United Nuclear Corporation Gallup, New Mexico

Annual Review Report – 2004 Groundwater Corrective Action Church Rock Site, Church Rock, New Mexico

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UNITED NUCLEAR CORPORATION GALLUP, NEW MEXICO

ANNUAL REVIEW REPORT – 2004 GROUNDWATER CORRECTIVE ACTION CHURCH ROCK SITE, CHURCH ROCK, NEW MEXICO

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- C Zone 1 Monitoring Data (Table C.1) with Introductory Text; Figure C-1 (Zone 1 2004 Monitoring Well Locations); and 2004 Laboratory Groundwater Analytical Reports.





List of Acronyms and Abbreviations

ACL	alternate concentration limit
ALARA	as low as reasonably achievable
EPA	U.S. Environmental Protection Agency
ft/yr	feet per year
gpm	gallons per minute
IC	institutional control
MCL	federal primary maximum contaminant level
mg/L	milligrams per liter
MNA	monitored natural attenuation
NA	natural attenuation
NMED	New Mexico Environment Department
NRC	Nuclear Regulatory Commission
pCi/L	picocuries per liter
POC	point of compliance
POE	point of exposure
ROD	Record of Decision
SFS	Supplemental Feasibility Study
SMCL	federal secondary maximum contaminant level
TDS	total dissolved solids
ТІ	technical impracticability
μg/L	micrograms per liter



Section 1 Introduction

On behalf of United Nuclear Corporation (UNC), N.A. Water Systems (formerly USFilter) has prepared this annual performance review of the groundwater corrective action at UNC's Church Rock Mill and Tailings Site near Gallup, New Mexico, pursuant to NRC Source Materials License 1475, Condition 30C. UNC has submitted an annual review report at the end of each operating year since 1989. This report is the sixteenth in the series and includes groundwater quality analyses and groundwater elevations for the first quarter of 2004 through the fourth quarter of 2004.

This report, similar to the 2003 report (USFilter, 2004a), focuses on the groundwater performance of the natural systems without active remediation. As indicated in the U.S. Environmental Protection Agency's (EPA's) *First Five-Year Review Report* (EPA, 1998) and by the approvals to decommission or temporarily shut off the three corrective action systems, the agencies recognized that the corrective actions have reached the limit of their effectiveness. EPA (1988) recommended that Technical Impracticability (TI) Waivers, Alternate Concentration Limits (ACLs), and Monitored Natural Attenuation (MNA) be used to complete the corrective action program. Presentations and reports prepared to document the geochemical processes in the Southwest Alluvium (Earth Tech, 2000d and 2002c) and the Zone 1 hydrostratigraphic unit (Earth Tech, 2000c) showed that the natural geochemical mechanisms are at least as effective as the active remediation systems in controlling the migration of constituents of concern. This annual report focuses on how these natural processes are performing.

During January 2004, UNC submitted the results of a study undertaken to evaluate the potential for the covered, dewatered tailings impoundments to serve as continuing sources of seepage impact in the upgradient parts of the Zone 3 hydrostratigraphic unit (USFilter, 2004b). That report included recommendations for follow-up work, the results of which are presented in this annual report.

During February 2004, the EPA provided comments to UNC on the *Final Report* and *Technical Impracticability Evaluation and Southwest Alluvium Natural Attenuation Test* (Earth Tech, 2002c), including the request that the natural attenuation (NA) test should be allowed to continue for approximately one more year, after which time the efficacy of natural attenuation should be reassessed and reported. This annual report provides a reassessment of the effectiveness of NA in the Southwest Alluvium.

EPA's Second Five-Year Review Report (2003) and a subsequent letter to UNC (EPA, 2004a) requested that a Supplemental Feasibility Study should be





conducted to assess the future actions that should be taken in Zone 3. The results of that study were submitted in October 2004 (MWH, 2004) and are briefly reviewed in this annual report.

1.1 Site Location

The Church Rock Site ("Site") is located approximately 17 miles northeast of Church Rock, McKinley County, New Mexico (see Figure 1). Figure 2 is a Site map that shows the location of the decommissioned and temporarily idled extraction wells, the performance monitoring wells, the evaporation ponds, and the reclaimed tailings areas. Figure 2 also shows the Remedial Action Target Area for each hydrostratigraphic unit, where the impacts of tailings seepage were originally identified and corrective action was implemented. Additional background information on Site facilities and activities is available in the previous annual reviews (Canonie Environmental Services Corp. [Canonie], 1989b, 1990, 1991, 1992, 1993 and 1995; Smith Technology Corporation [Smith Technology], 1995 and 1996; Rust Environment and Infrastructure [Rust], 1997; Earth Tech, 1998, 1999, 2000e, 2002a and 2002d; and USFilter, 2004a).

1.2 Corrective Action Systems

The corrective action systems for tailings seepage remediation were installed and began operating during the summer and fall of 1989. These systems have been decommissioned or, in the case of the Southwest Alluvium, temporarily shut off, and performance monitoring is ongoing. The Zone 1 system was decommissioned in July 1999 in accordance with the letter from the Nuclear Regulatory Commission (NRC) dated July 30, 1999 (NRC, 1999a). 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 agencies agreed that the existing system should be decommissioned (NRC, December 29, 2000 License Amendment). This decision 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. UNC is conducting an ongoing, extended pilot investigation to evaluate the suitability of hydrofracturing to impacted area enhance the extraction potential within the of this hydrostratigraphic unit (MACTEC, 2003; MWH, 2004). The Southwest Alluvium system was temporarily shut off in January 2001 to allow implementation of the NA test, which was discussed and approved during the November 14 and 15, 2000, meeting in Santa Fe, New Mexico, and documented in the November 15, 2000, letter from the EPA. As requested by the EPA (2004a; and during a meeting in Santa Fe on February 26, 2004), UNC continues to acquire





groundwater quality data from wells in the Southwest Alluvium to continue assessing the effectiveness of natural attenuation.

1.3 Performance Monitoring

The *Corrective Action Plan* (UNC, 1989a), *Remedial Design Report* (Canonie, 1989a) and *Remedial Action Plan* (UNC, 1989b), approved by the NRC and EPA, described the groundwater performance monitoring program. The program has been modified over time, as described in the annual reports (Canonie, 1989b, 1990, 1991, 1992, 1993 and 1995; Smith Technology, 1995 and 1996; Rust, 1997; and Earth Tech, 1998, 1999, 2000e, 2002a and 2002d), to adjust the monitoring requirements as the corrective action has progressed. The NRC and EPA have approved all modifications.

In accordance with the EPA's request in 1999, UNC developed a revised monitoring program that began with the second quarter 2000 sampling event. The revised program is documented in the letters dated January 13, 2000 (Earth Tech, 2000a), and April 26, 2000 (Earth Tech, 2000b). Details of the revised monitoring program for each hydrostratigraphic unit are provided in the performance-monitoring portion of the following sections and in the appendices.

The field and laboratory data collected from the fourth quarter of 1989 through the fourth quarter of 2004 are tabulated in Appendices A (Southwest Alluvium), B (Zone 3), and C (Zone 1). These tables include the revised background standards for sulfate, nitrate, and total dissolved solids (TDS) recommended by the NRC in its report evaluating background for the Site (NRC, 1996) and supported by the New Mexico Environment Department (NMED) in its letter to the EPA dated January 6, 1998 (NMED, 1998). These revised standards are 2,125 milligrams per liter (mg/L) for sulfate, 190 mg/L for nitrate, and 4,800 mg/L for TDS. Quarterly laboratory analytical data sheets for the 2004 operating year are included at the end of each appendix. The original field and laboratory data for the period from 1989 to 2003 are included in the previous annual reviews.

Two new piezometers were installed in the southeastern, updip part of Zone 3 during 2004, following the recommendation made in UNC's evaluation of the potential for the tailings cells to continue to source seepage impact (USFilter, 2004b). Observations from these piezometers are discussed in Section 3 of this annual report (they are dry). These piezometers are not a formal part of the performance monitoring program.

Following EPA's request on November 15, 2000 (meeting in Santa Fe), a new well was installed in the downgradient part of the Southwest Alluvium during 2004. This well is not a formal part of the performance monitoring program.





1.4 Southwest Alluvium

The NA test assessment report was submitted during the 2002 reporting year. The test involved temporarily shutting off the pump-back wells and monitoring the water quality and water levels on a monthly basis. The results were presented in a "final" report submitted in November 2002 (Earth Tech, 2002c). The former extraction wells have continued to be idle since they were shut off in January 2001. This annual report presents a continuing assessment of the effectiveness of natural attenuation in the Southwest Alluvium.

1.5 Report Organization

This report has been organized with each hydrostratigraphic unit presented in a separate section:

Section 2 Southwest Alluvium

Section 3 Zone 3

Section 4 Zone 1

Section 5 Conclusions and Recommendations

Section 6 References

The monitoring data are contained in separate appendices for each hydrostratigraphic unit:

Appendix A Southwest Alluvium Monitoring Data

Appendix B Zone 3 Monitoring Data

Appendix C Zone 1 Monitoring Data



Section 2 Southwest Alluvium

2.1 Corrective Action Summary

The Southwest Alluvium corrective action system remained idle in 2004. The pumps remain shut off pending further discussion with the EPA regarding the efficacy of NA.

2.2 Mass of Chemical Constituents Removed

The mass of chemical constituents removed was calculated for the 12-year period from November 1989 through January 2001. These calculations were presented in the previous annual reviews, and the final summary was presented in the *2001 Annual Review* (Earth Tech, 2002a).

2.3 Performance Monitoring Evaluation

The current performance monitoring program in the Southwest Alluvium is summarized in Table 1 and comprises quarterly monitoring of water levels in 16 wells and water quality in 14 wells. The monitoring well locations are shown on Figure 2. A summary of constituents detected in the Southwest Alluvium in October 2004 is provided in Table 2. Historic groundwater quality and groundwater elevation data through October 2004 are provided in Appendix A (Table A.1).

2.3.1 Water Level Evaluation

Groundwater in the Southwest Alluvium in the vicinity of the tailings impoundments was created by the infiltration of pumped mine water that was discharged to the Pipeline Arroyo. This water percolated into the alluvium and created temporary saturation in the vicinity of the tailings impoundments. This temporary saturation caused by discharged mine water is the recognized Southwest Alluvium background water (EPA, 1988; 1998). Saturation has been declining since the mine water discharge ceased in 1986. As a result, the flanks of the alluvial valley and the northern property boundary alluvium have been completely de-saturated and, as of 2000, a 31 percent saturation loss had been observed further to the south (Earth Tech, 2000d). The October 2004 saturated thickness for each well in the performance monitoring program is provided in Table 3. During 2004, all wells have shown overall decreasing groundwater elevations (with small fluctuations), indicating that the Southwest Alluvium





potentiometric field that drives groundwater flow and constituent migration continues to become lower as the groundwater further drains down the arroyo.

The Southwest Alluvium potentiometric surface map for October 2004 is shown in Figure 3. The depiction of the approximate limits to the saturated alluvium (shown with heavy dashed green lines) is different than in earlier Site annual reports, including the report for 2003 (USFilter, 2004a). Between Wells 509 D and EPA 23, the limits to the saturated alluvium are shown to be beneath the northwestern part of the South Cell. This is because Figure 3 has been developed using Surfer[™] contouring software applied to both the saturated alluvium thickness measurements (Table 3) and the elevations along the top-ofbedrock underlying the alluvium. This local, eastward turn to the saturated alluvium reflects the presence of an upward bulge in the bedrock between Wells 509 D and EPA 23. This bulge encompasses the area including the "Nickpoint" along Pipeline Arroyo. The Nickpoint has been referred to in earlier reports. It is a local, rim-like bedrock high along the arroyo, below which the streamway becomes incised and continues downgradient as Pipeline Canyon.

Southwest Alluvium groundwater flows to the southwest, along the Pipeline Arroyo. Based on calculations of the volume of background groundwater drainage through the valley in comparison to historic pumping rates, the drainage had exceeded the pumping rate throughout the corrective action period by 30 percent or more (Earth Tech, 2000d).

Figure 4 shows water levels over time in Southwest Alluvium wells, illustrating the overall long-term trend of decreasing levels as water continues to drain through the Southwest Alluvium. Water levels in the vicinity of the pumping wells increased temporarily after they were turned off in January 2001 for the start of the NA test (see Figure 5). Water levels in the former pumping wells have since stabilized at elevations similar to those measured in nearby monitoring wells. These stable to declining water levels indicate that the hydraulic system has fully recovered from the effects of pumping. A summary of operational data for the Southwest Alluvium extraction wells is provided in Table 4.

Groundwater pumping did not fully contain seepage-impacted water and would not do so in the future (Earth Tech, 2000d); however, it is important to realize that hydraulic containment is not a necessary feature of the corrective action program in the Southwest Alluvium because of the strong geochemical attenuation that occurs naturally.

A new monitoring well (SBL 1, Figure 3) was installed in July 2004; it is located 500 ft to the southwest of Well 624. This well has a depth of 64 ft below ground at the base of the alluvium; a construction and geologic log will be presented under separate cover.





2.3.2 Water Quality Evaluation and Current Extent of Seepage-Impacted Water

The current area that contains the seepage-impacted groundwater in the Southwest Alluvium is shown on Figure 6. This depiction is explained more fully below to encompass the region that has been demonstrated to have undergone a shift in common ion geochemistry brought on by the neutralization of tailings fluids during transport through the alluvium. It extends approximately 4,980 ft, trending to the southwest along the western margins of the North, Central, and South Cells, and continuing to the southwest. From the tailings cells, the area of impacted water extends approximately 1,400 ft across the southeastern corner of adjacent Section 3 and approximately 240 ft into the north-central portion of adjacent Section 10.

Currently only two constituents, sulfate and TDS, exceed the Site standards in the Southwest Alluvium seepage-impacted groundwater outside the United Nuclear property boundary in Sections 3 and 10. Sulfate and TDS, which are non-hazardous constituents, also exceed groundwater quality standards in the background water (Wells 627, EPA 28 and SBL 1). The majority of TDS is composed of sulfate; therefore, TDS concentrations mimic sulfate concentrations (Earth Tech, 2000d).

Historic sulfate concentrations through October 2004 are shown graphically in Figure 7. This figure shows that the long-term concentrations in most wells have overall remained approximately steady (with some fluctuations). However, the concentrations in Wells 801 and 509 D decreased in January 2000 and October 1999, respectively, and have remained at these relatively lower levels since. The single data point in the upper right part of this chart represents the first sulfate measurement that was made from new Well SBL 1 in October 2004. This well showed the highest sulfate concentration (5,390 mg/L) of any well in the Southwest Alluvium (including all historic measurements), including the nearest, hydraulically upgradient Well 624 which is impacted by seepage and had a sulfate level in October 2004 of 3,140 mg/L.

Figure 8 shows a bicarbonate isoconcentration map of the Southwest Alluvium during October 2004. As explained in earlier annual reports and in the natural attenuation evaluation (Earth Tech, 2002c), bicarbonate concentration is the main attribute by which the presence and extent of seepage-impacts can be evaluated. The seepage-impacted area has near-neutral pH values as a result of the high capacity of the alluvium to neutralize the acidic tailings seepage. The neutralization capacity is also responsible for preventing the migration of metals from the former tailings impoundments. The neutralization capacity is strongly tied to relatively large amounts of alluvium calcite available for buffering: Canonie (1987, Table 4.4) reported measured alluvium CaCO₃ contents of 2.58





percent (sample collected during drilling of Well EPA 23); from 0.77 to 0.28 percent near the Pipeline Arroyo Nickpoint; and from 0.02 to 12.6 percent elsewhere.

In Figure 8 of this annual report, we are able to further refine the depiction of the neutralization reaction zone because of the installation of the new sentinel well, SBL 1. For the first time, it is possible to present bicarbonate isoconcentration contours throughout the seepage-impacted area. The advantage of showing isoconcentration contours is that the zone of seepage-impacted water can be seen in finer resolution. The seepage-impacted zone was depicted in earlier reports as a "sharp-line" area based on assumptions of seepage migration rates and where bicarbonate concentrations exceeded 1000 mg/L. It can now be recognized to exhibit a core of more significant impact (bicarbonate concentrations exceeding 2000 mg/L) progressing outwards to less and less impact (approximated by the 1000 mg/L contour).

Well SBL 1 was installed at the request of the EPA. EPA wanted to gain an ability to monitor groundwater beyond the area that currently exhibits seepage impacts. This was necessary to further EPA's ongoing evaluation of the effectiveness of monitored natural attenuation in the Southwest Alluvium groundwater system. EPA wanted to show first, that the extent of seepage impacts are in general agreement with predictions made on hydraulic principles via estimates of groundwater velocity (see Section 2.3.3); and second, to provide a sentinel well that can be used to track the groundwater quality changes that occur with the eventual passing of the seepage-impacted water front.

The groundwater quality characteristics of the non-seepage-impacted water sample from Well SBL 1 differ in several important aspects from seepage-impacted water (refer to Figure 9 and Appendix A). The water from well 624 is the closest known seepage-impacted water that is located upgradient from well SBL 1. Well 624 lies 500 ft up the flow field from Well SBL 1 (Figure 3). Although the following observations compare these two wells in particular, they apply equally well to most, if not all, of the seepage-impacted wells:

- Well SBL 1 contains a magnesium-sulfate (Mg-SO₄) type water while Well 624 contains a calcium-sulfate (Ca-SO₄) type. The presence of much higher magnesium concentrations in SBL 1 is suggestive of the dissolution of magnesium-salts in the alluvium (for example, epsomite or magnesite) during the earlier flushes of mine discharge water down Pipeline Arroyo.
- The alkalinity (bicarbonate or HCO₃) of Well SBL 1 water is much less than the seepage-impacted water in Well 624 samples. As acidic tailings liquids seeped into the alluvium beneath the tailings impoundments, the acid was neutralized by dissolution of carbonate minerals. The reaction between the





acidic water and carbonate-bearing minerals released bicarbonate in relatively high concentrations. Chloride concentrations in Well SBL 1 are also lower than those indicative of seepage-impacted groundwater (see Appendix A and the discussion below in Section 2.3.4).

- Geochemical speciation calculations using EPA's MINTEQ numeric modeling code confirm that several aluminum-hydroxide (AI-OH) salts are oversaturated in Well SBL 1 water while they are not in Well 624 water. Similar to the explanation given above for the high magnesium concentrations, it is inferred that the water further downgradient than the seepage-impacted water may show signs of the dissolution of soluble salts associated with earlier flushes of the alluvium.
- Well SBL 1 water and seepage-impacted water are alike in that both appear • to be in approximate equilibrium with an assemblage of Ca-SO₄ (as anhydrite or gypsum), magnesium-carbonate (Mg-CO₃, as magnesite or dolomite), and calcium-carbonate (CaCO₃, as calcite). MINTEQ simulations show that when acidic water (i.e., tailings liquid) is exposed to these mineral phases, there is a geochemical shift toward higher bicarbonate concentrations and lower sulfate concentrations (e.g., Well 624) than would occur in the absence of the acid (e.g., Well SBL 1). This type of re-equilibration is exactly the type of shift in water chemistry that is observed in seepage-impacted water compared to water that lies outside the zone of seepage-impacted water. It is a natural consequence of the law of mass action wherein the release of calcium and bicarbonate that occur when acidic fluids were added to the alluvium are accompanied by the tendency of the system to maintain constant calcium concentrations via the precipitation of additional gypsum. The result is a tendency to increase bicarbonate, decrease sulfate, and maintain constant calcium concentrations as the seepage-impact front migrates. By the Phase Rule, the presence of two calcium-bearing phases forces the system to try to maintain constant calcium concentrations.

An interesting consequence of the migration of the seepage front should be that the ratio of sulfate to bicarbonate is at a minimum where the tailings seepage front meets and reacts with non-impacted areas in the alluvium. Sulfate is greater within the core of the seepage-impacted areas because sulfate concentrations in the tailings liquids were up to two orders-of-magnitude greater than the amount that remains in the seepage-impacted water. A significant amount of gypsum had to precipitate in proximity to the concentrated tailings liquids to cause the reduction of sulfate concentrations to levels that are in equilibrium with gypsum. Out in front of the seepage-impacted water, the dissolution of the alluvium gypsum (or anhydrite) produced sulfate in the background water at levels above the standard. The general areas where sulfate concentrations are lower than the Site standard of 2,125 mg/L are shown





in Figure 8 with stippled pattern, and they confirm the expectation that sulfate concentrations should be lowest along the periphery of the tailings seepage front.

Figure 8 shows that the area comprising sulfate below the standard is relatively small and mostly confined to the area of impacted groundwater. Relatedly, sulfate is expected to exceed the standard over an openly large area of background water, as well as within the core zone of seepage impact. The area depicting sulfate less than 2,125 mg/L in Figure 8 is elongate parallel to the bicarbonate isoconcentration contours. This area represents a migrating reaction zone separating relatively elevated sulfate due to seepage impact in its transport "wake," from relatively elevated sulfate downgradient (or side-gradient) in background water that the reaction zone has not reached. The area of seepage-impact is very small in comparison to the area of background sulfate levels above the standard; the latter condition is likely to persist downgradient within the alluvium for miles. This large area of background sulfate exceedances has an origin unrelated to the tailings impoundments and seepage impacts.

These same conceptual geochemical models, for both the earlier evolution of the background water chemistry and the later, progressive evolution of seepageimpacted water chemistry, can be constructively applied to consideration of the groundwater chemistry data shown in Figure 9. Figure 9 shows the primary components of TDS in the Southwest Alluvium in October 2004. The chart arrangement of the wells runs approximately from those located upgradient, on the left of the chart, to those downgradient on the right. Three background wells (627, EPA 28 and SBL 1) show relatively elevated sulfate combined with high ratios of sulfate to bicarbonate. Background Well EPA 25 shows a relatively lower ratio of these two parameters in conjunction with relatively elevated calcium. The long-term geochemistry there (Appendix A) suggests that full seepage impact waters have been nearby, consistent with its hydraulically sidegradient location with respect to the bicarbonate isoconcentration map in Figure 8. Figure 9 shows the highest contribution of sulfate to the TDS is in Well SBL 1 (this also had the historically highest sulfate concentration of any Southwest Alluvium well), which also shows the lowest contribution from bicarbonate (HCO₃) and a very low contribution from chloride.

The above observations and analysis confirm that Well SBL 1 has been placed further downgradient than the current extent of seepage-impacted water. They also confirm, as do the raw analytical data, that the quality of both the seepageimpacted water and non-seepage-impacted water do not meet New Mexico water quality standards for TDS. There is a shift in the composition of the dissolved solids in each case, with magnesium and sulfate in higher concentrations in the non-seepage-impacted water and calcium and bicarbonate being higher in seepage-impacted water (Figure 9). There is no situation that can be envisioned





in which the natural quality of alluvium groundwater can be degraded by the migration of seepage-impacted water. In some respects, particularly regarding sulfate concentrations, the seepage-impacted water may be viewed as an improvement. Groundwater quality within the Southwest Alluvium is further discussed in Section 2.3.4.

Two other constituents are present at concentrations that exceed the Site standards only within the property boundary:

- Chloride Chloride concentrations exceed the Site standard (250 mg/L) at Well 509 D. This well has exhibited gradual concentration increases at an average rate of approximately 11 mg/L per year since 1990. The chloride concentration at Well 632 has fluctuated about the standard with no discernible trend since 1990, and continued to do so during 2004 (Appendix A). Historically, chloride concentrations also exceeded the standard in Well 801, but a long-term, gradual decreasing trend (average -2 mg/L per year) has produced recent concentrations below the standard (see Appendix A). Chloride concentrations are discussed more in Section 2.3.4.
- Chloroform Exceedances of chloroform (>0.001 mg/L) were measured in ٠ wells 632, 801, 802, 803, and 808. Concentrations in Wells 632 and 801 have fluctuated about respective averages of approximately 0.002 and 0.003 mg/L, with no discernible trend since 2001 (see Appendix A). Chloroform concentrations at Well 803 fluctuated about the standard from mid-2002 through the second guarter of 2003. Since then, the concentration has risen to approximately 0.002 mg/L. Prior to April 2002, the only detection (0.0017 mg/L) was in July 2000. A similar pattern of change, with different timing, occurred at Well 802. Chloroform was rarely detected prior to 1998, fluctuated about the standard from 1998 through 2001, and subsequently rose to 0.0084 mg/L by the fourth guarter of 2004. The record at Well 808 began in January 2001, but is indicative of a pattern similar to that at Wells 802 and 803. Chloroform concentrations above and below the standard were recorded in the first half of 2001. Thereafter, the concentrations increased, reaching 0.0072 mg/L in the fourth quarter of 2004 (see Appendix A). Although the chloroform concentrations measured in October 2004 were the highest to date in Wells 802, 803, and Well 808, these concentrations are approximately ten times lower than the EPA's primary Maximum Contaminant Level (MCL; the federal drinking water standard). Spatial clustering of these wells indicates that the chloroform was probably derived from the western part of the South Cell (see Figures 2 and 8). The increasing chloroform concentration trends at former extraction Wells 802, 803, and 808 all postdate the cessation of pumping from the Southwest Alluvium in January 2001. These wells were also the more strongly influenced hydraulically by that event





(see Figure 5), having experienced a more significant degree of resaturation than other wells. It is likely that the low-level increases noted in these wells is a localized phenomenon. During the same period concentrations in downgradient Wells 632 and 801 lacked any trend and there has been a continued absence of detections in the point-of-compliance (POC) wells (GW 1, GW 2, and EPA 28) (see Appendix A).

Prior to the installation of new Well SBL 1 and its first groundwater quality analysis in October 2004, the only historic exceedances of manganese (>2.6 mg/L) were within the Site boundary. In October 2004, Well SBL 1 showed a manganese exceedance of 3.35 mg/L (Table 2). Manganese exceedances occurred in onsite Wells 509 D (overall steady concentrations but fluctuating about the Site standard), EPA 23 (overall steady but fluctuating about an approximate level of 5 mg/L), and 801 (declining concentration trend since January 1993). Historically, the standard for manganese has occasionally been exceeded in Wells 802, 803, and 808 (Earth Tech, 2002c) (see Appendix A).

Off-site seepage impacts to the groundwater are limited to exceedances of the sulfate and TDS standards, both of which are non-hazardous constituents. Unlike Zone 1 and 3 impacted waters, the pH of the Southwest Alluvium impacted water is nearly neutral. Consequently, there are no exceedances of the metals or radionuclides standards within the seepage-impacted water, with the exception of the noted exceedances of manganese located well within the property boundary. However, the non-impacted background water at downgradient Well SBL 1 showed October 2004 exceedances of manganese (3.35 mg/L), nickel (0.17 mg/L), and cobalt (0.06 mg/L). These metals exceedances are unrelated to seepage impact to the groundwater because seepage-impacted water has not yet migrated to this location.

2.3.3 Rate of Seepage Migration

Earth Tech (2002c) has previously analyzed concentration trends of chloride and bicarbonate to infer the rate of constituent migration. Seepage impacts were observed to have migrated beyond the Site property boundary by 1982, but the only constituents showing exceedances in the impacted water offsite have been sulfate and TDS. However, bicarbonate and chloride have been determined to be the more effective indicators of seepage impact for reasons described in Section 2.3.2. Using chemical trends and estimates of hydraulic conductivity, hydraulic gradient, and effective porosity, Earth Tech calculated an average migration rate of 77 ft/yr beyond Well 624. Their transport rate was applied to the updated depiction of the inferred, southern edge of the impacted water during October 2003 (Figure 3 in USFilter, 2004a).

New groundwater velocity calculations have been made to estimate the rate of downgradient seepage-impact transport. These estimates are Darcy seepage





velocities equal to the product of the hydraulic conductivity and the hydraulic gradient, divided by the effective porosity. The resultant groundwater velocities are upper-bound estimates of constituent transport velocities because no retardation or attenuation factors are applied.

Table 5 shows Southwest Alluvium groundwater velocities determined using hydraulic gradients based on the October 2004 measurements of groundwater elevations at wells 805, 624, 627 and SBL 1. Upper and lower estimates of seepage velocity are based on a range of effective porosities adopted from Canonie (1989b) and Earth Tech (2002c). The average calculated velocities are effectively based on a median porosity estimate of 0.31. Application of the mean hydraulic conductivity value of 3.69×10^{-3} cm/sec formerly used by Earth Tech (2002c) results in the prediction that seepage impact should already have arrived at Well SBL 1, which is not the case. The hydraulic conductivity value used in this annual report is 2×10^{-3} cm/sec, which was determined to be an appropriate mean value based on an extensive review of relevant site reports (USFilter, 2004b). This same mean alluvium hydraulic conductivity value was used in the groundwater modeling accomplished as part of the Zone 3 Supplemental Feasibility Study (MWH, 2004).

The average calculated groundwater velocity from Well 624 to Well SBL 1 is 30 ft/yr. This is approximately half the velocities associated with the other two upgradient well pairs, because the hydraulic gradient from 624 to SBL 1 is approximately half that associated with the other pairs (Table 5).

The onset of persistent attainment of the "full impact threshold" values for bicarbonate (1000 mg/L) and chloride (150 mg/L) in Well 624 occurred in October 1996 (eight years prior to October 2004). Using the updated average groundwater flow rate from Wells 624 to SBL 1 of 30 ft/yr, it is inferred that the October 2004 location of the seepage-impact front is 240 ft downgradient from Well 624. This is consistent with the groundwater chemistry at Well SBL 1, which indicates no seepage impact. At the calculated velocity of 30 ft/yr, it would take approximately 8.7 years, or until 2013, for the seepage impact front to traverse the 260 ft from its present inferred position to Well SBL 1. This estimate assumes a constant seepage velocity, which may only be approximately the case as saturation levels continue to decline. There are also uncertainties in the hydraulic parameters used to make this estimate. Therefore, the timing of the arrival of seepage impacts at SBL 1 is not subject to precise prediction.

It took more than seven years of gradual concentration increases, from the start of monitoring in July 1989, for full seepage-impact levels of bicarbonate and chloride to develop at Well 624. Therefore, the start of future possible gradual increases in the bicarbonate and chloride levels in Well SBL 1 might occur in approximately 1.5 years (~ April 2006). Continued monitoring of the water quality





at this location should eventually allow back-calculation of the relevant average hydraulic conductivity.

2.3.4 Continuing Assessment of Southwest Alluvium Natural Attenuation and Earlier Technical Impracticability Waiver Request

UNC conducted a natural attenuation test from February 2001 to July 2002 to determine whether shutting off the Southwest Alluvium extraction wells would adversely affect water quality. The Southwest Alluvium extraction wells were shut off in January 2001 for the duration of the test. The NA report was submitted to the EPA, NMED, and NRC on November 4, 2002 (Earth Tech, 2002c). The NA test report concluded that turning off the extraction wells does not have an adverse effect on water quality and that the natural system is as effective as, or more effective than, pumping for controlling the migration of the constituents of concern. EPA has not reached the same conclusion based upon the *Second Five-Year Review Report* (EPA, 2003) and further comments on the NA report (EPA, 2004a), and so additional monitoring is being performed.

The Technical Impracticability (TI) evaluation concluded that natural conditions maintain sulfate and TDS concentrations at non-impacted background concentrations, which are nonetheless greater than Site standards. Physical and geochemical processes that reduce the tailings-impacted groundwater concentrations to background (or lower than background) concentrations have operated since mine water discharge began. This is demonstrated by the sulfate concentrations from impacted wells that contain constituent concentrations equivalent to, or variously higher or lower than, the non-impacted background concentrations. (See Figures 7 and 8; compare background Wells 627, EPA 28, and SBL 1 with wells located within the area impacted by tailings seepage.) The same is true of TDS, for which historic concentrations are shown in Figure 10. Overall, ranges of TDS concentrations are no higher in impacted wells than in background wells. Background Well 627 has fluctuated about the Site standard (4.800 mg/L); background Well EPA 28 has persistently exceeded the standard; and background Well SBL 1 had the highest concentration of any well during October 2004 (the most recent concentration that exceeded this value was in impacted Well 801 during January 2000). The remediation system did remove sulfate and TDS mass, but this is irrelevant because concentrations are dependent on the chemical equilibrium of gypsum; therefore, they have been and will continue to remain similar to those previously achieved through geochemical processes that occur within the existing groundwater system. Thus the concentrations are not dependent on continuing the former pump-and-evaporate corrective action program, but are instead controlled by natural geochemical reactions; in particular, equilibrium between the groundwater and naturally occurring gypsum (or anhydrite).





Furthermore, under the federal drinking water standards, sulfate and TDS are listed as the secondary drinking water standards (SMCLs), which are nonenforceable guidelines regulating chemical constituents that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water (EPA, July 1992). EPA recommends secondary standards to water systems, but does not require those systems to comply. Under applicable New Mexico regulations (20 N.M.A.C.1101(TT)), TDS and sulfate are not defined as "toxic pollutants" for purposes of groundwater and surface water protection. Additionally, they are not included on NRC's hazardous constituent list applicable to groundwater. The standards set for sulfate and TDS are not for the protection of human health. The secondary standards are not federally enforceable, but are intended as guidelines. Therefore, a TI waiver has previously been deemed appropriate for sulfate and TDS (Earth Tech, 2002c; USFilter, 2004a).

UNC believes that the earlier part of this report demonstrates an understanding of, as well as the distinctions between, the geochemical evolution and characteristics of both background water and seepage-impacted water. The concepts demonstrated above require that a zone to be covered by a TI Waiver be viewed in a non-traditional manner. Sulfate and TDS exceedances in the background water are unrelated to seepage impact. It is inappropriate to apply the TI zone concept to the extensive downgradient area of exceedances of sulfate and TDS. Instead, UNC is presenting the extrapolated location of the seepage-impacted water 200 years from now (shown in Figure 58), and has concluded that the area meets ALARA (as low as reasonably achievable) principles, and that Alternate Concentration Limits (ACLs) should be established by the NRC and applied to the management of this zone. This depiction derives from application of the average groundwater velocity from Well 624 to Well SBL 1 (Table 5) over a 200-year period, and it assumes purely advective transport of seepage impacts with no retardation, dilution, or attenuation. The extrapolated impact-area along the alluvium is predicted to advance by approximately 6,000 ft with the impact front of year 2204 located as shown in Figure 58.

2.3.5 Reassessment of the Performance of the Natural System

The natural attenuation evaluation report (Earth Tech, 2002c) included nonparametric trend analysis to determine whether increases in contaminant concentration occurred during the test and whether the changes were significant. Increases in upward trends were identified for bicarbonate, chloride, and TDS, although bicarbonate was evaluated as an indicator parameter only, not as a constituent of concern. These increases were attributed to the elimination of the partial capture provided by the extraction wells. No change in trend was observed for the sulfate concentrations because these are naturally equilibrated





with gypsum. The natural attenuation evaluation (Earth Tech, 2002c) also concluded that there was no change in trend for manganese, chloroform, or uranium (however, as discussed above in Section 2.3.2, groundwater quality data through October 2004 indicate increasing post-shutoff chloroform concentration trends at former extraction Wells 802, 803, and 808). It was concluded from these analyses that, athough seepage-impacted water continues to migrate as shown by upward trends in bicarbonate, the migration of metals and radionuclides is arrested by attenuation processes (i.e., adsorption and precipitation). Continued groundwater quality monitoring through October 2004 supports this conclusion.

Table 6 shows the predicted performance of natural attenuation in the Southwest Alluvium. Sulfate and TDS concentrations are not expected to meet Site standards within seepage-impacted areas because calcium availability and gypsum equilibrium in the groundwater limits reduction of sulfate concentrations. Sulfate and TDS concentrations within the background waters are unrelated to seepage impact and application of the Site standards is inappropriate. Groundwater quality in new background Well SBL 1, and our understanding of the geochemical systems associated with both background water and seepageimpacted water, have been incorporated into the entries in Table 6. Within seepage-impacted water the metals and radionuclides are expected to meet the standards through attenuation by neutralization and adsorption. The individual indicator parameters and constituents of concern are discussed below.

Calcium and Bicarbonate

Figure 11 illustrates the long-term stability of calcium and bicarbonate concentrations at Wells 627 and EPA 28, which are examples of background wells that have not been impacted by tailings seepage. Calcium concentrations in Wells 627, EPA 28, and 624 have been essentially the same through time. In general, calcium concentrations do not vary appreciably anywhere in the groundwater flow system (e.g., Figure 9). Figure 12 shows calcium concentrations from 1999 through October 2004, and includes a vertical line indicating when the extraction pumps were shutoff in January 2001. Wells GW 1, GW 2, and GW 3 show moderate increases in calcium concentrations since shutoff that fluctuate but appear to have stabilized. Figure 13 shows the bicarbonate concentrations over the same period. The bicarbonate concentration trends in these same three wells are conspicuously upward since shutoff. These observations indicate an increased degree of seepage impact has been reaching the GW-series wells since shutoff, and that neutralization and geochemical attenuation is still occurring naturally. Calcium concentrations in these wells will re-equilibrate under changed





groundwater quality flux, becoming relatively quickly fixed in the presence of calcite and gypsum by the Phase Rule, and their long-term consistency in the Southwest Alluvium attests to the established equilibrium between the groundwater and these minerals. Bicarbonate concentrations in these wells are expected to eventually achieve a chart "plateau" level of relatively constant values, once the natural neutralization processes have attained readjusted equilibrium (for example, see Well 624 in Figure 11). This appears to already be the case in Well GW 3, starting in January 2003, and it may also be the case for GW 1 starting at the same time.

Sulfate and TDS

Sulfate concentrations exceed the standard in both the seepage-impacted water and the background water in the Southwest Alluvium. Regardless of whether the extraction wells were operating, sulfate concentrations in the Southwest Alluvium are controlled by the system's equilibrium with gypsum. Figure 14 shows sulfate concentrations from 1999 through October 2004; Figure 15 presents TDS concentrations over the same period. Figure 14 shows that sulfate concentrations in Well GW 1 increased modestly after shutoff until January 2002; since then this parameter has been stable. TDS here has shown an increasing trend since shutoff. Before July 1997 and since July 2001, TDS has exceeded the standard (4,800 mg/L) in this well. The TDS value of 6,800 mg/L measured in October 2004 is the highest value measured in GW 1 since installation in 1989.

Well GW 2 sulfate has fluctuated but remained overall stable over the chart period of Figure 14, which spans shutoff. Since 1989, sulfate and TDS here have exceeded the standards. Since approximately March 2002, TDS concentrations have overall been increasing in this well. The TDS concentration of 6,600 mg/L measured here in October 2004 is the highest value measured in this well since installation in 1989.

Well GW 3 sulfate has generally been below the standard, but since shutoff the concentration has increased modestly to levels fluctuating about the standard. Since April 2001, the TDS concentration has been trending upward in this well. The TDS concentration of 5,720 mg/L is slightly less than the highest level that was measured in July 1992.

Of these three wells, post-shutoff increases have been the highest in GW 1 for sulfate and TDS. Increasing TDS in all three wells corresponds with the generally increasing values for bicarbonate and calcium, and to varying degrees sulfate and magnesium (typically the largest components of TDS; see Figure 9). TDS may continue to increase in these locations





as seepage-impact neutralization reactions trend toward post-shutoff geochemical equilibrium.

By comparison, the TDS and sulfate concentrations are approximately constant in Figures 14 and 15 in idled extraction wells 801, 803, and 808. Well 802 shows apparently moderate, post-shutoff increasing trends for TDS and sulfate. Of these four wells, 802 also shows a moderate post-shutoff increasing trend for bicarbonate (Figure 13). These observations indicate that, of the four former extraction wells, Well 802 water is still trending toward post-shutoff geochemical equilibrium.

Based on the results of the geochemical investigation presented by Earth Tech (2000d), sulfate is not expected to meet the clean-up standards in the Southwest Alluvium. As shown on Figure 9 (and consistent with Zone 1 and Zone 3), most of the TDS comprises sulfate. Accordingly, TDS concentrations are not expected to meet the clean-up standards.

Chloride

Figure 16 presents chloride concentrations from 1999 through October 2004. Chloride concentrations have persistently exceeded the standard at Well 509 D, and Well 632 has fluctuated about the standard since well installation in 1989.

Since shutoff, upward chloride concentration trends are shown for Wells GW 1, GW 2, and GW 3. GW 2 briefly exceeded the standard with a concentration of 260 mg/L in January 2004. As with the post-shutoff increases in TDS and bicarbonate in these same wells, the increased levels of chloride indicate that an increased degree of seepage impact has been reaching these wells.

By comparison, the chloride levels in former pumping wells 801, 802, 803, and 808 have remained approximately constant over the entire time period shown in Figure 16.

Manganese

Figure 17 presents manganese concentrations from 1999 through October 2004. The only metal that exceeds its current standard in seepage-impacted areas is manganese. Exceedances continue to occur at Well 801; however, a post-shutoff downward concentration trend is shown. Exceedances also continue at Well EPA 23 where concentrations have been fluctuating about the level of 5 mg/L since May 2000. Concentrations at Well 509 D have been fluctuating about the standard





since approximately the time of shutoff; however, this upgradient well was not hydraulically influenced by the former downgradient extraction well pumping. Manganese was temporarily at concentrations exceeding the standard in Wells 802, 803, and 808 in early 2001, but they have since reduced below the standard. These observations indicate that manganese natural attenuation continues effectively in the seepageimpacted waters. It is expected that concentrations will continue to diminish to below the standard in all seepage-impacted wells.

As noted earlier, Well SBL 1 showed an exceedance of manganese in October 2004 (see the datum point on the lower right of Figure 17), and it also showed exceedances of cobalt and nickel. This well also contains a relatively high concentration of magnesium (Figure 9; Appendix A). These characteristics do not reflect the presence of seepage-impacted water at this location. Rather, as explained earlier in Section 2.3.2, this water's geochemistry reflects background conditions that are very likely related to earlier alluvium flushing associated with the discharge of mine waters.

Uranium

Uranium concentrations do not exceed the current Site standard of 5 mg/L, as listed in the ROD, or the NRC License standard of 0.3 mg/L. A summary of historic Southwest Alluvium uranium concentrations through October 2004 is provided in Appendix A.

The statistics included in the NA report determined that there was not a significant increase in trend for uranium; however, the graphs of uranium concentration in several wells indicated a possible increase prior to and during the NA test. Graphs showing uranium concentrations through October 2003 were presented in the 2003 annual report (USFilter, 2004a).

Graphs of uranium concentrations in all fourteen wells comprising the Southwest Alluvium water-quality performance monitoring program, through October 2004, are included as multi-well plots in Figures 18 and 19. These plots cover the period from April 1999 through October 2004, thus providing a visually expanded time (horizontal) scale spanning shutoff. Graphs of uranium concentrations are shown separately for each well in Figures 20 through 33. These plots show the entire historic record for each well, from 1989 through October 2004. These charts show the following key observations:

• Well 509 D (Figure 20): The uranium concentration in Well 509 D, which is located upgradient of the South Cell and the other Southwest Alluvium wells, increased one full year prior to the NA test starting in October 1999 (pumps were shut off in January 2001). Relatively large fluctuations have been





characteristic since shutoff and during earlier periods. The concentration trend has been overall stable since July 2000, at the higher end of the historic range. Well 509 D is located outside the zone of influence of the former pumping wells; Well 509 D is not a good indicator of whether there is a benefit to pumping. However, if Well 509 D were postulated to be in the zone of influence, then the uranium data would indicate that there is no benefit to pumping because the concentrations increased while the pumps were operating and stopped increasing when they were shut off.

- Well 801 (Figure 21): The uranium concentration in Well 801 increased to its maximum just prior to shutdown and decreased through most of the NA test. The concentrations decreased and stabilized, approaching the long-term average concentration that had been extant during pumping. This indicates that although slugs of uranium-bearing water may pass through the system, they will tend to approach a stable, average concentration whether or not the pumps are running.
- Well 802 (Figure 22): Well 802 was a pumping well that was shut down on January 8, 2001. Subsequent concentrations increased through September 2001, were stable through October 2003, and have been decreasing since then. The October 2004 concentration was lower than those measured from January 1998 through October 1999. The decreasing trend since October 2003 is within the upper part of the historic range. If a long-term linear trend line were to be established for this well, it would seem that the discontinuance of pumping in 2001 would have no discernible effect on the long-term trend.
- Well 803 (Figure 23): The uranium concentration in Well 803 spiked in the year 2000, more than one year before the NA test. Only one of the 25 samples collected since shutdown showed higher uranium concentrations than the two relatively high concentrations that were measured during 2000, before the shutdown. Post-shutoff concentrations increased through July 2002 to a similar value measured pre-shutoff during May and July 2000. Since July 2002, the trend has been decreasing and concentrations are consistent with the historic range. There is no statistically discernible advantage to pumping based on well 803.
- Well GW 1 (Figure 24): The uranium concentrations in Well GW 1 began to increase in 1999, well before the NA test, and therefore cannot be attributed to the cessation of pumping. Post-shutoff concentrations continued to increase at an accelerated rate through July 2002, then decreased through January 2004. Concentrations have since been stable at levels consistent with the early- to mid-1990s, but slightly above the lowest concentrations reached in the late 1990s. It appears that concentrations are stabilizing





above those that were attained during pumping, but not at concentrations that have regulatory significance.

- Well GW 2 (Figure 25): Post-shutoff concentrations were stable through October 2002; since then the trend has been increasing. The post-shutoff range concentrations have been lower than most historic concentrations and similar to concentrations that were achieved prior to the cessation of pumping. Stabilization appears to be occurring.
- Well GW 3 (Figure 26): Post-shutoff concentrations were stable through October 2002; since then the trend has been increasing. The post-shutoff range concentrations have been lower than most historic concentrations and similar to concentrations that were achieved prior to the cessation of pumping. Stabilization cannot yet be recognized.
- Well 624 (Figure 27): Post-shutoff concentrations have been stable at the lower end of the historic range. There is no statistically discernible advantage to pumping based on Well 624.
- Well 632 (Figure 28): Post-shutoff concentrations have been stable at the lower end of the historic range (excluding a drop to nondetect in April 2004). There is no statistically discernible advantage to pumping based on Well 632.
- Well 627 (Figure 29): Post-shutoff concentrations have been stable along the historic trend that is associated with a low range. There is no statistically discernible advantage to pumping based on Well 627.
- Well 808 (Figure 30): This well was installed in conjunction with the planned shutoff of the extraction well system; it has no pre-shutoff history. The post-shutoff uranium concentration showed a large upward spike through September 2001; since then the trend has been strongly downward.
- Well EPA 23 (Figure 31): Post-shutoff concentrations have been stable at the lower end of the historic range that is associated with a low range. There is no statistically discernible advantage to pumping based on Well EPA 23.
- Well EPA 25 (Figure 32): Concentrations have been quite stable since July 1999 along the upper part of the historic range. There is no statistically discernible advantage to pumping based on Well EPA 25.

This comprehensive review of historic uranium concentrations demonstrates that most of the seepage-impacted wells have shown overall stable to decreasing trends since shutoff. The two exceptions through October 2004 are Wells GW 2 and GW 3, where post-shutoff trends were stable through October 2002 and have since been increasing. However, none of the concentrations measured in these wells have exceeded higher historic concentrations that were measured for very extended periods at these wells; these extended periods included significant spans of extraction time. Overall, none of the wells have shown post-shutoff





concentrations that exceed historic values, and many of the wells show that both gradual and sudden variations are common.

None of the wells have shown exceedances of the standards. The timeconcentration plots indicate that natural attenuation, by neutralization and adsorption, is at least equally as effective as a pumping remedy. This conclusion is bolstered by earlier discussion indicating that in comparison to background water quality, the passage of the seepage-impact front presages an improvement in sulfate and TDS concentrations.









Section 3 Zone 3

3.1 Corrective Action Summary

While operating, the corrective action in Zone 3 performed as designed to enhance dewatering of the seepage-impacted area and remove constituent mass. Historic corrective action in Zone 3 consisted of pumping the three sets of extraction wells shown on Figure 34: (1) Northeast Pump-Back System (green triangles), (2) Stage I Remedial Action System (filled blue squares), and (3) Stage II Remedial Action System (empty black squares). The Northeast Pump-Back wells started operation in 1983; the Stage I and II wells were added later as part of the *Remedial Action Plan* (UNC, 1989b) implemented in 1989.

Eighteen years of remedial pumping have shown that once the saturated thickness falls to approximately 25 ft or less, well efficiency declines and pumping rates fall to less than 1.0 gpm (Earth Tech, 2001). Table 7 presents the reductions in saturated thickness for Zone 3 wells between the third quarter of 1989 and the fourth quarter of 2004. Values of saturated thickness greater than 25 ft are shaded. The number and pumped volumes of the former extraction wells, during the period of Zone 3 corrective action from 1989 through 2000, have been summarized in Earth Tech (2002d, Figure 3-2).

The saturated thickness in Zone 3 has declined substantially. As discussed in the "Technical Memorandum, Change in Zone 3 Saturated Thickness" (Earth Tech, 2001) submitted to the NRC on April 23, 2001, the loss of saturated thickness over time resulted in a decrease in the efficiency of the extraction wells to the point that only three of the total 24 wells were still pumping at rates greater than 1.0 gpm in June 2000. UNC's May 2000 License amendment request to shut off remaining Zone 3 pumping wells (Earth Tech, 2000b) concluded that operation of these pumping wells accelerated the rate of downgradient constituent migration. UNC requested that these extraction wells be shut off to reduce the migration rate, allowing more time for the background water to neutralize the seepage and attenuate the hazardous constituents. Additionally, these wells were pumping background-quality water and served no purpose in reducing contaminant mass in seepage-impacted waters. The NRC amended the License (with approval from NMED and EPA) to shut off the three remaining wells (716, 717, and 718) in December 2000. This decision 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 EPA (2004b), UNC has conducted a Supplemental Feasibility Study (SFS) to evaluate all appropriate remedial options for Zone 3. Prior to reporting the SFS, UNC submitted (2004) a Technical Memorandum including a chronology of events that led to UNC's initiative to aggressively develop remedy modifications or enhancements that might improve the performance of the remedy in Zone 3. The SFS report was submitted in October 2004 (MWH, 2004). This report presented (1) groundwater modeling of the Zone 3 sandstone unit and the locally overlying alluvium, (2) the pilot-hole hydrofracturing study results, (3) a remedial alternatives analysis, and (4) conclusions and recommendations for enhancing or optimizing remedies for Zone 3. The hydraulic modeling indicated that for most of the alternative remedies to be effective (excluding Alternative 6 – Cutoff/Containment Wells), the recharge from the alluvium to Zone 3 should be reduced or eliminated.

The work leading up to the submittal of SFS report, and related recommendations made in that report, were developed into a formal work plan (MACTEC, December 2003; revised by letter March 2004; approved by EPA in letter of May 21, 2004). UNC is conducting an ongoing, extended pilot program to determine the efficacy of hydrofracturing in enhancing extraction potential along the basal part of Zone 3 to contain the advancing seepage-impacted water. This work included the drilling and hydrofracturing of seven new wells shown as RW-11 through RW-17 in Figure 35. These well are arranged in two lines approximately 700 ft apart. The northern line (RW-11 through RW-14) is located approximately 400 ft south of the seepage-impact front. They were drilled during June 2004 and hydrofractured in September 2004. UNC is in the process of completing well construction and conveyance pipe installation. The construction and geologic logs will be presented under separate cover, as will the results of the hydrofracturing, testing, and other related work. The work plan includes bringing the new pilot recovery wells on-line, the installation of an extraction water collection and distribution line to an evaporation pond, and a 6 to 12 month evaluation of the effectiveness of the remedy enhancement. The main question to be answered is whether this work (constituting Alternative 6 -Cutoff/Containment Wells per the SFS) can be expanded into full-scale dewatering of the seepage-impacted water (Alternative 5 - Enhanced Well Field per the SFS).

The former remediation system wells accelerated the process of natural drainage of the water from Zone 3. In this sense, "natural" drainage refers to the reduction of saturated thickness and potential energy by gravity flow and dissipation into the contiguous unsaturated parts of the Zone 3 hydrostratigraphic unit. Figure 34 shows that between 1989 and the fourth quarter of 2004, a very large portion of the Zone 3 Remedial Action Target Area has been desaturated (effectively dewatered). The eastern limit of Zone 3 saturation has shifted to the northwest





over this time period (from the location of the wavy blue line, showing the saturation limit in 1989, to the dashed brown line showing the approximate October 2004 "zero" saturation limit). The effects of former remediation pumping in partially, locally dewatering Zone 3 are presented in Figure 36.

3.2 Mass of Chemical Constituents Removed

The mass of chemical constituents removed was calculated for the 12-year period from July 1989 through June 2000. These calculations were presented in the previous annual reviews, and the final summary is presented in the *2000 Annual Review* (Earth Tech, 2000e).

3.3 Performance Monitoring Evaluation

The current Zone 3 performance monitoring program is summarized in Table 8 and comprises quarterly monitoring of water levels in 23 wells and water quality in 11 wells. This program went into effect in the second quarter of 2000 and was modified in the second quarter of 2001, at the request of the NRC, to include the following additional components:

- Water quality monitoring at Wells EPA 13, 717, and 719;
- Water level and water quality monitoring at Well 708; and
- Installation of Well NBL 1 (July 2001) as a new downgradient monitoring well.

The location of Well NBL 1 (see Figure 34) was selected to both bound the downgradient extent of the impacted water and function as a sentinel well.

To supplement the performance monitoring program, four new monitoring wells were installed (June 2002) between Wells 504 B and NBL 1: PB 1, PB 2, PB 3, and PB 4 (Figure 34). Drilling logs and well completion forms are included in Earth Tech (2002d, Appendix B). These wells serve to track the advance of the northernmost seepage-impact boundary. Monthly water levels and water quality data are collected from three of these wells: PB 2, PB 3, and PB 4. (Well PB 1 was installed within impacted water and has been excluded from further monitoring that is intended to track the advancing front.) Water quality analyses conducted monthly include field measurements of pH, specific conductivity, bicarbonate, and chloride. The latter two analyses are performed using Hach field testing kits. Quarterly samples from these four boundary "sentinel" wells are submitted to a laboratory to check the field results (the laboratory analyzes TDS in lieu of specific conductivity). Overall, the field parameters provide a good indication of the migration of the impacted water.





Following recommendations in UNC's investigation (USFilter, 2004b) of the potential for the covered tailings cells to continue to source seepage impact and recharge to the updip part of the Zone 3 hydrostatigraphic unit, two new piezometers were installed just north of the northeastern boundary of the Central Cell. They were installed during July 2004 and are called Z3 M-1 (depth 68.5 ft below ground) and Z3 M-2 (77.25 ft below ground); the locations are shown in the southern part of Figure 34. Their construction and geologic logs will be reported under separate cover. Both piezometers have bottom caps along the base of Zone 3, which was penetrated at depths consistent with expectations based on historic well logs.

3.3.1 Water Level Evaluation

Water level data from 1989 through the fourth guarter of 2004 are presented in Appendix B. Water levels from October 2004 are shown on the potentiometric surface map in Figure 37. These potentiometric contour lines indicate groundwater flows toward the north and northeast, approximately parallel with the eastern limit of Zone 3 saturation. This potentiometric field closely mirrors that depicted for the fourth quarters of 2001 (Earth Tech, 2002a), 2002 (Earth Tech, 2002d) and 2003 (USFilter, 2004a). Mine water discharge into Pipeline Arroyo ceased in 1986. Since then, Zone 3 groundwater flow directions have shifted from easterly-to-northeasterly to north-northeasterly-to-northeasterly as recharge from, and groundwater mounding within, the alluvium to the southwest and west have decreased. This earlier, east-to-northeast flow direction caused the groundwater impacts that formed the original basis for delineation of the Zone 3 Remedial Action Target Area shown on Figure 34. The effects from alluvium recharge (mine water discharge) and extraction-well pumping drawdowns have largely dissipated, and rates of water level change in Zone 3 are mostly very small. Variation from the current direction of groundwater flow is very unlikely. Since cessation of mine water discharge, water levels have been declining. Extraction wells temporarily accelerated the local rates of water level decline until the saturated thickness was reduced to less than ~ 25 ft, after which the decline in levels slowed to natural rates of drainage. Since about 1997, the water level trends in Zone 3 have asymptotically flattened, as shown on Figure 36.

Contours of saturated thickness during the fourth quarter of 2004 (Figure 38) show the combined effects of former pumping and natural drainage on Zone 3. This map was developed by evaluating the differences between two interpolated surfaces: the base of Zone 3 and the potentiometric surface for October 2004. The eastern extent of saturation has contracted to the west, so that the current boundary of saturation is approximately where the 25-ft saturated thickness contour was located in 1989 (for comparison, see Earth Tech, 2002d, Figure 3-1). Also, the wells located to the west, closer to the recharge area, have lost




substantial saturation. For example, Well EPA 14 had 76 ft of saturation in 1989 and 36 ft in the fourth quarter of 2004. Table 9 shows the saturated thickness in each Zone 3 well during October 2004. From 2002 through 2004, most wells have shown overall decreasing groundwater elevations (usually with small fluctuations), indicating that the Zone 3 potentiometric field that drives groundwater flow and constituent migration continues to become lower as the groundwater further drains away.

The new, updip piezometers Z3 M-1 and Z3 M-2 were effectively dry in October 2004. Both contained water columns approximately 3.5 in tall, such that the water level was below the lowest part of the well screen (both screen bottoms are 6 in above the bottom well caps). On October 15, 2004, the water in Z3 M-1 had a pH of 7 and an alkalinity of 283 mg/L (the other piezometer was not successfully sampled). All of these observations indicate the small amount of water in each piezometer was drilling fluid. Although these piezometers are not part of the formal Zone 3 performance monitoring program, UNC will monitor them quarterly. It is likely that neither well will ever recharge; this updip, southeasterly part of Zone 3 appears to be entirely unsaturated. Regardless, the piezometer installation and monitoring indicates that neither groundwater recharge nor seepage impact into Zone 3 are occurring from the adjacent Central Cell.

3.3.2 Water Quality Evaluation and Current Extent of Seepage-Impacted Water

Figure 34 shows the recharge area, located to the north and northeast of the North Cell, where mine water in the alluvium percolated into the underlying Zone 3 hydrostratigraphic unit. This figure shows the saturated portion of the alluvium/Zone 3 contact as well as the unsaturated portion of this same contact zone. In the absence of a naturally occurring shallow aquifer, the temporary saturation caused by the mine water discharge is considered the background water for Zone 3 (EPA, 1988; 1998).

This background water was later impacted by acidic seepage from tailings in the North Cell. These seepage fluids contained elevated concentrations of metals, radionuclides, and major ions including sulfate and chloride. Source control (neutralizing and later dewatering of the North Cell), neutralization of the seepage by natural attenuation, and mixing with the background water has reduced constituent concentrations.

Seepage-impacted water, some of which exceeds Site standards, is contained within the property boundary in Section 36. The portion of the impacted water that extends off the property into Section 1 (Figures 6 and 34) was eliminated as a point-of-exposure (POE) because there is now less than 5 ft of saturation,





which is projected to drain out in about 10 years. The decision to eliminate this area as a POE is documented in a letter from the NRC (1999b).

It is important to note that exceedances of Site standards in some Site wells represent background water quality. For example, exceedances of the combined radium and sulfate standards in Well EPA 14 significantly pre-date the beginning of strong seepage impacts that were first observed at that well during 2000 (the water quality history of this well is discussed below). From 1989 through 1997, Well 411 showed long-term background exceedances in combined radium, cobalt, molybdenum, nickel, and sulfate. Background water quality is discussed further in the natural attenuation system performance evaluation.

Delineation of the extent of the seepage-impacted water in Zone 3 (Figure 34) is based primarily on the values of two parameters: pH and bicarbonate concentrations. The following threshold or bracketing values for pH and bicarbonate, which indicate seepage impact to the water, have been discussed in the Technical Memorandum (General Electric, 2000):

- A pH <5.0 indicates seepage impact. Such impacted water has not yet migrated far enough to reach equilibrium, or to react sufficiently, with carbonate minerals in the Zone 3 strata (Canonie, 1987, Table 4-5 indicates a measured CaCO₃ content of 0.02 percent in the Zone 3 bedrock). A pH >5.0 indicates either no seepage impact, or acid neutralization to varying degrees (usually a function of residence time and migration distance).
- Bicarbonate (HCO₃) concentrations <100 mg/L and >500 mg/L indicate • seepage impact. In non-impacted areas, background water has approximately reached equilibrium with the carbonate minerals resulting in bicarbonate concentrations ranging from approximately 100 to 500 mg/L. These threshold values reflect sequential chemical reactions. When acidic seepage-impacted water first entered Zone 3, it lacked bicarbonate. Once the seepage water migrates a short distance from its point of entry, bicarbonate is generated by reaction with calcite in the bedrock. With increasing time of neutralization at a given location, the bicarbonate typically shows a gradual increase to levels above background (generally >500 mg/L). Eventually, the neutralization capacity is exceeded and bicarbonate values . reduce to near zero. Further discussion of bicarbonate concentration trends is provided below.

Seepage-impact extent is primarily based on evaluation of pH and bicarbonate concentrations over time in (1) seepage-impacted wells (e.g., Wells 613, 518, and 517), (2) background and former background wells (e.g., Wells EPA 1, 411, and 420), and (3) the new boundary wells PB 2 through PB 4. Table 10 presents the monthly field parameter measurements for the boundary sentinel wells (from





south to north, Wells 504 B, PB 2, PB 4, PB 3, and NBL 1). (The quarterly laboratory analytical results are provided in the back part of Appendix B.) Evaluation of these data indicates that bicarbonate concentrations at Well PB 4 have decreased since February 2003, and the pH has fluctuated while showing an overall decrease. The bicarbonate concentration continued to decline in 2004, with a value of 18 mg/L in October.

By comparison (Table 10), Well PB 3 has also shown decreasing bicarbonate concentrations and pH values since February 2003, but in January 2004 there was a temporary increase in both bicarbonate and pH. Since then, both parameters have continued to overall decrease, and in October 2004 the bicarbonate concentration was 102 mg/L. This indicates that the geochemical precursors to the arrival of seepage-impacted groundwater presage the imminent arrival of full seepage impact at this location. The pH and bicarbonate measurements at Wells PB 4 and PB 3 indicate the northernmost edge of the impacted water is a short distance to the south of Well PB 3 (Figure 34). As discussed more below, historic groundwater quality data (see Appendix B) from fully impacted wells indicate that these precursory geochemical changes can occur for approximately one to three years prior to the arrival of seepage-impacted groundwater.

Until the cessation of mine water discharge in 1986, seepage impacts in Zone 3 migrated to the east and northeast, due to groundwater mounding in the alluvium recharge area to the west. As the hydraulic head in the alluvium recharge area has decreased, migration has been toward the north (in relatively southern locations) and northeast (in more northerly locations), subparallel to the eastern edge of saturation and the bedrock dip direction.

As predicted in the EPA's *First Five-Year Review Report* (EPA, 1998) and discussed in the Technical Memorandum (General Electric, 2000), continued pumping of the downgradient Stage II extraction wells caused the seepage-impacted waters to migrate to the northwest and north toward the pumping locations. For example, until May 2000, Wells 708 and 711 had pH values greater than 4.0, but after that time they dropped below 3.0.

The acidic "core" of the impacted water is shown in Figure 34, with two separate, closed dashed red lines indicating the pH value of 4.0 (the other red line shows the approximate location where the pH values are 5.0). At many of the well locations, the October 2004 pH values are slightly higher than those in October 2003.

These pH increases may indicate improving groundwater quality at these (and other) wells, due to more effective natural attenuation subsequent to shutoff of the last extraction wells in 2000. Continued monitoring will show whether these





increases define a trend of water quality improvement as shown by, for example, decreasing concentrations of dissolved metals. By contrast, it appears that the water quality at Well EPA 14 has been in flux during 2004: field pH values have oscillated by 0.32 standard units; alkalinity trends have reversed and are now increasing; the values for combined radium ($Ra^{226} + Ra^{228}$) have decreased by more than a factor of two; aluminum concentrations have increased by a factor of two; and gross alpha oscillated by a factor of two, but still is at levels indicative of impact. It may be that the negative effects of Zone 3 pumping at this well are in the early stage of reversal, though it is too soon to make a firm conclusion.

The EPA's *Second Five-Year Review Report* (2003, Figure 6-7) presented Stiff diagrams for Well EPA 14 in annual "snapshots" of water quality from October 1998 through October 2002. Before October 2000, the calcium-to-magnesium (Ca/Mg) ratio was greater than one and the bicarbonate concentrations were elevated; from October 2000 to October 2002, the Ca/Mg ratio was less than one and the bicarbonate was depleted. Modest exceedances of the aluminum and cobalt standards in this well began in 2000, when the bicarbonate concentration decreased suddenly and sharply.

The EPA (2003, Figure 6-8) also presented Stiff diagrams for ten Zone 3 wells during October 2002. The major ion concentrations measured in these wells during 2004 indicate that their Stiff diagram representations would be extremely similar (virtually identical) to those previously presented for October 2002. For this reason, new Stiff diagrams have not been produced for October 2004, and the following discussion refers to the Stiff diagrams shown in EPA's (2003) Figure 6-8.

Well NBL 1, to the north of the present edge of the seepage impact, contains a calcium-sulfate type of water that remains non-impacted and is representative of background water quality.

Well 420, located along the western edge of the impacted area in Figure 34, contains a calcium-sulfate type of water that is predominantly background (largely non-impacted). In the first half of 2003, exceedances of combined radium Site standards were detected in this well, but concentrations have been below the standards from July 2003 through October 2004. In July 2004, water collected from Well 420 had a bicarbonate concentration of 684 mg/L (the highest value since 1989); bicarbonate concentrations have been increasing since 1994 (see Appendix B). These observations are interpreted as indicating that the seepage-impacted region is nearby.

Well 717, near the western edge of the seepage-impacted area in Figure 34, provides a third example of a calcium-sulfate type of water that is interpreted as predominantly background (largely non-impacted). From 2001 and through





October 2004 (the time period for which water quality data are available), only combined radium has been persistently detected at concentrations above its standard. The first exceedances of manganese in this well occurred in January 2004 through October 2004. During this same period, bicarbonate concentrations decreased and during the second half of 2004 the first measured sulfate exceedances occurred at this location. These observations are interpreted as indicating that an increasing degree of seepage impact is occurring at this location.

All of the other seven wells depicted with Stiff diagrams (EPA, 2003, Figure 6-8) contain impacted magnesium-sulfate types of waters. For example, in October 2004 (see Appendix B) Well 613 (in the southwestern part of the impacted area shown in Figure 34) showed very high sulfate, a Ca/Mg ratio less than one, a non-detect for bicarbonate, a chloride concentration of 159 mg/L, a pH of 2.78, and exceedances for most parameters except several metals, lead, and some of the major ions. This well's water is the most impacted of any of the wells. Although some of the downgradient wells also show significant impacts (e.g., Wells 708 and 719), these same well waters indicate that neutralization accompanies migration from the waters' source area.

The EPA (2003, Figures 6-9 through 6-12, and 6-6) has presented annual "snapshots" of the Zone 3 seepage-impacted area from October 1998 through October 2002. Viewed together with the seepage-impact maps from October 2003 (USFilter, 2004a) and October 2004 (Figure 34), these seven maps indicate that the constituents have migrated both northward and westward at various times during the last seven years. During this time period, the eastern limit of Zone 3 saturation gradually shifted to the northwest under the influence of extraction well pumping (terminated in 2000) and dewatering. This is no longer occurring and there are some indications that the seepage-impacted area may be withdrawing along its western edge.

3.3.3 Rate of Seepage Migration

Table 11 summarizes the key factors, locations, and criteria underpinning the calculations of seepage travel times for Zone 3. This table has been updated to include the first arrivals of full seepage impact at boundary wells PB 2 and PB 4, as determined by the first and persistent attainment of bicarbonate concentrations equal to, or lower than, 50 mg/L (see Table 10). The impact source starting location was assumed to be the northeastern corner of the North Cell in 1980. The calculated rates vary from 60 ft/yr to 204 ft/yr, with a geometric mean of 99 ft/yr. Extrapolating the migration rate of 60/yr derived from PB 2 to PB 4, full seepage impact is predicted to arrive at sentinel Well NBL 1 in approximately June 2006.







3.3.4 Natural Attenuation System Performance Evaluation

The Zone 3 natural attenuation system comprises the hydro-geochemical interactions between the bedrock matrix, the anthropogenic background waters (derived from former mine water discharge), and the tailings fluids. The natural system is attenuating the seepage impacts by the processes of neutralization, precipitation, adsorption, and mixing with the background waters. However, Zone 3 has not yet fully stabilized. For this reason, UNC is currently conducting an extended pilot study program of hydrofracturing to enhance extraction rates along the leading edge of the seepage impact to cutoff and contain the advancing impact front.

Natural geochemical processes slow the migration of constituents associated with the acidic seepage in Zone 3 (as in the Southwest Alluvium and Zone 1). These processes neutralize the acidic seepage, which causes the precipitation and adsorption of metals and radionuclides. Evidence of this neutralization process includes: (1) increase in pH and corresponding decrease in concentrations of metals and radionuclides with increasing distance from the source area; and (2) gradual increase in bicarbonate for a few years followed by dramatic decreases in wells such as EPA 14, 420, and 717, when acidic seepage begins migrating into a previously non-impacted (background water) area (Earth Tech, 2002d). Shutoff of the remaining Stage II wells in 2000 has enhanced the effectiveness of the natural attenuation processes in many parts of the impacted area.

A summary of constituents detected in Zone 3 in October 2003 is provided in Table 12. Historic data are provided in Appendix B. These data indicate that the following constituents exceeded the Site standards in Zone 3:

- Sulfate and TDS;
- Metals (aluminum, arsenic, beryllium, cadmium, cobalt, lead, manganese, molybdenum, and nickel);
- Radionuclides (lead-210, uranium, combined radium-226 and –228, thorium, vanadium, and gross alpha); and

• Chloroform.

The geochemical processes influencing the migration of these constituents are discussed below.

Sulfate and TDS

Figure 39 presents a graph showing sulfate concentrations from 1989 through 2004. Earth Tech (2002d, Figure 3-12) previously presented a map showing the approximate extent of sulfate exceeding the Site





standard (2,125 mg/L) in October 2002. October 2004 concentrations below the standard occurred only in well 420 (located near the northwestern edge of the impacted area). However, earlier in 2004 Wells 717 and EPA 14 were below the standard (EPA 14 showed a relatively wide range in sulfate concentrations in 2004). October 2004 sulfate exceeded the standard in all the other wells within the seepage-impacted water. Concentrations are relatively high where seepage impacts have been greatest. Background water in Well NBL 1 has shown sulfate concentrations below the standard during October 2002 (2,070 mg/L) and October 2003 (1,940 mg/L), but in 2004 the concentrations gradually increased and exceeded the standard in October 2004 (2,340 mg/L).

Although bicarbonate is not a constituent of concern, the concentrations in impacted wells are related to the waters' degree of neutralization of acidic seepage. Although strongly subordinate to sulfate, bicarbonate is a component of the TDS in Zone 3. Figure 40 shows historic bicarbonate concentrations through October 2004. Figure 41 shows historic bicarbonate concentrations for wells located near the present impact-zone perimeter, plus the boundary sentinel wells used to track the northward advance of the constituents. The increasing concentration trend in Well EPA 14 during 2004 suggests that neutralization has been renewed in this location; this increasing trend started in July 2002.

Natural attenuation has reduced sulfate concentrations substantially from those reported in the tailings source area. Earth Tech (2002d, Figure 3-13) has demonstrated that the concentrations decrease by about 85 percent between the North Cell and the seepage-impacted water at Well 613. Concentrations decrease another 11 percent from Well 613 to the non-impacted water at Well NBL 1.

However, neither natural attenuation nor active remediation will reduce sulfate concentrations below the Site standard because the concentrations are controlled by groundwater equilibrium with the mineral gypsum (as in the Southwest Alluvium and Zone 1). For example, from 1989 through 1997, Well EPA 1 consistently had sulfate concentrations in the range of 2,500 mg/L to 3,000 mg/L. This well is located approximately 800 ft downgradient of the current northeastern edge of the seepage-impacted water (see Figure 34) and showed background water quality until this part of Zone 3 lost saturation. TDS will continue to exceed the Site standard because sulfate comprises most of the TDS (as in the Southwest Alluvium and Zone1).

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Metals

Figures 42a and 42b contain graphs showing concentrations of metals (from 1989 through 2004) that exceeded the Site standards: aluminum, arsenic, beryllium, cadmium, cobalt, manganese, molybdenum, and nickel (the metals uranium and vanadium are discussed later with the radionuclides). Lead is not included in the charts because the first exceedance of the standard (0.05 mg/L) occurred in Well EPA 14 starting in January 2004 (Appendix B). The fluctuating water quality in this impacted well is discussed below.

Arsenic and molybdenum exceed Site standards primarily in the background water. These two constituents have historically shown elevated concentrations in background Wells EPA 1 (now dry) and NBL 1, while very low to non-detect concentrations are found in most impacted wells, including Well 613. The only exception (continuing in 2004) is where the molybdenum standard (1 mg/L) was exceeded in impacted Well 504 B (concentrations in 2004 continued the decreasing trend since October 1999). Arsenic in Well EPA 13 continued a decreasing trend since April 1999 and was below the standard in October 2004 (see Appendix B). This pattern of exceedances is the opposite of what is expected for metals associated with the seepage impact and indicates that, for at least arsenic and molybdenum, the primary source is the background water. During 2004, background water concentrations of arsenic at Well NBL 1 continued to show a large range of exceedance Decreasing concentration trends are associated with the two values. impacted wells, indicating that natural attenuation of these two constituents is occurring.

Many of the other metals exceed the Site standards in at least one background well, usually EPA 1. For example, during 2004 nickel and cobalt both exceeded their Site standards, by very small amounts, in background Well NBL 1 (concentration trends are approximately stable). Therefore, although neutralization of the acidic seepage will continue to reduce metals concentrations, the natural Site conditions (i.e., background) may prevent them from being reduced below the current Site standards (Earth Tech, 2002d). UNC recommends that the NRC revise the ROD background concentrations that were established for these metals constituents, just as they did in 1996 for the background standards for sulfate, nitrate, and TDS.

The metals exhibit a consistent pattern of higher concentrations in wells such as 613, 517, and 719, which have an acidic pH, and much lower concentrations where the pH is more neutral. This difference in





concentrations is due to attenuation as the acidic seepage is neutralized along the groundwater flowpath.

Figures 42a and 42b show that attenuation occurs throughout the seepage-impacted area, including areas where the pH is less than 4.0. Well 613 is located near the center of the impacted area, closest to the source area, where pH has ranged from 2.77 to 3.24 since this well was first monitored in 2000. On graphs for six of the eight constituents, this well shows the highest metals concentrations. The effectiveness of natural attenuation and seepage impact mitigation is shown by the metals concentrations at Well 719. In October 2004, this well had a pH (3.42) only moderately higher than that measured in Well 613 (2.78); however, the concentrations of metals are generally much lower in Well 719. In fact, the concentrations are similar to those in other wells located further downgradient, and in October 2004 they were either below the standards (arsenic, cadmium, and molybdenum) or they were exceedances that continue to show decreasing trends (aluminum, beryllium, cobalt, nickel, and manganese). These decreasing trends suggest that since the pumping wells were shut off, the downgradient seepage migration is slowing and the natural system is becoming more effective in attenuating seepage impacts. Figure 43 illustrates that the October 2004 distribution of aluminum exceedances was restricted to the southwestern part of the impacted area and an outlier (Well 719).

Starting in October 2003 and through October 2004, aluminum (Figure 42a) and beryllium (Figure 42b) concentrations have increased sharply in Well EPA 14. The first detections of lead in this well were exceedances starting in January 2004 (Appendix B). From July 2004 to October 2004, both manganese and nickel increased (Appendix B). A slug of more impacted water is moving through the location of Well EPA 14 (discussed more below regarding radionuclides). Relatively steady pH and the increasing trend of bicarbonate suggest that the groundwater here is successfully buffering the pH and undergoing neutralization reactions.

Certain metals, such as manganese, continue to be present at higher concentrations at more neutral pH values (e.g., Well 717, which showed minor exceedances during all of 2004). Cobalt and nickel have patterns of exceedances similar to manganese. These two metals generally do not attenuate until the pH is about 6.5 or more (e.g., Earth Tech, 2002d). Cobalt and nickel will remain stable at or near current concentrations until the pH increases. During October 2004, all wells within the seepageimpacted area continued to show exceedances of manganese, cobalt, and nickel, except two wells near the northwestern edge: 420 (pH of 6.62) and





717 (pH of 6.57, but showed first minor exceedances of manganese during 2004). The pH values of these two wells were the highest among the impacted group of wells (Figure 34). It is important to realize that background water quality is associated with metals exceedances. For example, since installation in August 2001 non-impacted sentinel Well NBL 1 has exceeded the standards for molybdenum, nickel, and manganese.

Uranium, Vanadium, and Radionuclides

Figure 44 presents graphs of the concentrations of uranium, vanadium, and the two radionuclides (combined radium and thorium-230) from 1989 through 2004. Combined radium concentrations exceed the Site standard (5 pCi/L) in the background water; consequently, radium concentrations in Zone 3 may never reach the standard.

Historically, uranium, vanadium, and thorium-230 are typically present above thestandards in wells such as 613 and 517, which have acidic pH. Much lower concentrations are reported where the pH is more neutral. These reductions are due to attenuation by neutralization and adsorption. In October 2004, the only exceedances of both vanadium and thorium-230 were in samples collected from Well 613, where the pH was 2.78.

Most wells show uranium concentrations below the Site standard of 0.3 mg/L. However, the exceedance of the uranium standard continued in Well 613 during 2004 (the longer-term pattern shows fluctuating to approximately steady concentrations above the standard). The uranium concentrations at Well EPA 14 continued to vary over a large range during 2004; the uranium concentration in October 2004 was 1.05 mg/L. Earlier mention has been made of large swings in other constituent concentrations at this well, and the groundwater quality here continues to flux sharply (see Appendix B).

In 2004, combined radium concentrations continued to exceed Site standards in the background water at well NBL 1. In Well 420, the decreasing trend since July 2003 continued during 2004 when all concentrations were below the Site standard of 5.0 pCi/L (the long-term pattern shows fluctuating concentrations). Exceedances in October 2004 occurred in Wells 708, 711 and EPA 14 (latter showed a large spike in April 2003 that peaked in April 2004 (205.9 pCi/L), and then decreased to 82.5 pCi/L in October 2004)).

The historic amounts of gross alpha within the Zone 3 groundwater indicate that this parameter tends to fluctuate by approximately one order





of magnitude in most of the impacted wells (except Well 613, which shows smaller fluctuations). The gross alpha Site standard of 15 pCi/L was exceeded in October 2004 in the following wells: 504 B (concentrations moderately stable during 2004), 517 (concentrations overall decreasing since July 2001), 613 (long-term fluctuations), 719 (long-term fluctuations, in 2004 both above and below the standard), and EPA 14. During 2004, Well EPA 14 concentrations fluctuated by a factor of approximately five, from 254 pCi/L in January to a minimum of 46.9 pCi/L in July. Well EPA 14 has demonstrated a distinctive pattern of gross alpha concentrations compared to all other impacted wells (see Appendix B). Since 1989, the values have consistently been below the standard until the last two quarters of 2003, when the values spiked upward by a factor of approximately ten. During these same two last guarters of 2003, the combined radium concentrations in this well also showed sharp upward spikes. The unusual (and singularly large) value for uranium in this well during July 2003, and the relatively large range in combined radium since July 2003, indicate that a slug of radioactive water migrated into this well location during approximately mid-year 2003; its source could be from either alluvial recharge or the tailings.

Although neutralization of acidic seepage will continue to attenuate the radionuclides, the natural conditions may prevent combined radium and gross alpha from being reduced to concentrations below the current Site standards.

Chloroform

Historic chloroform concentrations through October 2004 are shown in Figure 45. Chloroform was detected above the Site standard in two wells during 2004: 613 and 517. The concentrations in Well 613 have always exceeded those in Well 517, consistent with the former being located closer to the North Cell (see Figure 34). Well 613 concentrations have shown long-term fluctuations but increased by approximately four times from July to October 2002 (0.166 pCi/L). Since then the concentration reduced to 0.126 pCi/L in April 2004 and then rose to 0.148 pCi/L in October 2004.

All other Zone 3 wells have shown historic non-detects for chloroform. This indicates that the groundwater to the northeast of Well 517 rapidly attenuates chloroform.

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Section 4 Zone 1

4.1 Corrective Action Summary

Zone 1 corrective action consisted of source remediation (neutralization and later dewatering of Borrow Pit No. 2) and pumping of a series of extraction wells from 1984 through 1999 (Earth Tech, 2002d). Well productivity in this hydrostratigraphic unit has always been very low. Earth Tech (2002d, Figure 4-1) summarized the pumping program for Zone 1, including the well systems pumped, the number of wells operating for each system, and the combined annual pumping rates. A maximum combined pumping rate of 14 gpm was achieved by the 17 East and North Cross-Dike Pump-Back wells. The productivity declined steadily over time, and by July 1999, when the system was decommissioned, the three remaining wells were yielding a combined annual average of 0.65 gpm. The three remaining Zone 1 wells (615, 616 and 617) were decommissioned at the end of July 1999 in accordance with a letter from NRC dated July 30, 1999 (Earth Tech, 2002a), with the concurrence of EPA.

4.2 Mass of Chemical Constituents Removed

The mass of chemical constituents removed was calculated for the 10-year period from July 1989 through July 1999. These calculations were presented in the previous annual reviews, and the final summary was presented in the *1999 Annual Review* (Earth Tech, 1999).

4.3 Performance Monitoring Evaluation

The Zone 1 performance monitoring program that is currently in effect is summarized in Table 13. As shown, this program consists of quarterly monitoring of water levels in 15 wells and water quality in eight wells. This program has not been modified since it went into effect the second quarter of the 2000 operating year.

4.3.1 Water Level Evaluation

Historic water level data for Zone 1 wells through October 2004 are presented in Appendix C. Water levels for the fourth quarter of 2004 are shown on the potentiometric surface map included as Figure 46. Water levels through time are shown on Figure 47. Saturated thickness along the Zone 1 wells during October 2004 is presented in Table 14. This table shows that the groundwater has completely saturated the Zone 1 hydrostratigraphic unit in most of the downdip





wells: 505 A, 502 A, and 412 (in Section 36), and (TWQ)142 and (TWQ)143 (along the northern boundary of Section 36) (see Figure 46). During 2004, most of the wells have continued to show overall decreasing groundwater elevations (usually with small fluctuations), indicating that the Zone 1 potentiometric field that drives groundwater flow and constituent migration continues to become lower as the groundwater further dissipates into unsaturated parts of this bedrock stratigraphic unit.

Groundwater levels in Well 504 A have shown a gradual long-term rise, and 100 percent saturation of the confined Zone 1 hydrostratigraphic unit may eventually reach this location (see Table 14; Figures 46 and 47; and Appendix C). The slowly rising groundwater levels at Wells 142, 143, and 412 represent slowly increasing potentiometric levels within these 100-percent saturated parts of the fully confined Zone 1 hydrostratigraphic unit. Long-term decreasing water levels updip to the south-southwest, at locations under less than fully saturated conditions, represent the slow dissipation of head levels there, providing groundwater flux downdip toward the fully saturated parts of the system.

Earlier groundwater flow in Zone 1 was approximately eastward, reflecting groundwater mounding and recharge within the alluvium to the west. Since the dewatering of Borrow Pit No. 2 and termination of mine water discharge into Pipeline Arroyo, the former mounding has declined as the groundwater drains. Zone 1 water levels have significantly dissipated, and they are trending toward asymptotic levels with very small rates of change (see Figure 47). The rate of groundwater drainage is relatively slow, which is consistent with the unit's relatively low transmissivity, the very low transmissivity of the underlying aquiclude, and low production from the former extraction wells.

4.3.2 Water Quality Evaluation and Current Extent of Seepage-Impacted Water

In the absence of a naturally occurring shallow aquifer, the temporary saturation created by the former mine water discharge is considered the background water for Zone 1 (EPA, 1988; 1998). This anthropogenic groundwater was later impacted by acidic seepage from Borrow Pit No. 2 in the Central Cell (compare Figure 2 and Figure 48). These seepage fluids contained elevated concentrations of metals, radionuclides, and major ions, including sulfate and chloride.

Source remediation (neutralization and subsequent dewatering of the borrow pit), continued neutralization of the seepage by natural geochemical processes, and mixing with the background water have reduced concentrations of most constituents below the Site clean-up standards. However, as discussed below, exceedances of some constituents still occur in Zone 1. Appendix C provides





historic constituent concentration data through October 2004. Table 15 summarizes the constituents detected in Zone 1 during October 2004.

It is important to realize that exceedances of Site standards in some wells represent background water quality. For example, since 1989 background Well EPA 4 (in Section 1) has persistently shown exceedances of sulfate, has generally shown exceedances of manganese, and has shown concentrations of combined radium that have fluctuated above and below the standard. Background water quality is discussed further in the subsequent section entitled Natural Attenuation System Performance Evaluation.

Water quality has continued to improve since shutoff of the pumping wells, indicating that the area of seepage impact is stable to diminishing. Zone 1 seepage impacts have been delineated by chloride concentrations greater than 50 mg/L (Earth Tech, 2000a). Figures 6 and 48 show the extent of seepage impacts in October 2004. The seepage has predominantly migrated toward the northeast. Further eastward components to migration are limited by the proximity of the eastern edge of saturation. The acidic "core" to the impacted zone is approximated by the red area in Figure 48, where pH is inferred to be less than 4.0. Comparison with the pH values in October 2003 (USFilter, 2004a, Figure 40) shows that the October 2004 values decreased in all of the impacted wells. However, these pH decreases fall within the range of long-term fluctuations (Appendix C). Figure 49 shows historic pH values for Zone 1 wells through October 2004.

The following constituents continue to exceed the Site standards outside the property boundary in Section 1:

- TDS Wells EPA 4, EPA 5, and EPA 7
- Sulfate Wells EPA 4, EPA 5, and EPA 7
- Metals Wells EPA 4 (manganese), EPA 5 (cobalt), and EPA 7 (manganese)

Well EPA 4 was just below the combined radium standard during October 2004 (4.8 pCi/L). All of these constituents have generally exceeded standards at the cited wells since 1989. Well EPA 4 is located approximately 220 ft to the north of the current edge of the impacted area, within an area of background water quality. Within the Site property, these constituents exceeded standards, and several wells also showed the following exceedances in October 2004: nickel (Wells 515 A, 604), aluminum (Well 604), chloroform (Wells 515 A, 604, and 614), and combined radium (Well 604).

The extent of seepage impacts, as delineated by a chloride concentration greater than 50 mg/L, has not changed in the past seven years, including the period since the shutoff of the extraction wells. However, water quality has continued to





improve since shutoff, indicating that the area of seepage impact is stable to diminishing. Natural attenuation processes include acid neutralization by (1) reaction with the Zone 1 bedrock (which has a calcite (calcium carbonate) content of 0.03 percent (Canonie, 1987, Table 4.5)); (2) mixing with the neutral background water; (3) precipitation of metals and radionuclides; and (4) adsorption of metals (excluding manganese) and radionuclides. These processes attenuate the pH, metals, and other seepage constituents. The relatively low transmissivity of Zone 1 and the underlying aquiclude promotes slow migration and increased residence time for the impacted water to successfully attenuate.

4.3.3 Natural Attenuation System Performance Evaluation

The Zone 1 natural attenuation system comprises the hydro-geochemical interactions between the bedrock matrix, the anthropogenic background waters (derived from former mine water discharge), and the tailings fluids. The natural system is successfully attenuating the seepage impacts by the processes of neutralization, precipitation, adsorption, and mixing with the background waters.

Table 16 shows the predicted geochemical performance of the Zone 1 natural attenuation system (Earth Tech, 2002d). In summary, sulfate and TDS concentrations are not expected to meet Site standards because gypsum equilibrium in the groundwater prevents any further reduction in sulfate concentration. Manganese may meet the Site standards if sufficient bicarbonate is available for attenuation. The remaining metals and radionuclides are expected to meet the standards through attenuation by neutralization and adsorption. The individual constituents of concern are discussed below.

Sulfate and TDS

Sulfate concentrations exceed the Site standard in both the seepageimpacted water and the background water in Zone 1. Figure 50 shows historic sulfate concentrations through October 2004; Figure 51 shows the extent of sulfate exceedances during October 2004. Regardless of whether the extraction wells were operating, sulfate concentrations in Zone 1 are controlled by the system's equilibrium with gypsum. Based on the overall stable concentrations and the results of the geochemical investigation presented by Earth Tech (2000a), sulfate is not expected to meet the clean-up standards within Section 1. As in the Southwest Alluvium and Zone 3, most of the TDS comprises sulfate. Accordingly, TDS concentrations are not expected to meet the clean-up standards in Section 1, although they should gradually decrease to background levels.





Manganese

Manganese concentrations exceed the Site standard in both the seepageimpacted water and the background water (Well EPA 4) in Zone 1. Concentrations in the seepage-impacted water are higher. These concentrations have decreased over time as the acidic seepage has been neutralized, but the magnitude of the decrease is largely controlled by the bicarbonate concentrations (Earth Tech, 2000a). Historic manganese concentrations through October 2004 are provided graphically on Figure 52 (these data are tabulated in Appendix C). The extent of manganese that exceeded the Site standard during October 2004 is shown on Figure 53.

Bicarbonate concentrations in impacted wells are related to the waters' degree of neutralization of acidic seepage. Figure 54 shows historic bicarbonate concentrations through October 2004. This figure shows that the bicarbonate concentration plunged steeply in Well EPA 5 from January 2000 to May 2000. As discussed above regarding Zone 3, such marked bicarbonate declines are indicative of (sometimes temporary) exhaustion of the local neutralization capacity of the natural geochemical system. However, the pH in Well EPA 5, while fluctuating, has remained quite steady over the period of historic measurements (Appendix C), indicating that dilution and dispersion are important natural attenuation processes. By contrast, Well 614 (Figure 54) has never shown such a falloff in bicarbonate concentrations, which is consistent with its side-gradient location with respect to former Borrow Pit No. 2. A third example of historic bicarbonate treads is provided by Well EPA 7 (Figure 54), where formerly very low bicarbonate concentrations increased sharply starting in January 1994, and the fluctuating levels have increased overall from October 1998 through July 2002; since then they have been relatively stable. The rising concentrations indicated that the natural attenuation neutralization capacity was recovering at this location for approximately 3.5 years through July 2002; since then neutralization has continued with the geochemical system in equilibrium.

The seepage-impacted wells that have had bicarbonate concentrations greater than 1,000 mg/L (Wells 614, 516 A, and EPA 5) either have never had manganese exceedances or have shown a decrease in manganese concentration below the standard. Wells 515 A, 604 and EPA 7 showed manganese exceedances in October 2004. Although neutralization has attenuated some of the manganese, bicarbonate concentrations are not sufficiently high to reduce the concentrations below the standard. Since July 1991, increasing bicarbonate concentrations in Well EPA 7 (in

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Section 1) have exceeded 500 mg/L (Figure 54), and the manganese concentration has steadily declined (Figure 52). The decreasing manganese trend continued through October 2004, although the bicarbonate concentrations have remained quite stable through the year. If the bicarbonate level proves sufficient then the manganese concentration is expected to decrease below the Site standard within the next two or three years. Long-term manganese exceedances at Well EPA 4 represent background water quality. Most of the other constituents at this location have been fluctuating to steady since 1989 (Appendix C).

Exceedance of the manganese standard within the property boundary will continue unless sufficient bicarbonate is generated by the neutralization process to reduce the manganese concentrations. It is important to realize that manganese exceeds the standard in the background water quality.

Cobalt and Nickel

The only metals other than manganese that exceed Site standards in Section 1 are cobalt and nickel (Well EPA 5 during part of 2004). Other metals were attenuated within the property boundary. Exceedances of cobalt and nickel are primarily limited to the area within the property boundary where the acidic seepage has not been fully neutralized. Historic concentrations for these two constituents through October 2004 are presented graphically in Figure 55. Relatively steep declines in nickel during 2004 occurred in Wells 604, 515 A, and EPA 5. The extent of cobalt and nickel exceedances during October 2004 is shown in Figure 56.

Cobalt and nickel typically do not adsorb sufficiently to reduce their concentrations below their standards until the pH is approximately 6.5 or more (Earth Tech, 2002d). Historic cobalt and nickel concentrations in Well EPA 7 have fluctuated around the Site standards as the pH has increased to above 6.0. During October 2004 (Figure 55), the cobalt concentration in this well was less than the Site standard (0.05 mg/L), and nickel was non-detect. Over time, it is expected that continued neutralization will lead to adsorption and attenuation of these two metals and that their concentrations will fall below the standards. In the meantime, their concentrations have been stable to decreasing since the termination of active remediation.





Combined Radium-226 and Radium-228

Similar to the metals, combined radium is attenuated by neutralization, precipitation, and adsorption. The primary exceedances of combined radium are within the property boundary where the pH is more acidic. Historic concentrations for combined radium through October 2004 are presented in Figure 57. During October 2004, the combined radium Site standard was exceeded within the property boundary only in Well 604 (where it has fluctuated about the standard since October 2003). Outside the property boundary, Wells EPA 2 and EPA 4 showed relatively sharp declines since April 2003, and through October 2004 they have fluctuated largely beneath the standard (Figure 57; Appendix C).

Historically, the combined radium standard has been exceeded in all three background wells (EPA 2, EPA 4, and EPA 8). The combined radium concentrations are expected to decrease to at least the background levels, and possibly to below the standard, with continued natural attenuation.

Chloroform

Exceedances of the Site standard for chloroform in October 2004 occurred only in wells within the property boundary: 515 A, 604, and 614. Wells 515 A and 614 have long-term concentrations in the low hundreds of μ g/L; Wells 604 and EPA 7 have shown long-term fluctuations between nondetects and concentrations to approximately four times the standard. The occasional exceedances in Well EPA 7 and the historic absence of detections in all wells farther to the north indicate that chloroform rapidly attenuates over relatively short distances of groundwater flow.







Section 5 Conclusions and Recommendations

This annual review evaluated the performance of the natural systems in all three Site hydrostratigraphic units, without the influence of active remediation. The conclusions and recommendations of this evaluation are provided below.

5.1 Conclusions

- Overall, the saturated thickness in the Southwest Alluvium continued to decline in 2004, indicating that the potentiometric field, which drives groundwater flow and constituent migration, continues to become lower as the groundwater drains down the arroyo.
- In the Southwest Alluvium, former extraction well pumping did not contain the constituents and will not do so in the future. However, hydraulic containment is not a necessary feature of the corrective action program because of the geochemical attenuation that occurs-naturally.
- The Southwest Alluvium seepage-impacted water is most meaningfully delineated by bicarbonate isoconcentration contours. Hazardous constituents derived from seepage impact are effectively attenuated and contained within Emphasis has been placed on understanding the the Site boundary. geochemical evolution of both the background water quality and later changes associated with passage of the seepage-impact front. Sulfate and TDS, which exceed standards outside the Site boundary, do so in both seepage-impacted and background wells. Sulfate (the primary component of TDS) tends to temporarily fall below the standard in the migrating reaction zone associated with the front and northwestern flank of the migrating seepage-impacted groundwater. Ahead of this migrating front, background concentrations for sulfate and TDS tend to exceed the standards but this water quality is unrelated to seepage impact and application of the Site standards is inappropriate. Behind this migrating front, impacted groundwater quality offsite will tend to have sulfate and TDS levels approximately equal to, or lower than, those in the background water. Ahead of the current seepageimpact front, new downgradient well SBL 1 shows very high sulfate and minor exceedances of magnesium, cobalt, and nickel that are not due to seepage impact.
- Concentrations of uranium in the Southwest Alluvium do not show that pumping is a more effective remedy than natural attenuation. Following the long-term trends, there are no exceedances of the Site standards. The uranium concentrations and concentration time trends have been mostly





stable to decreasing since the pumps were turned off. The main exceptions are increasing concentration trends in point-of-compliance wells GW 2 and GW 3. However, the highest post-shutoff concentrations in these wells are below the upper values of historic ranges and well below the standards. The historic and recent records of uranium concentrations in the Southwest Alluvium show that within impacted water, both gradual and sudden variations are characteristic and unrelated to former extraction pumping.

- Both the Zone 3 and Zone 1 natural systems are at least as effective as, if not more effective than, the active remediation systems in attenuating the seepage-impacted water. Acidic seepage is being neutralized, resulting in attenuation of metals and radionuclides. Geochemical conditions related to gypsum equilibrium and bicarbonate availability will limit the reduction of sulfate and manganese concentrations in both hydrostratigraphic units, regardless of whether or not the extraction wells are operated.
- Overall, the saturated thickness in Zone 3 continued to decline in 2004, indicating that the potentiometric field, which drives groundwater flow and constituent migration, continues to become lower as the groundwater further dissipates.
- Zone 3 water levels have recovered from the effects of former downgradient pumping. The long-term increase in bicarbonate concentrations and neutral pH values at Well 420 indicate continuing neutralization by the natural system in this location. Well EPA 14 continues to show concentrations of uranium and aluminum at levels indicative of impact. However, combined radium and alkalinity trends suggest the negative effects of Zone 3 pumping at this well may be in the early stage of reversal, though it is too soon to make a firm conclusion. Acidic seepage continues to migrate downgradient past Wells 719 and 504 B. Cessation of pumping in 2000 resulted in rapid hydraulic recovery, but in some locations at least several years are required for the natural geochemical processes to complete the attenuation process. The metals and radionuclide concentrations are expected to continue to attenuate to background concentrations; however, it is presently unknown whether this will occur before the seepage reaches the property boundary. The seepageimpact front reached boundary Well PB 4 during 2004 and it is migrating northward at approximately 60 ft per year. The boundary well array is successfully allowing tracking of the northward migration of the seepage UNC is conducting an ongoing, expanded pilot study toward impact. evaluating the effectiveness of hydraulic fracturing to enhance the remedy of cutoff and containment of the seepage-impact front.
- The seepage-impacted area in Zone 1 is stable to diminishing. Overall, the saturated thickness in Zone 1 continued to decline in 2004, indicating that the





potentiometric field, which drives groundwater flow and constituent migration, continues to become lower as the groundwater further dissipates into unsaturated parts of this bedrock stratigraphic unit.

5.2 Recommendations

5.2.1 Recommendations for Closure of Southwest Alluvium Remedial Action

Predicted performance of the Southwest Alluvium natural attenuation system is summarized on Table 6. The continuing assessment of natural attenuation in this annual report is the basis for the following recommendations for the Southwest Alluvium corrective action system:

- 1. Decommission the pumping wells.
- 2. Continue to perform monitoring on an annual basis because the seepageimpacted water quality is stable, the offsite impacted water quality is not hazardous, and a yearly frequency is sufficient for tracking the migration of the seepage-impact front (estimated to be moving southwestward toward new Well SBL 1 at an average rate of 30 ft per year).
- 3. Closure of the Southwest Alluvium corrective action program using Monitored Natural Attenuation (MNA) for chloride, chloroform, metals, and radionuclides.
- 4. The Southwest Alluvium seepage-impacted area has attained ALARA goals. In the future, it should be managed via ACLs established by NRC and/or TI Waiver. A TI Waiver would be non-traditional in the sense that there would not be a classic TI zone. Instead, UNC proposes that the projected 200-year seepage front be used, which we understand to be compatible with NRC guidance.

The background water quality may exceed the Site standards for sulfate and TDS downgradient for miles, but this water quality is unrelated to seepage impact. The estimated location of the seepage-impact front 200 years from now, during 2204, is shown in Figure 58. This prediction is based on the October 2004 location of the 1000 mg/L bicarbonate isoconcentration contour, linear extrapolation of a mean groundwater velocity of 30 ft per year, and an assumption of purely advective transport with no bicarbonate attenuation, retardation, dilution, or dispersion. This results in a 200-year predicted seepage front location approximately 6,000 ft south-southwest of the current front location along Pipeline Arroyo.





5.2.2 Recommendations for Zone 3 Remedial Action

Continue Zone 3 remediation using the natural system to stabilize the seepage impacts. The revised monitoring program requested by the NRC and implemented in 2001, combined with the boundary wells that UNC installed in 2002, have proven to be very useful for evaluating the migration of the seepage and the performance of the natural system in attenuating constituents. UNC is currently conducting an ongoing, extended pilot program toward evaluating the use of hydrofracturing to enhance the remedy for cutoff and containment of the migrating seepage-impacted water.

UNC recommends that the NRC revise the ROD background concentrations for Zone 3 metals, just as they did in 1996 for sulfate, nitrate, and TDS. The background metals of relevance include arsenic, molybdenum, nickel, cobalt and manganese.

5.2.3 Recommendations for Closure of Zone 1 Remedial Action

Predicted performance of the Zone 1 natural attenuation system is summarized on Table 16. Proceed to closure of the Zone 1 corrective action program using a combination of:

- 1. Monitored Natural Attenuation (MNA) for metals and radionuclides;
- 2. TI Waiver for sulfate, TDS, and manganese in the TI zone shown on Figure 58; and
- 3. Institutional Controls for support of MNA and the TI Waiver.





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Southwest Alluvium Performance Monitoring Program, 2004 Operating Year United Nuclear Corporation, Church Rock Site

14/-11	· · · ·	Mater Level		NDO DOO	Dumage
weit	Use	water Level	water Quality	NHCPUC	Purpose
509 D	Monitor	<u> </u>	<u> </u>	<u> </u>	Seepage extent
624	Monitor	<u> </u>	<u> </u>	·	Downgradient background, seepage extent
627	Monitor	X	<u> </u>		Downgradient background, seepage extent
632	Monitor	<u> </u>	<u> </u>	<u>Y</u>	Seepage extent
801 ²	Pumping (idled)	X	X	•	Seepage and saturation extent
802	Pumping (idled)	X	X		Seepage and saturation extent
803	Pumping (idled)	X	X		Seepage and saturation extent
805	Monitor	X			Water level only
807	Monitor	<u> </u>			Water level only
808 ³	Pumping (idled)	X	X		Seepage extent
EPA 23	Monitor	Х	· X.	Y	Problematic completion
EPA 25	Monitor	X	X		Downgradient background, seepage extent
EPA 28	Monitor	X	X .	Y	Seepage extent
GW 1	Monitor	X	X	Y	Seepage extent
GW 2	Monitor	Χ.	X	Y	Seepage extent
GW 3	Monitor	X	X		Downgradient background, seepage extent
	Total	16	14		l
Eliminate	d From Monitorir	a	r <u></u>		Reason for Elimination
GW 4	X	X			
FPA 22A		<u>`</u>		Y	Drv
29A					Dry
639					Drv
642		, <u></u>		•	Drv
644				•	Dry
645			·		Drv
804]		Not needed, use 632
806					Not needed, use 805
EPA 27					Dry

Notes:

1 Pumping wells turned off in January 2001 after final baseline samples were collected. Well 801 is the exception, see Note 2.

2 Well 801 was turned off at the end of July 1999 because it met decommissioning criteria. Sample collection ceased after the first quarter 2000. Well 801 water quality is included in the test program, therefore sampling recommenced January 2001 and has continued through 2003.

3 Well 808 was not included in the Performance Monitoring Program prior to the NA Test, therefore no data are available prior to January 2001.

TABLE 2
Detected Constituents in Southwest Alluvium, October 2004
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

		Action				1	. (
Chemical Name	Unit	Level	801	802	803	808	GW 1	GW 2	GW 3	627	509 D	EPA 23	632	EPA 25	EPA 28	624	SBL-01
ALUMINUM	mg/l	5															0.4
AMMONIA (AS N)	mg/l		4.0 D		0.95	0.13	0.23		0.06		0.59	1.06	0.33	0.06			0.43
BICARBONATE (HCO3)	mg/l		1470	2350	1830	1840	1570	2240	1680	600	2310	1080	1750	838	684	1380	251
CADMIUM	mg/l	0.01		0.006												_	
CALCIUM	mg/l		565 D	666 D	695 D	742 D	699 D	761 D	935 D	571 D	853 D	670 D	738 D	712 D	528 D	666 D_	572 D
CHLORIDE	mg/l	250	221	215	171	185	249	224	165	54	*** 349 /*	79	252	87	125	172	96
	ug/l	1	12:13.1 /10	8.4	1007 2 TUC	1							2.6-				
COBALT	mg/l	0.05															₩ 0.06 @
GROSS ALPHA	pci/l	15											1.1		1.2	•	
MAGNESIUM	mg/l		727 D	955 D	741 D	681 D	572 D	569 D	315 D	294 D	322 D	398 D	945 D	230 D	498 D	422 D	1070 D
MANGANESE	mg/l	2.6	<i>⊡</i> -4/15∺	0.80	1.99	0.62	0.05	0.69	1.76		**3.13	-7 5.03 🕬	1.42	2.32	0.51	0.06	**• 3.35 %*
NICKEL	mg/l	0.05											_				0.17
NITRATE (NO3)	mg/l	190	0.7	83 D	44 D	118 D	93 D	12.8 D	80.0 D	125 D	17.1 D	0.4	59.5 D	89.3 D	36.8 D	85.9 D	94 D
POTASSIUM			12.6	6.8	11.1	4.6	5.8	11.5	8.0	4.5	11.7	9.9	9.3	7.6	12.2	6.4	15.3
RADIUM-226	· pci/l		1.1							0.3		0.4	2.3	·	0.3		0.4
RADIUM-228	· pci/l									2.0		1.3	3.5	1.3			2.8
RADIUM 226 & 228	_pci/l	5	1.1	· · ·						2,3	•	1.7	5.8 Tut	1.3	0.3		3.2
SELENIUM	mg/l	0.01		0.001		0.001				0.009				0.001			
SODIUM	mg/l		379	397	307	334	354	346_	272	530 E	308	140	395	186	224	237	368
SULFATE (SO4)	mg/l	2125	3390 D	3580 D1	3140 D -	2840 D -	12590 D 1	2570 D	2080 D	:2470 D -	1660	·2380 D 1	• 4020 D *	1740 D	2750 D -	2020 D	65390 D#
TOTAL DISSOLVED SOLIDS (LAB)	mg/l	4800	🗵 6670 🔨	s 8200 - ·	7-7200	7070	6800 4	tt 6600 th	5720 *	5440	: 5430 4	4570	- 7470 -	4250	7° 5460 🐔	5520 ::	18450.14
	mg/l	0.3	0.0370 D	0.194 D	0.133 D	0.116 D	0.0870 D	0.102 D	0.107 D	0.0261 D	0.211 D	0.0226 D	0.0652 D	0.0969 D	0.0368 D	0.0321 D	0.0267 D

d01-6209-08

Veolia Water

Southweat Alluvium Saturated Thickness, October 2004 United Nuclear Corporation, Church Rock Site Church Rock, New Mexico

Well	Water Level Measurement Date	SW Alluvium Unsaturated Thickness (ft)	SW Alluvium Saturated Thickness (ft)	SW Alluvium Percentage Saturated
624	10/4/2004	70.66	39.34	36%
627	10/5/2004	48.82	26.18	35%
632	10/5/2004	55.84	15.16	21%
801	10/4/2004	40.33	26.67	40%
802	10/4/2004	45.38	15.12	25%
803	10/4/2004	43.26	38.24	47%
805	10/4/2004	57.73	60.27	51%
807	10/26/2004	44.97	75.03	63%
808	. 10/26/2004	50.30	49.70	50%
509-D	10/4/2004	44.63	87.37	66%
EPA-23	10/4/2004	47.05	72.95	61%
EPA-25	10/5/2004	48.96	21.04	30%
EPA-28	10/5/2004	58.37	19.63	25%
GW-1	10/4/2004	57.46	19.54	25%
GW-2	10/4/2004	51.16	38.84	43%
GW-3	10/5/2004	49.69	7.31	13%
SBL-1	10/18/2004	47.38 ⁻	17.62	27%

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Summary of Operational Data Southwest Alluvium Extraction Wells 1989 to 2001 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

					/ Ann	ual Avera	age Pum	ping Rat	e (gpm)	_			
Well No.	1990 ⁽¹⁾	1991 ⁽²⁾	1992 ⁽³⁾	1993 ⁽⁴⁾	1994 ⁽⁵⁾	1995 ⁽⁶⁾	1996 ⁽⁷⁾	1997 ⁽⁸⁾	1998 ⁽⁹⁾	1999 ⁽¹⁰⁾	2000 ⁽¹¹⁾	2001 ⁽¹²⁾	1990- 2001
801 ⁽¹³⁾	1.2	0.5	0.4	0.2	0.2	0.1	0.1	0.1	0.08	0.08	0.00	0.00	0.25
802	11.1	12.5	11.9	9.0	9.8	9.7	9.1	10.1	11.02	9.62	9.31	5.80	9.91
803	2.0	2.6	2.5	3.0	3.2	3.5	3.1	2.9	3.84	3.56	3.83	3.68	. 3.14
808 (14)		<u>10.0</u>	15.5	19.9	15.6	12.3	12.2	7.2	4.34	3.50	2.50	3.35	9.67
Total Pumping Rate	14.3	25.6	30.3	32.1	28.8	25.6	24.5	20.3	19.29	16.76	15.64	11.94	22.98
Volume Pumped (millions of gallons) ⁽¹⁵⁾	7.4	12.4	17.2	18.1	15.7	12.9	12.2	9.2	9.0	7.5	7.7	1.7	131.0 ⁻

Notes:

1. Average pumping rate calculated for the period between October 13, 1989, and October 12, 1990.

2. Average pumping rate calculated for the period between October 13, 1990, and October 11, 1991, except Well 808, which calculated for the period between June 26, 1991 (i.e., well startup) and October 11, 1991.

3. Average pumping rate calculated for the period between October 12, 1991, and October 8, 1992.

4. Average pumping rate calculated for the period between October 9, 1992, and October 8, 1993.

5. Average pumping rate calculated for the period between October 9, 1993, and October 14, 1994.

6. Average pumping rate calculated for the period between October 15, 1994, and September 29, 1995.

7. Average pumping rate calculated for the period between September 30, 1995, and September 27, 1996.

8. Average pumping rate calculated for the period between September 28, 1996, and September 26, 1997.

9. Average pumping rate calculated for the period between September 27, 1997, and September 25, 1998.

10. Average pumping rate calculated for the period between October 02, 1998, and September 27, 1999.

11. Average pumping rate calculated for the period between September 28, 1999, and September 29, 2000.

12. Average pumping rate calculated for the period between September 30, 2000, and January 12, 2001.

13. Well 801 decommissioned at the end of July 1999.

14. Well 808 began operation on June 26, 1991.

15. Data obtained from system flowmeter.

gpm = gallons per minute Source: Earth Tech, December 2002, Figure 2.1

Southwest Alluvium Groundwater Velocities, October 2004 United Nuclear Corporation, Church Rock Site Church Rock, New Mexico

Well Pair 805 and 624

Groundwater Elevations: 6865.08 (Well 805) and 6849.34 (Well 624) ft amsl Separation Distance: 1902 ft Average Linear Horizontal Hydraulic Gradient: 0.0083 Velocity 1 = 64 ft/yr Velocity 2 = 49 ft/yr Average Velocity = 57 ft/yr

Well Pair 805 and 627

Groundwater Elevations: 6865.08 (Well 805) and 6835.97 (Well 627) ft amsl Separation Distance: 3203 ft Average Linear Horizontal Hydraulic Gradient: 0.0091 Velocity 1 = 70 ft/yr Velocity 2 = 54 ft/yr Average Velocity = 62 ft/yr

Well Pair 624 and SBL 1

Groundwater Elevations: 6849.34 (Well 624) and 6847.15 (Well SBL 1) ft ams Separation Distance: 500 ft Average Linear Horizontal Hydraulic Gradient: 0.00438 Velocity 1 = 33 ft/yr Velocity 2 = 26 ft/yr Average Velocity = 30 ft/yr

Darcy seepage velocity calculation input values:

Mean hydraulic conductivity used = 2×10^{-3} cm/s (USFilter, 2004b).

Range of effective porosities = 27% (velocity 1) to 35% (velocity 2) (Canonie, 1989b; Earth Tech, 2002c).

	Wills	Standards Be	Met?	
Constituent	Section 2	Section 3	Section 10	Remarks
Manganese	No	Yes?	No	Section 2 includes onsite seepage impact; Section 3 includes offsite seepage impact with Mn attenuated and known background water with Mn below standard; Section 10 includes advancing front of seepage impact with Mn below standard and Mn exceedance in new background Well SBL 1
Sulfate	No	No	No	Seepage impact areas limited by calcium availability; background waters characterized by exceedances unrelated to seepage impact
TDS	No	No	. No	Governed by sulfate concentration
Metals	Yes	Yes?	No	Attenuation by neutralization and adsorption. Section 2 includes onsite seepage impact with no exceedances; Section 3 includes offsite seepage impact and known background water with no exceedances; Section 10 includes advancing front of seepage impact with no exceedances but small exceedances of cobalt and nickel in new background Well
Radionuclides	Yes	Yes	Yes	Attenuation by neutralization and adsorption

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TABLE 7 Change in Zone 3 Saturated Thickness Over Time United Nuclear Corporation, Church Rock Site Church Rock, New Mexico

		Saturated *	Thickness	•	
/ Well Numb	er ¹	3rd Quarter 1989	4th Quarter 2004	Change (feet)	Change
402			28,52	· · · · ·	
411		62.5			
420		56.3	19.13	-37.2	-66%
424			30,78		
446			11.42		
501 B		20.2			
502 B		48.5			
504 B	•	40.1	12.76	-27.4	-68%
517		42.7	. 13.01	-29.7	-70%
518 ²		37.2			
613 ³	*********	67.2	19.83	-47.4	-70%
EPA 01		14.7			••
EPA 03	**************	8.3	·		
EPA 09	•••••••••••••••••	8.1	4.24	-3.9	-48%
EPA 11		30,8	· · · · · · · · · · · · · · · · · · ·	······································	
EPA 12	•••••••	10.7		· · · ·	•••
EPA 13		-24.8	10.89	-13.9	-56%
EPA 14		76.3	36,40	-39.9	-52%
EPA 15		60.8	-		
EPA 17		1.4	• •••		
EPA 18		2.5			
701		46.1	16.32	-29.8	-65%
702		24.1	10.20	-13.9	-58%
703		32.6	20.17	-12.4	-38%
705	** **************				.
706		-	18.88		
·707		58.8	21.20	-37.6	-64%
· 708		49.8	19.66	-29.8	-60%
709		56.1		·	
710		45.5	17.24	-28.3	-62%
711		43.7	20.94	-22.8	-52%
712		39.1	11.87	-27.2	-70%
713	•••••••	34.2	12.15	-22.1	-64%
714		50.1	19.69	-30,4	-61%
7154	*******	47.6			
7164		58.3			
7174		57.6	29.64	-28,0	
7184	*******	51:1			
7194		3 9 9	17 99	-22 7	-57%
715		20.4			
120 MDI 045	••••	<u>کې ا</u>		••	•••
INBL-01	Aug == ==		10.05		
·	Average	37.3	18.65	-26.5	-60%

Notes:

 Wells 9 D and 106 D were not included because they appear to be completed above the bottom of Zone 3. Measurements of saturated thickness in these wells may be less than actual conditions. Well 126 was not included because it w completed above the bottom of Zone 3. Measurements of saturated thickness in this well are less than actual condition Wells 600, 610 and 672 were not included because they were used solely as pumping wells, therefore no water level data are available Well 608 was not included because no water level data were available in 1989 and the last water level measurement was in February 2

2. Water level for Well 518 last measured in January 2000.

3. Water level for Well 613 measured in 1983 before pumping started. Water level data for 1989 are not available because the well was pumping.

4. Water levels for the Stage II wells were measured June 1991 when wells were installed. Not included in 1989 average saturated thickness calculation.

5. Well NBL-01 installed in July 2001and first water level measured in August 2001.

Shading Indicates saturated thickness greater than 25 feet.

"--" indicates that no data is available.

TABLE 8
Zone 3 Performance Monitoring Program, 2004 Operating Year
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

	[NRC	
Well	Water Level	Water Quality	POC	Purpose
Continue Monitor	ing			
420	X	X		Postmining-pretailings background, track plume.
711	x	X		Track saturation and plume, replace 502 B based on results of low flow purge testing performed in January 2000.
504 B	X	X		Track saturation and plume, extensive data set.
517	X	X	Y	Track plume, extensive data set.
EPA 9	X			Extent of saturation, water quality not necessary.
EPA 13	X	X		Extent of saturation. Water quality added 2nd quarter 2001.
EPA 14	X	X_		Postmining-pretailings background, track plume.
702	X			Water level only, track saturation.
710	X			Water level only.
712	X		i	Water level only.
713	x			Water level only.
714	x			Water level only.
613	X	X		Extensive data set, track saturation and source.
701	X			Water level only (decommissioned pumper).
706	X			Water level only (decommissioned pumper).
707	X			Water level only (decommissioned pumper).
708	x	X		Added to program 2nd quarter 2001.
717	X	X		Water level. Water quality added 2nd quarter 2001.
719	<u> </u>	X		Water level. Water quality added 2nd quarter 2001.
Additional Wells,	Not Included Ir	n Original Perform	nance Mor	nitoring Program
402	X			Long-term water level for migration path.
424	X			Long-term water level for migration path.
446	<u> </u>			Long-term water level for migration path.
NBL-01	×	X		Well drilled and Installed June 2001. Water level and water quality to track downgradient extent of seepage.
Total	23	11		

Eliminated From Monitoring		Reason For Elimination		
9 D		Dry		
106 D		Dry		
411		Oil, cannot get water level or sample.		
501 B .	Y	Dry		
EPA 1		Dry		
EPA 3	Y	Dry		
EPA 11 .		Unuseable since 1990 - water level below pump, pump cemented in well.		
EPA 12		Dry		
EPA 15		Dry		
EPA 17		Dry		
EPA 18		Dry		
126		Dry		
502 B	•	Failed low-flow test, use 711		
518	Y	Failed low-flow test, use 517		
608		Not needed (formerly water level only)		
703		Not needed (formerly water level only)		
715	· · ·	Not needed (formerly water level only)		
709		Not needed (decommissioned pumper)		
716		Not needed (pumper)		
718		Not needed (pumper)		
720		Not needed (decommissioned pumper)		

.

Notes: NRC POC = Nuclear Regulatory Commission Point of Compliance well Source: Earth Tech, December 2002, Table 3.2

Zone 3 Saturated Thickness, October 2004 United Nuclear Corporation, Church Rock Site Church Rock, New Mexico

Well	Water Level Measurement Date	Zone 3 Unsaturated Thickness	Zone 3 Saturated Thickness	Zone 3 Percentage Saturated
402	10/26/04	34.48	28.52	45%
420	10/11/04	31.87	19.13	38%
424	10/26/04	42.22	30.78	42%
446	10/26/04	53.58	11.42	18%
504-B	10/11/04	53.24	12.76	19%
517	10/11/04	48.99	13.01	21%
613	10/5/04	48.17	19.83	29%
701	10/26/04	47.68 ·	16.32	25%
702	10/26/04	70.80	10.20	13%
703	10/26/04	71.83	20.17	22%
706	10/26/04	59.12	18.88	24%
707	10/26/04	66.80	21.20	24%
708	10/12/04	65.34	19.66	23%
710	10/26/04	63.76	17.24	21%
711	10/12/04	64.06	20.94	25%
712	10/26/04	74.13	11.87	14%
713	10/26/04	60.85	12.15	17%
714	10/26/04	18.31	19.69	52%
717	10/11/04	41.36	29.64	42%
719	10/11/04	27.78	17.22	· 38%
EPA-09	10/12/04	45.76	4.24	8%
EPA-13	10/12/04	53.11	10.89	17%
EPA-14	10/5/04	36.60	36.40	50%
NBL-01	10/11/04	8.63	25.37	· 75%
PB-02	10/11/04	25.21	24.79	50%
PB-03	10/11/04	18.76	30.24	62%
PB-04	10/11/04	11.01	25.99	70%

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TABLE 10
Zone 3 Field Parameter Measurements of Sentinel Wells, Through October 2004
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

		Bicarbonate (mg/L)					Conductivity (umhos/cm)					pH (s.u.)					Chloride (mg/L)				
Month		504B	PB-2	PB-4	PB-3	NBL-01	504B	PB-2	PB-4	PB-3	NBL-01	504B	PB-2	PB-4	PB-3	NBL-01	504B	PB-2	PB-4	PB-3	NBL-01
1	Jun-02	NA	141	270	341	339	NA	3950	3660	3400	NA	4.55	6.18	6.38	6.23	6.65	NA	29.9	21.8	2.0	NA
3	Aug-02	NA	94	211	311	NA	4900	3780	3540	3200	3140	NA	5.93	6.77	6.68	NA	NA	26.0	24.5	4.0	NA
4	Sep-02	NA	105	178	327	NA	NA	3930	3770	3330	NA	NA	5.95	6.8	6.56	NA	NA	24.1	24.5	24.7	NA
5	Oct-02	NA	58	194	224	330	5010	4040	3730	3670	3160	5.06	7.09	7.1	7.1	7.18	NA	25.3	23.8	113.0	NA
6	Nov-02	0	41	188	299	285	4930	3080	2860	2510	3120	_NA	5.95	6.47	6.6	6.51	14.0	26.5	24.3	23.8	21.0
7	Dec-02	NA	57	178	283	NA	5040	4120	3950	3330	NA	5.4	5.75	6.4	6.68	NA	22.9	26.2	23.2	25.7	NA_
8	Jan-03	NA	34	148	239	311	5180	3930	3716	3460	3300	5.54	4.97	6.92	6.41	6.43	NA	NA	22.9	22.8	NA
9	Feb-03	NA	58	193	324	328	3620	2910	2660	2570	2300	3.52	5.57	6.96	6.92	6.53	26.7	30.1	30.4	28.5	21.5
10	Mar-03	NA	60	188	311	326	4000	3090	2890	2680	2500	3.49	5.59	6.71	6.95	6.73	26.4	30.1	29.7	29.7	22.1
11	Apr-03	NA	34	172	310	321	4210	4460	4220	3820	2650	5.14	5.46	5.94	6.26	6.87	26.6	30.5	30.0	30.1	21.6
12	May-03	0	31	167	293	322	5510	4460	4210	3820	3390	5.01	5.36	5.99	6.31	6.37	28.0	31.0	30.2	31.9	32.7
13	Jun-03	0	21	129	267	316	5470	4480	4060	3820	3380	4.28	5.15	6.17	6.2	6.36	27.7	30.8	29.6	30.6	28.0
14	Jul-03	0	32	126	257	311	5480	4560	4330	3920	3500	5.35	5.28	5.85	6.32	6.29	26.5	30.6	29,7	31.1	25.8
15_	Aug-03	NA	5	100	234	307	5210	4280	3960	3630	3230	5.14	5.18	5.76	6.18	6.28	27.0	30.4	29.7	31.1	23.1
16	Sep-03	NA	7	91	218	295	5260	4400	4160	3770	3340	4.68	5.23	5.79	6.28	6.39	28.0	30.5	29.3	31.5	26.7
17	Oct-03	NA-	0	65	211	295	5360	4450	4210	3390	3390	5.27	5.18	5.81	6.34	6.41	27.7	21.0	30.0	32.7	26.8
18	Nov-03	NA	0	73	197	285	5290	4510	4210	3880	3490	5.09	5.25	5.81	6.24	6.42	27.3	30.6	30.2	32.1	24.8
18	Dec-03	NA	NA	41	166	265	5370	4540	4290	3910	3510	4.41	5.14	5.77	6.76	6.48	27.7	30.2	29.8	31.5	25.2
. 19	Jan-04	NA	NA	73	194	327	5340	4610	4310	4030	3550	5.39	5.16	5.82	7.51	6.5	32.5	30.5	29.5	32.6	26.8
20	Feb-04	_NA_	NA	50	190	323	5410	4630	4260	3970	3590	3.4	3.81	5.99	6.25	6.4	28	30.1	30.3	32.7	26.6
21	Mar-04	· NA	15		179	316	5560	4730	NA	4130	3780	3.89	4.75	5.7	6.31	6.29	27.5	30.1	30.2	33.3	25.9
22	Apr-04	_NA	<u>15</u>	48	174	315	5370	4560	NA	4010	3630	5.36	5.08	5.52	6.03	6.34	28.1	32.1	32.3	36.2	31.1
23	May-04	NA	0	27	166	· 312	6190	4390	NA	3870	3510	3.26	5.02	5.34	5.88	6.23	28.4	33.2	32.8	38.1	31.9
24	Jun-04	NA	0	22	152	294	5510	4530	NA	4040	3750	4.48	4.92	5.46	6.05	6.4	28.2	32.6	32.9	37.7	34.1
25	Jul-04	NA	0	20	140	274	5450	4510	NA	4000	3740	5.48	5.04	5.58	6.05	6.45	27.8	31.9	32.8	36.9	34.1
26	Aug-04	NA	0	17	124	272	5500	4450	NA	4040	3710	3.77	4.26	5.45	5.98	6.39	28.3	31.0	32.3	36.2	33.7
27	Sep-04	0	0	20	117	251	5480	4500	NA	4030	3790	4.04	4.46	5.48	6.05	6.45	28.5	30.9	32.5	36.0	34.0
28	Oct-04	0	0	18	102	245	5520	4540	NA	4110	3940	5.56	5.15	5.62	6.08	6.47	27.8	31.5	32.0	30.2	33.2

Note:

• NA indicates not analyzed
TABLE 11Zone 3 SeepageMigration Travel Time CalculationsUnited Nuclear Corporation, Church Rock SiteChurch Rock, New Mexico

			Time	for		
Well	Measuring Point	Distance From Measuring Point (ft)	Seepage Impacts at Measuring Point (date)	Seepage Impacts at End Point (date)	Travel Time (ft/yr)	Basis for Determining Date for "Seepage Impacts At End Point"
420	North Cell	2,100	1980	Oct-02	95	Bicarbonate concentration greater than 500 mg/L
504 B	North Cell	2,450	1980	Jul-92	204	Bicarbonate concentration less than 100 mg/L
EPA 14	North Cell	1,520	1980	Åpr-96	95	Bicarbonate concentration greater than 500 mg/L
PB 2	North Cell	3,080	1980	Oct-02	140	Bicarbonate concentrations first reaching @ 50 mg/L at Well PB-02
PB 2	_504 B	630	Jul-92	Oct-02	61	Bicarbonate concentrations first reaching @ 50 mg/L at each well
PB 4	PB 2	52	Apr-03	Feb-04	60	Bicarbonate concentrations first persistently at or below 50 mg/L at each well
·			Geometric M	ean	99	

TABLE 12

Detected Constituents in Zone 3, October 2004 United Nuclear Corporation, Church Rock Site Church Rock, New Mexico

Chemical Name	Unit	Level	504B	420	517	EPA 13	EPA 14	613	708	717	711	719	NBL-01	PB-02	PB-03	PB-04
ALUMINUM	mg/l	5	0.2		···· 5.8		40.552***	*687 D	1.8		0.9	16:5				
AMMONIA (AS N)	mg/l		0.91	0.17	10.6 D	0.66	40 D	284 D	1.70	1.81	0.93	2.54	0.38			
ARSENIC	mg/l	0.05	0.015	0.003		0.274 D					0.021		0.889 D+			
BERYLLIUM	mg/l	0.017					··· 0.68	St 0.18 ??"				0.03				
BICARBONATE (HCO3)	mg/l			579		83	188			559			242		107	31
CADMIUM	mg/l	0.01	_				0.044 D	:0.058 D								
CALCIUM	mg/l		485 D	646 D	512 D	452 D	743 D	435 D	442 D	729 D	491 D	496 D	616 D			
CHLORIDE	mg/l	250	29	69	48	42	71	159	30	69	19	34	36	31	37	30
CHLOROFORM	ug/l	1		•	**** 3.5 ***			7 148 D 🕾							•	
COBALT	mg/l	0.05	0.19		· 🗄 0,57 🖗	0.05	0.24	ಾಷ 1:87 ೪೧	5:0.27.5	0.01	··· ·0.37 문	b2 0.34 72	10.09			
GROSS ALPHA	pci/l	15	10 20 70 9	3.0	15.4	7.1	⊆_120 st	art 47.4	9.5	7.9	12.7	9.9	9.4			
LEAD	mg/l	0.05	· ·				0.29 😁									
LEAD-210	pci/l	1					State: 86.771									
MAGNESIUM	mg/l		685 D	144 D	469 D	768 D	437 D	703 D	_562 D	270 D	533 D	440 D	234 D			
MANGANESE	mg/l	2.6	⊠:6.88≆	1.95	## 6.98 :::	# 6.13 de	···· 12.4 \@	61.475	H# 9:12.7	3.14	₽-6.79⊅	T25.9515	≫ .3:41 ⊡:			
MOLYBDENUM	mg/l	1	57.F*3.57**	0.1		0.2			· ·				2441:478.5			
NICKEL	mg/l	0.05	· 0.28 · 1		0.58	0.13	910.34	1 :8 12	:::: 0.26		34 0.34 2.5	:t:::0.42 ···	-:0.15			
NITRATE (NO3)	mg/l	190	•	13.6 D	0.41		19.0 D	11.6 D		26.8 D			•			
POTASSIUM	mg/l		12.5	7.2	10	11.9	15.9		12.5	9.6	10.9_	9.8	7.1			
RADIUM-226	_pci/l		11.4	2.4	6.5	4.6	51.1	9.7	7.1	4	7.3	4.7	8			
RADIUM-228	pci/l		8.5	2.5	11.1	5.4	30.4		7.2	6.2	12.2	9.1	4.8			
RADIUM 226&228	pci/l	5	19.9	4.9	• 17.6	:::: 10 ≪::	**** 81.5 ***	9.7 10	14.30	-10.2 Ja	19.5	* 13.8	·-: 12.8			
SODIUM	mg/l		163	146	151	139	181	295	115	148	93.7	136	141			
SULFATE (SO4)	mg/l	2125	4120 D.	1650 D	(3330 D)	- 4070 D 🕅	2800 D -	9210 D	3620 D	2330 D*	-3450 D :	3200 D1	:2340 D 🗄			
THORIUM-230	pci/l	5			0.3			:: :1371 ::∵				0.7				
TOTAL DISSOLVED SOLIDS (LAB)	mg/l	4800	12 ⁷ 6210 🔝	3520	<u>4890 🗠</u>	** 6410 🕫	VC 5170 🗹	12600	JE 5660 🗟	4180	-* 5370 😯	🔚 4920 🖓	4000	2×4860 * 3	4190	4880
URANIUM	mg/l	0.3	0.0236	0.101	0.0504	0.0119	*1.05 D *	**1:41 D.**	0.0160	0.0692	0.0339	0.0578	0.0906			
VANADIUM	mg/l	0.1						2.5								

.

TABLE 13
Zone 1 Performance Monitoring Program, 2004 Operating Year
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Well ¹	Water Level ²	Water Quality ²	NRC POC	Purpose		
Continue Monito	pring	·	•			
515 A	X	X		Track transition area		
604	X	X	Y	Track center of seepage		
614	X	X	Y	Track transition area		
EPA 2	X	X		Postmining-pretailings background water quality		
EPA 4	X	Χ.	Y	Postmining-pretailings background water quality		
EPA 5	X	X		Track transition area		
EPA 7	X	X	Y	Track transition area, edge of saturation		
EPA 8	X			Track edge of saturation		
142	X	X		Premining background		
143	X			Water level only, use 142		
Additional Wells	, Not Included In	Original Performa	ance Mor	nitoring Program		
505 A	X			Long-term water level for migration path		
502 A	X			Long-term water level for migration path		
501 A	X			Long-term water level for migration path		
504 A	X			Long-term water level for migration path		
412	X			Long-term water level for migration path		
Tota	15	8				

Eliminated From Monitoring		Reason For Elimination
141		No longer useable, plugged during arroyo flooding
516 A	Y	Failed low-flow testing
619	· · ·	Anomalous water quality and water level
615	·]	Decommissioned pumper, not needed - use 515 A
616		Decommissioned pumper, not needed - use 604
617		Decommissioned pumper, not needed

Notes:

No wells within the tailings reclamation cap were included.
 Water level and water quality monitored on a quarterly basis.

TABLE 14

Zone 1 Saturated Thickness, October 2004 United Nuclear Corporation, Church Rock Site Church Rock, New Mexico

	Water Level	Zone 1	Zone 1	Zone 1	
	Measurement	Unsaturated	Saturated	Percentage	
Well	Date	Thickness	Thickness	Saturated	
TWQ-142	10/11/2004	0.00	55.00	100%	
TWQ-143	10/26/2004	0.00	52.00	100%	
412	10/26/2004	0.00	76.00	100%	
501-A	10/26/2004	8.32	56.68	87%	
502-A	10/26/2004	0.00	59.00	100%	
504-A	10/26/2004	7.76	60.24	89%	
505-A	. 10/26/2004	0.00	46.00	100%	
515- <u>A</u>	10/6/2004	23.87	17.13	42%	
604	10/6/2004	21.28	. 23.72	53%	
614	10/6/2004	19.99	25.01	56%	
EPA-02	10/13/2004	18.11	31.89	64%	
EPA-04	10/12/2004	14.66	40.34	73%	
EPA-05	10/12/2004	25.87	23.13	47%	
EPA-07	10/12/2004	26.57	56.43	68%	
EPA-08	10/12/2004	25.98	40.02	61%	

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TABLE 15 Detected Constituents in Zone 1, October 2004, United Nuclear Corporation, Church Rock Site Church Rock, New Mexico

		Action			•		· · ·		•	
Chemical Name	Unit	Level	· 614	604	515 A	EPA 05	EPA 07	EPA 04	EPA 02	142
ALUMINUM	mg/l	5			2.0		0.6			
AMMONIA (AS N)	mg/l		45 D	0.45	2.94	10,1 D	0.48	1.02	0.55	0.09
BICARBONATE (HCO3)	·mg/l		1450	10	199	93	529	201	378	233
CALCIUM	mg/l		600 D	440 D	473 D	483 D	486 D	586 D	367 D	21.0
CHLORIDE	mg/l	250	343	59	······································	71	195	37	23	. 19
CHLOROFORM	ug/l	·1	≨2.0• 165 D # 7€	2.7	: 110 D					
COBALT	mg/l	0.05		···· :::::::::::::::::::::::::::::::::	A 0.08	1277 0.08 million	0.03			
GROSS ALPHA	pci/l	15		3.4	3.5	1,9	1.5	1.9	2.6	
MAGNESIUM	mg/l	•	665 D	802 D	857 D	586 D	890 D	408 D	176 D	9.5
MANGANESE	mg/l	2.6	0.23	arran1122503	mart12114.8.1229*1	1.23	······ 3.43	555.83 3.172 Bet	1.25	0.02
NICKEL	mg/1	0.05		0.18	977061 0,11 30851					
NITRATE (NO3)	mg/l	190	76.5 D	65.8 D	58 D	25,1 D	139 D			
POTASSIUM	mg/l		9.9	12.2	13.9	10.8	7.6	8.4	6.5	3.8
RADIUM-226	pci/l			2	2.3	1.7	0.8	1.5	1	
RADIUM-228	pci/l		1.7	5.1	2.5	1.5	1.7	3.3	2.3	
RADIUM 226 &228	рсі/І	5	1.7	2007.1.1.20mm	4.8	3.2	2.5	4.8	3.3	
SELENIUM	mg/l	0.01	0.001			0.002	0.002			
SODIUM	mg/l		481	292	440	146		188	180	308
SULFATE (SO4)	mg/l	2125	+#: 3230 Dirte	2 4390 D 442	₩0+ 4700 D*4+*#	5.00 ± 3300 Derman	10	27	1600 D	527
TOTAL DISSOLVED SOLIDS (LAB)	mg/l	4800	6850	3. 2. 7350	A 174 8000 TOTA	5300 milite	8030	4850	2810	1090
URANIUM	mg/l	0.3	0.0516 D	0.0017 D	0.0009 D	0.0015	0.0022 D	0.0004	0.0010	

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TABLE 16

Predicted Performance of the Zone 1 Natural System United Nuclear Corporation, Church Rock Site Church Rock, New Mexico

	Will Standa	rds Be Met?	
Constituent	Section 1	Section 36	Remarks
Manganese	Maybe	Maybe	Dependent on bicarbonate availability
Sulfate	No	No	Limited by calcium availability
TDS	. No	No -	Governed by sulfate concentration
Metals	Yes	Yes	Attenuated by neutralization and adsorption
Radionuclides	Yes	Yes	Attenuated by neutralization and adsorption



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Date: 12/15/2004



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Legend

Southwest Alluvium

- Idled Extraction Well
- Monitoring Well
- Water Level Monitoring Well
- Dry Monitoring Well

Zone 3

- Idled Extraction Well Used for Monitoring Decommissioned or Idle Extraction Well
- Monitoring Well
 - Dry or Decommissioned Monitoring Well

Zone 1

- Decommissioned Extraction Well
- Decommissioned Monitoring Well
- Monitoring Well

0 400	800 1 Feet	,600					
FIC	GURE 2						
Site Layout a Monitoring 2004 Op	Site Layout and Performance Monitoring Well Locations 2004 Operating Year						
United Nuclear Corporation Church Rock Site, Church Rock, New Mexico							
WATERSYSTEMS							

Date: 12/21/2004



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Legend

- Southwest Alluvium Monitoring Well
- ----- Groundwater Elevation Contour
- ----- Inferred Groundwater Elevation Contour
- ----- Approximate Extent of Alluvium
- ---- Approximate Extent of Saturated Alluvium
- Property Boundary
- ----- Section Boundary
- ----- Cell Boundary

Notes:

- 1. Groundwater elevation values are displayed in feet above mean sea level.
- 2. Well names are displayed with black text.
- 3. Groundwater elevations are shown with blue text and enclosed in parentheses.
- 4. Aerial photo taken on August 1, 1996.



Date: 12/17/2004



FIGURE 4 Southwest Alluvium Water Levels Over Time United Nuclear Corporation, Church Rock Site, Church Rock New Mexico









Southwest Alluvium Pumping Well Water Levels Over Time United Nuclear Corporation, Church Rock Site, Church Rock New Mexico







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FIGURE 7

Southwest Alluvium Sulfate Concentraions Over Time United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico







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Date: 12/16/2004



Primary Components of Total Dissolved Solids in the Southwest Alluvium, October 2004 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



CO9 Veolia Water



Southwest Alluvium Total Dissolved Solids Concentrations Over Time United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico







Calcium and Bicarbonate Concentrations in Selected Backgound and Seepage-Impacted Wells United Nuclear Corporation, Church Rock site, Church Rock, New Mexico















CI3 Veolia Water







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0.35 0.3 0627 Start of NA Test **Pumps Turned Off** ~~0632 0.25 January 2001 Concentration, mg/L **EPA 23** 0.2 **EPA 25** 0.15 **EPA 28 GW 1** 0.1 -X-GW 2 -*- GW 3 0.05 Standard 0 Apr-99 Sep-99 Mar-00 Sep-00 Mar-01 Sep-01 Mar-02 Sep-02 Mar-03 Sep-03 Mar-04 Sep-04

Date





FIGURE 20 Uranium Concentrations in Well 509 D United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



FIGURE 21 Uranium Concentrations in Well 801 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



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Veolia Water

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FIGURE 22 Uranium Concentrations in Well 802 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



FIGURE 23 Uranium Concentrations in Well 803 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



Red line indicates uranium standard (0.3 mg/L).

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FIGURE 24 Uranium Concentrations in Well GW 1 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



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FIGURE 25 Uranium Concentrations in Well GW 2 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



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FIGURE 26 Uranium Concentrations in Well GW 3 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



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FIGURE 27 Uranium Concentrations in Well 624 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



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FIGURE 28 Uranium Concentrations in Well 632 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



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FIGURE 29 Uranium Concentrations in Well 627 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



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FIGURE 30 Uranium Concentrations in Well 808 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



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FIGURE 31 Uranium Concentrations in Well EPA 23 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



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Veolia Water

FIGURE 32 Uranium Concentrations in Well EPA 25 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



Red line indicates uranium standard (0.3 mg/L).

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FIGURE 33 Uranium Concentrations in Well EPA 28 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico



Red line indicates uranium standard (0.3 mg/L).

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Date: 12/20/2004



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Legend

Pro	perty	Bo	oundary		

- ----- Zone 3 Target Remedial Action Area
- Section Boundary
- ----- Cell Boundary

Approximate Area Impacted by Tailings Seepage

- - - pH contour

Well Type

- Monitoring
- Dry Monitoring
- Stage I Extraction
- Stage II Extraction
- Plume Boundary
- Northeast Pump-Back
- Piezometer
- Hydrofractured Well

Approximate Eastern Boundary of Zero Saturation

Notes:

- 1. Well names are displayed with black text.
- 2. Values for field measured pH are shown with purple text and enclosed in parentheses.
- 3. Aerial photo taken on August 1, 1996.



Date: 12/21/2004