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In-Situ Alkalinity Stabilization Pilot Study Report

UNC Church Rock Site
Gallup, New Mexico

June 2007

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UNC Church Rock Site
Gallup, New Mexico

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1. Introduction and Site Background

1.1 General

This In-Situ Alkalinity Stabilization Pilot Study Report (Report) presents the results of the in-situ alkalinity pilot study (pilot study) conducted at the United Nuclear Corporation (UNC) Church Rock Site (site) located in Gallup, New Mexico.

The pilot study was conducted between October 2006 and February 2007 to evaluate the use of alkalinity injection wells to enhance the ongoing remediation of Zone 3. Figure 1 presents the pilot study location in relation to the general site layout, and a detailed layout of the pilot study setup is shown on Figure 2.

This report has been prepared by ARCADIS of New York, Inc. (ARCADIS BBL) on behalf of UNC. The pilot study was conducted in accordance with the United States Environmental Protection Agency (USEPA)-approved *In-Situ Alkalinity Stabilization Pilot Study* (BBL, 2006).

1.2 Background Information

1.2.1 Hydrogeologic Setting

The site is located approximately 17 miles northeast of Gallup, New Mexico, in McKinley County. Located in an arid, remote setting, the site operated as a uranium mill and an unlined tailings pond area from 1977 until early 1982.

The stratigraphy at the site includes the following units in increasing order of depth below grade (MWH, 2004):

- Alluvium
- Dilco Coal Member of Crevasse Canyon Formation
- Upper Gallup Sandstone, comprised of:
  - Zone 3, upper sandstone
  - Zone 2, shale and coal
  - Zone 1, lower sandstone

- Mancos Shale

Mine water in the alluvium percolated into the underlying Zone 3 hydrostratigraphic unit. The mine water discharge, along with the existing saturation, if any, from the alluvium (prior to tailing disposal) is considered by Nuclear Regulatory Commission (NRC) and USEPA to be the background water for Zone 3 (USEPA, 1988; 1998). The background water was later impacted by acidic seepage from mine tailings. The seepage fluids contained elevated (i.e., above background conditions) concentrations of metals, radionuclides, and major ions including sulfate and chloride.

Zone 3 water level data from 1989 through the fourth quarter of 2004 indicate groundwater flows toward the north and northeast, approximately parallel with the eastern limit of Zone 3 saturation (Veolia, 2004). Since the Pipeline Arroyo ceased discharging in 1986, Zone 3 groundwater flow directions have shifted from easterly-to-northerly to north-northeasterly-to-northeasterly as recharge from, and groundwater mounding within, the alluvium to the southwest and west have decreased (Veolia, 2004). The Zone 3 effects from alluvium recharge and extraction-well pumping drawdowns have largely dissipated, and the rates of water level change are mostly very small (Veolia, 2004). Extraction wells temporarily accelerated the local rates of water level decline until the saturated thickness was reduced to less than 25 feet, after which substantial losses in well yield occurred (Earth Tech, 2001).

In January 2004, UNC submitted the results of a study undertaken to evaluate the potential for the covered tailings to still provide recharge to Zone 3 via leakage (US Filter, 2004). The report concluded that it was very unlikely, but recommended that additional investigation be conducted in one area where possible leakage could not be ruled out with certainty. In July 2004, two piezometers (Z3 M-2 and Z3 M-1) were installed north of the northeastern boundary of the Central Cell. Water levels were measured in October 2004 and indicated that the piezometers Z3 M-1 and Z3 M-2 were effectively dry and the southeasterly portion of Zone 3 appeared to be entirely unsaturated (Veolia, 2004). As indicated in Veolia's 2004 annual report, the piezometer installation and groundwater monitoring data collected from 1989 through the fourth quarter of 2004 indicate that neither groundwater recharge nor seepage impact into Zone 3 are occurring (Veolia, 2004).

1.2.2 Remedial History

Several remedial activities have been conducted at the site to address tailings seepage in groundwater. The remedial activities that have taken place in Zone 3 of the site are

briefly discussed below. Additional information may be obtained in the following documents:

- Reclamation Engineering Services, Geohydrologic Report (Canonie Environmental, 1987)
- Record of Decision (USEPA, 1988)
- Memorandum, Change in Zone 3 Saturation, United Nuclear Church Rock Site, Gallup, New Mexico (Earth Tech, 2001)
- Five-Year Review Report, Second Five-Year Review Report for the United Nuclear Corporation Ground Water Operable Unit (USEPA, 2003)
- Annual Review Report – 2004 Groundwater Corrective Action (Veolia, 2004)
- Supplemental Feasibility Study Zone 3 Hydrostratigraphic Unit (MWH, 2004)

Following placement on the National Priorities List (NPL), the USEPA conducted a Remedial Investigation from 1984-1987. On September 30, 1988, the USEPA issued a ROD which presented a site remedy that included pumping impacted groundwater from Zone 3 and disposing of the water in evaporation ponds. On June 29, 1989, the USEPA issued Unilateral Administrative Order (UAO) Docket No. Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) 6-11-89 to UNC requiring UNC to implement the site remedy selected in the ROD. In August 1989, the USEPA-selected remedy of extracting groundwater from Zone 3 and pumping the groundwater to evaporation ponds was implemented; 12 new extraction wells were installed and operated.

The performance of the remedial activities was monitored as described in the USEPA- and NRC-approved Corrective Action Plan (UNC, 1989a), Remedial Design Report (Canonie, 1989a), and Remedial Action Plan (UNC, 1989b). Several modifications were made to the monitoring program and are discussed in the annual reports (Canonie, 1989b, 1990, 1991, 1992, 1993, and 1995; Smith Technology, 1995 and 1996; Rust, 1997; and Earth Tech, 1998, 1999, 2000a, 2002a and 2002c), to adjust the monitoring requirements as the corrective action has taken effect.

On July 30, 1999, NRC approved the decommissioning of 10 Zone 3 wells because they met the decommissioning criteria of producing less than 1 gallon per minute

(gpm). In May 2000, UNC submitted a license amendment request to shut off remaining Zone 3 pumping wells (Earth Tech, 2000b). The request was based on the conclusion that the operation of the Zone 3 pumping wells increased the hydraulic gradient and accelerated the rate of downgradient plume migration. The Zone 3 system was shut down in June 2000 for maintenance and repairs. Prior to the Zone 3 system being brought back on line, the NRC amended the license to shut off the remaining Zone 3 pumping wells (NRC, December 29, 2000 License Amendment). This amendment included a provision for UNC to submit a modified corrective action plan, an application for Alternate Concentration Limits (ACLs), or an alternative to the specific requirements of 10 CFR Part 40, Appendix A if the license standards are not achievable.

At the request of the USEPA, a Supplemental Feasibility Study (SFS) (MWH, 2004) was conducted by MWH on behalf of UNC. The SFS was conducted to develop conceptual alternatives and/or enhancements to the existing remedy that would better contain, and ideally withdraw, seepage-impacted groundwater. The report presented the following information:

- Groundwater modeling of the Zone 3 sandstone unit
- Pilot-hole hydrofracturing study results
- An analysis of remedial alternatives
- Conclusions and recommendations for enhancing or optimizing remedies for Zone 3

UNC is conducting an ongoing, extended pilot investigation to evaluate the suitability of hydrofracturing to enhance the extraction potential within the impacted area of Zone 3 and to prevent seepage-impacted groundwater from migrating off-site (MACTEC, 2003). The pilot investigation included installing and hydrofracturing several new wells. Preliminary data suggested that the new wells were better positioned to capture tailing-impacted water, but hydrofracturing did not improve the yields.

1.3 Pilot Study Strategy

The strategy of the alkalinity stabilization pilot study involved injecting alkalinity-rich groundwater from an unimpacted aquifer (Mill Well water [amended with sodium bicarbonate for increased alkalinity]) into areas where seepage-induced acidic

conditions exist in the Zone 3 aquifer. The injected water (fixiviant) would flow through the Zone 3 formation to recovery wells where the fixiviant would be pumped to the surface for treatment and disposal. The alkaline solutions were intended to neutralize the acidic water along a mixing front and ultimately displace the seepage-impacted groundwater. Recovery wells within the pilot test well field were designed to remove the seepage-impacted groundwater and the water that was mixed with the injected solutions. It was anticipated that the increased pH associated with the injected alkaline groundwater would reduce migration and/or immobilize constituents of concern (COCs) via chemical precipitation and surface adsorption reactions.

1.4 Objectives

The objectives of the pilot study were:

- To assess the effectiveness of the proposed remedial approach
- To provide the information needed to subsequently prepare a full-scale design, if groundwater remediation via injection and extraction is deemed a viable and effective remedy

2. Description of Pilot Study Activities

2.1 General

The pilot study was performed within the seepage-impacted area and utilized some of the wells already in place, as well as new wells. Figure 1 presents the pilot study location in relation to the general site layout, and a detailed layout is shown on Figure 2.

Existing wells 0608, 0517, 0518 were used in the pilot study along with the following newly installed wells IW-1, IW-2, IW-3, IW-4, EW-1, and EW-2. The pilot test well field was a nine-spot pattern, which built upon the five-spot layout traditionally used by the in-situ leach (ISL) industries, with the addition of four hydraulic-control extraction wells on the perimeter of the well field.

The pilot study well field included a central extraction well (EW-1) surrounded by four injection wells (IW-1 through IW-4). The central extraction well provided the primary monitoring location to evaluate the effectiveness of the technology in terms of removing and/or immobilizing the target COCs. The four surrounding injection wells provided a means to inject fixiviant. In addition, the injection wells were designed to hydraulically isolate the central extraction well from the surrounding groundwater flow system and provide a controlled, closed hydraulic system for monitoring the effectiveness of treatment over time during the pilot test. The four outer extraction wells (wells 608, 517, 518, and EW-2) were intended to provide overall hydraulic control during the pilot study. The pilot study calculations were based on the hydraulic parameters in the Reclamation Engineering Services Geohydrologic Report (Canonie Environmental, 1987) and the Supplemental Feasibility Study (MWH, 2004), with extraction and injection wells screened over the entire saturated thickness of Zone 3; drawdown to within 1 foot of the base of Zone 3 inside each extraction well; and assumed well efficiency of 50 percent. The pilot study well field design is summarized as follows:

- 9 wells (3 existing, 6 new), relative spacing and locations shown on Figure 2
- 5 extraction wells with a combined design rate of approximately 4.0 gallons per minute (gpm)
- 4 injection wells with a combined design rate of 3.3 gpm
- designed net pumping rate = 0.7 gpm (net extraction to maintain hydraulic control)

- time for initial breakthrough of injected water at central extraction well estimated as 14 days

- time for one complete pore volume exchange between injection wells and central extraction well estimated as 37 days

Presented below is a description of the pilot study activities that were conducted prior to and during the pilot study.

2.2 Pilot Study Setup

2.2.1 Installation of New Wells

UNC subcontracted the installation of six new wells, which included four injection wells (IW-1, IW-2, IW-3, and IW-4) and two extraction wells (EW-1 and EW-2). The locations of these wells are shown on Figure 2.

The wells were installed using similar well installation practices used during previous well installations at the site. The injection well installation procedure included the following steps:

- Drilling a rotary hole of 12 ¼-inch diameter to a depth determined from previous geologic data obtained from existing wells 0517, 0518, and 0608, at least 10 feet into the Gallup (Zone 3) Sandstone

- Setting a capped 6-inch diameter Schedule 80 PVC casing and grouting it from the bottom upward using a neat cement

- Drilling out the cap with a 5 ½-inch rotary bit and finishing the hole as an open borehole to just below the top of the coal seam at the base of Zone 3

The extraction well installation procedure included the following steps:

- Drilling a rotary hole of 12 ¼-inch diameter to the depth of the coal seam at the base of Zone 3

- Setting a 6-inch diameter, 20-foot long, Schedule 80 PVC slotted well screen at the bottom of the borehole, with PVC casing to ground surface

- A sandpack was placed in the annulus from the bottom of the borehole to approximately 5 feet above the top of the screen, 5 feet of bentonite was placed above the sand, and the remainder of the annulus was sealed with bentonite slurry to the ground surface

UNC assisted in determining the final design and installation approach for the injection and extraction wells.

2.2.2 Modification of Existing Wells

Three existing wells (0517, 0518, and 0608) were converted to extraction wells (EW-3, EW-4, and EW-5, respectively). ARCADIS BBLES installed piping, fittings, stainless steel bladder pumps, and instrumentation to outfit these existing wells to function as extraction wells.

2.2.3 Installation of Pilot Study Equipment

ARCADIS BBLES installed the following pilot study equipment:

- The new wells (IW-1, IW-2, IW-3, IW-4, EW-1, and EW-2) were outfitted to function as either injection or extraction wells, as required, using the necessary piping, fittings, equipment, and instrumentation. Pneumatic piston pumps were installed in extraction wells EW-1 and EW-2.

- An 18,000-gallon metal storage tank was staged at the pilot study area to store groundwater conveyed from the Mill Well, to be used for injection. The location of the storage tank is shown on Figure 2. The tank contained multiple top-mounted electric mixers.

- Piping, flow control valves, and flow meters were installed between the storage tank and the four injection wells, providing the means for the amended Mill Well water to be gravity-injected from the storage tank to the injection wells.

- Conveyance piping was installed from the five extraction wells to a pre-existing surge tank used for discharge to an on-site evaporation pond. The piping from the extraction wells combined into one header near EW-2 that was connected to an existing 6-inch buried pipe, which conveyed extracted groundwater to the surge tank located to the south of the pilot study area.

- Above and below-ground conveyance piping was installed from the Mill Well water supply to the injection water storage tank.

2.2.4 Specific Capacity Tests

On August 23 and 24, 2006, prior to commencement of the pilot study, ARCADIS BBL performed specific-capacity tests at each of the nine wells within the pilot study well field to provide additional hydraulic conductivity data for the pilot study area. The average depth to water was approximately 97 feet, and the average Zone 3 saturated thickness was approximately 15 feet at the 9 pilot-test wells during the specific capacity tests. Each test well was pumped at a relatively steady rate of between 0.1 and 0.4 gpm, and the water level changes in the tested well were measured to characterize the drawdown versus time. These data were then plotted and analyzed for transmissivity and K using the Cooper-Jacob straight-line method. In calculating K values, the volume of water removed from the well and (where applicable) the sand pack was subtracted from the pumped volume to correct for the actual flow rate from the formation. The results of the specific capacity tests are presented in Section 3.2.

2.3 Pilot Study Implementation

2.3.1 Conveyance of Mill Well Water

During the pilot study implementation, groundwater from the Mill Well was conveyed to the injection water storage tank via piping installed and maintained by ARCADIS BBLES. Water was also trucked from the Mill Well to the storage tanks during periods when freezing conditions restricted the flow within the conveyance pipe. The injection water storage tank was filled, and the water level was maintained such that the tank continuously contained between 5,000 and 15,000 gallons of amended Mill Well water.

2.3.2 Injection and Extraction of Mill Well Water

To achieve the desired result of enhancing the alkalinity of the injection water, ARCADIS BBLES manually added sodium bicarbonate to the Mill Well water in the injection water storage tank. Sodium bicarbonate was added to maintain the design ratio of 16.6 pounds of sodium bicarbonate per 1,000 gallons of Mill Well water. When the water level in the storage tank reached the low level mark, Mill Well water was added to the tank, and an appropriate amount of sodium bicarbonate was added to the water to maintain the design ratio. The water in the storage tank was mixed for a period

of approximately 30 minutes or until the mixture was visibly clear (sodium bicarbonate went into solution).

The injection/extraction activities began on October 24, 2006 and ceased on February 15, 2007.

Injection of Mill Well Water

Due to low injection well efficiency, the amended Mill Well water could not be injected at a constant flow rate as originally designed. The amended Mill Well water was injected into the Zone 3 groundwater via injection wells IW-1, IW-2, IW-3 and IW-4 twice daily. In the early morning, ARCADIS BBLES measured the water level in each injection well. These levels were typically 40 to 50 feet below the ground surface. At that time, the injection valves were opened and the in-line flow meters were allowed to reach the minimum required flow rate (0.25 gpm). Amended Mill Well water was injected into each well until it was filled to the top of casing (due to the poor infiltration into the formation, each well would fill up with water in 1 to 2 hours). The injected water was then allowed to slowly infiltrate, on average approximately 2 to 3 feet of water level decline per hour within the injection well casing During the late afternoon, the water levels were measured again. At that time, the injection valves were opened, and the wells were "topped off" for the overnight period.

Extraction of Zone 3 Water

Extraction wells EW-1 and EW-2 contained pumps that operated based on a "bubbler" type level control system. The water level in the wells was maintained by a bubbler tube approximately 2.5 feet above the well bottoms. The water level in the well was controlled within a 5-inch span at that level (pump on 15 inches above bottom of bubbler tube, pump off 5 inches above bottom of bubbler tube).

Extraction wells EW-3, EW-4, and EW-5 contained bladder pumps that were set up to operate on timers to maintain water level in the well at approximately the same level as EW1 and EW-2.

The hydraulic head in the injection and extraction wells was monitored during the pilot study. The elapsed time (minutes) for each interval of activity and the volume of water (gallons) injected or extracted at each location daily were recorded or calculated as appropriate. These data were used to calculate the injection and extraction rates. The

injection and extraction rates as well as the total volume of water injected into the wells are discussed in Section 3.2.

2.3.3 Groundwater Monitoring Activities

The water from the outlet of the injection water storage tank and from the extraction wells was monitored during the pilot study. Samples were collected at frequent intervals (minimum of once per week) to monitor the quality of the fixiviant and to identify arrival and breakthrough of the fixiviant at the extraction wells. The samples were analyzed in the field for pH, specific conductance, and chloride.

ARCADIS BBLES used a portable water quality meter to measure the pH and the specific conductance of the samples. Chloride test strips were used to analyze the samples for chloride.

The results of the groundwater monitoring activities are described in Section 3.

2.3.4 Groundwater Sampling Activities

The groundwater sampling activities consisted of two groundwater sampling events, a baseline sampling event and a final sampling event. The work scope indicated that the pilot study would consist of three events, one at the beginning of the pilot study (baseline), one following the replacement of the first pore volume, and a third following the replacement of the second pore volume. Breakthrough of the fixiviant at the extraction wells (and pore space replacement) was not observed during the pilot study. As a result, the final sampling event was conducted in lieu of the two sampling activities associated with the pore space replacement.

A description of the two groundwater sampling events is presented below.

<u>Baseline Groundwater Sampling Event</u>

On October 19 and 26, 2006, ARCADIS BBLES conducted baseline groundwater sampling to determine the pre-modified chemistry of the groundwater. One sample was collected from each of the five extraction wells and one sample was collected from the amended Mill Well water in the injection water storage tank. Quality assurance/quality control (QA/QC) samples including a blind duplicate, matrix spike, and matrix spike duplicate, were also collected. The groundwater samples were analyzed for the

chemical constituents included in Table 1 by ACZ Laboratories in Steamboat Springs, Colorado.

Final Groundwater Sampling Event

On February 20, 2007, ARCADIS BBLES conducted final groundwater quality sampling at the conclusion of the pilot study. One sample was collected from each of the five extraction wells and one sample was collected from the amended Mill Well water in the injection water storage tank. QA/QC samples including a blind duplicate, matrix spike, and matrix spike duplicate, were also collected. The groundwater samples were analyzed at ACZ Laboratories for the same constituents as the baseline groundwater sampling event.

2.4 Well Underreaming

During the pilot study, observed injection rates were significantly lower than anticipated in the pilot study design (see Section 3.2 for further discussion on the injection rates). Based on the low injection rates, ARCADIS BBL's subcontractor, HydroGeologic Services, Inc., underreamed the four injection wells to increase the well diameters in an effort to increase the injection rates. On January 9, 2007, the wells were each underreamed until the diameter at the bottom portion of the well increased from approximately 5.5 inches to approximately 12 inches. During the underreaming activities a white milky substance was observed in the Zone 3 formation cuttings.

2.5 Collection of Gallup Formation Cores

Based on the low injection and extraction rates observed during the pilot study, as well as the white milky substance observed during underreaming activities, ARCADIS BBL retained Dr. Bruce Selleck, of Colgate University, to evaluate on-site cores to identify potential causes of the low injection and extraction rates. Dr. Selleck studied three Gallup Formation cores from the site to examine the mineralogy and qualitatively evaluate the permeability of the formation.

On March 22, 2007, new boring CDNEW-1 was drilled within the alkalinity pilot study area, approximately 6 feet east of EW-1. The core collected at CDNEW-1 penetrated the entire thickness of the Zone 3 Gallup Formation for a total boring depth of 110 feet. The boring was drilled using mud rotary methods from grade to approximately 70 feet below the ground surface; the interval from approximately 70 to 110 feet below the ground surface was cored.

Samples were also collected from existing cores CCHF-2 and RW-13C, which were stored at the Church Rock site. CCHF-2 was previously drilled through the Gallup Formation to the northwest of the area affected by the acidified leachate plume. RW-13C was previously drilled at the northern margin of the leachate plume.

The samples from the Gallup Formation cores that were examined consisted of chips that preserved the original grain-pore relationships. The samples were imaged using a Scanning Electron Microscope (SEM), which utilized a JEOL 6300LV system. A PGT Energy Dispersive X-Ray Spectral (EDS) analyzer and Spirit acquisition/analysis software were used to determine the elemental composition of the mineral phases. The results of the core evaluation are discussed in Section 3.

3. Pilot Study Results

3.1 Specific Capacity Test Results

The K value calculated from the specific capacity test for well 0608, 8.8×10^{-5} cm/sec, was approximately 7 times lower than the value of 5.9×10^{-4} cm/sec previously reported for the same well approximately 20 years earlier by Canonie Environmental (1987). Wells 517 and 518 did not produce calculable K values because the drawdown exceeded the expected magnitude based on well storage and the total pumped volume. The geometric mean hydraulic conductivity value for the 7 other wells within the 9-spot pilot test well field was 5×10^{-5} cm/sec, which is 10 times lower than assumed in the pilot study design.

3.2 Groundwater Monitoring Results

The injection and extraction rates were monitored daily, and the results are presented in Graphs 1 and 2, respectively. The injection rates ranged from approximately 0.016 to 0.16 gpm with a maximum combined rate of 0.56 gpm. The maximum combined injection rate was approximately 6 times less than the design injection rate of 3.3 gpm, and the average injection rate was almost 30 times less than the design injection rate. The extraction rates ranged from 0 to approximately 0.25 gpm with a maximum combined rate of 0.28 gpm. The maximum extraction rate noted during the pilot study was approximately 20 times less than the design extraction rate of 4 gpm. The total volume injected was 33,928 gallons. The total volume extracted was 28,243 gallons. Tables 4 and 5 present the injection and extraction rates recorded during the pilot study.

Monitoring samples were collected at a minimum of once per week and analyzed in the field for pH, specific conductance, and chloride. The pH, specific conductance (conductivity) and chloride results are presented in Graphs 3, 4 and 5, respectively. As shown on the graphs, the values for these parameters remained nearly constant in each well throughout the pilot study.

3.3 Groundwater Sampling Results

The analytical laboratory results for the groundwater samples collected during the baseline and final groundwater sampling events are presented in Tables 2 and 3, respectively. The pre- and post-pilot study groundwater sampling results indicate that there was no significant change in the concentrations of the analyzed constituents.

3.4 Gallup Formation Core Evaluation Results

The core evaluation results are summarized in *Petrologic Analysis of Gallup Zone 3 Sandstone Scanning Electron Microscopy and Energy Dispersive X-Ray Analysis, Church Rock Site, NM*, included as Attachment A.

Quartz, potassium feldspar, and kaolinite were the predominant mineral phases observed in the samples. Abundant finely crystalline kaolinite was observed in samples from CDNEW-1 that lie within the zone of saturation. Based on the SEM analysis, the pore throats in the saturated zone of CDNEW-1 appear to be clogged with fine kaolinite clay. Samples from the unsaturated zone and those from the other cores did not contain the finely crystalline kaolinite. The kaolinite clay effectively clogs the pore space of the sandstone, thus significantly limiting the potential for water flow through this media. The presence of kaolinite in the pore space within the Zone 3 formation at the pilot study location is the likely reason the pilot study system was unable to inject and extract the fixiviant at the design flow rate. Section 4 presents a detailed analysis of the results.

4. Pilot Study Evaluation

4.1 Hydrogeologic Evaluation of Pilot Study

This section presents an evaluation of hydrogeologic conditions within the pilot study well field area. Of particular interest is the difference between the pumping rates that were estimated as part of the original pilot study design and those that were observed in the field during pilot study implementation. Contrary to the design calculations, the empirical results of the pilot study indicates that injecting at a rate required to improve groundwater quality within the zone of seepage impacts is not feasible.

4.1.1 Pre-Pilot Study Conditions

The pre-pilot study conditions were evaluated as part of the pilot study design and also during specific capacity testing of the pilot study well field prior to pilot study startup.

Original Design

The key parameter affecting pumping rates is the hydraulic conductivity (K). The pilot study design assumed a hydraulic conductivity value of $5x10^{-4}$ cm/sec based on test results reported in the Reclamation Engineering Services Geohydrologic Report (Canonie Environmental, 1987; Table 2.2) and groundwater flow modeling reported in the Supplemental Feasibility Study (MWH, 2004). Historical K values measured in the vicinity of the pilot study well field included well 0608 ($5.9x10^{-4}$ cm/sec) and well USEPA 15 ($1.4x10^{-3}$ cm/sec) (Canonie Environmental, 1987). Groundwater flow modeling of Zone 3 included K values in the range of $3.4x10^{-5}$ to $1x10^{-3}$ cm/sec. Based on these numbers, the design K value of $5x10^{-4}$ cm/sec was assumed to be representative of Zone 3 within the pilot study area.

Assuming a total saturated thickness of 14 feet, available drawdown of 13 feet, and 50 percent well efficiency, the total extraction rate for the five extraction wells in the 9-spot pilot study pattern was predicted to be approximately 4 gpm. Similarly, assuming an inverse potentiometric change (13-foot water level rise and 50% efficiency) in each of the 4 injection wells in the 9-spot pattern, the total injection rate was estimated as 3.3 gpm. Based on the anticipated extraction rate at the center of the pilot study grid (1.05 gpm at well EW-1), it was estimated that a pumping period of 37 days would be required to achieve one pore volume exchange within the square bounded by the four injection wells. Also, based on the design gradients between the injection wells and the

central extraction well (EW-1), a travel time of 14 days was estimated for initial breakthrough of injected water at the central extraction well.

Pre-Pilot Study Specific Capacity Tests and Revised Travel Time Estimates

The new K value calculated for well 0608, 8.8×10^{-5} cm/sec, was approximately 7 times lower than the value of 5.9×10^{-4} cm/sec reported for the same well approximately 20 years earlier by Canonie Environmental (1987). Wells 517 and 518 did not produce calculable K values because the drawdown exceeded the expected magnitude based on well storage and the total pumped volume. The geometric mean hydraulic conductivity value for the 7 other wells within the 9-spot pilot test well field was 5×10^{-5} cm/sec, which is 10 times lower than assumed in the pilot study design. Based on this revised K value, the revised total extraction rate was estimated as 0.4 gpm (including an estimated 0.1 gpm at central extraction well EW-1), and the revised total estimated injection rate was 0.33 gpm (assuming 13 feet of water level rise in the injection wells). These numbers still assume 50 percent efficiency of injection and extraction wells. The time estimates to achieve 1 pore volume exchange and initial breakthrough were revised to 370 days and 140 days, respectively.

4.1.2 Pilot Study Results

Pilot study pumping rate data were collected over the period from October 24, 2006 through February 15, 2007 (total of 114 days). Pilot study pumping rates (injection and extraction) are summarized in Tables 4 and 5 and Graphs 1 and 2. Both the injection and extraction rates were considerably lower than the original design rates, or even the revised rates calculated using the pre-pilot K data measured at the pilot-test well field.

Extraction Rates

The average overall extraction rate was approximately 0.17 gpm, versus the initial design rate of 4 gpm or the revised total extraction rate estimate of 0.4 gpm. Nearly all of the extracted water was produced by central extraction well EW-1. Well EW-1 initially produced approximately 0.2 gpm for the first month of operation. Its rate generally declined to between 0.1 and 0.15 gpm during the last few weeks of the test, which was similar to the revised estimate of 0.1 gpm. The other four extraction wells demonstrated negligible yield during the pilot study, and therefore did not contribute in terms of hydraulic control or circulation of injected water for the purpose of treatment.

Injection Rates

The injection well performance was also very poor in comparison to expectations based on hydraulic test data, and showed a generally declining rate during the pilot study. The average overall injection rate was approximately 0.21 gpm, versus the initial design rate of 3.3 gpm or the revised estimate of 0.33 gpm. The injection rates were much more uniform than the extraction rates, however. Each of the four injection wells injected between 19 and 27 percent of the total injected volume. The uniformity of the injection rates suggests that the pilot study hydraulics were relatively symmetrical, as assumed during the pilot study design. The injection well efficiency, however, was extremely low. Rather than the 13-foot water level rise in each injection well assumed during design, due to the extremely low rate of injection, each injection well was "topped off" at ground surface, an approximately 97-foot average rise in the water levels in the injection wells. The injected water was then allowed to slowly infiltrate, on average approximately 2 to 3 feet of water level decline per hour within the injection well casing, and then replenished by topping off the injection wells again. The design calculations had assumed that the injection wells would have an efficiency of 50 percent. The actual efficiency of the injection wells can be recalculated as:

$$E = 0.50\ (Q_{actual} / Q_{pred})\ (s'_{pred} / s'_{actual}),$$

where Q_{actual} is the actual injection rate (0.21 gpm), Q_{pred} is the predicted injection rate (0.33 gpm), s'_{pred} is the predicted water level rise in the injection wells (13 feet), and s'_{actual} is the actual water level rise (assumed to be approximately 75 feet on average, accounting for "topping off" and infiltration periods). Based on these numbers, the estimated average injection well efficiency during the pilot study was approximately 6 percent. After underreaming, the injection rates increased slightly at first, but then declined to rates similar to those prior to underreaming (approximate average of 0.2 gpm). Thus, underreaming does not appear to have produced any overall improvement in injection well efficiency.

Flushing Timeframes

The travel time estimates, which were based on re-calculated pumping rate estimates, using pre-pilot specific capacity test results, suggested that the extraction rate at the central extraction well (EW-1) may be approximately 0.1 gpm. At this flushing rate, the

time for 1 pore volume exchange, or initial breakthrough of injected water at the central extraction well, was estimated as 370 and 140 days, respectively.

In contrast, the actual pilot study extraction rate at EW-1 was approximately 0.17 gpm. At this rate, the time for 1 pore volume exchange, or initial breakthrough of injected water at the central extraction well, would be estimated as 220 and 80 days, respectively. Given the approximately 114-day duration of the pilot test, it is possible that some of the injected water migrated to the central extraction well. The geochemical evaluation of the pilot test discussed below, however, suggests little change in pumped water quality.

These calculations, in combination with the low pumping rates, extremely low injection well efficiency, and small scale of the pilot study target zone, indicate that the pilot-tested technology of in-situ alkalinity stabilization is infeasible for full-scale aquifer restoration.

4.2 Geochemical Evaluation of Pilot Study

Review of water quality data for groundwater samples collected before and after the pilot study indicates that few, if any, meaningful changes are apparent in groundwater chemistry. These results are consistent with findings from the pilot study that the permeability of Zone 3 in the test area is much less than anticipated, as evidenced by the minimal pumping rates achieved in both injection and extraction wells. Interpretation of the geochemical aspects of the pilot study, therefore, focuses on reactions likely contributing to the reduced permeability within the Zone 3 sandstone formation.

Results of the petrologic analysis of core samples from the Zone 3 sandstone indicate that feldspar dissolution and kaolinite precipitation have modified porosity and permeability within the area of seepage impacts. It is important to assess the time frames over which such reactions have occurred, as well as the potential magnitude of such reactions with respect to modifying and reducing the hydraulic properties of Zone 3.

ARCADIS BBL performed kinetic modeling of potassium feldspar (Kspar) dissolution and kaolinite precipitation, using the geochemical program PHREEQC (Parkhurst and Appelo, 1999). The approach applied data collected during the pilot study from extraction well EW-1. This well had the best production during the test, and also had an unusual pH trend (see Graphs 6 and 7), whereby it decreased to about 3.5, and then increased to a roughly constant pH value of approximately 5.3 throughout the testing

period. It is suspected that the initial higher pH in the well may have reflected water used during the drilling, and the initial decreasing pH trend identified recovery of the true formation water.

Alteration of Kspar to kaolinite can be described by the following reaction (e.g. Appelo and Postma, 2005, p. 376):

$$2K(AlSi_3)O_8 + 2H^+ + 9H_20 \rightarrow Al_2Si_2O_5(OH)_4 + 2K^+ + 4H_4SiO_4$$

According to this reaction, hydrogen ions will be consumed, which will promote a pH increase, along with increasing concentrations of dissolved potassium and silica. The primary driver of this overall reaction will be the rate at which Kspar dissolves. An equation describing the rate of Kspar dissolution that can be simulated using the PHREEQC program includes the following (Merkel et al, 2005):

$$R_{Kspar} = k\frac{A}{V}\left(\left(\frac{m_t}{m_0}\right)^{0.67}\left(1-\left(\frac{IAP}{K}\right)_{Kspar}\right)\right)$$

where:

R_{Kspar} = overall dissolution rate (mol/L/s)

k = kinetic rate constant (mol/cm^2/s)

A = initial surface area (cm^2)

V = volume of solution (L)

m_t = mineral mass at time t (mol)

m_0 = initial mineral mass (mol)

IAP = ion activity product (dimensionless)

K = equilibrium constant (dimensionless)

Aquifer parameters for PHREEQC simulations, which include input needed for variables identified in the above equation, included the following:

k = 1 x10-16 mol/cm^2/s

porosity = 0.15

bulk density = 2.25 g/cm^3

Kspar = 10% of solids, assuming that Kspar grains consist of cubes possessing 0.1 mm sides

Water quality of the initial solution was based on analytical results for the pre-pilot study sampling event, with the exception of dissolved silica, which was only analyzed during the final sampling event. Equilibrium phases allowed to precipitate if saturated according to PHREEQC calculations included: kaolinite; gibbsite, $Al(OH)_3$; and potassium mica, $KAl_3Si_3O_{10}(OH)_2$.

Graphs 6 and 7 present comparisons between observed pH in EW-1, and model-predicted pH, assuming an initial pH of 3.5 for the onset of Kspar dissolution. The yellow vertical line indicates when kaolinite precipitation would begin under the conditions simulated. Graph 7 also contains pumping rates for EW-1, which appears to indicate a greater reduction in pumping rates around the predicted onset of kaolinite precipitation. It is likely that the overall similarity between the observed and modeled trend in pH is more important in explaining reactions occurring during the test, rather than exact agreement in pH, since other reactions not simulated in the modeling probably influence the observed pH values.

Graphs 8 through 10 identify cumulative changes in mass and volume of Kspar and kaolinite, which provide insight about how fast and to what extent porosity and permeability alterations may occur in areas with seepage impacts. Graph 9 also shows the predicted reaction for a longer time frame than the pilot study, which shows pH increasing up to approximately 4.5.

Graph 10 illustrates how the predicted mass changes may relate to changes in porosity, or more importantly, rearrangement of the pore throats through Kspar dissolution and kaolinite precipitation, which likely results in reduced permeability.

Presented in this graph are the cumulative volume changes (in cm^3) resulting from Kspar dissolution and kaolinite precipitation according to the model simulations. These data indicate that in less than 2 years, more than 4 times (0.68 cm^3) the original porosity (0.15 cm^3) precipitates. This suggests that sufficient mass/volume can easily be rearranged over relatively short time spans to plug pore throats, and greatly reduce withdrawal rates, as well as migration of seepage-impacted groundwater.

The net-change in pore volume indicated in Graph 10 suggests that total porosity may actually increase in response to the simulated dissolution/precipitation reactions. Such a process may appear counterintuitive, as one typically expects increased porosity to result in enhanced permeability. Examination of the SEM microphotographs (e.g. Figure 11 of Attachment A - *Petrologic Analysis of Gallup Zone 3 Sandstone Scanning Electron Microscopy and Energy Dispersive X-Ray Analysis, Church Rock Site, NM,*), however, suggests that significant porosity exists throughout the mass of fine-grained kaolinite particles that clog the original pore throats of the Zone 3 sandstone. It is likely that the distribution and interconnectedness of pores is more important to the permeability/production of the modified sandstone than the total porosity.

Historic observations at the site within the impacted area of the Zone 3 aquifer are consistent with the findings of this pilot study. According to Mr. Larry Bush of UNC, a milky-white clay-like substance was observed during historic pump tests in the wells EPA-14 and RW-16. In 2004 the milky-white clay-like substance was collected from well EPA-14 and analyzed using the x-ray fluorescence (XRF) and x-ray diffraction (XRD). The results of the analysis are provided in Attachment B. The results indicated that the milky-white clay-like substance consisted almost entirely of "amorphous" (non-crystalline) alumino-silicate material. The formation of the "amorphous" (non-crystalline) alumino-silicate can result in the reduction of porosity as well as reduced permeability.

5. Summary and Conclusions

The pilot study was conducted over the period from October 24, 2006 through February 15, 2007. The injection and extraction rates observed during the pilot study were not the expected rates, and the total amount of cumulative extraction was considerably lower than calculated. As a result, the estimated travel time between the injection wells and extraction wells became prohibitive with respect to pore volume extraction rates, and the pilot test was terminated.

As discussed in Section 4, the K value for Zone 3 appears to have been reduced by the alteration of the rock by the acidic groundwater plume. Although original design calculations had suggested that groundwater injection and extraction rates may render plume remediation feasible, these calculations were based in part on hydraulic testing conducted approximately 20 years ago (Canonie Environmental, 1987). The new K data measured at the pilot study well field suggested that the present K value is approximately 10 times lower than previously reported.

The lower than expected K values, extremely low injection well efficiency, and negligible yield from 4 of the 5 extraction wells may be attributed to alteration of the Zone 3 aquifer minerals by the acidic leachate that comprises the groundwater plume. Data obtained as part of the pilot study support the interpretation that kaolinitie, generated by feldspar alteration, has largely "clogged" the pore spaces within Zone 3. The presence of clay-like material has been observed during drilling within the seepage impacted zone, and when the injection wells were underreamed in an effort to improve injection rates. Geochemical sampling and petrologic analysis conducted on the cores, and geochemical reaction models, further support the inference that the acidic groundwater plume has caused kaolinite production and "clogging" of the Zone 3 aquifer.

Based on information presented above, it would take 10 times longer to accomplish remedy goals than was hypothesized. Using what might have been envisioned as an approximate 5 year remedy enhancement could actually take 50 years or more.

Alternate locations for the in-situ alkalinity stabilization technology within the impacted areas of the Zone 3 aquifer were evaluated following the completion of the pilot study. ARCADIS BBL's evaluation indicated that application of the in-situ alkalinity stabilization technology at different locations within the impacted area of the Zone 3 aquifer would not achieve significant results based on the current hydrogeologic and geochemical properties of the impacted aquifer.

6. Acronyms and Abbreviations

ACLs – Alternate Concentration Limits

BBL – Blasland, Bouck & Lee, Inc.

CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act

COC – Constituent of Concern

EDS – PGT Energy Dispersive X-Ray Spectral

gpm – gallons per minute

ISL – In-Situ Leach

K – Conductivity

Kspar – kinetic modeling of potassium feldspar

n – Porosity

NPL – National Priorities List

NRC – Nuclear Regulatory Commission

QA/QC – Quality Assurance/Quality Control

ROD – Record of Decision

SEM – Scanning Electron Microscope

SFS – Supplemental Feasibility Study

UAO – Unilateral Administrative Order

UNC – United Nuclear Corporation

USEPA – United States Environmental Protection Agency

XRD – X-Ray Diffraction

XRF – X-Ray Fluorescence

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ARCADIS BBL

Tables

TABLE 1

UNC CHURCH ROCK
GALLUP, NEW MEXICO

IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

2004 AVERAGE WATER QUALITY

			Formation:	Zone 3	Zone 3	Zone 3	Dakota
			Water Type:	Seepage-Impacted (PHREEQC Modeled)	Seepage-Impacted (Pilot Test)	Background	Injectant
				Monitoring Wells			
Constituent	Units	NRC Standard	EPA Standard	613	517	NBL-01	Mill Well 1
Field pH	SU	NA	NA	2.82	4.28	6.44	8.6
Lab TDS	mg/l	NA	4800	12950	4820	3800	2180
Ca	mg/l	NA	NA	462	502	662	16.1
Mg	mg/l	NA	NA	734	446	202	4.2
Na	mg/l	NA	NA	307	156	131	716
K	mg/l	NA	NA	1.1	12.2	7.7	3.6
HCO3	mg/l	NA	NA	< 1	< 1	288	196
SO4	mg/l	NA	2125	9523	3213	2315	1180
Chloride	mg/l	NA	250	170	48	37	154
NH4 as N	mg/l	NA	NA	296	11	0.46	0.65
NO3 asN	mg/l	NA	190	11.9	0.81	< 0.10	0.02
Chloroform	mg/l	0.001	NA	0.13	0.005	< .001	NA
Al	mg/l	NA	5	744	7	< 0.1	<0.06
As	mg/l	0.05	0.05	< 0.001	< 0.001	0.79	<0.0005
Be	mg/l	0.05	0.017	0.17	< 0.01	< 0.01	<0.004
Cd	mg/l	0.01	0.01	0.030	0.005	< 0.005	0.0001
Co	mg/l	NA	0.05	1.84	0.65	0.073	<0.02
Pb	mg/l	0.05	0.05	< 0.05	< 0.05	< 0.05	0.034
Mn	mg/l	NA	2.6	55.4	6.9	2.8	0.04
Mo	mg/l	NA	1	< 0.1	< 0.1	1.75	<0.02
Ni	mg/l	0.05	0.2	1.70	0.58	0.117	0.07
Se	mg/l	0.01	0.01	< 0.001	< 0.001	< 0.001	0.002
V	mg/l	0.1	0.7	2.43	< 0.1	< 0.1	<0.01
U	mg/l	0.3	5	1.48	0.0557	0.14	0.0081
Rad-226	pci/l	NA	NA	10.7	7.9	7.1	1.7
Rad-228	pci/l	NA	NA	< 1.0	10.5	3.9	0.69
Rad Total	pci/l	5	5	10.7	18.3	10.9	2.39
Th-230	pci/l	5	NA	411	0.325	< 0.2	-0.14
Pb-210	pci/l	1	NA	< 1.0	< 1.0	< 1.0	NA
Gross Alpha	pci/l	15	15	33.8	14.2	8.1	16

Notes:
1. mg/l = milligrams per liter.
2. NA = not applicable.
3. pci/l = pico curies per liter.
4. SU = standard units.
5. < = constituent was not detected at concentrations above the detection limit.
6. The concentrations for monitoring wells 613, 517, and NBL-01 represent the average of 2004 data. The Mill Well 1 sample was collected on February 28, 2006.

TABLE 2

UNC CHURCH ROCK
GALLUP, NEW MEXICO

IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

BASELINE WATER QUALITY

				Sample ID								
Constituent	Units	NRC Standard	EPA Standard	INJPS1	EW1PS1	DUP1	EW1PS1F	EW2PS1	EW2PS1F	517PS1	518PS1	608PS1
Lab pH	SU	NA	NA	8.6 H	5.1 H	3.8 H	NA	5.8 H	NA	3.7 H	3.3 H	3.3 H
Lab TDS	mg/l	NA	4800	3550	6240	6190	NA	4770	NA	5030	7230	12800
Ca	mg/l	NA	NA	16.2	447	445	432	325	321	446	402	408
Mg	mg/l	NA	NA	3.3	673	669	647	397	395	452	664	699
Na	mg/l	NA	NA	1230	147	146	140	312	312	142	125	289
K	mg/l	NA	NA	3.4	19.1	19.5	18.0	14.8	14.6	10.2	16.6	8.7
HCO3	mg/l	NA	NA	1280	< 2	< 2	NA	7 B	NA	< 2	< 2	< 2
SO4	mg/l	NA	2125	1190	4170	4190	NA	3080	NA	3400	4210	4290
Chloride	mg/l	NA	250	145	21	22	NA	69	NA	39	26	123
NH4 as N	mg/l	NA	NA	0.61	4.28	4.31	NA	2.15	NA	7.72	6.70	217
NO3 as N	mg/l	NA	190	0.04 B	< 0.02	< 0.02	NA	< 0.02	NA	< 0.02	< 0.02	11.3
Chloroform	mg/l	0.001	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Al	mg/l	NA	5	< 0.06	8.29	10.1	7.49	2.52	1.75	2.85	52.70	713
As	mg/l	0.05	0.05	< 0.0005	0.025	0.023	0.021	0.014	0.0072	< 0.0005	0.0062	< 0.01
Be	mg/l	0.05	0.017	< 0.004	0.04	0.039	0.038	0.010 B	0.009 B	0.002 B	0.056	0.276
Cd	mg/l	0.01	0.01	< 0.0001	< 0.0005	0.0008 B	< 0.0005	0.0022 B	0.0020	0.0055	0.0019	0.024
Co	mg/l	NA	0.05	< 0.02	0.66	0.66	0.65	0.60	0.59	0.70	0.95	1.66
Pb	mg/l	0.05	0.05	< 0.0001	0.0372	0.04	0.0366	0.0386	0.0002 B	0.0061	0.0065	0.167
Mn	mg/l	NA	2.6	0.16	11.700	11.700	11.300	7.910	7.850	7.780	14.800	50.500
Mo	mg/l	NA	1	0.02 B	0.01 B	0.02 B	< 0.01	0.03 B	0.03 B	< 0.01	0.02 B	0.02 B
Ni	mg/l	0.05	0.2	< 0.02	0.81	1.19	0.78	1.11	1.09	0.66	0.83	1.49
Se	mg/l	0.01	0.01	0.0096	< 0.0005	< 0.0005	< 0.0005	< 0.0005	0.0014	< 0.0005	0.0006 B	0.124
V	mg/l	0.1	0.7	< 0.01	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.128	0.493
U	mg/l	0.3	5	0.0018	0.0016 B	0.0009 B	0.0009 B	0.0150	0.0167	0.0338	0.1670	2.180
Rad-226	pci/l	NA	NA	0.24	12	12	14	6.2	7.4	19	14	30
Rad-228	pci/l	NA	NA	6	15	12	13	10	14	7.9	12	12
Rad Total	pci/l	5	5	6.24	27	24	27	16.2	21.4	26.9	26	42
Th-230	pci/l	5	NA	-0.31	0.11	-0.56	-0.36	-0.1	-0.14	0.15	9.1	310
Pb-210	pci/l	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Gross Alpha	pci/l	15	15	16	50	74	67	31	33	130	230	1300

Notes:
1. mg/l = milligrams per liter.
2. NA = not applicable.
3. pci/l = pico curies per liter.
4. SU = standard units.
5. < = constituent was not detected at concentrations above the detection limit.
6. Groundwater samples were collected on October 19, 2006, with the exception of samples 517PS1 and 518PS1, which were collected on October 26, 2006.
7. B indicates analyte concentration detected at a value between MDL and PQL.
8. H indicates analysis exceeded method hold time.
9. DUP1 is a field duplicate of sample EW1PS1.

TABLE 3

UNC CHURCH ROCK
GALLUP, NEW MEXICO

IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

FINAL WATER QUALITY

				Sample ID						
Constituent	Units	NRC Standard	EPA Standard	INJPS2	EW1PS2	DUP2	EW2PS2	517PS2	518PS2	608PS2
Lab pH	SU	NA	NA	8.6 H	5.2 H	5.2 H	3.2 H	4.0 H	3.1 H	3.4 H
Lab TDS	mg/l	NA	4800	3470	5530	5520	5540	5000	7160	13800
Ca	mg/l	NA	NA	14.3	418	417	481	474	455	439
Mg	mg/l	NA	NA	3.3	573	573	612	452	731	706
Na	mg/l	NA	NA	1320	280	280	157	153	141	303
K	mg/l	NA	NA	3.3	17	16	16	10	15	6 B
HCO3	mg/l	NA	NA	1290	6 B	5 B	<2	< 2	< 2	< 2
SO4	mg/l	NA	2125	1070	3700	3900	3640	3440	4760	9600
Chloride	mg/l	NA	250	150	41	42	34	42	30	140
NH4 as N	mg/l	NA	NA	0.24 B	6.32	6.26	1.26	7.66	5.65	283
NO3 as N	mg/l	NA	190	0.12	0.06 B	0.06 B	<0.02	< 0.02	< 0.02	17.2
Chloroform	mg/l	0.001	NA	NA	NA	NA	NA	NA	NA	NA
Al	mg/l	NA	5	<0.3	20.7	21.1	4.3	4.2	56.80	863
As	mg/l	0.05	0.05	< 0.0005	0.035	0.045	0.005 B	< 0.003	0.011	< 0.01
Be	mg/l	0.05	0.017	< 0.004	0.08	0.09	0.02B	< 0.01	0.07	0.33
Cd	mg/l	0.01	0.01	< 0.0001	< 0.0005	0.0005 B	0.0023 B	0.0069	0.003	0.029
Co	mg/l	NA	0.05	< 0.02	0.63	0.64	0.77	0.77	1.07	2.3
Pb	mg/l	0.05	0.05	< 0.0001	0.0068	0.0144	0.0106	0.0104	0.0214	0.056
Mn	mg/l	NA	2.6	0.17	11.50	11.40	10.60	8.50	17.200	66.40
Mo	mg/l	NA	1	< 0.02	0.06 B	0.07 B	<0.05	< 0.05	<0.05	< 0.1
Ni	mg/l	0.05	0.2	< 0.02	0.88	0.92	1.54	0.75	1.39	2.0
Se	mg/l	0.01	0.01	0.0006	0.0058	0.0059	0.0013 B	0.0024 B	0.0046	0.068
V	mg/l	0.1	0.7	< 0.01	< 0.03	< 0.03	<0.03	< 0.03	0.15	0.38
U	mg/l	0.3	5	0.0042	0.0127	0.0124	0.0162	0.0550	0.2040	2.680
Rad-226	pci/l	NA	NA	0.45	28	30	8.8	12	7.7	20
Rad-228	pci/l	NA	NA	0.97	21	22	9.2	9.7	6.9	8
Rad Total	pci/l	5	5	1.42	49	52	18.0	21.7	14.6	28
Th-230	pci/l	5	NA	0.23	-0.39	0.0	0.04	-0.31	11	440
Pb-210	pci/l	1	NA	NA	NA	NA	NA	NA	NA	NA
Gross Alpha	pci/l	15	15	1.9	110	110	58	100	150	1300

Notes:
1. mg/l = milligrams per liter.
2. NA = not applicable.
3. pci/l = pico curies per liter.
4. SU = standard units.
5. < = constituent was not detected at concentrations above the detection limit.
6. Groundwater samples were collected on February 20, 2007.
7. B indicates analyte concentration detected at a value between MDL and PQL.
8. H indicates analysis exceeded method hold time.

TABLE 4

UNC CHURCH ROCK
GALLUP, NEW MEXICO

IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

INJECTION RATES

Injection Wells	24-Oct	25-Oct	26-Oct	27-Oct	28-Oct	29-Oct	30-Oct	31-Oct	1-Nov	2-Nov	3-Nov	4-Nov	5-Nov	6-Nov	7-Nov	8-Nov	9-Nov	10-Nov	11-Nov	12-Nov	13-Nov	14-Nov
IW-1	0.080	0.101	0.104	0.079	0.076	0.016	0.081	0.059	0.083	0.073	0.075	0.066	0.060	0.072	0.064	0.060	0.066	0.069	0.040	0.040	0.062	0.064
IW-2	0.099	0.112	0.109	0.080	0.078	0.017	0.087	0.063	0.097	0.085	0.087	0.074	0.067	0.085	0.076	0.070	0.079	0.084	0.043	0.043	0.074	0.079
IW-3	0.057	0.069	0.076	0.046	0.057	0.022	0.057	0.047	0.061	0.055	0.058	0.050	0.047	0.053	0.048	0.047	0.050	0.052	0.034	0.034	0.048	0.049
IW-4	0.084	0.107	0.102	0.082	0.077	0.017	0.086	0.063	0.096	0.081	0.085	0.072	0.066	0.083	0.074	0.068	0.076	0.079	0.043	0.043	0.070	0.073
Total IWs =	**0.320**	**0.389**	**0.391**	**0.287**	**0.288**	**0.072**	**0.311**	**0.232**	**0.337**	**0.294**	**0.305**	**0.262**	**0.240**	**0.293**	**0.262**	**0.245**	**0.271**	**0.284**	**0.160**	**0.160**	**0.254**	**0.265**

Notes:
1. Rates are in gallons per minute (gpm).
2. NC = Data not collected.

TABLE 4

UNC CHURCH ROCK
GALLUP, NEW MEXICO

IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

INJECTION RATES

Injection Wells	15-Nov	16-Nov	17-Nov	18-Nov	19-Nov	20-Nov	21-Nov	22-Nov	23-Nov	24-Nov	25-Nov	26-Nov	27-Nov	28-Nov	29-Nov	30-Nov	1-Dec	2-Dec	3-Dec	4-Dec	5-Dec	6-Dec
IW-1	0.063	0.063	0.063	0.061	0.137	0.100	0.060	0.057	0.117	0.114	0.106	0.100	0.099	0.056	0.092	0.018	0.057	0.054	0.050	0.054	0.056	0.055
IW-2	0.078	0.078	0.077	0.074	0.161	0.078	0.071	0.068	0.135	0.132	0.123	0.115	0.115	0.068	0.106	0.067	0.067	0.063	0.058	0.064	0.068	0.065
IW-3	0.049	0.049	0.048	0.048	0.107	0.080	0.047	0.045	0.093	0.091	0.085	0.079	0.078	0.044	0.074	0.019	0.044	0.042	0.040	0.042	0.043	0.042
IW-4	0.073	0.073	0.073	0.070	0.154	0.110	0.069	0.066	0.131	0.128	0.119	0.111	0.110	0.065	0.104	0.064	0.064	0.061	0.055	0.061	0.065	0.063
Total IWs =	**0.263**	**0.263**	**0.261**	**0.253**	**0.559**	**0.367**	**0.247**	**0.237**	**0.476**	**0.464**	**0.433**	**0.406**	**0.401**	**0.232**	**0.375**	**0.169**	**0.232**	**0.221**	**0.203**	**0.221**	**0.233**	**0.225**

TABLE 4

UNC CHURCH ROCK
GALLUP, NEW MEXICO

IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

INJECTION RATES

Injection Wells	7-Dec	8-Dec	9-Dec	10-Dec	11-Dec	12-Dec	13-Dec	14-Dec	15-Dec	16-Dec	17-Dec	18-Dec	19-Dec	20-Dec	21-Dec	22-Dec	23-Dec	26-Dec	27-Dec	28-Dec	29-Dec	30-Dec
IW-1	0.056	0.057	0.053	0.052	0.047	0.054	0.055	0.052	0.054	0.053	0.048	0.047	0.047	0.050	0.052	0.057	0.049	0.027	NC	0.029	0.057	0.053
IW-2	0.068	0.067	0.062	0.062	0.053	0.064	0.065	0.061	0.064	0.065	0.054	0.053	0.054	0.058	0.063	0.063	0.056	0.028	NC	0.029	0.056	0.053
IW-3	0.042	0.042	0.041	0.041	0.038	0.041	0.042	0.041	0.041	0.042	0.038	0.037	0.038	0.039	0.040	0.040	0.038	0.024	NC	0.018	0.038	0.037
IW-4	0.064	0.063	0.060	0.059	0.053	0.062	0.063	0.060	0.061	0.062	0.054	0.054	0.054	0.057	0.060	0.061	0.055	0.028	NC	0.028	0.056	0.053
Total IWs =	0.229	0.229	0.216	0.214	0.191	0.220	0.224	0.214	0.220	0.222	0.194	0.192	0.193	0.204	0.215	0.221	0.199	0.108	NC	0.104	0.207	0.195

TABLE 4

UNC CHURCH ROCK
GALLUP, NEW MEXICO

IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

INJECTION RATES

Injection Wells	1-Jan	2-Jan	3-Jan	4-Jan	10-Jan	11-Jan	12-Jan	13-Jan	15-Jan	16-Jan	17-Jan	18-Jan	19-Jan	20-Jan	22-Jan	23-Jan	25-Jan	26-Jan	28-Jan	29-Jan	30-Jan	31-Jan
IW-1	0.037	0.056	0.035	NC	0.012	0.110	0.080	0.070	0.021	0.085	0.078	0.079	0.074	0.067	0.042	0.076	0.042	0.080	0.043	0.068	0.079	0.073
IW-2	0.038	0.056	0.036	NC	0.009	0.075	0.062	0.057	0.020	0.068	0.063	0.064	0.061	0.056	0.039	0.062	0.038	0.062	0.039	0.056	0.064	0.060
IW-3	0.030	0.038	0.023	NC	0.012	0.078	0.058	0.052	0.019	0.056	0.052	0.052	0.051	0.051	0.035	0.051	0.035	0.050	0.035	0.047	0.048	0.046
IW-4	0.038	0.056	0.035	NC	0.011	0.075	0.063	0.058	0.020	0.067	0.063	0.064	0.060	0.056	0.040	0.063	0.039	0.062	0.040	0.057	0.063	0.060
Total IWs =	**0.144**	**0.206**	**0.129**	NC	**0.044**	**0.339**	**0.264**	**0.236**	**0.080**	**0.276**	**0.256**	**0.258**	**0.246**	**0.230**	**0.156**	**0.253**	**0.154**	**0.254**	**0.158**	**0.229**	**0.254**	**0.239**

TABLE 4

UNC CHURCH ROCK
GALLUP, NEW MEXICO

IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

INJECTION RATES

Injection Wells	1-Feb	2-Feb	4-Feb	5-Feb	6-Feb	7-Feb	8-Feb	9-Feb	11-Feb	12-Feb	15-Feb
IW-1	0.072	0.070	0.040	0.072	0.075	0.073	0.071	0.073	0.039	0.069	0.029
IW-2	0.059	0.058	0.036	0.059	0.061	0.060	0.058	0.060	0.035	0.057	0.028
IW-3	0.045	0.045	0.033	0.049	0.047	0.046	0.045	0.045	0.032	0.044	0.026
IW-4	0.059	0.058	0.038	0.059	0.060	0.060	0.058	0.059	0.037	0.056	0.029
Total IWs =	**0.236**	**0.230**	**0.148**	**0.239**	**0.243**	**0.239**	**0.232**	**0.237**	**0.142**	**0.226**	**0.112**

TABLE 5

UNC CHURCH ROCK
GALLUP, NEW MEXICO

IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

EXTRACTION RATES

Extraction Wells	24-Oct	25-Oct	26-Oct	27-Oct	28-Oct	29-Oct	30-Oct	31-Oct	1-Nov	2-Nov	3-Nov	4-Nov	5-Nov	6-Nov	7-Nov	8-Nov	9-Nov	10-Nov	11-Nov	12-Nov	13-Nov	14-Nov
EW-1	0.27	0.25	0.24	0.22	0.20	0.20	0.21	0.10	0.19	0.18	0.18	0.19	0.20	0.20	0.20	0.20	0.19	0.19	0.19	0.21	0.21	0.20
EW-2	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.01	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
EW-3 (517)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EW-4 (518)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EW-5 (608)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.03	0.03	0.04
Total EWs =	**0.27**	**0.25**	**0.236**	**0.22**	**0.20**	**0.24**	**0.23**	**0.11**	**0.22**	**0.2**	**0.2**	**0.21**	**0.22**	**0.22**	**0.22**	**0.22**	**0.21**	**0.25**	**0.24**	**0.26**	**0.26**	**0.26**

Notes:

1. Rates are in gallons per minute (gpm).
2. NC = Data not collected.

TABLE 5

UNC CHURCH ROCK
GALLUP, NEW MEXICO

IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

EXTRACTION RATES

Extraction Wells	15-Nov	16-Nov	17-Nov	18-Nov	19-Nov	20-Nov	21-Nov	22-Nov	23-Nov	24-Nov	25-Nov	26-Nov	27-Nov	28-Nov	29-Nov	30-Nov	1-Dec	2-Dec	3-Dec	4-Dec	5-Dec	6-Dec
EW-1	0.18	0.20	0.20	0.20	0.19	0.19	0.19	0.19	0.19	0.20	0.21	0.20	0.20	0.20	0.20	0.12	0.21	0.19	0.18	0.18	0.19	0.19
EW-2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
EW-3 (517)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EW-4 (518)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EW-5 (608)	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total EWs =	**0.24**	**0.25**	**0.26**	**0.26**	**0.26**	**0.26**	**0.26**	**0.25**	**0.22**	**0.22**	**0.23**	**0.21**	**0.22**	**0.22**	**0.22**	**0.14**	**0.23**	**0.21**	**0.20**	**0.20**	**0.21**	**0.20**

TABLE 5

UNC CHURCH ROCK
GALLUP, NEW MEXICO

IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

EXTRACTION RATES

Extraction Wells	7-Dec	8-Dec	9-Dec	10-Dec	11-Dec	12-Dec	13-Dec	14-Dec	15-Dec	16-Dec	17-Dec	18-Dec	19-Dec	20-Dec	21-Dec	22-Dec	23-Dec	26-Dec	27-Dec	28-Dec	29-Dec	30-Dec
EW-1	0.19	0.18	0.19	0.19	0.19	0.18	0.18	0.19	0.18	0.19	0.19	0.19	0.18	0.20	0.17	0.17	0.16	0.17	0.17	0.18	0.17	0.17
EW-2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
EW-3 (517)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EW-4 (518)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EW-5 (608)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total EWs =	0.20	0.20	0.20	0.21	0.21	0.20	0.20	0.21	0.20	0.21	0.21	0.20	0.20	0.22	0.19	0.18	0.18	0.18	0.19	0.19	0.19	0.19

TABLE 5

UNC CHURCH ROCK
GALLUP, NEW MEXICO

IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

EXTRACTION RATES

Extraction Wells	1-Jan	2-Jan	3-Jan	4-Jan	10-Jan	11-Jan	12-Jan	13-Jan	15-Jan	16-Jan	17-Jan	18-Jan	19-Jan	20-Jan	22-Jan	23-Jan	25-Jan	26-Jan	28-Jan	29-Jan	30-Jan	31-Jan
EW-1	0.17	0.16	0.16	0.17	NC	0.03	0.23	0.21	0.17	0.17	0.17	0.17	0.17	0.17	0.14	0.14	0.15	0.11	0.13	0.14	0.14	0.12
EW-2	0.02	0.02	0.02	0.02	NC	0.005	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
EW-3 (517)	0.00	0.00	0.00	0.00	NC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EW-4 (518)	0.00	0.00	0.00	0.00	NC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EW-5 (608)	0.00	0.00	0.00	0.00	NC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total EWs =	**0.18**	**0.18**	**0.17**	**0.18**	NC	**0.04**	**0.25**	**0.23**	**0.19**	**0.19**	**0.18**	**0.19**	**0.19**	**0.19**	**0.16**	**0.16**	**0.17**	**0.13**	**0.15**	**0.16**	**0.16**	**0.14**

TABLE 5

UNC CHURCH ROCK
GALLUP, NEW MEXICO

IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

EXTRACTION RATES

Extraction Wells	1-Feb	2-Feb	4-Feb	5-Feb	6-Feb	7-Feb	8-Feb	9-Feb	11-Feb	12-Feb	15-Feb
EW-1	0.12	0.10	0.13	0.15	0.15	0.14	0.14	0.15	0.26	0.21	0.0045
EW-2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
EW-3 (517)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EW-4 (518)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EW-5 (608)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total EWs =	**0.14**	**0.12**	**0.14**	**0.17**	**0.16**	**0.16**	**0.16**	**0.17**	**0.28**	**0.23**	**0.02**

ARCADIS BBL

Graphs

05/08/07 SYR-D85-DJH
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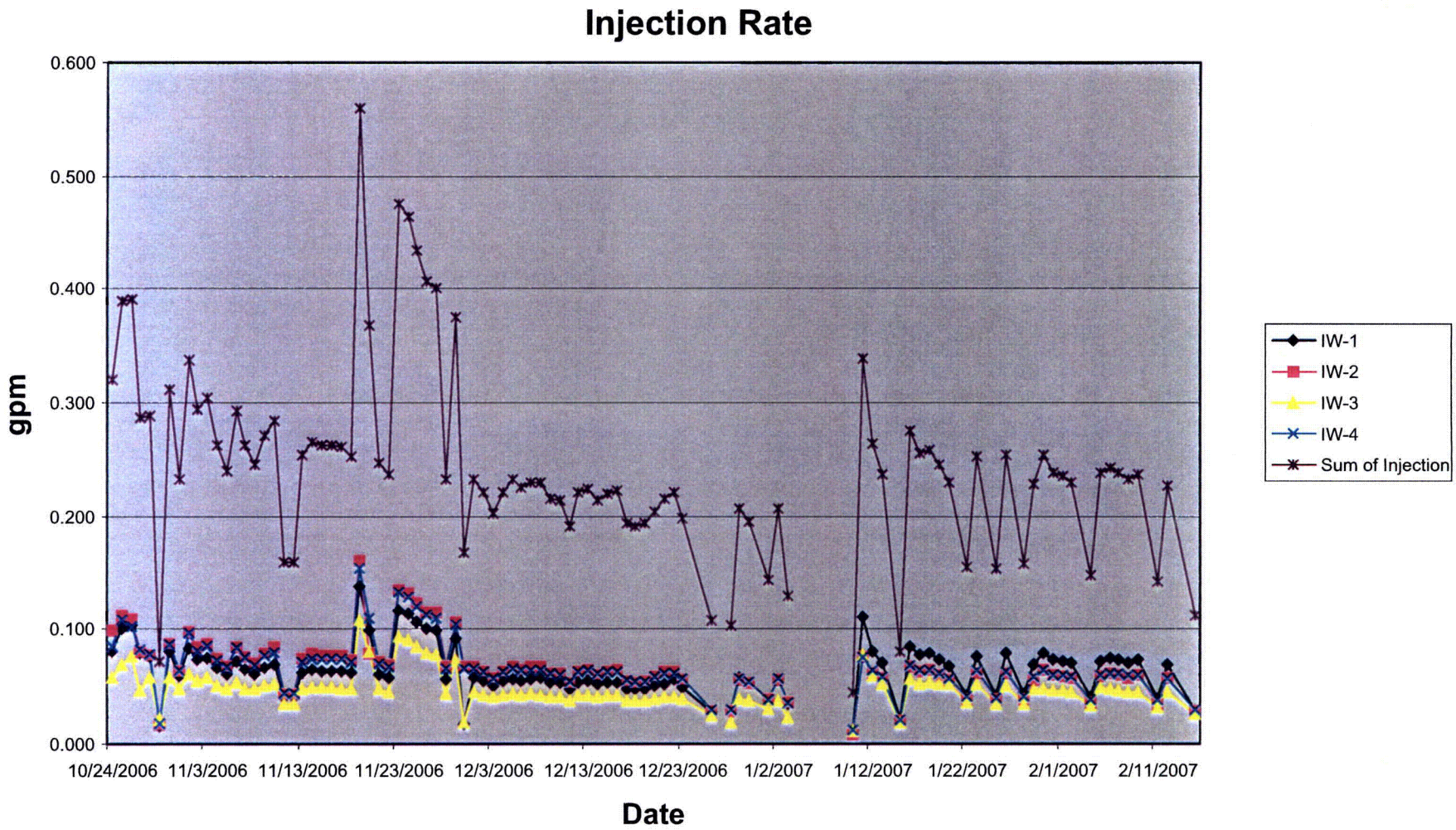

UNC CHURCH ROCK
GALLUP, NEW MEXICO
IN-SITU ALKALINITY
STABILIZATION PILOT STUDY REPORT

INJECTION RATE

ARCADIS BBL
Infrastructure, environment, facilities

GRAPH
1

05/08/07 SYR-D85-DJH
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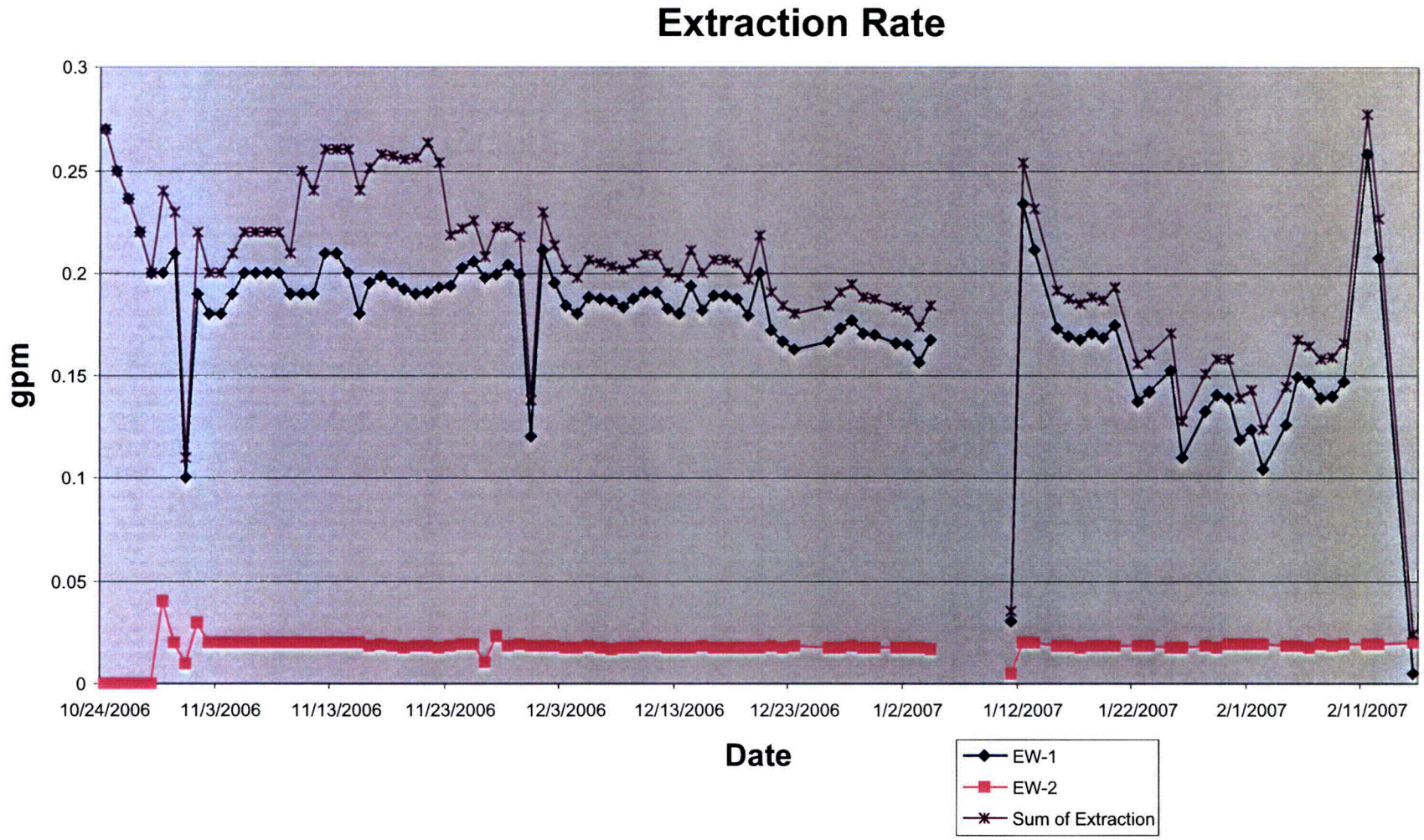

UNC CHURCH ROCK
GALLUP, NEW MEXICO
IN-SITU ALKALINITY
STABILIZATION PILOT STUDY REPORT

EXTRACTION RATE

ARCADIS BBL
infrastructure, environment, facilities

GRAPH
2

05/08/07 SYR-D85-DJH
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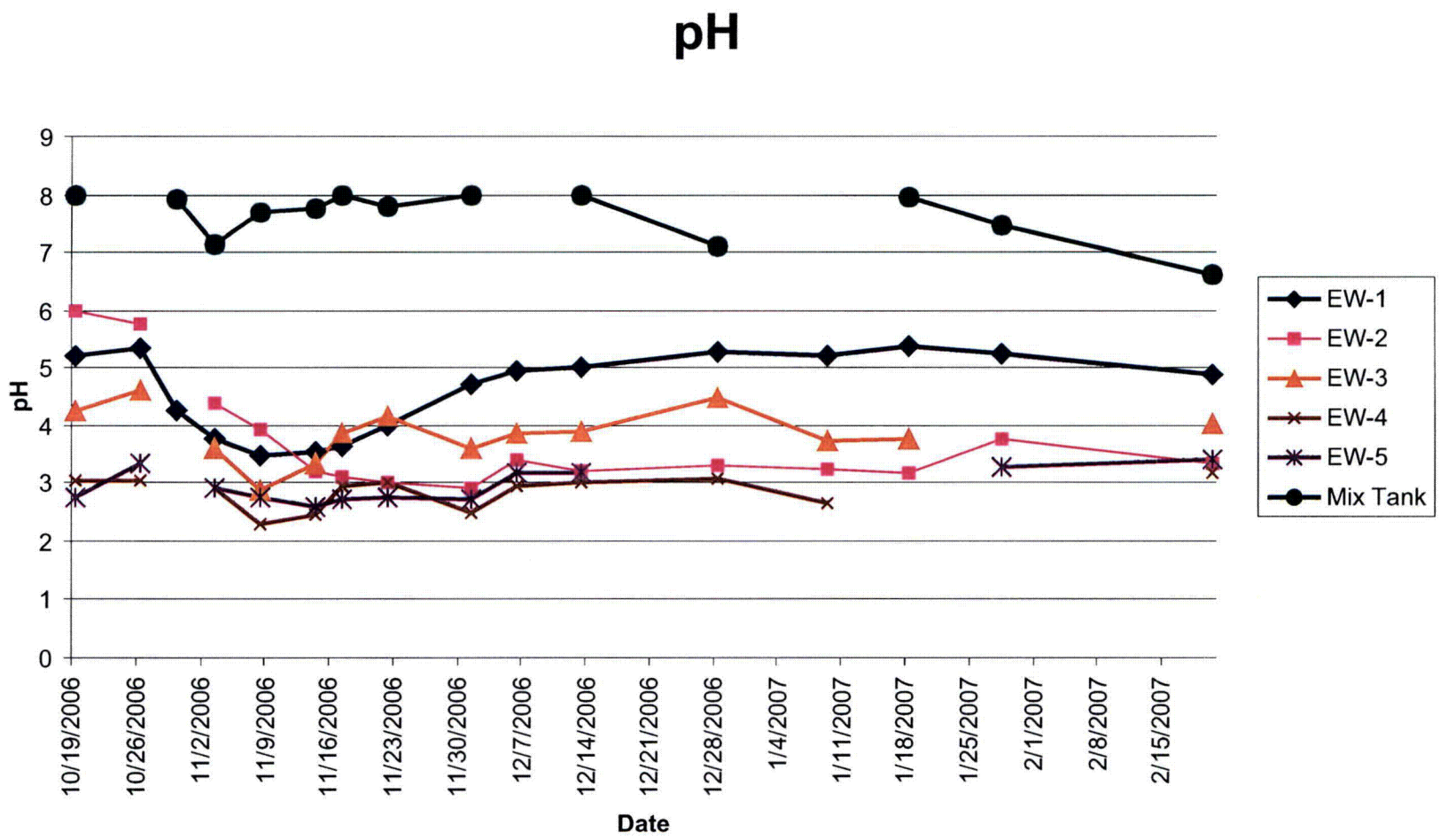

UNC CHURCH ROCK
GALLUP, NEW MEXICO
IN-SITU ALKALINITY
STABILIZATION PILOT STUDY REPORT

pH

ARCADIS BBL
Infrastructure, environment, facilities

GRAPH
3

05/08/07 SYR-D85-DJH
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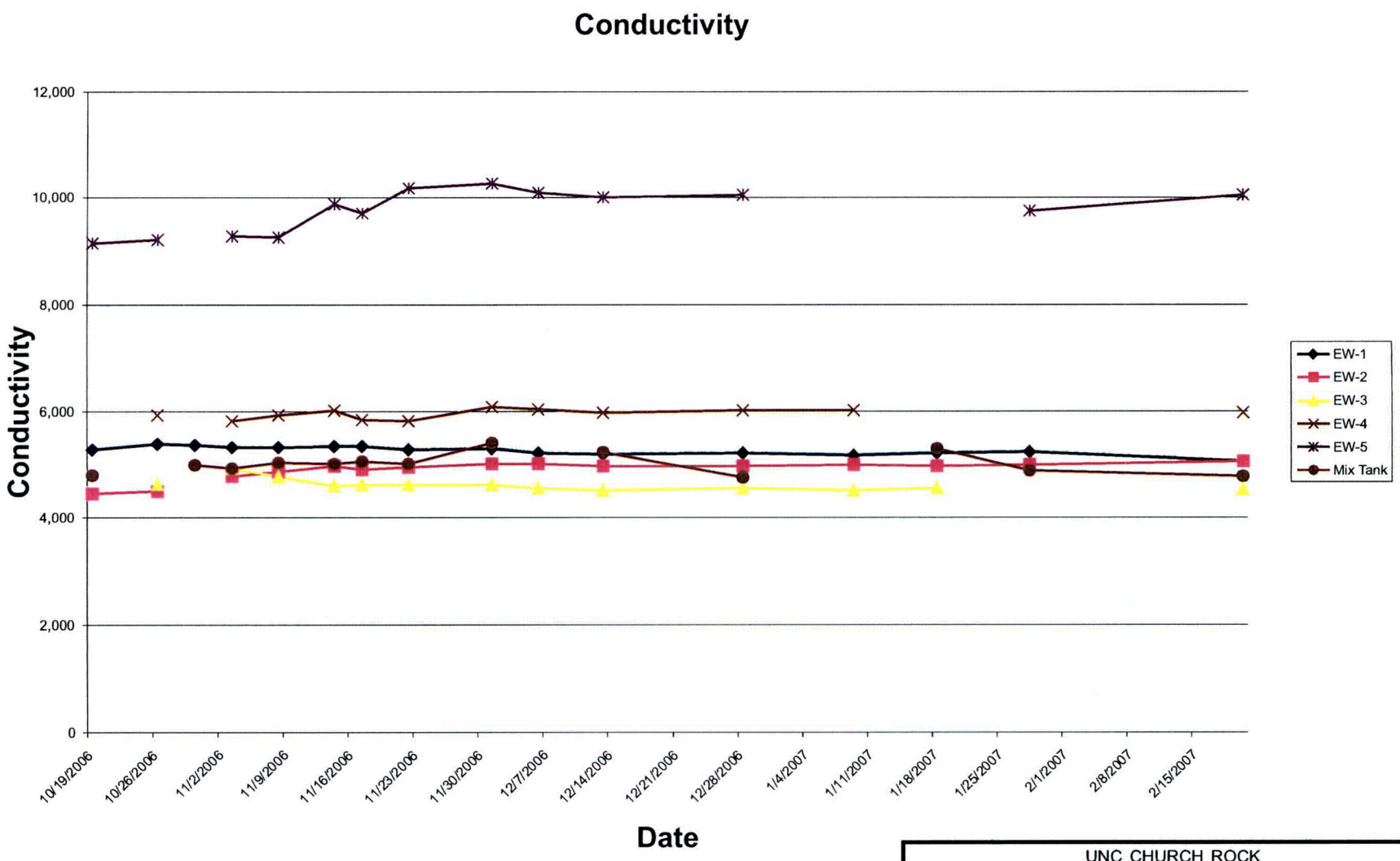

UNC CHURCH ROCK
GALLUP, NEW MEXICO
IN-SITU ALKALINITY
STABILIZATION PILOT STUDY REPORT

CONDUCTIVITY

ARCADIS BBL
Infrastructure, environment, facilities

GRAPH
4

05/08/07 SYR-D85-DJH
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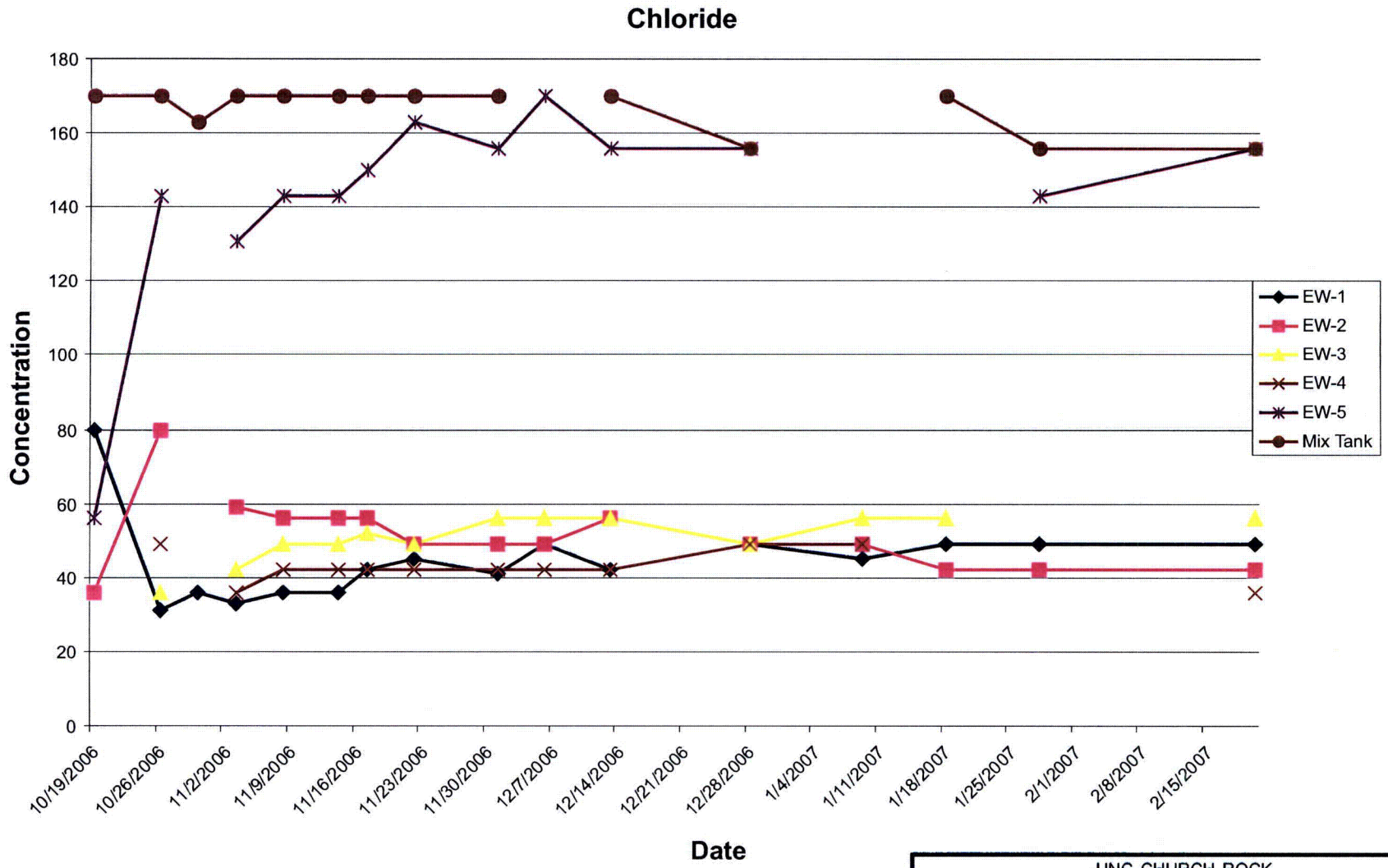

UNC CHURCH ROCK
GALLUP, NEW MEXICO
IN-SITU ALKALINITY
STABILIZATION PILOT STUDY REPORT

CHLORIDE

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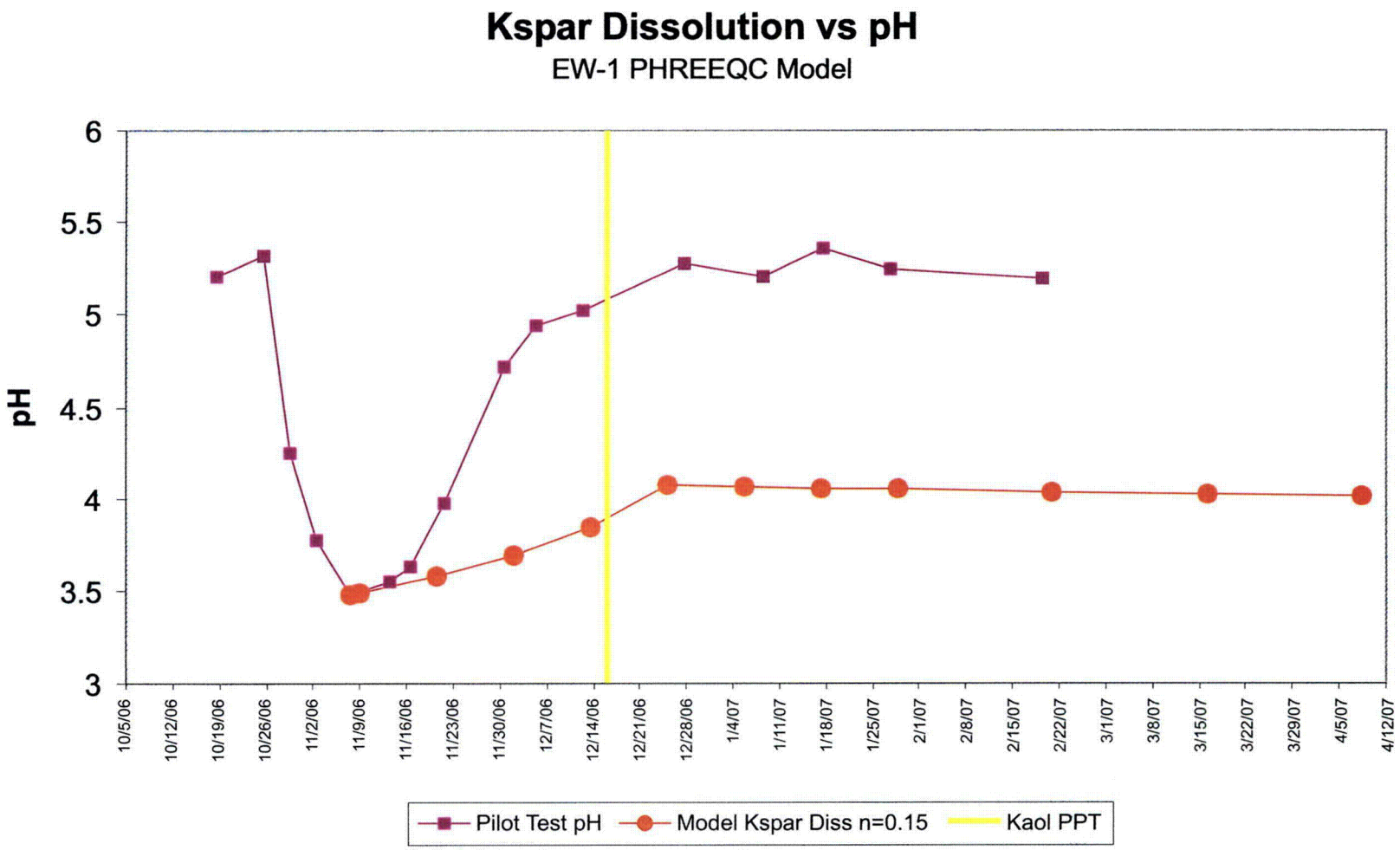
Infrastructure, environment, facilities

GRAPH
5

05/08/07 SYR-D85-DJH
C:/20871002/CDR/20871g03.cdr (6-10)



UNC CHURCH ROCK
GALLUP, NEW MEXICO
IN-SITU ALKALINITY
STABILIZATION PILOT STUDY REPORT

KSPAR DISSOLUTION VS pH
EW-1 PHREEQC MODEL

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GRAPH
6

05/08/07 SYR-D85-DJH
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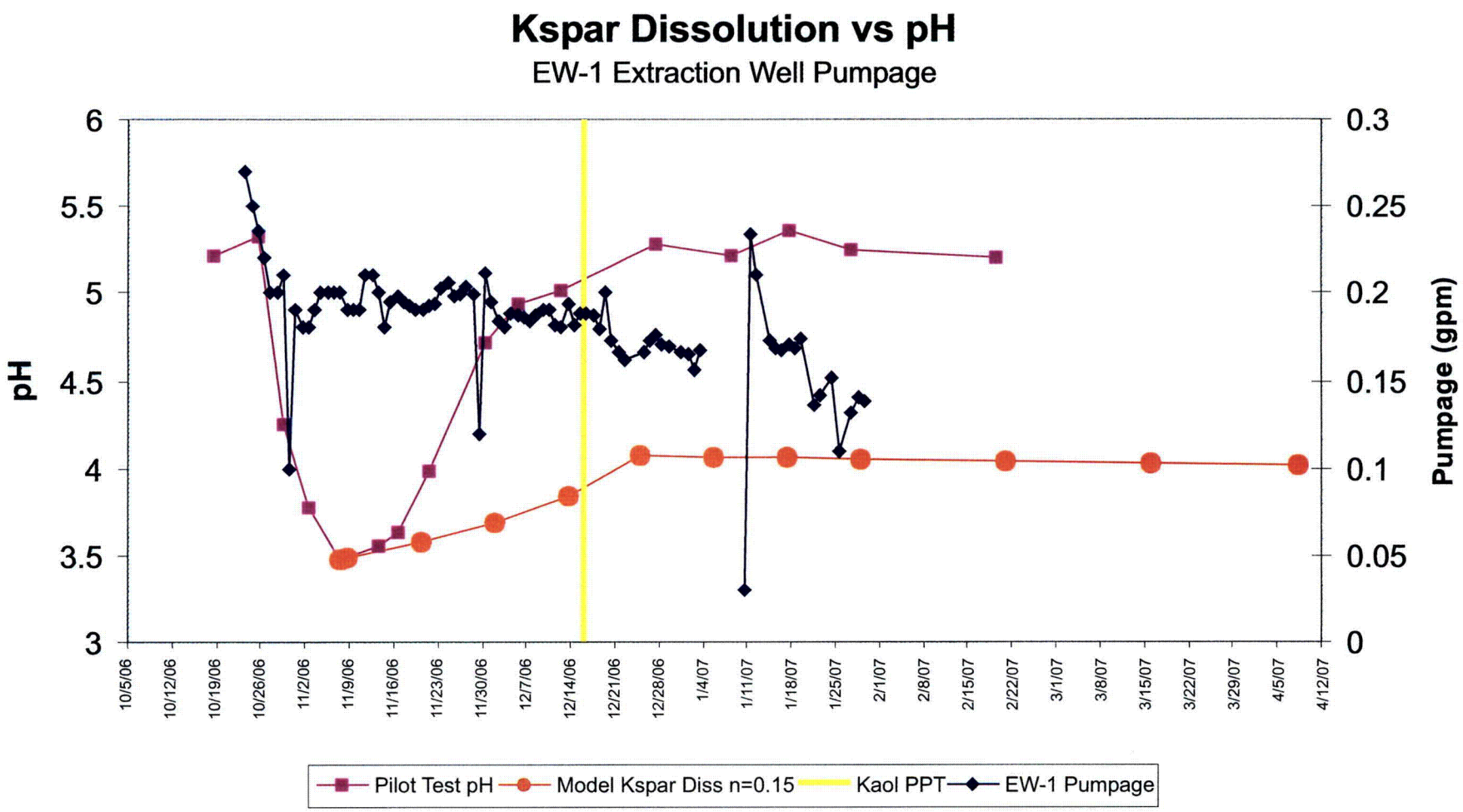

UNC CHURCH ROCK
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IN-SITU ALKALINITY
STABILIZATION PILOT STUDY REPORT

KSPAR DISSOLUTION VS pH
EW-1 EXTRACTION WELL PUMPAGE

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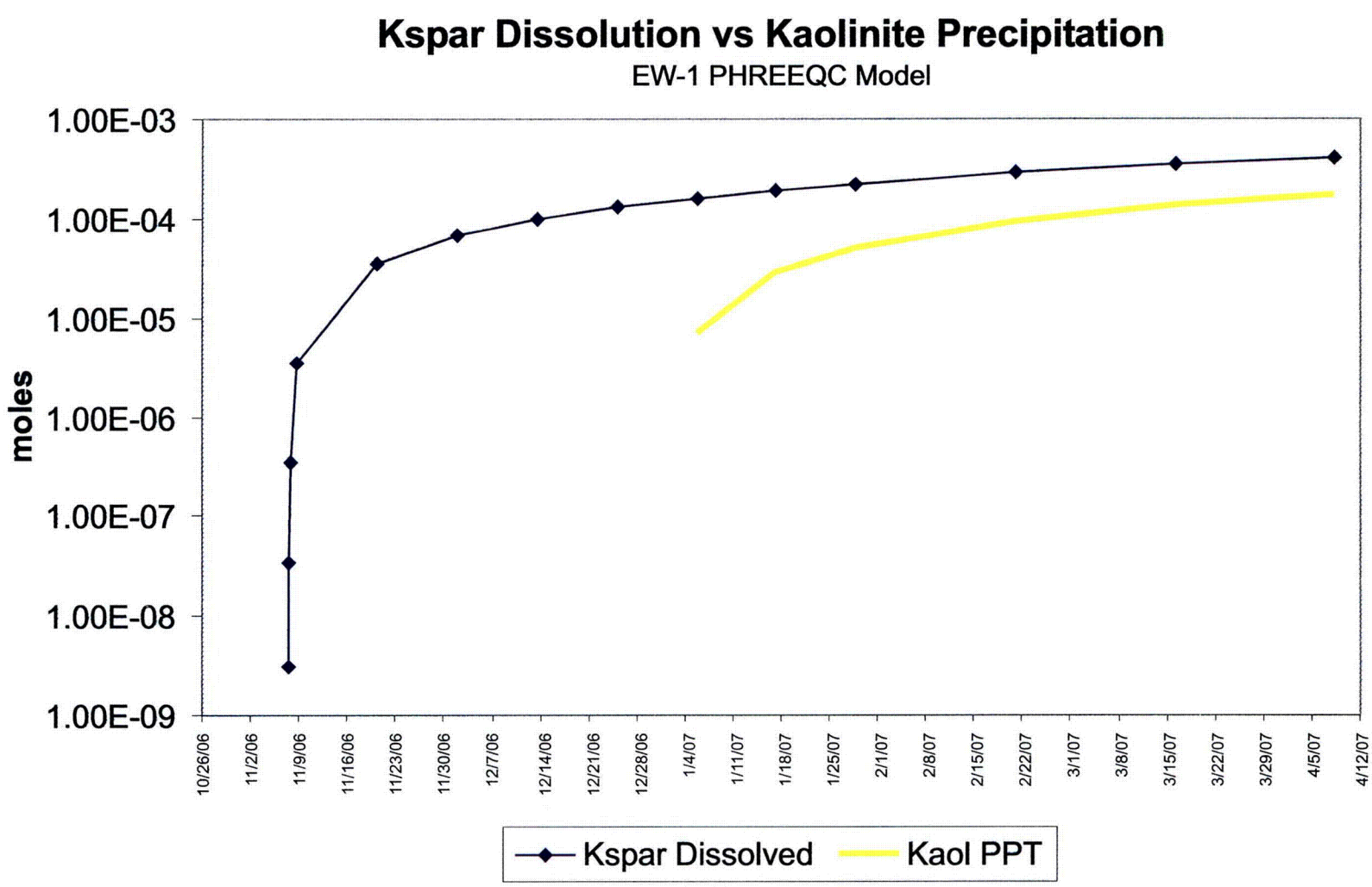
GRAPH
7

05/08/07 SYR-D85-DJH
C:/20871002/CDR/20871g03.cdr (8-10)



UNC CHURCH ROCK
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STABILIZATION PILOT STUDY REPORT

KSPAR DISSOLUTION VS
KAOLINITE PRECIPITATION
EW-1 PHREEQC MODEL

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GRAPH
8

06/19/07 SYR-D85-DJH
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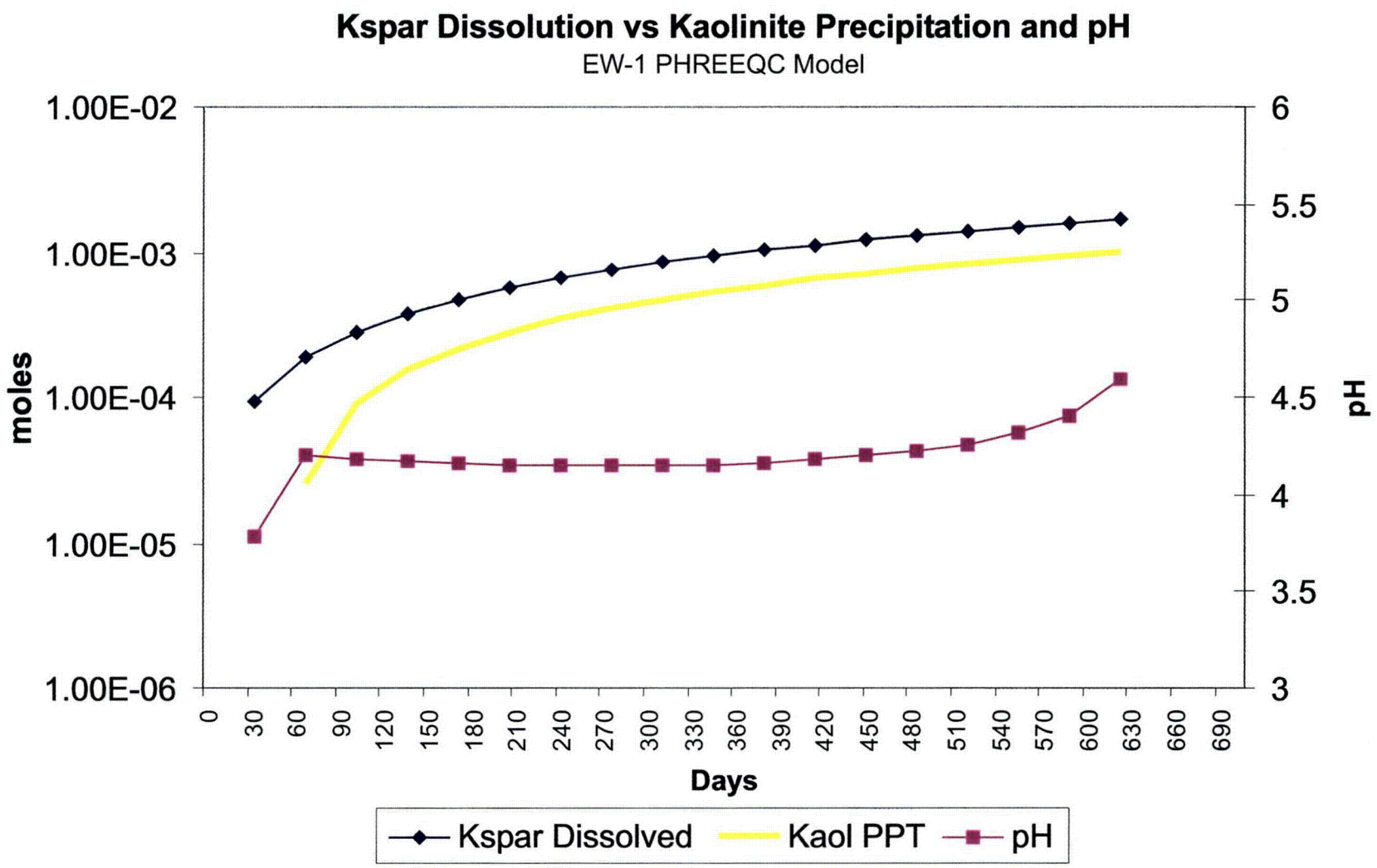

UNC CHURCH ROCK
GALLUP, NEW MEXICO
IN-SITU ALKALINITY
STABILIZATION PILOT STUDY REPORT

KSPAR DISSOLUTION VS KAOLINITE PRECIPITATION AND pH EW-1 PHREEQC MODEL

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GRAPH
9

05/08/07 SYR-D85-DJH
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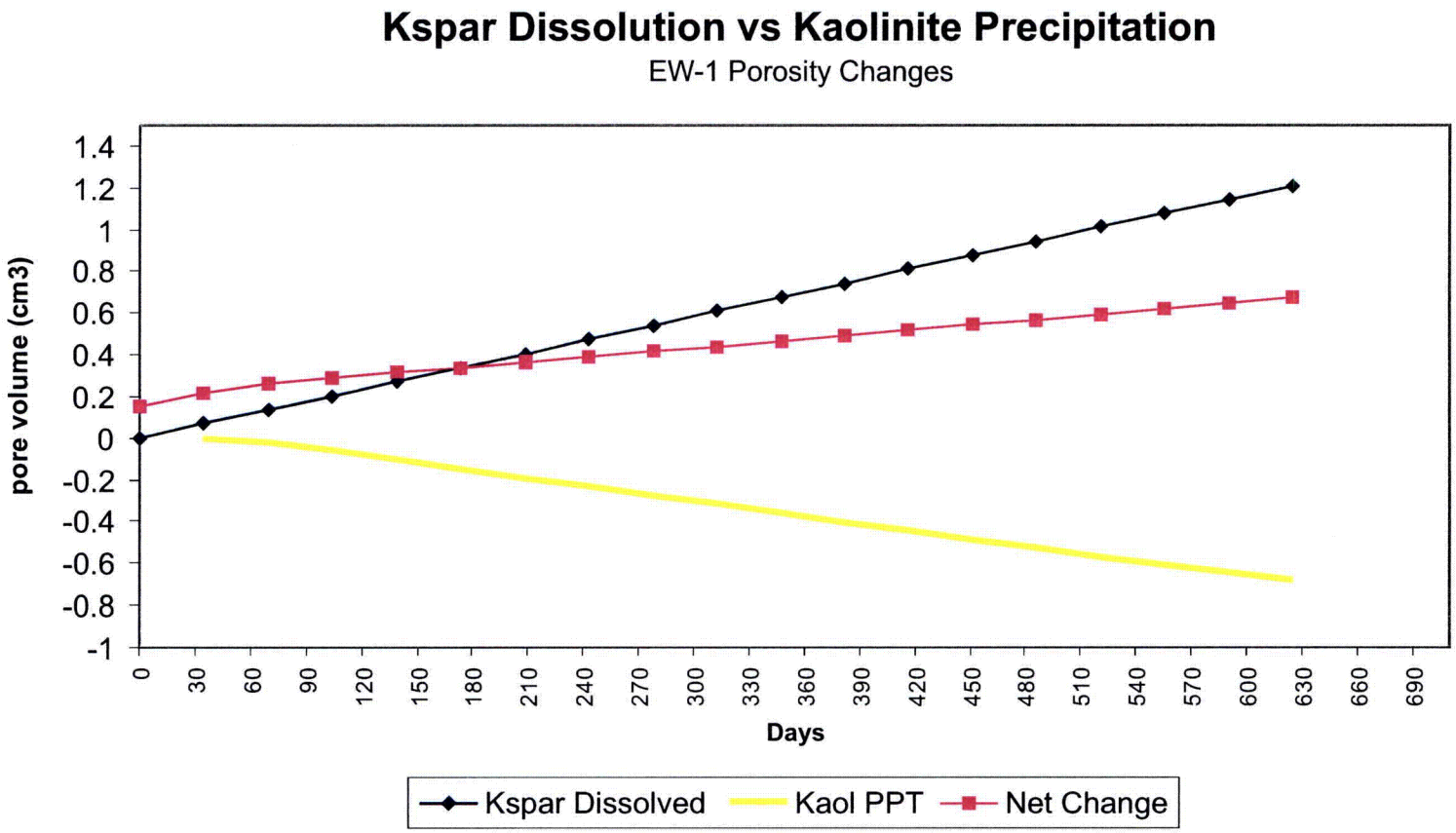

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IN-SITU ALKALINITY
STABILIZATION PILOT STUDY REPORT

KSPAR DISSOLUTION VS KAOLINITE PRECIPITATION EW-1 POROSITY CHANGES

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GRAPH
10

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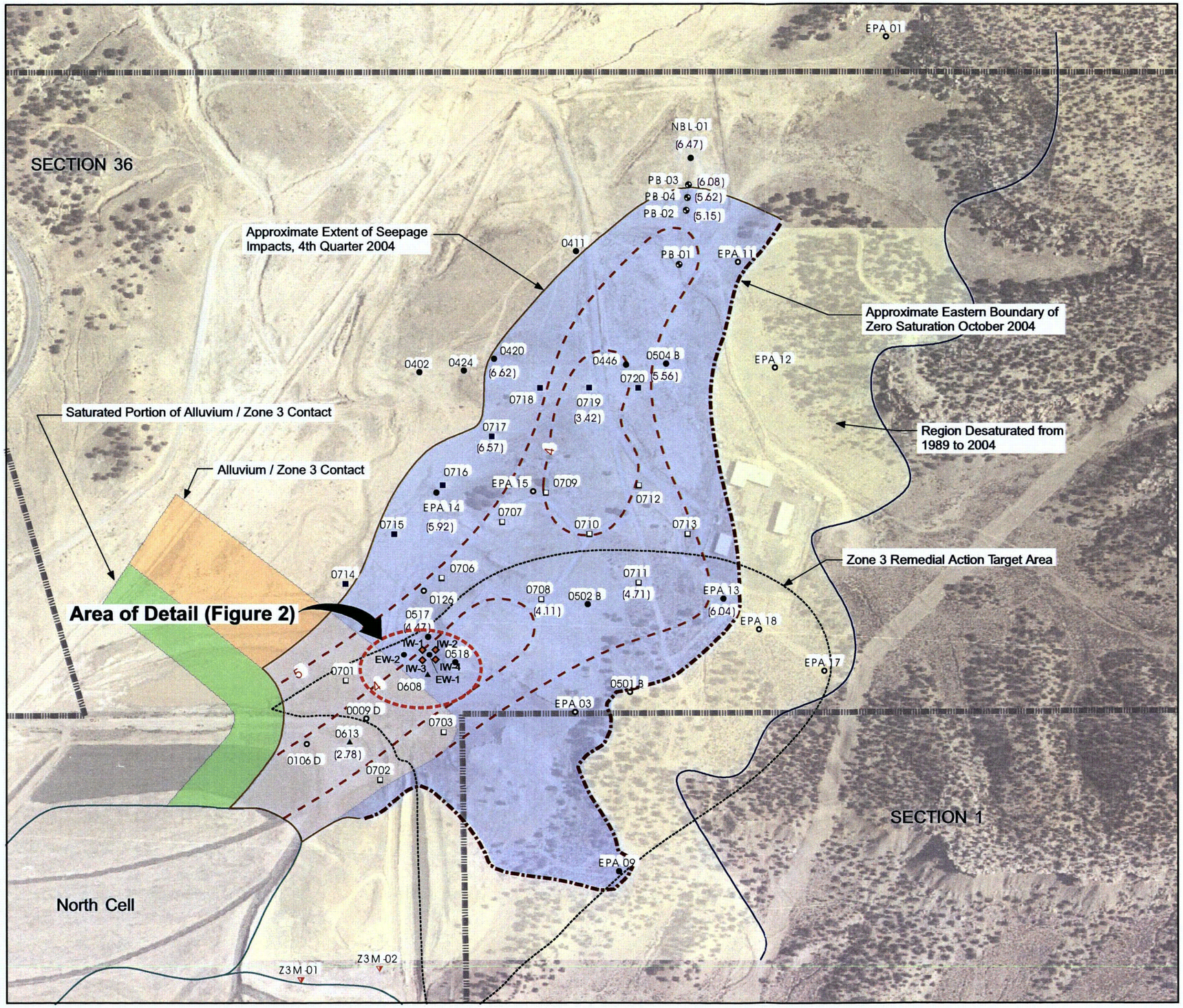
Figures



05/08/07 SYR-D85-DJH
C:/20871002/CDR/20871g01.cdr

LEGEND:

- Property Boundary
- Zone 3 Target Remediation Action Area
- Section Boundary
- Cell Boundary
- Approximate Area Impacted by Tailings Seepage
- pH Contour

WELLS:

- Monitoring
- Dry Monitoring
- Stage I Extraction
- Stage II Extraction
- Plume Boundary
- Northeast Pump-Back
- Piezometer
- Extraction Well
- Injection Well
- Approximate Eastern Boundary of Zero Saturation

NOTES:

1. All locations are approximate.
2. Values for field measured PH are shown with purple text and enclosed in parentheses.
3. Aerial Photo taken August 1, 1996.
4. Figure taken from *Annual Review Report - 2004 Groundwater Corrective Action* by NA Water Systems, dated December 2004.

0 200 400 800
Feet

UNC CHURCH ROCK
GALLUP, NEW MEXICO
IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

PILOT STUDY LOCATION

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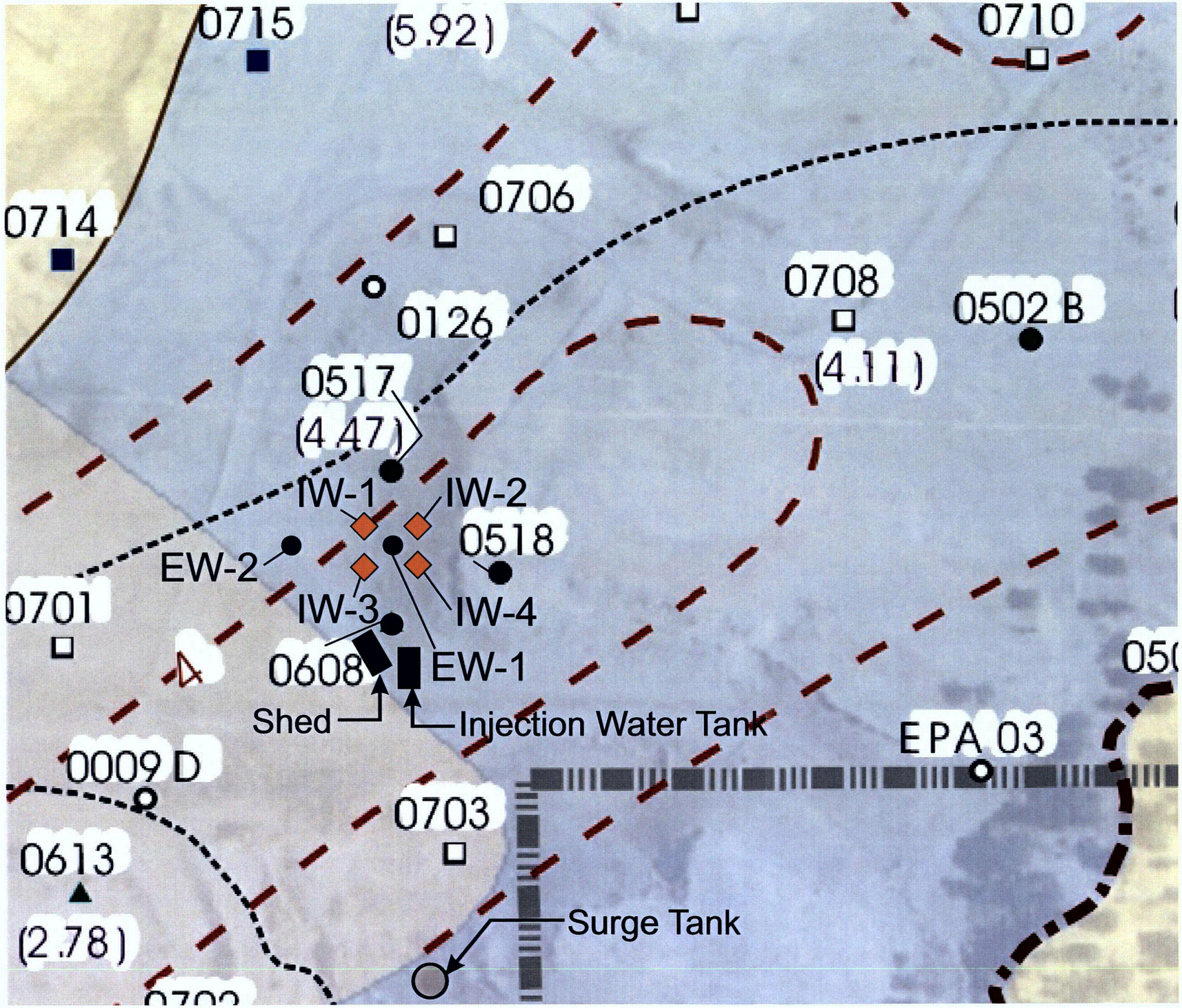
FIGURE
1



05/08/07 SYR-D85-DJH
C:/20871002/20871g02.cdr

LEGEND:

- Property Boundary
- Zone 3 Target Remediation Action Area
- Cell Boundary
- pH Contour

WELLS:

- Monitoring
- Dry Monitoring
- Stage I Extraction
- Stage II Extraction
- Northeast Pump-Back
- Piezometer
- Extraction Well
- Injection Well
- Approximate Eastern Boundary of Zero Saturation

NOTES:

1. All locations are approximate.
2. Figure taken from *Annual Review Report - 2004 Groundwater Corrective Action* by NA Water Systems, dated December 2004.

0 50 100 200
Feet

UNC CHURCH ROCK
GALLUP, NEW MEXICO
IN-SITU ALKALINITY STABILIZATION PILOT STUDY REPORT

PILOT STUDY LAYOUT

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FIGURE
2

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Attachments

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Attachment A

Petrologic Analysis of Gallup Zone 3 Sandstone Scanning Electron Microscopy and Energy Dispersive X-Ray Analysis, Church Rock Site, New Mexico

Petrologic Analysis of Gallup Zone 3 Sandstone
Scanning Electron Microscopy and Energy Dispersive X-Ray Analysis
Church Rock Site, NM

Bruce Selleck, Colgate University
May 4, 2007

Introduction:

This report summarizes the results of Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray Spectral (EDS) of samples of Gallup Zone 3 sandstone from the UNC Church Rock, New Mexico. The analyses were undertaken in response to concerns regarding low hydraulic conductivity in the Zone 3 aquifer during an in-situ alkalinity pilot study.

Well CDNEW-1 (Figures 1, 2) was sited within the alkalinity pilot study area, approximately 25 feet from well EW-1, the extraction well for the pilot study. (Well locations are taken from "UNC Church Rock Site In-Situ Alkalinity Study, BBL, June 2006"). The core taken at CDNEW-1 penetrated the entire thickness of the Zone 3 Gallup Sandstone (Figures 3, 4). The core was sampled during drilling on March 22, 2007.

Samples were also taken from existing cores stored at the Church Rock site; well CCHF-2, drilled outside the impacted area (see Figure 1), is representative of the Gallup Zone 3 sandstone that has not been affected by the acidified leachate plume from the North Cell tailings. Well RW-13C is at the northern margin of the leachate plume, and was expected to show only minor effects of interaction with acidified water.

Observations during drilling:

As shown in figures 4 and 5, the core retrieved from CDNEW-1 was marked by a well-defined oxidation-reduction (redox) boundary at 92.5' depth. Above the boundary, ferric iron oxide staining is abundant in the coarser sand unit. Below the boundary, the color is greenish-gray with no ferric iron staining. Pyrite was observed in freshly cored rock in finer-grained units below the redox boundary. The redox boundary in CDNEW-1 occurs at the top of the zone of saturation in Zone 3.

Methods:

Samples of cored rock were removed using a rock hammer to break off ~2" of core interval. Subsamples 1/4-1/2" in size were dried, cleaned using compressed air, mounted on aluminum stubs using carbon emulsion cement and coated with gold for SEM observation. SEM imaging utilized a JEOL 6300LV system operated in both low vacuum and high vacuum modes with secondary and backscattered electron detectors used to examine samples. A PGT EDS analyzer and Spirit acquisition/analysis software were used to determine elemental abundances and identify mineral phases

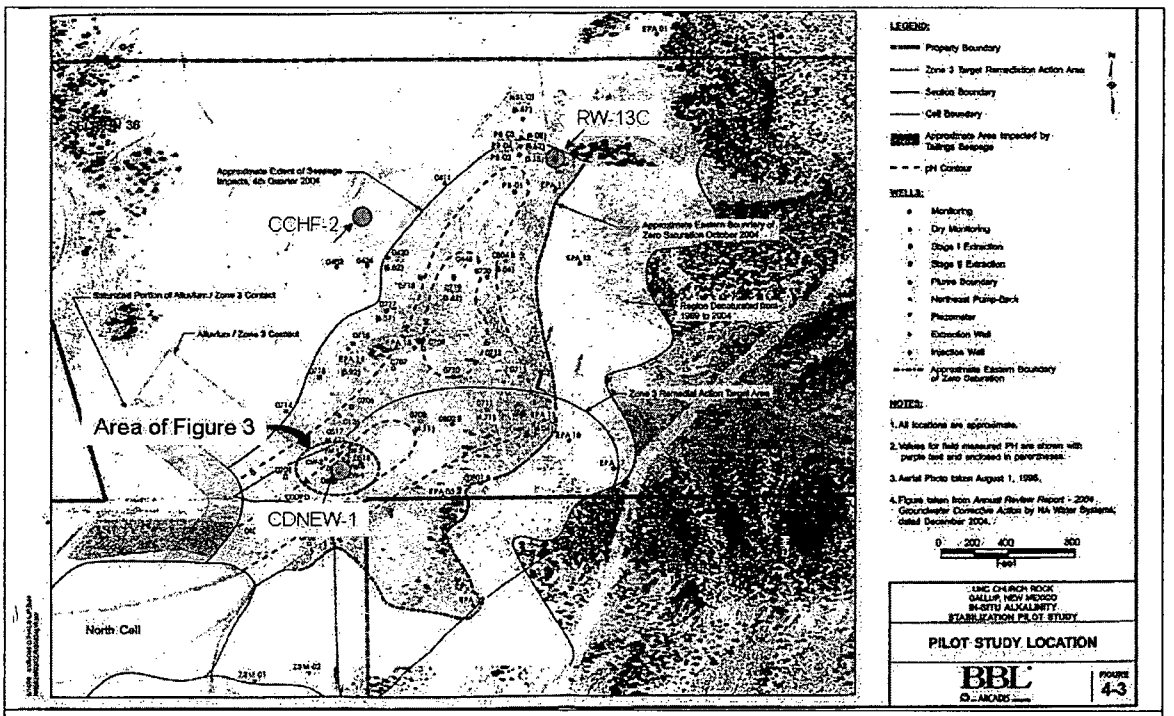

Figure 1 – Location of wells with sampled cores – this study

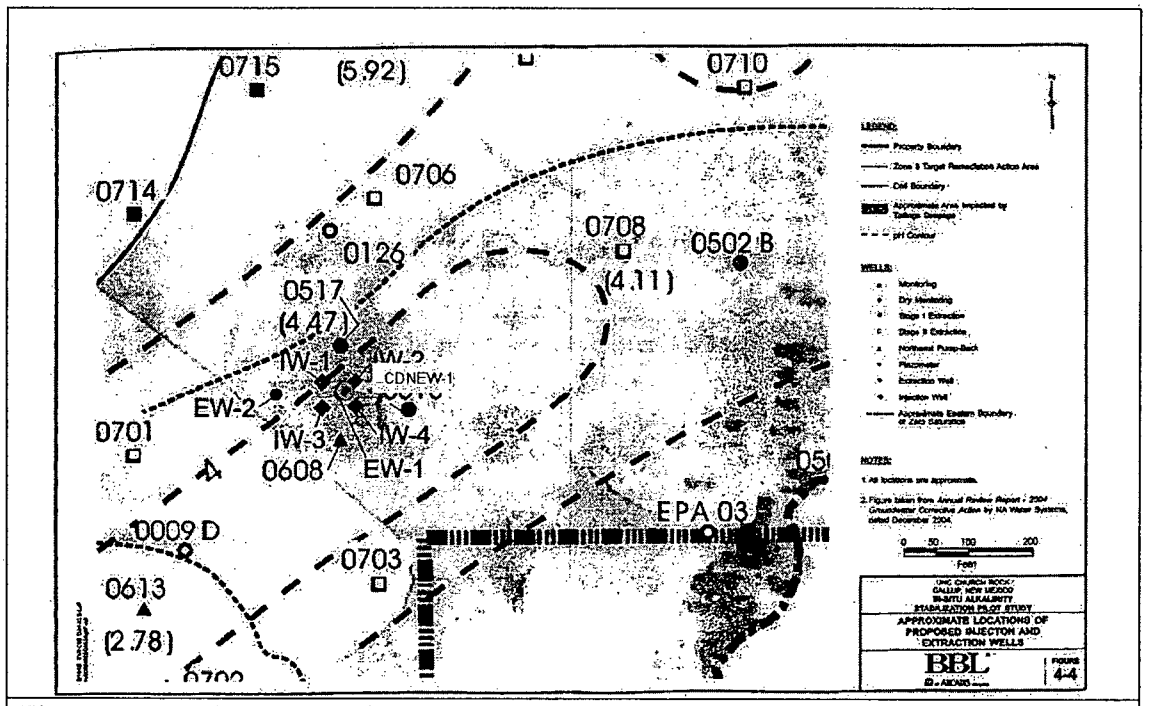

Figure 2 – Detail location of Well CDNEW-1

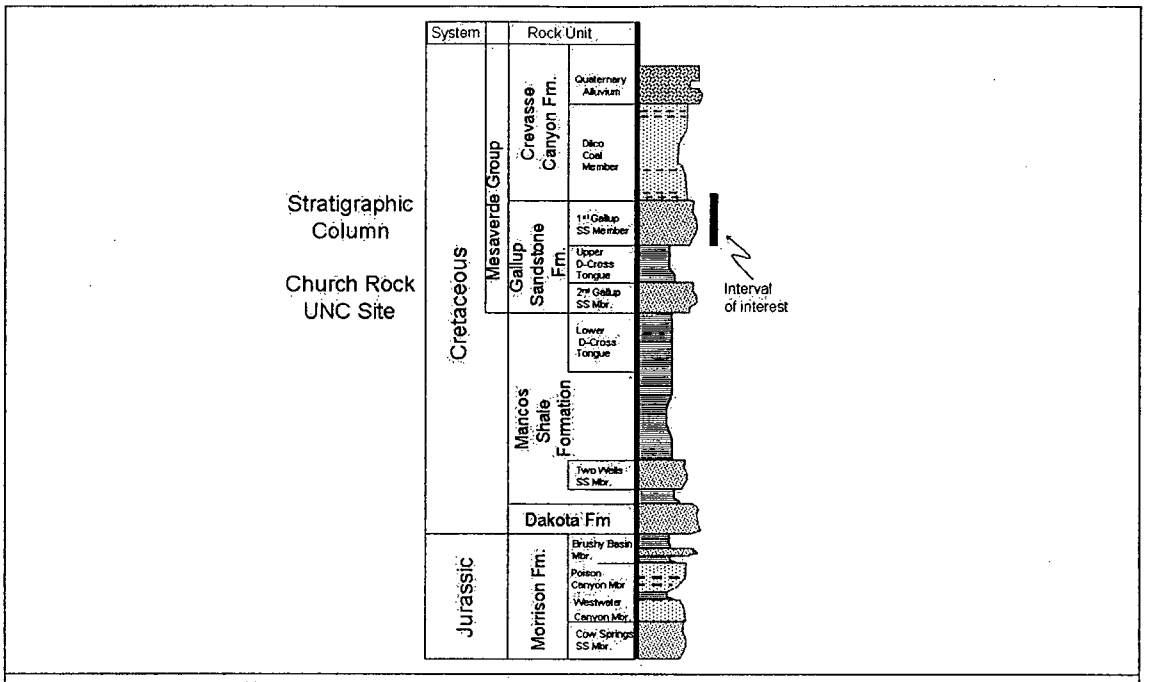

Figure 3 – Generalized stratigraphy at UNC Church Rock Site. Interval of interest is upper portion of 1st Gallup Sandstone Member

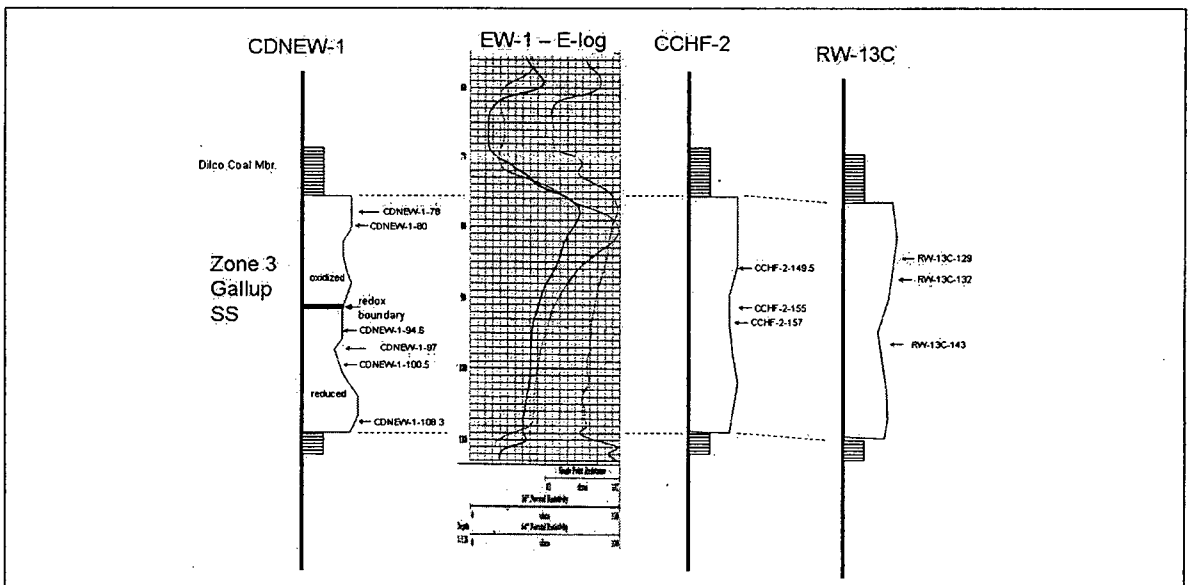

Figure 4 – Stratigraphic sections of sampled cores showing approximate location of samples examined using SEM-EDS, and lateral correlations. E-log of well EW-1 (extraction well of alkalinity pilot study) is shown for reference purposes.

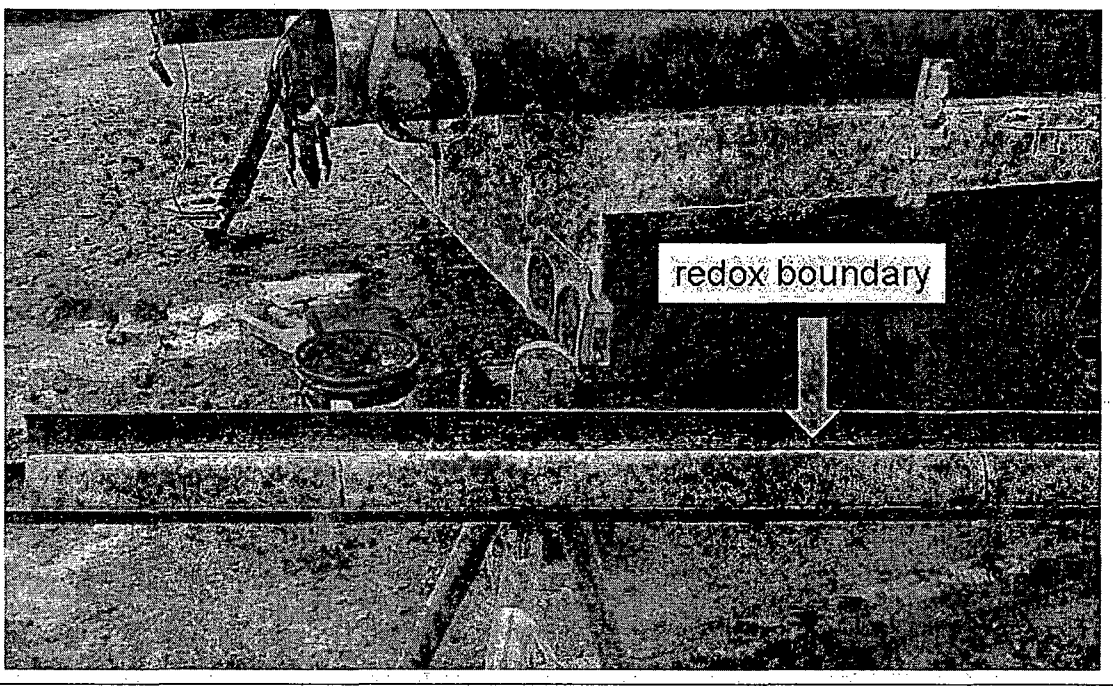

Figure 5 – Oxidation-reduction boundary at 92.5' in core CDNEW-1. Top of core to left. Redox boundary represents top of saturated zone.

Summary of Mineralogical Results:

The following minerals were observed in the samples:

quartz: identified by solitary Si peak on EDS spectra
K-feldspar: identified by subequal Al and K peaks, Si peak on EDS spectra
plagioclase: Na and Ca peaks, plus Al and Si
kaolinite: subequal Al and Si peaks on EDS; K peak reduced or absent
illite: Al peak about 2X Al peak, Si peak on EDS
smectite/vermiculite: Mg peak, plus Al, Si, minor K
Ti-oxide (or hydroxide?): Ti peak
Fe-oxide (or hydroxide): Fe peak
zircon: Zr and Si peaks subequal
pyrite: Fe and S peaks
gypsum/anhydrite: Ca and S peaks

Table 1 summarizes mineral abundance (last number in the sample ID indicates depth in feet of sample at each cored site). Minerals are listed in order of approximate relative abundance in each category

Table 1 – Mineral abundance

Sample Number	Major minerals	Minor minerals	Comments
CDNEW-1-78	quartz, K-feldspar	kaolinite, illite?, Ti-oxide, zircon, Fe-oxide	medium-grained sandstone; open pore throats
CDNEW-1-80	quartz, K-feldspar	illite, smectite/vermiculite?, Ti-oxide, Fe-oxide	medium-grained sandstone
CDNEW-1-94.6	quartz, K-feldpar	kaolinite, pyrite, zircon, Ti-oxide	medium-grained sandstone; kaolinite common in pore throats
CDNEW-1-97	quartz, K-feldpar, kaolinite	Ti-oxide, zircon, pyrite	medium-coarse sandstone; notable alteration of K-feldspar
CDNEW-1-100.5	quartz, kaolinite, K-feldspar	zircon, pyrite	medium-coarse sandstone; notable alteration of K-feldspar; kaolinite in pore throats
CDNEW-1-108.3	quartz, K-feldpar, kaolinite	illite, Ti-oxide, zircon, pyrite	medium-coarse sandstone; notable alteration of K-feldspar
CCHF-2-149.5	quartz, K-feldspar	zircon, Ti-oxide, gypsum/anhydrite	coarse sandstone; no clay minerals observed
CCHF-2-155	quartz, K-feldspar	Ti-oxide, kaolinite, illite, smectite/vermiculite?	medium-fine sandstone; coal fragments
CCHF-2-157	quartz, K-feldspar	illite, smectite/vermiculite	medium-fine sandstone
RW-13C-129	quartz, K-feldspar	plagioclase, Ti-oxide, zircon, Fe-oxide	medium sandstone
RW-13C-132	quartz, K-feldspar	Ti-oxide, zircon	coarse sandstone; clay very minor
RW-13C-143	quartz, K-feldspar	plagioclase, illite, kaolinite, Ti-oxide	medium sandstone
Zone 3 Gallup Outcrop	quartz, K-feldspar	Fe-oxide, zircon, Ti-oxide	coarse sandstone; "weathered"

EDS Elemental Ratio Analyses:

Whole-sample EDS spectra (5 x 4 mm scan area, 200 second count time) were obtained for 6 six samples from the CDNEW-1 core, and 6 samples from CCHF-2 and RW-123C. An EDS spectral quantification routine was applied to determine elemental weight percent ratios of Al/K. These results are presented graphically in Figure 5, and are consistent with the SEM-EDS observations of more abundant kaolinite in the samples from CDNEW-1 taken below the redox boundary in the core.

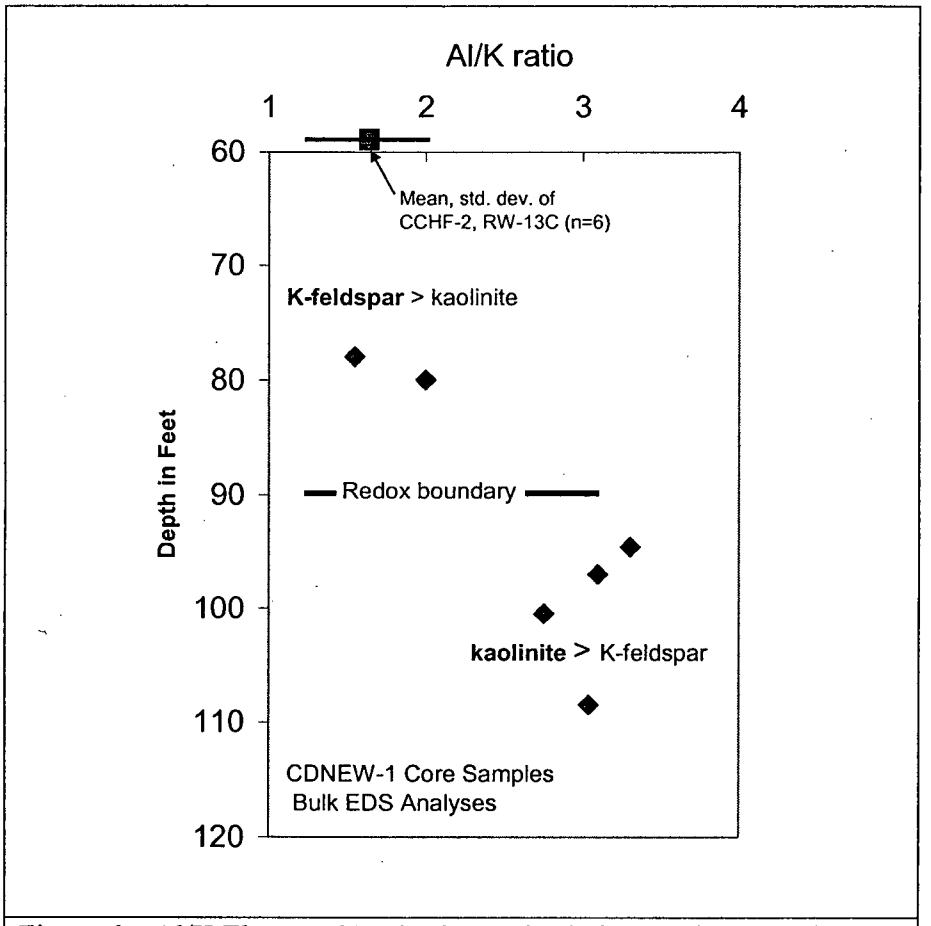

Figure 6 – Al/K Elemental Ratios by EDS whole-sample spectral analysis

SEM observations:

Typical SEM images of the samples examined are presented in figures 7-15. Samples of CCHF-2 and RW-13C retain relatively clear pore throats, with clay development generally limited to grain boundaries. Similarly, samples from CDNEW-1 above the redox boundary also have relatively open pores with limited kaolinite present. Samples from CDNEW-1 below the redox boundary generally exhibit abundant kaolinite in pore spaces.

The low relative abundance of kaolinite in samples other than those from the reduced zone in CDNEW-1, the altered appearance of K-feldspar grains in the reduced zone, and the fine grain size of the kaolinite in the reduced zone are all consistent with relatively recent production of the kaolinite by alteration of feldspar in contact with acidified water from tailings leachate. This suggests that alteration is ongoing, and will continue until natural buffering of the leachate is accomplished by feldspar hydrolysis.

Images are secondary electron imaging mode unless otherwise noted.

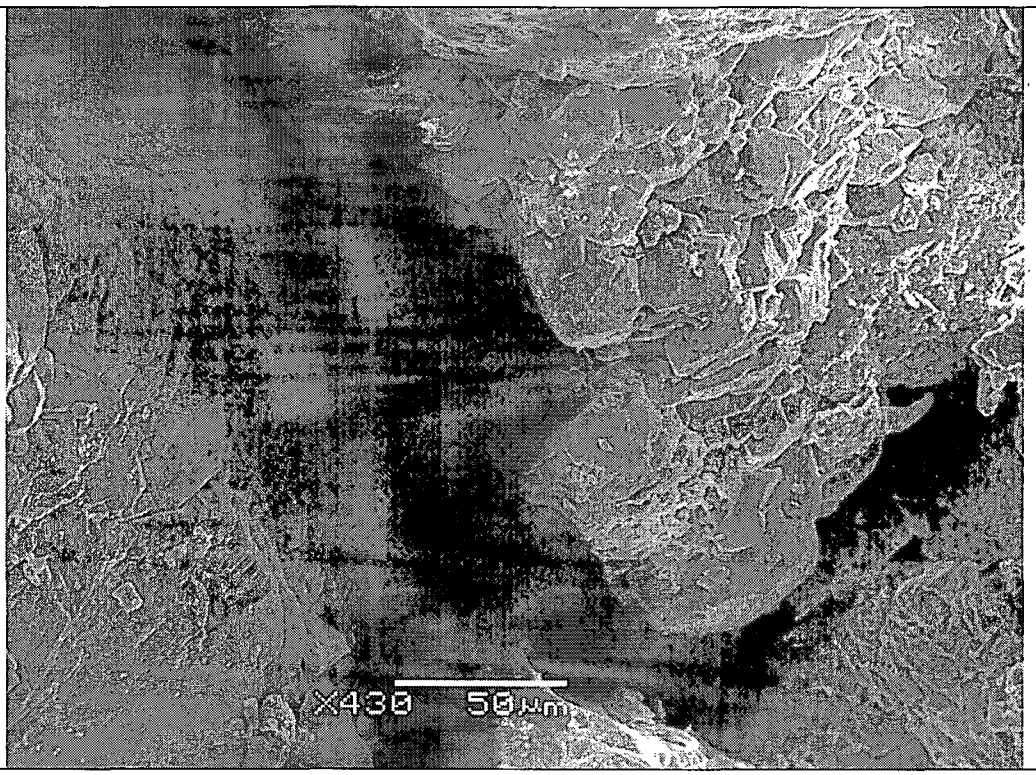

Figure 7 – CDNEW-1-78. Quartz grain (to left) and K-feldspar grain with authigenic overgrowth (center); note open pore space; fresh (unaltered) feldspar

Figure 8 – CDNEW-1-78 – open pore network

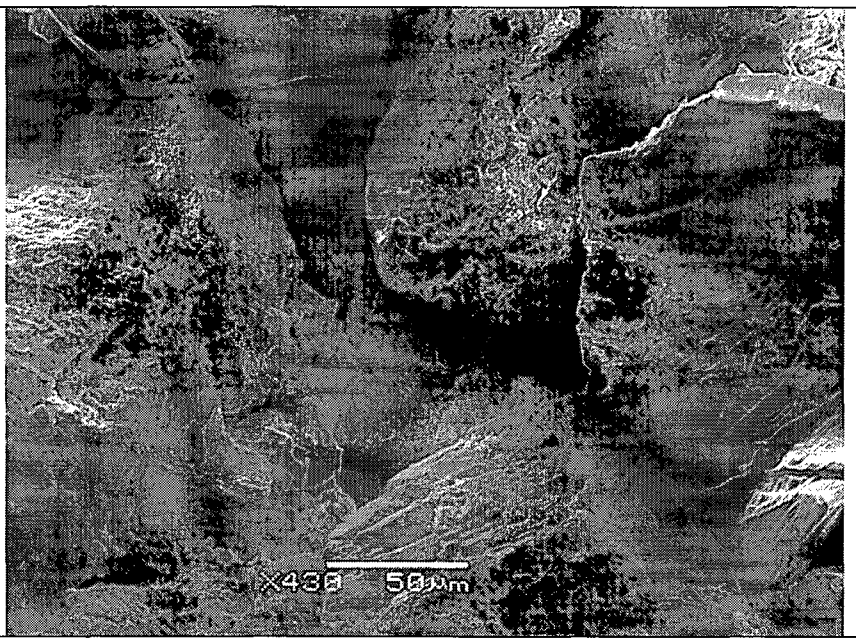

Figure 9 – CDNEW-1-80

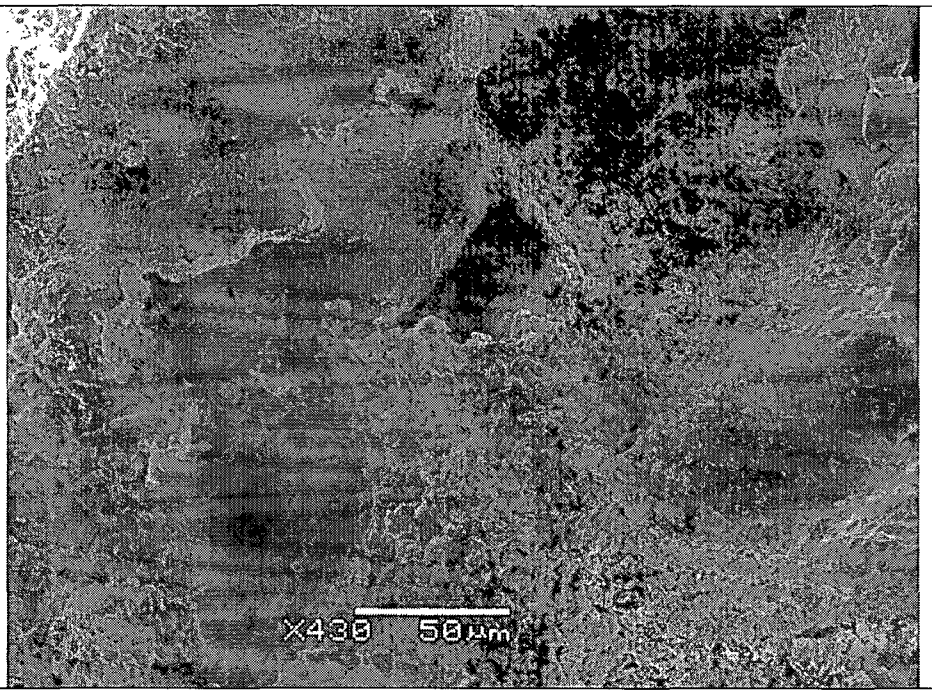

Figure 10 – CDNEW-1-94.6 Note abundant kaolinite; compare with figure 9 (same magnification)

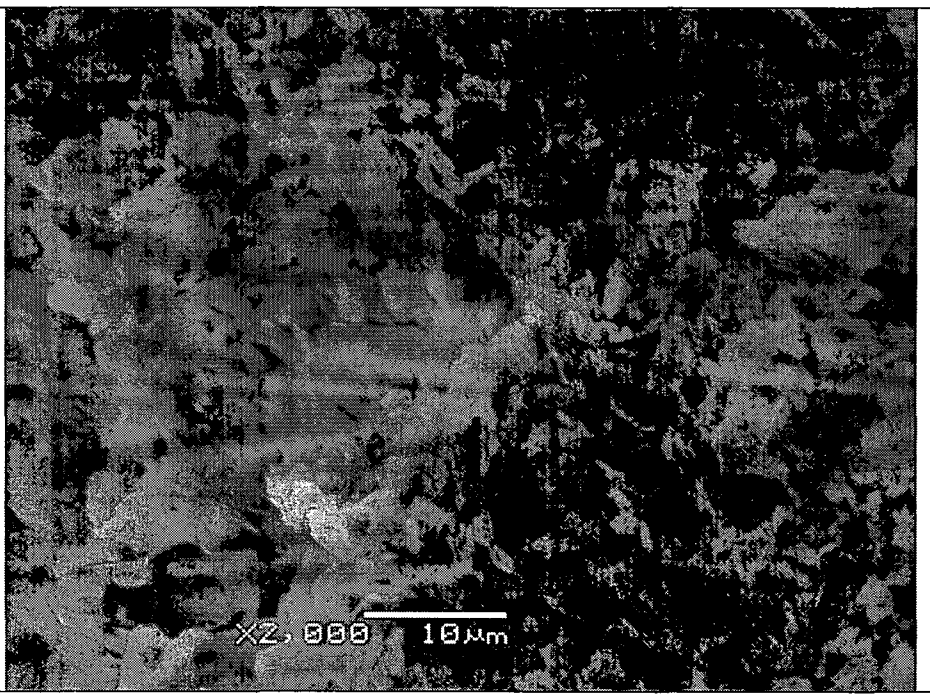

Figure 11- CDNEW-1-94.6 Detail of kaolinite in image above. Note grains are 1-2 microns.

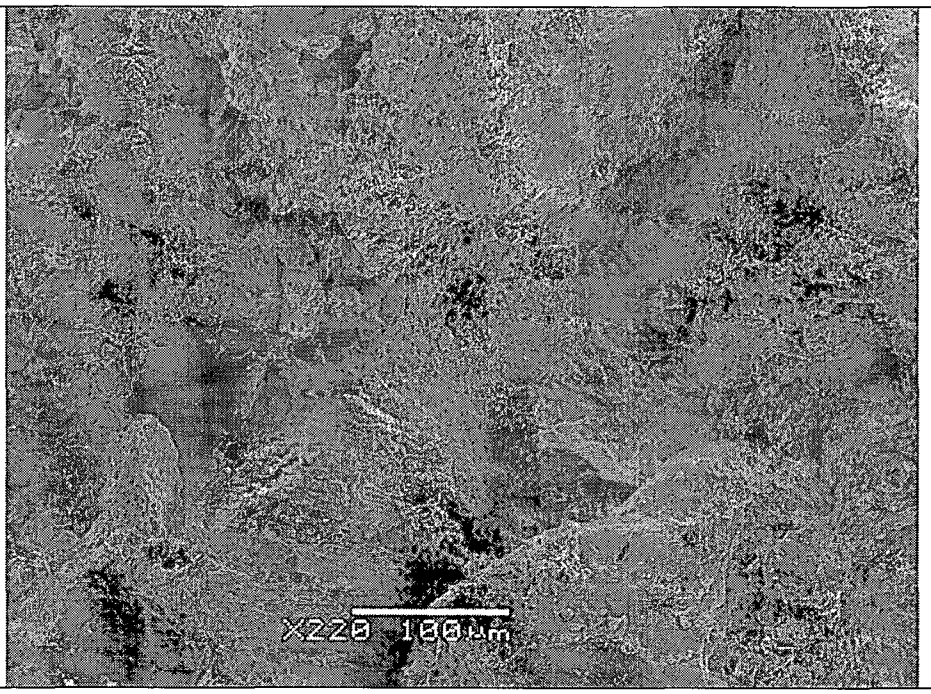

Figure 12 – CDNEW-1-100.5. Note abundant kaolinite; 'etched' K-feldspar in lower left-center.

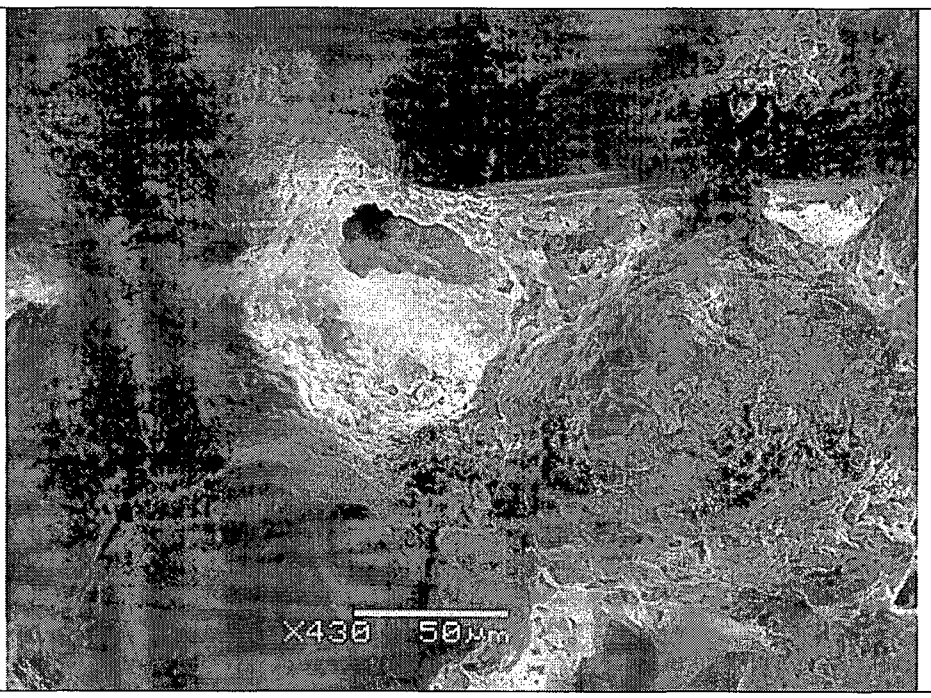

Figure 13 – CDNEW-1-108.5 – Kaolinite lining, but not yet occluding pore space.

Figure 14 – CCHF-2-149.5. Backscatter electron imaging mode. Note open pore space, unaltered feldspar grains in middle of view.

Figure 15 – RW-13C-132

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Attachment B

EPA-14 Analytical Results

ENERGY LABORATORIES, INC. · 2393 Salt Creek Highway (82601) · P.O. Box 3258 · Casper, WY 82602
Toll Free 888.235.0515 · 307.235.0515 · Fax 307.234.1639 · casper@energylab.com · www.energylab.com

ANALYTICAL SUMMARY REPORT

April 07, 2004

Max Chischilly
United Nuclear Corporation
21 Miles NE of Gallup State Road 566 (87301)
PO Box 3077
Gallup, NM 87305

Workorder No.: C04020881 Quote ID: C129

Project Name: Quarterly Long List

Energy Laboratories Inc. received the following 2 samples from United Nuclear Corporation on 2/25/2004 for analysis.

Sample ID	Client Sample ID	Collect Date	Receive Date	Matrix	Test
C04020881-001	EPA-14F	02/25/04 0:00	02/25/04	Aqueous	Alkalinity QA Calculations Arsenic-III, Dissolved Selenium-IV, Dissolved Metals by ICP, Dissolved Metals by ICP-MS, Dissolved Nitrogen, Ammonia Nitrogen, Nitrate + Nitrite pH Solids, Total Dissolved
C04020881-002	EPA-14F Solid	02/25/04 0:00	02/25/04	Solid	Metals by ICP, Total Digestion, Total Metals Subcontracted, The Mineral Lab

There were no problems with the analyses and all data for associated QC met EPA or laboratory specifications except where noted in the Case Narrative or Report.

If you have any questions regarding these tests results, please call.

Report Approved By:

The Mineral Lab, Inc.
2700 Youngfield Suite 105
Lakewood, CO 80215
(303) 232-8708

April 1, 2004
Lab no. 204251

Mr. Roger Garling
Energy Laboratories, Inc
P.O. Box 3258
Casper, Wyoming 82602

Dear Mr. Garling:

Enclosed are the x-ray diffraction (XRD) analytical results for sample, "C04020881-002A" submitted with PO no. 44595. This sample was analyzed previously by x-ray fluorescence (XRF) under our lab no. 204215.

A representative portion of the ground sample was packed into a well-type holder and then scanned with the diffractometer over the range, 3-61 °2θ using Cu-Kα radiation. The results of the scan are summarized as approximate mineral weight percents on the enclosed table. Estimates of mineral concentrations were made using our XRF-determined elemental composition and the relative peak heights/areas on the XRD scan. This sample appears to consist almost entirely of "amorphous" (noncrystalline) material. Amorphous material appears only as a broad elevation in the background of the XRD scan so its composition cannot be determined and the estimate of its concentration must be considered an educated guess based on the difference between the total mineral concentration and 100%. The detection limit for an average mineral in this sample is ~1-3% and the analytical reproducibility is approximately equal to the square root of the amount. "Unidentified" accounts for that portion of the XRD scan which could not be resolved and a "?" indicates doubt in both mineral identification and amount.

Thank you for the opportunity to be of continuing service to Energy Laboratories.

Sincerely,

Peggy Dalheim

Peggy Dalheim

Energy Laboratories, Inc
XRD Results for Sample, "C04020881-002A" (PO no. 44595)

April 1, 2004
Lab no. 204251

Mineral Name	Chemical Formula	Approx. Wt %
Bassanite	$CaSO_4 \cdot 1/2H_2O$	5
"Amorphous"	?	>90
"Unidentified"	?	<5

Analysis performed by The Mineral Lab, Inc

The Mineral Lab, Inc.
2700 Youngfield Suite 105
Lakewood, CO 80215
(303) 232-8708

MAR 25 2004

March 22, 2004
Lab no. 204215

Mr. Roger Garling
Energy Laboratories, Inc
P.O. Box 3258
Casper, Wyoming 82602

Dear Mr. Garling:

Enclosed are the x-ray fluorescence (XRF) analytical results for sample, "C04020881-002A" submitted with PO no. 44595.

A representative portion of the sample was ground to approximately -400 mesh in a steel swing mill and then analyzed by our standard XRF procedure for 31 major, minor and trace elements. The relative precision/accuracy for this procedure is ~5-10% for major-minor elements and ~10–15% for trace elements (those elements listed in ppm) at levels greater than twice the detection limit in samples of average geologic composition. A replicate sample and a standard reference material ("SY3", a CANMET standard rock) were analyzed with the sample to demonstrate analytical reproducibility for your sample and analytical accuracy for a geologic standard, respectively. The accepted ("known") values for the quality control standard are listed with the XRF results.

Thank you for the opportunity to be of continuing service to Energy Laboratories.

Sincerely,

Peggy Dalheim

Peggy Dalheim

Energy Laboratories, Inc
XRF Results for Sample, "C04020881-002A" Received with PO# 44595

March 22, 2004
Lab no. 204215

Ident	Wt %												
	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	S	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	BaO
SAMPLE	0.14	0.61	38.7	5.13	<0.05	4.04	0.06	0.01	1.83	<0.01	<0.01	0.18	<0.01
Quality Control - Replicate (R) sample and standard reference material (SY3) analyzed with sample													
SAMPLE(R)	0.14	0.61	38.9	5.17	<0.05	4.05	0.06	0.01	1.83	<0.01	<0.01	0.18	<0.01
SY3-XRF	4.38	2.49	12.7	61.6	0.75	<0.05	<0.02	4.29	8.17	0.12	0.29	6.27	0.05
SY3-known	4.15	2.67	11.8	59.7	0.54	0.05	0.014?	4.20	8.26	0.15	0.32	6.45	0.05

Ident	PPM												
	V	Cr	Co	Ni	W	Cu	Zn	As	Sn	Pb	Mo	Sr	U
SAMPLE	<10	10	18	33	26	25	343	48	<50	57	13	187	273
Quality Control													
SAMPLE(R)	<10	10	17	34	26	25	344	49	<50	57	13	188	278
SY3-XRF	53	<10	16	<10	47	13	256	<20	<50	143	<10	306	655
SY3-known	51	10	12	11	--	16	250	20	--	130	--	306	650

Ident	PPM				
	Th	Nb	Zr	Rb	Y
SAMPLE	17	<10	22	<10	488
Quality Control					
SAMPLE(R)	21	<10	21	<10	485
SY3-XRF	1028	168	324	200	802
SY3-known	990	145	320	208	740

Analysis Performed By The Mineral Lab, Inc