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This Report Delivered by Email Only

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Re: Technical Memorandum Summarizing Two Reports on Zone 3 Tailings Seepage Sourcing and Groundwater Recharge, with Information Update
United Nuclear Corporation's Church Rock Tailings Site, Gallup, New Mexico
Administrative Order (Docket No. CERCLA 6-11-89)
Materials License No. SUA-1475

Dear Ms. Higgins-Coltrain and Ms. Norman:

Introduction

On behalf of United Nuclear Corporation (UNC), Chester Engineers has prepared this summary of two reports germane to sourcing of tailings seepage and groundwater recharge to Zone 3 of the Upper Gallup Fm. The two reports are USFilter (2004) and N.A. Water Systems (2008), referred to here respectively as the Zone 3 sourcing report and the Zone 3 hydrogeologic analysis. Both of these reports are attached. It is assumed that the reader is familiar with both reports.

"Tailings" refers to the mixture of waste rock, chemicals, and water from uranium ore milling and extraction, typically occurring as slimes or sandy slurries. The term "tailings seepage" refers to leakage of tailings liquids from a disposal cell, and such an occurrence can act as a "source" for contamination of groundwater beneath or downgradient of a disposal cell. Such "sourcing" of contamination is distinguished from recharge of the groundwater, which is also discussed in this report. Recharge may occur naturally, from the infiltration of rainwater or snow melt, or, as in the case of the Church Rock site, it may have an anthropogenic origin (i.e., the former deep mine water that was pumped and discharged to the arroyo).

Included with this summary are updates to selected Zone 3 well hydrographs originally made for the Zone 3 hydrogeologic analysis, but not shown in N.A. Water Systems (2008). The provision of this summary fulfills an action item that arose from discussions during the May 24, 2011 meeting in Albuquerque of UNC and regulatory agencies.

Zone 3 Sourcing Report

The Zone 3 sourcing report (USFilter, 2004) specifically considered the potential for ongoing releases of contaminants of concern into Zone 3 from the north and central cells of the tailings impoundments. The report constructed the geometric relationship between the tailings cells and the hydrostratigrahic units, including the alluvium and underlying rock formations. A significant body of information about subsurface and historical conditions was included in the construction, including logs for more than 500 borings and wells, water level data, historic topographic maps and plans, aerial photography, geophysical survey data, geologic maps, and tailings cell reclamation reports.

The resulting geometric relationships were used to analyze whether there may be ongoing sources of seepage, as well as to identify the locations and significance of such sources, particularly as they may affect Zone 3. A field investigation also was proposed (and accomplished) to investigate the locations more likely to be ongoing sources of tailings seepage, to test *if* seepage and groundwater were present, and, if so, were capable of migration.

The field investigation focused on two areas (see Figure 14 in the attached USFilter (2004) document). One of these, the area northeast of the north cell, was determined to be a potential area of groundwater recharge from occasional ponding of water along the north end of the drainage diversion trench. The plan proposed water level measurements in Zone 3 wells within this area to verify whether the direction of the hydraulic gradient (and groundwater flow) was to the north (away from tailings stored in the north cell). A gradient directed toward the south would be necessary for groundwater derived from the area of ponding to approach the area of tailings storage. A substantial rise of the water table would also be required for there to be contact with the tailings, as the typical water table in Zone 3 was at least 60 feet below the base of the tailings in that area in 2003 (see the Zone 3 sourcing report (USFilter, 2004, Section 3.0 and Figure 10).

Hydraulic gradients evidenced by water levels measured in Zone 3 monitoring wells have consistently been directed northward, away from the area of tailings storage in the north cell. Furthermore, these water level measurements gave no evidence of groundwater mounding in area of Zone 3 north of the north cell, which had been hypothesized as a potential consequence of ongoing groundwater recharge. For example, the water table in Zone 3 as measured in wells proximal to the northeast corner of the north cell (702, 613, and 701; see Figure 1) in October

2010 was 60 feet or more beneath the bottom of the tailings in the adjacent north cell. This configuration is shown in cross section A-A' in Figure 2 (the location of the section line is shown in black in the southwestern part of Figure 1). This configuration will not allow contact of the tailings with groundwater in Zone 3. Water level data from these wells and Zone 3 potentiometric surface maps have been reported annually and have consistently verified these conditions – of tens of feet of separation between the base of the tailings and the water table with groundwater flow to the north – most recently in Chester Engineers, January 2011. Figure 3 shows the potentiometric map from this most recent annual report.

The second area of focus of the field investigation plan was north of the former borrow pits 1 and 2, located east of the former central tailings pond (see Figure 14 in USFilter (2004), which is attached). This area was a focus, because the two borrow pits contained relatively thick deposits of tailings that were in direct contact with Zone 3 rock (particularly in the unlined borrow pit 1). If groundwater was being recharged from the diversion trench to the south and east of the former borrow pits or from the former borrow pits, it was conceivable that water might contact the tailings and subsequently enter Zone 3. Two wells were proposed to be drilled to the base of Zone 3 north and down-gradient of the former borrow pits to test this possibility.

Two piezometers, designated Z3M-01 and Z3M-02, were installed north of former borrow pits 1 and 2 in July 2004, in accordance with the plan described in the Zone 3 sourcing report (see Figure 1 for well locations in Zone 3). Water levels were measured in these piezometers, starting in October 2004 and at an annual or greater frequency since 2008 (see Table 1). On each occasion too little water was found to be sampled and what was found was interpreted to be residual drilling fluid stored at the bottom of each well just below the screen. On the basis of these findings it was concluded that the area of the former borrow pits 1 and 2 was not an ongoing source of measurable quantities of recharge or tailings seepage (N.A. Water Systems, 2004).

Minor differences of the measured depths to water over time at Z3M-02 (standard deviation of 0.08 ft) appear to be random measurement error. The height of water measured in Z3M-01 has ranged from 0.15 to 1.0 ft (Table 1). This amount of variation is greater than expected from measurement error. This raises the possibility that the measurements are representative of transient resaturation at the base of Zone 3 at this locality. We recently installed pressure transducers in both of these piezometers in order to obtain more frequent water level measurements.

Zone 3 Hydrogeologic Analysis

The Zone 3 hydrogeologic analysis was made in support of the design of a pumping well system to intercept and recover impacted groundwater from the northern portion of Zone 3. The summary presented here is of the portion of N.A. Water Systems (April 2008) document that addressed the hydrogeologic analysis rather than the design of the well field. Estimates of hydraulic conductivity and flux were made using empirical data (e.g. well hydrographs) that were broadly based in time and geographical area. It is the estimates of groundwater flux that are most germane to Zone 3 sourcing. Therefore, this summary focuses on that aspect of the analysis.

An examination of well hydrographs indicated that, from April 2002 through January 2005, Zone 3 underwent gravity-induced drainage, unaffected by well pumping. By April 2002, water levels had equilibrated from the cessation of groundwater pumping in 2000 (i.e. rebound ceased). Renewed pumping of Zone 3 from the RW-series wells began after January 2005. Therefore, groundwater fluxes could be estimated from these data without the complicating effects of pumping. This fact and the roughly uniform northward hydraulic gradient in Zone 3 enabled the use of the relatively simple one-dimensional Darcy flux equation for making the flux estimates.

For the purpose of making flux estimates the portion of Zone 3 affected by seepage impact was divided into sections by three lines mapped perpendicular to the hydraulic gradient (see N.A. Water Systems (April 2008), Figure 7): a south section line located about 250 ft north of the north cell, a north section line located in the vicinity of the northernmost monitoring well at that time (NBL-1), and a mid section line located mid-way between the south and north lines. A flux was estimated for each of these lines.

In one dimension, groundwater flux can be expressed as a function of hydraulic conductivity, hydraulic gradient, and wetted cross sectional area:

$$Q = -k * i * A$$

where,

Q is volumetric flux

k is hydraulic conductivity

i is hydraulic gradient, and

A is the wetted cross - sectional area

Values of i and A in the above expression are directly estimable from empirical data. For example, well water levels measured in January 2005 were used to map the potentiometric surface (water table) in Zone 3 (see N.A. Water systems (April 2008), Figure 7). The slope of this surface at any point is equivalent to the hydraulic gradient, i. Similarly, the wetted height at any point can be estimated by subtracting the elevation of the base of Zone 3 (see N.A. Water systems (April 2008), Figure 4) from the potentiometric surface. These empirical measures were made for multiple divisions of the three section lines (e.g. 33 divisions in the case of the south section line). The reason for doing this is that i, and particularly A, are variable along each section line. This variability is approximated by making separate calculations for each division.

Hydraulic conductivity was assumed to be constant along each section line, but could vary between the sections. An independent estimate of mean hydraulic conductivity near the south section line was available from well tests reported by ARCADIS BBL (2007). Based on this estimate (5 x 10^{-5} cm/sec) and the empirical calculations of hydraulic gradient and wetted cross sectional area described above, the total flux across the 1642-ft long south section line, in January 2005, was estimated to be ***96.7 ft^3/d (cubic feet per day) or approximately 0.5 gpm (gallons per minute)***. This estimate of 0.5 gpm represents the entire flux derived from all sources up-gradient (south) of the south section line. This includes any potential contributions from the overlying alluvium, from gravity drainage of Zone 3, and from the tailings cells.

The Zone 3 hydrogeologic analysis also made estimates of hydraulic conductivity. This was done by using empirical data to estimate the flux, Q, in the Darcy equation (see above) and solving for hydraulic conductivity, k. The flux was estimated by integrating the time-rates of groundwater drainage over the areas separating each of the section lines. Rates of water level decline were estimated from well hydrographs and mapped over the areas between the section lines and the area up-gradient (south) of the south section line (see N.A. Water systems (April 2008), Figure 8). The measured decline of water level over time was a consequence of the drainage of groundwater from the portion of the rock capable of storing water, which is its effective porosity. Therefore, the measured rates of water level decline can be expressed as a volumetric flux of groundwater from storage with knowledge of the porosity of the rock. The average porosity of Zone 3 rock had been estimated to range from 5% (Canonie, 1987) to 8% (MACTEC, 2006). Using data and methods similar to MACTEC (2006) the Zone 3 hydrogeologic analysis independently estimated the effective porosity of Zone 3 rock to be 5.9%. The 5.9% estimate contrasts with that by MACTEC (2006) in accounting for the effects of gravity drainage and a longer period of empirical data.

Based on the estimated porosity of Zone 3 rock and the measured rate of water level decline in Zone 3 south of the south section line, a volumetric flux was estimated. This flux, representing gravity-induced drainage, was estimated to be 133 ft^3/day or approximately 0.7 gpm. That estimate is 138% of the 96.7 ft^3/day estimated using the Darcy equation (see above). Therefore, it is not necessary to postulate sources other than gravity-induced drainage to explain the estimated total flux traversing the area of seepage impact down-gradient of the tailings cells.

Well Hydrograph Updates

Well hydrographs originally made for the Zone 3 hydrogeologic analysis were updated to include water level measurements made through October 2010. Hydrographs were updated for Zone 3 monitoring wells located in the vicinity of the tailings cells and to the immediate north of the north cell. This is an area that encompasses portions of Zone 3 where the saturated thicknesses, and therefore rates of drainage, are less. It is also the area nearest to where Zone 3 subcrops beneath the north cell and the alluvium.

Figures 4 and 5 present hydrographs for wells EPA-9, 702, 517, 701, and 613. In Figure 4 the hydrographs are plotted as a function of time from January 2001 through October 2010. Regression lines are fitted to each hydrograph for the period April 2002 through January 2005. This period was determined to be a time of gravity-induced drainage without influence from well pumping. The regression lines are projected forward to October 2010. Figure 5 shows the same data plotted as with saturated thickness on a log scale. In this graph the regression trend lines are seen to be linear with respect to the log of saturated thickness (see the Appendix for an explanation of the log-linear relationship of saturated thickness to time). Figures 6 and 7 show hydrographs and regression trend lines for wells EPA-13, 711, 708, 706, 713, and 714.

Two factors appear to affect the slope of the regression trend lines: saturated thickness and relative impact from seepage. Drainage rates increase proportionally with saturated thickness and wetted cross sectional area, as predicted by the Darcy equation (compare, for example, the slopes of the regression trend lines for wells EPA-9 and 701 in Figure 4). The effect of seepage impact has been to reduce hydraulic conductivity, because of the alteration of feldspar minerals to clay (see the Zone 3 hydrogeologic analysis for further explanation). For example, well 613 had a relatively thick saturated interval compared to wells 701 and 517. However, well 613 has been more severely affected by seepage impact. This is interpreted to be the reason why it has experienced slower drainage rates than wells 701 and 517 (see Figure 2 or 3).

Downward deviations of measured water levels from the projected regression lines, where they appear, are typically evidenced by accelerated drawdown induced by pumping of Zone 3 extraction wells. The hydrographs of wells 713 and 708 show such downward deviations. The hydrographs of most other wells show continued drawdown, but at slower rates than the projected trend lines. The hydrographs of two wells, 701 and 714, show a reversal of drawdown, beginning between October 2006 and January 2007. These are the only Zone 3 wells to show such a reversal of drawdown during this period.

This trend reversal followed a significant precipitation event in October 2006. The local NCDC (National Climatic Data Center) cooperative station (Gallup Sand and Gravel) recorded 3.48 in of precipitation in October 2006, which is about three times the average for October. This is interpreted to have resulted in geographically localized recharge to Zone 3. The trend reversal at well 714 was delayed by one quarter from that at well 701. Water levels at both wells rose for seven quarters before peaking, which was also delayed at well 714. The relative timing at these two wells and evidence of relatively minor (if any) effects at other wells is interpreted to indicate a source nearer to, and probably west of, well 701. The most likely source of the recharge is interpreted to be ponding north of the north cell from which sufficient water infiltrated the alluvium to sustain recharge to Zone 3 for at least seven quarters.

Hydrographs of most of the more up-gradient monitoring wells (e.g. EPA-9, 702, and 517) show continued drawdown, but at a slower rate than their projected regression trend lines (fit to data through January 2005). The log-linear trends should account for the effects of diminishing saturated thickness (see Appendix for explanation). Therefore, other factors are interpreted to have further slowed the rate of water level decline in these wells. The most likely factor, in light of the discussion above, is that recharge from the alluvium was sufficient to slow the rate of water level decline, but without a reversal such as observed at wells 701 and 714. .

The previous section of this report describes conclusions drawn from the Zone 3 hydrogeologic analysis. The flux of groundwater through Zone 3 extant in 2005 could be explained entirely by drainage of groundwater from storage. No additions from recharge were required to account for the calculated flux. Water levels in Zone 3 have reduced from the 2005 levels that were the basis for the 0.5 gpm flux estimate. With less saturated thickness to convey the water the flux will also have declined over time. Therefore, if recharge to Zone 3 occurred in the period following October 2006 (as described above) its contribution to groundwater flux in the area of water level monitoring has been very minor.

Conclusions

This technical memorandum summarizes portions of two previous reports that are germane to determination of tailings seepage and isolated recharge of runoff through the alluvium into Zone 3. The Zone 3 sourcing report (USFilter, 2004) synthesized tailings cell construction and reclamation information and geologic data to evaluate where and how sourcing of tailings seepage might have been occurring in 2004. A plan of field investigation was made to test for evidence of ongoing sources of tailings seepage to Zone 3. The results were interpreted (N.A. Water Systems, 2004) to indicate that Zone 3 was dry in the area of the field investigation. The review of water level measurements presented in this report indicates the possibility of periodic resaturation at the base of Zone 3 of less than 1 ft at one of the two monitored locations. As such, the associated groundwater flux is concluded to be much less than 0.5 gpm.

The Zone 3 hydrogeologic analysis made quantitative estimates of groundwater fluxes through Zone 3 from long-term empirical data (well hydrographs) from wells across the study area. These comprehensive, long-term data support the conclusion that the total flux across the area of tailings impact 250 ft north of the North tailings cell was approximately 0.5 gpm in January 2005. All of this flux was found to be accounted for by gravity drainage. Inputs from the tailings cells or the alluvium, if present at that time, were an indeterminable fraction of the 0.5 gpm flux.

The theory of groundwater flow, as expressed by the Darcy equation, predicts that the flux of groundwater from gravity drainage must have reduced with declining water levels over the period since January 2005. Updated well hydrographs presented in this report demonstrate ongoing declines of water levels even in the most up-gradient Zone 3 monitoring well (EPA-9). Where compared to pre-January 2005 drainage trends, the rates of drainage at many wells appear to be slowing more than can be explained solely by reductions of saturated thickness. Spatially and temporally limited recharge to Zone 3 from the alluvium is interpreted to have been a factor in the slowing of drawdown in some Zone 3 wells and a temporary reversal of drawdown in two wells nearest to an area of occasional water ponding following unusually high runoff events.

References

ARCADIS BBL, 2007, United Nuclear Corporation, In-Situ Alkalinity Stabilization Pilot Study, UNC Church Rock Site, Gallup, New Mexico. June 2007.

Canonie Environmental Services Corp., 1987, Geohydrologic Report, Church Rock Site, Gallup, New Mexico. May 1987.

Chester Engineers, 2011, Annual Review Report 2010 – Groundwater Corrective Action, Church Rock Site, Church Rock, New Mexico. January 26, 2011.

MACTEC, 2006, Final Report, Phase I Full Scale Hydraulic Fracturing. June 2006.

N.A. Water Systems, 2004, Annual Review Report 2004 – Groundwater Corrective Action, Church Rock Site, Church Rock, New Mexico. December 30, 2004.

N.A. Water Systems, 2008, 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, UNC Church Rock Tailings Site, Gallup, New Mexico. April 25, 2008.

USFilter, 2004, Rationale and Field Investigation Work Plan to Evaluate Recharge and Potential Cell Sourcing to the Zone 3 Plume, Church Rock Site, Gallup, New Mexico. January 19, 2004.

If you have any questions, please contact us by phone or email.

Sincerely,

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Technical Consultant	Project Manager
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Attachments: Table; Figures; Appendix; USFilter (2004) Report; N.A. Water Systems (2008) Report.

email cc: Cynthia Wetmore, EPA; Roy Blickwedel, GE; Larry Bush, UNC; Sarah Jacobs, EPA; Randall McAlister, GE; Lance Hauer, GE

TABLE 1

Water Level Measurements in Zone 3 Piezometers Z3M-01 and Z3M-02

Well No.	Measurement Date	Depth To Water (ft)	Reference Elevation (ft amsl)	Base of Zone 3 Elevation (ft amsl)	Top of Water Elevation (ft amsl)	Height of water above Zone 3 base (ft)
Z3 M-01	10/15/2004	68.21	6996.34	6927.84	6928.13	0.29
Z3 M-01	4/17/2008	68.35	6996.34	6927.84	6927.99	0.15
Z3 M-01	7/16/2008	67.95	6996.34	6927.84	6928.39	0.55
Z3 M-01	10/15/2008	67.5	6996.34	6927.84	6928.84	1.00
Z3 M-01	4/15/2009	67.85	6996.34	6927.84	6928.49	0.65
Z3 M-01	10/14/2009	68.15	6996.34	6927.84	6928.19	0.35
Z3 M-01	10/14/2010	68	6996.34	6927.84	6928.34	0.50
Z3 M-02	10/15/2004	77.5	7009.31	6932.06	6931.81	-0.25
Z3 M-02	4/17/2008	77.34	7009.31	6932.06	6931.97	-0.09
Z3 M-02	7/16/2008	77.5	7009.31	6932.06	6931.81	-0.25
Z3 M-02	10/15/2008	77.48	7009.31	6932.06	6931.83	-0.23
Z3 M-02	4/15/2009	77.3	7009.31	6932.06	6932.01	-0.05
Z3 M-02	10/14/2009	77.45	7009.31	6932.06	6931.86	-0.20
Z3 M-02	10/14/2010	77.5	7009.31	6932.06	6931.81	-0.25

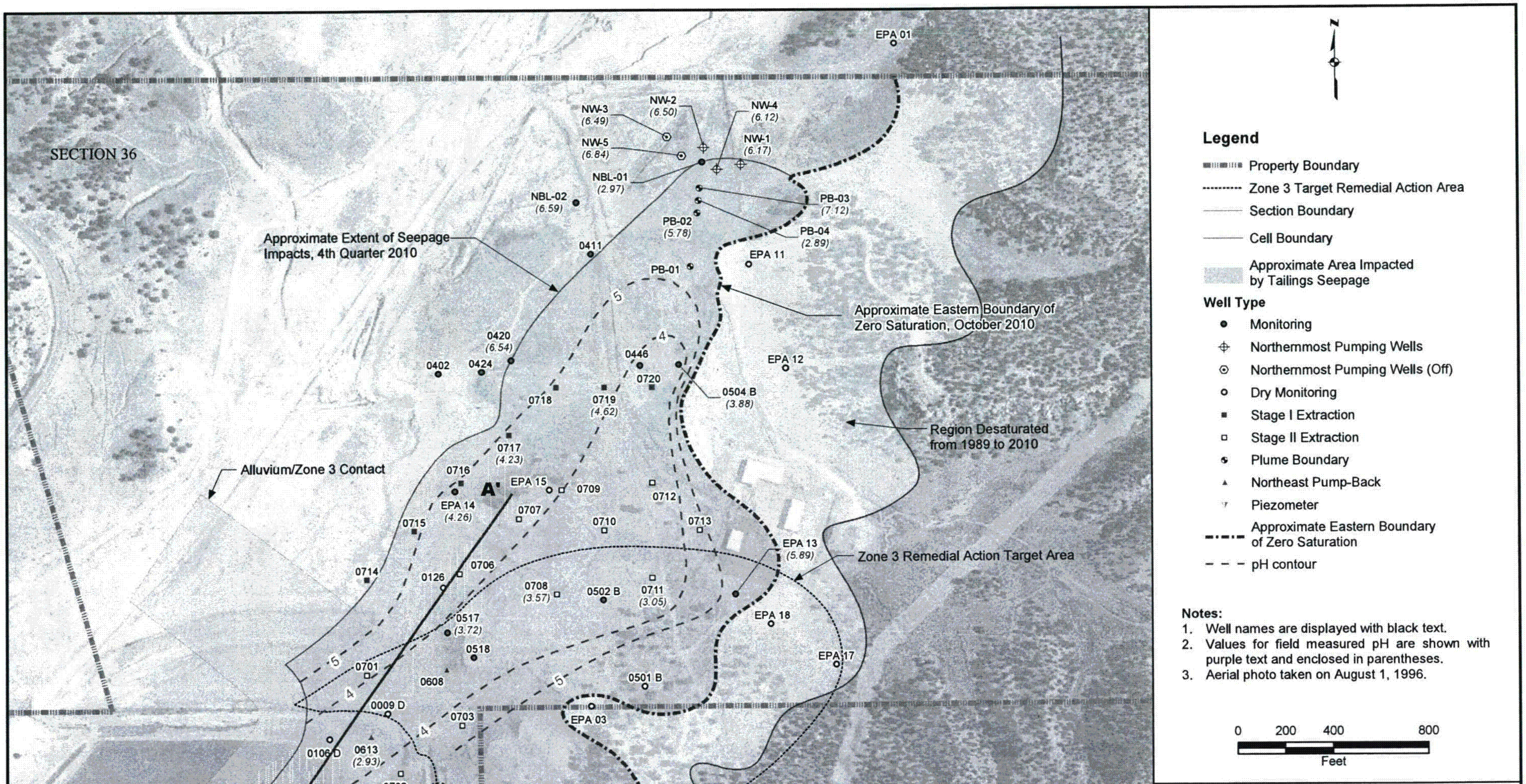

FIGURE 1

Zone 3 Approximate Extent of Seepage Impacts, October 2010

United Nuclear Corporation Church Rock Site, Church Rock, New Mexico

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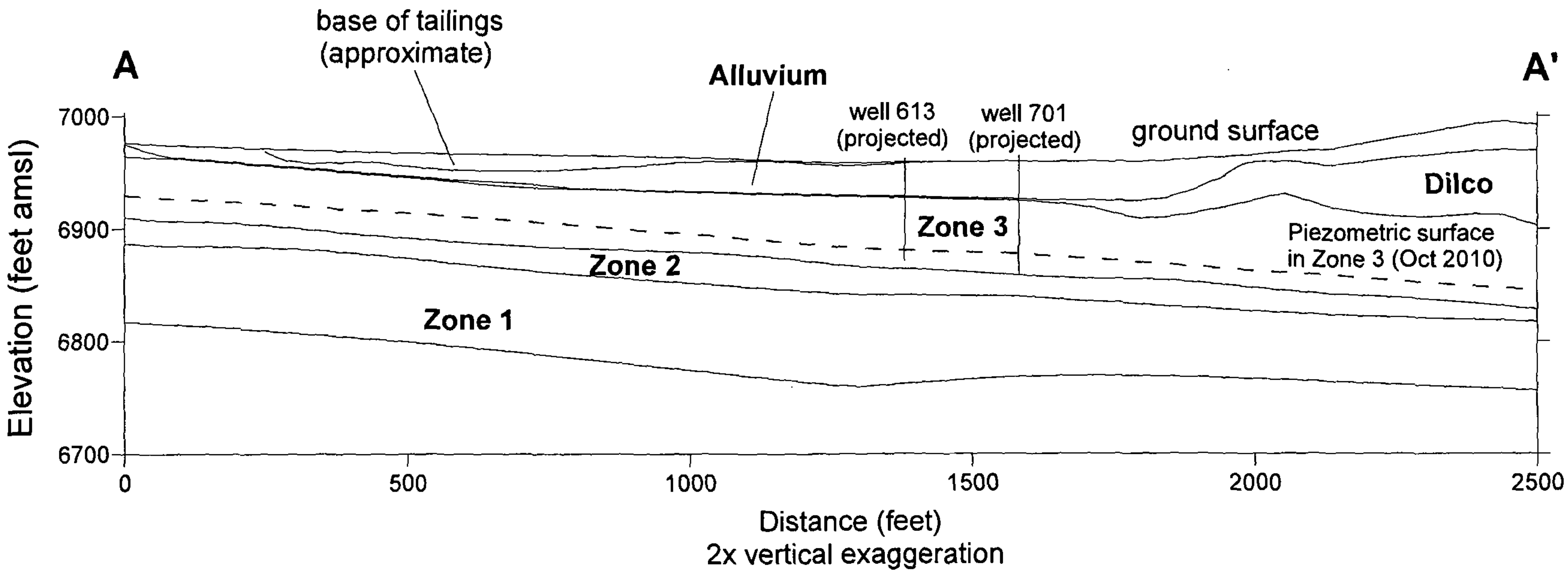
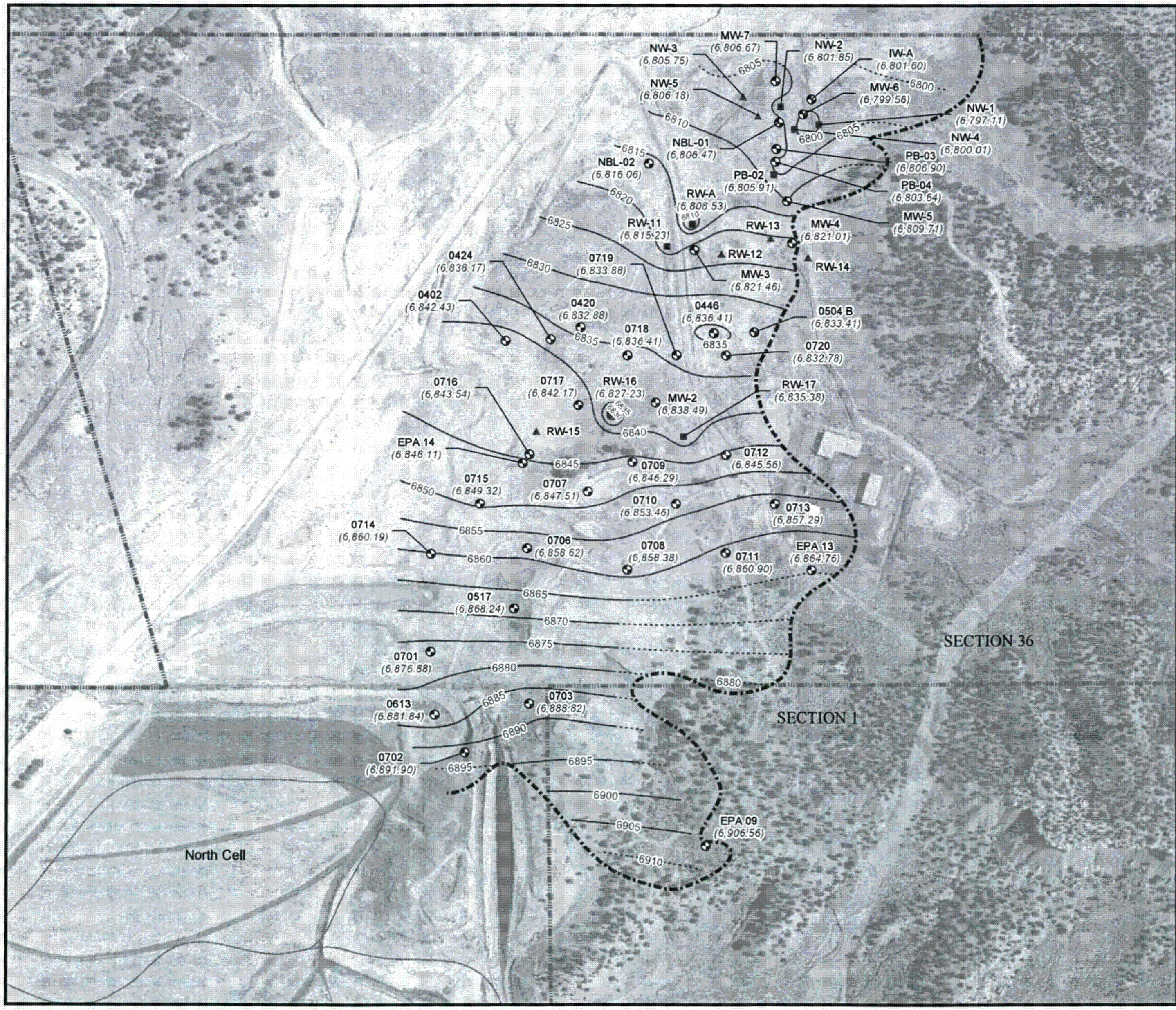


FIGURE 2
Northwest-looking view of cross section A-A'
(see Figure 1 locations of cross section and wells)



N

Legend

- Monitoring Well
- ▲ Non-Pumping Well
- ■ Pumping Well
- Cell Boundary
- Property Boundary
- Approximate Eastern Boundary of Zero Saturation
- Groundwater Elevation Contour
- Inferred Groundwater Elevation Contour
- *(6906.46)* Measured Groundwater Elevation

Notes:

1. Groundwater elevation values are displayed in feet above mean sea level.
2. Well names are displayed with black text.
3. Aerial photo taken on August 1, 1996.

0 200 400 800
Feet

FIGURE 3

Zone 3 Potentiometric Surface Map
October 2010

United Nuclear Corporation Church Rock Site,
Church Rock, New Mexico

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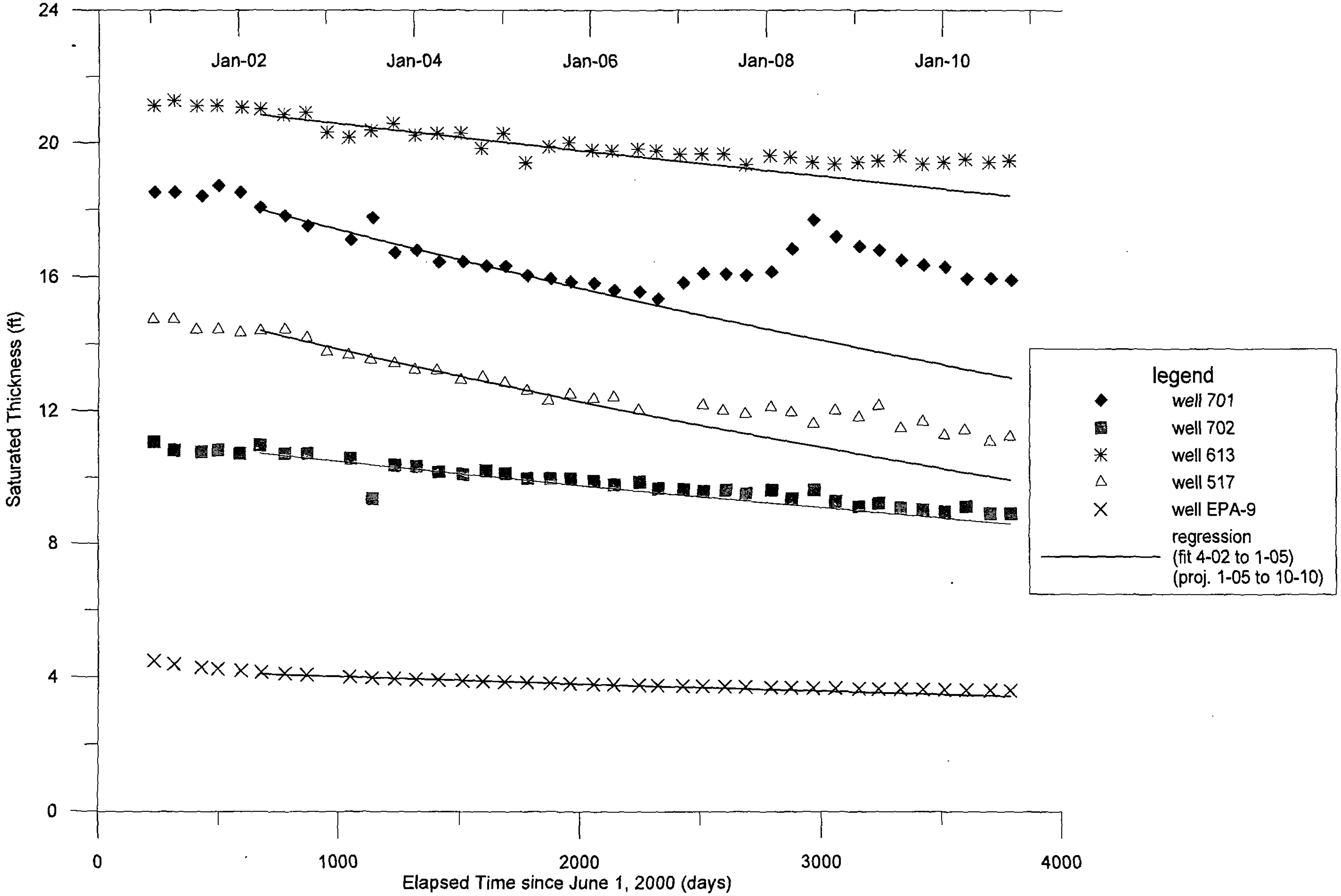

FIGURE 4
Hydrographs of southernmost Zone 3 wells,
Jan 2000 to Oct 2010. Regression fit to period of
purely gravity drainage: Apr 2002 to Jan 2005.

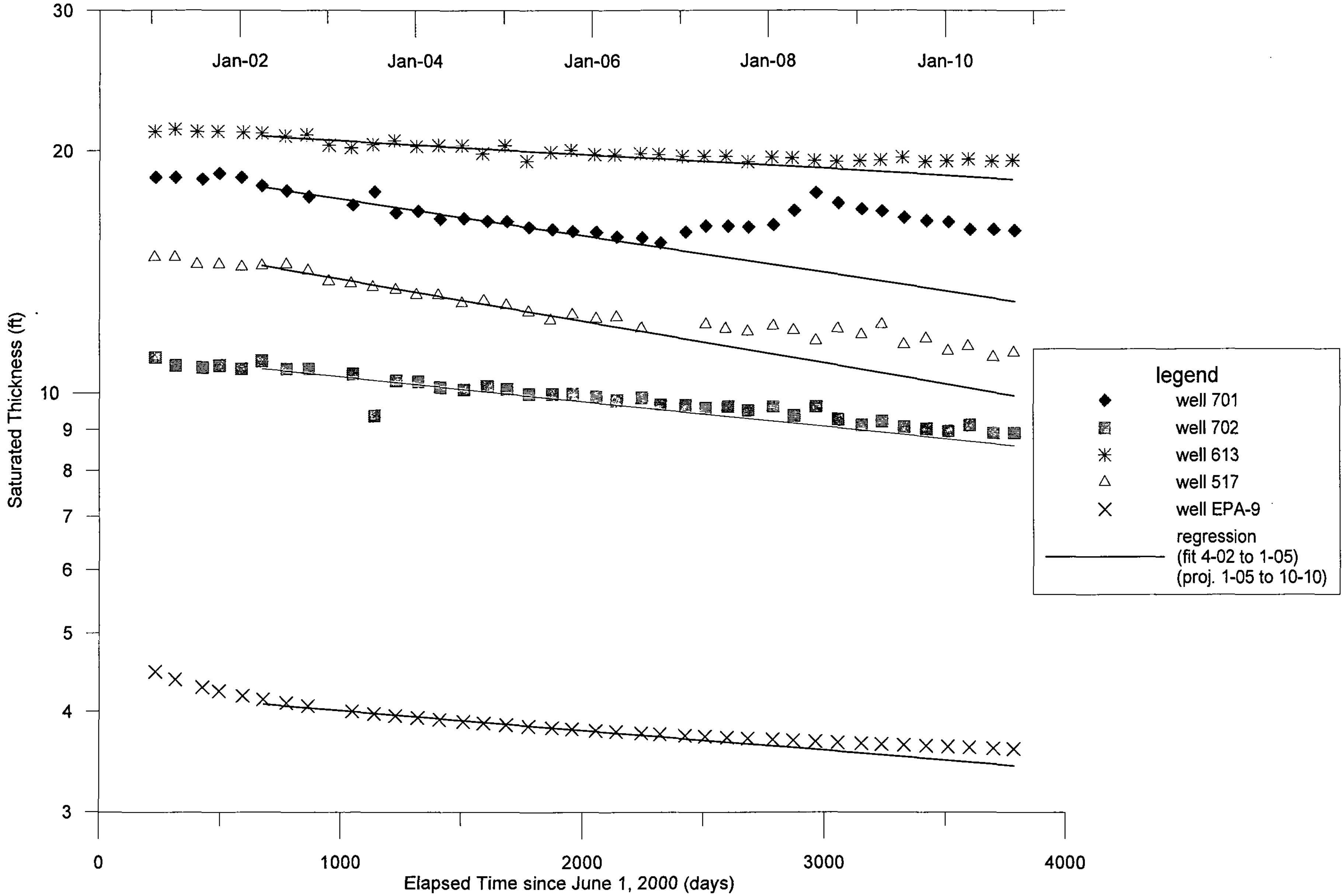

FIGURE 5
Hydrographs of southernmost Zone 3 wells,
Jan 2000 to Oct 2010. Regression fit to period of
purely gravity drainage: Apr 2002 to Jan 2005.

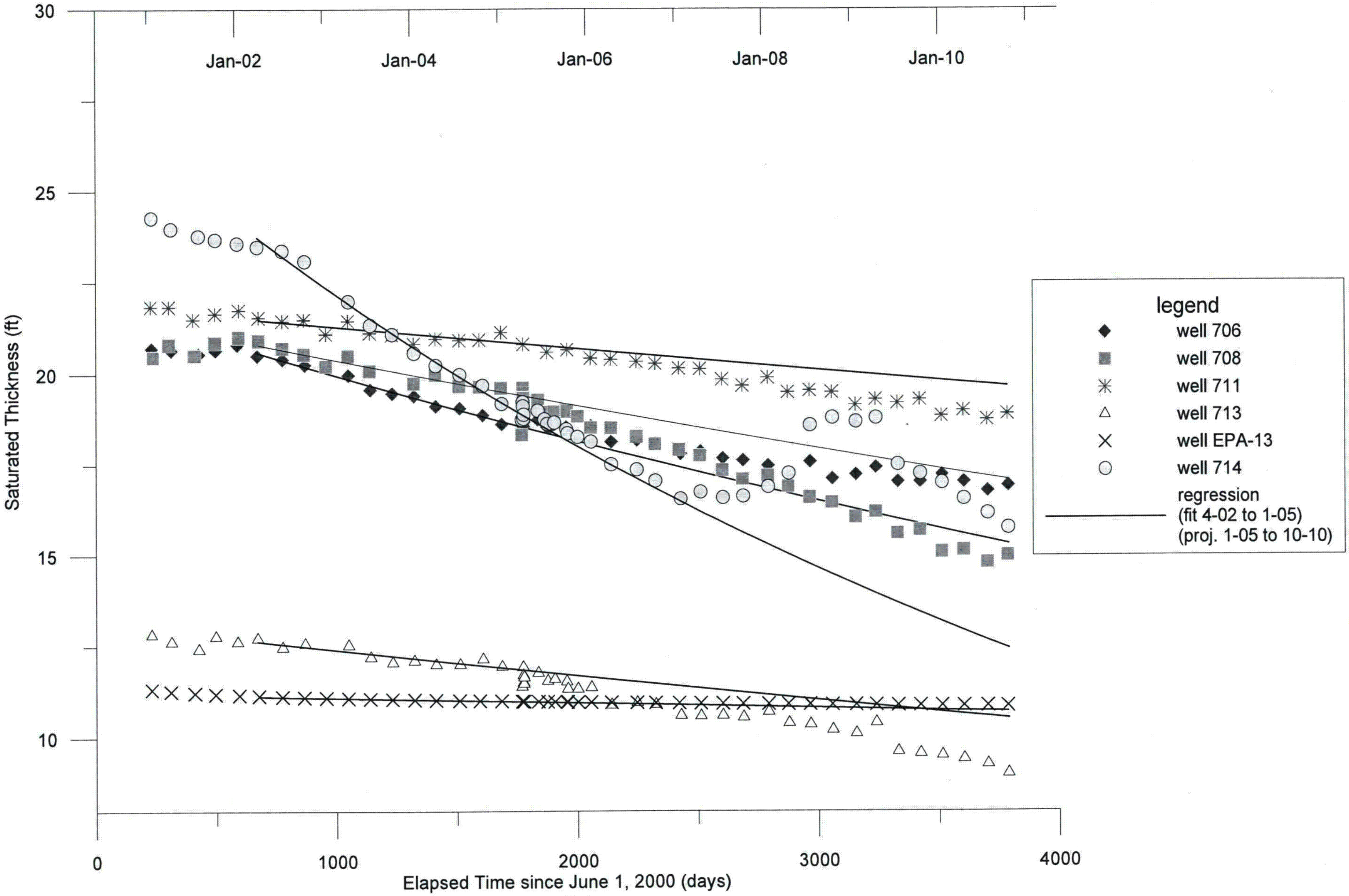

FIGURE 6

Hydrographs of Zone 3 wells south of recovery wells,
Jan 2000 to Oct 2010. Regression fit to period of
purely gravity drainage: Apr 2002 to Jan 2005.

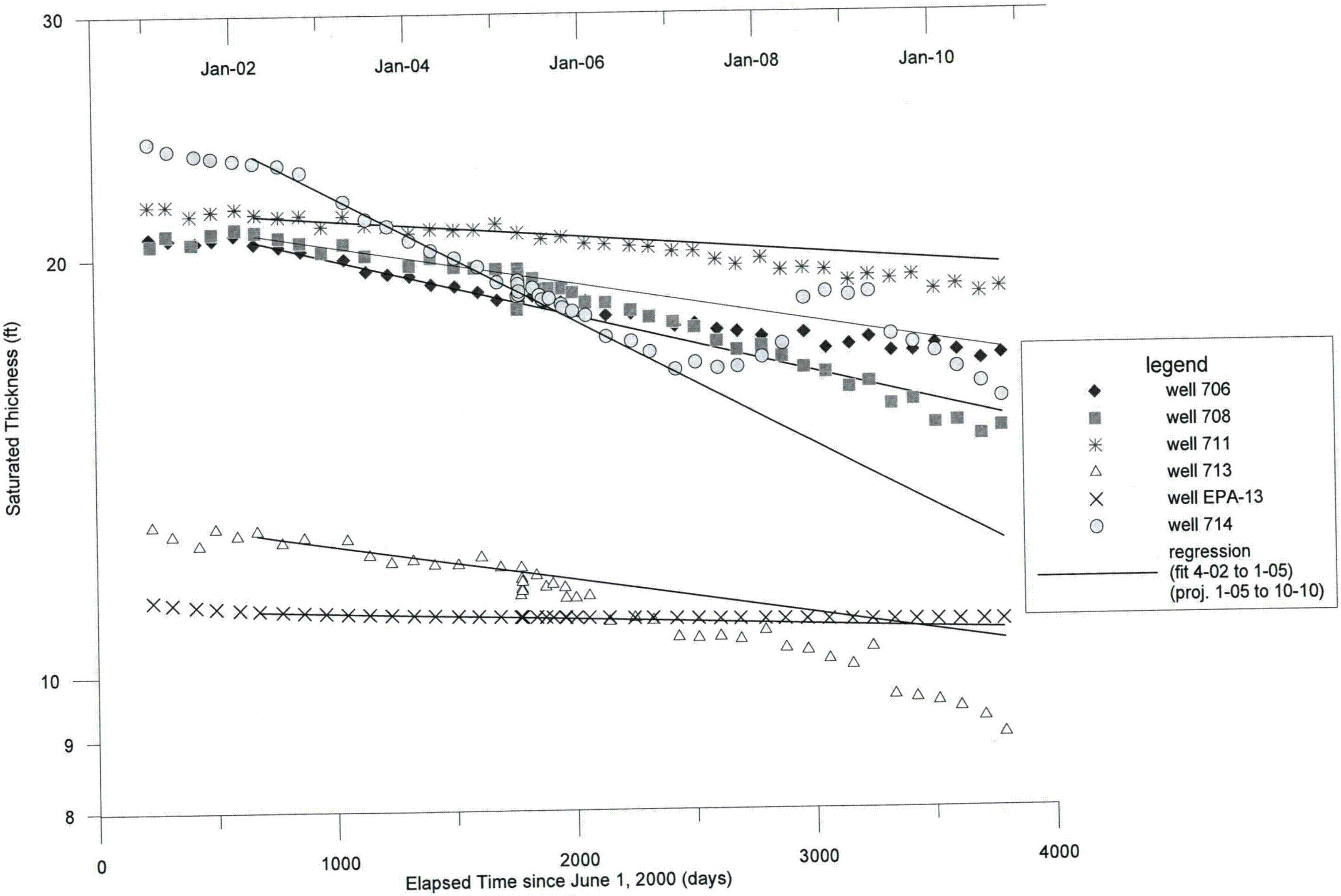

FIGURE 7

Hydrographs of Zone 3 wells south of recovery wells, Jan 2000 to Oct 2010. Regression fit to period of purely gravity drainage: Apr 2002 to Jan 2005.

APPENDIX

Explanation of Log-linear Drainage-Time Trends

An explanation for the log-linear relationship of rates of groundwater level decline (drainage) to time can be found by analogy of the one-dimensional Darcy equation with the well known equation for radioactive decay:

$$N = -\frac{\Delta n}{\Delta t} = k'*n$$

where,

N is the number of nuclei decaying per unit time, t

k' is the first order rate constant, and

n is the remaining number or concentration of nuclei

This is a first-order rate equation, because the rate depends on the first power of the concentration, n.
By integrating over time, t, the rate equation can be converted into an expression relating the number of nuclei remaining to time:

$$n = n_0 e^{-k'(t-t_0)}$$

where,

n is the number of nuclei remaining at time t-t_0

k' is the first order rate constant, and

n_0 is the original number of nuclei at time t_0

A log transformation allows the second equation to be rewritten in terms of time, which is commonly done to solve for the time required for half of the remaining nuclei to decay - the half life. This transformation results in the following equation:

$$\ln(n) - \ln(n_0) = -k(t - t_0)$$

A mathematical analogy can be drawn between the one-dimensional Darcy equation and the first order rate equation shown above. First, consider an application of the Darcy equation to an area of unit dimensions (e.g. 1 ft x 1 ft). Then the wetted cross sectional area, A, in the Darcy equation is replaced by the saturated thickness, D times a unit area. Next, combine the product of hydraulic conductivity and hydraulic gradient as a single term, $K = k * i$. The following analogies are then made between variables and constants in the two equations:

the flux, Q, with N, the number of nuclei decaying per unit time,
the product of hydraulic conductivity and hydraulic gradient, $K = k * i$, with the first order rate constant, k',
the saturated thickness, D, with n, the number of nuclei remaining.

With these modifications the one-dimensional Darcy equation may be rewritten as:

$$Q = -\frac{\Delta D}{\Delta t} = K * D$$

and by integration over time:

$$D = D_0 e^{-K(t-t_0)}$$

and by log transformation,

$$\ln(D) - \ln(D_0) = -K(t - t_0)$$

In physical terms the analogy may be thought of in the following way. From the first-order rate equation for radioactive decay it is clear that when the number of nuclei are reduced by half the rate of decay with time, N, will similarly be reduced by half. In an analogous way the one-dimensional Darcy equation predicts that when the saturated thickness is reduced by half the flux, Q, also will be reduced by half.

The final equation above illustrates a linear relationship of the log of saturated thickness with time. This completes the explanation of the empirical log-linear relationship of drainage rates appearing in the well hydrographs. However, some additional explanation and caveats are necessary.

Certain assumptions were necessary for this analogy to be made. One assumption is that the hydraulic gradient is invariant with time, a constant. This is only approximately true with the Zone 3 flow system, even if only periods without pumping are considered. We know from well hydrographs that rates of drainage vary from place to place. Therefore, at any location the slope of the piezometric surface (the hydraulic gradient) will slowly change over time. We also know that the hydraulic conductivity is subject to change from the chemical effects of acidity on constituent minerals. However, the changes to both variables are gradual and the error created by ignoring them is limited if the Darcy equation is applied piecewise in time, much as it was applied piecewise in place in making the Zone 3 flux estimates.

January 19, 2004
dll-524-6209-09

RATIONALE AND FIELD INVESTIGATION WORK PLAN TO EVALUATE RECHARGE AND POTENTIAL CELL SOURCING TO THE ZONE 3 PLUME CHURCH ROCK SITE, GALLUP, NEW MEXICO

Prepared for:

General Electric – Corporate Environmental Programs
King of Prussia, Pennsylvania

Prepared by:

USFilter Engineering and Construction
State College, Pennsylvania

Project No: d02-6209-09

January 2004

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1.0 INTRODUCTION

The Church Rock technical team met on April 30 and May 1, 2003 to discuss remediation alternatives for managing the groundwater plume in Zone 3 that is overall to the north and east of the North and Central Cells at the Church Rock site in Gallup, New Mexico. During that meeting and in subsequent discussions with GE, it was decided that the team needed a better understanding of the nature of any ongoing releases of constituents of concern into Zone 3 from the North and Central Cells in order to properly evaluate the remediation alternatives.

USFilter technical experts reviewed older technical information (in the project files we received from Earth Tech, Inc., in order to perform the Five-Year Review for the USEPA). Review of that information was used to focus and refine the conceptual model of fate and transport from the North and Central Cells to address questions of whether there may be ongoing sources of leachate, as well as the locations and potential significance of such sources, particularly as they may affect the Zone 3 hydrostratigraphic unit. The refined conceptual model was used to develop a plan for field work to verify the conceptual model. This report presents the refined conceptual model and a Zone 3 field investigation work plan.

The scope of this study did not include an evaluation of the design and construction of the tailings deposits and their cover system. Therefore, this report does not draw conclusions regarding the likelihood, or lack thereof, of surface water migrating through engineered barriers. Instead, the conceptual model uses the subsurface geometric relationships of Zone 3 and the tailings deposits to identify those areas more likely to be ongoing sources, *if* groundwater were present and capable of migration. The types of groundwater considered include residual pore water and groundwater potentially recharged from surface water.

Our original proposal work scope included the following:

- Inventory and evaluate older technical information
- Rerun the HELP model based on the older technical information
- Develop the most probable conceptual model for groundwater flow and constituent migration, with a few alternative model features to be tested via a pending field investigation, and
- Develop a scope of work to verify the conceptual model

In addition, the proposal suggested that the work plan would likely include new monitoring well or piezometer installation, water quality sampling, water level monitoring, and the application of one or more surface geophysical methods.

As the conceptual model was developed it became apparent that a rerun of the HELP model would provide limited benefit. This judgment was reached through an increased appreciation of controlling factors (e.g. the continuity and thickness of native clay deposits beneath the tailings) that would be difficult to adequately quantify or model with a 1-dimensional percolation simulator, such as HELP. Instead, it was recognized that a limited program of field investigation could more directly, and more appropriately, address the question of whether there are extant sources affecting Zone 3.

2.0 CONCEPTUAL MODEL

The geometry of the Church Rock tailings cells and substrate materials have been reconstructed from map, geophysical survey, and boring log data. These reconstructions are the central element of a conceptual model of the tailings cells that includes qualitative evaluation of their potential to generate leachate capable of entering surrounding geologic materials. The reconstructions were necessary because as-built diagrams of the bottoms of the tailings cells are not available. However, boring logs and topographic maps that were made before, during, and after the construction of the cells make it possible to estimate the configuration of the cells and the spatial relationships of tailings deposits with native subsurface formations, including the Zone 3 sandstone.

2.1 Data Sources

Over the past 20 years, various contractors have issued reports regarding the nature and geometry of the tailings deposits and the geologic materials with which they are in contact. Two of the more comprehensive studies were prepared by Bechtel National, Inc. (December 1984, *Church Rock Uranium Mill, Tailings Ponds, Conceptual Seepage Abatement Plans*) and Canonie Environmental (May 1987, *Reclamation Engineering Studies, Geohydrologic Report*). Much of the data used by these investigators was also employed to prepare the present conceptual model. Furthermore, the syntheses of information made by these investigations, particularly those of Canonie, were reviewed and adopted where appropriate. However, the present conceptual model also incorporates significant modifications of the tailings cells made during their interim and final reclamation, which occurred after these earlier studies.

Many borings and wells were drilled in the area of the tailings cells during the time of their planning and early phases of construction and use. For example, Sergent, Hauskins & Beckwith (S, H & B, October 1974, May 1976, July 1976, July 1978, October 1978, July 1979) reported geologic logs for 215 borings and wells made between 1974 and 1979 throughout the area of the cells. The locations of all of these borings are shown in Figure 1 on a 1978 topographic map with a construction plan of the area of the tailings deposits. Each of these logs was reviewed and incorporated into estimates made of the elevations of the contact between the alluvium and underlying rock formations. Geologic logs of 332 additional wells made in areas surrounding and between the cells were also incorporated in this analysis, as were the results of a 1976 seismic refraction survey that transected the length of the tailings deposit area (Figure 1). These data, and topographic maps made during the same period, allowed estimation of the topography of the base of the tailings cells. Most of these logs, and those of approximately 40 additional wells unavailable to this investigation, were taken into account by Canonie (May 1987) in their interpretation of the distribution of geologic formations in map view and in several cross sections. For this reason, Canonie's interpretations of the configuration of geologic materials beneath the tailings have been adopted in USFilter's study (rather than reconstructed from a subset of the same basic data). Instead, our study has focused on physical changes resulting from post-1987 reclamation of the cells and on the development of isopach maps for the tailings, cover materials, and the natural local unconsolidated materials (referred to collectively as alluvium by past investigators and in this report) that typically lay between the tailings and the underlying rock formations.

Topographic maps and several aerial photographs shown in Figures 1 through 6 illustrate stages from pre-development to final reclamation of the tailings cells. These data, supplemented by the logs of 15 borings that penetrated the tailings deposits, were used to reconstruct the base of the tailings deposits.

2.2 Estimates of the Distribution of Tailings and Underlying Geologic Materials

The reconstructions presented here divide the materials in and beneath the tailings cells into three categories: capping materials and tailings, alluvium, and rock formations. The order of this list of materials also describes the order in which they have typically been encountered in borings. The rock formations underlie the alluvium and the alluvium typically, but not everywhere, lies between the rock and the tailings deposits. The rock formation of particular interest to this study is the Zone 3 sandstone, which is a locally defined submember of the Upper Gallup Sandstone. Zone 3 has experienced more widespread distribution of tailings-affected groundwater than the other submembers (Zone 1 and Zone 2). Therefore, Zone 3 is expected to be the object of future mitigation measures and it is a focus of interest in the question of whether the tailings cells may continue to be a source of affected groundwater.

Figure 7 is a geologic map (reproduced from Canonie, May 1987, figure 2-3) that shows the distribution of various rock formations and the extent of the alluvium in the vicinity of the tailings cells. Most of the subsurface area of the tailings cells was originally (and probably remains) underlain by alluvium. Zone 3 and Zone 1 sandstones (labeled Z3 subcrop and Z1 subcrop in Figure 8) underlie the alluvium beneath most of the tailings deposit area. The Zone 1 subcrop occurs in two lobes; the larger lobe parallels the Pipeline Arroyo and straddles the long axis of the tailings pond dam. The other lobe extends east beneath the Central Tailings Cell. Zone 2, an aquitard, occupies a narrow band separating the areas of Zone 1 and Zone 3 subcrop. Cross section lines shown on Figure 7 refer to figures presented by Canonie (May 1987), but not reproduced in this report.

It should be noted that the definition of Zone 3 depicted in Figure 7 follows that of Canonie (May, 1987), which differs from that of previous workers. An explanation and rationale for this difference was given by Canonie:

> "Previous site investigators incorporated the uppermost part of Zone 3, also called the Torrivo Sandstone member, as part of the Dilco (SAI and Bearpaw, 1980). However, recent review of drilling and geophysical logging, as well as field investigations at the site, have indicated that the Torrivo Sandstone cannot be distinguished from the underlying Zone 3 of the Upper Gallup Sandstone. Moreover, these two sandstones are in hydraulic communication. Therefore, the Torrivo Member is considered to be part of Zone 3."

The differing definitions of Zone 3 are sufficient to affect considerations of which parts of the tailings deposits may overly or contact Zone 3. For example, SAI and Bearpaw (1980) stated this: "In the Central Cell and Borrow Pit areas the Dilco occurs on the flanks of the pits and is thought to underlie the eastern two thirds of the North Pond." We adopted the more recent definition of Zone 3 depicted in Figure 7, because of the reasons cited by Canonie and because the Dilco (exclusive of the Torrivo Sandstone member) is considered to be an aquitard, unlike Zone 3.

Figure 8 is a contour (isopach) map of the thickness of alluvium beneath the tailings cells. This Figure, like those that follow showing isopachs of the tailings deposits, employs a post-reclamation (circa 1997) aerial photographic base having geologic contacts traced from Figure 7. The thickness of alluvium is the calculated difference of two estimated surfaces: the top of rock (Figure 9) and the base of tailings (Figure 10). The top-of-rock surface was estimated from boring logs and a seismic refraction survey, the locations of which are shown in Figure 1. The base-of-tailings surface was also estimated from boring logs, but is primarily based on topographic maps from several stages in the development of the tailings deposits. Uncertainty in this reconstruction arises from the lack of definitive as-built maps of various excavations made to accommodate the tailings deposits. Therefore, the estimates of alluvium thicknesses made by this study are probably maximum values, because the available topographic maps may not have captured the full extent of excavation. For the same reason, estimates of the thickness of tailings are minimum values.

Figure 8 illustrates that the alluvium is thicker (as much as 110 feet) along the western margin of the tailings deposits. It thins to near zero thickness at the eastern margins of the North and South Cells and around the margins of a topographic divide between the North and Central Cells. The alluvium is also thick under most of a former erosional depression that underlies the Central Cell and is coincident with the Zone 1 subcrop beneath the Central cell (see Figure 9 for top-of-rock surface). However, in the eastern portion of the Central Cell much of the alluvium was removed prior to the placement of the tailings. The alluvium was partially to completely removed in the excavation of Borrow Pits 1 and 2 (see Figure 3 for location). This is significant, because it is interpreted that in these pits tailings and tailings leachate came into direct contact with the Zone 1 and Zone 3 sandstones.

Tailings thicknesses were estimated for two time periods: prior to interim reclamation in 1985 and following final reclamation in 1997. These isopach maps are shown in Figures 11 and 12. These estimates are based on the difference between the estimated base-of-tailings surface (Figure 10) and the ground surface topography in 1985 (Figure 3) and 1997 (Figure 5). In the latter case, the thickness also includes cover materials placed on the cells during reclamation.

The most prominent difference between the tailings isopach maps is the 15 to 55 feet of tailings introduced into Borrow Pit 2 by 1997. The thickness of tailings in former Borrow Pit 1 is based on limited information and may be underrepresented in Figure 12. The 1997 map (Figure 12) also illustrates a typically greater thickness of tailings and fill materials relative to the 1985 map (Figure 11), particularly in the eastern portion of the cells. Both maps show significantly thinner tailings deposits in the North Cell relative to the Central and South Cells.

2.3 Textural and Hydraulic Characteristics of the Tailings and the Alluvium

Our review of the S, H & B boring logs indicates that the tailings, where they have been penetrated by borings, have almost invariably been logged as loose sands or silty sands of typically fine or fine to medium grain size. Tailings logged as clay are rare and thin where found. In contrast, more than half of the native soils have been logged as clay and the sands are rarely clean (typically logged as clayey sand or silty, clayey sand). Gravels are very rare and appear only as an accessory where they are logged.

Logged observations of ubiquitous clay layers separating sand layers lead to the conclusion that the alluvium in most locations may be significantly more resistant to vertical as opposed to horizontal flow of groundwater. Canonie (1987) reports "representative" hydraulic conductivities of 1×10^{-2} cm/sec in the alluvium, 5×10^{-3} cm/sec in Zone 3, and 1×10^{-4} cm/sec in Zone 1. The nature of the pumping tests makes these estimates representative of horizontal rather than vertical hydraulic conductivities. These estimates were based on tabulated results (in Canonie, 1987) of six to eight tests in each hydrostratigraphic unit made by Billings & Associates, Inc. (1982; 1983; 1985). Geometric averages calculated from tabulated conductivity estimates are significantly lower in the alluvium and in Zone 3 than the "representative" values cited by Canonie: 2×10^{-3} cm/sec in the alluvium, and 6×10^{-4} cm/sec in Zone 3. An examination of more than 200 logs of the alluvium lead us to suspect that the geometric average of alluvium hydraulic conductivities may be closer to what is typical than the significantly higher "representative" value cited by Canonie. In support of this inference, we note that S, H & B reported an average hydraulic conductivity of the alluvium of 2.7×10^{-5} cm/sec, based on 27 borehole tests (May, 1976, *Geotechnical Investigation Report, United Nuclear Corporation Tailings Dam and Pond*). We further suspect, as did S, H & B, that the aggregate vertical hydraulic conductivity of the stratified alluvium is typically even lower.

It is concluded from this evaluation that the tailings are probably more permeable to vertical seepage than the alluvium. This conclusion echoes a prediction made by S, H & B (May, 1976) that, "...the tailings will be considerably more pervious than the underlying alluvium." This prediction was based on their testing of the alluvium and of a representative sample of the tailings, which resulted in a hydraulic conductivity estimate of 2.3 x 10^{-3} cm/sec for the tailings sediments. Their additional conclusion, that no potential exists for affecting present or potential producing aquifers by vertical or lateral seepage through the bedrock was, unfortunately, only accurate in the sense that the affected bedrock should not be construed as a "producing aquifer."

Although in situ testing of the hydraulic conductivity of the tailings does not appear to have been done, there are field data that illustrate the tendency of the alluvium to impede vertical seepage and perch groundwater in the tailings. This illustration comes from eight borings made at the northeast and southwest margins of the North Pond (later the North Cell) in 1979. The borings penetrated tailings into Zone 3 sandstone or into native sands that appear to have been in communication with Zone 3 sandstone. In two borings at the southwest margin of the pond, water levels are reported to have dropped from 10 feet depth (similar to the pond surface) to 30 and 35 feet depth within 2 hours. This is indicative of perched water in the tailings draining via the boring into a much lower water table in the Zone 3 sandstone. The logs for the five borings made at the northeast margin of the pond do not indicate a similar water level drop during drilling. However, the reported water levels in the borings are about 20 feet below the elevation of the reported pond water level. This indicates that by the time water levels were measured in the borings, which were open to Zone 3, they had dropped well below the head that probably existed in the tailings at that time.

These are only a few borings, made at the margins of the North Cell 24 years ago, so it is risky to generalize. However, water levels in the alluvium have dropped significantly since 1979, when these borings were made. For example, measured water levels in alluvial well 509D, located near the western part of the boundary between the North and Central Cells, have dropped 37 feet between July 1989 and October 2002. Water levels in well EPA 23, located near the Pipeline Arroyo adjacent to the South Cell, experienced a water level decline of 19.5 feet over the same time. By October 2002, water levels in the alluvium ranged from 40 to 70 feet below the estimated base of the tailings (see Figure 10 for this comparison). In other words, there is a significant thickness of unsaturated alluvium beneath the west side of the tailings deposits. This concept, taken with the likelihood that the tailings are more freely draining than the alluvium, suggests that significant drainage from the tailings into the alluvium had ceased well before October 2002.

Figure 13 summarizes the extents of the former ponds and borrow pits, the location of surface water drainages, and potential areas of groundwater recharge that could conceivably contact tailings and enter Zone 3. Based on this figure and the discussion presented above, the question of whether the tailings may represent an ongoing source of affected water to Zone 3 should be focused on the east side of the tailings deposits, where groundwater recharge could hypothetically occur where there is no tailings cover system to prevent infiltration. On the east side of the deposits the alluvium is generally thinner or absent where it has been removed by excavation. The data indicate that the principal areas where alluvium was replaced by significant thicknesses of tailings were Borrow Pits 1 and 2 on the east side of the Central Cell. The ramifications of this key historic conclusion for potential field investigations are discussed in the following section.

3.0 DISCUSSION OF RESULTS RELATIVE TO FUTURE FIELD INVESTIGATIONS

The results of this investigation indicate that areas having the potential of being future sources of leachate-affected groundwater are located on the east margin of the Central Cell, where Borrow Pits one and two were formerly located, and northeast of the North Cell. These areas are illustrated in Figure 13.

Of the two areas, the one northeast of the North Cell seems less likely to be an ongoing source of leachate generation. There are several reasons for this judgment. The area of potential groundwater recharge is 500 feet or more to the north of the northern extent of tailings in the North Cell. Also, this area is underlain by 30 to 40 feet of alluvium *below* the estimated elevation of the base of the tailings in the North Cell. Therefore, recharge in this area would not be expected to contact the tailings unless there was at least 40 feet of mounding of the groundwater table that extended 500 feet to the south of the area of recharge. There aren't available groundwater level measurements in the alluvium north of the North Cell. However, piezometric heads in Zone 3 directly beneath this area are 60 feet or more below the estimated elevation of the base of the tailings. Furthermore, the distribution of piezometric heads in Zone 3 indicates a flow direction to the north, not to the south. The top-of-rock surface, which might be expected to influence groundwater flow in the overlying alluvium, is inclined to the west-northwest (Figure 9) – not to the south.

The only potential areas of groundwater recharge (which might also contact tailings) that lie to the south are those around the margins of the eastern half of the Central Cell, where Borrow Pits 1 and 2 were formerly located, and to the south of the South Cell. The area to the south of the South Cell is probably too far removed from the known limits of contamination in Zone 3 to merit further field investigation. This may not be true of the potential recharge areas bordering the former borrow pits (Figure 13). The linear dark blue recharge areas shown in Figure 13, along the eastern perimeter of the site correspond with manmade surface channels for diversion of potential runon from the uplands to the covered cells. The northern portion of the channel slopes to the north, the southern portion slopes to the south.

The former borrow pits straddled an erosional "cut-out" that penetrated through Zones 3 and 2 into Zone 1. The borrow pits also contain relatively thick deposits of tailings. As a result of this geometry, groundwater, if it could recharge Zone 3 to the south and east of the former borrow pits, might migrate north and, if so, contact tailings. Tailings leachate might thence enter Zone 1 or reenter Zone 3 to the north of the former borrow pits. Borrow Pit 1 seems to have the greater potential to be an ongoing source of residual tailings leachate, because the tailings in it were placed "wet" and the native soil "floor" beneath the tailings slopes upward from Borrow Pit 1 toward the adjacent tailings deposits in the Central Cell. The place to investigate this potential may be to the north and northeast of the former borrow pits in the Central Cell. This can be done by constructing one or two monitoring wells screened in Zone 3 sandstone to the north of the former borrow pits. If the wells are dry then the question of whether there is an ongoing source will be resolved in the negative. If there remains measurable saturation in Zone 3 it will be proximal to the upgradient margin of the Zone 3 “cut-out” and the leachate source (the tailings in either former Borrow Pit 1 or Borrow Pit 2), if one exists. Therefore, a pumping test designed to dewater the monitoring well(s) would be an indirect measure of whether groundwater recharge is being sourced from the tailings. If, after being pumped down, the water levels in these wells do not fully recover and remain depressed, this will be an indication that there is not a significant source of recharge to the south of these wells (i.e., from the tailings).

Although this investigation has concluded that the North Cell is unlikely to be an ongoing source of leachate, there are several relatively simple measures that would tend to support or contradict this conclusion. Figure 3-5 from the 2002 annual report (Earth Tech, December 2002) illustrates the October 2002 piezometric surface contour map for Zone 3. It shows a cluster of Zone 3 wells near the northeast corner of the North Cell. The map was based on data from a small subset of these wells. As such it would be prudent to obtain water levels from as many of these wells as possible to better define the hydraulic gradients in this area of Zone 3. As it is presently drawn, the flux arrows labeled on this figure as "alluvial recharge" and "tailings seepage" are internally inconsistent. Based on the well water levels and the head contours shown, a south to north groundwater flux is indicated. The arrows shown on the map locally indicate fluxes from due west and seepage from the southwest. Those are the directions from which one would find the North Cell and the arroyo, but those are not the directions the hydraulic gradient indicates the flux should be coming from. A more complete set of water level measurements may better define the local hydraulics in this critical subarea. If the results of these measurements do not clarify this issue, it would be prudent to install a well screened in the base of Zone 3 located further west on the north margin of the North Cell cap. If the Canonie geologic map (Figure 7) is correct, the well should not be located more than a couple of hundred feet west of well 106D. Farther to the west, Zone 3 would be missing.

In summary, this analysis suggests two conceivable sources of groundwater recharge to Zone 3. One is the segment of diversion channel over Zone 3 subcrop bordering the borrow pits in the Central Cell. This is the potential source to the south and should be evidenced by a south to north gradient as shown on figure 3-5 from the 2002 Annual Report. This potential source of groundwater recharge is also a potential ongoing source of tailings leachate. The other source (of recharge, but probably not leachate) is the portion of the diversion channel north of the North Cell, where it also overlies Zone 3 subcrop (see Figure 14 for location). This would be evidenced by a groundwater mound centered on this segment of the diversion channel. If flux arrows shown on Earth Tech's (December 2002) figure 3-5 are correct, we should see an unambiguous west to east gradient to the north of the North Cell.

4.0 CONCLUSIONS

1) Zone 3 rock subcrop underlies nearly all of the North Cell and about half of the Central and South cells. Much of the remaining areas are underlain by Zone 1 subcrop.

2) With few exceptions, the tailings are separated from the rock subcrop by alluvium that contains significant (typically greater than 50%) sequences of clay which are interpreted to be an impediment to vertical drainage.

3) The thickness of alluvium between the tailings and the rock ranges from about 100 feet on the west side to zero feet on the east side and at the margins of two "spits" of elevated rock that separate the North Cell from the Central Cell and the Central Cell from the South Cell.

4) The thickness of alluvium was reduced to zero feet (by excavation) beneath Borrow Pit 2 and possibly to only a few feet beneath Borrow Pit 1 (definitive data are lacking regarding pit 1).

5) The thickness of tailings deposits is 25 to 40 feet on the west side of the South and Central Cells. The thickness decreases to 0 feet on the east side of the South Cell and to about 10 feet in the middle of the Central Cell. Up to 50 feet of tailings were deposited in Borrow Pits 2 and (with less certainty) 1 in the eastern portion of the Central Cell. Tailings thicknesses of 5 to 15 feet occur in the North Cell.

6) Borrow Pit 2 was used for the storage of mostly liquids, particularly in the late 1980s when water pumped from Zone 1 was stored there. It was drained in 1989, after which the placement of relatively dry wind blown tailings, building debris, and affected soils began. Until it was drained, pit 2 was an acknowledged source of inflow to Zone 1 and very likely also a source of inflow to Zone 3. The pit was completely filled and "reclaimed" by 1994. In other words, much of the fill in Borrow Pit 2 was probably fairly dry when placed. The same was probably not true of Borrow Pit 1, which received wet tailings and was an area of problematic consolidation during interim reclamation (1990-1991).

7) Areas of direct or nearly direct contact between tailings and Zone 3 rocks include the northeast and south margins of the North Cell (though tailings are only 5-10 feet thick there) and at the margins of the eastern extension of the Central Cell (where the alluvium thins significantly). Borrow Pits 1 and 2, in particular, are areas where significant thicknesses of tailings are present and probably in contact with Zone 3 where it subcrops along the north and south margins of both pits and the east margin of pit 2.

8) It is concluded (from very general descriptions) that the materials placed in Borrow Pit 2 after 1989 probably did not have high water contents and were not a likely source of direct recharge to Zone 3. This may not be true of the materials placed in Borrow Pit 1.

9) The drainage diversion channel along the east side of the tailings cells is over Zone 3 subcrop along much of its length. It also traverses areas where the alluvium is thin (particularly to the south of the Central Cell). This raises the possibility of groundwater recharge from the diversion channel into Zone 3. If it occurs, this recharge may encounter tailings in the borrow pits before moving through thin to no alluvium and into Zone 3.

10) The portion of the diversion channel near the northeast corner of the North Cell is a source of groundwater recharge to Zone 3. However, this investigation concludes that this area, and the North Cell generally, is unlikely to be an ongoing source of tailings affected groundwater (leachate).

11) In order accomplish effective long-term mitigation of the Zone 3 contaminant plume, it is important to determine: (a) whether groundwater recharge continues to cause flux through the covered cells; and (b) whether such flux is transporting tailings-impacted water (primarily or exclusively leachate) downgradient such that the Zone 3 plume continues to be sourced headward.

5.0 RECOMMENDATIONS

1) Install two new monitoring wells in the area shown in Figure 14 (just north of the former Borrow Pits 1 and 2 in the eastern half of the Central Cell). These two wells should be screened into the base of Zone 3.

   The presence of groundwater in these wells would indicate that recharge is occurring along either the adjacent diversion trench, the diversion trench segment along the southern perimeter of the Central Cell, or both.

   The quality of any water in these wells will indicate whether the eastern part of the Central Cell (areas of Borrow Pits 1 and 2) continues to source tailings-impacted groundwater.

   The groundwater elevations in these wells may aid understanding of the downgradient configuration of the Zone 3 piezometric field, including the relatively high, persistent head level at well EPA 9.

   If these new wells contain groundwater, then after the above information has been acquired these wells can be pumped dry (causing local dewatering of the Zone 3 aquifer). If, after being pumped down, the water levels in these wells do not fully recover and remain depressed, this will be an indication that there is not a significant source of recharge to the south of these wells (i.e., from the tailings).

2) Acquire groundwater elevation measurements in all of the Zone 3 wells shown in Figure 14. These wells are to the northeast of the northeast corner of the North Cell. This will allow better definition of the directions of the hydraulic gradient in this critical subarea, which should bolster the present conclusion that the North Cell is unlikely to be an ongoing source of affected groundwater.

   This subarea is located near the northern limit of the surface diversion trench (which ponds after heavy runoff events). The trench may be acting as a local source of groundwater recharge; however, it is unlikely that this groundwater fluxes through the North Cell tailings located to the south. Comprehensive well water-level measurements should show whether there is groundwater mounding beneath the diversion trench, and whether there is an easterly component to the groundwater flux (the latter has been suggested in recent technical reports concerning Zone 3).

   If the results of the comprehensive well water-level measurements are not definitive, then a new monitoring well should be installed approximately 250 feet to the west of existing well 106 D. This new well should be screened into the base of Zone 3. Head levels from this new well, in conjunction with the comprehensive set of head levels, should show whether there is locally an eastward direction to groundwater flow – or if the groundwater in this critical subarea is flowing northward, as suggested by recent potentiometric mapping.

6.0 REFERENCES

Bechtel, December 1984, Church Rock Uranium Mill, Tailings Ponds Conceptual Seepage Abatement Plans, United Nuclear Corporation, Church Rock, New Mexico.

Canonie Environmental, May 1987, Geohydrologic Report, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico.

Canonie Environmental, April 1989, Seepage Travel Distance/Time Calculation – Amendment II, project file, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico.

Canonie Environmental, January 1990, As-Built Report, North Cell Interim Stabilization, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico.

Canonie Environmental, April 1992, As-Built Report, South Cell Interim Stabilization, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico.

Canonie Environmental, April 1992, As-Built Report, Central Cell Interim Stabilization, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico.

Canonie Environmental, June 1995, As-Built Report, Central Cell Final Reclamation, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico.

Fletcher, J., October 11, 1985, Water Balance – NECR Tailings, Internal UNC Mining and Milling memo to C. Johnson.

Sergent, Hauskins & Beckwith, October 1974, Preliminary Geotechnical Investigation Report, Tailings Dam, Church Rock Uranium Mill, United Nuclear Corporation, Church Rock, New Mexico. (amended by frontice piece letter in January 1975)

Sergent, Hauskins & Beckwith, May 1976, Geotechnical Investigation Report, Tailings Dam and Ponds, Church Rock Uranium Mill, United Nuclear Corporation, Church Rock, New Mexico.

Sergent, Hauskins & Beckwith, July 1976, Seismic Refraction Investigations Report, Tailings Dam and Ponds, Church Rock Uranium Mill, United Nuclear Corporation, Church Rock, New Mexico.

Sergent, Hauskins & Beckwith, July 1978, Geotechnical and Design Development Investigation Report, Tailings Dam and Ponds, Church Rock Uranium Mill, United Nuclear Corporation, Church Rock, New Mexico.

Sergent, Hauskins & Beckwith, October 1978, Engineering Analysis Report, Tailings Disposal Systems Analysis, Church Rock Uranium Mill, United Nuclear Corporation, Church Rock, New Mexico.

Sergent, Hauskins & Beckwith, July 1979, Geotechnical Investigation Report, Stability and Integrity Assessment, Church Rock Uranium Mill, United Nuclear Corporation, Church Rock, New Mexico, Volume 1.

The following references were examined for the investigation, but not referenced in the report

Canonie Environmental, October 1985, Phase I Field Study, Remedial Investigation/Feasibility Study, Technical Memorandum, United Nuclear, Church Rock, New Mexico.

Canonie Environmental, April 1987, Reclamation Plan, Engineering Concepts, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico.

Canonie Environmental, January 1988,Remedial Investigation, vol. 1, United Nuclear, Church Rock, New Mexico.

Canonie Environmental, July 1988, Reclamation Plan License No. SUA-1475, Amendment 1, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico.

Canonie Environmental, December 1990, Response to Comments and Proposed Reclamation Plan Modifications, Vol. 1 – Text, Tables, and Figures, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico.

Penick, Michael, May 1986, Southwest Alluvial: Resistivity Study, United Nuclear Corporation, Mining and Milling Division, Albuquerque, New Mexico.

Science Applications, Inc. and Bearpaw Geosciences, July 1980, Geology of the Church Rock Area, New Mexico, UNC Mining and Milling Division, Albuquerque, New Mexico.

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.

Smith Environmental Technologies Corporation, April 1996, As-Built Report, South Cell Final Reclamation, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico.

Smith Environmental Technologies Corporation, March 1997, Draft As-Built Report, 1996 Final Reclamation Construction, Church Rock Site, UNC Mining and Milling, Gallup, New Mexico.

Western Technologies, Inc., December 1991, 1991 Reclamation Testing, United Nuclear Corporation, Church Rock, New Mexico.

ADDENDUM

After the preparation of the first draft of this workplan, additional relevant information was discovered in a project calculation file (Canonie, April 1989) and an internal UNC Mining and Milling memorandum (Fletcher, October 1985). This information is in the form of two map figures from Canonie (April 1989), which have been reproduced as Figures 15 and 16 of this report. The figures are reduced from their original scale and annotated for clarity. The information from the UNC memorandum describes the tailings handling process and the nature of the tailings deposited in the Central Cell, Borrow Pit 1 and Borrow Pit 2.

The following description is quoted from the UNC memorandum (Fletcher, October 1985):

> When the tailings slurry consisting of sands, slimes and liquid comes from the mill to the tailings area, it is deposited in the Central Pond either by spigotting or by cycloning. The cyclone method separates the tailings into two different portions, one consisting of largely coarse sands, called cyclone underflow, and the other consisting of fine sands, slimes (particles which are finer than sands) and tailings liquids. The whole tailings (sands, slimes, and liquids) are deposited without separation when the spigotting method is used. The methods are used intermittently
>
> During cycloning, the cyclone underflow (coarse sands) is deposited in the East Cell of the Central Pond area, where it remains. The overflow (fine sands, slimes, and liquid) is deposited in the West Cell of the Central Pond. The sands drop out of the overflow and largely remain in the western area of the Central Pond. The liquids, which are carrying the slimes and some fine sands, begin a gravity flow from west to east towards the borrow pits. Two trenches have been excavated to facilitate the flow through the central area. When the flow arrives in Borrow Pit No. 1, the slimes settle out and most of the liquid is pumped to Borrow Pit No. 2. Consequently, the central area contains sands, Borrow Pit No. 1 contains slimes, and Borrow Pit No. 2 mostly contains liquids.

The memorandum also states that, between 1980 and 1985, the Borrow Pit 1 had been almost entirely filled by slimes and fine overflow sands to a depth of approximately 20 feet, except for a two foot pond at it's eastern side. The memorandum concludes that much of this filling had occurred by January 1981, on the basis of aerial photography.

The significance of this information to the present study is that Borrow Pit 1 contains a significantly greater proportion of fine-grained tailings than other areas of the tailings deposits. Therefore, Borrow Pit 1 might be expected to have had a greater potential to retain pore fluids in it's approximately 20 feet of accumulated slimes than other most other areas. This includes Borrow Pit 2, which received primarily liquids, until it was drained and backfilled with local soil fill, mill building debris, and wind-blown tailings of relatively low moisture content. This newly reviewed information source also indicates that the thickness of tailings shown within the footprint of Borrow Pit 1 in Figures 11 and 12 is underestimated by about 20 feet. This underestimate resulted from the unavailability of a map showing Borrow Pit 1 fully excavated.

Taken as a whole, this information suggests that the former Borrow Pit 1 is an appropriate candidate site to investigate regarding the possibility that any portion of the tailings deposits might remain a source to Zone 3 of residual tailings-affected pore water.

Figure 15 shows contours of pH in Zone 3 groundwater based on sample data collected in 1989. The extent of the tailings affected groundwater plume, as interpreted by Canonie in 1989, is indicated by shading. The figure illustrates two points germane to conclusions drawn in this report on the bases of other data. The first point is that the Central Cell, and the former borrow pits in particular, were in hydraulic communication with Zone 3. The second point is our interpretation of the data shown in Figure 15: the plume in Zone 3 extended to the borrow pits and was probably sourced from those pits (as well as from the North Pond). Therefore, if there is residual pore fluid or recharged groundwater in contact with tailings in the former borrow pits it would be possible for the fluid to enter Zone 3.

We believe that the additional information tends to support conclusions reached in the report, which were based on other data. Therefore, our recommendations regarding field work have not changed.

Figure 16 shows a Zone 3 piezometric surface map based on 1987 measurements. It is a much broader aereal representation than more recent maps, encompassing the tailings area in addition to areas southwest and northeast of the tailings. The map shows an area of saturation that extends as far to the southwest of the Central Cell as it does to the northeast. A groundwater mound (in Zone 3) depicted beneath the tailings ponds is shown with its highest point beneath the former borrow pits. The depiction is interpretive in many areas. However, the depiction of a groundwater mound in Zone 3 in the vicinity of the borrow pits is supported by well water levels. This further supports the conclusion that the borrow pits were an important contributor of tailings-affected water to Zone 3. If the piezometric surface shown in Figure 16 is accurate, a wholly northeast gradient would have established only after the mound, and the southwestward hydraulic gradient it induced, had dissipated. Only then would the saturated portions of Zone 3 to the southwest have begun to drain to the north under the influence of the gentle dip of Zone 3.

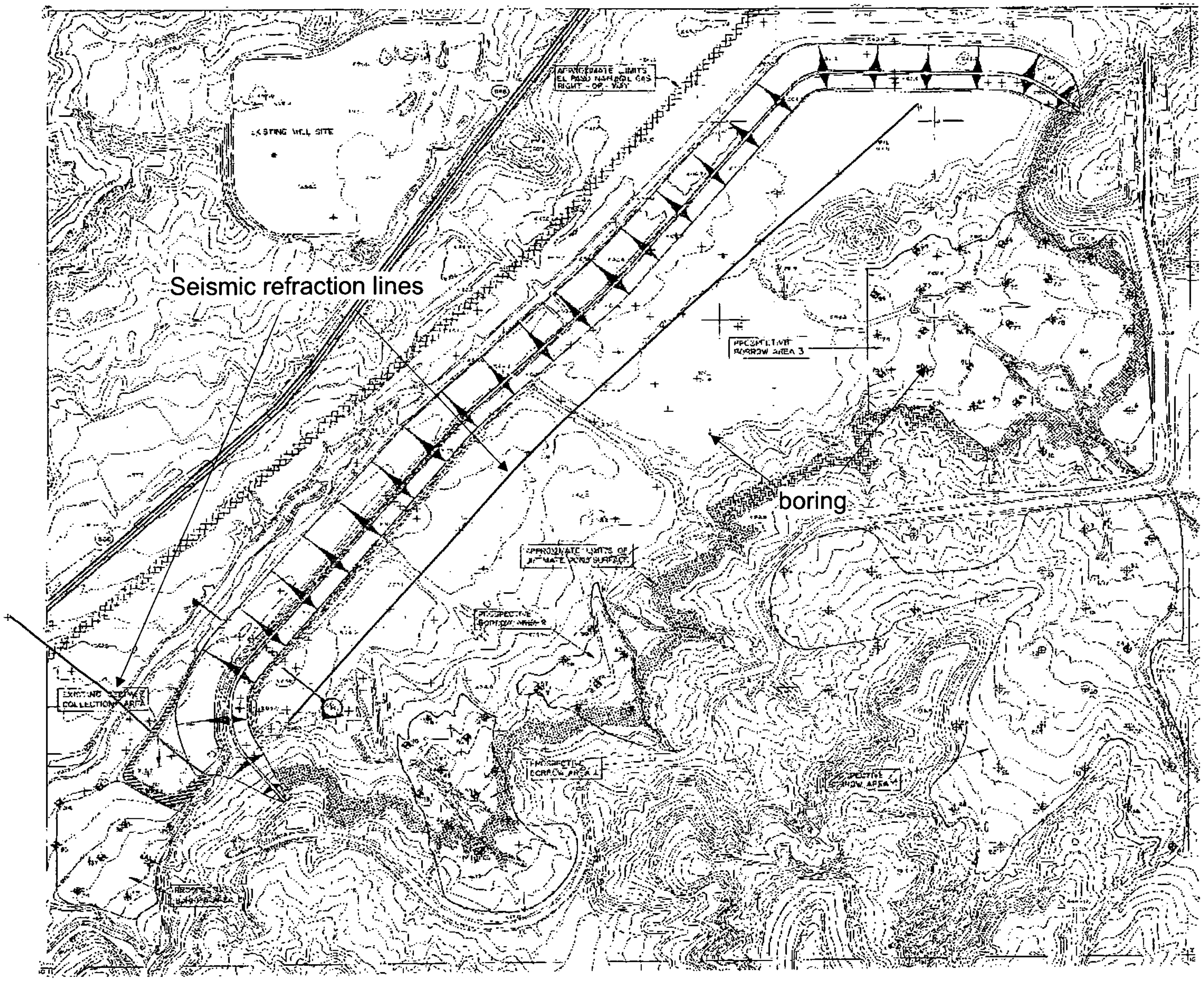

FIGURE 1
May 1978 Topographic map showing planned modification of the "starter" dam, 1974-1979 borings, and 1976 seismic refraction survey used to estimate top-of-rock and base-of-tailings elevations (topographic base reproduced from Sergent, Hauskins & Beckwith, October 1978; seismic refraction lines from Sergent, Hauskins & Beckwith, July 1976)

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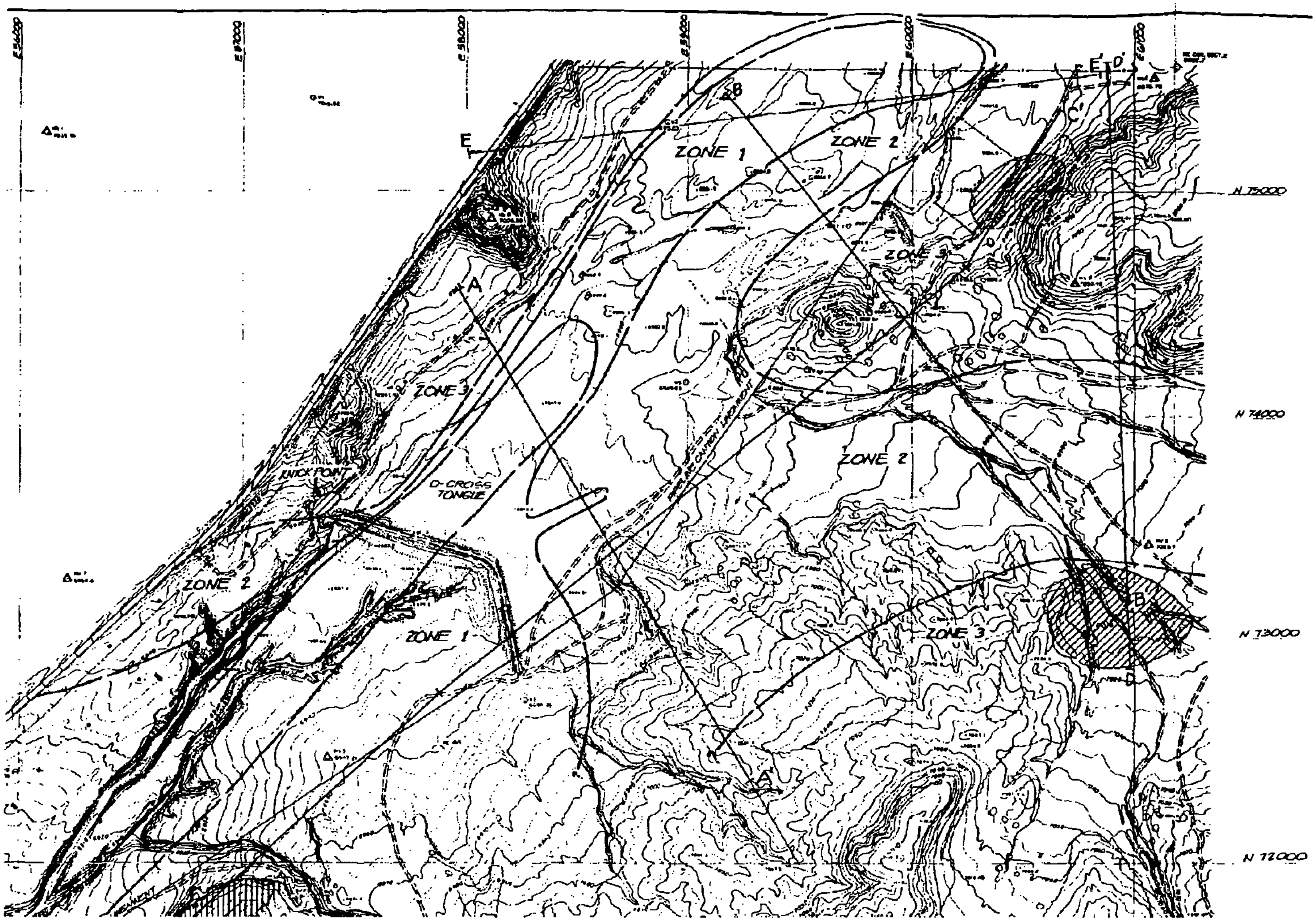

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FIGURE 2
Pre-tailings deposit (pre-1977) topographic map showing geologic interpretation
(reproduced from Bechtel, December 1984)

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FIGURE 3
Topography and geology (after Canonie, May 1987) on circa 1983 aerial photograph of tailings ponds
(5-foot contour interval)

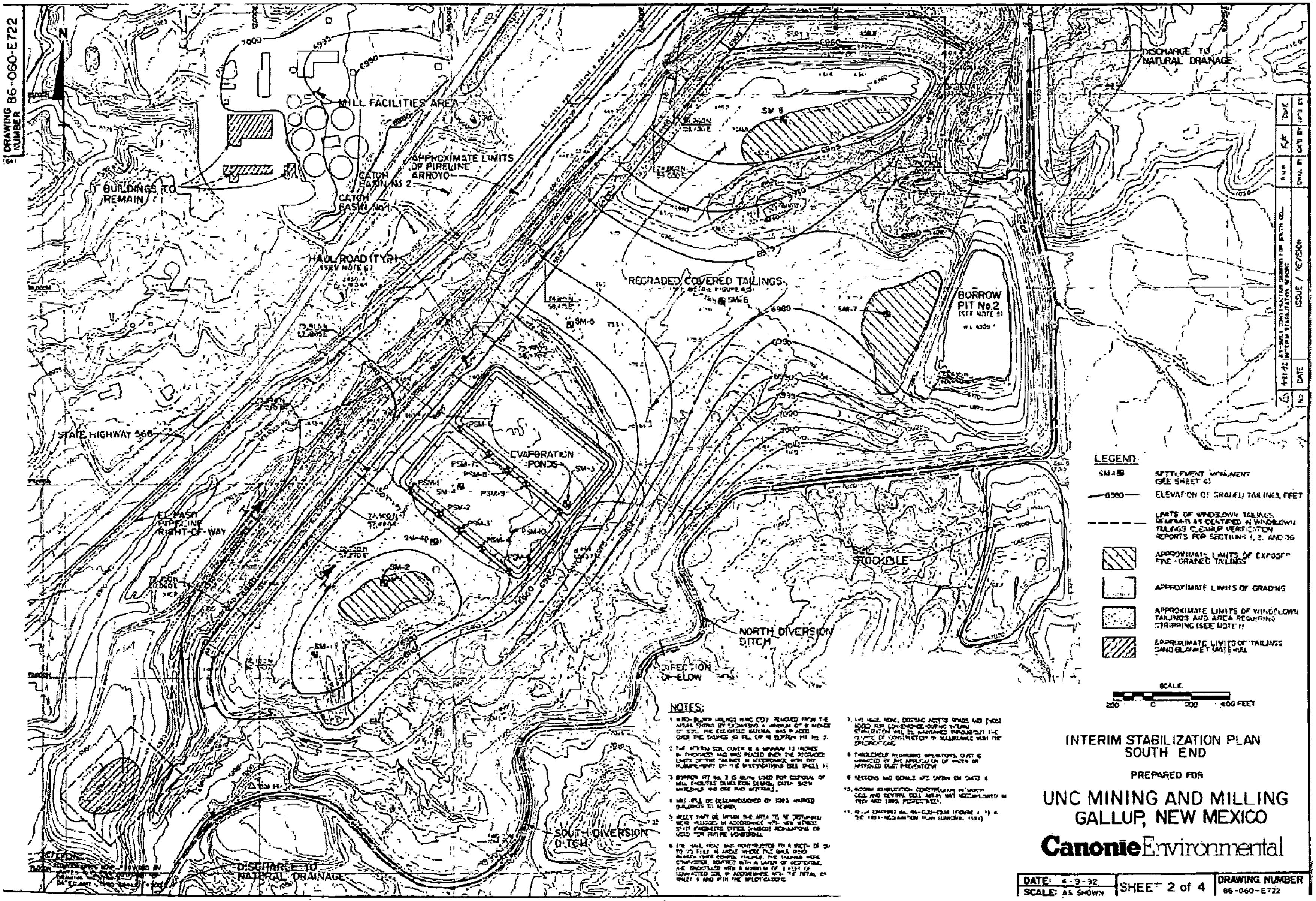

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FIGURE 4
May 1985 Topographic map showing planned elevation contours for the interim reclamation of 1989 - 1991 (reproduced from Canonie, April 1987)

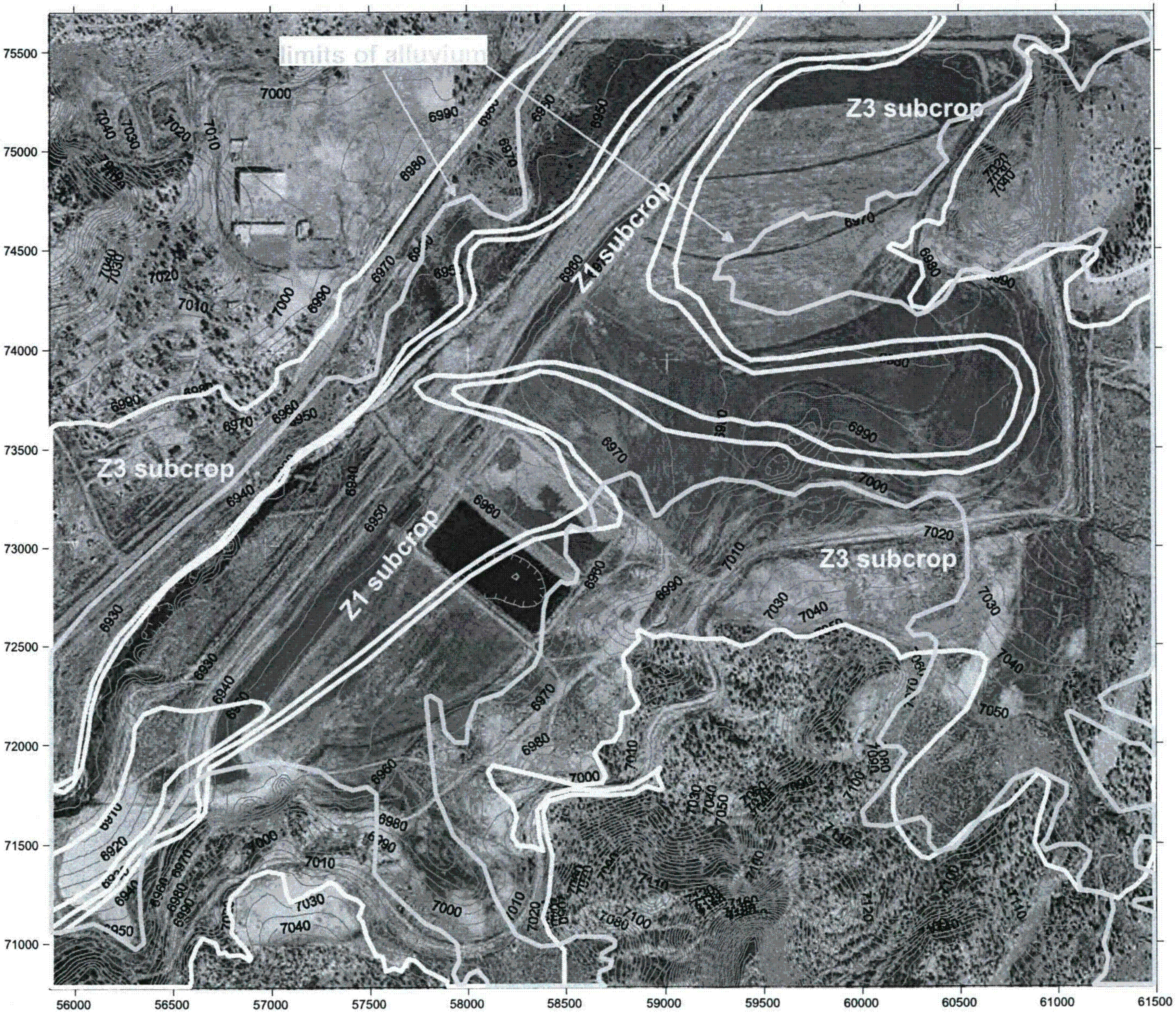

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FIGURE 5
Topography and geology on circa 1997 aerial photograph of covered tailings following final reclamation
(5-foot contour interval; geology after Canonie, May 1987)

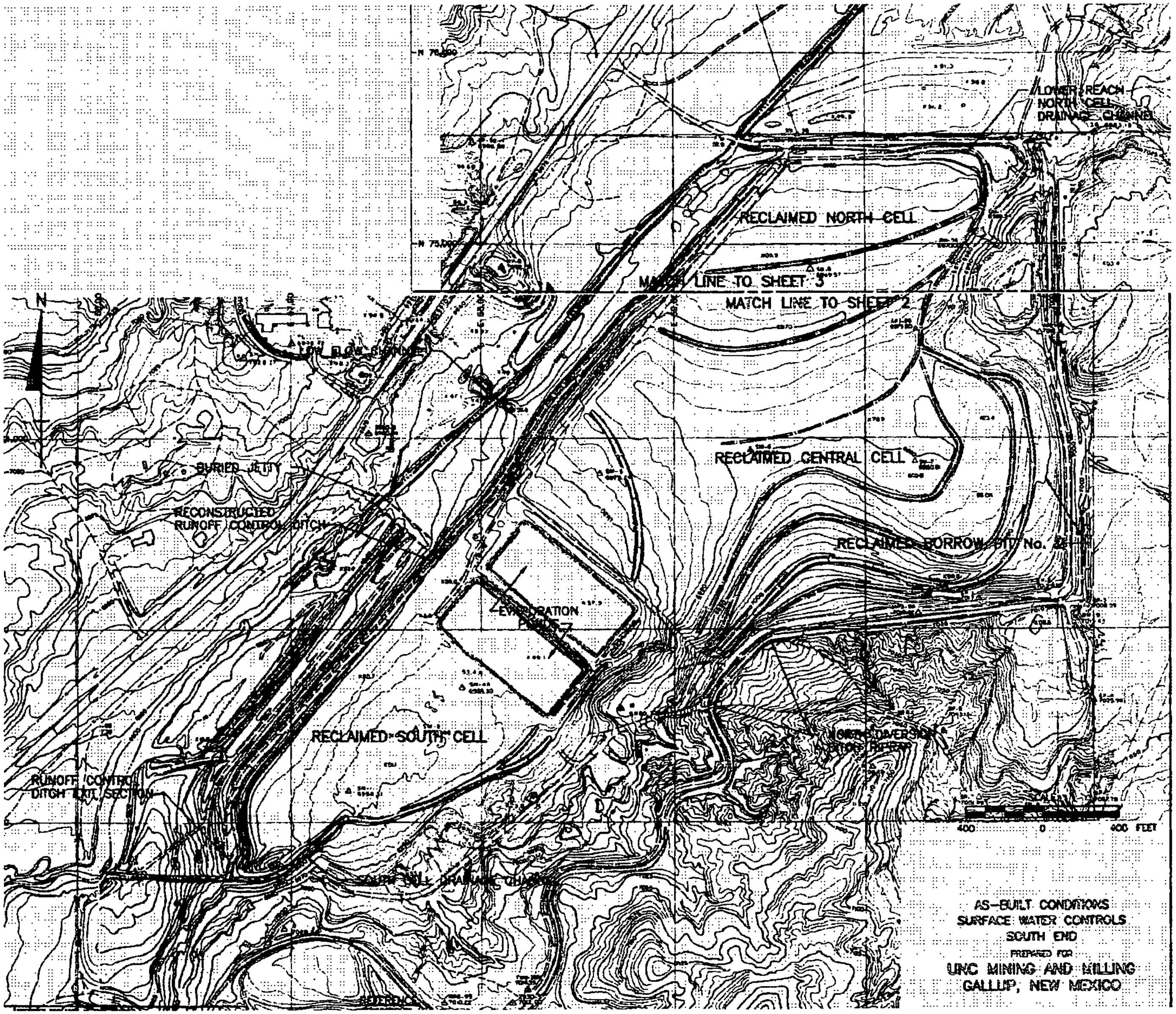

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FIGURE 6
August 1996 Topographic map showing final reclamation as-built elevations
(reproduced from Canonie, March 1997)

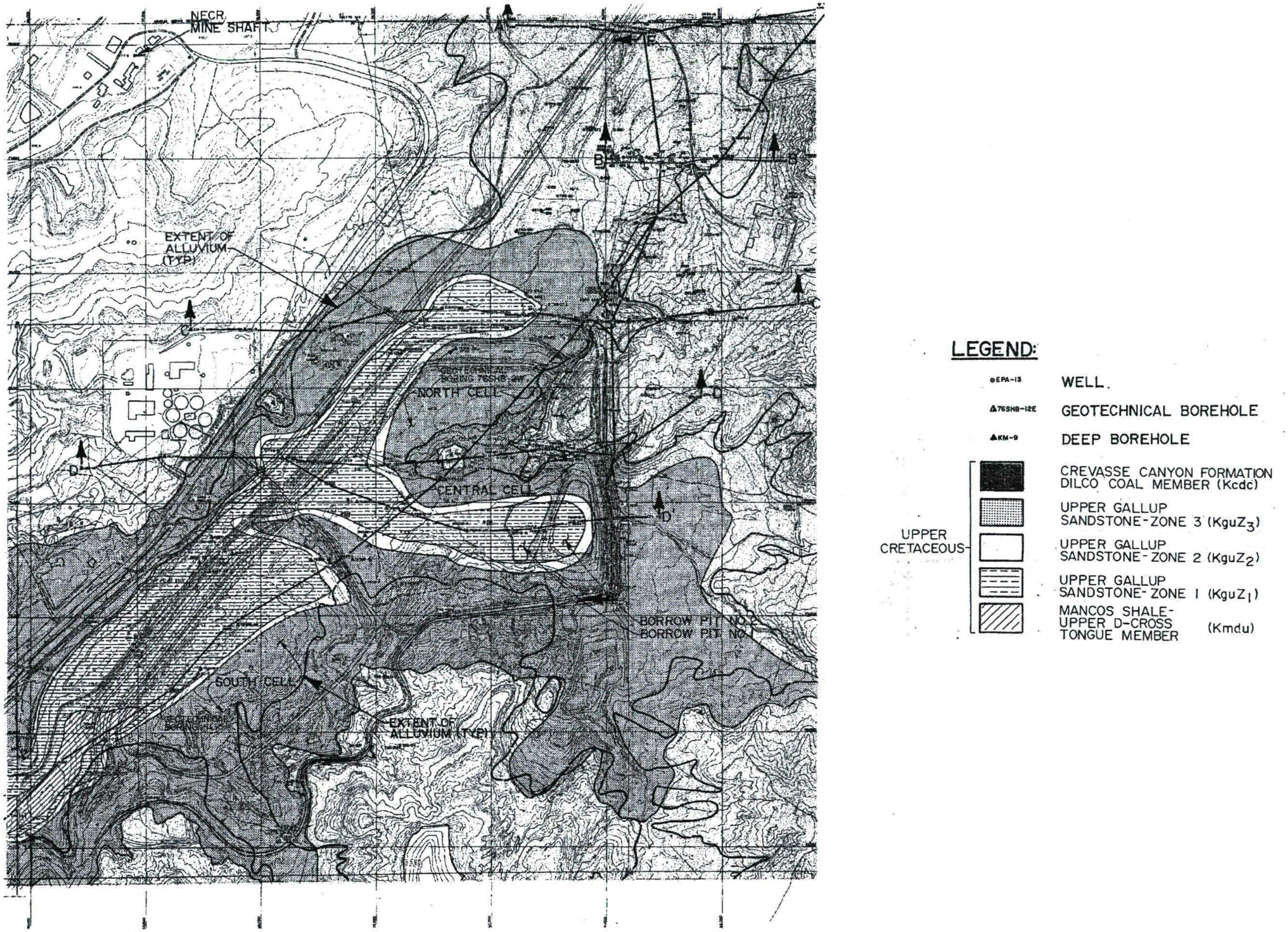

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FIGURE 7
Geologic map on May 1985 topographic base
(reproduced from Canonie, May 1987)

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FIGURE 8
Estimated thickness of alluvium between tailings and rock on circa 1997 aerial photographic base
(10-foot contour interval; geology after Canonie, May 1987)

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FIGURE 9

Estimated elevation contours at the top of rock on circa 1997 aerial photographic base
(10-foot contour interval; geology after Canonie, May 1987)

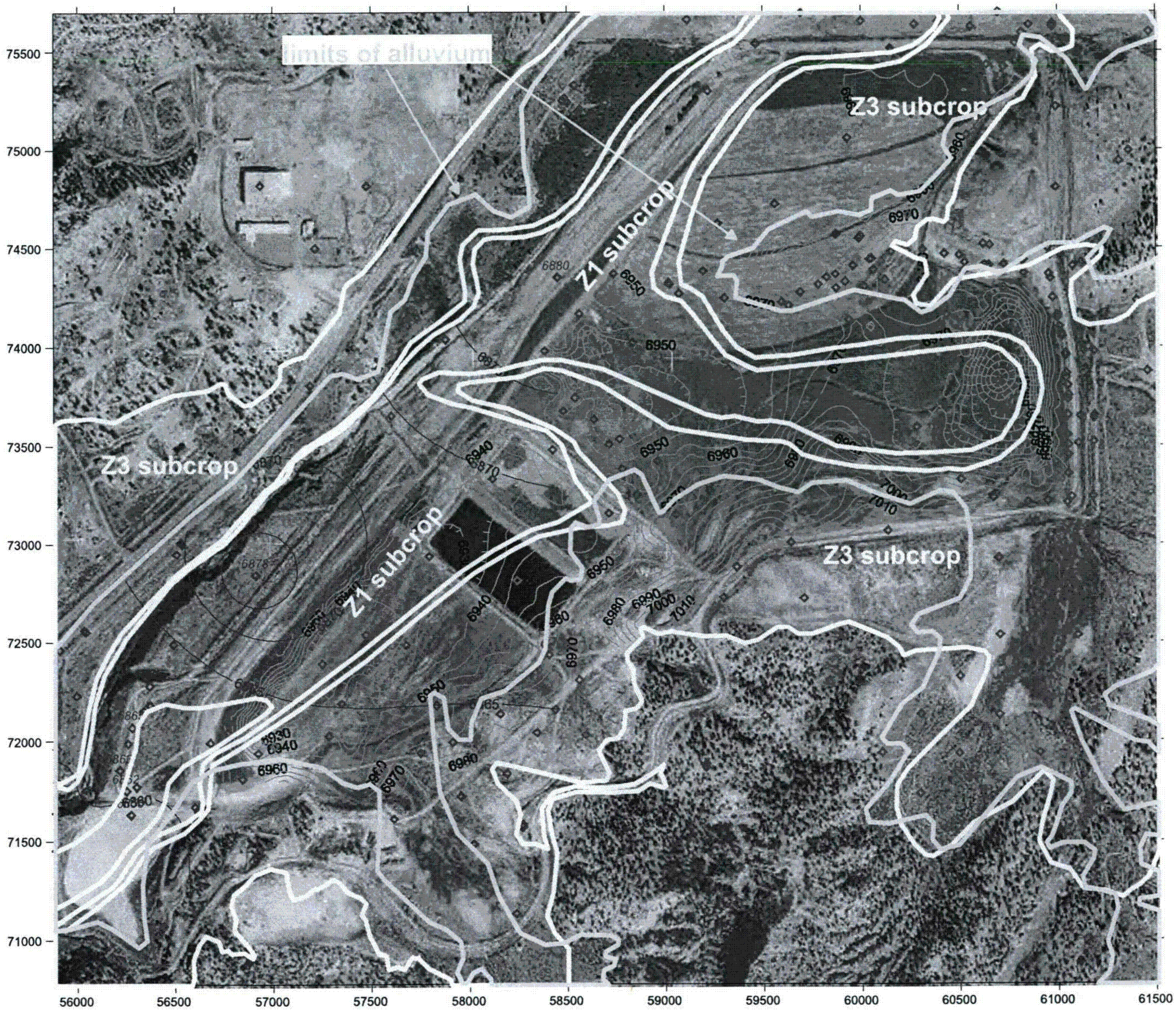

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FIGURE 10
Estimated elevation contours at the base of the tailings (orange) and
water levels in the alluvium measured in October 2002 (blue; data from Earth Tech, December 2002)
(5-foot contour intervals; geology after Canonie, May 1987)

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FIGURE 11
Estimated thickness of tailings in 1985, prior to interim regrading and cover,
on circa 1997 aerial photographic base
(5-foot contour interval; geology after Canonie, May 1987)

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FIGURE 12
Estimated thickness of tailings and cover in 1997, following final reclamation, on circa 1997 aerial photographic base
(5-foot contour interval; geology after Canonie, May 1987)

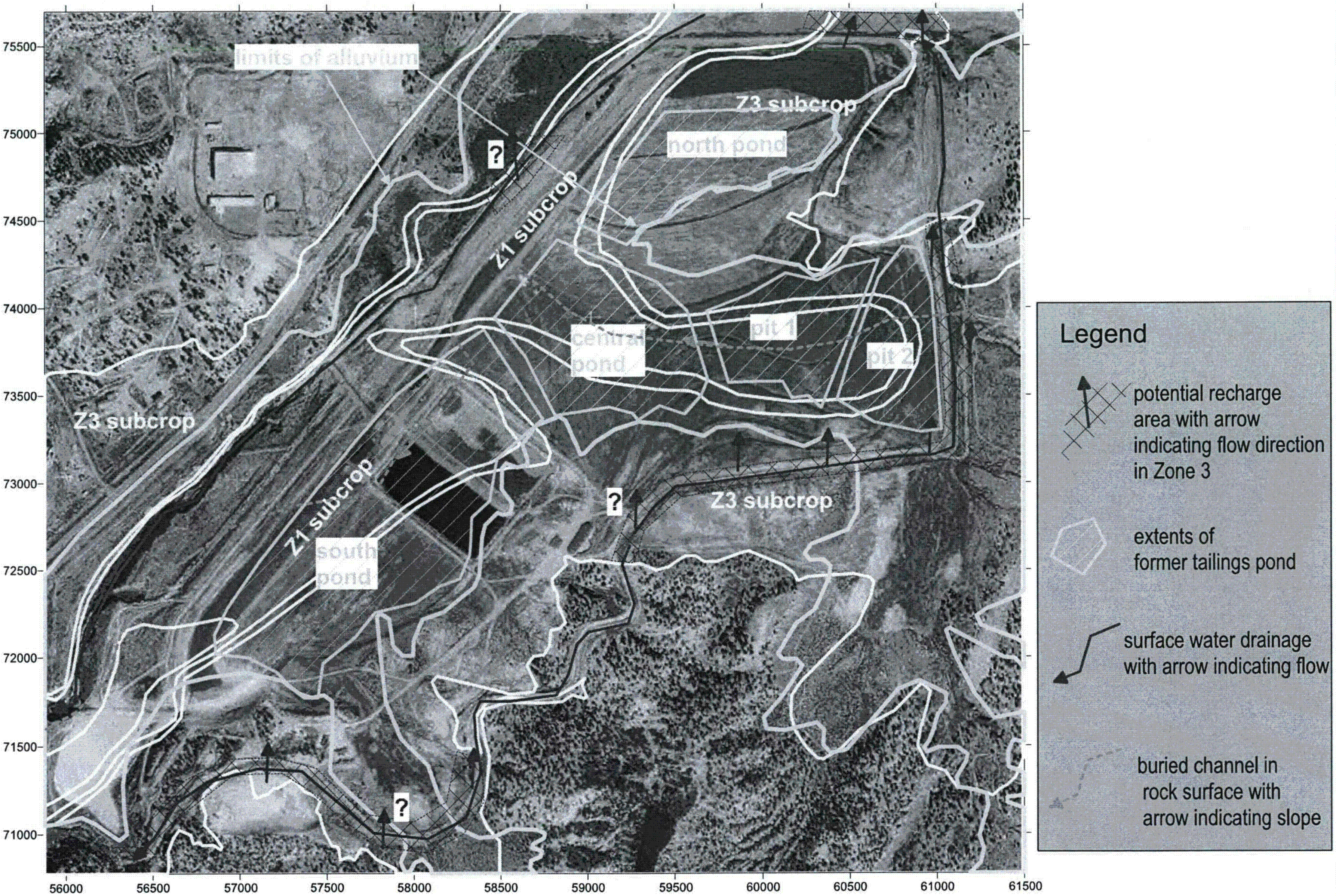

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FIGURE 13
Summary of tailings cell features, surface water channels and potential areas of recharge to zone 3, on circa 1997 aerial photographic base
(geology after Canonie, May 1987)

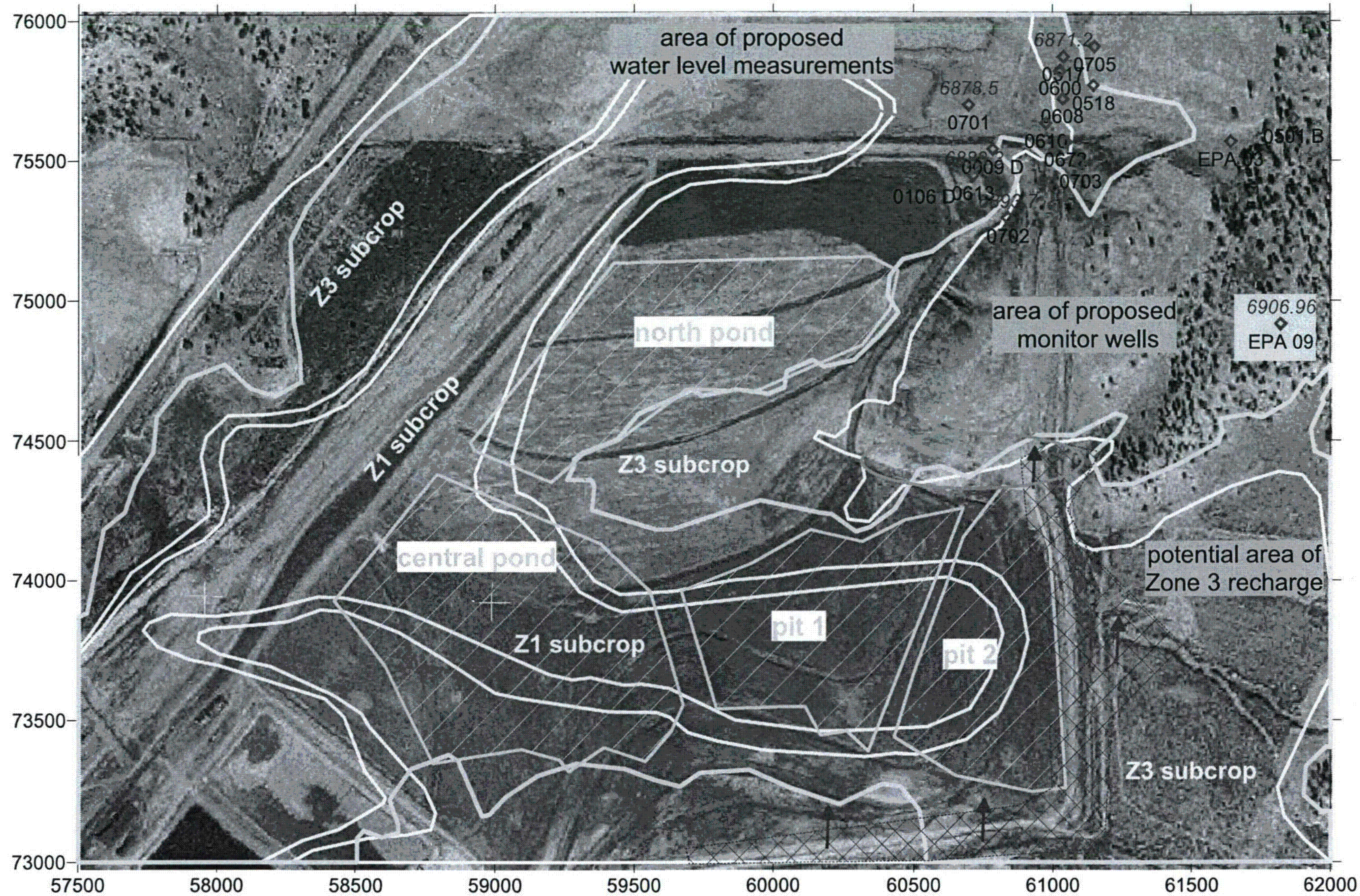

FIGURE 14
Detail from Figure 13 showing potential areas of Zone 3 field investigation,
on circa 1997 aerial photographic base
(geology after Canonie, May 1987)

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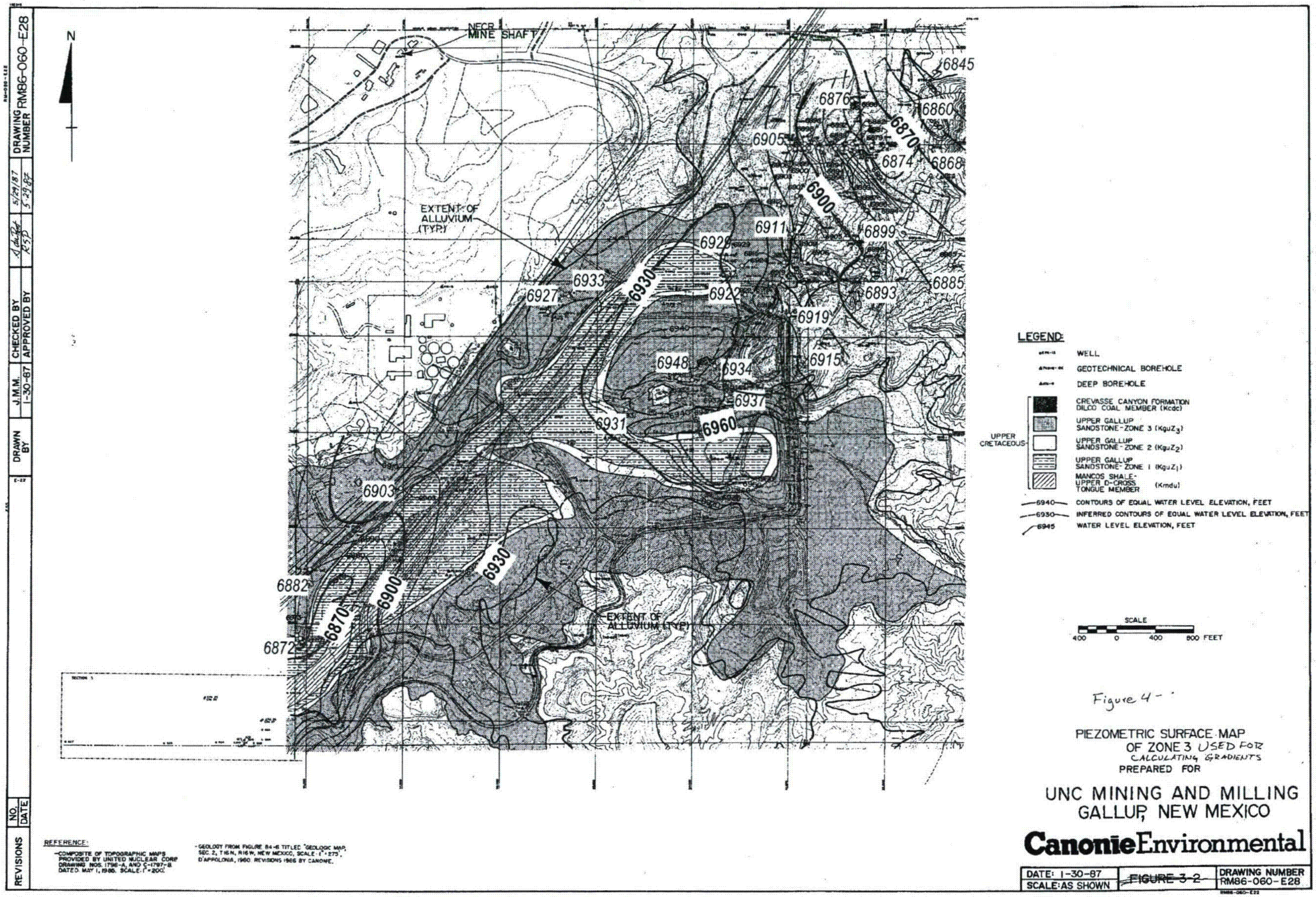

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FIGURE 15
Zone 3 piezometric surface map (1987) and geology on May 1985 topographic base (reproduced from Canonie, April 1989)

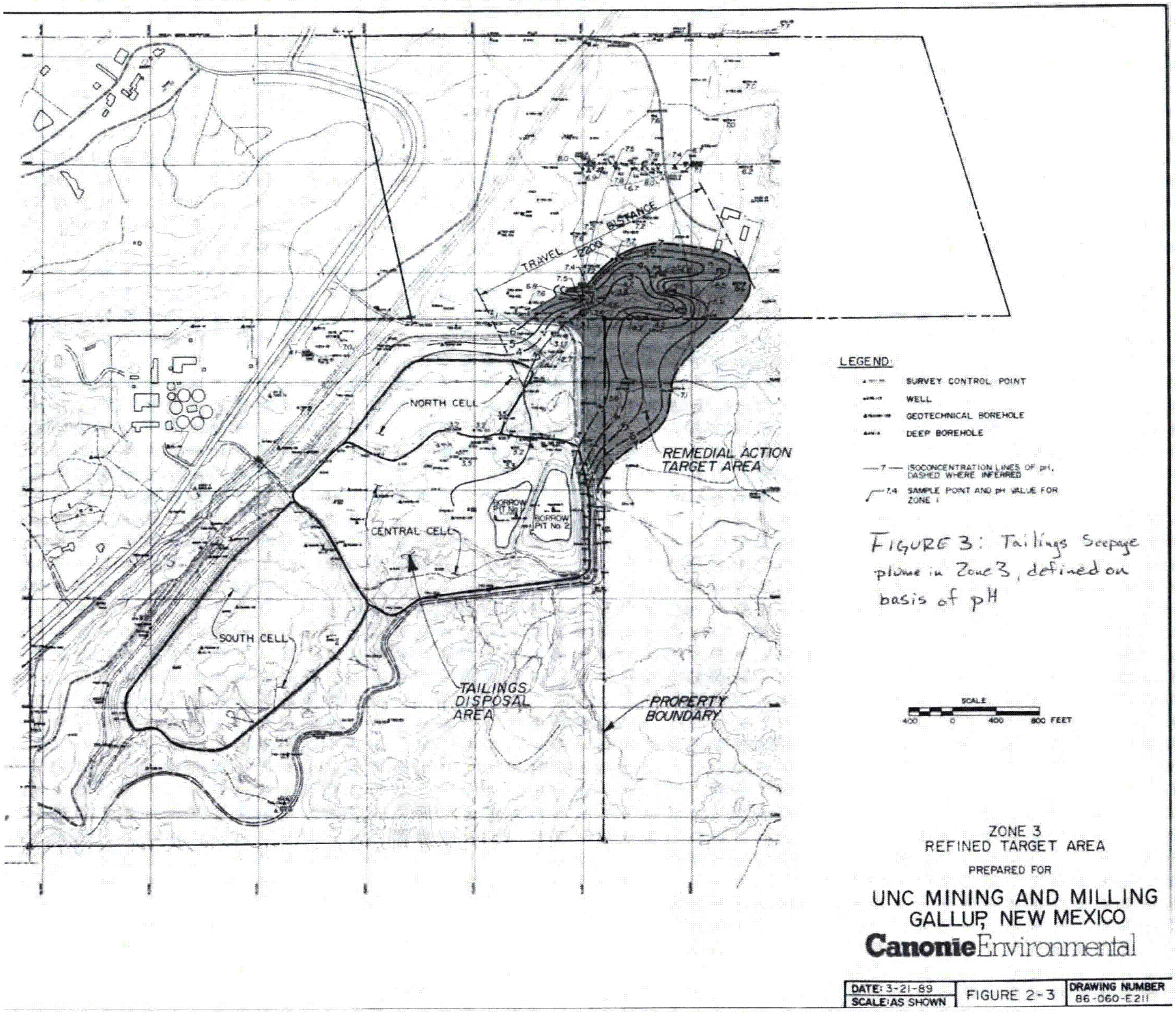

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FIGURE 16
Contours of pH in Zone 3 in 1989 on May 1985 topographic base
(reproduced from Canonie, April 1989)

N.A. Water Systems

April 25, 2008

Ref. No: D01-56007749.Z3

Mr. Mark Purcell
Superfund Division (6SF-RL)
U.S. Environmental Protection Agency
1445 Ross Avenue, Suite 1220
Dallas, TX 75202

Mr. Myron Fliegel
U.S. Nuclear Regulatory Commission
11545 Rockville Pike
#2 White Flint, Mail Stop T8F5
Rockville, MD 20852

Re: 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
Administrative Order (Docket No. CERCLA 6-11-89)
Materials License No. SUA-1475

Dear Messrs. Purcell and Fliegel:

Introduction

On behalf of United Nuclear Corporation (UNC), N.A. Water Systems has prepared this report regarding UNC's Mill and Tailings Site near Gallup, New Mexico. The subject of this report was discussed at the annual Church Rock multi-agency meeting that was held on March 12, 2008 in Santa Fe, New Mexico.

This report presents recommended well layouts for hydraulic capture at the leading edge of seepage-impacted groundwater in the Zone 3 hydrostratigraphic unit at the Church Rock Site. The recommendation is based on analyses of groundwater drainage rates and flow patterns prior to and during the pumping of wells in Zone 3, which began

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(most recently) in early 2005. A summary of this hydrogeologic analysis follows the recommendations.

Recommendations

Two pumping well array layouts have been designed as options for the hydraulic capture of impacted groundwater from Zone 3 at the Church Rock Site. The primary objective of the proposed pumping arrays is to intercept the plume of impacted groundwater before it reaches the Section 36 boundary. It is for this reason that the proposed wells are arrayed near to and down-gradient of the most northern known location of impacted groundwater (well NBL-1). Recovery of impacted groundwater is a secondary objective.

The two optional layouts were developed to accomplish the primary objective, while taking into account previously experienced limitations of the productivity of Zone 3 and the tendency of well yields to degrade with time. Two optional layouts were prepared, because of uncertainty in the applicability of empirical information about these limitations to the vicinity of the proposed wells.

The less extensive of the options includes three wells aligned parallel to the estimated piezometric potential line approximately 60 feet down-gradient of well NBL-1. These three pumping wells are provisionally identified as NW-1, NW-2, and NW-3. The array spans a distance of 322 feet (at 161 feet spacing) perpendicular to the estimated current direction of groundwater flow. The predicted piezometric surface configuration from pumping these wells for 15 months is shown in Figure 1 and for 27 months in Figures 2 and 2B. Both predictions were based on the conservative assumption that the initial yield from the wells would be 1 gallon per minute (gpm). It was also assumed that the yield would degrade with time at the same rate as that experienced from the onset of pumping in nearby well PB-2. The scenarios shown in Figures 1 and 2 also incorporate continued pumping from well PB-2, as well as RW-A, RW-11, and RW-16. The rates of pumping from each of those wells were projected to degrade at rates derived from empirical data (discussed below). The coordinates of wells NW-1 through NW-3 are listed in Table 1.

The configurations of the predicted piezometric surfaces shown in Figures 1 and 2 show evidence of the influence of the pumped wells. However, these configurations do not lead to the conclusion that complete capture (between the wells of the array) is certain. The water level drawdown predicted in the near vicinity of the pumped wells is approximately 9 feet or about 40 percent of the estimated saturated thickness of Zone 3 in this vicinity during October 2007. Approximately 5 feet of drawdown is predicted mid-way between the hypothetical wells. This may be enough to indicate the possibility of continuous hydraulic capture between the wells of the array.

Analogous predictions based on a five-well hypothetical array are shown in Figures 3 and 3B. The projected piezometric surface configurations for the five-well array lead to an unambiguous prediction of complete capture between the wells of the array. The only change from the three-well scenarios is the addition of two wells, each initially yielding 1 gpm. The locations of the two additional hypothetical wells are designed to "fill" the gaps between the three wells of the prior scenario, but are offset to the up-gradient side of those wells (NW-4 and NW-5 in Table 1). This was done to reduce the tendency for overdraft of the available drawdown and to effect a greater inflection of the piezometric surface in the up-gradient direction. This increases the breadth of flow that is redirected into the combined capture zone of the wells. However, the predicted drawdown in the vicinity of the pumped wells increases in this scenario, such that the saturated thickness remaining is predicted to be as little as six feet. With the likelihood of well inefficiencies such a drawdown outside the well may portend more rapid than assumed degradations of well yields. Therefore, the 5-well array may represent the closest practical limit of pumped well spacing.

It is worth noting that the contributions of wells RW-11, RW-16, and RW-A to the predicted piezometric surface configurations in the area of the proposed well arrays are not substantial. The pumping of PB-2 has a greater influence, the absence of which could be simulated if desired.

Pilot testing is probably the best available method to determine which of the two alternatives may be better in practice. If the five wells were installed, then the two up-gradient wells could be employed for water level monitoring as the three down-gradient wells are pumped for a period of several months. Data collected from the pilot pumping could be used to determine whether it is advisable then, or at some future time, to expand the pumping regime to all five wells.

Hydrogeologic Analysis

The recommendations made in the previous section are based on various predictions of future pumping at existing wells (e.g. PB-2, RW-11, RW-A, and RW-16) and at hypothetical wells located further down-gradient in the vicinity of Well NBL-1. The predictions were made with a computer program based on analytical functions (an analytical model). The analytical functions account for several characteristics of Zone 3, including that it is unconfined, bounded on the east, has an inclined water table, and will be pumped from multiple locations at time-variable rates. The accuracy of these predictions depend on knowledge of constituent properties (e.g. hydraulic conductivity), boundary conditions (e.g. the eastern limit of saturation), the distribution of saturated thickness and its time-dependence on natural drainage as well as pumping, the slope of the water table, and future rates of yield degradation at pumped wells.

The primary purpose of the hydrologic analyses was to develop the best possible input data for the analytical model. These analyses were for the most part empirical, based on measurements of water levels in monitoring wells (2000-2008), well pumping rates (2005-2008), and aquifer test data developed in the Phase I Full Scale Hydraulic Fracturing Report (MACTEC, Final Report, Phase I Full Scale Hydraulic Fracturing, June 2006) and in In-Situ Alkalinity Stabilization Pilot Study (ARCADIS BBL, June 2007). While the input data were empirically derived the analytical model is based on a well function for sloping unconfined aquifers derived by Hantush (Hydraulics of Wells, in Advances in Hydroscience, vol. 1, p. 368, Academic Press, 1964). Image wells were used to simulate a no-flow boundary at the eastern limit of Zone 3 saturation. Superposition, involving multiple well pumping stress and recovery periods, was used to simulate pumping rates that degrade steadily through time.

The analyses begin with a mapping of the base of the Zone 3 hydrostratigraphic unit. The mapping of structure contours on the base of Zone 3, shown in Figure 4, is based on interpretations of drilling logs at the control points shown in the figure. Estimates of saturated thickness were made by subtracting the Zone 3 base elevations from piezometric surface elevations. The Zone 3 piezometric surface elevations are estimated from quarterly measurements of well water levels. These measurements are the bases of maps presented in annual reports (most recently in N.A. Water Systems, January 2008). They were also the basis for estimates of groundwater flux, pumping drawdown, and gravity drainage made for this report.

Plots of saturated thickness as a function of time are shown for two sets of Zone 3 wells in Figures 5 and 6. The plots show data from wells identified by their proximity to Zone 3 wells (distinguished by a RW prefix) that were pumped regularly after January 10, 2005. The data span the period from June 2000 through October 2007. June 2000 was selected as a starting time for analysis of drainage, because this was when the former Zone 3 pumping system was shut down. The shutdown was followed by an approximate two-year period of modest water level changes (either recovery or lowering) at most wells. Progressive reduction of saturated thickness began in or about April 2002 at most wells. The reduction of saturated thickness prior to January 2005 is interpreted to represent gravity drainage, promoted by the inclination of Zone 3.

Trend lines were fit to the pre-pumping drainage data at each of the monitored wells, including those not shown in Figures 5 and 6. The fitted trends were used to estimate the rate of gravity drainage throughout the monitored area of Zone 3, and to project future drainage. For example, forward projections of these trends were used to estimate water level drawdown attributable to the pumping after January 2005. Drawdown was estimated by subtracting measured saturated thicknesses from those projected on the basis of pre-pumping drainage rates. The purpose in doing this is to quantify the fluxes of groundwater induced independently by gravity drainage and pumping.

Figure 7 is a contour map showing the estimated piezometric surface in Zone 3 prior to the initiation of sustained pumping in January 2005. Hydraulic gradient vectors plotted on the same map illustrate the directions of gravity drainage. The theory of groundwater flow predicts that in a uniform, homogeneous system the direction of drainage should be dictated by the slope of that system. A comparison of Figures 4 and 7 shows that this is not the case in the northern part of Section 36, where the hydraulic gradient vectors are oblique to the structure contours on the base of Zone 3. This indicates that heterogeneities of hydraulic conductivity, historic recharge, or both factors must be responsible for the eastward rotation of hydraulic gradients relative to the structural slope in the northern part of Section 36. (There were relatively few wells in the northern part of Section 36 at the time represented in Figure 7. However, the north-northeastward convergence of impacted groundwater in Zone 3 and recent water level measurements in monitoring well NBL-2 indicate that the eastward rotation of hydraulic gradients shown in the northern part of Section 36 is probably accurate.)

Armed with empirical information on the distribution of hydraulic gradients, saturated thickness, and rates of drainage it is possible to estimate variations of the transmissive capacity (e.g. hydraulic conductivity) in Zone 3. The Darcy flow equation can be used for this purpose. The equation, written in terms of flux in one dimension, is:

$$Q = -k * i * A$$

where,

Q is the volumetric flux

k is the hydraulic conductivity

i is the hydraulic gradient, and

A is the wetted cross-sectional area

The flux and hydraulic conductivity are the principal unknowns in this equation. The hydraulic gradient and saturated thickness (the vertical dimension of A) have been empirically estimated, as illustrated in the preceding figures. The horizontal dimensions of three cross-sectional areas of flow are mapped as lines (labeled sections) in Figure 7. The lines are oriented approximately perpendicular to the hydraulic gradients (and interpreted flux directions). The two more northerly lines span a breadth of the flow system that is estimated to be equivalent to the most up-gradient line (labeled south section). The interpretation is that any groundwater flux that traverses the south section must also traverse the more northerly sections. To this flux would be added any groundwater that drains by gravity between the section lines (i.e. the change of stored groundwater).

There are relatively few wells providing drainage data south of the south section line shown in Figure 7 (not all are shown). The amount of drainage into Zone 3 from the Southwest Alluvium, if any, is also unknown. However, well test data from the In-Situ Alkalinity Stabilization Study has provided an independent estimate of the hydraulic conductivity (5×10^{-5} cm/s) on the western side of the south section line. (This value of hydraulic conductivity is less by an order of magnitude than that previously interpreted to be representative of Zone 3 materials. Investigation of the mineralogy of the local Zone 3 materials indicated pore clogging (by clay), which was interpreted to be a reaction product of tailings-derived acidity with native feldspar.) If this value is assumed to be applicable to the whole of the south section then it can be integrated with the saturated thickness and hydraulic gradient data to estimate the flux, Q, traversing that section line from the south. This was done by calculating the flux across 33 divisions of the 1642-foot section line using the Darcy flow equation. The calculated sum or total flux is 96.7 ft^3/day or 723 gallons per day (gpd) or 0.5 gpm (see attachment for calculation details). This flux must pass through each of the more northerly lines. To that flux would be added groundwater derived by gravity drainage.

Gravity drainage rates were estimated for each of the monitoring wells (e.g. as shown in Figures 5 and 6). The map distribution of those rates is shown in Figure 8. There is a clear pattern of increasing drainage rates from southeast to northwest. This trend is attributable in part to increases of saturated thickness. However, normalizing the drainage by dividing by saturated thickness does not entirely remove this trend. It is likely that hydraulic conductivity (the other factor of transmissive capacity) also increases in the western areas of Zone 3, where it has not been degraded by reactions with tailings impacted groundwater.

Drainage volumes can be calculated by factoring the rates shown in Figure 8 over time. However, the porosity of the Zone 3 materials must be factored in the calculation of the volume of water drained. An estimate of this porosity was made by comparing the known volume of water pumped from Zone 3 wells with the volume of Zone 3 estimated to have been dewatered by pumping (independently of contemporaneous gravity drainage). Estimates of water level drawdown from pumping were made for each of the wells monitored between January 2005 and January 2006. The map distribution of these estimates is shown in Figure 9. The total volume of dewatering calculated from the combined cone of depression (using Surfer, Version 8, Golden Software) is 7,780,500 ft^3 and the volume of groundwater pumped from wells during the same period was measured to be 457,433 ft^3. Dividing the volume of water by the estimated volume of pumping drawdown gives an estimate of porosity of 5.9 percent, which is applicable as an average over the area affected by pumping (see attachment for calculation details). This estimate is slightly lower than the estimate of 8 percent derived by MACTEC (June, 2006). Although they used a similar method, they calculated drawdown over a shorter period and did not account for contemporaneous gravity drainage.

Estimates of the rates of change of groundwater storage applicable to the period prior to January 2005 were made for the areas between the section lines shown in Figures 7 and 8. For the area between the south and mid-section lines the calculated rate of storage change is -153 ft^3/day and that between the mid- and NBL-section lines is -262 ft^3/day. An estimate was also made for the area between the south section line and the southern subsurface limit of Zone 3. This estimate, which is based on limited well information, is 133 ft^3/day or about 138 percent of the 96.7 ft^3/day flux derived using the Darcy equation. This raises the possibility that most, if not all, of the flux from the south is derived from gravity drainage within Zone 3 rather than drainage across the buried part of Zone 3 beneath the Southwest Alluvium.

The Darcy flux estimate of flow across the south section line was used in calculations of the total flux across the two more northerly section lines. Those estimates, which account for the accumulations from changes of storage, are 250 ft^3/day (1.3 gpm) across the mid-section line and ***512 ft^3/day (2.7 gpm) across the 1200-ft long NBL section line. The latter estimate represents the total flux from the area of seepage impact without any pumping.*** This flux estimate, which is based on conditions in January 2005, will decrease with time, more or less proportionally to the ongoing reduction of saturated thickness.

Having estimates of the total flux across each of the section lines it is possible to integrate this with the saturated thicknesses and hydraulic gradients to estimate hydraulic conductivity. Using the Darcy equation in a process similar to that employed at the south section line (except that average hydraulic conductivity rather than flux is the unknown to be solved for) the average hydraulic conductivity is estimated to be 2.16 x 10^{-4} cm/sec at the mid section and 2.95 x 10^{-4} cm/s at the NBL section (see attachment for calculation details).

The difficulties that have been experienced extracting groundwater by pumping wells are understandable given the very low density of groundwater flux (less than 3 gpm over a breadth of more than 1200 feet) in Zone 3. Furthermore, the well yields have degraded as a result of clogging by suspended solids and precipitated solids. The combination of decreased saturated thickness and clogging at well screens is likely to have progressively reduced the efficiency of pumped wells. Empirical measures of the rates of yield degradation were made using pumping records. Those estimates are shown in Figures 10 to 13 for pumped wells that were still in service after October 2007. The roughly linear relationship of yield degradation to the log of time is characteristic of all the pumped wells, including those not shown in the figures. This is partly attributable to the typically linear relationship of pumping dewatering (and transmissivity reduction) to the log of time.

The empirical data developed by these analyses are sufficient to construct the analytical model used to predict the future configurations of piezometric surfaces and hydraulic gradients based on pumping from hypothetical well arrays. A final step was taken to test the analytical model and to provide some independent verification of the empirically derived hydraulic conductivity and porosity estimates. The same analytical model used to test hypothetical pumping scenarios was first used in an inverse solution to estimate an average transmissivity and storage parameter for the drawdown caused by historic pumping between January 2005 and January 2006.

The time-drawdown data for each monitored well was estimated using the method illustrated by Figures 5 and 6. This gave estimates of drawdown through time that are independent of contemporaneous gravity drainage. The inverse solution was formed by a simultaneous fit to all of these data using the same well function (Hantush, 1964) used for the hypothetical pumping scenario predictions. Also used were the same methods of superposition for pumping rate changes (including recovery), and image wells to represent the eastern no-flow boundary. The resulting best-fit estimates are an average transmissivity of 25.5 ft^2/day and a specific storage of 0.11.

The transmissivity value is comparable to the empirical estimates of hydraulic conductivity times saturated thickness. For example, the average hydraulic conductivity estimated for the NBL section (which is closest to the area of interest for the predictive scenarios) is 2.95 x 10^{-4} cm/s or 0.84 ft/day. Multiplying by an average saturated thickness of roughly 25 feet results in an estimated average transmissivity of 21 ft^2/day, which is remarkably similar to the model-derived estimate. The specific storage of 0.11

or 11 percent is 1.86 times the empirically derived estimate of 5.9 percent porosity, but closer to the specific storage of 8 percent reported by MACTEC (also based on pumping test data). The best-fit hydraulic properties derived using the analytical model, and described here, were also used for the predictive models. This was done in recognition that the analytical model, while constructed to be as accurate as feasible, is an approximation. Therefore, the hydraulic properties that make the output of the model fit best to empirical data are also likely to make the most accurate predictions. On the other hand, the empirically derived hydraulic conductivities and porosity are likely to be the more accurate measures of those properties. The differences of the estimates are extremely small given the uncertainties inherent in applying such analyses to a flow system that deviates significantly from "textbook" assumptions.

Closing

UNC has selected the five-well option (described earlier) and is planning on drilling the wells during May or June 2008. Water-level data collected during the first several months of pilot pumping will be used to determine whether it is advisable then, or at some future time, to expand the pumping regime to all five wells. To keep to an aggressive schedule, UNC seeks your concurrence to proceed at your earliest possible convenience.

If you have any questions please do not hesitate to contact me (814-231-2170 x 236) or James Ewart (412-809-6719).

Very Truly Yours,

Mark D. Jancin, PG
Project Manager

James A. Ewart, PhD, PG
Technical Consultant

Attachments

MDJ: dll-2091

cc: Earle Dixon, NMED
David Mayerson, NMED
Diane Malone, Navajo Nation EPA
Roy Blickwedel, GE
Larry Bush, UNC

TABLE 1

Locations of Hypothetical Wells Used for Zone 3 Pumping Scenarios

Well ID	X-coordinate (feet)	Y-coordinate (feet)	Distance from NBL-1 (feet)	Direction Azimuth (degrees)*	Estimated Depth (ft bgs)
NW-1	62275	77820	160	94.8	~205
NW-2	62125	77895	62	8.5	~205
NW-3	61980	77950	179	310.6	~205
NW-4	62178	77805	68	114.6	~205
NW-5	62030	77859	90	286.6	~205

* direction based on coordinate north, not magnetic north

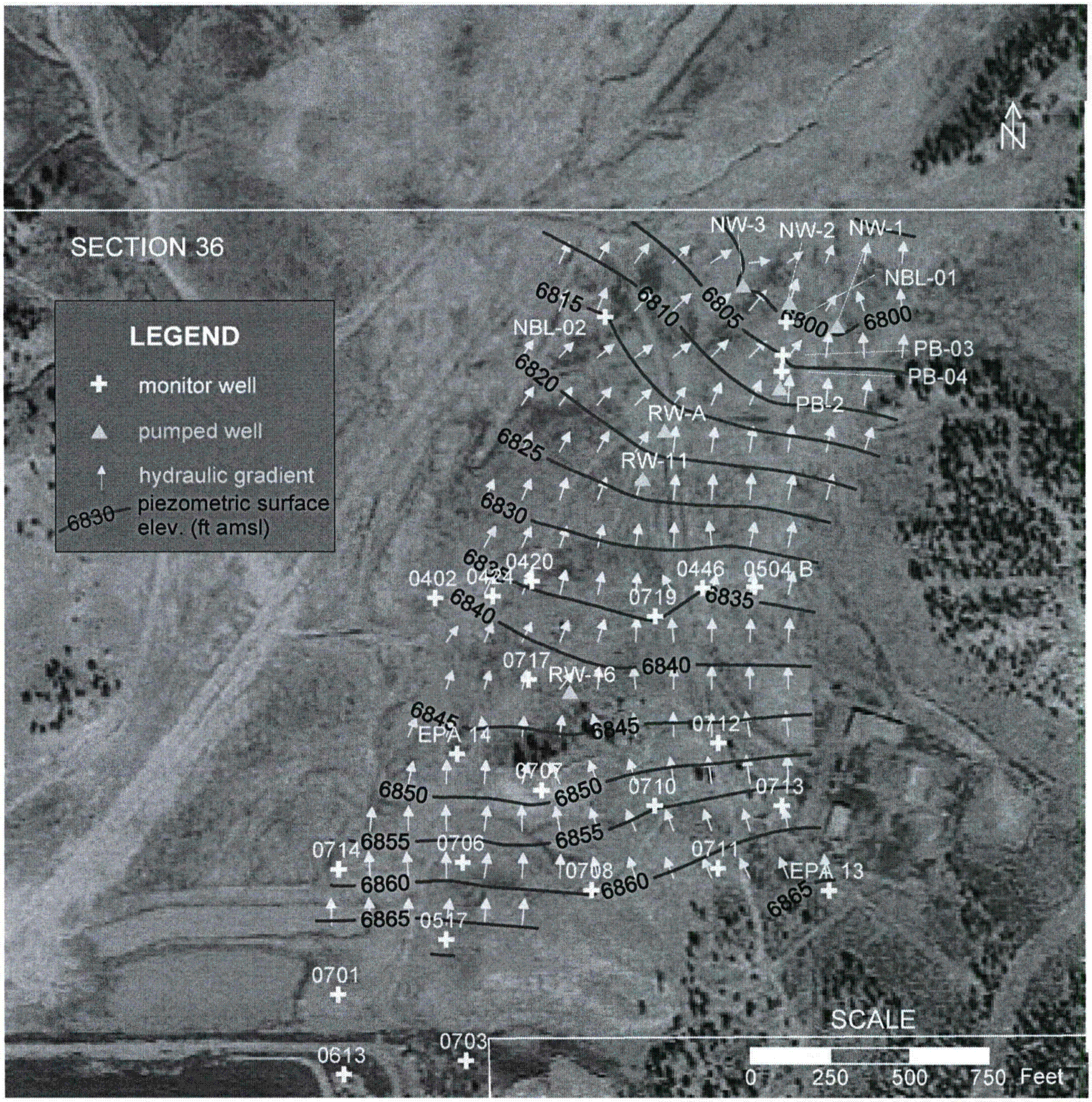

FIGURE 1
Piezometric surface elevations in Zone 3, projected to October 10, 2009, based on continued pumping of PB-2, RW-11, RW-16, and RW-A with degrading rates, addition of 3 hypothetical wells NW-1 through 3, each intitially at 1 gpm starting June 30, 2008

N.A. Water Systems

FIGURE 2
Piezometric surface elevations in Zone 3, projected to October 10, 2010, based on continued pumping of PB-2, RW-11, RW-16, and RW-A with degrading rates, addition of 3 hypothetical wells NW-1 through 3, each intitially at 1 gpm starting June 30, 2008

N.A. Water Systems

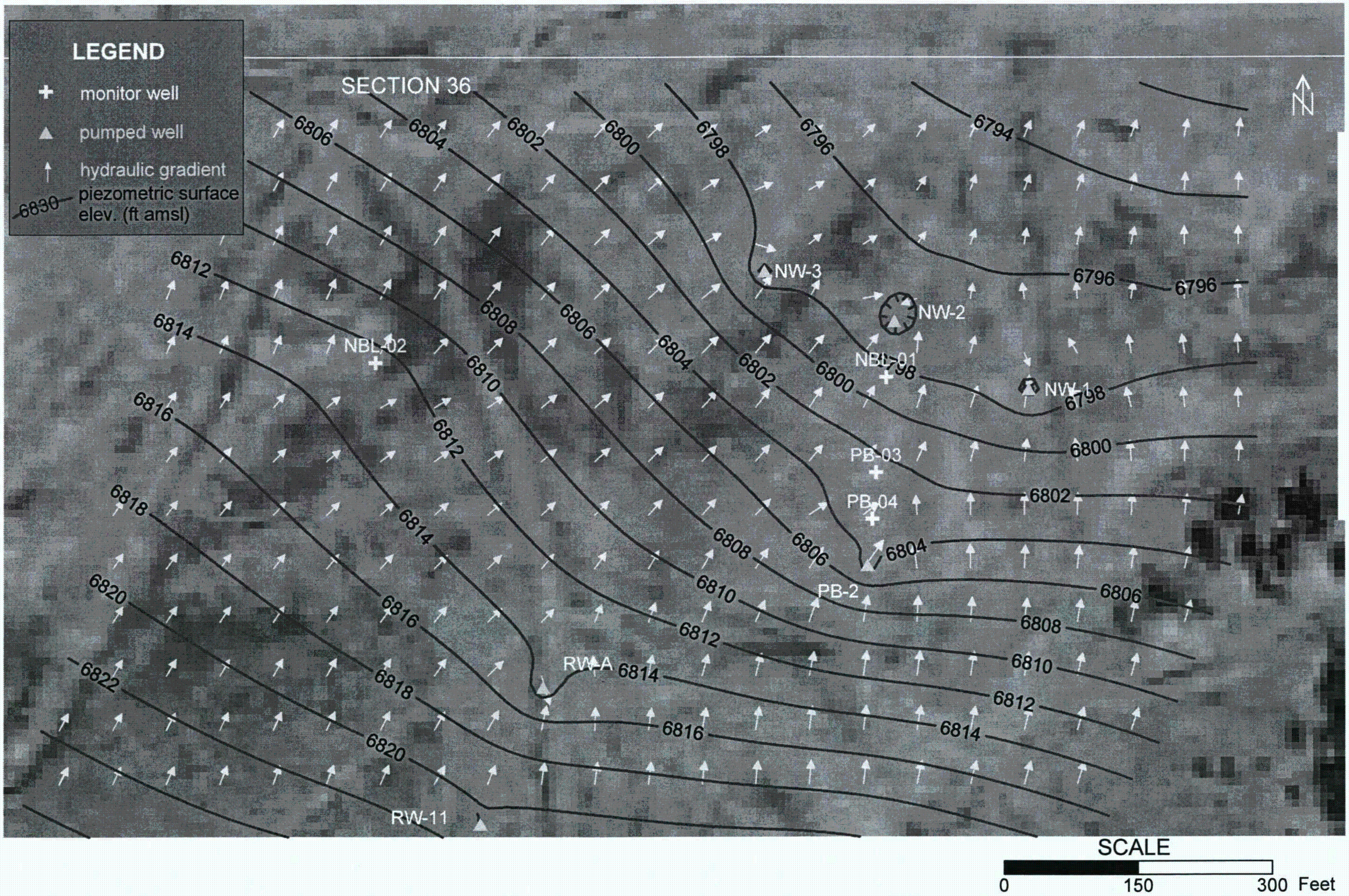

FIGURE 2B
Detail of piezometric surface elevations in Zone 3, projected to October 10, 2010, based on continued pumping of PB-2, RW-11, RW-16, and RW-A with degrading rates, addition of 3 hypothetical wells NW-1 through 3, each intitially at 1 gpm starting June 30, 2008

N.A. Water Systems

FIGURE 3
Piezometric surface elevations in Zone 3, projected to October 10, 2009,
based on continued pumping of PB-2, RW-11, RW-16, and RW-A with degrading rates,
addition of 5 hypothetical wells arrayed near NBL-1,
each intitially at 1 gpm starting June 30, 2008

N.A. Water Systems

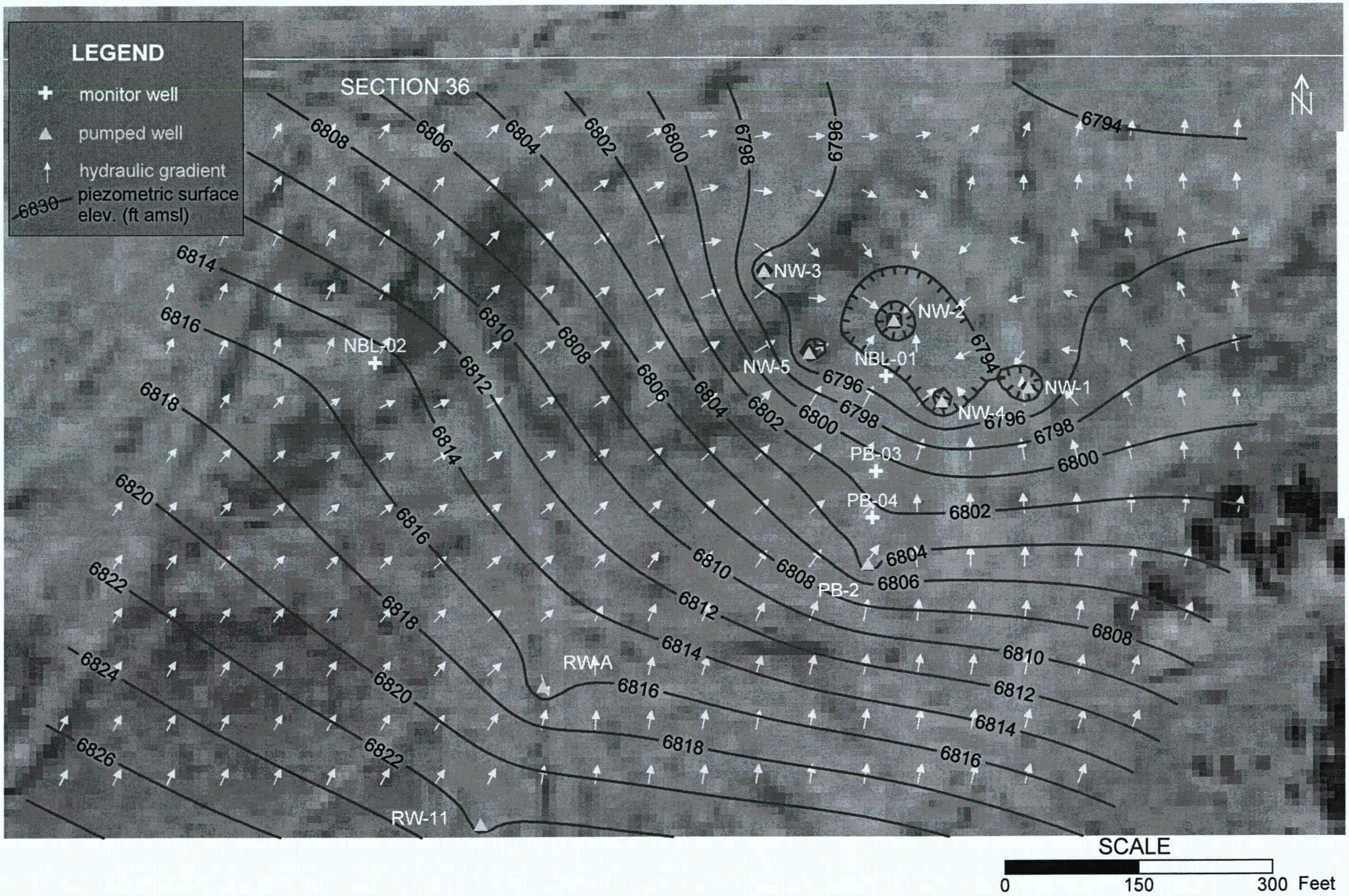

FIGURE 3B
Detail of piezometric surface elevations in Zone 3, projected to October 10, 2009, based on continued pumping of PB-2, RW-11, RW-16, and RW-A with degrading rates, addition of 5 hypothetical wells arrayed near NBL-1, each intitially at 1 gpm starting June 30, 2008

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FIGURE 4
Contour map of the elevation of the base of Zone 3,
control points based on drilling logs are shown by yellow symbols

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FIGURE 5

Changes of Zone 3 Saturated Thickness near Southern Frac Wells Since June 1, 2000

used to estimate pre-pumping drainage rate (April 02 - Jan 05) and pumping drawdown (Jan 05 - Jan 06)

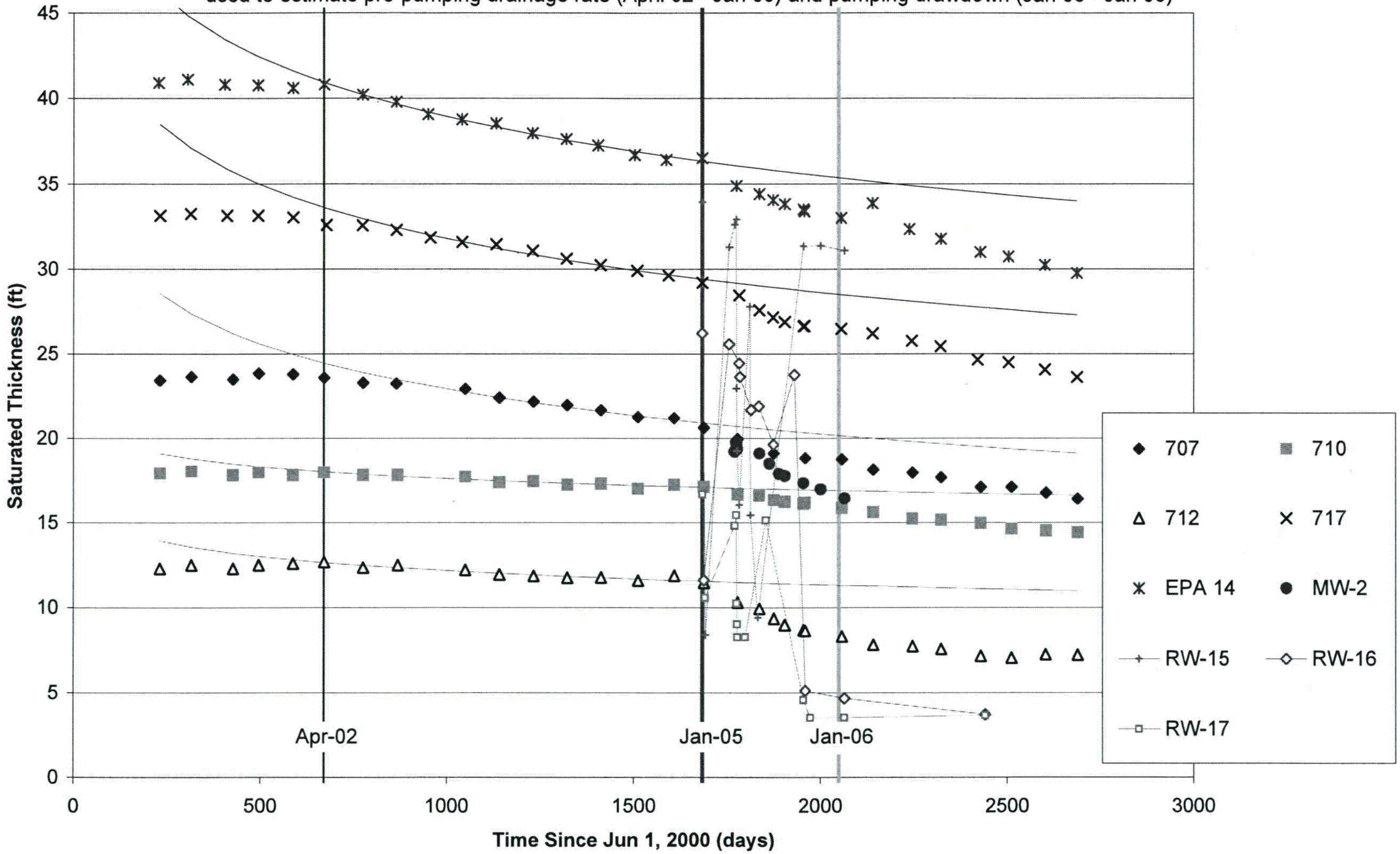
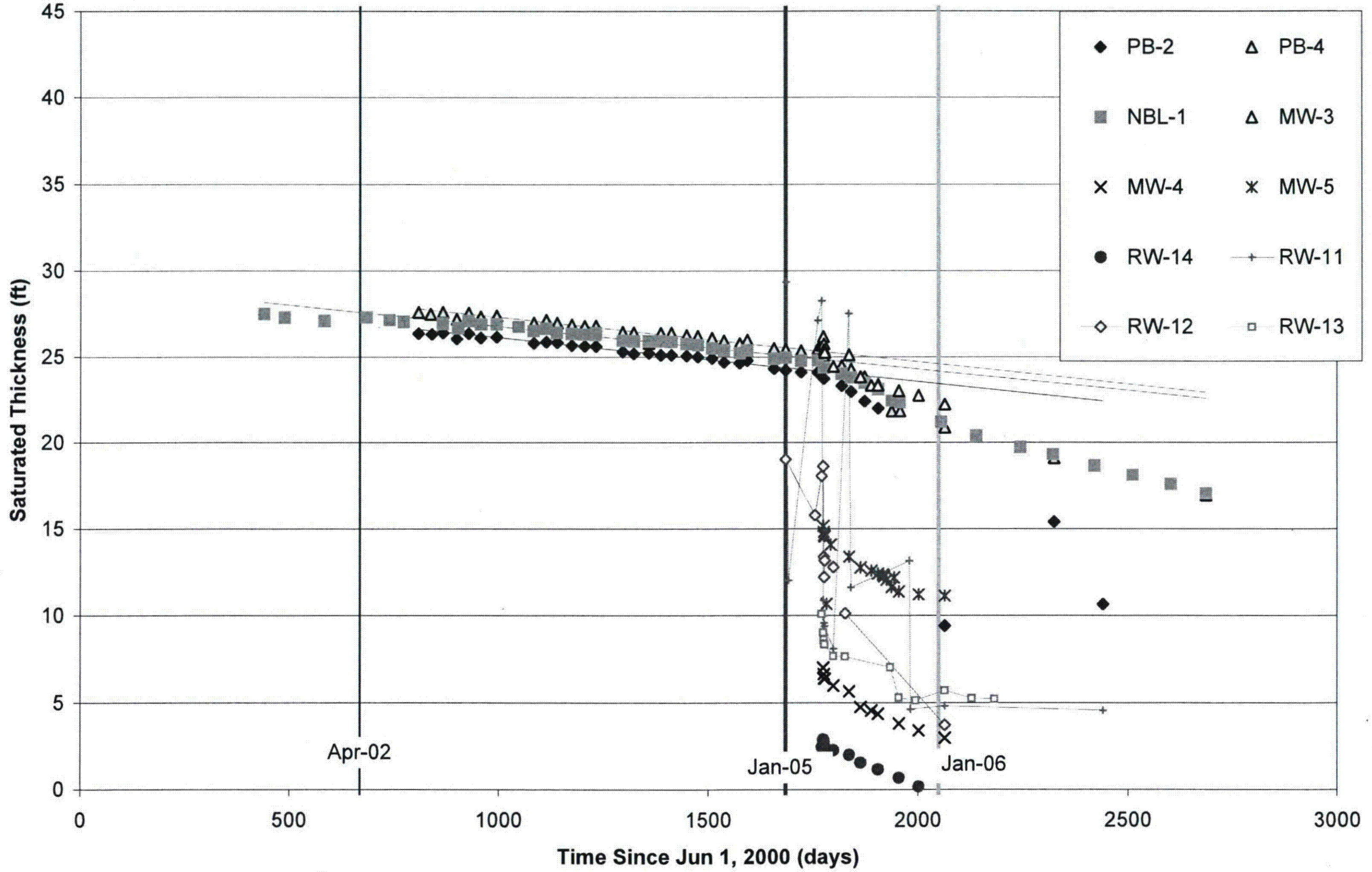


FIGURE 6
Changes of Zone 3 Saturated Thickness near Northern Pumped Wells Since June 1, 2000
used to estimate pre-pumping drainage rate (April 02 - Jan 05) and pumping drawdown (Jan 05 - Jan 06)



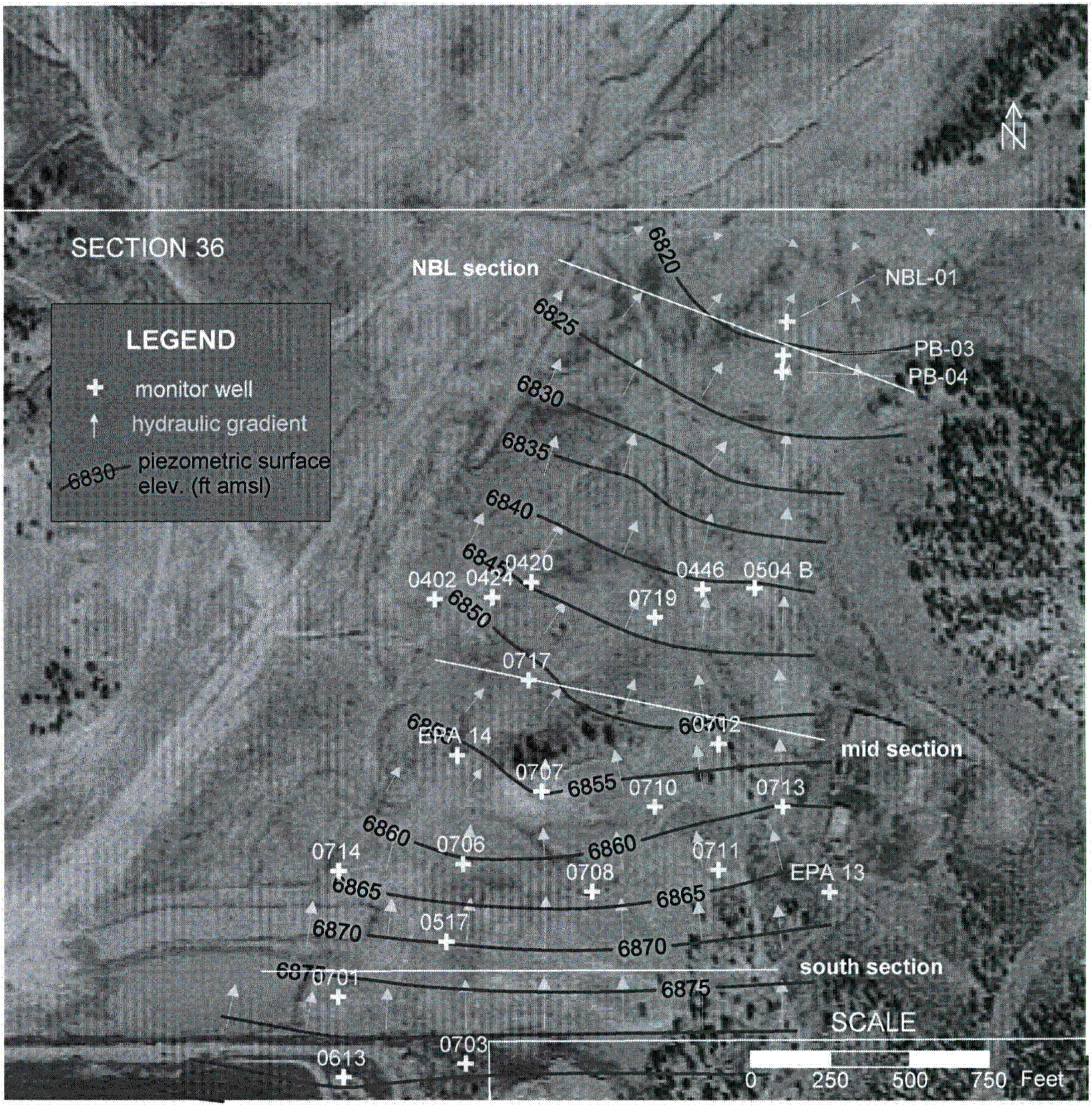


FIGURE 7
Piezometric Surface Elevations in Zone 3, based on January 2005 measurements, made prior to sustained pumping

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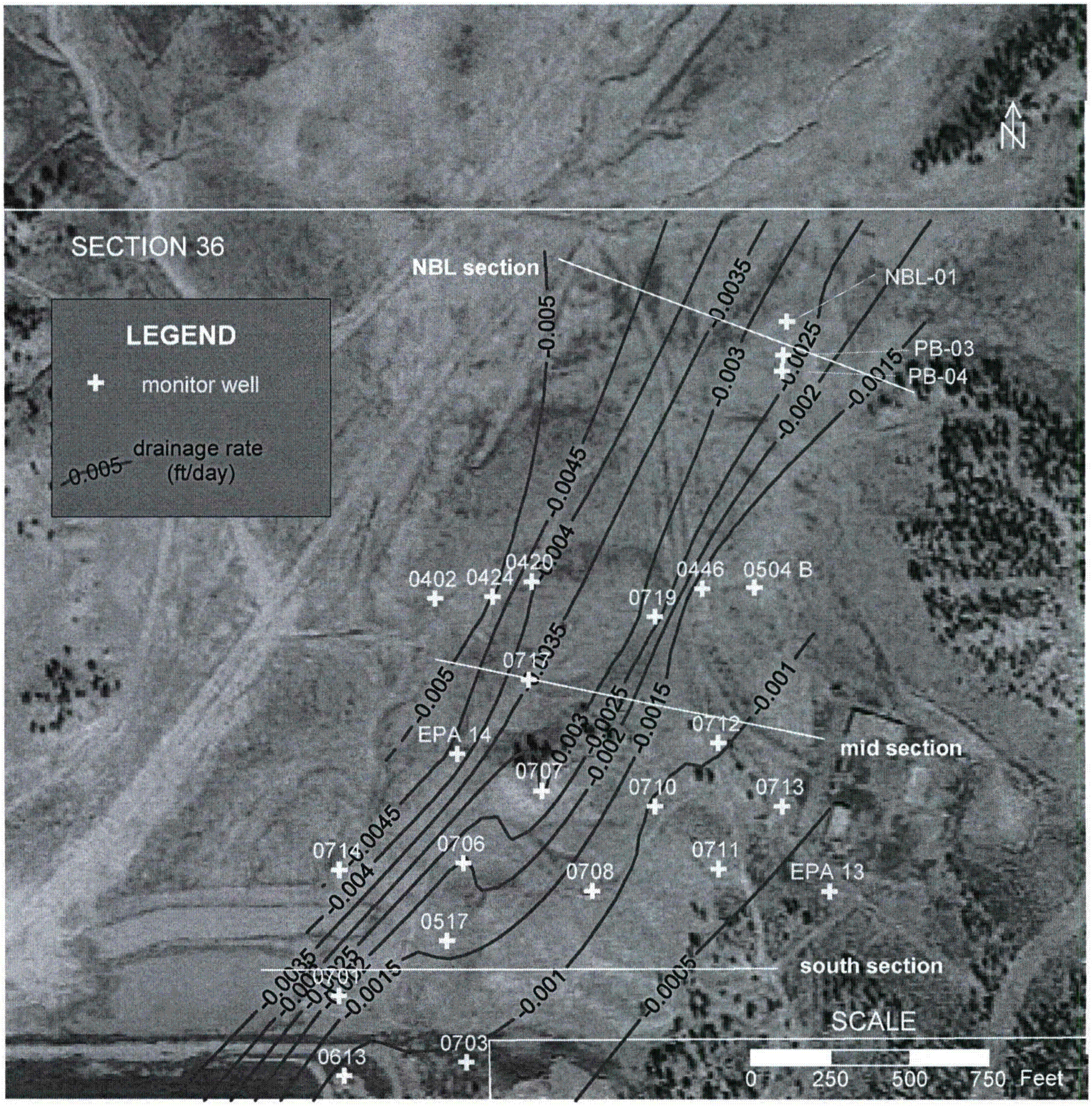

FIGURE 8
Pre-Pumping Drainage Rate in Zone 3
based on 2002-2005 measurements in (ft/day)

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FIGURE 9
Estimated Drawdown from Pumping in Zone 3, between January 2005 and January 2006

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FIGURE 10
Empirical Fit and Projection of Pumping Rates from Well RW-11, based on monthly average pumping 2005 - 2007

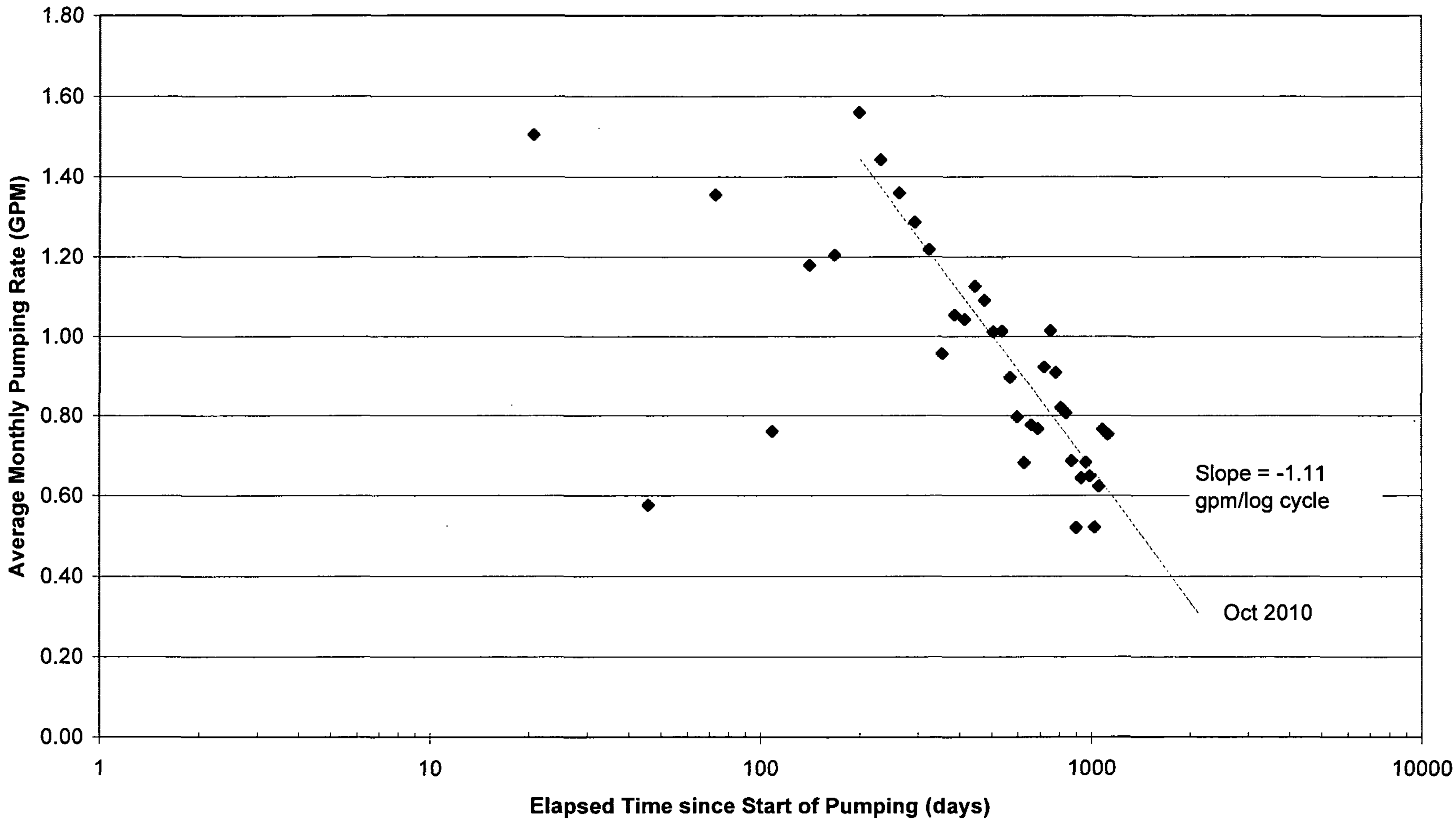


FIGURE 11
Empirical Fit and Projection of Pumping Rates from Well RW-16, based on monthly average pumping 2005 - 2007

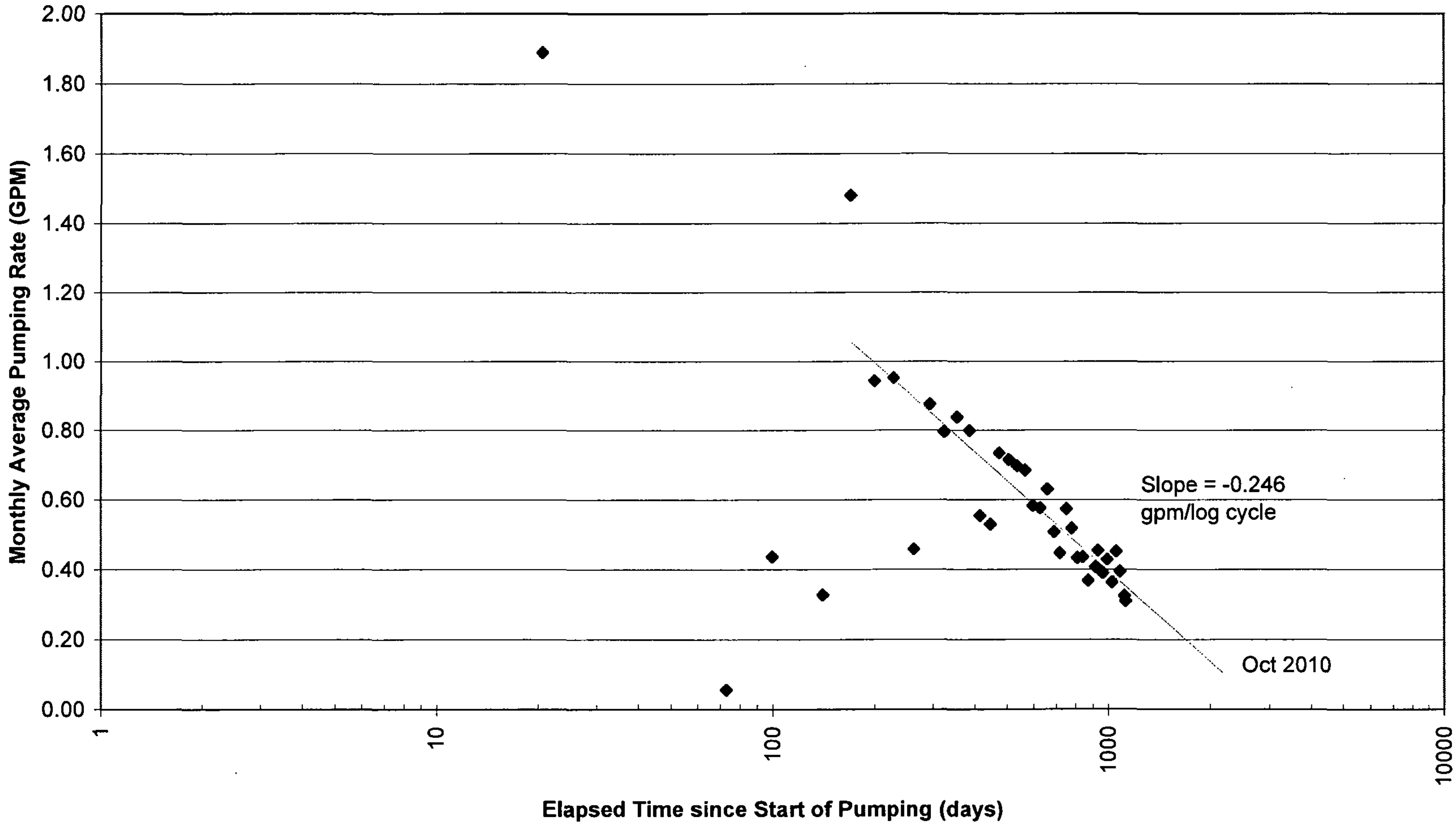


FIGURE 12
Empirical Fit and Projection of Pumping Rates from Well RW-A, based on monthly average pumping 2007-2008

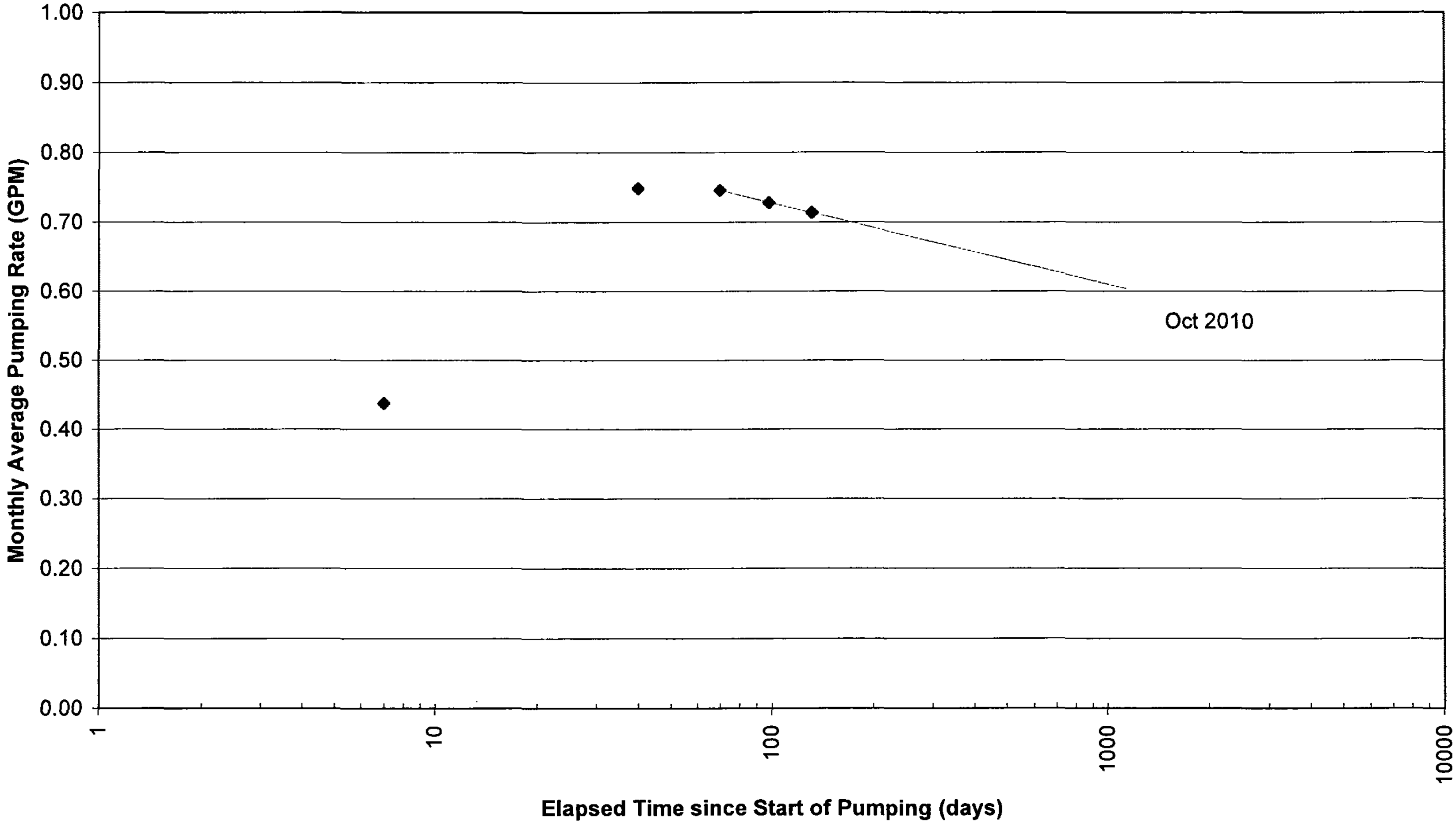
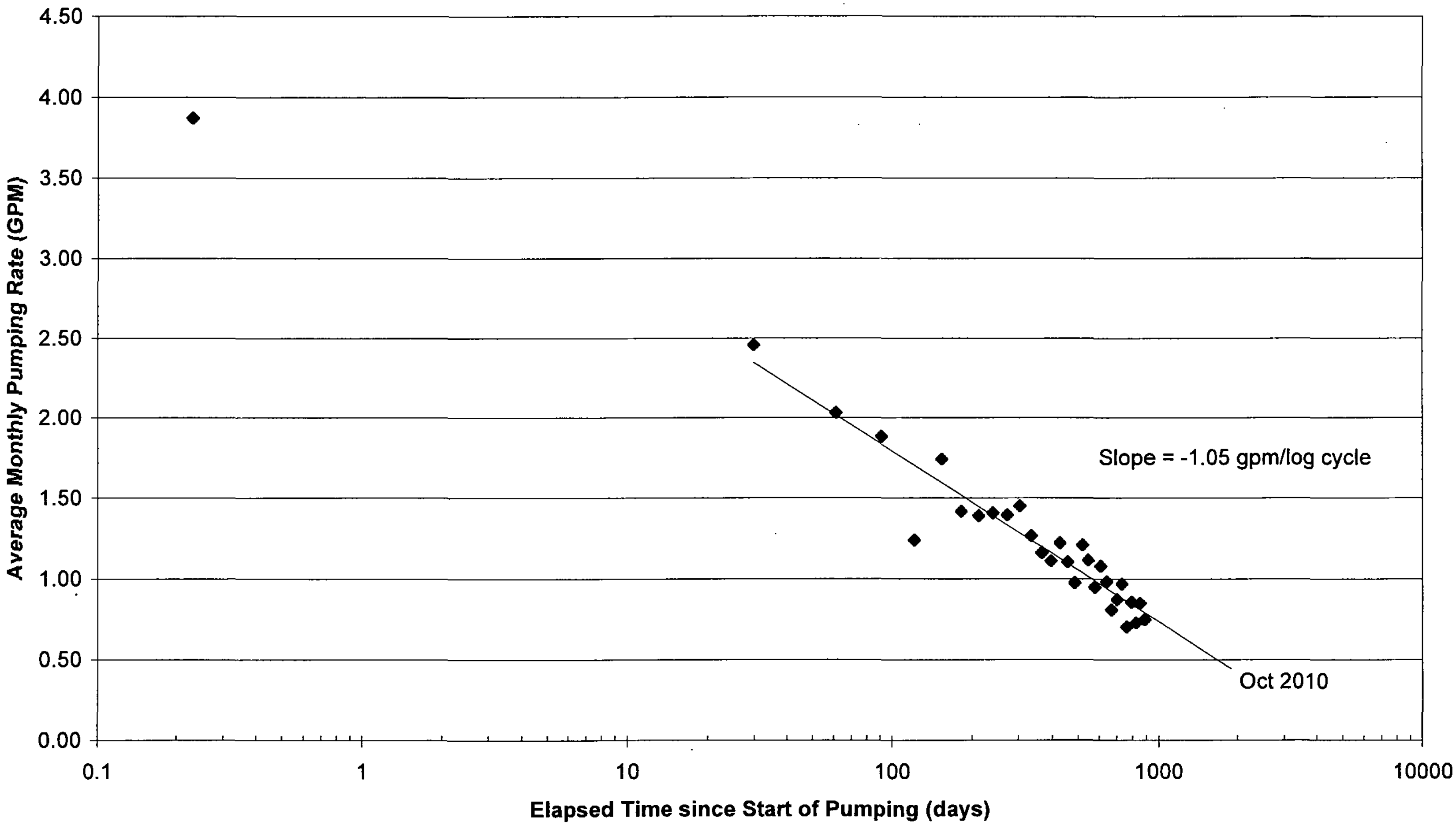


FIGURE 13

Empirical Fit and Projection of Pumping Rates from Well PB-2, based on monthly average pumping 2005 - 2007



Estimated Pre-Pumping Groundwater Flux across Three Saturated Cross Sections of Zone 3

Based on conditions measured on January 10, 2005.

Pre Pumping Drainage Rate

southern area (south of southern section)

Aquifer Volume	Porosity	Water Volume
2273 ft^3/day	0.0588	133.6 ft^3/day
		1000 gal/day

mid area (between southern and mid sections)

Aquifer Volume	Porosity	Water Volume
2606 ft^3/day	0.0588	153.2 ft^3/day
		1,146 gal/day

north area (between mid section and NBL section)

Aquifer Volume	Porosity	Water Volume
4459 ft^3/day	0.0588	262.2 ft^3/day
		1,961 gal/day

Estimated Flux across Section Lines

South Section

Darcy Formula Estimate based on hydraulic conductivity of 1.42E-01 ft/day 5.00E-05 cm/s

96.7 ft3/day
722.9 gal/day

Drainage rate estimate

133.6 ft3/day
978 gal/day

Mid Section

249.9 ft3/day
1869 gal/day

North Section

512.0 ft3/day
3830 gal/day 2.659645

Estimated Hydraulic Conductivity at Section Lines

South Section

1.42E-01 ft/day (based on well testing by BBL)
5.00E-05 cm/s

Mid Section

6.13E-01 ft/day (based on above estimated fluxes and Darcy formula)
2.16E-04 cm/s

North Section

8.37E-01 ft/day (based on above estimated fluxes and Darcy formula)
2.95E-04 cm/s

Estimation of Zone 3 Porosity from Pumping Drawdown

Time Period January 10, 2005 to January 25, 2006

Pumping Induced Drainage Volume

Estimate of volume based on pumping induced drainage

7780516 ft^3

Volume of water pumped

Well	badger #	Start Date	End Date	Start Pump (gal)	End Pump (gal)	Total Pump (gal)	Total Time (min)	Average Pumping Rate (gpm)
PB-02	32631438	8/31/05	1/25/06	0	397,167	397,167	211,050	1.9
RW-11	29660744	1/10/05	1/25/06	100,329	751,131	650,802	546,210	1.2
RW-12	29607642	1/25/05	1/25/06	0	347,265	347,265	525,480	0.7
RW-13	?	3/22/05	1/25/06	0	474,579	474,579	444,015	1.1
RW-15	29607641	1/10/05	9/27/05	0	728,068	728,068	373,380	1.9
RW-16	29607650	1/10/05	8/26/05	16	237,730	237,715	327,966	0.7
RW-16	?	9/15/05	1/25/06	641	163,304	162,663	189,120	0.9
RW-17	29607649	1/10/05	1/25/06	356	414,195	413,839	546,200	0.8
MW-5	?	4/18/05	4/28/05	89,480	98,985	9,505	14,605	0.7
Total						3,421,602	gallons	
						457,433	cubic feet	

Porosity Calculation

Volume of water pumped / Aquifer volume drained

0.058792

5.88%