH TO WATER = 122.72 ft.
STATIC ATM. PRESS. = 28.61 in. Hg
B.E. = 82.75%

Time (min)	Drawdown (ft)	Atmospheric Pressure (in. Hg)	Barometrically Corrected Drawdown (ft)	Jacob Corrected Drawdown (ft)
33	-0.01	28.60	0.00	0.00
69	-0.01	28.59	0.01	0.01
114	-0.01	28.56	0.04	0.04
176	0.01	28.55	0.07	0.07
235	0.02	28.55	0.08	0.08
296	0.03	28.55	0.09	0.09
356	0.07	28.55	0.13	0.13
408	0.07	28.55	0.13	0.13
528	0.14	28.59	0.16	0.16
710	0.20	28.61	0.20	0.20
907	0.26	28.61	0.26	0.26
1071	0.33	28.65	0.29	0.29
1258	0.37	28.65	0.33	0.33
1438	0.41	28.66	0.36	0.36
1623	0.38	28.60	0.39	0.39
1801	0.39	28.55	0.45	0.44
2078	0.52	28.62	0.51	0.51
2549	0.57	28.69	0.50	0.49
2955	0.60	28.61	0.60	0.59
3327	0.63	28.64	0.60	0.60
4009	0.73	28.71	0.64	0.63
4283	0.75	28.68	0.68	0.68
4430	0.75	28.65	0.71	0.70
5461	0.88	28.75	0.75	0.74

Table 4-8

WELL #439 (PUMPING WELL #438)
r = 50.2 ft.
Q = 5.25 gpm

STATIC DEPTH TO WATER = 127.35 ft.
STATIC ATM. PRESS. = 28.61 in. Hg
B.E. = 82.75%

Time (min)	Drawdown (ft)	Atmospheric Pressure (in. Hg)	Barometrically Corrected Drawdown (ft)	Jacob Corrected Drawdown (ft)
30	0.00	28.60	0.01	0.01
65	0.01	28.59	0.03	0.03
105	0.04	28.58	0.07	0.07
135	0.07	28.56	0.12	0.12
173	0.09	28.55	0.15	0.15
223	0.11	28.55	0.17	0.17
263	0.14	28.55	0.20	0.20
303	0.17	28.55	0.23	0.23
348	0.19	28.55	0.25	0.25
396	0.21	28.55	0.27	0.27
540	0.30	28.59	0.32	0.32
706	0.37	28.61	0.37	0.37
900	0.44	28.61	0.44	0.44
1078	0.52	28.64	0.49	0.49
1248	0.58	28.65	0.54	0.54
1428	0.55	28.66	0.50	0.50
1619	0.55	28.61	0.55	0.55
1797	0.57	28.55	0.63	0.62
2557	0.73	28.69	0.66	0.65
2974	0.70	28.61	0.70	0.69
3319	0.75	28.64	0.72	0.71
4017	0.88	28.71	0.79	0.78
4290	0.89	28.68	0.82	0.81
4439	0.86	28.65	0.82	0.81
5451	1.03	28.75	0.90	0.89

Table 4-9

WELL #431 (PUMPING WELL #438)
r = 68.6 ft.
Q = 5.25 gpm

STATIC DEPTH TO WATER = 126.46
STATIC ATM. PRESS. = 28.61 in. Hg
B.E. = 82.75%

Time (min)	Drawdown (ft)	Atmospheric Pressure (in. Hg)	Barometrically Corrected Drawdown (ft)	Jacob Corrected Drawdown (ft)
31	0.01	28.60	0.02	0.02
67	0.03	28.59	0.05	0.05
113	0.06	28.57	0.10	0.10
174	0.08	28.55	0.14	0.14
238	0.12	28.55	0.18	0.18
298	0.17	28.55	0.23	0.23
358	0.19	28.55	0.25	0.25
411	0.20	28.55	0.26	0.26
532	0.30	28.59	0.32	0.32
703	0.36	28.61	0.36	0.36
898	0.42	28.61	0.42	0.42
1075	0.49	28.65	0.45	0.45
1261	0.56	28.66	0.51	0.51
1441	0.54	28.66	0.49	0.49
1628	0.51	28.60	0.52	0.52
1799	0.53	28.55	0.59	0.58
2083	0.65	28.62	0.64	0.63
2553	0.70	28.69	0.63	0.62
2970	0.67	28.61	0.67	0.66
3316	0.72	28.63	0.70	0.69
4013	0.86	28.70	0.78	0.77
4288	0.86	28.68	0.79	0.78
4437	0.84	28.64	0.81	0.80
5456	0.99	28.75	0.86	0.85

Table 4-10

WELL NO. 438

4-25-81 to 4-29-81

Time (min)	Q (gpm)	Airline Drawdown (ft)	Time (min)	Q (gpm)	Airline Drawdown (ft)
0	0.00	0.00	721	5.55	6.92
5	4.93	4.62	915	5.16	6.92
16	5.14	3.69	1070	4.89	6.92
39	5.07	4.15	1088	5.27	6.92
50	5.07	4.62	1148	5.32	6.92
70	5.61	4.62	1218	5.45	6.92
92	5.41	4.62	1278	5.50	6.92
118	5.35	5.08	1398	5.65	6.92
148	5.07	5.31	1443	5.29	6.92
178	4.92	5.31	1503	5.23	6.92
210	4.04	5.31	1558	5.49	6.92
243	5.39	5.31	1628	5.57	6.92
273	5.27	5.77	1693	5.65	6.92
303	5.45	6.23	1778	5.63	7.38
338	5.24	6.23	2088	5.53	7.38
373	5.27	6.00	2603	5.33	7.38
391	5.29	6.00	2953	5.40	6.69
444	5.73	6.00	3335	5.63	6.92
480	5.57	6.23	4029	5.38	7.38
506	5.36	6.46	4298	5.28	7.38
546	5.18	6.23	4444	5.64	7.38
612	5.96	6.46	5452	5.54	7.38

Table 4-11

The foregoing type curve method was originally developed assuming that the decline of the piezometric surface remains above the bottom of the uppermost confining layer. For cases where this is not so, the Jacob (1944) correction may be applied prior to the analysis of the pump test drawdown data. Thus the data may be corrected according to:

$$s_c = s^2/2b \tag{17}$$

where s is the observed drawdown (or barometrically corrected drawdown), and b is the aquifer saturated thickness. Originally the Jacob correction given by equation (17) was derived for phreatic aquifers where drawdown is very small in comparison to b. In these cases, s_c then represents the drawdown that would occur in an equivalent non-leaky Theis type confined aquifer. However, this correction has recently been shown to be applicable to a wide variety of situations (Elbakhbekhi, 1976), including the one encountered here. With the small drawdowns encountered during testing at 43S relative to our value for b, however, the Jacob correction makes very little difference (see Tables 4-7 through 4-11) in the resulting T and S values.

The single most interesting result obtained in all observation wells are the consistent values for T and S. The high BE value of 83% would suggest a characteristic S value near 10^{-4} or 10^{-5}, (i.e., a high BE would suggest a confined aquifer condition). Instead, we obtain consistent results for S midway between truly confined (10^{-4}) and truly phreatic (10^{-1}) aquifer conditions (i.e., near 10^{-2}), even for those wells which appeared to remain confined (i.e., wells 430 and 437). In all probability, a delayed gravity drainage effect may be occurring at very early times as the aquifer makes the transition from confined to phreatic. As an equally valid argument, one might suggest that by moving the interpreted bottom of the upper hydraulic confining layer upward from its former interpreted position by only a few feet, a phreatic condition would have existed prior to pumping. This argument would then have to explain why the S values of 10^{-2} are lower than normal phreatic cases (i.e., lower than 10^{-1}). One explanation may lie in the poorly sorted grain size distribution characterizing the coarse zone being tested (see Appendix E), as seen in Figure 4-14. This distribution indicates the presence of about a 15% coarse grain matrix, but with substantial fines present (about 40%). Hence, a storage coefficient (or specific yield) value on the order of 0.02 seems realistic.

One may use the individual T values computed for the observation wells to estimate the major and minor directions of anisotropy (Hantush, 1966; Kruseman and de Ridder, 1976). Such a technique employs only three observation wells, however. If wells 437, 430, and 431 or wells 430, 431, and 439 are selected, the major axis is apparently oriented between N62°E and N72°E, respectively; if wells 437, 431, and 439 are utilized, this major axis is approximately oriented N27°W. Actually these results are not surprising because wells 437, 439, and 431 have nearly identical T values, but data from well 430 produces a substantially lower T value. In fact, well 430 probably extends into a lower

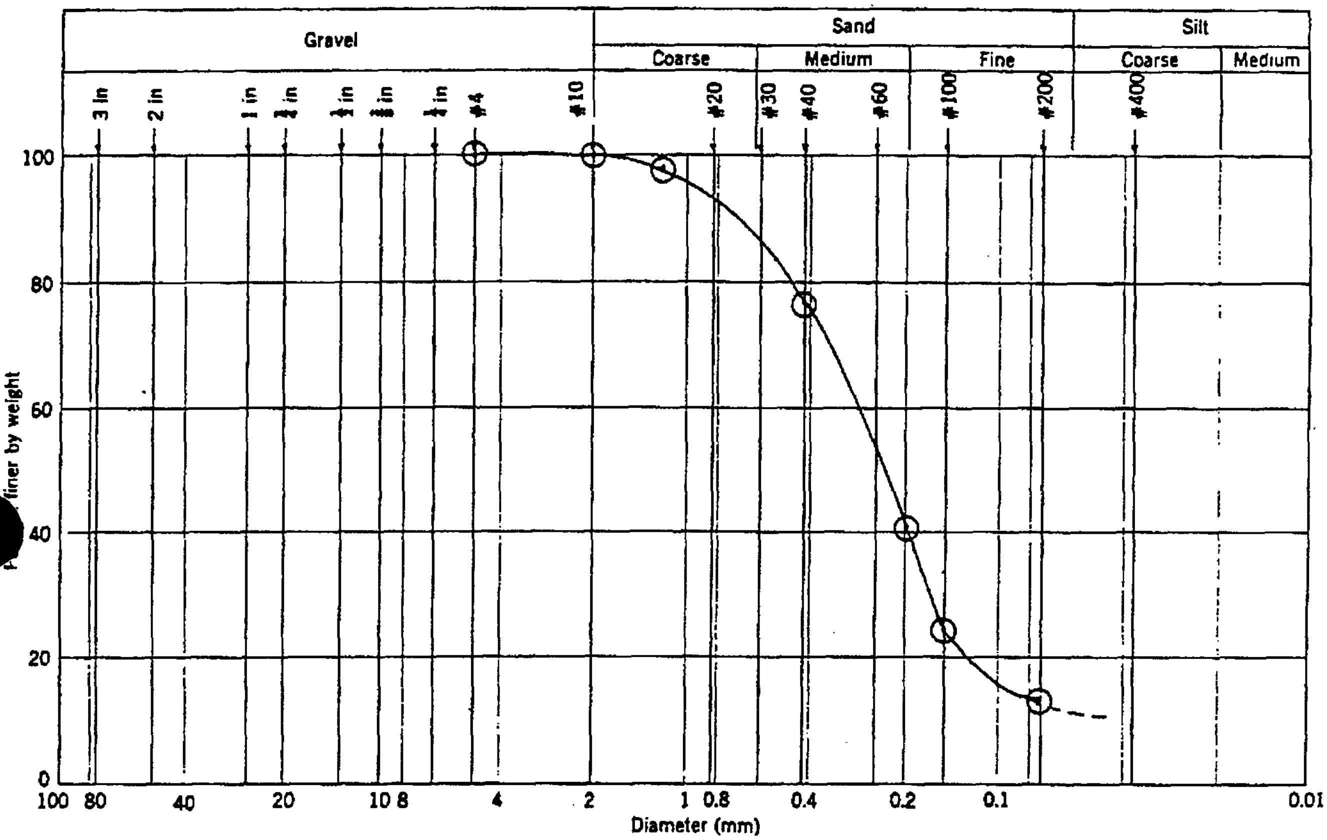


Fig. P3.10

FIGURE:4 -14

GRAIN SIZE DISTRIBUTION FOR ZONE 3 (SEE APENDIX E)

geological zone having a lower hydraulic conductivity. Hence, the major axis for anisotropy is probably N27°W, perhaps reflecting a major local sea and/or wind current direction at deposition, while the corresponding minor axis (N63°E) may reflect an ancient local shoreline trend. Transmissivities along these major and minor axes are about 340 ft^2/day and 205 ft^2/day, respectively; the storage coefficient is about $2.2*10^{-2}$. Results of the anisotropy analysis are briefly summarized in Figure 4-15. With these results in mind, it would be incorrect to interpret flow lines as being perpendicular to the indicated hydraulic gradient on Plate 4-2.

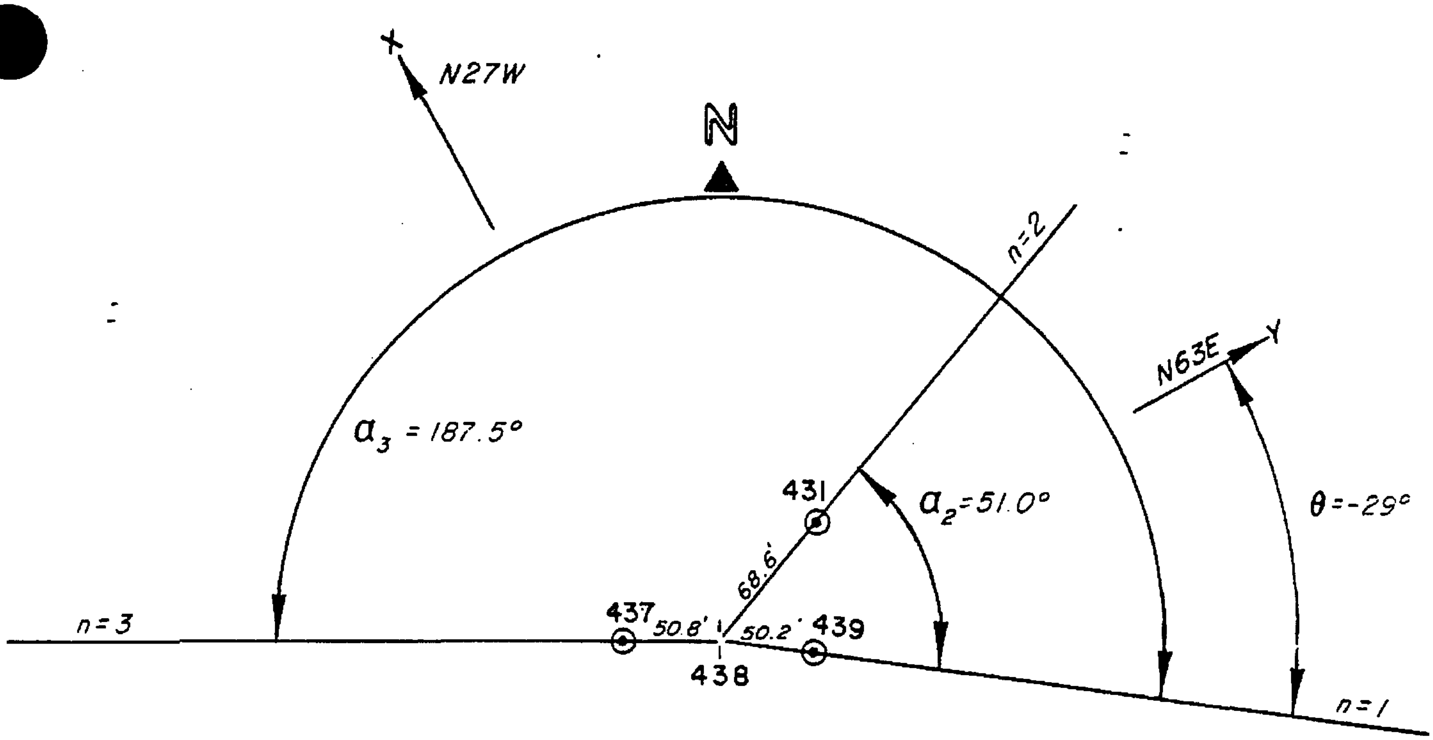
4.2 EFFECTIVENESS OF EXTRACTION WELLS

The pumping system is effective in controlling ground water flow. This is indicated by the evidence of intersecting cones of depression observed in 26 of the system's 34 pumping and observation wells that were analyzable or could reasonably be expected to show intersecting cones of depression. Water level declines of 2' or more were noted in 42 of the 45 system pumping and observation wells completed in the pumped aquifer (Zone 3 of the Upper Gallup Sandstone).

4.2.1 INTERSECTING CONES OF DEPRESSION

The water level data available as of May 13, 1981, indicate that effective intersecting cones of depression have formed around the pump-

CALCULATIONS OF ANISOTROPY ORIENTATION



$a_1 = 1.00$ $\qquad$ $m = 0.60$ for Θ

$a_2 = 1.04$ $\qquad$ $m = 1.66$ for $\Theta + 90^0$

$a_3 = 1.04$

$$T_x = (T_1 \cdot T_2 \cdot T_3)^{1/3} = ((350^{ft^2/day})(335^{ft^2/day})(335^{ft^2/day}))^{1/3}$$

$$T_x \simeq 340^{ft^2/day}$$

$$Ty = \frac{Tx}{m} = \frac{340}{1.66} = 205^{ft^2/day}$$

$$S \simeq (S_1 \cdot S_2 \cdot S_3)^{1/3} = ((3.2 * 10^{-2})(1.8 * 10^{-2})(1.9 * 10^{-2}))^{1/3} = 2.2 * 10^{-2}$$

Reference: Kruseman and deRidder, 1976, p. 125-128.

Figure 4-15

ing system. The wells indicating intersecting cones of depression are roughly located within 100 feet of the extraction line between wells 402 and 438.

Evidence of an intersecting cone of depression was indicated by the observation of two or more significant water level declines occurring in an observation well. Each decline had to occur shortly after a pump was started. To be considered significant, a water level decline had to be 0.4 feet greater than any declines predicted by trends in the data. Static water level measurements indicated that a water level change of 0.4 feet or more is larger than changes that can be attributed to noise in the system.

For pumping a well, it was assumed it would intersect its own cone of depression. Therefore, it was only necessary to show a significant water level decline prior to pumping as a sufficient condition for intersection of cones of depression.

A total of 13 pumping or observation wells were dropped from the intersecting cone of depression analysis. Eight of these dropped wells were pumping wells whose water level measurements were erratic. Water levels in these wells were measured with an air line and a pressure gauge set-up which consistently gave bad readings. Five additional wells were dropped because they were either completed in a different aquifer than the pumped aquifer or located so far away that water level declines could not reasonably be expected to occur in them.

Table 4-12 summarizes the results from the system's 47 pumping and observation wells. The thirteen wells dropped from consideration are indicated with either double or triple or quadruple asterisks. The table is based on water level plots and descriptions of water level declines for the 47 wells. These are presented in Appendix 2-C.

The table indicates that 26 of the 34 wells usable for analysis have definite evidence of intersecting cones of depression. The locations of these wells are shown as solid dots on Figure 4-16.

The 8 pumping wells, considered unusable for analysis, probably have cones of intersection occurring at them. After reviewing the table to determine which pumping wells are causing water level declines on the various observation wells and comparing that information with Plate 3-1 which shows the 47 well locations, one finds that the pumping wells are causing water level declines between 100 feet to 150 feet away. This indicates that a pumping well can cause water level declines on a neighboring pumping well because pumping well spacing in this system is typically 100 feet. This coupled with the fact that a pumping well causes water level declines on itself leads one to conclude that all the pumping wells are intersecting cones of depression.

The same type of thinking further leads one to conclude that several observation wells, which do not show intersecting cones of depression, probably do. Several cones of depression probably arrive at wells

7

EFFECTIVENESS OF EXTRACTION SYSTEM

Well #	Type	Formation Completed	Evidence of Intersecting Cone	Wells Causing Intersection	Total Water Level Decline as of May 13, 1981 (feet)
401	P	Kcd, Kguc, Kguf	**	--	~60
402	P	Kguc	**	--	~40
403	0	Kguc, Kguf	Yes	403A, 438	9
403A	P	Kguc, Kguf	**	--	~55
404	0	Kguc	Yes	402, 433, 424?	7
405	0	Kguc	No	--	0
406	0	Kguc	Yes	402, 433	11
407	0	Kguc	Yes	422?, 424?, 433?	9
408	0	Kguc, Kguf	Yes	402?, 422?, 424?, 433?, 438?	9
409	0	Kguf	***	--	0
410	0	Kcd, Kguc, Kguf	****	--	0
4[illegible]	0	Kguc	****	--	2
4[illegible]	0	Kguc, Kguf	****	--	0
413	0	Kguc, Kguf	Yes	403A, 438	7
414	0	Kguc, Kguf	Yes	403A, 435, 438	6
415	0	Kguc	No	--	4
416	0	Kguc, Kguf	No	--	4
420	0	Kcd, Kguc	Yes	422, 433, 424	10
421	0	Kcd, Kguc	Yes	422, 424, 433?, 438?	8
422	P	Kcd, Kguc	**	--	28
423	0	Kcd, Kguc	Yes	403A?, 422?, 438	10
424	P	Kcd, Kguc	Yes	402, 424, 433	48
425	0	Kcd, Kguc	Yes	402?, 422*, 424?, 433?, 435*, 438?	11
426	0	Kcd, Kguc	Yes	402, 424, 433	13
427	0	Kcd, Kguc	Yes	422?, 424, 433, 435?	11

Table 4-12

Table 4-12
EFFECTIVENESS OF EXTRACTION SYSTEM (Con'd.)

Well #	Type	Formation Completed	Evidence of Intersecting Cone	Wells Causing Intersection	Total Water Level Decline as of May 13, 1981 (feet)
28	0	Kcd, Kguc	Yes	422, 433	10
29	0	Kcd, Kguc	Yes	422, 433	10
30	0	Kcd, Kguc	Yes	403A*, 438, 443*	5
31	0	Kcd, Kguc	Yes	403A*, 438, 443*	5
32	0	Kcd, Kguc	Yes	402, 433	11
33	P	Kcd, Kguc	Yes	402, 433	~25
34	0	Kcd, Kguc	Yes	402, 422, 424, 433	16
35	P	Kcd, Kguc	**	--	~28
36	0	Kcd, Kguc	Yes	403A, 438	8
37	0	Kcd, Kguc	Yes	403A, 438	6
38	P	Kcd, Kguc	**	--	8
[illegible]	0	Kcd, Kguc	Yes	403A*, 438, 443*	6
40	0	Kcd, Kguc	Yes	403A*, 438, 443*	5
41	0	Kcd, Kguc	Yes	403A*, 438, 443*	5
42	0	Kcd, Kguc	No	--	4
43	P	Kcd, Kguc	**	--	12
44	0	Kcd, Kguc	No	--	5
45	0	Kcd, Kguc	No	--	5
46	P	Kcd, Kguc	**	--	Data noisy
47	0	Kcd, Kguc	No	--	3
IQ-115	0	Kcd	**	--	0
IQ-148	0	Kguc, Kguf, Kmdx	No	--	3

- Pumping well
- Observation Well
d - Dike Coal Member
uf - Zone 1 of Upper Gallup Sandstone
uc - Zone 3 of Upper Gallup Sandstone
dx - D-Cross Tongue of Mancos Shale
- indicates that this well may be affecting water levels but effects are masked by
by pumping wells
cates that this well or the one simultaneously started are definitely causing water level declines in observation well
- could not be analyzed because of erratic water levels
* - completed in wrong zone to indicate intersecting cones
** - wells too far away to show intersecting cones

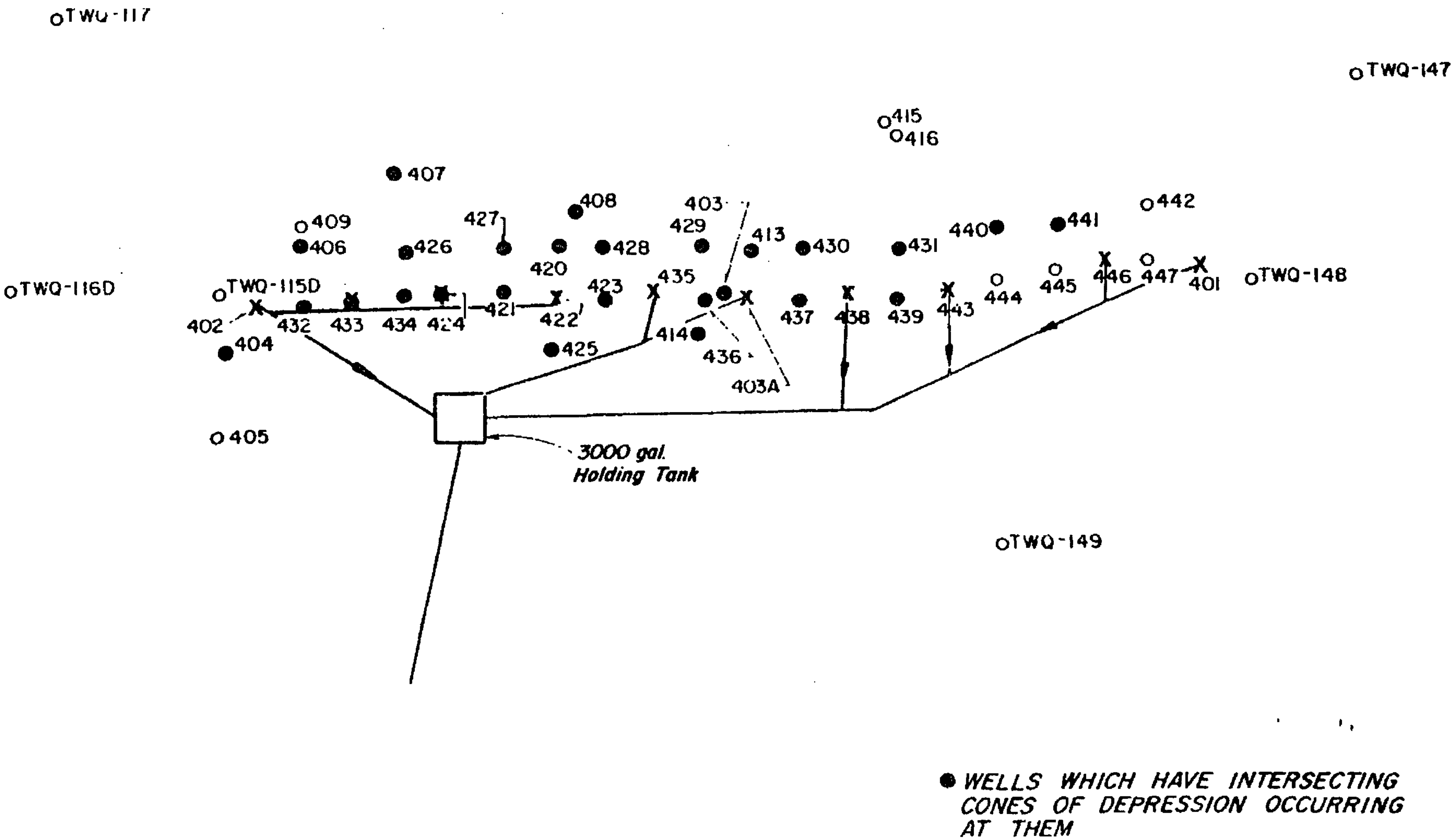


Figure 4-16: Location of Wells Showing Evidence of Intersecting Cones of Depression

442, 444, 445 and 447 simultaneously because the pumping wells that affect them the most (401, 438, 443, and 446) are all started pumping within 24 hours of each other. Because these four observation wells are located approximately 50 feet from two pumping wells, whose radius of influence is 100 feet to 150 feet, one can conclude that intersecting cones of depression are also occurring at these wells.

The results of the preceding paragraphs indicate that as many as 33 of the 42 wells reasonably expected to have intersecting cones of depression can have them. The remaining 9 wells do not have intersecting cones formed at them because they are located more than 150 feet away from the pumping line or are completed in different zones than the pumping wells.

4.2.2 WATER LEVEL DECLINES

The pumping and observation wells responded to the pumping system quite well. Of the 47 well responses looked at, 42 wells responded to pumping of the system. Of the 5 wells that did not respond to pumping, three (409, 412, and TWO-115), were completed in either the Dilco Coal Member or Zone 1 of the Upper Gallup. Two wells (405 and 410) did not respond to pumping because they were far away from the pumping system. Well 405 was expected to respond, but did not respond. Well 441, which did respond, was not expected to respond.

Water level declines ranged from a minimum of 2 feet to a maximum of 13 feet in the observation wells affected by the pumping system as of May 13, 1981. In general, water level declines were greater for observation wells in line with the pumping wells than in observation wells off the line of pumping wells. Water levels in the pumping wells dropped from a minimum of 8 feet to a maximum of 60 feet. Because they are pumped, these wells can be expected to show greater water level declines than the observation wells. Plate 4-4 shows water level declines throughout the system.

A rather large area of depression has formed around the pumping line of wells. The plate indicates the area affected by pumping extends from about 120 feet south to about 400 feet north of the pumping line. The deepest part of the depression is located in the western one half of the pumping line. The deepest part of the depression probably occurs there because the Zone 3 aquifer is confined at that location and has a small storage coefficient. The small storage coefficient makes large declines of head possible when an aquifer is pumped.

The combination intersecting cones of depression occurring in the pumping line's observation wells and the large area of depression indicate that an effective barrier to ground water flow can be maintained north of the tailings pile.

4.2.3 PIEZOMETRIC HEAD CHANGES

DILCO COAL MEMBER

Shown on Plate 4-1 located in the plate section of this report is a piezometric map constructed from water level data obtained on April 13, 1981 from 12 wells completed only into this geological unit; these 12 wells are depicted as dark solid circles on the map. While there is not a complete spatial distribution of Dilco wells in the area covered by this map, some indication of subsurface water gradients are obvious. There appears to be the potential for ground water flow in a southeasterly or easterly direction. While a complete flow picture cannot be determined with the sparce data available, a western recharge boundary is indicated. The hydraulic depression around well TWQ-106 strongly suggests a very localized phenomenon, considering the established water level control at wells TWQ-7, TWQ-123, TWQ-9, and TWQ-121. Vertically downward water movement outside the wellbore of TWQ-106 into the next lower hydraulic unit is indicated by this cone of depression, although Zone 3 (see Plate 4-2) shows no effect of this seepage.

ZONE 3 OF THE UPPER GALLUP SANDSTONE

Plate 4-2, located in the plate section of this Report, is a piezometric head map constructed from water level data obtained on April 13, 1981, from 42 wells completed into Zone 3 of the Upper Gallup

Sandstone. Thirteen of these wells are in partial hydraulic contact with the overlying Dilco, especially at the west end of the pumping line. Water levels in these wells, however, reflect water levels from Zone 3; hence they are also included in Plate 4-2. Zone 3 is the same geohydrologic unit where pump testing was performed at wells 402 and 438; it lies immediately below the Dilco member presented in Plate 4-1. Plate 4-2 indicates a general east to northeast hydraulic gradient existed in this horizon before extractive pumpage began on April 13, 1981, at well 402, and on April 29, 1981, from all extraction wells. It is interesting to note that the preferred direction of aquifer anisotropy (i.e., with respect to hydraulic conductivity) near well 438 appears to be nearly parallel to the indicated piezometric contours there. Thus ground water flow directions may have been oriented more northeasterly than easterly prior to extractive pumpage, as the piezometric head map alone would suggest. That is, in using a piezometric map alone, one generally assumes a homogeneous, isotropic media in order to draw flow lines perpendicular to the hydraulic gradient. This is obviously an incorrect procedure in this case (Bear, 1972, p. 222-241). It should be noted that a western recharge boundary is also indicated on Plate 4-2. In all likelihood mine water discharge enters both the Dilco and Zone 3 below the stream channel route west of TWQ-115, probably along an ancient erosion surface overlain by alluvium. This alluvium, in turn, is in hydraulic connection with the surface stream. Finally it should be pointed out that the hydraulic gradient in the vicinity of 402 prior to pumpage was about three times steeper than that near 438, an indication that transmissivity values increase from 402 toward 438. Furthermore, the transmissivity estimated from the 402 test is about one third of that obtained for the 438 test. These separate observations tend to confirm the validity of the T values obtained from the pump tests.

Plate 4-3 is the piezometric head map constructed from the same wells used for Plate 4-2, except water level observations were made on May 10, 1981, after all extraction wells between 401 and 402 were pumping. The effect of simultaneous pumpage has not changed the direction of the hydraulic gradient in Zone 3. Instead these piezometric contours have become more closely spaced.

Plate 4-4 depicts drawdown resulting from extractive pumpage in the 400 series wells, as measured on May 10, 1981, (i.e., April 13th water levels minus May 10th levels). This drawdown is occurring mainly in Zone 3 (i.e., TWQ-115 remains unaffected by pumpage from 433 and 424, which are screened from Zone 3 up into the overlying Dilco).

ZONE 1 OF THE UPPER GALLUP SANDSTONE

Plate 4-5, contained in the plate section of this Report, is a piezometric head map constructed from water level data obtained on April 13, 1981, from the ten wells completed only into the fine-grained Zone 1 of the Upper Gallup Sandstone. This hydrogeologic unit lies below the coarse zone depicted in Plates 4-2, 4-3, and 4-4. Plate 4-5 indicates a general northerly hydraulic gradient represented by an inverted U shape centered around the 400 series extraction wells. In the absence of any hydraulic aquifer properties one can not reasonably assume only northerly flow, however, as already indicated for Plate 4-2.

When one views Plates 4-1, 4-2, and 4-5 together, it would seem that very little natural vertical hydraulic communication exists between the Dilco, or either zone within the Upper Gallup Sandstone throughout the northern area, as indicated by large systematic head differences; furthermore, the indicated gradient directions for each individual unit appears unaffected by the others. This observation is further borne out by lack of water level fluctuations in wells TWQ-115 (a Dilco well) and 409 (a Zone 1 well) during pumping from 402 (a Zone 3 well). Instead a western recharge boundary (Plates 4-1 and 4-2), the tailings area recharge mound (Plates 4-1, 4-2, and 4-5), and differences in hydraulic conductivity appear to control the piezometric heads within individual stratigraphic units.

4.3 CONCLUSIONS AND RECOMMENDATIONS

The following general conclusions have been reached with regard to the subsurface hydrology surrounding the 400 series wells.

1. The pump test at well 438 yields consistent and reliable results for Zone 3 of the Upper Gallup Sandstone. This test indicated that the major axis of transmissivity here has a value of about

340 ft^2/day, oriented in a direction of N27^{o}W; and a minor axis of about 205 ft^2/day oriented N63^{o}E. Furthermore, the specific yield of this zone is about 2.2 * 10^{-2}; this low value for S_y probably results from the high percentage (about 40%) of fine sandstone and silt contained within the coarse sandstone matrix (about 15%). The pump test at 402 yielded less consistent, and hence only approximate, results. Even so, a decreasing value for hydraulic conductivity toward the test is indicated, since aquifer thickness varies only slightly. The pre-pumping (Plate 4-2) hydraulic gradients near wells 402 and 438 confirm this observation.

2. Piezometric head maps for the Dilco Coal Member, Zone 3, and Zone 1 of the Upper Gallup Sandstone indicate little or no vertical hydraulic communication between these units. The Zone 1 map indicates a general northerly hydraulic gradient resulting from a hydraulic "ridge" within this unit, whereas the Dilco and the middle Zone 3 maps indicate an easterly gradient. This easterly gradient, coupled with the major and minor axes of anisotropy, indicate a subsurface flow direction towards the northeast, especially within Zone 3. This fact, coupled with an indicated recharge boundary located to the west of well TWQ-115 for these upper two units and the presence of the north pump line makes extensive far northern migration within these units seem highly unlikely. The detailed three-dimensional hydrologic picture is not

complete; however, the composite two-dimensional peizometric map submitted with the original seepage study may still approximate the real three-dimensional flow regime in the northern tailings area.

3. Of those wells expected to show intersection of drawdown (a) they were completed in the test formation; (b) they were close enough to pumps to anticipate drawdown; (c) they were not in that part of the line where several pumps were started synchronously; and (d) were not pumping wells with noisy water level data, most demonstrate intersection. Those that do not would not be expected to demonstrate intersection because of the above reasons. Those wells which do not show evidence of intersection because of either synchronous pumping of several pumping wells or noisy data nevertheless are most likely to have been intersected by drawdown from more than one pumping well as evidenced by the radius of influence of the various pumping wells.

One could check each observation well at some time in the future by pulsing the system, but the total evidence of creation of a hydrologic barrier indicates this is unnecessary.

The following general recommendations are made with regard to the northern and eastern areas of the tailings area.

1. Water level and water quality data collection efforts should continue on a selected, but generally less frequent, basis.

2. A sufficient number of additional piezometers should be located into specific hydrogeological horizons between and to the east of wells TWQ-148, TWQ-124, TWQ-151, and 303. Information from these additional observation points would complement that currently available so that a complete hydrologic and geochemical picture could be drawn for the major individual rock units (i.e., the Dilco, Zone 3 and Zone 1). The necessity for completing wells into individual hydrogeologic zones cannot be overemphasized. Reference to the fifth recommendation should be noted.

3. It is generally recognized that subsurface flow away from the recharge mound below the tailings site is a complex three-dimensional hydraulic phenomenon. As such wells completed into multiple hydrogeologic rock units can only supply depth averaged hydraulic and geochemical data. Hence, careful thought should be given to the elimination of certain composite wells. Furthermore, such a procedure would eliminate the potential for cross-formational fluid flow outside individual well casings.

4. Depth to water measurements should be obtained for all wells within a two-mile radius of the tailings site; these measurements

could be obtained from the same wells that UNC currently samples for water quality. Additional information from these same wells should include: (a) total depth, (b) completion technique, (c) perforation interval, (d) well location, and (e) geologic unit opposite perforated interval. This type of information is essential to establish the regional flow system into which the local regime surrounding the tailings area obviously fits.

5. A computer-based mathematical simulation of subsurface flow should be eventually undertaken. Such an effort would help clarify certain boundary or cross-formational hydraulic phenomena that appear to mask the system's actual behavior. Furthermore, all subsequent drilling and testing operations should be undertaken in order to supplement this modeling effort. The simultaneous transport of contaminants should not be incorporated in these initial efforts. The objective of any modeling effort should be to clarify the three-dimensional nature of the hydrologic flow regime surrounding the site. Finally, a modeling effort would tend to add continuity of understanding between the apparently unrelated phases of this project.

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SECTION 5.0 WATER QUALITY OBSERVATIONS

As was discussed in Sections 2.4.3, 2.4.7, and 2.5 of Report 1, water quality monitoring since submittal of the Ground Water Discharge Plan in December, 1980, has been directed toward three major areas of concern:

(1) Water quality assessment of areas north of the tailings area on a short turnaround time basis for a limited number of water quality parameters on a biweekly sampling frequency, and

(2) more extensive full suite analyses for wells adjacent to the tailings area and north, and

(3) evaluation of the extent of contamination near well TWQ-124.

To the extent possible, these data requirements have been responded to and discussed in Report 1.

The water quality data base which has been assembled since the beginning of the investigation at Church Rock is considerable. Aside from the presentation in the discharge plan regarding statistical evaluation of the background concentrations, very little additional analysis of the water quality data has been made. The major efforts have instead been directed toward implementation of different sampling programs and data management. As is discussed in the Summary and Recommendations section of this report, additional water quality data analysis should be implemented prior to additional modification to the sampling program.

However, some general observations concerning the water quality data that have been generated to date are warranted. Because the focus of this report is directed toward assessment of the effectiveness of the extraction pumping wells north of the tailings area, the discussion of the water quality data from the 400 series pumping wells is emphasized herein.

The concentration levels of TDS, sulfate, manganese, molybdenum and uranium all show increasing trends from the westernmost pumping well (402) to the easternmost pumping well (401). Other observations relative to this aspect of deteriorating water quality toward the east end of the pumping line are:

- The flow direction based on water level data for Zone 3 wells is generally toward the east or northeast and not from the south; that is, not from the tailings area.

- The occurrence of "organic traces" and other indications of carbonaceous deposits (tar sands) from driller's logs on the 400 series extraction and observation wells increase toward the east. This suggests that high concentrations of the previously mentioned parameters may be correlatable to these localized carbonaceous zones in the Dilco shale and sandy shale.

- The high concentrations of molybdenum in wells 438, 446, and 401 are of the same magnitude as in the North Pond tailings liquid, which was analyzed prior to complete evaporation of the North Pond. Because of the obvious decrease in TDS and SO_4 between the tailings area and the pumping wells, dilution or attenuation of the molybdenum concentrations in waters pumped from the 400 series wells must have occurred had those waters in fact been derived from tailings seepage. It is noteworthy that the molybdenum concentrations in well TWQ-124, which is contaminated, are consistently less than one milligram per liter (a 10 to 20 fold dilution from the tailings liquid concentrations) at a considerably less radial distance than the 400 series pumping wells from the tailings source area.

These above facts indicate that the chemical concentrations and the increasing concentrations of numerous water quality parameters toward the east side of the 400 series pumping wells are of a localized nature and not due to seepage migration from the tailings area. The increased level of molybdenum in wells TWQ-151 and TWQ-150 are also higher than the molybdenum levels in TWQ-124. The proximity of these two wells to both the tailings areas and the zones of Dilco shale which produce hydrocarbons raises some question as to whether these wells are contaminated from tailings seepage or from in-place organic shales. Coal and other hydrocarbon deposits are known to concentrate heavy metals such as molybdenum, uranium and radium.

Because the Dilco shale has such close association with both the Upper Gallup Zone 3 sand and the tailings area, it is important to note that the wells which are completed in the Dilco or at the Dilco/Zone 3 interface have a fairly consistent water quality, which is of inferior quality to those wells completed only in Zone 3 or Zone 1 of the Upper

Gallup sandstone in the northern area (Section 36). Considering wells TWQ-115D, 449, 450B, TWQ-154 and TWQ-155, it is apparent that the Dilco shale has TDS concentrations ranging from about 4000 to 6000 mg/l. TWQ-154 and TWQ-155 are both completed south and east of the tailings area in the Dilco shale and are unaffected by seepage. It is apparent that the TDS levels in the Dilco shale are relatively constant throughout the area. These ranges of TDS levels suggest that the Dilco shale does contribute some poorer quality water to the Zone 3 sandstone in some areas particularly if allowed to do so by well completion. The vertical hydraulic head distributions between the Dilco and Zone 3 imply the potential for vertical leakage from the Dilco shale to Zone 3 although such leakage is not shown if wells are completed properly.

Assuming the water quality of 450A results from an ineffective bentonite seal (this assumption must be checked), some further conclusions can be reached, using data from the North Extraction Line and 450, 499, 498, and TWQ-124.

- Zone 1 is clean near TWQ-124 and northward.

- The Dilco is not noticeably contaminated near TWQ-124 nor along the North Extraction Line.

- Natural poor water quality with elevation of molybdenum and probably other heavy metals occurs in the Dilco, particularly near the North Extraction Line.

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December 7, 1981

Mr. S. E. Reynolds
State Engineer
New Mexico Natural Resources Department
Water Resources Division
Bataan Memorial Building
Santa Fe, New Mexico 87503

Re: QUARTERLY REPORT - UNC MINING & MILLING
Northeast Church Rock Tailings Facility
File No. 3346

Dear Mr. Reynolds:

In response to the April 2, 1981 letter from the NMSEO, and pursuant to Section 72-5-9 NMSA 1978, the following report is submitted to document the tailings disposal operations and condition of the tailings dam at the NE Church Rock site for the three month period of September, October and November 1981:

DETAILS OF MILL PRODUCTION AND TAILINGS DISPOSAL

Actual mill production for the last three months period, along with tonnages used for mine backfill and tailings solution from Borrow Pit No. 2 returned to the mill, are summarized below:

Item	Sept.	Oct.	Nov.	Total	% Diff. from Last Quarter
Ore processed (dry tons)	38,351	34,814	38,260	111,425	+5.5%
Tons of cycloned tailings sand hauled out from tailings area for mine backfill	1,674	4,929	2,139	8,742	-32.0
Tons of sand actually placed in the mine	0	1,905	2,523	4,428	-53.3%
Tailings solution returned to the mill (gallons)	9,082,000	10,589,000	7,429,000	27,1?0,000	+7.9%

The tailings from the mill were conveyed as a slurry which averaged about 50% solids. Approximately 62.8% of the time, the tailings were passed through the cyclone located on the south side of the central cell. The underflow from the cyclone was discharged in the vicinity of the cyclone, as shown on the map. The cyclone overflow was discharged in the vicinity of the crescent dike. The remaining 37.2% of the time the tailings were spigotted as whole tailings in the north and middle portion of the western part of the central cell. Attached map shows the total hours tailings were discharged at various locations.

The tailings material being used for the mine backfill operation was obtained from the coarse cyclone underflow, being loaded into trucks from a staging area near the cyclone. 8742 tons of sand were trucked during this quarter.

As shown in the summary, the amount of ore processed and the tailings solution returned to the mill increased slightly. The ratio of tailings solution returned to the mill to the tonnage milled remained more or less the same compared to the last quarter. The ten 400-Series seepage extraction pumps on Section 36 were turned off on September 14, 1981, and so were the three 300-Series pumps around the tailings area on November 30, 1981. Therefore, no seepage extraction water is being returned to the borrow pits now.

Tailings fluid which naturally separates from the tailings solids during deposition was contained within the borrow pits. Borrow Pit No. 1 has been filled to about 6968' elevation with slimes and sand and a 2' increase in the elevation of the liquid and/or slimes was permitted by NMEID on November 30, 1981. Borrow Pit No. 2 is also being filled slowly with slime; the maximum permissible liquid level by NMEID in this pit is 6968'. The method of tailings disposal, direction of flow of tailings solution in the central cell, location of pumps and the cyclone remained the same as in the last quarter. The mill operated on a weekly schedule of roughly two and one-third days on.

RELATED ENGINEERING WORK

UNC proposal for construction of central cell embankment raise by 10' was approved by NMEID on September 14, 1981 and by NMSEO on September 15, 1981. The construction of the southeast evaporation ponds and the central cell embankment raise have been deferred at this time, since UNC has taken recourse to other alternatives.

The present plan, which is the culmination of past several months' studies to investigate the feasibility and economies of tailings slurry neutralization, is to neutral ze all the tailings coming out of the mill, as well as the tailings liquids in the borrow pits to pH 7.0 by lime and make use of the north and south cells for neutralized tailings solid and liquid storage. This approach will significantly reduce and ultimately prevent the introduction of contaminated liquids into the aquifers underlying the tailings site. The beneficial effects will be more immediate than commencing construction of evaporation ponds. The proposal has been approved by NMEID on November 17, 1981, and UNC is in the process of answering certain questions asked by NMSEO in their November 17, 1981 letter, to get their approval.

UNC completed the repair of cracks that occurred due to drying in the downstream sandy zone at the breach repair section of the main dam on October 16, 1981. Storage of dry coarse tailings in the north cell has also been deferred since the present plan is to store neutralized tailings liquid there. The project to install the demonstration sprinkling system on the dry beaches of the south cell to control windblown dust has not been commissioned. UNC determined that while operating the sprinkler system, some accumulation of tailings liquid (maximum 2') could not be avoided in the south pond, which is dry. NMEID by their October 22, 1981 letter disapproved any storage of tailings liquid when the installation of the pipe lines was stopped. Again, since the present proposal is to use the south pond for neutralized tailings solids and liquid storage, windblown dust problems will be minimized.

Three other projects were completed during this quarter as follows: Seeding of the Section 36 area where 400-Series wells were drilled was completed in September, the commercial power line was extended in October 1981, to cover various parts of the tailings area; drilling of the new 500-Series wells was completed on November 25, 1981. These wells are planned to identify the extent of seepage, stratigraphic zone-wise around the tailings impoundment area, and thus will enable UNC to design and install a complete seepage control program. The work to seal off certain composite wells to stop communication between aquifers, which may cause additional contamination to the lower zone, is currently in progress. This is to comply with NMEID's letter of July 10, 1981. Final seepage extraction wells of the 500-Series will be drilled in the next quarter, and it is anticipated that the final seepage control plan will be in effect toward the end of next quarter. A request was made by UNC on November 19, 1981 to the NMEID for their approval to modify the water level and water quality monitoring program. This was approved on November 30, 1981. The weekly reporting frequency was also changed to monthly.

CONDITION OF THE TAILINGS DAMS

The stability of the north and south cross dikes and the main dam had remained essentially unchanged during the recent quarterly reporting period. The cross section geometry for the cross dikes and the main dam at the critical locations passing through NP-2, SP-2A and HP-1841, where previous stability analyses (quarter ending May 1981) were performed, remained unchanged, as determined by recent surveying. The changes in the piezometric surfaces affecting the stability of these structures at the cross section locations are summarized below:

PIEZOMETRIC SURFACE ELEVATIONS (FEET)

	Piezometer No.	Previous Period 5/22/81	Current Period 11/30/81	Difference
North Cross Dike	NP-2	6956.71	6956.98	+0.27
South Cross Dike	SP-2A	6964.91	6964.51	-0.40
Main Dam	HP-1841	6951.67	6952.10	+0.43

Changes in the critical factor of safety resulting from the miniscule changes in the phreatic surface, as noted above, will be very very minor. Therefore, there was no need to perform stability analysis and it is concluded that the critical factors of safety for the three structures will be very similar to those reported in the previous quarter, as noted below:

MINIMUM FACTOR OF SAFETY

Structure	Static Loading	Pseudo-Static Loading (g=0.1)
North Cross Dike	3.3	2.2
South Cross Dike	5.6	2.7
Main Dam	2.1	1.5

Tailings deposition during the quarter progressed from the central part of the central cell toward the Borrow Pit No. 1. The level of the slimes and liquid in this pit now exceeds 6968.0' and more and more slimes are flowing into the Borrow Pit No. 2, where the liquid now stands at 6966.0' elevation. The Wells 107, 108, 326, 327, 328, 14-D, and Piezometer B1 and B2 are inaccessible and surrounded by tailings. As mentioned earlier, the minor shrinkage cracks on the downstream sandy zone in the breach repair area of the main dam were recently repaired, and a report was sent to the NMSEO. No other cracks, nor any unusual condition was noticed during this quarter. Compliance has been maintained with all the directives of the NMEID and NMSEO pertaining to the tailings disposal operation, dam safety, ponding of liquid, free board, liquid level in borrow pits, etc.

The plots of the recorded settlement for the monuments along the north and south cross dikes and the main dam are enclosed. Though settlement is still in progress, it is my opinion that the primary settlement has already taken place and the recent settlements are very slow and small.

DISPOSAL PLAN FOR THE NEXT QUARTER

It should be noted that the mill is operating on an extension until the Discharge Plan is approved by the NMEID. It is anticipated that tailings deposition will continue in the central cell area, gradually filling up the central portion and the Borrow Pit No. 1.

A low ground pressure Kamatsu dozer is currently in use, which has been very helpful in spreading out the deposited tailings and leveling up the tailings mounds to make room for the cyclone underflow sand without moving the cyclone. The dozer is also used to push aside some of the coarse cyclone underflow tailings for better dewatering before being loaded into trucks for mine backfilling operation.

Very soon UNC will start neutralizing the tailings fluid stored in the borrow pits. The neutralization of the tailings slurry and use of the north and south pond for storage of neutralized solids and liquids will follow as soon as the NMSEO's requirements are satisfied and approval is granted.

This report has attempted to document the significant aspects of tailings disposal operations, engineering works and general conditions of the tailings impoundment area at the UNC NE Churchrock site during the fall quarter of 1981.

If you should require any further documentation of these operations, or have any comment, please do not hesitate to contact me.

Respectfully submitted,

Satya Deb Misra

Satya Deb Misra, P.E.
Senior Engineer

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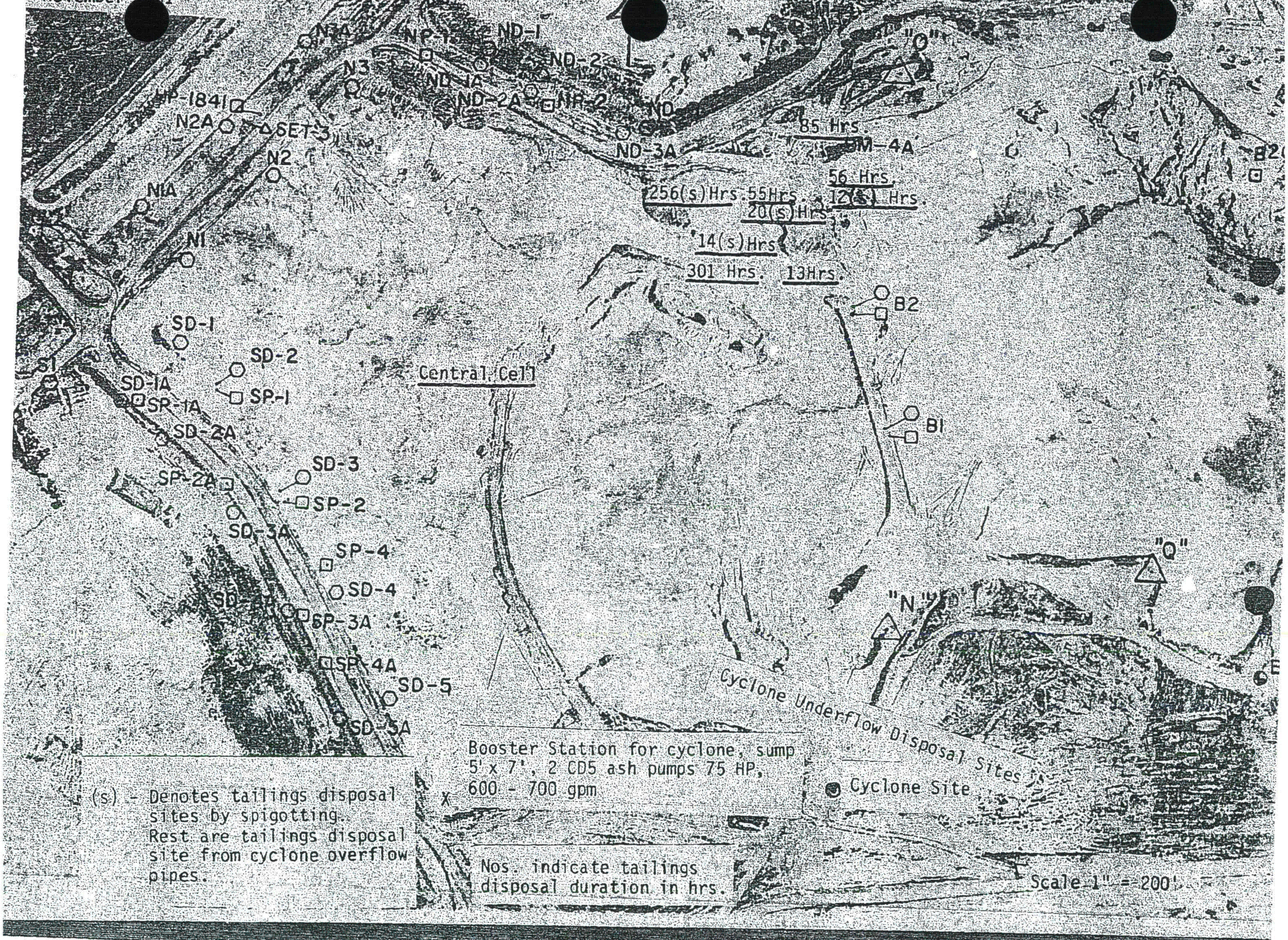
REGISTERED PROFESSIONAL ENGINEER

cc: Mr. Thomas Baca, Director NMEID
Mr. Thomas M. Hill, Director UNC Tailings Management

Enclosures

November 1981



HISTORICAL WATER-QUALITY DATA, PUERCO RIVER BASIN, ARIZONA AND NEW MEXICO

By Laurie Wirt, Peter C. Van Metre, and Barbara Favor

U.S. GEOLOGICAL SURVEY
Open-File Report 91—196

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Tucson, Arizona
June 1991

U.S. DEPARTMENT OF THE INTERIOR

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Table 7.--Monthly average, minimum, and maximum values for treated mine discharge, Kerr-McGee Church Rock I Mine, 1980-84

[Values are in the following units: °F, degrees Fahrenheit; MGD, million gallons per day; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; dashes indicate no data]

Month		Tem-pera-ture (°F)	Discharge (MGD)	pH (Stand-ard units)	Total suspended sediment, (mg/L)	Molyb-denum, total (µg/L as Mo)	Sele-nium, total (µg/L as Se)	Uranium, total (µg/L as U)	Vana-dium, total (µg/L as V)	Radium-226, dissolved (pCi/L as Ra-226)
					1980					
January	Average	------	-----	-----	-----	-----	----	-----	---	-----
	Minimum	------	-----	-----	-----	-----	----	-----	---	-----
	Maximum	------	-----	-----	-----	-----	----	-----	---	-----
February	Average	------	-----	-----	-----	-----	----	-----	---	-----
	Minimum	------	-----	-----	-----	-----	----	-----	---	-----
	Maximum	------	-----	-----	-----	-----	----	-----	---	-----
March	Average	------	-----	-----	-----	-----	----	-----	---	-----
	Minimum	------	-----	-----	-----	-----	----	-----	---	-----
	Maximum	------	-----	-----	-----	-----	----	-----	---	-----
April	Average	------	-----	-----	-----	-----	----	-----	---	-----
	Minimum	------	-----	-----	-----	-----	----	-----	---	-----
	Maximum	------	-----	-----	-----	-----	----	-----	---	-----
May	Average	------	5.5	-----	<2	-----	----	-----	---	-----
	Minimum	------	-----	8.5	-----	-----	----	-----	---	-----
	Maximum	------	5.5	8.8	<2	-----	----	1,400	---	1.5
June	Average	------	5.5	-----	<2	-----	----	-----	---	-----
	Minimum	------	-----	8.7	-----	-----	----	-----	---	-----
	Maximum	------	5.5	8.8	<2	-----	----	1,300	---	1.2
July	Average	------	5.5	-----	<2	-----	----	-----	---	-----
	Minimum	------	-----	8.6	-----	-----	----	-----	---	-----
	Maximum	------	5.5	9.0	<2	460	38	1,300	12	2.4
August	Average	------	5.5	-----	<2	-----	----	-----	---	-----
	Minimum	------	-----	8.5	-----	-----	----	-----	---	-----
	Maximum	------	5.5	8.7	<2	420	38	1,200	17	1.4
September	Average	------	5.5	-----	<2	-----	----	-----	---	-----
	Minimum	------	-----	8.5	-----	-----	----	-----	---	-----
	Maximum	------	5.5	8.7	<2	450	25	1,200	13	1.8
October	Average	------	5.5	-----	<2	-----	----	-----	---	-----
	Minimum	------	-----	8.6	-----	-----	----	-----	---	-----
	Maximum	------	5.5	8.8	<2	440	25	1,000	20	1.7
November	Average	60	5.5	-----	<2	-----	----	-----	---	-----
	Minimum	------	-----	8.6	-----	-----	----	-----	---	-----
	Maximum	62	5.5	8.7	<2	430	35	1,600	31	1.6
December	Average	58.9	5.5	-----	<2	-----	----	-----	---	-----
	Minimum	------	-----	8.6	-----	-----	----	-----	---	-----
	Maximum	61	5.5	8.7	<2	440	34	1,100	28	1.3
Standard deviation (σ)	Average	.778	0	-----	0	-----	----	-----	---	-----
	Minimum	------	-----	.071	-----	-----	----	-----	---	-----
	Maximum	.707	0	.104	0	14	6	185	8	.376
Mean	Average	59.5	5.5	-----	<2	-----	----	-----	---	-----
	Minimum	------	-----	8.58	-----	-----	----	-----	---	-----
	Maximum	61.5	5.5	8.78	<2	440	33	1,260	20	1.61

Table 7.--Monthly average, minimum, and maximum values for treated mine discharge, Kerr-McGee Church Rock I Mine, 1980-84--Continued

Month		Temperature (°F)	Discharge (MGD)	pH (Standard units)	Total suspended sediment, (mg/L)	Molybdenum, total (µg/L as Mo)	Selenium, total (µg/L as Se)	Uranium, total (µg/L as U)	Vanadium, total (µg/L as V)	Radium-226, dissolved (pCi/L as Ra-226)
					1981					
January	Average	36.0	5.5	-----	<2.0	-----	----	-----	---	-----
	Minimum	------	-----	8.5	-----	-----	----	-----	---	-----
	Maximum	59.0	5.5	8.7	<2.0	450	38	1,300	26	0.94
February	Average	56.0	5.5	-----	<2.0	-----	----	-----	---	-----
	Minimum	------	-----	8.6	-----	-----	----	-----	---	-----
	Maximum	60.0	5.5	8.8	<2.0	460	56	1,350	16	3.2
March	Average	57.6	5.5	-----	<2.0	-----	----	-----	---	-----
	Minimum	------	-----	8.6	-----	-----	----	-----	---	-----
	Maximum	60.0	5.5	8.8	<2.0	440	33	1,600	9	.6
April	Average	61.0	3.5	-----	<2.0	-----	----	-----	---	-----
	Minimum	------	-----	8.5	-----	-----	----	-----	---	-----
	Maximum	68.0	3.5	8.8	<2.0	480	49	1,400	6	1.0
May	Average	63.25	3.5	-----	<2.0	-----	----	-----	---	-----
	Minimum	------	-----	8.6	-----	-----	----	-----	---	-----
	Maximum	66.0	3.5	8.9	3.1	490	61	1,400	12	2.85
June	Average	61.25	3.4	-----	<2.0	-----	----	-----	---	-----
	Minimum	------	-----	8.5	-----	-----	----	-----	---	-----
	Maximum	68.0	3.4	8.9	3.1	490	61	1,300	9	.93
July	Average	74.0	3.72	-----	<2.0	450	40	-----	8	-----
	Minimum	------	-----	8.7	-----	-----	----	-----	---	-----
	Maximum	78.0	3.95	8.8	<2.0	470	48	1,400	9	1.48
August	Average	72.0	3.78	-----	<2.0	560	47	-----	9	.44
	Minimum	------	-----	8.4	-----	-----	----	-----	---	-----
	Maximum	75.0	4.54	8.8	<2.0	850	54	1,400	19	.86
September	Average	69.0	3.67	-----	<2.0	910	25	-----	16	-----
	Minimum	------	-----	8.7	-----	-----	----	-----	---	-----
	Maximum	72.0	4.42	8.9	<2.0	1,000	28	1,200	20	.51
October	Average	63.0	3.20	-----	<2.0	480	68	1,180	50	1.04
	Minimum	58.0	-----	8.25	-----	-----	----	-----	---	-----
	Maximum	67.0	3.56	8.82	<2.0	480	91	1,300	55	2.2
November	Average	57.9	3.48	-----	2.2	480	52	1,100	15	.42
	Minimum	52.0	-----	8.7	-----	-----	----	-----	---	-----
	Maximum	62.0	3.77	8.8	3.0	490	91	1,300	50	.51
December	Average	54.0	3.38	-----	<2.0	450	48	1,100	6	.62
	Minimum	49.0	-----	8.6	-----	-----	----	-----	---	-----
	Maximum	59.0	3.90	8.8	<2.0	480	59	1,300	12	1.08
Standard deviation (σ)	Average	------	0.911	-----	0.058	179	14	46	16	0.288
	Minimum	------	-----	0.134	-----	-----	----	-----	---	-----
	Maximum	------	.829	.052	0.410	180	20	99	16	.913
Mean	Average	------	4.01	-----	2.02	560	47	1,130	17	.63
	Minimum	------	-----	8.55	-----	-----	----	-----	---	-----
	Maximum	------	4.25	8.81	2.18	550	56	1,350	20	1.35

Table 7.--Monthly average, minimum, and maximum values for treated mine discharge, Kerr-McGee Church Rock I Mine, 1980-84--Continued

Month		Temperature (°F)	Discharge (MGD)	pH (Standard units)	Total suspended sediment, (mg/L)	Molybdenum, total (µg/L as Mo)	Selenium, total (µg/L as Se)	Uranium, total (µg/L as U)	Vanadium, total (µg/L as V)	Radium-226, dissolved (pCi/L as Ra-226)
					1982					
January	Average	50.9	3.46	-----	<2.0	460	45	1,500	17	0.39
	Minimum	46.0	-----	8.3	-----	-----	----	-----	---	-----
	Maximum	54.0	3.81	8.6	<2.0	480	51	1,700	41	.64
February	Average	54.8	3.56	-----	<2.0	470	46	1,400	12	.24
	Minimum	50.0	-----	8.6	-----	-----	----	-----	---	-----
	Maximum	60.0	3.85	8.8	<2.0	480	53	1,600	23	.35
March	Average	56.1	3.59	-----	<2.0	460	42	1,400	14	.29
	Minimum	51.0	-----	8.6	-----	-----	----	-----	---	-----
	Maximum	62.0	3.86	8.9	<2.0	480	51	1,500	46	.32
April	Average	59.3	3.71	-----	<2.0	440	29	1,400	30	.30
	Minimum	54.0	-----	8.8	-----	-----	----	-----	---	-----
	Maximum	66.0	4.06	9.03	<2.0	450	39	1,500	33	.51
May	Average	63.8	3.71	-----	<2.0	470	61	1,400	48	.52
	Minimum	59.0	-----	8.7	-----	-----	----	-----	---	-----
	Maximum	68.0	3.96	8.9	<2.0	470	65	1,500	94	.77
June	Average	67.8	3.59	-----	<2.0	450	37	1,500	27	2.25
	Minimum	64.0	-----	8.7	-----	-----	----	-----	---	-----
	Maximum	72.0	3.82	8.9	<2.0	460	38	2,000	28	8.0
July	Average	72.3	3.45	-----	<2.0	500	40	2,000	30	.69
	Minimum	67.0	-----	8.5	-----	-----	----	-----	---	-----
	Maximum	75.0	3.69	8.9	<2.0	510	48	2,700	80	.90
August	Average	74.0	3.43	-----	<2.0	440	30	1,750	20	1.23
	Minimum	72.0	-----	8.3	-----	-----	----	-----	---	-----
	Maximum	76.0	3.80	8.8	<2.0	500	37	2,100	45	1.89
September	Average	68.0	3.46	-----	<2.0	400	26	1,980	9	.46
	Minimum	61.0	-----	8.1	-----	-----	----	-----	---	-----
	Maximum	73.0	3.72	8.9	<2.0	560	33	2,100	17	.57
October	Average	62.0	3.36	-----	<2.0	-----	----	-----	---	.00
	Minimum	59.0	-----	8.2	-----	-----	----	-----	---	-----
	Maximum	64.0	3.80	8.9	<2.0	600	42	2,600	29	.45
November	Average	58.0	3.42	-----	<2.0	-----	----	-----	---	.00
	Minimum	55.0	-----	8.5	-----	-----	----	-----	---	-----
	Maximum	59.0	3.79	8.8	<2.0	470	68	2,100	17	.59
December	Average	57.0	3.27	-----	<2.0	490	----	-----	---	.00
	Minimum	50.0	-----	8.6	-----	-----	----	-----	---	-----
	Maximum	59.0	3.50	9.0	<2.0	510	70	1,500	29	.40
Standard deviation (σ)	Average	7.27	0.134	-----	0	28	11	250	12	.66
	Minimum	7.77	-----	0.219	-----	-----	----	-----	---	-----
	Maximum	17.37	0.138	.111	0	44	18	430	24	2.16
Mean	Average	62.0	3.50	-----	<2.0	460	40	1,590	23	.70
	Minimum	57.3	-----	8.5	-----	-----	----	-----	---	-----
	Maximum	61.67	3.81	8.9	<2.0	500	46	1,910	40	1.28

Table 7.--Monthly average, minimum, and maximum values for treated mine discharge, Kerr-McGee Church Rock I Mine, 1980-84--Continued

Month		Temperature (°F)	Discharge (MGD)	pH (Standard units)	Total suspended sediment, (mg/L)	Molybdenum, total (µg/L as Mo)	Selenium, total (µg/L as Se)	Uranium, total (µg/L as U)	Vanadium, total (µg/L as V)	Radium-226, dissolved (pCi/L as Ra-226)
					1983					
January	Average	58.0	3.33	-----	<2.0	-----	----	-----	---	-----
	Minimum	55.0	-----	8.5	-----	-----	----	-----	---	-----
	Maximum	60.0	3.69	8.9	<2.0	510	82	1,600	<4	.05
February	Average	59.0	3.45	-----	<1.0	-----	----	-----	---	-----
	Minimum	57.0	-----	8.5	-----	-----	----	-----	---	-----
	Maximum	63.0	3.70	8.9	<1.0	510	27	1,300	14	.00
March	Average	60.0	3.40	-----	<1.0	-----	----	-----	---	-----
	Minimum	56.0	-----	8.6	-----	-----	----	-----	---	-----
	Maximum	64.0	3.60	8.8	<1.0	480	29	1,100	14	.03
April	Average	61.0	3.42	-----	<2.0	-----	----	-----	---	-----
	Minimum	55.0	-----	8.7	-----	-----	----	-----	---	-----
	Maximum	66.0	4.97	8.8	<2.0	460	28	1,000	<40	.08
May	Average	66.0	3.34	-----	<2.0	-----	----	-----	---	-----
	Minimum	60.0	-----	8.7	-----	-----	----	-----	---	-----
	Maximum	72.0	3.52	8.8	<2.0	550	32	1,200	<40	.06
June	Average	71.0	3.23	-----	<2.0	-----	----	-----	---	-----
	Minimum	66.0	-----	8.6	-----	-----	----	-----	---	-----
	Maximum	74.0	3.45	8.8	<2.0	560	43	1,500	<40	.22
July	Average	76.0	3.35	-----	<2.0	-----	----	-----	---	-----
	Minimum	75.0	-----	8.5	-----	-----	----	-----	---	-----
	Maximum	77.0	3.80	8.8	<2.0	650	97	1,200	40	.35
August	Average	77.0	3.44	-----	<2.0	-----	----	-----	---	-----
	Minimum	75.0	-----	8.5	-----	-----	----	-----	---	-----
	Maximum	78.0	3.67	8.8	<2.0	560	12	1,300	22	.80
September	Average	73.0	3.80	-----	<2.0	-----	----	-----	---	-----
	Minimum	65.0	-----	8.3	-----	-----	----	-----	---	-----
	Maximum	76.0	4.00	8.7	<2.0	510	10	1,400	5	.53
October	Average	67.0	3.51	-----	<2.0	-----	----	-----	---	-----
	Minimum	66.0	-----	8.4	-----	-----	----	-----	---	-----
	Maximum	70.0	3.74	8.8	<2.0	540	75	1,500	8	.035
November	Average	61.0	3.52	-----	<2.0	-----	----	1,450	---	.132
	Minimum	52.0	-----	8.4	-----	-----	----	-----	---	-----
	Maximum	68.0	3.88	8.7	<2.0	580	63	1,600	30	.27
December	Average	57.0	3.46	-----	<2.0	-----	----	1,670	---	.08
	Minimum	52.0	-----	8.4	-----	-----	----	-----	---	-----
	Maximum	60.0	3.62	8.7	<2.0	600	76	1,820	36	.11
Standard deviation (σ)	Average	7.217	0.141	-----	-----	-----	----	156	---	0.037
	Minimum	8.167	-----	0.124	-----	-----	----	-----	---	-----
	Maximum	6.481	0.397	0.067	-----	55	32	237	15	.410
Mean	Average	65.5	3.44	-----	<2.0	-----	----	1,560	---	0.106
	Minimum	61.2	-----	8.5	-----	-----	----	------	---	-----
	Maximum	69.0	3.80	8.8	<2.0	540	64	1,380	24	.295

Table 7.--Monthly average, minimum, and maximum values for treated mine discharge, Kerr-McGee Church Rock I Mine, 1980-84--Continued

Month		Temperature (°F)	Discharge (MGD)	pH (standard units)	Total suspended sediment, (mg/L)	Molybdenum, total (µg/L as Mo)	Selenium, total (µg/L as Se)	Uranium, total (µg/L as U)	Vanadium, total (µg/L as V)	Radium-226, dissolved (pCi/L as Ra-226)
					1984					
January	Average	59.0	3.44	-----	-----	-----	----	1,030	---	0.12
	Minimum	56.0	-----	8.4	-----	-----	----	-----	---	-----
	Maximum	62.0	3.73	8.6	-----	570	73	1,320	320	.14
February	Average	60.0	3.34	-----	-----	-----	----	1,690	---	.13
	Minimum	56.0	-----	8.4	-----	-----	----	-----	---	-----
	Maximum	63.0	3.67	8.7	-----	480	74	1,940	410	.18
March	Average	62.0	3.49	-----	-----	-----	----	1,770	---	.17
	Minimum	59.0	-----	8.3	-----	-----	----	-----	---	-----
	Maximum	64.0	3.91	8.6	-----	<587	<101	1,930	<27	.28
April	Average	------	-----	-----	-----	-----	----	-----	---	-----
	Minimum	------	-----	-----	-----	-----	----	-----	---	-----
	Maximum	------	-----	-----	-----	-----	----	-----	---	-----
May	Average	------	-----	-----	-----	-----	----	-----	---	-----
	Minimum	------	-----	-----	-----	-----	----	-----	---	-----
	Maximum	------	-----	-----	-----	-----	----	-----	---	-----
June	Average	------	-----	-----	-----	-----	----	-----	---	-----
	Minimum	------	-----	-----	-----	-----	----	-----	---	-----
	Maximum	------	-----	-----	-----	-----	----	-----	---	-----
July	Average	------	-----	-----	-----	-----	----	-----	---	-----
	Minimum	------	-----	-----	-----	-----	----	-----	---	-----
	Maximum	------	-----	-----	-----	-----	----	-----	---	-----
August	Average	------	-----	-----	-----	-----	----	-----	---	-----
	Minimum	------	-----	-----	-----	-----	----	-----	---	-----
	Maximum	------	-----	-----	-----	-----	----	-----	---	-----
September	Average	------	-----	-----	-----	-----	----	-----	---	-----
	Minimum	------	-----	-----	-----	-----	----	-----	---	-----
	Maximum	------	-----	-----	-----	-----	----	-----	---	-----
October	Average	------	-----	-----	-----	-----	----	-----	---	-----
	Minimum	------	-----	-----	-----	-----	----	-----	---	-----
	Maximum	------	-----	-----	-----	-----	----	-----	---	-----
November	Average	------	-----	-----	-----	-----	----	-----	---	-----
	Minimum	------	-----	-----	-----	-----	----	-----	---	-----
	Maximum	------	-----	-----	-----	-----	----	-----	---	-----
December	Average	------	-----	-----	-----	-----	----	-----	---	-----
	Minimum	------	-----	-----	-----	-----	----	-----	---	-----
	Maximum	------	-----	-----	-----	-----	----	-----	---	-----
Standard deviation (σ)	Average	1.528	0.076	-----	-----	-----	----	406	---	0.026
	Minimum	1.732	-----	.058	-----	-----	----	-----	---	-----
	Maximum	1.000	.125	.058	-----	58	16	355	200	.072
Mean	Average	60.0	3.42	-----	-----	-----	----	1,500	---	.14
	Minimum	57.0	-----	8.4	-----	-----	----	-----	---	-----
	Maximum	63.0	3.77	8.6	-----	550	83	1,730	252	.20

Table 8.--Water-quality data for mine discharges, United Nuclear Corporation Old Church Rock Mine, 1980-82

[Values are in the following units: µS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; dashes indicate no data]

Date	pH (Standard units)	Molybdenum, total (µg/L as Mo)	Selenium, total (µg/L as Se)	Uranium, total (µg/L as U)	Vanadium, total (µg/L as V)
Untreated water					
11-17-80[1]	----	---	--	-----	--
11-02-82[1]	----	---	--	-----	--
Treated water					
11-17-80[1]	----	---	--	-----	--
07-20, 21-82[2] [3]	9.03	110	15	1,160	28
11-02-82[1]	----	---	--	-----	--

Date	Zinc, total (µg/L as Zn)	Gross beta, total (pCi/L)	Radium-226, dissolved (pCi/L as Ra-226)	Radium-226, total (pCi/L as Ra-226)	Total suspended sediment (mg/L)
Untreated water					
11-17-80	---	4,008±879	--------	--------	---
11-02-82	---	530±100	--------	--------	---
Treated water					
11-17-80	---	646±64	--------	--------	---
07-20, 21-82[2]	<50	------	5.37±.12	5.49±.11	4.8
11-02-82	---	322±30	--------	--------	---

[1]Data from United Nuclear Corporation

[2]24-hour composite sample.

[3]Data from U.S. Environmental Protection Agency.

Table 9.--Water-quality data for mine discharges, United Nuclear Corporation Northeast Church Rock Mine, 1975-82

[Values are in the following units: µS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; dashes indicate no data]

Date	Specific conductance (µS/cm)	pH (Standard units)	Calcium, total (mg/L as Ca)	Sodium, total (mg/L as Na)	Potassium, total (mg/L as K)	Sulfate, total (mg/L as SO_4)	Chloride, total (mg/L as Cl)	Bicarbonate, (mg/L as HCO_3)	Total solids dissolved (mg/L)
				Untreated water					
11-13-80	---	----	----	-----	-----	-----	-----	-----	---
11-17-80[1]	---	----	----	-----	-----	-----	-----	-----	---
10-06-81[2]	---	----	----	-----	-----	-----	-----	-----	---
11-02-82[1]	---	----	----	-----	-----	-----	-----	-----	---
				Treated water					
03-04-75[1] [3]	---	----	----	-----	-----	-----	-----	-----	---
03-05-75[1] [3]	---	----	----	-----	-----	-----	-----	-----	---
03-06-75[1] [3]	---	----	----	-----	-----	-----	-----	-----	---
10-24-77[4]	681	8.82	----	144.9	-----	67.2	24.2	-----	383
11-13-78[4]	623	----	8.0	149.5	1.56	107.6	25.4	229.6	419
08-29-79[1]	---	----	----	-----	-----	-----	-----	-----	---
11-01-79[4]	923	7.66	27.6	144.9	1.56	361.5	20.4	32.6	587
03-05-80[4]	725	----	13.4	147.2	1.56	126.1	26.2	256	453
11-17-80[1]	---	----	----	-----	-----	-----	-----	-----	---
10-06-81[3]	---	----	----	-----	-----	-----	-----	-----	---
11-02-82[1]	---	----	----	-----	-----	-----	-----	-----	---
07-20,21-82[3] [5]	---	8.16	----	-----	-----	-----	-----	-----	---

Date	Nitrate+ nitrite, total (mg/L as NO_2+NO_3)	Ammonia, total (mg/L as NH_3)	Aluminum, total (µg/L as Al)	Antimony, total (µg/L as Sb)	Arsenic, total (µg/L as As)	Barium, total (µg/L as Ba)	Beryllium, total (µg/L as Be)	Cadmium, total (µg/L as Cd)	Chromium, total (µg/L as Cr)	Copper, total (µ/L as Cu)
					Untreated water					
11-13-80	----	-----	----	---	---	-----	---	---	---	---
11-17-80	----	-----	----	---	---	-----	---	---	---	---
10-06-81	----	-----	----	---	---	-----	---	---	---	---
11-02-82	----	-----	----	---	---	-----	---	---	---	---
					Treated water					
03-04-75[3]	----	-----	----	---	---	-----	---	---	---	---
03-05-75[3]	----	-----	----	---	---	-----	---	---	---	---
03-06-75[3]	----	-----	----	---	---	-----	---	---	---	---
10-24-77	----	0.036	----	---	<5	880	---	---	---	---
11-13-78	0.46	.19	----	---	<5	381	---	<1	---	---
08-29-79	----	-----	----	<20	<20	-----	<20	<20	<20	<20
11-01-79	0.34	1.25	<250	---	<5	707	---	<1	---	---
03-05-80	----	-----	----	---	<5	311	---	<1	---	---
11-17-80	----	-----	----	---	---	-----	---	---	---	---
10-06-81	----	-----	----	---	---	-----	---	---	---	---
11-02-82	----	-----	----	---	---	-----	---	---	---	---
07-20,21-82[3]	----	-----	----	---	---	-----	---	---	---	---

See footnotes at end of table.

Table 9.--Water-quality data for mine discharges, United Nuclear Corporation Northeast Church Rock Mine, 1975-82--Continued

Date	Lead, total (µg/L as Pb)	Mercury, total (µg/L as Hg)	Molybdenum, total (µg/L as Mo)	Nickel, total (µg/L as Ni)	Selenium, total (µg/L as Se)	Silver, total (µg/L as Ag)	Uranium, total (µg/L as U)	Vanadium, total (µg/L as V)	Zinc, total (µg/L as Zn)
				Untreated water					
11-13-80	---	-----	----	----	--	-----	-----	-----	-----
11-17-80	---	-----	----	----	--	-----	-----	-----	-----
10-06-81	---	-----	----	----	--	-----	-----	-----	-----
11-02-82	---	-----	----	----	--	-----	-----	-----	-----
				Treated water					
03-04-75[3]	---	-----	200	----	60	-----	7,600	500	-----
03-05-75[3]	---	-----	200	----	60	-----	6,500	400	-----
03-06-75[3]	---	-----	100	----	10	-----	7,600	400	-----
10-24-77	---	-----	<10	----	94	-----	1,200	-----	-----
11-13-78	<5	-----	65	----	74	-----	1,320	30	<1
08-29-79	<20	<0.20	<20	<20	22	<20	-----	50	<20
11-01-79	<5	-----	<10	----	53	-----	1,260	<10	<250
03-05-80	<5	-----	10	----	82	-----	516	24	<250
11-17-80	---	-----	----	----	--	-----	-----	-----	-----
10-06-81	---	-----	----	----	--	-----	-----	-----	-----
11-02-82	---	-----	----	----	--	-----	-----	-----	-----
07-20,21-82[3]	---	-----	14	----	43	-----	870	10	<50

Date	Gross alpha, total (pCi/L)	Gross beta, total (pCi/L)	Lead-210, total (pCi/L as Pb-210)	Polonium-210, total (pCi/L as Po-210)	Radium-226, dissolved (pCi/L as Ra-226)	Radium-226, total (pCi/L as Ra-226)
			Untreated water			
11-13-80	---------	----------	---------	---------	---------	24.1±0.8
11-17-80	---------	6,442±551	---------	---------	---------	---------
10-06-81	3,100±100	----------	1,200±100	900±200	---------	550±170
11-02-82	---------	876±150	---------	---------	---------	---------
			Treated water			
03-04-75[3]	---------	----------	---------	---------	19.8	---------
03-05-75[3]	---------	----------	---------	---------	22.9	---------
03-06-75[3]	---------	----------	---------	---------	27.3	---------
10-24-77	---------	----------	---------	9.7±5.6	---------	1.9±.8
11-13-78	900±60	----------	---------	---------	---------	2.0±.1
08-29-79	---------	----------	---------	---------	---------	---------
11-01-79	650±80	----------	---------	---------	---------	.81±.24
03-05-80	282±18	----------	---------	---------	---------	3.89±.15
11-17-80	--------	326±32	---------	---------	---------	---------
10-06-81	280±30	----------	10±2	10±1	---------	2.5±.8
11-02-82	--------	342±32	---------	---------	---------	---------
07-20,21-82[3]	--------	----------	---------	---------	1.35±.07	1.14±.10

See footnotes at end of table.

Table 9.--Water-quality data for mine discharges, United Nuclear Corporation Northeast Church Rock Mine, 1975-82--Continued

Date	Radium-228, total (pCi/L as Ra-228)	Thorium-228, total (pCi/L as Th-228)	Thorium-230, total (pCi/L as Th-230)	Thorium-232, total (pCi/L as Th-232)	Total suspended sediment, (mg/L)
		Untreated water			
11-13-80	---	-------	-------	-------	----
11-17-80	---	-------	-------	-------	----
10-06-81	---	0.0±.1	210±10	0.1±0.1	----
11-02-82	---	-------	-------	-------	----
		Treated water			
03-04-75[3]	---	-------	-------	-------	33
03-05-75[3]	---	-------	-------	-------	47
03-06-75[3]	---	-------	-------	-------	71
10-24-77	---	-------	-------	-------	----
11-13-78	0±2	-------	-------	-------	4.2
08-29-79	---	-------	-------	-------	----
11-01-79	---	-------	-------	-------	0
03-05-80	---	-------	-------	-------	4.5
11-17-80	---	-------	-------	-------	----
10-06-81	---	-0.2±.2	0.1±.1	0.0±.1	----
11-02-82	---	-------	-------	-------	----
07-20,21-82[3]	---	-------	-------	-------	2.6

[1]Data from United Nuclear Corporation

[2]Data from Bruce Gallaher (New Mexico Health and Engineering Department, written commun., 1982).

[3]24-hour composite sample.

[4]Data from New Mexico Health and Engineering Department, Environmental Improvement Division, Water Pollution Control Board.

[5]Data from U.S. Environmental Protection Agency.

Table 10.--Water-quality data for tailings-pond solution, 1979-80

[Values are in the following units: µS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; dashes indicate no data]

Date	Specific conductance (µS/cm)	pH (Standard units)	Calcium, total (mg/L as Ca)	Magnesium, total (mg/L as Mg)	Sodium, total (mg/L as Na)	Potassium, total (mg/L as K)	Sulfate, total (mg/L as SO_4)	Chloride, total (mg/L as Cl)	Fluoride, total (mg/L as F)
02-05-79[1] [2]	-----	1.92	----	50.8	519	----	4,802	50.0	2.47
11-01-79[1] [2]	1,589	8.66	20.0	4.5	315.1	1.95	434.7	19.4	----
03-05-80[3] [4]	702	----	10.0	----	-----	1.56	108.6	12.2	----

Date	Bicarbonate, (mg/L as HCO_3)	Total solids dissolved (mg/L)	Nitrate+nitrite, total (mg/L as NO_2+NO_3)	Ammonia, total (mg/L as NH_3)	Aluminum, total (µg/L as Al)	Arsenic, total (µg/L as As)	Barium, total (µg/L as Ba)	Cadmium, total (µg/L as Cd)	Chromium, total (µg/L as Cr)
02-05-79[1]	-----	---	----	----	-----	70	<100	--	150
11-01-79[1]	372.1	899	0.02	0.07	5,170	<5	940	<1	---
03-05-80[3]	258.2	441	----	----	-----	<5	201	<1	---

Date	Cobalt, total (µg/L as Co)	Iron, total (µg/L as Fe)	Lead, total (µg/L as Pb)	Manganese, total (µg/L as Mn)	Molybdenum, total (µg/L as Mo)	Selenium, total (µg/L as Se)	Uranium, total (µg/L as U)	Vanadium, total (µg/L as V)	Zinc, total (µg/L as Zn)
02-05-79[1]	950	157,500	200	14,000	40	--	4,090	---	----
11-01-79[1]	----	-------	<5	------	<10	29	1,140	95	<250
03-05-80[3]	----	-------	<5	------	9	82	3,260	<10	<250

Date	Gross alpha, total (pCi/L)	Radium-226, total (pCi/L as Ra-226)	Thorium-230, total (pCi/L as Th-230)	Total suspended sediment, (mg/L)
02-05-79[1]	---------	209.5	10,225	-----
11-01-79[1]	5,300±300	4.2±1.3	------	175
03-05-80[3]	1,890±100	38.9±1.3	------	11.1

[1]Sample from United Nuclear Corporation Old Church Rock, last settling pond.

[2]Data from United Nuclear Corporation

[3]Sample from United Nuclear Corporation, Northeast Church Rock.

[4]Data from New Mexico Health and Engineering Department, Environmental Improvement Division, Water Pollution Control Board.

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This document provides the United Nuclear Corporation (UNC) response to the U.S. Nuclear Regulatory Commission's (NRC's) June 4, 2013, Request for Additional Information (RAI) on the Supplemental Report Entitled "Groundwater Flow Model of the Church Rock Site and Local Area Church Rock, New Mexico, October 2012". NRC comments are shown in blue text and UNC responses are shown in black text.

Responses to General Comments

1. Comment: The Zone 1 Sandstone and Southwest Alluvium aquifer were not the focus of the groundwater model in the report; instead, effort and attention was applied to the Zone 3 Sandstone portion of the flow model. [From page 1, "As the potential for such applications is anticipated to be greatest for the Zone 3 hydrostratigraphic unit, that unit is the focus of interest of the Flow Model."] Consequently, the groundwater model in its current state should not be used to support decision-making for issues related to Zone 1 Sandstone and the Southwest Alluvium aquifer. This qualification should be clearly stated in the introductory section.

UNC Response: While the focus of the Flow Model is Zone 3, we recognize a potential for the Flow Model to provide insights or address questions related to groundwater flow in the Zone 1 and Southwest Alluvium hydrostratigraphic units. Indeed, this has already occurred with respect to groundwater flow in portions of Zone 1 that are no longer actively monitored. Therefore the following sentence is proposed to be added to the cited paragraph of the report: While the Flow Model may provide insights about groundwater flow in in the Southwest Alluvium and the Zone 1 hydrostratigraphic units, the capabilities of the Flow Model should be evaluated prior to addressing specific questions outside of the general scope of those presented in this report.

2. Comment: Electronic copies of the input files the from the groundwater flow model need to be provided.

UNC Response: The requested files will be provided.

3. Comment: Technical bases for major assumptions relied upon to construct a site conceptual model and to interpret results from the groundwater flow model were not adequately described and the validity of these assumptions were not adequately demonstrated. Various aspects of the model were qualitatively described with terms such as "reasonable to conclude," "likely reason," "expected," "judged," "estimated," and "implied," that are usually associated with some types of assumption.

UNC Response: There is a distinction between an assumption and a qualitative expression of likelihood or confidence that is rooted in professional judgment. The distinction rests not only on the basis of a concept, but also on how it is acted upon. For example, the American Heritage Dictionary provides this definition for assumption: "A statement accepted or supposed true without proof or demonstration." The implied implication for the development of the Flow Model is that assumptions were made in such a manner and employed without further consideration of their validity. This is addressed in responses to the subparts of general comment 3.

Comment (continued): For example, additional information is needed to support the following assumptions:

3a) The slow rates of migration found in the Morrison Formation are applicable to the Gallup Sandstone.

UNC Response: The cited statement in the report is the following: "It is reasonable to conclude that similarly slow rates of migration may prevail in the Gallup Sandstone." This statement was made in reference to a flow rate in the Morrison Formation cited by Kernodle (1996) of less than 20 miles in 40,000 years. The inclusion of this information in the Flow Model report was intended to provide an example of the constraints on groundwater migration rates created by the scale and depth of migration pathways from outcrop to points of discharge in the San Juan Basin. Kernodle (1996) does not specify similar evidence of groundwater velocities in the Gallup Sandstone. However, he does indicate that groundwater in the formations of the San Juan Basin is old enough to have been affected by the pluvial climates of the Pleistocene Epoch. Kernodle (1996) also presented results from a three-dimensional flow model of groundwater in the formations present in the San Juan Basin, including the Gallup Sandstone. The model predicted that over approximately half of the area of the Gallup Sandstone vertical hydraulic gradients are downward into the Dakota Fm., and from the Dakota Fm. downward into the Morrison Fm. In these areas, the relatively lower heads in the Morrison Fm. are consistent with the interpretation of a relatively higher rate of groundwater migration (toward points of discharge) than in the overlying formations. Kernodle (1996) cites isotopic data reported by Dam (1995) as evidence supporting the idea that groundwater in the Morrison Fm. was derived in part from overlying formations, including the Gallup Sandstone. However, an interpretation of relatively slower rates of migration toward points of discharge is applicable to other areas of the Morrison Fm., where the vertical hydraulic gradient is predicted to be upward.

Based on these considerations, the statement suggesting similarly slow rates of migration in the Gallup Sandstone and the Morrison Fm. may be considered an over simplification. Therefore, that statement will be removed and the modification (in italic) made:

Kernodle (1996) reports that isotopic age dating of groundwater in the Gallup Sandstone is consistent with the theory that recharge rates in the past (pluvial climates of the Pleistocene Epoch) were greater than at present. *Evidence from groundwater flow modeling (Kernodle, 1996) and isotopic ratios (Dam, 1995) indicate that groundwater migration pathways in formations of the San Juan Basin (including the Gallup Sandstone) are three-dimensional and that this cross-formation flow to points of discharge constrains the migration rates. For example,* Kernodle (1996) cites carbon-14 dating of water in the Morrison Formation (which occurs below the Gallup Sandstone) as evidence that groundwater had migrated less than 20 miles from outcrops in 40,000 years.

The proposed change of wording has no effect on the Flow Model, because the cited rate of groundwater migration in the Morrison Fm. had no role in the development of the model.

3b) There are conflicting statements regarding the Pipeline Canyon lineament. Raymondi and Conrad (1983) state that lineament-related fractures facilitate infiltration of mine discharge water. McLin and Tien (1982), however, note that when observing the fractures in an outcrop near the Pipeline Canyon lineament, "the fractures are typically filled with secondary mineralization (gypsum or limonite) and they concluded that their influence on groundwater migration is secondary to the geometry of surface-water sources." Without providing further argument or evidence, the modelers assume that the geologic units near the 'lineament' have a greater hydraulic conductivity in their conceptual model. The aforementioned is a major assumption and appears to be a major influence on direction of water movement (see particle tracking shown in Figures 20 and 21).

UNC Response: The "conflicting statements" are references to differences of opinion regarding the influence fractures associated with Pipeline Canyon lineament had on the infiltration of mine discharge water into hydrostratigraphic Zones 1 and 3. The citations are from published professional papers and were made to acknowledge the differences of opinion. It would have been an unwarranted omission in the development of the Flow Model to not allow for the possibility that the lineament, which has been mapped as a regional feature, might augment groundwater flow through associated fractures. Evidence for such augmentation is interpreted from contour maps of the piezometric surfaces in Zones 1 and 3, which postdate both of the cited references. These maps were made by Canonie (1987) and are reproduced in Appendix D of the Flow Model Report. The maps show marked changes of both the magnitudes and the directions of hydraulic gradients in directions parallel to and perpendicular to the alignment of Pipeline Canyon lineament. The noted changes are consistent with hydraulic conductivities that are greater along the lineament alignment than elsewhere in both hydrostratigraphic zones. This is evident on both sides of the lineament alignment in both Zones, but particularly so on the east side where there was a greater concentration of monitoring wells. Comparable maps were not available prior to 1987, because there were fewer wells and less comprehensive surveys of those wells.

Material property zones were established in the Flow Model to allow for the potential augmentation of flow that was interpreted from the Canonie (1987) maps. Values of hydraulic conductivity in those material property zones were subjected to variation during the process of model calibration. An important aspect of that calibration was to test whether the model was capable of replicating the measured extent of seepage impact (as of October 2011). The demonstration of that capability is described in section 4.2 of the report.

The effect of the material property zones representing the Pipeline Canyon lineament on the model output was tested in a sensitivity analysis whereby these zones were assigned properties associated with areas outside of the lineament alignment. In other words, the estimated influence of the lineament-associated fractures was removed from the model. The model was found to be relatively sensitive to this change as average and root mean squared error was increased in each hydrostratigraphic zone.

3c) Although Wells 0141, 0142, and 0143 are approximately a mile away from NECR Mine Shaft 1, it is assumed by the authors that the two sites should have the same water table elevation: "The earliest water-level measurements from these wells, made in November 1980, indicate piezometric elevations ranging from 6749 to 6755 (ft amsl), or about 60 feet higher than the measured elevation of the pre-mining water table (6692 ft amsl in NECR shaft 1). The likely reason for this is that, by 1980, piezometric heads in the portion of Zone 1 occupied by pre-mining groundwater had been elevated by contact with background groundwater introduced after March 1968. However, evidence from the sampling history of these wells indicates that contact between these two classes of groundwater (background and natural) had little if any apparent effect on the quality of the sampled groundwater, either before or subsequent to July 1989 (the date of initial routine sampling)."

UNC Response: The idea that a pre-mining water table in Zone 1 occurred at a similar elevation as the pre-mining water table encountered in Zone 3 at NECR Mine Shaft 1 is supported by two kinds of evidence. Empirical evidence comes from the screen elevations of Wells 0141, 0142, and 0143 and chemical composition of water sampled from those wells. This evidence is described in section 1.3 of the Flow Model Report. The other evidence is based on the reported stratigraphic relationships of sandstone bodies in the Gallup Formation, which provide a theoretical basis for the expectation of hydraulic communication (and equilibration of water table elevations) between Zones 3 and 1 prior to the introduction of mine water.

Cross sections illustrating the stratigraphic relationships of sandstone bodies in the Gallup Sandstone are shown in Figure 1. The cross sections, which are reproduced from Mizell and Stone (1979), show two sandstone bodies mapped in the vicinity of the model domain. These are mapped as the Torrivio Sandsone and sandstone body C. In the vicinity of the Church Rock Mill Site the Torrivio Sandstone is mapped as Zone 3, while the sandstone body designated C in the cross section is mapped as Zone 1. They are separated in the vicinity by the non-sandstone aquatard, which is mapped as Zone 2 at the Site. However as shown in cross section B- B', the Torrivio Sandstone (Zone 3) and sandstone body C (Zone 1) merge with sandstone bodies A and B. Merger of these sandstone bodies would theoretically allow for hydraulic communication and equilibration of hydraulic pressures. Such an equilibration of the atmospheric pressure surface (i.e., water table) between Zones 3 and 1 provides a mechanism for the empirical evidence described in section 1.3 of the Flow Model Report.

3c) (continued) Is there any evidence that the piezometric heads at Wells 0141, 0142, and 0143 had ever been lower? If so detail such evidence.

If a technical basis can be documented showing that a "portion of Zone 1 occupied by pre-mining groundwater had been elevated by contact with background groundwater introduced after March 1968," a conceptual model should be presented demonstrating how contact between these two classes of groundwater (background and natural) could have had such apparent diminutive effect on the quality of the sampled groundwater: "However, evidence from the sampling history of these wells indicates that contact between these two classes of groundwater (background and natural) had little if any apparent effect on the quality of the sampled groundwater, either before or subsequent to July 1989."

UNC Response: Trends of increasing head were recorded in each of Wells 0141, 0142, and 0143 from the time of the first water level measurements in October 1980. Figure 2 is a hydrograph for Well 0143, which shows the relationship between the well screen, piezometric heads and elevations of the top and bottom of Zone 1 (at the well location). Similar relationships exist for Wells 0141 and 0142. The most straightforward interpretation of the hydrograph is that water levels were lower prior to the first measurements in October 1980 and that water levels rose as a consequence of accumulating pressure heads imposed by groundwater derived from mine discharge water.

Water quality data from samples of Wells 0141, 0142, and 0143 indicate a sustained presence (from first samples in July 1989) of groundwater having a chemistry distinct from Zone 1 groundwater derived from mine discharge water (i.e., background groundwater). Table 1 lists summary statistics for parameters analyzed from all groundwater samples taken from Wells 0141, 0142, and 0143. Sampling of Wells 0141 and 0143 ceased after January 2000, while sampling of Well 0142 has continued to present. Also shown in Table 1 are summary statistics for analytical parameters from samples of Zone 1 background groundwater (i.e., per the methodology reported in N.A. Water Systems, 2008b). Five parameters, in particular, illustrate the distinct chemical character of Zone 1 background groundwater from the groundwater sampled from Wells 0141, 0142, and 0143, which has been interpreted to be pre-mining groundwater. Those parameters are calcium (Ca), magnesium (Mg), total dissolved solids (lab TDS), sulfate (SO4), and manganese (Mn). There is no overlap of the concentration ranges of these parameters in Zone 1 background groundwater and what has been interpreted as pre-mining groundwater. Furthermore, with the exception of one result for lab TDS, none of the results for these five parameters found in the interpreted pre-mining groundwater even approaches the concentration ranges found in Zone 1 background groundwater. This exception was a TDS concentration in the last sample taken from Well 0141 of 2280 mg/L (compare to minimum concentration in Zone 1 background groundwater of 2490 mg/L). The next highest lab TDS result from the interpreted pre-mining groundwater was 1500 mg/L in a sample from Well 0142. Therefore, the sustained presence of groundwater having a chemical character distinct from Zone 1 background groundwater is not an assumption, but rather a demonstrable fact.

According to the conceptual model, groundwater interpreted to be pre-mining in origin occupied a portion of Zone 1 extending above the screened intervals of Wells 0141, 0142, and 0143. At the location of Well 0143, for example, this pre-mining water table would have been above elevation 6683 (ft amsl) (see Figure 2). Otherwise, samples drawn from this well would have exhibited the chemical character of background groundwater, which was and continues to be not the case. A corollary of this hypothesis is that the pre-mining water table in Zone 1 that became the locus of contact with the subsequently introduced background groundwater was above the screened intervals of these three wells. Accordingly, the subsequent rise of water levels in these wells was the result of a transmission of pressure head in contrast to the physical mixing or displacement of the pre-mining water by the post-mining water. Mixing of background and the interpreted pre-mining groundwater *at the elevations of the wells screens* is not supported by the water quality data and is not demanded by any consideration of groundwater hydraulics.

4. Comment: The groundwater model calibration efforts were not adequately documented and discussed.

Technical Basis: Reviewing and evaluating the quality of the model calibration is not possible without the accompanying documentation. The usefulness and applicability of the model output remains uncertain without assessing how the model is calibrated and the outcomes of the calibration.

Path Forward: Provide documentation of the model calibration efforts and results. This documentation should address the identification of calibration targets and acceptable residuals and the rationale behind the choice of which model inputs were varied and which were not varied during the course of calibration.

UNC Response: Documentation of the model calibration effort is provided below.

Calibration targets

The primary targets used during model development and calibration were water levels measured in wells screened in one of three hydrostratigraphic zones: the alluvium, Zone 1, or Zone 3. Water levels (heads) measured in wells screened across multiple hydrostratigraphic zones were not used, except in cases where the wells had been deemed by previous workers (see for example, Canonie, 1987) to provide measurements representative of one hydrostratigraphic zone. A typical example of the latter case is a well having a screened interval that extends from a transmissive zone into a nontransmissive zone (e.g., from the alluvium into underlying Dilco coal), in which case measured heads were deemed to be representative of the transmissive zone. The time frame of head measurements used as targets extended from the earliest available in November 1979 through October 2011. However, surveys of water levels in more than a few wells did not commence until the second quarter of 1980.

The well water level surveys prior to 1989 tended to be of separate well groups measured over periods spanning several months. Water levels at some wells were measured at higher frequencies during certain time periods and these in some cased exhibited a greater than typical variance of water levels. For these reasons the head measurements were averaged by quarters. Doing so reduced the tendency for spatial bias from more frequently measured wells and aligned the timing of the calibration targets more closely with the model stress periods. This was deemed reasonable, because a capacity to replicate short-duration head fluctuations (e.g., from pumping variations at nearby extraction wells) was neither feasible nor necessary to achieve the objectives of the Flow Model. Time series of the averaged well heads are listed in Tables 2A through 2C for wells in alluvium, Zone 3, and Zone 1 hydrostratigraphic units.

An additional alignment of the calibration targets was made using a feature of the GMS software that interpolates input head time-series for each well to estimate heads matching the time steps at which model heads are output. Furthermore, the model generated heads, which are cell centered, are spatially interpolated to estimate model heads at the location and depths of each well screen. Therefore, the estimates of model residuals (the difference between input well heads and model heads) were made in a way that best matched the model estimates to both the locations and times of measured well heads.

An important additional calibration target for the Flow Model was the mapped extent of seepage impacted groundwater in Zone 3. Specifically, a capacity to replicate by particle tracking the extent of the plume based on October 2011 sample data was deemed to be important to the objective of predicting future migration of seepage impacted groundwater. This part of the model calibration effort was made after the Flow Model had been sufficiently developed to replicate with sufficient accuracy the target heads. A description of the model development and calibration process follows.

Process of Model Development and Calibration

The three-dimensional Flow Model was preceded by a preliminary two-dimensional flow model. The two-dimensional model was created to test the feasibility of using MODFLOW to simulate a flow system that was entirely unsaturated above the pre-existing, pre-mining water table and became progressively saturated by infiltrating mine-discharge water beginning in March 1969. Results from the preliminary model, completed in January 2011 and presented to agencies at the 2011 annual meeting (*Albuquerque Technical Meeting, May 24, 2011*), indicated that development of a three-dimensional flow model of such a system was feasible. Another outcome of the two-dimensional flow model was a preliminary estimate of the extent of the groundwater mound created in the Gallup sandstone by the migration of anthropogenic groundwater subsequent to March 1969. This estimate was the basis for a significant expansion of the domain of the three-dimensional model.

Development and calibration of the Flow Model was done as a combined process, rather than as separate phases. During this process, the model was refined by adding (and removing) material property zones, adjusting the values of hydraulic parameters associated with material property zones, adjusting bed conductances and stages in river cells (representing arroyos during times of mine water discharge), and adjusting recharge rates (associated with tailings ponds and with arroyos during times of natural recharge runoff). Structural changes were also made to the model grid. These included the increases of grid cell densities in certain areas and the addition of a model layer to the portion of the model representing Zone 3. After each change to the model its output was tested against the target heads.

Table 3A is a listing of changes made to the Flow Model during the development and calibration process. Hydraulic parameter changes are listed explicitly, while other changes such as adjustments to the grid, river cells and recharge are described in notations. Table 3A also lists measures of the results of the changes quantified as model error (mean and root mean squared) in each of the three transmissive hydrostratigraphic zones.

Ranges of values assigned to property zone hydraulic parameters during the development and calibration process are listed in Table 3B. Most material properties were varied during this process. Some material properties were not changed, for various reasons. The horizontal anisotropy ratio in the alluvium was not varied from 1 (representing isotropy), because there was less reason on hydrogeologic grounds to expect horizontal anisotropy in the unconsolidated alluvium than in the consolidated (fractured rock) hydrostratigraphic units. The row-wise (northeast) horizontal hydraulic conductivity in the primary property zones of the Dilco coal (Dilco_M1) and Zone 2 (Z2_M1) were not varied, because horizontal fluxes in these zones were not considered to be significant factors in the over-all flow system, unlike the vertical components of hydraulic conductivity, which were varied. The storage properties, specific storage (SS) and specific yield (SY), in property zones representing the lower portion of Zone 3 were not varied, because these were considered to have been adequately constrained by analyses of pumping tests and other field data (for example, N.A. Water Systems, 2008a).

Through much of the development and calibration process model simulations and comparisons to target heads were run through January 2005. This was done to expedite the process by limiting execution times (typically about 30-40 minutes) and file sizes. January 2005 was selected, because it marked the end of a relatively long period of groundwater recession (since 2000) that was unaffected by extraction well pumping. This period ended with renewed pumping from Zone 3 starting in February 2005. After much of the development and calibration process was thought to be complete and the stage of calibration to the extents of the plume of seepage impact approached, model simulations were extended, first to October 2010 and later to October 2011 (as work on the model continued into 2012).

Other measures of the model output were examined during the development and calibration process. These included maps of model heads and model residuals at various time periods. These observations were made using figures like those shown for 1987 and 2011 in Figures 16A through 17C in the Flow Model report. These observations were useful for identifying spatial correlations of error as well as areas of unexpected drying. Areas and episodes of unexpected drying may have had various causes including excessive inter-cell and intra-cell hydraulic gradients related to extraction well pumping or tailings pond recharge. Mass balance errors also were commonly associated with these events. In several of the development and calibration steps, increases of the grid cell density were found to alleviate this problem (see Table 3A notations). Also examined were graphs of model residuals versus observed heads and as time series, such as shown in Figures 22A through 24C in the Flow Model report. These observations were particularly useful for tracking mean and root mean model error as a function of time, which was used to identify potential problems associated with particular stress periods. These observations were also useful not only for gauging overall model error, but also to guide an objective of reducing model error with simulation time, such that error levels in the simulation of recent times (e.g. 2011) would not impede the objectives of the Flow Model. Judgment of the potential influence of model error on the capacity to meet its objectives was subjective, but based on the various quantitative measures discussed above. However, a direct test of this judgment would be made in the subsequent stage of model calibration, which is described below.

The last stage of model development and calibration was made to test the capability of the Flow Model to simulate the current (2011) extent of the tailings-seepage-impact plume in Zone 3 using the method of particle tracking. This was an important prerequisite for the objective of predicting future extents of the plume. The methods and results of this test are described in section 4.2 of the Flow Model report. Adjustments were made to material property zones, including the addition of a property zone in Zone 3, adjustments of hydraulic parameters, and adjustments of recharge rates associated with the north pond (see Table 3A). These adjustments to the model were made to improve its capacity to simulate the extent of the seepage-impact plume. At the same time effort was taken to avoid adverse effects on the capacity of the model to simulate target heads.

An additional test of the model output is described in section 4.3 of the Flow Model Report. This test consisted of a comparison of the model-predicted volume of background groundwater in hydrostratigraphic Zones 1 and 3 with the measured volume of mine water discharged to Pipeline Arroyo. The volume of background groundwater calculated from the model output was determined to be approximately 10 percent of the total volume of mine water discharge. This percentage compared closely to the percentage of mine water discharge lost to infiltration, estimated from weir measurement made in Pipeline Arroyo over four months in 1981. There was no guarantee that this would be the case, other than an accurate representation of input from river cells in the model. River cells simulated the infiltration water in the arroyos during the period of mine water discharge, which was the dominant source of background groundwater. Input of groundwater from river cells in MODFLOW is calculated on the basis of the head differences between the defined river stages and the model estimated groundwater heads in the cell. Flow may be into or out of the groundwater flow system depending on whether the river stage exceeds or is less than the underlying groundwater head. Furthermore, the flux depends on the conductance assigned to the river bed in each river cell. In other words, the predicted total volume of background groundwater depended not on a defined-flux input, but rather on the interplay of heads and river stages in dozens of river cells simulated over the 20-year period from 1969 to 1989. The test of the predicted total volume of background groundwater first was made after final calibration adjustments to the model. No additional testing or calibration adjustments were required, because the test was successful.

5. Comment: A water balance for the entire model domain is not presented (e.g., table showing the water volume rates entering, and exiting the model domain). The volume should be further subdivided into the main components of a water balance including surface recharge (precipitation minus runoff minus evapotranspiration), influent and effluent streamflow, lateral boundary recharge, lateral boundary drainage, water storage change, and deep percolation.

Technical Basis: The constructed model involves a number of inputs in and outputs from the aquifer system, including recharge from the Pipeline Arroyo (mine water discharge and periodic runoff events), some tributaries due to surface runoffs, and tailings ponds, and discharge from groundwater extraction wells. Examination of water balance is imperative to understand the conceptual model of the groundwater flow. A water budget for the groundwater flow model is used to understand how a groundwater flow system functions. This water balance information and the water budgets from various time periods provide insight into the flow model and the flow system.

Path Forward: Provide a water balance for the entire model domain. For example, a table could be constructed showing the water volume rates entering, and exiting, the model domain each year. This should then be further divided into the main components of a water balance including surface recharge, influent and effluent stream flow, lateral boundary recharge, lateral boundary drainage, water storage change, and deep percolation.

UNC Response: The requested water balances are presented in Table 4A for water year 1986, in Table 4B for water year 2011, and in Table 4C for water year 2026. It should be noted that the calculated mass balances show cumulative volume discrepancies of several percent, which is higher than might be expected for a flow model representing a natural flow system. Mass balance discrepancies associated with the Flow Model are affected by MODFLOW's cell rewetting procedure. This procedure was used throughout most of the model domain, except for areas upgradient of the tailings ponds and other recharge areas. This was necessary, because all of the hydrostratigraphic zones above the pre-mining water table started out dry and became "rewetted" only as they were saturated by infiltrating mine water. The MODFLOW cell rewetting procedure is an empirically-derived approximation that iteratively selects whether to introduce groundwater into each dry cell that is subject to rewetting, depending on conditions in adjacent or underlying cells. While some cells may dry as others are rewetted, there is no guarantee that the water masses will balance, particularly as in the Flow Model where a wetting front progressively advanced over a large portion of the model domain. The rewetting procedure also affected the tendency of the simulation to converge relative to what is typically a minimum head change criterion of a small fraction of a foot. With iterative wetting and drying of cells minimum head changes typically exceeded one foot.

6. Comment: A sensitivity analysis should be provided to identify the input parameters that have the most impact on the degree of model calibration and on the conclusions of the modeling prediction.

Technical Basis: Given that site-specific data (e.g., recharge rates) is very limited, a detailed model sensitivity analysis needs to be performed for better evaluating the model. The purpose of a sensitivity analysis is to identify the input parameters that are the major contributors to the results. The identification of these major parameters is important in providing users with an understanding of the level of confidence in model results and identifying data deficiencies contributing to a reliable decision making process.

Path Forward: Provide a section on the sensitivity analysis identifying significant processes and features that impact model performance. The documentation should state which model inputs were varied, which computed outputs are examined and, in addition, provide figures and tables of the results.

UNC Response: Documentation of the sensitivity analysis is provided below.

Sensitivity Analysis

The sensitivity of model output to changes in parameters encompassed 14 hydraulic parameters in 8 material zones and in each of the 6 layers of the Flow Model. In most cases the parameters were multiplied and divided by factors of 2.5 and 5.0, resulting in four model runs for each of the parameters analyzed. Three additional sets of parameters were analyzed, river bed conductances, recharge fluxes, and material property zones simulating effects of the Pipeline Canyon lineament. In the latter case a single run was made with the heterogeneities associated with the lineament removed from the Flow Model.

Table 5 summarizes the residual statistics from each of the sensitivity runs and compares them with the statistics from the calibrated Flow Model (labeled "base" in Table 5). The listed material property zones correspond with those shown in plan view in Figures 15B to 15F in the model report (Chester Engineers, October 2012). Figures 3 through 22 present the information in Table 5 in graphical form. Table 6 lists the values of all material property zone hydraulic parameters for each model run made in the sensitivity analysis, except those made with adjusted river bed conductances, adjusted recharge fluxes, and with the removal of heterogeneities associated with the Pipeline Canyon lineament.

The hydraulic properties adjusted in the sensitivity analysis are predominantly horizontal and vertical hydraulic conductivity components. The vertical and column-wise components of hydraulic conductivity are specified in the Flow model by anisotropy ratios with respect to the row-wise (northeast) horizontal component. Therefore, changes to the row-wise hydraulic conductivity make proportional changes to the column-wise and vertical components. In contrast, changes to the anisotropy ratios affect only one component of hydraulic conductivity. Note also that the horizontal anisotropy ratio (ah) is defined as the column-wise component divided by the row-wise component. Therefore, an increase of ah increases the column-wise component relative to the row-wise component. In contrast, the vertical anisotropy ratio (av) is defined as the row-wise component divided by the vertical component.

Therefore, an increase of av decreases the vertical component relative to the row-wise component. Table 5 does not show results for the 5-fold division of av in the alluvium, because such a division would have caused the physically unrealistic result of having the vertical component of hydraulic conductivity exceed the horizontal component.

The residual statistics listed in Table 5 and graphed in Figures 3 through 22 were calculated separately for each of the three transmissive hydrostratigraphic zones. The residuals are based on comparisons of model predicted heads to heads measured through October 2011. Residuals are calculated by subtracting the model-predicted heads from the measured heads. So for example, a positive mean error statistic indicates that the model predicted heads were on average lower than the measured heads. The root mean squared error statistics are unaffected by the numerical sign of the residuals and are representative of the average magnitude of error. The numbers of residuals tabulated in Table 5 and graphed in Figures 3 through 22 are presented to account for an aspect of the method by which the residuals are calculated. If a well having water level measurements lies within a model cell that becomes dry in a particular time step of a simulation, then a model-predicted head will not be available for the calculation of a residual. In some cases this may result in a reduction of the other residual statistics, even though the model has predicted drying at a location that was not observed to by dry. Therefore, a higher number of residuals is indicative of a better outcome with respect to drying.

Sensitivities of the residual statistics to parameter changes are described below relative to the three hydrostratigraphic zones from which the statistics were derived.

Alluvium

Residual statistics for the alluvium were found to be more sensitive to changes of the following parameters:

1. Hydraulic conductivity in property zone Z1_M1, which encompasses most of the Zone 1 (Table 5, Figure 14). This is reflected primarily in the mean error and the number of residuals, changes of which are consistent with increased drying of the alluvium with increased hydraulic conductivity in Zone 1.
2. Hydraulic conductivity in property zone alluv_M1, which encompasses all of the alluvium (Table 5, Figure 16). This is reflected primarily in changes of the mean error and number of residuals that are consistent with increased drying of the alluvium with increased hydraulic conductivity in the alluvium. However this trend seems to reverse with reductions of alluvium hydraulic conductivity by a factor of 5.
3. Bed conductances in river cells (Table 5, Figure 20). There is strong sensitivity of the residual statistics to reductions of river bed conductances, particularly when by more than a factor of 2.5. Changes of the mean error and numbers of residuals are consistent with increased drying of the alluvium with lower river bed conductances.
4. Fluxes in recharge cells (Table 5, Figure 21). Residual statistics are sensitive to increases of fluxes in recharge cells. Changes of the mean error and numbers of residuals are consistent with rising heads in the alluvium with increased recharge fluxes.

Zone 3

Residual statistics for Zone 3 were found to be more sensitive to changes of the following parameters:

1. Hydraulic conductivity in property zone Z3_M1, which encompasses most of the Zone 3 in model layer 3 (Table 5, Figure 3). This is reflected primarily in the mean error, changes of which are consistent with lowered heads in Zone 3 with increases of hydraulic conductivity in Zone 3 up to a factor of 2.5.
2. Horizontal conductivity anisotropy ratio in property zone Z3_M1, which encompasses most of the Zone 3 in model layer 3 (Table 5, Figure 5). Increases of the horizontal conductivity ratio above the base case (1 = isotropic) had a strong adverse effect on the residual statistics. Increases of the ratio cause the column-wise (northwest) component to be increased relative to the row-wise (northeast) component of hydraulic conductivity.
3. Hydraulic conductivity in property zone Z3_M2, which corresponds with an area of estimated influence from fractures associated with the Pipeline Canyon lineament (Table 5, Figure 6). Increases of hydraulic conductivity over the range of 1/2.5 to 2.5 (relative to the base case) caused a modest improvement of the residual statistics.
4. Hydraulic conductivity in property zone Z3_M3, which encompasses most of Zone 3 in model layer 4 (Table 5, Figure 7). Increases of hydraulic conductivity in the range of 1/2.5 to 5 (relative to the base case) caused adverse effects on the residual statistics.
5. Horizontal conductivity anisotropy ratio in property zone Z3_M3, which encompasses most of the Zone 3 in model layer 4 (Table 5, Figure 9). Increases of the horizontal conductivity ratio above the base case (1 = isotropic) had an adverse effect on the residual statistics. Increases of the ratio cause the column-wise (northwest) component to be increased relative to the row-wise (northeast) component of hydraulic conductivity.
6. Hydraulic conductivity in property zone Z4_M4, which parallels the Pipeline Canon lineament in model layer 3 and also occupies an area beneath and to the northeast of the eastern half of the former north pond in model layers 3 and 4 (Table 5, Figure 10). Reductions of the hydraulic conductivity relative to the base case had a modest adverse effect on all of the residual statistics. Increases relative to the base case had the mixed effect of modestly increasing the number of residuals, while modestly increasing the mean error.
7. Hydraulic conductivity in property zone Z2_M1, which encompasses most of Zone 2 (Table 5, Figure 12). Increases of hydraulic conductivity caused increases in the numbers of Zone 3 residuals, while having little effect on the other residual statistics. Commensurate increases of Zone 1 mean errors is consistent with higher heads in Zone 1, which may have reduced drying in overlying cells (e.g., in Zone 3).
8. Vertical conductivity anisotropy ratio in property zone Z2_M1, which encompasses most of Zone 2 (Table 5, Figure 13). Decreases of the vertical conductivity anisotropy ratio (relative to the base case) caused increases in the numbers of Zone 3 residuals. Decreases of this ratio cause the vertical component of hydraulic conductivity to increase. The effect of this increase on numbers of Zone 3 residuals and on Zone 1 mean error are similar to those described in case 7 (above), indicating that the vertical component of hydraulic conductivity in property zone Z2_M1 was the principal factor in both cases.
9. Hydraulic conductivity in property zone Z1_M1, which encompasses most of Zone 1 (Table 5, Figure 14). Increases of hydraulic conductivity caused an adverse effect on residual

statistics. Changes of mean error and numbers of residuals are consistent with lower heads and increased drying in Zone 3.

10. Hydraulic conductivity in property zone alluv_M1, which encompasses all of the alluvium (Table 5, Figure 16). Increases of hydraulic conductivity caused an improvement of residual statistics in Zone 3. This is particularly evident for increases at values less than the base case. Increases of hydraulic conductivity relative to the base case caused less significant improvements of the residual statistics and were accompanied by increased drying of the alluvium.
11. Bed conductances in river cells (Table 5, Figure 20). There is strong sensitivity of the residual statistics to reductions of river bed conductances, particularly when relative to the base case. Changes of the mean error and numbers of residuals are consistent with lowered heads and increased drying of the Zone 3 with lower river bed conductances.
12. Fluxes in recharge cells (Table 5, Figure 21). Strong decreases of mean error with increases of recharge cell fluxes are consistent with rising heads in Zone 3. Effects on other residual statistics are mixed. Mean squared errors increased with either increases or decreases of the recharge fluxes relative to the base case. Numbers of residuals increased, consistent with rising heads.
13. Removal of property zones associated with Pipeline Canyon lineament (Table 5, Figure 22). The removal of property zones associated with Pipeline Canyon lineament had an adverse effect on all residual statistics.

Zone 1

Residual statistics for Zone 3 were found to be more sensitive to changes of the following parameters:

1. Hydraulic conductivity in property zone Z2_M1, which encompasses most of Zone 2 (Table 5, Figure 12). Increases of hydraulic conductivity caused a strong decrease of mean error in Zone 1, which is consistent with increased heads. Root mean squared error increased with both increases and decreases of hydraulic conductivity relative to the base case.
2. Vertical conductivity anisotropy ratio in property zone Z2_M1, which encompasses most of Zone 2 (Table 5, Figure 13). Decreases of the vertical conductivity anisotropy ratio (and commensurate increases of the vertical component of hydraulic conductivity) caused strong decreases of the mean error in Zone 1. Root mean squared error increased with both increases and decreases of anisotropy ratio relative to the base case. These are the same effects noted in case 1 (above), indicating that the vertical component of hydraulic conductivity in property zone Z2_M1 was the principal factor in both cases.
3. Hydraulic conductivity in property zone Z1_M1, which encompasses most of Zone 1 (Table 5, Figure 14). Increases or decreases of hydraulic conductivity relative to the base case had adverse effects on most error statistics.
4. Vertical conductivity anisotropy ratio in property zone Z1_M1, which encompasses most of Zone 1 (Table 5, Figure 15). Increases or decreases of hydraulic conductivity relative to the base case had adverse effects on mean error and a minor influence on other residual statistics.

5. Hydraulic conductivity in property zone alluv_M1, which encompasses all of the alluvium (Table 5, Figure 16). Increases or decreases of hydraulic conductivity relative to the base case had modest adverse effects on root mean squared error and numbers of residuals. Mean error was adversely affected by reductions of hydraulic conductivity.
6. Bed conductances in river cells (Table 5, Figure 20). There is strong sensitivity of the residual statistics to reductions of river bed conductances, particularly when relative to the base case. Changes of the mean error and numbers of residuals are consistent with lowered heads and minor increased drying of the Zone 1 with lower river bed conductances.
7. Fluxes in recharge cells (Table 5, Figure 21). Strong decreases of mean error with increases of recharge cell fluxes are consistent with rising heads in Zone 1. Effects on other residual statistics are mixed. Mean squared errors increased with either increases or decreases of the recharge fluxes relative to the base case. Numbers of residuals increased, consistent with rising heads.
8. Removal of property zones associated with Pipeline Canyon lineament (Table 5, Figure 22). The removal of property zones associated with Pipeline Canyon lineament had an adverse effect on all residual statistics.

Residual statistics provide a useful measure of the sensitivity of the Flow Model's performance with respect to replication of measured heads. However, other tests were made of the performance of the calibrated model that are at least as important to the objective of predicting the current and future dispositions of the three genetic classes of groundwater: pre-mining (natural), mine-water derived (background), and impacted (from tailings seepage). These tests are described in the response to general comment number 4. In short, the tests were of the Flow Model's capability to replicate (by particle tracking) a recent (October 2011) extent of the seepage impact plume and a test of its capability to accurately predict the volume of background groundwater that infiltrated Zones 1 and 3.

It is expected that the capability to replicate the transport of seepage impacted groundwater is very sensitive to hydraulic conductivities, particularly those assigned to portions of the model representing Zone 3. This expectation derives from the proportional relationship of flow velocity, and therefore travel times and distances, to hydraulic conductivity. This relationship is exemplified in one dimension by the Darcy flow equation. Similarly, the capability to accurately predict the volume of infiltrated background groundwater is expected to be very sensitive to river cell inputs, such as bed conductances, to recharge cell inputs, such as fluxes in the arroyos, and to alluvium hydraulic properties, such as the components of hydraulic conductivity.

7. Comment: The report should discuss which parts of the model have the greatest uncertainty and what consequence that may have on the results. Any discussion should identify how much uncertainty is associated with the major assumptions, the most significant parameters, and key components of the model.

Technical Basis: There will always be some uncertainty associated with conceptual model and input parameters that influence the performance of a numerical model, and also with the appropriateness of the simulation software to truly represent the real-world processes and events. Understanding of the extent of model uncertainty, and the type of uncertainty associated with model results is essential in order to make well-informed decisions.

Path Forward: Provide the documentation discussing the uncertainty associated with the conceptual model(s), the most significant parameters, and the major assumptions.

UNC Response: The sharpest division of certainty in the domain of the Flow Model occurs at the Section 36 boundary. With a few notable exceptions, such as the NECR mine shaft and a small number of well logs, virtually all of the point data sources (e.g., wells and borings) for model inputs and calibration targets are from areas on UNC property south of the Section 36 boundary. To the north of this boundary the construction of the Flow Model was based on published information that is described and cited in the Flow Model report. This information included a digital elevation model, regional mapping of structure contours for the Gallup sandstone, and aerial photography. The digital elevation model was used, for example, to define the upper (ground) surface of the model and to estimate the size of basins feeding runoff to Pipeline Canyon Arroyo. Aerial photography was used to estimate extents of the alluvium. The regional structure contour maps were used to expand the estimated bounding surfaces of hydrostratigraphic zones by interpolation and extrapolation from on-site data. Nevertheless, there is a demarcation of decreasing detail and confidence begins at the Section 36 boundary and continues with increasing distance from on-site data sources. This uncertainty applies also to hydraulic properties, which are based on the results of tests and measurements made in wells south of the boundary. All of these factors contribute to diminishing confidence in model predictions with increasing distance from on-site sources of information.

Other significant divides of certainty occur in time. The beginning of the time domain of the Flow model is at the initiation of mine water discharge in March 1968. However, the earliest available measurements of well water levels are from late 1979 and expansive surveys of well water levels didn't begin until several years later. Therefore, there aren't measurements of the evolution of the groundwater system available to compare with Flow Model output during the initial 12 years of the simulation. Therefore, the accuracy of that portion of the simulation can only be judged by comparisons to later measurements. Fortunately, there is a substantial body of information about the evolution of the groundwater system from the mid-1980s to present, particularly in areas impacted by tailings seepage. This provided a similar focus to the calibration and testing of the Flow Model, which supported the objectives of predicting current and future conditions – not reconstruction of early conditions.

The other divide in time, one that affects all predictive models, is the future. Predictions of future conditions will have a degree of uncertainty that increases with time from the data base of the model. This is mitigated by having a history matching period of more than 30 years, which is long relative to the 45 year life of the anthropogenic flow system. However, it may not be long relative to future-cast simulations that may be required of the Flow Model. It is also the case that the areas of greatest interest in such simulations will, with time, fall increasingly north of the Section 36 boundary. That will introduce additional uncertainty for the reasons described at the beginning of this response.

The cell rewetting procedure introduces numerical error with respect to mass balance and predicted heads. This procedure is extensively used by the model to simulate the migration of mine-discharge-derived groundwater through previously unsaturated geologic formations. Cell rewetting is an empirical procedure that iteratively compares heads in cells adjacent to and underlying each dry cell to determine whether to rewet the dry cell. The threshold of head for rewetting and the depth of saturation applied to rewetted cells are input parameters derived during model calibration. Without this procedure, simulation of the evolution of the anthropogenic flow system with MODFLOW would not have been possible. Raising these rewetting input parameters reduced cycling of cells from dry to wet, but also reduced the capacity of the model to simulate the historic rates and extents of anthropogenic groundwater spreading. As it is formulated, the procedure enables the flow model to simulate the historic spread of anthropogenic groundwater, but it also introduces local and temporal instances of mass balance and head estimation errors that exceed typical thresholds for solution convergence. The model was set to continue the execution of simulations when such errors occurred. One consequence of this is uncertainty of the extent and depth of saturation near margins of saturation. This is manifested by an irregular, rather than sharply defined, margin of saturation (for example, along the predicted eastern margin of saturation in Zone 3). There are also variations in the definition of these margins of saturation that arise from one iterative cycle of wetting and drying to the next.

As indicated above there is a substantial body of information from the many wells (and borings) in areas and hydrostratigraphic zones impacted by tailings seepage. This information extends not only to the evolution of piezometric heads, but also the evolution of groundwater chemistry and hydraulic properties (e.g., hydraulic conductivity, storage coefficients, and effective porosities). There is also a substantial database of structural elevations from well and boring logs. Therefore, the model inputs and design elements based on such information carry a relatively higher degree of confidence inside the UNC property bounds. However, there is some uncertainty associated with differing interpretations of structural elevations from the logs of some wells in particular areas of the site, such as the Zone 1 base elevation in the vicinity of vicinity of the Section 36 boundary. The following describes the sources of this uncertainty and an evaluation of model sensitivity to uncertainty in the Zone 1 base elevation.

Some of the well log reinterpretations are documented in files made by Canonie in preparation for their hydrogeologic report on the site (Canonie, 1987). The reinterpreted structural elevations were recorded in the site database. The flow model was designed from the structural elevations recorded in the database. This was done, because understanding of the local stratigraphy and even the definition of Zone 3 had evolved by the time Canonie reinterpreted earlier well logs. It is also the case that original drilling and/or geophysical logs are no longer available for many wells. A recent reevaluation of original drilling logs of Zone 1 wells 141, 142, and 143 showed that these logs were among those whose structural elevations differed from those in the database. The reinterpreted structural elevations at these wells are, with one exception, more consistent with stratigraphic elevations and thicknesses recorded at subsequently drilled, nearby wells. The exception is the reinterpreted base of Zone 1, which may have been more accurately recorded in the original logs of wells 141, 142, and 143. While original logs for wells 138 and 139 are no longer available, it appears that structural elevations at these well may have similarly been reinterpreted. All of these wells are located near the Section 36 boundary, but Canonie (1987) chose not to utilize any of their logs in the compilation of a hydrogeologic cross section aligned with the boundary.

A revised estimate of the base of Zone 1 was made to test the sensitivity of the model to the cited uncertainty of interpreted Zone 1 base elevations. The revised estimate was made without Zone 1 base elevations from all but one of the wells that Canonie (1987) chose to exclude from their cross section. The exception was the elevation in the original log of well 143, which was retained because it filled what would otherwise have been a significant data gap and because that elevation is consistent with those recorded in the other wells whose data were retained in the estimate.

The effects of the re-estimated base of Zone 1 (layer 6 of the flow model) on error statistics are illustrated in Figure 23 and listed in Table 5. The error statistics were calculated in the same way as in the sensitivity analysis presented in response to General Comment 6. The error statistics are insensitive to the model revision relative to many of the parameters varied in the sensitivity analysis. While the estimated heads are substantially the same in the revised model, there are measurable differences and those differences extend to model estimated heads in cells near to and removed from the immediate area of the revised elevations (an example is provided below for heads estimated at well 143). Some of these differences are attributable to the influence of the revision on groundwater hydrology. However, many of the differences are interpreted to have resulted from differing expressions of the numerical error inherent in wetting and drying cycles, as described above.

The tested revision does not improve the capability of the flow model to reproduce heads in Zone 3, as illustrated by Figure 23 and Table 5. Differences of detail in estimated heads are interpreted to have been caused by differing expressions of numerical error, as much as or more so than to a change of groundwater hydrology. Therefore, there appears to be little benefit to be gained by replacing the existing flow model and the simulations made with it with the revised model. There would be no expectation of meaningful differences, much less improvement of the model's intended capabilities.

The Flow Model report describes in detail model inputs related to river cells and recharge cells for which there is comparatively less confidence. The report also describes the field data, simplifying assumptions, and methods that were used to estimate these inputs. The sensitivity analysis provided in response to general comment 6 also indicates that residual statistics are sensitive to changes of both river cell and recharge cell inputs. Therefore it was important that predictions of the Flow Model that may be sensitive to these inputs be tested. Residual statistics measure the capacity of the Flow Model to reproduce measured heads and adjustments made to improve this capacity are described in the response to general comment 4. Also described in the response to general comment 4 was the test of the Flow Model's capacity to accurately predict the volume of background groundwater residing in Zones 1 and 3. This capacity of the model is sensitive to the sources of the background groundwater, which are the inputs from the river cells and those recharge cells that are located in arroyos.

The response to general comment 3 described empirical and theoretical bases for two conceptual model hypotheses that influenced the design of the Flow Model. One of the hypotheses is that fractures associated with the Pipeline Canyon lineament might have promoted the infiltration of discharged mine water into Zone 1 and Zone 3. The other hypothesis is that a pre-mining water table was present in Zones 1 and 3 at a common elevation of approximately 6700 ft (amsl) at the time the NECR mine shaft was constructed (in 1969). Furthermore, subsequent migration of the pre-mining groundwater was not sufficient over the period from mid-1989 to present (October 2012) to measurably affect the chemistry of water sampled from Zone 1 wells (e.g., Well 0143) screened beneath the pre-mining water table. Several outcomes of the Flow Model simulations have reduced the uncertainty of these hypotheses.

The sensitivity analysis provided in response to general comment 6 indicates that the inclusion of material property zones simulating effects of Pipeline Canyon lineament measurably improved the capacity of the Flow Model to replicate heads measured in each hydrostratigraphic zone. These material property zones also improved the capacity of the model to replicate by particle tracking the extent of seepage impact in Zone 3 (described in Section 4.2 of the Flow Model report).

Similarly, the hypothesis of a pre-mining water table at the elevation of approximately 6700 ft (amsl) is supported by the error characteristics of the Flow Model. These error characteristics were presented for the entire calibration target set in Section 5 of the Flow Model report. A point not made explicitly in the report is that if the initial condition of the hypothesized pre-mining water table differed significantly from reality, then the capacity of the Flow Model to replicate measured heads would have been significantly diminished. To illustrate this point Figure 24 shows the hydrograph of Zone 1 well 0143 (also shown in Figure 2) with the addition of the model-simulated hydrograph. The simulation is not perfect. In particular, it appears that the onset of pressure head rise from background groundwater may have occurred earlier in reality than in the model simulation. However, the mean error of 5 ft and root mean squared error of 7.8 ft of the simulation are small compared with the 32 ft dynamic range of measured heads and even more so relative to the 77 ft dynamic range of simulated heads. It is difficult to imagine conditions that would cause to the Flow Model to accurately simulate both the volume of background groundwater and the degree of its effect on pressure heads if the initial condition of the pre-mining water table was significantly in error.

8. Comment: Model validation in Section 5 is not adequately documented in the Groundwater Flow Model Report – October 2012. It is not clear what data set or measurements were used in the hydraulic head comparison with the model-predicted heads. Based on the discussion about the relationship between hydraulic head residuals and time (Figure 24A in Section 5.3), it appears that the hydraulic head data collected from 1979 to 2011 are used in the model validation analysis. It then raises the question as to what data set or subset was used for the model calibration.

Technical Basis: N/A

Path Forward: Provide clarification on hydraulic head data sets used in the model validation and calibration analysis.

UNC Response: Data sets used for model calibration are described in the response to general comment 4. Early in the calibration and development process simulations were limited to shortened time frames. Later in the process simulations were extended to October 2010 and calibrated against a 1979-2010 target data set. That target data set was extended to October 2011 after that data became available. The description of error characteristics in Section 5 of the Flow Model report was made to represent the capacity of the Flow Model to reproduce heads measured over the simulated time frame.

Head data are now available from seven quarterly surveys made subsequent to October 2011, so it is possible to calculate residual statistics by comparing model output to these measurements. However, a more direct and rigorous validation of the predictions of the model is anticipated. To this end, locations have been proposed for the drilling of wells to test the predictions of the model in areas north of the Section 36 boundary. These will test not only model predictions of heads, but also the chemical characteristics of sampled groundwater.

Specific Comments

1) In Section 1.2.2 (page 4): Due to the assumed importance of the Pipeline Canyon lineament and the Pinedale monocline, more detailed descriptions from a geological and hydrogeological perspective are needed. The yellow lines in Figures 4 and 10 indicate the location of the Pinedale monocline, but nothing is seen in the cross-section of Figure 11B. If the term "Pinedale monocline" is exclusively referring to Gallup Sandstone's regional dip, this should clearly be stated.

UNC Response: The degree of importance of the two named structural features to the design of the Flow Model was not equal. The Pinedale monocline was included in the description of the local geologic setting, because it had been mapped as a flexure by others in the location shown in Figure 4 of the Flow Model report. However, the mapped position of this feature was not used to modify the quantitative estimates of structural surfaces bounding (i.e., top and bottom) the hydrostratigraphic zones. Instead, these estimates were based solely on data (from boring and well logs as well as regional mapping of structure contours). This decision was made, because there is insufficient data to support a superposition of effects that might be attributed to the Pinedale monocline.

Figures 11b and 11a were prepared prior to the flow model for the purpose of illustrating aspects of the conceptual model. They were based on extrapolations of on-site data by a local polynomial method that tends to smooth irregularities. Estimates of structure surface elevations made for the flow model employed regional as well as on-site data and were made by the method of kriging, which retains irregularities defined in the data. Revised versions of Figures 11a and 11b (attached) have been made by the same methods used to design the flow model.

The Pipeline Canyon lineament was hypothesized to potentially have an important effect on the groundwater flow system, particularly on the infiltration and migration of mine discharge water in Zones 1 and 3. For this reason the structure is described in greater detail in Section 1.2.2 of the Flow Model report, including not only its mapped location, but also measured fracture spacings and conclusions of earlier workers on the potential effects of those fractures on groundwater flow. The Flow Model was designed to allow for these hypothesized effects. Additional rationale for this decision is provided in the response to general comment 3. Methods by which the hypothesized effects were tested in the development and calibration process are described in the response to general comment 4. The outcome of having incorporated the hypothesized effects on the Flow Model's capacity to replicate measured heads is described in the response to general comment 6.

2) In Section 2.2 (page 9, paragraph 1): It states, "...the extents were limited to the north downgradient of the pre-mining water table at a sufficient distance to allow for migration ...." Please modify this section to explain how this distance was estimated to be sufficient to allow for migration of the pre-mining groundwater.

UNC Response: One part of the answer, which was described in the response to general comment 4, was information learned from a two-dimensional model that was made to test the feasibility of making the three-dimensional Flow Model. That information led to an expansion of the model domain to accommodate migration not only of pre-mining groundwater, but also of the background groundwater. After continuous saturation was established over a broad front between the two classes of groundwater there would also be a continuity of hydraulic gradients and, therefore, of flow. Such a situation is illustrated by the saturated thickness map shown in Figure 21 of the Flow Model report. The map depicts simulated conditions in October 2026. The figure shows the simulated rise of piezometric heads measured as saturated thickness above the initial pre-mining water table at 6700 ft. The rise in heads near the eastern and western margins of the view depicted in the figure is less than one foot. This indicates that, while the Flow Model's no-flow boundaries have begun to exert an influence, that influence is still small enough to have a negligible influence on groundwater flow over most of the model domain.

The influence of the no-flow boundaries will increase as longer simulations are made, because the groundwater mound shown in Figure 21 of the Flow Model report will continue to spread as its height diminishes. Therefore, adjustments of the boundaries may become necessary, depending on the time span that future simulations are required to encompass. A conversion from no-flow to general head boundary conditions is envisioned as a step that could be taken to accommodate such simulations.

3) In Section 2.3.1 (page 10, paragraph 3): Drain cells allow for discharge of groundwater out of the model domain; however, Section 2.3.1 states, "MODFLOW river cells operate similarly to drain cells, with the important difference that they also allow for discharge of groundwater out of the model domain." The report seems to indicate that there are no differences between MODFLOW's river cells and drain cells. Are any river cells in the current model allowing for discharge of groundwater out of the model domain?

UNC Response: The quoted statement was not written as intended. The words "discharge out of" will be modified to "recharge in to".

The current model does include river cells that discharge groundwater out of the model domain. This occurs when the groundwater head in the cell exceeds the elevation of the river stage. In the simulation this occurred in two situations. When mine water discharge ceased a condition quickly developed where groundwater heads in most river cells were above the bed elevations of "dry" river cells. Discharge from the model domain continued until the groundwater heads dropped below the river bed elevations.

The other condition that led to localized discharge to river cells occurred during the time of mine water discharge in river cells located on river (arroyo) segments having a steeper slope than the up-stream segment. However, the net effect of river cells during this period was overwhelmingly that of recharge to the model domain. The situation of localized discharge arises where there is a steepened drop of the river bed elevation that exceeds the groundwater hydraulic gradient (typically in alluvium). Therefore, there is a rise of the groundwater elevation relative to the river bed and stage elevations. This effect is accentuated by another calculation that was made to derive river stage inputs. Manning's equation was used to calculate time-variant stages based on discharge, estimated channel slope, and a uniform trapezoidal cross section. This calculation is described in Section 2.3.1 of the Flow Model report. If discharge is constant from an upstream channel segment to a more steeply sloped downstream segment then the calculated stage will be lower in the downstream segment, because it can accommodate the discharge with a lower stage.

4) In Section 2.3.2 (page 12, paragraph 6): It states, "...the model-predicted rates of drainage out of the area of water-level measurements that surpassed those implied by the measurements." The referred measurements should be documented in the model report, or referenced.

UNC Response: The cited passage will be revised to: "...the model-predicted rates of drainage surpassed the rates of drainage implied by well water level measurements." These measurements are provided as the tables of calibration targets referenced in the response to general comment 4.

5) In Section 3.2 (page 18): Provide information on how the boundaries between the active cells representing the Dilco Coal and neighboring inactive cells were determined. See Figure 15B.

UNC Response: One of the steps taken during the process of model development and calibration was to define these boundaries. These boundaries were initially set with broader areas of active cells (this applied also to the alluvium). The boundaries were adjusted so that areas that were perennially dry in the simulations were inactivated. This was done to reduce numerical overhead (excess computer time and storage). Any area having evidence of saturation from well measurements was retained regardless of whether there was drying in the model simulations.

6) In Section 6 (page 31): The terms "sufficient accuracy" and "functionality goals" should be defined or discussed in more detail.

UNC Response: Section 6 (Conclusions) of the Flow Model report uses the cited phrases in statements that draw context from references to other sections of the report where bases for the conclusions are described in greater detail. The context of "sufficient accuracy" is the following statement: "This was done after verifying the capacity of the model to simulate, with sufficient accuracy, the historic development of the anthropogenic part of the groundwater system recorded by monitor well observations (water levels) and samples (presence or absence of seepage impacts." This conclusion is drawn from information provided in detail in Section 4 of the report, and particularly in Sections 4.2 and 4.3.

The context of "functionality goals" is the following statement: "The Flow model has met the functionality goals outlined in the Introduction." The following two statements in Section 6 plainly describe those goals and paragraph 2 of the Introduction section explains why those goals were selected.

7) In Section 7 (pages 32 -35): All references should be readily available for review. Staff suggests that the licensee incorporate all references on a computer disc to facilitate ease of review. Outlined below are documents which were referenced, but not readily available for review.

- McLin, S.G., and P.L. Tien, 1982, Hydrogeologic characterization of seepage from uranium mill tailings impoundment in New Mexico, in Proceedings of the Second Ann. Symp. on aquifer restoration and groundwater monitoring, Columbus OH, Nat. Water Well Assoc., pp. 343-358. May.
- Raymondi, R.R., and R.C. Conrad, 1983, Hydrogeology of Pipeline Canyon, Groundwater, V.21, N.2, pp. 188-198.

- Science Applications, Inc., November 1981, Status Report – Geology of the United Nuclear Corporation's N.E. Church Rock Tailings Area, United Nuclear Corporation, Mining and Milling Division, Albuquerque, New Mexico.
- Stone, William J., 1981, Hydrogeology of the Gallup Sandstone, San Juan Basin, Northwest New Mexico, Groundwater, v.19, n. 1, pp. 4-11.

UNC Response: An electronic copy of the report by Science Applications, Inc., will be provided. The other references are subject to copyright restrictions. Copies of these references can be obtained from the National Ground Water Association.

8) Table 5: Justification for values used in the model should be documented in a transparent and traceable manner. Technical bases supporting the parameter values used should be provided.

UNC Response: The response to general comment 4 presents the steps taken during the model development and calibration process that lead to the values listed in Table 5 of the Flow Model report.

9) Figure 9: This figure is not legible.

UNC Response: The resolution of the figure is limited by that of the log, which is in the form of a bitmap image. However, a more legible printed version is attached and will be included in the revised report.

10) Figure 10: The "Upper Gallup Sandstone" is being identified in this figure; however, it is not clear if the arrow is pointing to the orange or the yellow unit. Both the orange and the yellow units should be labeled.

UNC Response: The arrow is pointing to the space between the orange and yellow surfaces. The orange and yellow surfaces represent the top and bottom of the Upper Gallup sandstone. The caption will be modified (as shown in italic font): "West-looking perspective view of topographic surface and *upper and lower surfaces* of the Upper Gallup Sandstone,..." The revised version is attached.

11) Figure 11A: "Elevation of pre-mining water table shown in Zone 1 is interpreted by analogy, but is also consistent with sampling data from Zone 1 monitoring wells." Provide, or reference, sample data from the Zone 1 monitoring wells. The pre-mining water table indicates the ineffectiveness of Zone 2 as an aquitard. Can this be explained?

UNC Response: Statistical summaries of the requested sample data are provided in the response to general comment 3. That response also provides an explanation of how hydraulic equilibrium may have established between Zones 1 and 3 prior to mining. This hydraulic communication is hypothesized to have been established north of the pre-mining water table (and the Church Rock tailings site) where Zone 2 is absent.

12) Figure 11A: Can the cross-section be extended beyond endpoint A so as to intersect the Pipeline Canyon lineament?

UNC Response: The requested cross section is shown in revised Figure 11a. Its location is shown in revised Figure 10.

13) Figure A-2: Provide the technical basis for coupling the drain cells with the measurements of Well 0627. Provide the technical basis for coupling the drain cell elevations at an elevation 10 ft below that of the Well 0627 measurements.

UNC Response: Well 0627 is the closest well in the alluvium to the locations of the drain cells. Therefore, the hydrograph of this well provided the best available record of piezometric heads in the alluvium in the vicinity of the drain cells. The 10-ft difference was estimated by extrapolating the average hydraulic gradient in the alluvium upgradient of Well 0627 to the locations of the drain cells.

REFERENCES FOR ENCLOSURE 2

Canonie Environmental Services Corp., 1987, Reclamation Engineering Services, Geohydrologic Report, Church Rock Site, Gallup, NM. May.

Dam, W.L., 1995, Geochemistry of groundwater in the Gallup, Dakota, and Morrison aquifers, San Juan Basin, New Mexico: U.S. Geological Survey Water-Resources Investigation Report 94-4253, 76 p.

Kernodle, John M., 1996, Hydrogeology and steady-state simulation of ground-water flow in the San Juan Basin, New Mexico, Colorado, Arizona, and Utah, U.S Geological Survey Water-Resources Investigations Report 95-4187, 117p.

Mizell, Nancy and William Stone, 1979, Maps showing the regional extent of sandstone bodies within the Gallup Sandstone compiled for the San Juan Basin hydrogeologic study, New Mexico Bureau of Mines and Mineral Resources, Open-File Report 105, 26p.

N.A. Water Systems, 2008a, Recommendations and Summary of Hydrogeologic Analysis, Evaluation of Groundwater Flow in Zone 3 for the Design of a Pumping System to Intercept and Recover Impacted Groundwater, United Nuclear Corporation's Church Rock Tailings Site, Gallup, New Mexico, Letter report from Mark Jancin and James Ewart, N.A. Water Systems to Mark Purcell, US EPA and Martin Fliegel, U.S. Nuclear Regulatory Commission. April 25, 2008

N.A. Water Systems, 2008b, Revised Submittal – Calculation of Background Statistics with Comparison Values, UNC Church Rock Mill & Tailings Site, Church Rock, New Mexico. October 17, 2008.