



Annual Review Report – 2012
Groundwater Corrective Action
Church Rock Site, Church Rock, New Mexico

United Nuclear Corporation
Gallup, New Mexico

February 2013





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February 20, 2013

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Re: Executive Summary
2012 Groundwater Corrective Action Annual Review Report
Materials License No. SUA-1475
United Nuclear Corporation's Church Rock Tailings Site, Gallup, New Mexico

Dear Mr. Persinko and Ms. Brooks:

On behalf of United Nuclear Corporation (UNC), Chester Engineers 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 License Condition 30C. This report is for the 2012 operating year and represents the period from January 2012 through October 2012. This cover letter serves as an Executive Summary of the report.

This report focuses on both active remediation and the groundwater performance of the natural geochemical 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 former pumping systems, the agencies recognized that those corrective action pumping systems had reached the limit of their effectiveness. EPA (1988b) recommended that Technical Impracticability (TI) Waivers, Alternate Concentration Limits (ACLs), and Monitored Natural Attenuation (MNA) be used to complete the corrective action program. Those Record of Decision (ROD) recommendations continue to be timely.

During 2011, part of Zone 3 underwent continued extraction well pumping that started during the hydrofracture program in 2005 and which was most recently supplemented, in 2009, with extraction started in the NW-series wells located along the northernmost area of impact. During 2012, in this same area, UNC terminated the injection of alkalinity-amended water due to loss of injection capacity in well IW A. The conclusions and recommendations of this annual report are provided below.

Conclusions

- Concentrations of uranium in the Southwest Alluvium are an indicator that natural attenuation is at least as effective a remedy as pumping. With the exception of point-of-compliance (POC) Well GW 3 and non-POC Well EPA 25, uranium concentrations and concentration time trends have either stabilized or shown decreasing trends since the pumps were turned off. The increasing trend of concentrations at GW 3 does not necessarily relate to the shutoff. During October 2012, the saturated thickness (water column height) in GW 3 was 3.3 ft and UNC has projected that this well will go dry in approximately seven years.
- Uranium concentrations in the Southwest Alluvium are not related to the migration of uranium in tailings fluids. The range of uranium concentrations in the background water has been empirically shown to be the same as the range within seepage-impacted water (GE, 2006). Uranium and bicarbonate concentrations are usually covariant in the Southwest Alluvium groundwater, i.e., when the concentration of the bicarbonate parameter changes, uranium changes with it provided that there is uranium available for dissolution or desorption in the sediments. This observation has held for most Southwest Alluvium wells for both the 11 years of active pumping and the 11.7 years of post-pumping monitoring, and is expected based on principles of aqueous chemistry.
- Mapping of bicarbonate isoconcentration contours is an important method of delineating seepage-impacted water in the Southwest Alluvium.
- At downgradient Well 624, in the Southwest Alluvium, the increase in bicarbonate to a chart plateau starting in May 2000 is attributed to the migration of the bicarbonate "front" associated with tailings seepage-impact. However, this well shows no covariance between the bicarbonate and uranium concentrations. At least two interpretations are possible: (1) at this well location there is little to no adsorbed or precipitated uranium (i.e., solid phase) within the alluvial sediments; and (2) aqueous uranium that originated from upgradient tailings seepage impact has been strongly attenuated during transport and it has not reached this location.
- Groundwater levels in the Southwest Alluvium continued to decline in 2012, indicating that the artificially recharged zone of saturation continues to become naturally dewatered

as the groundwater drains down the arroyo. Groundwater to the north of the Nickpoint has become ponded and is no longer flowing to the southwest – this water is slowly infiltrating into the underlying bedrock.

- Hydraulic containment is not a necessary feature of the corrective action program in the Southwest Alluvium because of the geochemical attenuation that occurs naturally. The natural system is as effective as, or more effective than, pumping for controlling the migration of the constituents of concern.
- The non-hazardous constituents sulfate, TDS, and manganese exceed standards 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 seepage-impacted groundwater in the Southwest Alluvium. Background concentrations for sulfate and TDS ahead of the seepage migration front tend to exceed the standards but this reflects local geochemistry and is not related to seepage impact. Behind this migrating front, seepage-impacted groundwater quality tends to have sulfate and TDS levels approximately equal to, or lower than, those in the background water due to equilibration with the mineral gypsum.
- Locally increasing trends in concentrations of common dissolved ions are unrelated to tailings seepage; they derive from the reaction of the anthropogenic recharge water with natural alluvium materials.
- Evaluation and prediction of constituent concentrations in the Southwest Alluvium is predicated on understanding the geochemical evolution of both the background water quality and later changes associated with passage of the seepage-impact front. Hazardous constituents derived from seepage impact are effectively attenuated to acceptable concentrations within the Site boundary.
- Both onsite and offsite groundwater quality in the Southwest Alluvium meets or exceeds the NRC groundwater protection standards (GWPSs).
- Both the Southwest Alluvium and Zone 1 natural systems are at least as effective as the former active remediation systems in attenuating the seepage-impacted water. Acidic seepage is being neutralized, resulting in attenuation of metals and radionuclides. Natural geochemical conditions related to gypsum equilibrium and bicarbonate availability will control sulfate and manganese concentrations in both hydrostratigraphic units, regardless of whether or not the extraction wells are operated.
- Groundwater elevations in Zone 1 continued to decline in 2012, causing the saturated thickness that accommodates groundwater flow and constituent migration to diminish in the updip parts of this bedrock stratigraphic unit.

- Outside the UNC property boundary in Zone 1, the post-pumping groundwater quality continues to improve overall (Tables 17 and 18). The exceedances of sulfate and TDS in Wells EPA 5 and EPA 7 reflect geochemical equilibrium of the groundwater with gypsum; these constituents are non-hazardous.
- With a single exception (a nickel detection of 0.06 mg/L at Well EPA 5), Zone 1 groundwater in Section 1 meets or exceeds the NRC GWPSs.
- The Zone 1 groundwater corrective action program has achieved success. Final closure and License transfer will require meeting the Site standards or Technical Impracticability waivers. It is likely that some standards will need to be revised.
- Groundwater levels in Zone 3 continued to decline in 2012, indicating that the artificially recharged zone of saturation continues to diminish as the groundwater drains down the dip of the bedrock layers. Pumping of extraction wells since 2005 has locally accelerated the rate of water level decline in Zone 3.
- Groundwater quality along the northern tracking wells in Zone 3 has been oscillating between degrading and improving trends over the last 10 years. Individual well water-quality trends of improvement and degradation have become collectively asynchronous since May 2007, which approximately coincides with an increase in the size and rapidity of water-quality oscillations. The variations in water quality indicate that there have been local and variable degrees of mixing of seepage-impacted water with background water drawn in from the west. This is interpreted to have been a consequence of the designed actions of extraction wells upgradient and, since February 2009, downgradient of the northern tracking wells.
- Pumping in the northernmost part of Zone 3 has created a mixing zone of background and seepage-impacted water, which makes a single-line plume boundary depiction in this area inappropriate. However, based on specific (though oscillating) water quality trends, fully seepage-impacted water has not advanced beyond NBL 1.
- UNC installed five new Zone 3 extraction wells (the NW-series) north of Well NBL 1 during September 2008. Pumping of three of these wells began in February 2009, and the pumping regime was adjusted during early November 2009 and during May and June of 2012. These extraction wells have provided significant containment of the northernmost seepage-impacted water in Section 36.
- UNC started injecting water amended with sodium bicarbonate at Zone 3 Well IW A during April 2011. The injection capacity at IW A has progressively declined from the original target rate of 1 gpm, and the injection rates became so low that injection was terminated on June 29, 2012. Subsequently, the July 2012 groundwater quality at nearby monitoring Well MW 6 showed (compared to July 2011) increased bicarbonate, sodium,

and uranium. Though a uranium increase was expected with increased bicarbonate, the uranium increase was large enough that UNC would have then terminated the injection program (had it not already been terminated due to critically diminished capacity). October 2012 lab results from MW 6 showed significant reductions in bicarbonate, sodium, and uranium (and some other parameters, e.g., molybdenum).

- In the Southwest Alluvium and Zone 3 there are no exceedances of NRC groundwater protection standards for hazardous constituents outside the UNC property within seepage-impacted groundwater.
- There is no basis to infer that recent Pb-210 results reflect increasing concentrations in groundwater. With very few exceptions (e.g., Zone 3 Well NBL 1) the analytical results fall within the lower end of the range of background concentrations in each hydrostratigraphic unit. The results do not inherently reflect the impact of tailings seepage, given the background distributions. Background water Pb-210 concentrations define the following ranges: 1 to 14 pCi/L (Southwest Alluvium); 1 to 11 pCi/L (Zone 3); and 1 to 9 pCi/L (Zone 1).
- Technical issues set out in an email dated April 30, 2012 (EPA (2012b)) must be resolved before the SWSFS can proceed further.

Recommendations

1. Site groundwater protection standards should be revised to reflect newly calculated background threshold values (95th percentile of the upper prediction limits).
- UNC has previously requested deletion of Pb-210 from the Site standards, which NRC denied (Earth Tech, 2001b and 2001c; NRC, 2001). An additional 12 years of chemical analytical data have accrued, and the revised laboratory protocols and analytical results indicate that it is important to consider Pb-210 issues including sample-specific minimum detectable concentrations and analytical results, and the implications of Site background water quality statistics. Relevant background information is found in NRC (1980), U.S. Geological Survey (2008), and N.A. Water Systems (2008d). UNC (2012) submitted a License amendment request for NRC that proposes the revision of some Site groundwater protection standards to newly calculated background threshold values (95th percentile of the upper prediction limits).
2. A pumping efficiency metric should be developed as a potential quantitative threshold for terminating pumping in Zone 3 in the future.
- A new metric for pumping system performance derives from analysis of the efficiency of seepage-impacted groundwater extraction. The pumping efficiency is less than 100%

because background groundwater, from outside the seepage-impacted area, flows toward the pumping.

- For some constituents the background water has higher concentrations than the seepage-impacted water.
- All Zone 3 pumping well capacities decline over time. One important cause is loss of saturated thickness. It will not be possible to pump out all of the seepage-impacted water.

Recommendations for Closure of Southwest Alluvium Remedial Action

1. The 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:
2. Decommission the pumping wells and implement a No Further Action remedial alternative. Attenuation via natural geochemical processes has been shown to be at least as effective as pumping.
3. Change performance monitoring from quarterly to an annual basis because the seepage-impacted water quality is largely stable and migrating very slowly (estimated to be moving southwestward toward Well SBL 1 at an average rate of 11 ft per year, which should continue to diminish in the future). The offsite seepage-impacted water quality is not hazardous, and a yearly frequency is sufficient for tracking the migration of the seepage-impact front.
4. Sulfate, TDS and manganese should be waived as constituents of concern based on NRC's (1996) background water quality analysis report and multiple reports by UNC (many of which are summarized in the SWSFS Part I, N.A. Water Systems, 2007b; and Chester Engineers, 2009b). A Technical Impracticability waiver should be issued for sulfate and TDS.
5. EPA should consider adopting the background threshold values (UPL95 calculations) that UNC has proposed for the Southwest Alluvium (Chester Engineers, 2012e, draft Table 4) in the context of a future compliance monitoring program with "not to exceed" standards.
6. As first put forth by the NRC (1996), and further developed in several geochemistry (Earth Tech, 2000d and 2002c) and annual reports (Earth Tech, 2002d; N.A. Water Systems, 2004, 2005b, 2007a), there is quite simply no method to achieve the standards for sulfate, TDS and manganese – short of completely dewatering the alluvium, which is technically infeasible. The last drop of water left in the alluvium would exceed the

standards for these parameters. UNC once again requests approval of a TI Waiver for sulfate and TDS to the extrapolated, downgradient impact zone in the year 2204 shown in Figure 58. The ongoing development of a SWSFS will formally evaluate and prioritize the most appropriate remedial course of action; however, many of the actions required to meet closure are administrative and have been the subject of longstanding discussions.

Recommendations for Zone 3 Remedial Action

Consider terminating extraction pumping, which is tending to draw in background water from the west. Some constituents have higher concentrations in background water, compared to seepage-impacted water. All Zone 3 pumping well capacities decline over time. It will not be possible to pump out all of the seepage-impacted water, and over time the pumping is capturing more background water. The approximate efficiency of seepage-impacted groundwater removal by pumping is 60% (i.e., 60% of the pumped volume is seepage-impacted water and 40% is inferred to be background water), and the efficiency is expected to decline with time. UNC recommends using the pumping efficiency metric as a potential quantitative threshold for terminating Zone 3 pumping in the future.

Declining yields from the current extraction-well array indicate that hydraulic control is temporary. This has always been the case for pumping in Zone 3. Zone 3 saturated thicknesses are quite low (especially considering well losses), and any future pumping to reduce the pressure head will obtain only limited short-term results. Because the bedrock slope drives groundwater flow to the north, there is an irreducible elevation head that cannot be decreased by pumping. Counteracting this force is the reduction of effective porosity by the seepage-induced chemical alteration of feldspar to clay. This reduces the bedrock permeability, which retards the migration of the seepage. Eventually, a balance will develop between the irreducible elevation head and the trapping of the seepage-impacted groundwater due to the diminished bedrock permeability, retarding further migration of seepage-impacted water. Although the timing and location of such a balance cannot be predicted, such a development is likely. UNC recommends that consideration be given to other regulatory tools to manage the inherent physical limitations to the Zone 3 bedrock-groundwater system. As with Zone 1 and the Southwest Alluvium, the tools might include: ACLs, TI Waivers, MNA, and ICs.

EPA should consider revision of the ROD background concentrations for the following metals in Zone 3: arsenic, molybdenum, nickel, cobalt and manganese. Uranium should also be addressed and UNC recommends that EPA adopt the NRC standard for uranium.

Sulfate, TDS and manganese should be waived as constituents of concern based on NRC's (1966) background water quality analysis report.

EPA should consider adopting the background threshold values (UPL95 calculations) that UNC has proposed for Zone 3 (Chester Engineers, 2012e, draft Table 6) in the context of a future compliance monitoring program with “not to exceed” standards.

Recommendations for Closure of Zone 1 Remedial Action


The Zone 1 seepage-impacted area has attained ALARA goals. The predicted performance of the Zone 1 natural attenuation system is summarized on Table 18. Implement the following recommendations toward closure of the Zone 1 corrective action system:

1. EPA should consider adopting the background threshold values (UPL95 calculations) that UNC has proposed for Zone 1 (Chester Engineers, 2012e, draft Table 5) in the context of a future compliance monitoring program with “not to exceed” standards.
2. As first put forth by the NRC (1996), and further developed in several geochemistry (Earth Tech, 2000c) and annual reports (Earth Tech, 2000e; N.A. Water Systems, 2004, 2005b, 2007a), there is no method to achieve the standards for sulfate and TDS, which are exceeded in background groundwater. Zone 1 has already been dewatered to the extent that is feasible. It is not appropriate to tie remediation progress to sulfate or TDS concentrations which reflect geochemical equilibrium of the groundwater with gypsum. The EPA should approve a TI Waiver for sulfate and TDS in the TI zone shown in Figure 58. Remedial alternatives to be presented in the final, complete SWSFS should be closely coordinated with the necessary TI Waiver(s), ACL applications, ICs, and potentially appropriate changes in Site remediation standards (EPA, 2008b).

Mr. Andrew Persinko and Ms. Janet Brooks
February 20, 2013

Please contact Mr. Roy Blickwedel (General Electric Company) at (610) 992-7935 if you have any questions or need additional information.

Sincerely,



Mark D. Jancin, Ph.D., P.G.
Project Manager

MDJ: 12-6209-SC-123

Enclosures (2 hard and 2 pdf copies for each addressee)

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Annual Review Report – 2012
Groundwater Corrective Action
Church Rock Site, New Mexico

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Groundwater Corrective Action
Church Rock Site, Church Rock, New Mexico

February 2013

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Project No.: 12-6209-SC-123



Table of Contents

	<u>Page Nos.</u>
SECTION 1 INTRODUCTION	1
1.1 SITE LOCATION	2
1.2 CHRONOLOGY OF SITE EVENTS	3
1.3 CORRECTIVE ACTION SYSTEMS	3
1.4 PERFORMANCE MONITORING AND SUPPLEMENTAL SAMPLING	5
1.4.1 PERFORMANCE MONITORING.....	5
1.4.2 SUPPLEMENTAL SAMPLING	6
1.4.3 LEAD-210 ANALYTICAL RESULTS	7
1.5 REPORT ORGANIZATION	8
SECTION 2 SOUTHWEST ALLUVIUM.....	9
2.1 CORRECTIVE ACTION SUMMARY	9
2.2 MASS OF CHEMICAL CONSTITUENTS REMOVED.....	9
2.3 PERFORMANCE MONITORING EVALUATION.....	9
2.3.1 WATER LEVEL EVALUATION	9
2.3.2 WATER QUALITY EVALUATION AND CURRENT EXTENT OF SEEPAGE-IMPACTED WATER.....	11
2.3.3 RATE OF SEEPAGE MIGRATION.....	16
2.3.4 CONTINUING ASSESSMENT OF SOUTHWEST ALLUVIUM NATURAL ATTENUATION AND EARLIER TECHNICAL IMPRACTICABILITY WAIVER REQUEST.....	17
2.3.5 REASSESSMENT OF THE PERFORMANCE OF THE NATURAL SYSTEM	19
SECTION 3 ZONE 3.....	27
3.1 CORRECTIVE ACTION SUMMARY	27
3.1.1 NORTHEAST PUMP-BACK AND STAGE I AND II REMEDIAL ACTION SYSTEMS	27
3.1.2 2004 SUPPLEMENTAL FEASIBILITY STUDY	27
3.1.3 IN-SITU ALKALINITY STABILIZATION PILOT STUDY	28
3.1.4 PHASE I HYDROFRACTURE PROGRAM AND CONTINUING ZONE 3 EXTRACTION WELL PUMPING.....	28
3.1.5 EVALUATION OF THE EFFECTS AND LIMITATIONS OF ZONE 3 EXTRACTION WELL PUMPING.....	29
3.1.6 INJECTION WELL FEASIBILITY TESTING.....	31
3.2 MASS OF CHEMICAL CONSTITUENTS REMOVED.....	32
3.3 PERFORMANCE MONITORING EVALUATION.....	33
3.3.1 WATER LEVEL EVALUATION	34
3.3.2 WATER QUALITY EVALUATION AND CURRENT EXTENT OF SEEPAGE-IMPACTED WATER.....	36
3.3.3 RATE OF SEEPAGE MIGRATION.....	41
3.3.4 NATURAL ATTENUATION SYSTEM PERFORMANCE EVALUATION	41
3.4 ANALYSIS OF THE EFFICIENCY OF SEEPAGE-IMPACTED GROUNDWATER REMOVAL BY PUMPING...47	47
SECTION 4 ZONE 1.....	49
4.1 CORRECTIVE ACTION SUMMARY	49
4.2 MASS OF CHEMICAL CONSTITUENTS REMOVED.....	49
4.3 PERFORMANCE MONITORING EVALUATION.....	49
4.3.1 WATER LEVEL EVALUATION	49
4.3.2 WATER QUALITY EVALUATION AND CURRENT EXTENT OF SEEPAGE-IMPACTED WATER.....	51
4.3.3 NATURAL ATTENUATION SYSTEM PERFORMANCE EVALUATION	53
4.4 ALTERNATE CONCENTRATION LIMITS APPLICATION.....	57
SECTION 5 CONCLUSIONS AND RECOMMENDATIONS.....	60
5.1 CONCLUSIONS.....	60
5.2 RECOMMENDATIONS.....	63
5.2.1 RECOMMENDATIONS FOR CLOSURE OF SOUTHWEST ALLUVIUM REMEDIAL ACTION	64
5.2.2 RECOMMENDATIONS FOR ZONE 3 REMEDIAL ACTION	65
5.2.3 RECOMMENDATIONS FOR CLOSURE OF ZONE 1 REMEDIAL ACTION	66
SECTION 6 REFERENCES	67

List of Tables

1A	CHRONOLOGY OF EVENTS JUNE 1977 TO DECEMBER 2012, UNC CHURCH ROCK MILL TAILINGS SITE
1B	SOUTHWEST ALLUVIUM PERFORMANCE MONITORING PROGRAM, 2012 OPERATING YEAR
2	DETECTED CONSTITUENTS IN SOUTHWEST ALLUVIUM, OCTOBER 2012
3	SOUTHWEST ALLUVIUM SATURATED THICKNESS, OCTOBER 2012
4	SUMMARY OF OPERATIONAL DATA, SOUTHWEST ALLUVIUM EXTRACTION WELLS 1989 TO 2001
5	SOUTHWEST ALLUVIUM GROUNDWATER VELOCITIES, OCTOBER 2012
6	PREDICTED PERFORMANCE OF SOUTHWEST ALLUVIUM NATURAL ATTENUATION, 2012
7	CHANGE IN ZONE 3 SATURATED THICKNESS FROM 1989 TO 2012
8	ESTIMATED MASS REMOVAL BY EXTRACTION WELL PUMPING IN ZONE 3, 2012
9	ZONE 3 PERFORMANCE MONITORING PROGRAM, 2012 OPERATING YEAR
10	ZONE 3 SATURATED THICKNESS, OCTOBER 2012
11	ZONE 3 FIELD PARAMETER MEASUREMENTS OF TRACKING WELLS THROUGH OCTOBER 2012
12	ZONE 3 FIELD PARAMETER MEASUREMENTS OF NW-SERIES WELLS THROUGH OCTOBER 2012
13	ZONE 3 SEEPAGE MIGRATION EVALUATION, 2012
14	DETECTED CONSTITUENTS IN ZONE 3, OCTOBER 2012
15	ZONE 1 PERFORMANCE MONITORING PROGRAM, 2012 OPERATING YEAR
16	ZONE 1 SATURATED THICKNESS, OCTOBER 2012
17	DETECTED CONSTITUENTS IN ZONE 1, OCTOBER 2012
18	PREDICTED PERFORMANCE OF THE ZONE 1 NATURAL ATTENUATION SYSTEM

List of Figures

- 1 SITE LOCATION MAP
- 2 SITE LAYOUT AND PERFORMANCE MONITORING WELL LOCATIONS, 2012 OPERATING YEAR
- 3A SOUTHWEST ALLUVIUM POTENTIOMETRIC SURFACE MAP, OCTOBER 2012
- 3B SOUTHWEST ALLUVIUM SATURATED THICKNESS MAP, OCTOBER 2012
- 4 SOUTHWEST ALLUVIUM WATER LEVELS OVER TIME
- 5 SOUTHWEST ALLUVIUM PUMPING WELL WATER LEVELS OVER TIME
- 6 EXTENT OF SEEPAGE-IMPACTED GROUNDWATER, OCTOBER 2012
- 7 SOUTHWEST ALLUVIUM SULFATE CONCENTRATIONS OVER TIME
- 8 SOUTHWEST ALLUVIUM BICARBONATE ISOCONCENTRATION MAP AND DISTRIBUTION OF SULFATE BELOW 2125 MG/L, OCTOBER 2012
- 9 PRIMARY COMPONENTS OF TDS IN SOUTHWEST ALLUVIUM GROUNDWATER
- 10 SOUTHWEST ALLUVIUM CHLORIDE CONCENTRATIONS FROM 1999 THROUGH OCTOBER 2012
- 11 SOUTHWEST ALLUVIUM MANGANESE CONCENTRATIONS FROM 1999 THROUGH OCTOBER 2012
- 12 SOUTHWEST ALLUVIUM TDS CONCENTRATIONS OVER TIME
- 13 CALCIUM AND BICARBONATE CONCENTRATIONS IN SELECTED BACKGROUND AND SEEPAGE-IMPACTED WELLS
- 14 SOUTHWEST ALLUVIUM CALCIUM CONCENTRATIONS FROM 1999 THROUGH OCTOBER 2012
- 15 SOUTHWEST ALLUVIUM BICARBONATE CONCENTRATIONS FROM 1999 THROUGH OCTOBER 2012
- 16 SOUTHWEST ALLUVIUM SULFATE CONCENTRATIONS FROM 1999 THROUGH OCTOBER 2012
- 17 SOUTHWEST ALLUVIUM TDS CONCENTRATIONS FROM 1999 THROUGH OCTOBER 2012
- 18 URANIUM CONCENTRATIONS IN SELECTED SOUTHWEST ALLUVIUM WELLS
- 19 URANIUM CONCENTRATIONS IN SELECTED SOUTHWEST ALLUVIUM WELLS
- 20 URANIUM CONCENTRATIONS IN WELL 509 D
- 21 URANIUM CONCENTRATIONS IN WELL 801
- 22 URANIUM CONCENTRATIONS IN WELL 802
- 23 URANIUM CONCENTRATIONS IN WELL 803
- 24 URANIUM AND BICARBONATE CONCENTRATIONS IN WELL GW 1
- 25 URANIUM CONCENTRATIONS IN WELL GW 2
- 26 URANIUM AND BICARBONATE CONCENTRATIONS IN WELL GW 3
- 27 URANIUM AND BICARBONATE CONCENTRATIONS IN WELL 624
- 28 URANIUM CONCENTRATIONS IN WELL 632
- 29 URANIUM CONCENTRATIONS IN WELL 627
- 30 URANIUM CONCENTRATIONS IN WELL 808
- 31 URANIUM CONCENTRATIONS IN WELL EPA 23
- 32 URANIUM AND BICARBONATE CONCENTRATIONS IN WELL EPA 25
- 33 URANIUM CONCENTRATIONS IN WELL EPA 28
- 34 URANIUM CONCENTRATIONS IN WELL SBL 1
- 35 ZONE 3 APPROXIMATE EXTENT OF SEEPAGE IMPACTS, OCTOBER 2012
- 36 EFFECTS OF PAST AND CURRENT PUMPING TO DEWATER ZONE 3
- 37 ZONE 3 POTENTIOMETRIC SURFACE MAP, OCTOBER 2012
- 38 ZONE 3 SATURATED THICKNESS MAP, OCTOBER 2012
- 39 ZONE 3 BICARBONATE CONCENTRATIONS OVER TIME
- 40 ZONE 3 IMPACT PERIMETER BICARBONATE CONCENTRATIONS OVER TIME
- 41 ZONE 3 SULFATE CONCENTRATIONS OVER TIME
- 42A ZONE 3 METALS CONCENTRATIONS OVER TIME
- 42B ZONE 3 METALS CONCENTRATIONS OVER TIME
- 43 ZONE 3 APPROXIMATE EXTENT OF ALUMINUM EXCEEDING 5.0 MG/L, OCTOBER 2012
- 44A ZONE 3 URANIUM, VANADIUM, AND RADIONUCLIDES OVER TIME
- 44B ZONE 3 URANIUM ISOCONCENTRATION MAPS, 2002 AND 2011 (IN MG/L)
- 45 ZONE 3 CHLOROFORM CONCENTRATIONS OVER TIME
- 46 ZONE 1 POTENTIOMETRIC SURFACE MAP, OCTOBER 2012

List of Figures, cont'd

47	ZONE 1 WATER LEVELS OVER TIME
48	ZONE 1 EXTENT OF SEEPAGE IMPACTS, OCTOBER 2012
49	ZONE 1 pH OVER TIME
50	ZONE 1 SULFATE CONCENTRATIONS OVER TIME
51	ZONE 1 APPROXIMATE EXTENT OF SULFATE EXCEEDING 2,125 MG/L, OCTOBER 2012
52	ZONE 1 MANGANESE CONCENTRATIONS OVER TIME
53	ZONE 1 APPROXIMATE EXTENT OF MANGANESE EXCEEDING 2.6 MG/L, OCTOBER 2012
54	ZONE 1 BICARBONATE CONCENTRATIONS OVER TIME
55	ZONE 1 COBALT AND NICKEL CONCENTRATIONS OVER TIME
56	ZONE 1 APPROXIMATE EXTENT OF COBALT AND NICKEL EXCEEDING 0.05 MG/L, OCTOBER 2012
57	ZONE 1 COMBINED RADIUM-226 AND RADIUM-228 OVER TIME
58	PROPOSED TECHNICAL IMPRACTICABILITY WAIVER FOR ZONE 1 AND EXTRAPOLATED EXTENT OF SOUTHWEST ALLUVIUM SEEPAGE IN 2204

List of Appendices

- A SOUTHWEST ALLUVIUM MONITORING DATA (TABLE A.1) WITH INTRODUCTORY TEXT; FIGURE A-1 (SOUTHWEST ALLUVIUM PROPOSED REVISED MONITORING WELL LOCATIONS); AND 2012 LABORATORY GROUNDWATER ANALYTICAL REPORTS.**
- B ZONE 3 MONITORING DATA (TABLE B.1) WITH INTRODUCTORY TEXT; FIGURE B-1 (ZONE 3 2012 MONITORING WELL LOCATIONS); AND 2012 LABORATORY GROUNDWATER ANALYTICAL REPORTS.**
- C ZONE 1 MONITORING DATA (TABLE C.1) WITH INTRODUCTORY TEXT; FIGURE C-1 (ZONE 1 2012 MONITORING WELL LOCATIONS); AND 2012 LABORATORY GROUNDWATER ANALYTICAL REPORTS**

List of Acronyms and Abbreviations

ACL	alternate concentration limit
ALARA	as low as reasonably achievable
ARARs	applicable or relevant and appropriate requirements
BTV	background threshold value
COPCs	constituents of potential concern
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
FS	feasibility study
ft/yr	feet per year
gpm	gallons per minute
GWPSs	NRC Source Materials License groundwater protection standards
HHRA	human health risk assessment
IC	institutional control
MCL	federal primary maximum contaminant level
mg/L	milligrams per liter
MDC	minimum detectable concentration
MNA	monitored natural attenuation
NA	natural attenuation
NMED	New Mexico Environment Department
NNEPA	Navajo Nation Environmental Protection Agency
NRC	U.S. Nuclear Regulatory Commission
pCi/L	picocuries per liter
POC	point of compliance
POE	point of exposure
ROD	Record of Decision
SFS	supplemental feasibility study
SWSFS	site-wide supplemental feasibility study
SMCL	federal secondary maximum contaminant level
TDS	total dissolved solids
TTHMs	total trihalomethanes
TI	technical impracticability
UCL95	upper confidence limit on the mean at the 95% confidence level
UPL95	95 th percentile upper prediction limit
µg/L	micrograms per liter

Section 1

Introduction

On behalf of United Nuclear Corporation (UNC), Chester Engineers 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 corrective action report at the end of each operating year since 1989. This report includes groundwater quality analyses and groundwater elevations for the first through fourth quarter of 2012.

This report focuses on both active remediation and 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) recognized that the corrective action pumping systems were at or reaching the limit of their effectiveness and recommended that Technical Impracticability (TI) Waivers, Alternate Concentration Limits (ACLs), and Monitored Natural Attenuation (MNA) be used to complete the corrective action program (EPA, 1988b). Subsequent presentations and reports prepared to document the geochemical processes in the Southwest Alluvium (Earth Tech, 2000d and 2002c; Chester Engineers, 2009a) and the Zone 1 hydrostratigraphic unit (Earth Tech, 2000c; Chester Engineers, 2009a) showed that the natural geochemical mechanisms in these areas are at least as effective as the active remediation systems in controlling the migration of constituents of concern. This annual report describes how these natural processes are performing in these areas, and updates active remediation efforts and investigations in Zone 3, including (1) the pumping of extraction wells along the northern front of seepage impact (based on the UNC's hydrogeologic analysis and recommendations submitted to the agencies in N.A. Water Systems, 2008c, and adjustment of the pumping scheme described in Chester Engineers (2009c) and Section 3.1.5 below; and (2) an assessment of the injection program in Well IW A, which is located between the northernmost extraction wells and the northern property boundary of Section 36 (Chester Engineers, 2010b; 2011e).

In addition, this annual report addresses the list of technical impediments (GE, 2009) to eventual Site closure which UNC submitted in 2009 at the request of the NRC. UNC proposed that this list can serve as a framework for working with the NRC, and the other agencies, to map out the administrative and technical issues that need to be addressed for closure of Site corrective action.

This report also provides an update of the status of the Site-Wide Supplemental Feasibility Study (SWSFS) that EPA directed UNC to provide in 2006 (EPA, 2006a). The SWSFS is being conducted as a three-stage process in keeping with the three structural components of EPA's FS process: Stage 1. develop remedial action objectives (SWSFS Part I); Stage 2. development and screening of alternatives (SWSFS Part II); and Stage 3. detailed analysis of alternatives (SWSFS Part III) (EPA, 1988c). Each stage is completed and approved before commencing with the next stage because each stage of evaluation builds upon the results and findings of its predecessor. EPA (2009) approved the SWSFS Part I (N.A. Water Systems, 2007b; 2008e; 2008f; 2008g).

In July 2009, UNC submitted to EPA the revised Part II of the SWSFS (Chester Engineers, 2009b), which addresses the development and screening of remedial alternatives. Based upon a series of comments and responses (EPA, 2010; and Chester Engineers, 2010c), UNC submitted the Revised Site-Wide Supplemental Feasibility Study Parts I and II during April 2011 (Chester Engineers, 2011b), for which EPA has provided additional comments (EPA, 2011b; 2012b). Work on the third stage of the SWSFS is pending resolution of issues raised in the preceding references.

During 2012 EPA and UNC discussed further revisions to the updated baseline human health risk assessment (HHRA) that had been required by EPA (2010). UNC submitted a final draft (Chester Engineers, 2012f) in August that was approved by EPA (2012c) in September.

This report discusses progress during 2012 in updating background threshold values (BTVs) for the Site. During 2012 there was extensive consideration (Chester Engineers, 2012a) of the most appropriate statistical methods to determine representative background water concentrations for two different purposes: a future long-term compliance monitoring program (where background threshold values (BTVs) are appropriate for “not-to-exceed” monitoring results) versus a risk assessment context (where confidence limits of mean background values are appropriate for estimation of exposure point concentrations (EPCs)). BTVs were generated as statistical UPL95 values (95th percentile upper prediction limit) and EPCs have previously been generated as statistical UCL95 values (upper confidence limit on the mean at the 95% confidence level; for the latter see N.A. Water Systems, 2008g).

Subsequent conference calls with the agencies resulted in UNC (UNC, 2012; GE, 2012b) submitting to NRC a License amendment request for revised groundwater protection standards based on updated background concentrations (BTVs). This License amendment request is presently under agency review. At the request of EPA, UNC also submitted (Chester Engineers, 2012e) an expanded list of BTVs that included contaminants of potential concern (COPCs) that are addressed in the EPA’s Record of Decision (ROD; EPA, 1988b) but not included in the NRC License set of regulated COPCs.

During 2012 UNC submitted to NRC and the other agencies a numerical groundwater flow model of the Church Rock Site and local area (Chester Engineers, 2012d; 2012g). The flow model includes all the Site hydrostratigraphic units though the focus of the model is on Zone 3.

At the request of EPA, UNC had the laboratory reduce the reporting limits for beryllium and lead. The new reporting limits are lower than the action levels. Beryllium’s former reporting limit of 10 µg/L has been reduced to 1 µg/L (using lab method E200.7), and lead’s former reporting limit of 50 µg/L has been reduced to 1 µg/L (using lab method E200.8). These changes were implemented during the July 2012 sampling event.

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 (EPA, 1988a). 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, 1995 and 1996; Rust Environment and Infrastructure, 1997; Earth Tech, 1998, 1999, 2000e, 2002a and 2002d; USFilter, 2004a; N.A. Water Systems, 2004, 2005b, 2007a, and 2008a; and Chester Engineers, 2009a, 2010a, 2011a, and 2012b).

1.2 Chronology of Site Events

Table 1A provides a chronologic summary of important Site events from June 1977 when UNC milling operations began, to December 2012.

1.3 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, shut off pending further evaluation, and performance monitoring is ongoing. The Zone 1 system was decommissioned in July 1999 in accordance with the letter from the NRC dated July 30, 1999 (NRC, 1999a).

Zone 1

During October 2012 and with one exception, offsite groundwater quality for all NRC-regulated constituents in all Zone 1 wells in Section 1 met or exceeded the NRC groundwater protection standards. For the first time since October 2006, nickel slightly exceeded the NRC standard of 0.05 mg/L in Section 1 point-of-compliance (POC) Well EPA 5 (0.06 mg/L).

Southwest Alluvium

The Southwest Alluvium system was temporarily shut off in January 2001 to facilitate implementation of the natural attenuation (NA) test. The NA test 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 meetings in Santa Fe on February 26, 2004, and at Church Rock on May 5, 2005), UNC continues to acquire groundwater quality data from wells in the Southwest Alluvium to monitor the effectiveness of natural attenuation and compare its performance to that of previous remedial efforts. During October 2012 groundwater quality has met or exceeded all NRC groundwater protection standards in the Southwest Alluvium, with the exception of a minor, non-seepage-impact-related nickel exceedance in background (i.e., non-impacted) Well SBL 1. This annual report presents a continuing assessment of the effectiveness of natural attenuation in the Southwest Alluvium.

Zone 3

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 ACLs, or an alternative to the specific requirements of 10 CFR Part 40, Appendix A, if the License standards are not achievable. During 2006 UNC completed an extended pilot investigation to evaluate the suitability of hydrofracturing to enhance the extraction potential within the seepage-impacted area of this hydrostratigraphic unit (MACTEC, 2006). The hydrofracture study indicated that the new pumping configuration had achieved nearly complete capture of the northward-advancing seepage-impacted water, while causing a notable improvement in the water quality within the northern tracking wells. For these reasons, pumping in the northern half of Zone 3 in Section 36 continued during 2012 (discussed in Section 3 of this report).

Subsequent analyses indicated that the improvement of water quality in northern tracking wells was temporary and that there was a need for additional extraction wells to enhance groundwater capture. A new extraction well (RW A) was installed and started pumping on September 24, 2007. Based on UNC's hydrogeologic analysis and recommended design (N.A. Water Systems, 2008c), five new wells (the NW-series) to intercept and recover seepage-impacted water were installed during September 2008. During February 2009, these extraction wells started pumping in the northernmost part of Zone 3. Pumping of all Zone 3 extraction wells removed more than 14 million gallons from 2005 through 2012. The pumped water is conveyed to an evaporation pond overlying part of the South Cell.

Groundwater quality in several of the Zone 3 northern tracking wells sharply degraded between May and December 2007 (N.A. Water Systems, 2008b). Groundwater quality along the northern tracking wells has been oscillating between degrading and improving trends over the last nine years. Individual well water-quality trends of improvement and degradation became collectively asynchronous starting in May 2007. During 2009, two of these wells (NBL 1 and PB 3) showed highly variable groundwater quality reflecting mixing of seepage-impacted and background waters that accompanies pumping; during 2010 and early 2011, the water quality improved in PB 3 but degraded in NBL 1 (these two wells are 110 ft apart). Since April 2011, intra-well water quality in this area has been stable overall, though variable on an inter-well basis. The groundwater quality in the northern part of Zone 3 is discussed further in Section 3.3.2 of this report.

On April 14, 2011 injection of water amended with sodium bicarbonate started at Zone 3 Well IW A (Chester Engineers, 2011e). The objectives of the injection were to (1) amend the injected water with alkalinity (sodium bicarbonate) to locally buffer and geochemically stabilize the seepage-impacted water, (2) redirect the seepage-impacted water into the capture zones of the northernmost extraction wells, (3) extend the life of the extraction wells by arresting the drawdown, and (4) improve upon a hydraulic barrier to the northerly advance of seepage-impacted groundwater. Injection well capacity declined over time and reached an impracticable

level by June 29, 2012, at which time injection was terminated. Prior to the termination of injection a total of 426,363 gallons had been injected. Extraction well pumping in this area continues. The injection performance is discussed further in Section 3.1.6 of this report.

1.4 Performance Monitoring and Supplemental Sampling

1.4.1 Performance Monitoring

The groundwater performance monitoring plan and has been approved by the NRC and EPA and is described by the Corrective Action Plan (UNC, 1989a), Remedial Design Report (Canonie, 1989a) and Remedial Action Plan (UNC, 1989b). 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; Earth Tech, 1998, 1999, 2000e, 2002a and 2002d; USFilter, 2004a; N.A. Water Systems, 2004, 2005b, 2007a, 2008a; Chester Engineers, 2009a, 2010a, 2011a, and 2012b), 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 pH, groundwater elevations, and laboratory analytical data collected from the fourth quarter of 1989 through the fourth quarter of 2012 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 (the latter two values are greater than those in the ROD). As part of the SWSFS background water statistical work, UNC has presented a comprehensive tabulation of contaminant-specific groundwater cleanup levels and other comparison values (N.A. Water Systems, 2008f, their Table 6; also provided in the revised SWSFS Part II, Chester Engineers, 2009b, Table 1; and in the Revised SWSFS Parts I and II, Chester Engineers, 2011b, Table 15, which includes updated values for several of the health-based criteria).

Quarterly laboratory summary analytical data sheets for the 2012 operating year are included at the end of each appendix. UNC directly submits the following semi-annual reports to NRC (as a License requirement), which are copied to the other agencies: (1) groundwater, effluent and environmental monitoring report (including the full laboratory analytical reports and field parameter data), and (2) groundwater quality assurance report (including quarterly field data sheets as filled by hand).

1.4.2 Supplemental Sampling

Southwest Alluvium: 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 (SBL 1) is not a formal requirement of the performance monitoring program; nonetheless, it is monitored, and the results are reported here.

Zone 1: At the request of EPA, for the first time since January 2000 Zone 1 Well 619 was sampled in October 2012 (for the full laboratory analyte list; both filtered and unfiltered samples were collected). During that same sampling event, Zone 1 Well 617 was sampled for the first time (this is a decommissioned pumping well).

Zone 3: Though not a formal requirement of the performance monitoring program, monthly measurements of select field parameters (pH, conductivity, chloride, and alkalinity (also called bicarbonate)) continued during 2012 in the tracking wells near the northern edge of the seepage-impact front in Zone 3. A new tracking well (NBL 2) was installed during August 2007. Starting in January 2008, monthly field parameter measurements have been made in Wells RW A and NBL 2, in addition to NBL 1, PB 2, PB 3, and PB 4; Well 504 B was dropped from this tracking program because the groundwater quality there has remained highly seepage-impacted for many years (see Table 11); since January 2011 water levels there had become too low to allow sampling; and during 2012 this well became dry. Starting in June 2009, monthly field parameters have been measured in all five of the NW-series wells.

During May to June 2010, northern monitoring wells MW 6 and MW 7 were installed in the area of injection Well IW A (Chester Engineers, 2010b). Though not a formal part of the performance monitoring program, the first sampling in these two wells for the full laboratory analyte list occurred in July 2011 (the results are discussed later in this report; also see Chester Engineers, 2011e). Monthly field parameter monitoring at these two wells started in August 2011. At the request of the agencies UNC started quarterly sampling of MW 6 and MW 7 during the July 2012 sampling event. In that same quarter, MW 6 showed chemical indicators of the effects of the alkalinity injection at Well IW A – this is discussed in Section 3.3.2 of this report.

At the request of EPA, turbidity measurements were made during the July and October 2012 sampling events (see discussion of results in GE, 2012c).

Though not a formal part of the performance monitoring program, to improve our understanding of the groundwater quality along the northern front of the seepage-impacted water in Zone 3 the following additional wells were sampled in 2012 for the full laboratory chemical parameter list: RW A (October only), RW 11, NBL 1, NBL 2 (October), PB 2 (October), PB 3 (October), and PB 4 (October). To serve as a check on the results of the monthly field parameter measurements, the following wells in the northern part of Zone 3 were sampled for laboratory analysis of bicarbonate, chloride, pH, and total dissolved solids (TDS): RW A, NBL 2, PB 2, PB 3, PB 4, NW 1, NW 2, NW 3, NW 4, NW 5, MW 6, and MW 7.

1.4.3 Lead-210 Analytical Results

One of the changes to laboratory analytical and reporting protocol for Pb-210 that has been phased in since April 2008 is that each sample is analyzed to determine its sample-specific Minimum Detectable Concentration (MDC). The MDCs vary from sample to sample. Pb-210 data in recent years have gone from, for example, an MDC of 5 pCi/L to now routinely approaching the MDC goal of 1.0 pCi/L. This is possible because of increased sample volumes, increased analytical count times, and lower background counts (the latter is due to the lower elevation of the liquid-scintillation counter). UNC and the lab have concluded that progressively over the last several years, and especially starting in 2010, the lab is capable of “seeing” very low concentrations that were not generally evident before.

There is no basis to infer that recent Pb-210 results reflect increasing concentrations in groundwater. With very few exceptions (e.g., Zone 3 Well NBL 1) the analytical results fall within the lower end of the range of background concentrations in each hydrostratigraphic unit (provided below). The results do not inherently reflect the impact of tailings seepage, given the background distributions.

The MDC analytical results are generally very low concentrations. For example, of the 24 Pb-210 detections during 2012, the highest result was 9.8 pCi/L (Zone 3 Well NBL 1, which is highly seepage-impacted); the next highest result was 3.4 pCi/L (Zone 3 Well 717, which is highly seepage-impacted); excluding NBL 1, all other results are less than 2.7 pCi/L. For one result of duplicate samples (711 in July 2012), the main sample result was 0.4 pCi/L with the lab qualifier U (meaning not detected) while the duplicate sample result was 1.6 pCi/L. During the entire year for 2012, five Zone 3 wells had detections in all four quarters (these wells are all highly seepage-impacted): Well EPA 14 (range from 1.4 to 1.6 pCi/L); 517 (range from 1.2 to 2.3 pCi/L); 708 (range from 1.2 to 1.6 pCi/L); 717 (range from 2.4 to 3.4 pCi/L); and NBL 1 (range from 1.6 to 9.8 pCi/L with the latter value being the highest Site measurement during 2012). Quantitative analytical errors (precision errors) indicate that some of the results are statistically not exceedances.

The current Site standard for Pb-210 is 1 pCi/L (NRC Source Materials License), which was the idealized lower limit of detection 32 years ago (see NRC, 1980). UNC (2012) has submitted a License amendment request for NRC to revise some of the groundwater protection standards to newly calculated background values as background threshold values (95th percentile of the upper prediction limits). With NRC concurrence, the Pb-210 background threshold values will be 5.9 pCi/L (Southwest Alluvium), 5.7 pCi/L (Zone 3), and 4.7 pCi/L (Zone 1). Application of these values will render most Pb-210 values as being in compliance. Background water Pb-210 concentrations define the following ranges: 1 to 14 pCi/L (Southwest Alluvium); 1 to 11 pCi/L (Zone 3); and 1 to 9 pCi/L (Zone 1).

1.5 Report Organization

This report presents each hydrostratigraphic unit 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

The monitoring data tables in the appendices to this report, unlike the report body, are printed and paginated double-sided.

Section 2

Southwest Alluvium

2.1 *Corrective Action Summary*

The Southwest Alluvium corrective action pumping system remained idle in 2012. Attenuation via natural geochemical processes has been shown to be at least as effective as pumping. The only exceedance of a hazardous constituent in seepage-impacted water outside the UNC property boundary was uranium in POC Well GW 3, which for the first time exceeded the Site standard in July 2012 (0.324 mg/L). The concentration declined to 0.295 mg/L in October 2012. Uranium concentrations in the Southwest Alluvium are discussed in Section 2.3.5.

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 1B 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 and Figure A-1 (Appendix A). A summary of constituents detected in the Southwest Alluvium in October 2012 is provided in Table 2. Historic groundwater quality and groundwater elevation data through October 2012 are provided in Appendix A (Table A.1).

2.3.1 *Water Level Evaluation*

Groundwater is present in the Southwest Alluvium as a result of the infiltration of groundwater historically discharged into the Pipeline Arroyo in connection with pumping of groundwater to lower water tables in the vicinity of the Quivera and NECR mines so that these mines could be constructed and operated. This water percolated into the alluvium and created temporary saturation in the vicinity of the tailings impoundments which diminishes gradually over time. The detailed history of infiltration of mine-dewatering groundwater, into the alluvium and the subcrop of Zone 3 and Zone 1, has been incorporated into the Site groundwater flow model (Chester Engineers, 2012g). This temporary saturation caused by discharged mine-dewatering groundwater is the recognized Southwest Alluvium background water (EPA, 1988a; 1988b; 1998; 2008b). The level of saturation has been declining since groundwater pumping in connection with historical mine operations ceased in 1986. As a result, the flanks of the alluvial valley and the northern property boundary alluvium have completely de-saturated and, by 2000, a 31 percent saturation loss had been observed further to the south (Earth Tech, 2000d). The October 2012 saturated thickness for each well in the performance monitoring program is provided in Table 3 (all table units are in feet unless otherwise specified). During 2012, all wells have shown overall decreasing groundwater elevations (with small fluctuations), indicating that

the groundwater flux continues to decline with the shrinking of the zone of saturation. The saturation measured in these wells has collectively declined by an average of 24 percent since 1989.

The Southwest Alluvium potentiometric surface map for October 2012 is shown in Figure 3A. This figure shows a local, eastward turn to the saturated alluvium, beneath the northwestern part of the South Cell, reflecting the presence of a relatively high area (bulge) in the bedrock surface between Wells 509 D and EPA 23. This bulge encompasses the area including the “Nickpoint” along Pipeline Arroyo. The Nickpoint (Figure 3A) 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.

Figure 3B shows a contour map of saturated thickness in the Southwest Alluvium in October 2012. This map was developed by integrating the potentiometric surface with a structure contour map of the base of the alluvium (and thus does not involve directly contouring the posted values of saturated thickness). The distribution of the groundwater suggests the likelihood that the northern portion of the groundwater system, upgradient of the Nickpoint and including Well 509 D, may have become “detached” or ponded (i.e., lost hydraulic continuity) from the groundwater to the south. Such detachment may occur along the local high in the top of bedrock that causes the saturated alluvium to jog to the east in the area of the Nickpoint (Figure 3B). The underlying data density is not sufficient to allow certainty on this issue. However, it is likely that this will eventually happen both to the north of the Nickpoint and in a large depression, along the top of bedrock, that is west of the South Cell and below the Nickpoint.

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 from the alluvium. Note that in 2007, the water level in EPA 23 (below the Nickpoint) became higher than the level in 509 D (above the Nickpoint). The slope (rate) of decline above the Nickpoint (509 D) is greater than the rate of decline below the Nickpoint (EPA 23) prior to January 2007, but later slowed relative to EPA 23. These observations mean that alluvium groundwater above the Nickpoint no longer flows to the south and it presumably infiltrates into bedrock.

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 (recovery was complete during approximately April to June 2002). A summary of operational data for the Southwest Alluvium extraction wells is provided in Table 4.

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 total pumping volume throughout the corrective action period by 30 percent or more (Earth Tech, 2000d). Groundwater pumping did not fully contain seepage-impacted water; 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. The revised SWSFS Part II has previously summarized the remedial alternatives appropriate to the Southwest Alluvium (Chester Engineers, 2011b); however, all potentially relevant alternatives will be further evaluated in conjunction with the next revisions of Parts I and II.

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

Excluding the single uranium exceedance in Well GW 3 in July 2012, no hazardous constituents exceed Site standards outside the UNC property boundary within seepage-impacted water. Most constituents show time-series variations that have become “routine” in the context of 23 years of groundwater quality monitoring. Prior pumping did not improve the groundwater quality, nor would future pumping do so.

The area currently containing seepage-impacted groundwater in the Southwest Alluvium is shown on Figure 6. As explained more fully below, common ion geochemistry in the delineated area has been changed by the neutralization of tailings seepage migrating through the alluvium. The area of seepage impact extends southwest along the western margins of the North, Central, and South Cells, and continues approximately 1,400 ft across the southeastern corner of adjacent Section 3 and approximately 435 ft into the north-central portion of adjacent Section 10. The total length of the area is approximately 6,075 ft.

Historically, only two constituents, sulfate and TDS, exceed the Site standards in the Southwest Alluvium seepage-impacted groundwater outside the UNC 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 2012 are shown graphically in Figure 7. This figure shows that the long-term concentrations in most wells have remained approximately steady with the following exceptions: (1) the concentrations in Wells 801 and 509 D decreased in January 2000 and October 1999, respectively, and have since remained at these relatively lower levels; and (2) the concentrations in Well GW 2 have shown overall increasing trends since the shutoff of pumping, although the increase appears to have leveled off starting in July 2010. The light-gray data points in the upper right part of this chart represent the sulfate measurements from Well SBL 1 (post-mining/pre-tailings; i.e., background water quality). In October 2012 as in all previous quarters, this well had the highest sulfate concentration of any well in the Southwest Alluvium (including all historic measurements of seepage-impacted wells), including the nearest, hydraulically upgradient Well 624 which is impacted by seepage.

Sulfate concentration increases in Well GW 2 do not necessarily reflect the influence of the shutoff of pumps in January 2001. For example, the post-shutoff trend in GW 2 was approximately stable to October 2004 (2,570 mg/L), after which the increasing trend started (the concentration was 4,700 mg/L in October 2012). Increasing levels of common dissolved ions

means that either (1) the diminishing saturation is being accompanied by increasing dissolved ion concentrations (consistent with the hypothesis developed by NRC, 1996), and/or (2) more of the alluvium minerals are being dissolved (also discussed by NRC, 1996). As shown by UNC's MINTEQ studies, the alluvium groundwater is generally at saturation (or in equilibrium) with respect to calcite, gypsum, and other soluble mineral salts.

Locally increasing trends in concentrations of common dissolved ions are unrelated to tailings seepage; they derive from the reaction of the anthropogenic recharge water with natural alluvium materials. Heterogeneous distribution of the soluble alluvium minerals is the most significant factor affecting the intra-well and inter-well variations in the concentrations of common dissolved ions.

Figure 8 is a bicarbonate isoconcentration map of the Southwest Alluvium during October 2012. As explained in earlier annual reports and in the first 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 has also prevented the migration of metals from the former tailings impoundments. The neutralization capacity is strongly tied to relatively large amounts of calcite (CaCO_3) in the alluvium that is available for buffering: Canonie (1987, Table 4.4) reported measured alluvium CaCO_3 fractions of 2.58 percent in a sample collected during drilling of Well EPA 23; 0.77 to 0.28 percent near the Pipeline Arroyo Nickpoint; and 0.02 to 12.6 percent elsewhere.

The bicarbonate isoconcentration contours shown in Figure 8 illustrate the zone of seepage impact with fine resolution. Prior to the 2004 annual report, the seepage impact zone was based on assumptions of seepage migration rates and delineated by a line encompassing estimated bicarbonate concentrations exceeding 1000 mg/L. It has since been recognized that there is a core of more significant impact (bicarbonate concentrations exceeding 2000 mg/L) surrounded by progressively less seepage-impacted groundwater (approximated by the 1000 mg/L contour).

The groundwater quality characteristics of the non-seepage-impacted (background) samples from Well SBL 1 differ in several important aspects from seepage-impacted water (refer to Figure 9 and Appendix A). Well 624 is the closest seepage-impacted well (500 ft) upgradient from Well SBL 1 (Figure 3A). 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-SO_4) type water while Well 624 contains a calcium-sulfate (Ca-SO_4) 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 HCO_3) 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 (Al-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 impact. It is a natural consequence of the law of mass action whereby the releases of calcium and bicarbonate, in reaction to acidic tailings fluids, were accompanied by the precipitation of additional gypsum as the system tended to maintain constant calcium concentrations. 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 be fixed with respect to aqueous 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-seepage-impacted areas in the alluvium. Sulfate concentrations are 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 are consistent with 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 seepage-impacted groundwater. Consequently, 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 concentrations less than 2,125 mg/L in Figure 8 is elongated parallel to the bicarbonate isoconcentration contours. This area represents a migrating reaction zone separating two areas of relatively elevated sulfate: one due to seepage impact in the transport “wake” of the reaction zone, and the other downgradient (or side-gradient) in background water (post-mining/pre-tailings) 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. It is important to recognize that 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 seepage-impacted 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 2012. 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. Former 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 side-gradient 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 (HCO_3) and a very low contribution from chloride (“Chl” on the figure) and calcium (Ca). These observations and analysis confirm that the current extent of seepage-impacted water has not reached Well SBL 1.

Neither the seepage-impacted water nor the background water that has not been impacted by seepage meets 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). In some respects, particularly regarding sulfate concentrations, the seepage-impacted water may be viewed as an improvement compared to the non-seepage-impacted (background) water. Groundwater quality within the Southwest Alluvium is further discussed in Section 2.3.4.

Two other constituents are present at concentrations that historically have exceeded the Site standards primarily within the property boundary:

- Chloride – Chloride is a non-hazardous constituent. Chloride concentrations exceed the Site standard (250 mg/L) at Well 509 D. This well has exhibited an overall stable trend

since 1996 with fluctuations ranging from 278 to 411 mg/L (see Figure 10). The chloride concentration at Well 632 has fluctuated about the standard with no discernible trend since 1990; however, since July 2010 all the measurements have been below the standard. Chloride has also fluctuated about the standard in Well GW 1 since January 2004 (Figure 10); however, since April 2008 all the measurements have been below the standard. Chloride concentrations are discussed more in Section 2.3.4.

- Chloroform – In August 2006 the NRC modified the Site License to change the former chloroform standard of 1 µg/L to a total trihalomethanes (TTHMs) standard of 80 µg/L (NRC, 2006b). Starting with the October 2006 sampling event, the laboratory has analyzed for TTHMs – all four component compounds (of which chloroform is one) are measured, and almost all Site groundwater samples (including the Southwest Alluvium) show that the TTHMs concentration equals the chloroform concentration (i.e., chloroform is the only TTHM compound present). In occasional discussion of “chloroform concentrations” in this report, the reader should bear in mind that the Site standard (and laboratory analysis) of relevance is now for TTHMs and not solely for chloroform as was previously the case. Table 2 shows that during October 2012 Southwest Alluvium TTHMs were detected at levels far below the Site standard of 80 µg/L in the following wells: 632, 801, 802, 803, 808, GW 1 and GW 2.

Well SBL 1 is located in front of the seepage-impacted water within background water (non-seepage-impacted water of post-mining/pre-tailings origin). Prior to the installation of 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. Well SBL 1 has had multiple manganese exceedances and was above the Site standard at 3.74 mg/L in October 2012 (Table 2).

Long-term offsite seepage impacts to the groundwater have been limited to exceedances of the sulfate and TDS standards, both of which are non-hazardous constituents. Unlike Zones 1 and 3 impacted waters, the pH of the Southwest Alluvium seepage-impacted water is nearly neutral. Consequently, there are very few exceedances of the metals or radionuclides standards within the seepage-impacted water, with the exception of some exceedances of manganese (a non-hazardous constituent) located well within the property boundary (Table 2); the single exceedance of the uranium standard in Well 509 D during October 2010 (subsequent to which all measurements have been below the standard); and the first-time exceedance of uranium in Well GW 3 during July 2012 (0.324 mg/L; the next measurement in October 2012 was below the standard).

The background water at downgradient Well SBL 1 showed October 2012 exceedances of nickel (0.08 mg/L) and manganese (3.74 mg/L), and occasional earlier exceedances of cobalt. These metals exceedances are unrelated to seepage impact to the groundwater because seepage-impacted water has not yet migrated to this location. Therefore, they should be viewed as a background condition, i.e., of post-mining/pre-tailings origin and age. The NRC’s statistical evaluation of background water quality led to their recommendation that manganese, sulfate, and

TDS should not be regulated Site constituents and they should not be used as bases for corrective action (NRC, 1996).

October 2012 analytical results showed one detection of Pb-210 within the Southwest Alluvium (Table 2; Appendix A): 1.0 pCi/L in the field duplicate (only) from Well EPA 28. Otherwise there were no detections during the entire year of 2012.

2.3.3 Rate of Seepage Migration

Earth Tech (2002c) 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 seepage-impacted water offsite typically have been sulfate and TDS (and very infrequent, seemingly random detections of Pb-210). However, bicarbonate and chloride have been determined to be the more effective indicators of seepage impact for reasons described in Section 2.3.2.

New groundwater velocity calculations have been made to update the estimate of 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 2012 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 new hydraulic conductivity value used in this annual report is 2.5×10^{-3} cm/sec (replacing the former value of 2×10^{-3} cm/sec), which was determined to be an appropriate value based on groundwater flow model calibration for the Southwest Alluvium (Chester Engineers, 2012g). The new value is 25% larger than the former value and this should generally be expected to result in higher calculated velocities than before.

The average calculated groundwater velocity from Well 624 to Well SBL 1 is 11 ft/yr. This is substantially lower than the velocities associated with the other two upgradient well-pairs, because the hydraulic gradient from 624 to SBL 1 is significantly lower than those associated with the other pairs (Table 5). This velocity is 31% lower than the velocity calculated for October 2011 (16 ft/yr), and the latter is 23% lower than the velocity calculated for October 2010 (21 ft/yr). These large decreases represent declining horizontal hydraulic gradients between this well pair (Table 5 shows a gradient of 0.0013, which is 44% lower than the gradient in the previous year).

By contrast, Table 5 indicates significant increases in the calculated average velocities for well pairs 805 and 624 (49 ft/yr in October 2011 versus 60 ft/yr for October 2012), and 805 and 627 (57 ft/yr in October 2011 versus 72 ft/yr in October 2012). These are increases of, respectively, 22% and 26%, which are close to the 25% increase in the current estimate of mean hydraulic conductivity versus last year's.

The downgradient limit ("nose") of the 1,000 mg/L bicarbonate isoconcentration contour shown in Figure 8 is 11 ft farther to the southwest than it was in the comparable figure in the 2011 Annual Report.

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 (16 years prior to October 2012). Using the updated average groundwater flow rate from Wells 624 to SBL 1 of 11 ft/yr, and accepting the inferred location of the plume "nose" near SBL 1 in Figure 8 (with a separation distance of 77 ft), extrapolation indicates it may take approximately 7 years for the seepage-impact front to reach SBL 1. This estimate assumes a constant seepage velocity, and the actual time for seepage impacts to arrive at SBL 1 will likely be longer because saturation levels and gradients will continue to decline. Overall, the timing of the arrival of seepage impacts at SBL 1 is not subject to precise prediction.

Figure 8 shows the downgradient "nose" of the 1,000 mg/L bicarbonate isoconcentration line passing to the east of Well SBL 1. This depiction is based on the inference that the seepage-impacted water will locally take this southerly course to parallel the southerly turn in the edge of the cuesta nearby to the east. However, we expect that the area of alkalinity impact will eventually include Well SBL 1.

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, Well SBL 1 may soon begin to exhibit gradual increases in the bicarbonate and chloride levels. Continued monitoring of the water quality at this location should eventually allow back-calculation of the relevant rate of reaction front migration.

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

UNC conducted a scheduled 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 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 in the NA report concluded that natural conditions maintain sulfate and TDS concentrations at non-seepage-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-dewatering groundwater discharge began. This is demonstrated by the sulfate concentrations from seepage-impacted wells that contain constituent concentrations equivalent to, or variously higher or lower than, the non-seepage-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 12. Background (post-mining/pre-tailings) 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 has usually had the highest concentration of any well. However, since July 2009, the TDS concentrations in GW 2 have exceeded those in SBL 1 four times, including October 2012 (when their concentrations were, respectively, 8,730 mg/L and 8,640 mg/L). The sharply increasing TDS trend for seepage-impacted Well GW 2 appears to have reached a maximum in January 2010. The previously increasing trends for sulfate and TDS in Well GW 2 are consistent with its location in the core area of the bicarbonate distribution mapped in Figure 8. It is important to recognize that the reaction of the alluvium water with the natural alluvium material causes the high TDS water – this is unrelated to the tailings seepage and would occur in any water placed into the formerly unsaturated alluvium.

The remediation system did remove sulfate and TDS mass, but this is irrelevant because concentrations are dependent on the chemical equilibrium of gypsum with the water; therefore, they have been and will continue to remain similar to those achieved through geochemical processes within the 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, the pervasive equilibrium between the groundwater and naturally occurring gypsum (or anhydrite).

Under the federal drinking water standards, sulfate and TDS are assigned secondary drinking water standards (SMCLs), which are non-enforceable 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, nor were they assigned Site groundwater protection standards by NRC. 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, UNC has repeatedly proposed that a TI Waiver is appropriate for sulfate and TDS (Earth Tech, 2002c; USFilter, 2004a; N.A. Water Systems, 2005a), and

remains concerned that the failure to grant the TI Waiver will needlessly complicate and confuse the ongoing SWSFS.

UNC believes that the earlier part of this report demonstrates an understanding of, as well as the distinctions between, background water and seepage-impacted water with respect to the character and evolution of their geochemistry. Application of a TI waiver zone must take the characteristics and geochemistry of the Site into consideration. 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 192 years from now (shown in Figure 58), and has concluded that the area meets ALARA (as low as reasonably achievable) principles. This depiction derives from application of the average October 2004 groundwater velocity from Well 624 to Well SBL 1 (30 ft/yr) over a 200-year period; it assumes purely advective transport of seepage impacts with no retardation, dilution, or attenuation; and it assumes that sufficient hydraulic head will exist to drive the flow of seepage-impacted water (which may not be the case given the absence of significant recharge and the preceding observations regarding declining water levels and ponding along deep depressions in the bedrock). 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. In conjunction with their review of the pending SWSFS, EPA must decide whether to address sulfate and TDS with a TI Waiver, ACLs, or possibly Institutional Controls (ICs; EPA, 2008b).

2.3.5 Reassessment of the Performance of the Natural System

The NA report (Earth Tech, 2002c) used 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. However, subsequent to the submittal of this report in 2002 and, as discussed earlier, Wells GW 2 and GW 1 had shown increasing sulfate trends; such increasing major ion concentrations reflect the influence of declining water levels and/or increased dissolution of the alluvium materials (NRC, 1996). The NA report (Earth Tech, 2002c) also concluded that there was no change in trend for manganese, chloroform, or uranium. It was concluded from these analyses that, although 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 2012 supports this conclusion for the vast majority of analytes in virtually all monitoring wells (with the possible exceptions of uranium in Wells GW 3 and EPA 25, discussed below).

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. Entries in Table 6 are based on groundwater quality in background Well SBL 1, as well as our understanding of the geochemical systems associated with both background water and seepage-impacted water. Metals and radionuclides in seepage-impacted water 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

Calcium and bicarbonate are non-hazardous constituents. Figure 13 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 these two wells have been essentially the same through time. Figure 13 shows that during the onset of seepage impact in Well 624 (indicated by the increasing bicarbonate), the calcium concentration increased by approximately 100 mg/L and then re-equilibrated at a concentration of 650 to 700 mg/L. Under changed groundwater quality flux, calcium concentrations remain fixed in the presence of calcite and gypsum by the Phase Rule; the long-term consistency of calcium concentrations in the Southwest Alluvium attests to the established equilibrium between the groundwater and these minerals. In general, calcium concentrations do not vary appreciably anywhere in the groundwater flow system (see Figures 9 and 14).

Figure 15 shows the bicarbonate concentrations over the same period. Bicarbonate is a non-hazardous constituent that serves as the primary indicator of seepage impact in the Southwest Alluvium. Three wells have shown post-shutoff uptrends in bicarbonate to present: EPA 25, GW 1, and 509 D. The other wells have, at different times, achieved post-shutoff stability. These observations indicate that neutralization and geochemical attenuation have been occurring naturally, and that alluvial mineral salts dissolve into the alluvium groundwater. We conclude that most of the system has largely attained a new steady-state with respect to bicarbonate following the termination of alluvial groundwater extraction.

Sulfate and TDS

Sulfate and TDS are non-hazardous constituents. They do not have federal drinking water MCLs; they do have SMCLs. The provisional Site standards (2,125 mg/L for sulfate and 4,800 mg/L for TDS) derived from a background water quality analysis by the NRC (1996), with which NMED concurred (NMED, 1998).

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 16 shows sulfate concentrations from 1999 through October 2012; Figure 17 presents TDS concentrations over the same period. Well GW 3 shows long-term stability in the concentrations of sulfate and TDS that were not affected by pumping. Well

GW 2 has previously shown increasing trends in both sulfate and TDS since shutoff, but the concentrations appear to have stabilized.

Concentrations of sulfate and TDS are lower within seepage-impacted waters than within non-seepage-impacted Well SBL 1, and they are not expected to rise above the values measured in SBL 1. 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 in the Southwest Alluvium regardless of whether the extraction wells are operated.

Chloride

The Site standard for chloride derives from the New Mexico Water Quality Act; 250 mg/L is also the federal SMCL (this constituent does not have a federal primary MCL).

Figure 10 presents chloride concentrations from 1999 through October 2012. Well 509 D is the only location where chloride concentrations have persistently exceeded the standard. Occasional minor exceedances have occurred in the past at Wells 632, 801, and GW 1.

Figure 10 shows that during the 18 months after the pumping shutoff, there were small Site-wide increases in chloride, after which concentrations returned to their pre-shutoff levels. The small increases may have been (at least partially) an artifact of the more frequent, monthly water quality measurements that were made for the 18 months following shutoff (after which the frequency returned to quarterly monitoring). Pumping had no effect on chloride concentrations with the apparent exception of Well GW 1, where post-shutoff increases stabilized in January 2004 at concentrations that occasionally show very small exceedances.

Manganese

Manganese is a non-hazardous constituent in water. It does not have a federal drinking water MCL; it does have a SMCL. The Site standard (2.6 mg/L) was cited as background water quality in the ROD (EPA, 1988b); as with other background estimates, however, subsequent studies indicate this level does not adequately reflect the characteristics of this site.

Figure 11 presents manganese concentrations from 1999 through October 2012. Manganese is the only metal that exceeds its current standard in seepage-impacted areas. Exceedances have occurred typically at three wells: 801, EPA 23, and 509 D. The concentration trends have been relatively flat at Well 801 since July 2004 and at Wells EPA 23 and 509 D since 2000. Well 509 D is an upgradient well that was not hydraulically influenced by the former downgradient extraction well pumping, and the changes of manganese concentrations are probably unrelated to previous pumping (the changes are slight and concentrations appear to be stable between ~ 2 to 4 mg/L). Well 803 had the first manganese exceedance (3.14 mg/L), in October 2012, since the sole previous exceedance at that well in March 2001.

Two of the monitoring wells in proximity to the southwestern “nose” of the South Cell (802 and 808) continued to show low manganese concentrations during October 2012 that were below the standard. Nearby, Well 632 maintained a very gradual increasing concentration trend that started in December 2001. Since January 2009, the concentrations have occasionally, slightly exceeded the standard. All three of the GW-series wells continued to show long-term stable trends below the Site standard.

These observations indicate that manganese natural attenuation in seepage-impacted water continues. It is expected that concentrations will continue to be below the standard in most of the seepage-impacted wells; however, exceedances are expected to continue at Well EPA 23, and sporadic exceedances appear likely to continue in Well 509 D (both of these are POC wells located significant distances upgradient of the Section 2 property boundary). Based on long-term trends, moderate exceedances may continue at Well 801. In addition, manganese is expected to exceed the standard in SBL 1 because it is a background well. Manganese is a common accessory element, and its concentrations in water are tied to Eh-pH conditions rather than any association with the tailings seepage.

Uranium

The statistical analysis included in the NA report (Earth Tech, 2000c) 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. For this reason, UNC has continued to reassess the uranium trends as part of the Site annual reporting. GE (2006) has evaluated the regulatory significance of the occurrence and distribution of dissolved uranium in the Southwest Alluvium. That report was prepared to assist EPA in deliberations about applying the current MCL for uranium (0.03 mg/L) as a formal cleanup criterion in the Southwest Alluvium. EPA has informally indicated that the agency is considering adoption of the current MCL for uranium as the standard at Church Rock, although a formal modification to their current standard in the ROD (5 mg/L) has yet to be proposed. Figures 18 through 34 (discussed below) show that most of both the seepage-impacted and background wells have long-term uranium concentrations exceeding 0.03 mg/L. The NRC standard for uranium is 0.3 mg/L; based upon the Site history and distribution of uranium in background and seepage-impacted water, this is the most supportable uranium standard for this Site (GE, 2006). The concentration of dissolved uranium in seepage-impacted water is often a function of the bicarbonate concentration, and uranium concentrations have been empirically found to lie within the same concentration range as the background (post-mining/pre-tailings) water. Graphs of uranium concentrations in all fourteen wells comprising the Southwest Alluvium water-quality performance monitoring program, through October 2012, are included as multi-well plots in Figures 18 and 19. Figure 18 shows only the seven POC wells; Figure 19 shows other select wells, including background wells.

Historically, there have been only three exceedances of the NRC uranium standard of 0.3 mg/L in the Southwest Alluvium: (1) a brief spike in 1993 to 0.602 mg/L in Well GW 3; (2) the October 2010 concentration of 0.312 mg/L in Well 509 D; and (3) the July 2012 concentration of

0.324 mg/L in Well GW 3. The 509 D value was part of an unusually large increase during 2010, from 0.235 to 0.312 mg/L (see Figures 18 and 20), which correlated with the highest bicarbonate concentrations measured in this well (Appendix A). All subsequent measurements at this location have been below the standard, although an upward trend started in January 2012.

Graphs of uranium concentrations are shown separately for each well in Figures 20 through 34:

- **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 had been overall stable (i.e., approximately horizontal on the chart) since July 2000, at the higher end of the historic range, until an increasing trend that started in October 2008 which appears to be continuing. Well 509 D is located outside the zone of influence of the former pumping wells; it is not a good indicator of whether there is a benefit to pumping.
- **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 heterogeneous uranium-bearing waters 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 October 2003 to present.
- **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 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.
- **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 and then decreased through January 2004, at which time they stabilized. Figure 24 shows that the covariance of uranium and bicarbonate here has been limited since 2002: in April 2002 the uranium measured 0.102 mg/L and the bicarbonate measured 1,100 mg/L, while in October 2012 the two values were, respectively, 0.103 mg/L and 1,950 mg/L (i.e., the uranium concentration was nearly unchanged while the bicarbonate concentration had increased significantly).

- **Well GW 2** (Figure 25): Post-shutoff concentrations were stable through October 2002; then they increased to October 2005, after which they have defined an overall decreasing trend. 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.
- **Well GW 3** (Figure 26): Since shutoff, the concentrations have increased from 0.059 mg/L in February 2001 to 0.283 mg/L in October 2012, defining a linear rate of increase of +0.019 mg/L per year over this period of 11.7 years. GW 3 is the only Southwest Alluvium well to show a persistent increase in uranium since shutoff. However, this does not necessarily indicate a causal relationship between the increasing trend and shutoff. For example, nearby wells GW 1 and GW 2 have exhibited different concentration changes over the same time-frame. It is not clear what physical or chemical mechanism stemming from the shutoff could account for changes so heterogeneous in degree and timing over a relatively small downgradient area. Uranium concentrations in many Southwest Alluvium wells have shown that variously gradual to steep uptrends and downtrends are typical, whether they occur during pumping or in the absence of pumping. Starting in approximately January 2008, there has been little to no covariance between the bicarbonate and uranium concentrations. This well has a very short water column (3.32 ft, or 6% saturated thickness, see Table 3) and we project that it will become dry in approximately seven years. By comparison, in October 2003 the water column here was 7.52 ft tall (representing 13% saturated thickness).
- **Well 624** (Figure 27): Post-shutoff concentrations have been stable at the lower end of the historic range. This chart also shows the bicarbonate time series at this well. Unlike the long-term covariance between uranium and bicarbonate shown in Wells GW 1 (through April 2002) and EPA 25, Well 624 conspicuously lacks covariance. This observation is discussed later in this section.
- **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).
- **Well 627** (Figure 29): Post-shutoff concentrations have been stable along the historic trend that is associated with a low range.
- **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 was strongly downward through October 2002, subsequent to which the concentrations have stabilized.
- **Well EPA 23** (Figure 31): Post-shutoff concentrations have been stable at the lower end of the historic low range.
- **Well EPA 25** (Figure 32): Concentrations have been quite stable from July 1999 to January 2007. This chart also shows the covariance of uranium and bicarbonate

concentrations over the entire history of monitoring. The onset of seepage impact at this well occurred during October 1995. An upward step in bicarbonate concentrations started in April 2006, while an apparent upward step in uranium concentrations started slightly later in January 2007 – these geochemical changes occurred many years after the shutoff of the pumps. Such covariance in uranium and bicarbonate concentrations is characteristic of most (but not all) wells in the Southwest Alluvium. This important relationship can be explained by the basic geochemical principles presented in GE (2006). EPA 25 is along the northwest flank of the bicarbonate impact area (see Figure 8).

- **Well EPA 28** (Figure 33): Concentrations have been quite stable since July 1989.
- **Well SBL 1** (Figure 34): Concentrations at this newest, downgradient background well have varied from 0.0066 mg/L to 0.0332 mg/L.

This comprehensive review of historic uranium concentrations demonstrates that most of the seepage-impacted wells have shown overall stable to decreasing trends since shutoff. Excluding the single exceedances of uranium in Well 509 D during October 2010 and Well GW 3 in October 2012, none of the other wells have shown post-shutoff concentrations that exceed historic values, and many of the wells show that both gradual and sudden variations are common. UNC concludes that pumping would not result in a general Southwest-Alluvium-wide improvement in groundwater quality with respect to uranium or any other constituent.

EPA (2008b) has stated (p. 53, Issue # 4):

“If the source of the uranium is the alluvial sediment, the increase in bicarbonate levels, as believed to be controlled by the shutoff, would be expected to influence the distribution and concentration of uranium. The bicarbonate levels are believed to determine whether or not the non-tailings-sourced uranium is dissolved, precipitated, or adsorbed. Thus, if the bicarbonate continues to migrate, then any uranium which could be sourced from the alluvium is expected to mimic the bicarbonate and migrate accordingly. In light of this, there remain questions regarding the effectiveness of the extraction wells to improve ground-water quality with respect to uranium.”

EPA (2008b) indicated that this and related statements in their third Five-Year Review report derived from their review of the 2007 Annual Review Report (N.A. Water Systems, 2008a) and GE (2006). UNC concurs that degrees of covariance between bicarbonate and uranium groundwater concentrations have been demonstrated in many Southwest Alluvium wells, and that the alkalinity of seepage-impacted water can be a strong determinant of how much uranium will be partitioned between the aqueous and (a typically surface-bound) solid phase (GE, 2006). UNC also believes that the weight of empirical evidence demonstrates that re-starting groundwater extraction will not improve groundwater quality in the Southwest Alluvium.

The likely heterogeneity of the uranium distribution (of non-tailings origin) within the Southwest Alluvium sediments may inherently limit one’s ability to predict the degree (or even presence) of

such covariance. For example, Figure 24 indicates a degree of covariance between these two chemical parameters in Well GW 1. However, from April 2002 to October 2012 (a period of 10.5 years) the bicarbonate concentrations in this well increased by +850 mg/L while the uranium concentration increased by +0.001 mg/L.

Another example worth noting is provided by Well 624 (Figure 27). The increase in bicarbonate to a plateau starting in May 2000 is attributed to the migration of the bicarbonate “front” associated with tailings seepage-impact. However, this well shows no covariance between the bicarbonate and uranium concentrations. At least two interpretations are possible: (1) at this well location there is little to no adsorbed or precipitated uranium (i.e., solid phase) within the alluvial sediments; and (2) aqueous uranium that originated from upgradient tailings seepage impact has been strongly attenuated during transport and it has not reached this location.

Excluding the sharp and singular increase in Well 509 D during October 2010, and in Well GW 3 in October 1992, January 1993, and July 2012, none of the wells have shown exceedances of the uranium standards. *The time-concentration 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*

3.1.1 *Northeast Pump-Back and Stage I and II Remedial Action Systems*

While operating, the corrective action system 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 35: (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.

The numbers of operating extraction wells were reduced as Zone 3 dewatering caused sustainable pumping rates to drop below 1 gpm. 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). Pumping from the last three extraction wells ceased in 2000. 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 ACLs, or an alternative to the specific requirements of 10 CFR Part 40, Appendix A, if the License standards are not achievable.

3.1.2 *2004 Supplemental Feasibility Study*

At the request of the EPA (2004b), UNC conducted a Supplemental Feasibility Study (SFS) to evaluate all appropriate remedial options for Zone 3. Prior to reporting the SFS (MWH, 2004), 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 presented (1) groundwater modeling of the Zone 3 sandstone unit and the locally overlying alluvium, (2) 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.

Two studies were conducted based on recommendations of the SFS. These were an in-situ alkalinity stabilization pilot study and the pilot and Phase I hydrofracture program. These studies are described below.

3.1.3 *In-Situ Alkalinity Stabilization Pilot Study*

UNC conducted an in-situ alkalinity stabilization pilot study to evaluate the potential to enhance the ongoing Zone 3 remediation through the use of alkalinity injection wells combined with carefully controlled extraction pumping at the Site. The proposed approach for the pilot study was presented in the In-Situ Alkalinity Stabilization Pilot Study (BBL, 2006), which was approved by EPA.

The pilot study was initially designed to test the injection of alkalinity-rich groundwater from a non-seepage-impacted part of the Southwest Alluvium into the Zone 3 aquifer. The injected water (so-called “fixiviant”) would flow through the Zone 3 formation to recovery wells where the fixiviant could be pumped to the surface for treatment and disposal. However, concerns were expressed by NMED that the groundwater from the Southwest Alluvium did not meet applicable groundwater standards for sulfate, total dissolved solids and manganese. Following the original submission of this pilot study (in October 2005) and subsequent discussions, NMED identified groundwater withdrawn from a formation below Zone 3 and the underlying Mancos Shale (the Westwater Canyon Formation), via the onsite Mill Well, as a potential alternative source of groundwater to use as the injection water. The pilot study approach was revised to include injection of the Mill Well water (amended with sodium bicarbonate to add alkalinity) into Zone 3, as described in the approved In-Situ Alkalinity Stabilization Pilot Study dated June 2006.

The pilot study was conducted from October 24, 2006, to February 15, 2007. The observed injection and extraction rates were unexpectedly low. As a result, the estimated travel time between the injection and extraction wells became prohibitively low and the pilot test was terminated. Data obtained as part of the pilot study indicated that the mineral feldspar in the Zone 3 arkosic sandstone had been altered by the acidic tailings liquids, generating kaolinitic clay that significantly clogged pore spaces and reduced hydraulic conductivity. The pilot study indicated that it would take 10 times longer to accomplish remedy goals than had been hypothesized. Using what had been envisioned as an approximate 5 year remedy enhancement could actually take 50 years or more. Based on these results, it was concluded that the use of alkalinity rich solutions to remediate the Zone 3 seepage-impacted groundwater in-situ was infeasible (ARCADIS BBL, 2007).

3.1.4 *Phase I Hydrofracture Program and Continuing Zone 3 Extraction Well Pumping*

Extraction of seepage-impacted groundwater from a new array of wells in the northern part of Zone 3 in Section 36 was tested in April 2005 as part of the Phase I (i.e., post-pilot) hydrofracture program (MACTEC, 2006). Continuous pumping of these wells began in May 2005. Phase I ended in January 2006; however, as discussed later in this section of the report, the pumping has been continued and supplemented by the installation of additional extraction wells. The locations of the Phase I pumping wells (RW 11, RW 12, RW 13, RW 15, RW 16, RW 17, and PB 2) are shown on Figure 37 and Figure B-1 in Appendix B. Also shown is the location of a newer extraction well, RW A, which started pumping on September 24, 2007. Due to fouling and/or insufficient yield, RW 12, RW 13, and RW 15 have been taken off-line and are

no longer pumping. Of this group, the pumping wells that were operational during 2012 are PB 2, RW 11, RW 16, RW 17 and RW A.

Based on UNC's hydrogeologic analysis and recommended pumping system design (N.A. Water Systems, 2008c), five new extraction wells to intercept and recover seepage-impacted water were installed during September 2008. These well locations are shown on Figure 35 and Figure B-1 (in the front of Appendix B) – they are designated NW 1, NW 2, NW 3, NW 4, and NW 5. After an initial test period to determine that all five wells were pumping properly, three of the wells started pumping during February 2009 (NW 1, NW 2, and NW 3). NW 2 and NW 3 were each pumping at approximately 1 gpm and NW-1 at 0.1 gpm. Yields have since declined at all of the wells and most dramatically at NW 1, which has a very low recharge rate and shallow saturated thickness. As discussed in the next section, the pumping scheme was adjusted during November 2009 and June 2012. NW 3 and NW 5 were not pumped to minimize the potential of drawing seepage-impacted groundwater to the northwest.

Approximately 14,141,544 gallons of groundwater have been pumped from this new Zone 3 extraction well network from January 2005 through the end of November 2012, and piped to the evaporation pond.

3.1.5 Evaluation of the Effects and Limitations of Zone 3 Extraction Well Pumping

Twenty-three years of remedial pumping have resulted in significant dewatering of Zone 3. One effect of this is 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 monitoring wells between the third quarter of 1989 and the fourth quarter of 2012. In previous versions of this table, values of saturated thickness greater than 25 ft were shaded. For the first time, in 2012, none of the monitored Zone 3 wells met this criterion (last year Well EPA 14 just barely met this threshold with a saturated thickness of 25.10 ft).

The saturated thickness measured in Zone 3 wells has declined by 75 percent on average since the third quarter of 1989. Figure 35 shows that between 1989 and the fourth quarter of 2012, 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 west-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 2012 “zero” saturation limit).

The effects of both the former and the present-day, reconfigured remediation pumping in partially, locally dewatering Zone 3 are presented in Figure 36. The figure marks the start of recovery pumping from the new well array installed during the hydrofracture study in April 2005.

The in-situ alkalinity stabilization study found that the seepage-induced alteration of feldspathic minerals is reducing the bedrock permeability. This tends to restrict the migration of tailings seepage. The main reason that the groundwater flows toward the north is that the Zone 3

bedrock unit dips toward the north. The hydraulic head that drives the flow comprises two components: the elevation head plus the pressure head. The long history of extraction pumping in Zone 3 has reduced the pressure head component of the total hydraulic head. However, it is not possible to reduce the slope-related elevation head – that is a driving force component that cannot be changed (N.A. Water Systems, 2008b). Continued pumping has been helping in the short-term as Figure 36 shows; however, the saturated thicknesses in this hydrostratigraphic unit are quite shallow and eventually there will be no further possible reduction in the pressure head. The effort to counteract the overall hydraulic head is gradually approaching practical limits as the well yields decrease. At some time in the future, seepage-induced permeability reductions will retard further northward migration of seepage-impacted water. The exact timing and location of the development of this critical balance cannot be predicted – but such a condition should inevitably occur.

Another way to look at the inherent difficulty of extraction pumping in the northern part of the seepage-impacted water is to note that along a 1200-ft long, west-northwest trending line of cross section located between Wells NBL 1 and PB 3, the total groundwater flux (without any pumping) was calculated to be 512 ft³/day (2.7 gpm) during January 2005 (N.A. Water Systems, 2008c), which is equivalent to the discharge from a home garden hose turned on low. This flux estimate will decrease with time approximately proportionally to the ongoing reduction of saturated thickness.

The revised Zone 3 pumping system has been declining in performance. Most of these wells have reduced yields that are below 0.5 gpm and RW 13 was taken off line due to low yields. The following physical factors controlled these declining yields:

- Encrustation along the wellbore of iron oxyhydroxides, carbonates, and/or gypsum;
- Precipitation of amorphous aluminosilicates (e.g., EPA 14);
- Alteration of feldspar to clays within the bedrock matrix; and
- Reduced saturated thicknesses.

Groundwater quality along the northern tracking wells has been oscillating between degrading and improving trends over the last 10 years. Individual well water-quality trends of improvement and degradation have become collectively asynchronous since May 2007.

UNC measures monthly field parameters in all five NW-series wells, and the alkalinity concentrations indicate the following: NW 1 is the most seepage-impacted and has the least saturated thickness; NW 4 shows lesser impact; NW 2 shows little to no impact; and NW 3 and NW 5 (not pumped in 2012) are predominantly background water and have the greatest saturated thicknesses. Note that NW 1 and NW 4 are the easternmost of these five new wells, and NW 3 and NW 5 are the westernmost. These observations are consistent with our general understanding that the seepage-impacted water is most prevalent towards the eastern limit of saturation; moving westward the prevalence of non-seepage-impacted water increases as does the formation's saturated thickness.

Consistent with UNC's original recommendations (N.A. Water Systems, 2008c) and a later update (Chester Engineers, 2009c), UNC adjusted the pumping regime along the NW-series wells to attempt to: (1) minimize the withdrawal of background water; (2) minimize any tendency for seepage-impacted water to be drawn westward; and (3) maximize the withdrawal of seepage-impacted water. As always, the goal is to strike the best balance between containing the seepage-impacted water while minimizing its transport to the more thickly saturated, but non-seepage-impacted parts of Zone 3. During November 9 and 10, 2009, the pumping regime was adjusted as follows:

NW 1 was left pumping at the current, maximum rate.

NW 2 pumping rate was reduced by one-half to ~ 0.5 gpm.

NW 3 was turned off.

NW 5 remains off.

NW 4 pumping was started at the maximum practicable rate.

On May 10, 2012 UNC applied another pumping adjustment because the yield from NW 1 had declined to critically low levels ($< 1 \text{ gpd} = < 6.9 \times 10^{-4} \text{ gpm}$) and this pump was shut off. To help compensate for this shutoff, in early June 2012 the pumping rate at NW 2 was increased from 0.5 gpm to 1 gpm.

All other non-NW-series pumping wells to the south will remain on. UNC continues to evaluate the chemistry and water levels in all these wells, which may result in further modifications to the pumping rates to iteratively re-optimize the extraction system operations.

3.1.6 Injection Well Feasibility Testing and Pilot Study

Injection well feasibility testing, and its historical context, has been discussed in the 2009, 2010, and 2011 annual reports (Chester Engineers, 2010a; 2011a; and 2012b). The first injection testing was in background well NBL 2 (Chester Engineers, 2009d). The second injection testing was in the pilot injection well, IW A (Chester Engineers, 2010b).

On April 14, 2011 injection of water amended with sodium bicarbonate started at Zone 3 Well IW A (Chester Engineers, 2011e). The objectives of the injection were to (1) amend the injected water with alkalinity (sodium bicarbonate) to locally buffer and geochemically stabilize the seepage-impacted water, (2) redirect the seepage-impacted water into the capture zones of the northernmost extraction wells, (3) extend the life of the extraction wells by arresting the drawdown, and (4) provide a hydraulic barrier to the northerly advance of seepage-impacted groundwater. The sodium bicarbonate was added to water in a mixing tank at the concentration of 2 grams per liter (equivalent to 16.6 pounds per 1,000 gallons of water). Prior to injection the water level at this location was approximately 191 ft below ground. During injection the operations staff has varied the injection rate causing water levels to vary from approximately 12 ft to 50 ft below ground. More details on the injection and nearby pumping are provided in Chester Engineers (2011e).

The injection capacity at IW A declined over time. In late June 2012 the capacity had declined to ~ 0.2 gpm (288 gpd) and it became very difficult to meet the target level for the well water level being adjusted to be between 10 ft and 20 ft below ground. On June 29, 2012, the injection at IW-A was terminated for this reason. Through this date, a total of 426,363 gallons of water had been injected.

The observed increase in uranium concentration at monitoring Well MW 6, from 0.082 mg/L in July 2011 to 0.321 mg/L in July 2012 (see Table B.1), provided an additional important reason to terminate the injection of alkalinity. As discussed by GE (2012a) there are two possible explanations for the increase in uranium concentration:

- The remedial system is drawing-in background water (post-mining/pre-tailings) which contains higher uranium concentrations than either the MCL or seepage-impacted water (N.A. Water Systems, 2008f, 2008g). It appears that background water in this area is gradually being drawn to the east by the pumping – this explanation is bolstered by comparing the two uranium isoconcentration maps for Zone 3 in GE (2012a); this issue is discussed further in Section 3.4.
- The uranium increase could also be due to the influence of the sodium bicarbonate (NaHCO_3) amended water that has been injected at Well IW A. The concentrations of sodium and bicarbonate at MW 6 were significantly higher in the July 2012 sampling results. In the October 2012 sampling results the uranium, sodium, and bicarbonate concentrations (and some other parameters) had reduced significantly, indicating that post-injection re-equilibration of the groundwater quality here has occurred quite quickly.

Some combination of both reasons likely explains the uranium concentration data, and because the relative contribution of each cause is unknown, it was prudent to permanently discontinue the injection of alkalinity-amended water.

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).

As previously discussed, a relatively recent phase of extraction well pumping that originated with the hydrofracture program has continued to present. Table 8 shows the estimated mass removal by this pumping from December 2011 through November 2012 (the similar Table 8 in the 2011 Annual Report showed data through November 2011); the RW-series extraction wells (and converted pumping well PB 2), and the NW-series extraction wells, are shown on Figure 37 and Figure B-1 in Appendix B. The recovered masses were estimated by multiplying the volume of groundwater pumped by the estimated concentration of each constituent in the pumped water. The constituent concentrations were estimated from concentrations measured in groundwater samples taken from the extraction wells and nearby monitoring wells during October 2012.

Table 8 shows the total volume of groundwater extracted from wells over this time period was 1,227,526 gallons.

3.3 Performance Monitoring Evaluation

The current Zone 3 performance monitoring program is summarized in Table 9 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 35) was selected to both bound the downgradient extent of the seepage-impacted water and function as a tracking well.

To supplement the performance monitoring program, four monitoring wells were installed (June 2002) between Wells 504 B and NBL 1: from south to north they are PB 1, PB 2, PB 4, and PB 3 (Figure 35). 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. Well PB 1 was installed within seepage-impacted water and was thence excluded from monitoring of the advancing front.

During August 2007, a new tracking monitoring well (NBL 2; 187 ft deep) was installed approximately 400 ft to the west-southwest of NBL 1 (see Figure 35). Monthly water levels and field water quality analyses (pH, specific conductance, chloride, and alkalinity) have been collected from the tracking wells. Monthly field parameter monitoring of Well NBL 2 started in January 2008; at that time, Well 504 B was removed from the monthly tracking list because it has been fully seepage-impacted for many years (and starting in January 2011 water levels in 504 B have become too low to allow sampling). Well PB 2 was converted to an extraction well in November 2005 to complement the RW-series pumping wells in the northern area of the seepage-impacted water. Chloride and alkalinity are analyzed with Hach field-testing kits. Quarterly samples from these boundary tracking wells are submitted to a laboratory to check the field results (the laboratory analyzes TDS in lieu of specific conductivity). Based on these comparisons, the field parameters provide a good indication of the migration of the seepage-impacted water. As discussed later in this section, the new pumping array had resulted in three beneficial effects:

- Capture of most if not all of the northward-advancing seepage-impacted water (i.e., partial hydrodynamic control);
- Marked groundwater quality improvement and recession of the seepage-impact front to the south; and

- Dewatering and mass removal.

The groundwater quality improvement has proven to be temporary (discussed earlier in Section 3.1 Corrective Action Summary, and discussed further below). Pumping rates have declined and this is expected to continue because this has been the case for all other pumping wells in the past.

A new recovery well (RW A) started pumping during September 2007, approximately 400 ft to the southeast of NBL 2 (see Figure 37). This location was based on MACTEC's (2006) recommendation that fuller hydraulic containment was needed here (see their Figure 3.11).

As described earlier, five new recovery wells were completed along the northern front area of seepage impact (Wells NW 1 through NW 5; Figure 35). The rationale for these well locations was provided in UNC's hydrogeologic analysis and recommendations for new extraction well locations (N.A. Water Systems, 2008c), which was approved in letters from EPA, NRC, and NMED. Pumping of wells NW 1, NW 2, and NW 3 started in February 2009. Monthly field parameters and water levels have been measured in all five NW-series wells since June 2009, and in August 2011 UNC started to collect monthly field parameters in MW 6 and MW 7 (in addition to continuing to measure monthly water levels).

Though not a formal part of the performance monitoring program, to improve our understanding of the groundwater quality along the northern front of the seepage-impacted water in Zone 3 the following additional wells were sampled in 2012 for the full laboratory chemical parameter list: RW A (October only), RW 11, NBL 1, NBL 2 (October), PB 2 (October), PB 3 (October), and PB 4 (October). To serve as a check on the results of the monthly field parameter measurements, the following wells in the northern part of Zone 3 were sampled for laboratory analysis of bicarbonate, chloride, pH, and TDS: RW A, NBL 2, PB 2, PB 3, PB 4, NW 1, NW 2, NW 3, NW 4, NW 5, MW 6, and MW 7. Field parameter measurements and laboratory measurements are generally in good agreement (though field pH tends to be more accurate than laboratory measurements of pH).

3.3.1 Water Level Evaluation

Water level data from 1989 through the fourth quarter of 2012 are presented in Appendix B. Water levels from October 2012 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 is similar to, though lowered from, those depicted in previous annual reports.

Figure 37 shows the locations of wells pumped during October 2012, and monitoring wells. Measured groundwater elevations were used to develop this potentiometric map, which shows a 5-ft contour interval. The pumping in Wells RW A, RW 16, and PB 2 are associated with southwestward deflection of the contour lines, and a cone of depression is suggested by the contours around RW 16. The pumping in NW 2 and NW 4 is associated with a strong southerly deflection of the 6800 ft contour, suggesting that groundwater flow lines here are strongly convergent toward this northernmost pumping.

Groundwater discharge into Pipeline Arroyo, associated with historical mining operations, ceased in 1986. Since then, Zone 3 groundwater flow directions became more generally north-northeasterly as recharge from, and groundwater mounding within, the alluvium to the southwest and west has steadily decreased (Chester Engineers, 2012g). The earlier east-to-northeast flow direction caused the distribution of groundwater impacts that was the original basis for delineation of the Zone 3 Remedial Action Target Area, as shown on Figure 35. Effects on the potentiometric surface from alluvium recharge (mine-dewatering groundwater discharge) have largely dissipated, and rates of water level change in Zone 3 are mostly very slow (excluding the influence of recent pumping and injection). Since cessation of groundwater discharge into Pipeline Arroyo, water levels have been declining. Pumping of extraction wells prior to January 2001 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. In October 2012, the collective average saturated thickness for all measured Zone 3 wells (Table 7) has reduced to approximately 11 feet.

Contours of saturated thickness during the fourth quarter of 2012 (Figure 38) show the combined effects of former pumping, current pumping, injection, 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 2012. 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 former recharge area, have lost substantial saturation. For example, Well EPA 14 had 76 ft of saturation in 1989 and 23.6 ft in the fourth quarter of 2012 (a 69 percent reduction in the saturated thickness; see Table 7). Table 10 shows the saturated thickness in each Zone 3 well during October 2012. From 2002 through 2012, 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. Pumping has removed more than 14 million gallons from 2005 through 2012.

The southwest part of Figure 35 shows the approximate contact area between the alluvium and the top of Zone 3. Former versions of this figure have shown an inferred area of saturation along this contact area (e.g., see Figure 35 in the 2008 annual report). N.A. Water Systems' (2008c) analysis of the groundwater flow through Zone 3 indicated little or no contribution from other sources (e.g., alluvium) than the ongoing self-drainage. There was very little flow crossing the southern, east-west directed cross section line near Well 613 (op cit, Figure 7), which is 1,642 ft long: the flux here in January 2005 was estimated to be 723 gallons per day (0.5 gpm). Chester Engineers (2011d) summarized the lack of empirical evidence for discernible recharge into Zone 3. However, accounting for episodic recharge via streambed infiltration was found to benefit the calibration of the numerical flow model in the accuracy of its simulation of Zone 3 piezometric heads. Without such an accounting the model simulated a decline of the Zone 3 piezometric surface that exceeded that measured over the past 12 years (Chester Engineers, 2012g). The basis for this interpretation of Zone 3 recharge remains theoretical rather than empirical.

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

The temporary saturation caused by the infiltration of groundwater discharged into Pipeline Arroyo, during mining activities, is considered the background water for Zone 3 (EPA, 1988a; 1988b; 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 have 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 seepage-impacted water that extends off the property into Section 1 (Figures 6 and 35) was eliminated as a point-of-exposure (POE) because of limited saturation. The decision to eliminate this area as a Zone 3 POE is documented in a letter from the NRC (1999b).

It is important to recognize 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 (see Section 3.3.4). Statistical analysis of Site background water quality, using EPA's preferred ProUCL software, has been presented by UNC (N.A. Water Systems, 2008f) during revisions to Part I of the SWSFS.

The following criteria have been used to distinguish background versus seepage-impacted groundwater quality in Zone 3:

- pH < 5 and bicarbonate < 100 and > 500 mg/L are useful (but not always definitive) indicators of seepage impact (see the Technical Memorandum (GE, 2000)). N.A. Water Systems (2008f, Figure 1) presented box-and-whiskers plots of bicarbonate and pH for the background wells. Seepage-impacted water with a pH < 5.0 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 CaCO_3 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).
- In non-seepage-impacted areas, background water has approximately reached equilibrium with the carbonate minerals resulting in bicarbonate concentrations ranging from approximately 100 to 500 mg/L.

- Time-series of these two indicator parameters are very helpful (sometimes essential). See N.A. Water Systems (2008f, Appendix A) for time-series of pH and bicarbonate for the background wells.
- Time trends in the concentrations of major ions; in particular, decreasing ratios of Ca/Mg are associated with degrading groundwater quality (see Appendix B; e.g., Well EPA 14).
- Zone 3 time trends in the concentrations of many metals and radionuclides will usually increase as the water quality degrades from background to seepage-impacted (see Appendix B; e.g., Well EPA 15).

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 and 411), and (3) the northern tracking wells. Table 11 presents the monthly field parameter measurements for the northern tracking wells (from south to north: Wells RW A, PB 2, PB 4, PB 3, and NBL 2 and NBL 1). (The quarterly laboratory analytical results are provided in the back part of Appendix B.) Table 12 presents the monthly field parameter measurements for the newer NW-series of wells (these measurements started in June 2009).

Bicarbonate time-series for all the Zone 3 wells are shown in Figure 39, while Figure 40 focuses on the northern tracking wells. Evaluation of these data indicates that bicarbonate concentrations at Well PB 4 have shown unusually large variations since December 2007 and since then the groundwater quality trend in PB 4 has overall been degrading; since November 2009, bicarbonate has been nondetect, and field pH < 3.

Historic groundwater quality data (see Appendix B) from fully seepage-impacted wells indicate that it takes from one to three years, from the onset of geochemical changes associated with the arrival of seepage-impacted groundwater, for full seepage-impact to develop (unless the constituent transport is effected by pumping). In discussing Table 11 in the 2005 annual report, it appeared that the development of full-stage seepage impact was imminent at Well PB 3 (i.e., it appeared likely that bicarbonate would very soon fall to levels persistently below 50 mg/L, accompanied by a subsequent decrease of pH to below 5.0). This is shown on the bicarbonate time-series charts in Figures 39 and 40 (it should be noted that the bicarbonate values plotted in these charts are those derived from *laboratory* analyses of the quarterly monitoring samples; see the laboratory analytical summary sheets in the back of Appendix B). The northern limit of seepage impact on Figure 35 of the 2005 Annual Report was shown passing through Well PB 3, because of the duration of bicarbonate decrease at this location, culminating with the bicarbonate value of 51 mg/L in October 2005. Subsequently (see Table 11, which includes the monthly *field* bicarbonate measurements from the northern tracking wells), bicarbonate at this location decreased during November and December 2005, but then started to increase during January 2006 – it continued to increase to October 2007 and then it very strongly fluctuated through April 2010, and since then it has been relatively stable. These water quality changes are interpreted as being caused by the revised pumping program that started in April 2005. The sharp increase starting in January 2006 represents an abrupt reversal of the long-term declining bicarbonate

concentrations at this location since well monitoring started in October 2002 (Table 11). During 2012 the bicarbonate concentrations have been relatively stable (219 mg/L in October).

Since the beginning of the new Zone 3 pumping scheme in May 2005, bicarbonate in PB 2 started to decline in September 2007 and fell to 0 mg/L in January 2008. The bicarbonate level here quickly increased and was 63 mg/L in October 2012.

Since October 2007, Well NBL 1 has shown unusually large variations in bicarbonate concentrations. From the most recent high of 198 mg/L during November 2009, the bicarbonate concentration fell to 0 mg/L in April 2010, and this concentration persisted through October 2012 (with infrequent detections, as high as 103 mg/L in January 2011; see Table 11 and Figure 40). A similar range in bicarbonate concentrations in Well PB 3 occurred over this same time frame (though the large variations were sometimes asynchronous to those in NBL 1).

Field pH values confirm the presence of strongly seepage-impacted water quality along Wells NBL 1 (2.73 during October 2012) and PB 4 (2.55 during October 2012). However, between these two well locations, along Well PB 3 the pH has remained relatively elevated (6.38 during October 2012) – see the posted pH values in Figure 35.

Collectively, these bicarbonate measurements in the northern tracking wells indicate that the groundwater quality is highly heterogeneous on the local scale of the related well array. The noted asynchronous changes of bicarbonate concentrations in the northern tracking wells indicates the seepage-impact front is proximal to the wells, and the geochemistry is dynamic due to the effects of pumping that started in September 2005. Field parameter measurements in the NW-series of wells provide the northernmost information on water quality. Table 12 presents the monthly field measurements of bicarbonate and pH. Figure 35 shows the location of the northern edge of the seepage-impact front during October 2012 at Well NBL 1. Table 13 explains the basis for selecting NBL 1 as the “end point well” of full seepage impact shown in Figure 35.

The groundwater quality in the NW-series of wells, MW 6, and MW 7 (e.g., see pH values in Figure 35), is consistent with the inference that highly seepage-impacted water has not “broken through” to the north of NBL 1. The depicted northern limit of seepage impact has had this same location for several years and it appears that pumping of the NW-series has provided some hydraulic benefit (though it cannot be demonstrated that full containment has been achieved).

Until the cessation of groundwater discharges to Pipeline Arroyo 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 and then very likely ceased, 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 (GE, 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.

The acidic “core” of the seepage-impacted water is shown in Figure 35 with the 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. Note that the pH shown for Well PB 2 (5.90) is significantly higher than that shown a short distance to the north for PB 4 (2.55); and a short distance to the north of PB 4, Well PB 3 had a pH of 6.38 in October 2012. To the north of PB 3, the pH again drops off sharply to 2.73 at NBL 1. This relatively large pH variation over short distances is inferred to be another effect of the pumping. That effect is interpreted to be the capacity of pumped wells to locally draw background quality groundwater into areas of seepage impact.

Well EPA 14 is fully impacted by tailings seepage (see Appendix B and Table 14). The EPA’s Second Five-Year Review Report (EPA, 2003, Figure 6-7) presented Stiff diagrams for Well EPA 14 in annual “snapshots” of water quality from October 1998 through October 2002 (these were also presented in GE, 2012c). Before October 2000, the calcium-to-magnesium (Ca/Mg) ratio was greater than one and the earlier bicarbonate concentrations were consistent with background water quality but then they became elevated (see Figure 39); from October 2000 to October 2002, the Ca/Mg ratio was less than one and bicarbonate became depleted. Modest exceedances of the aluminum and cobalt standards in Well EPA 14 began in 2000, when the bicarbonate concentration decreased suddenly and sharply. Figure 40 shows that the bicarbonate at this location fell sharply to nondetect (zero) in July 2001, then increased to 188 mg/L in October 2004, and then fell to nondetect again in October 2006. When the bicarbonate “comes off the floor” for either a short or extended period of time, this is interpreted as due to occasional mixing with background water (which is presently located nearby to the west; see Figure 35 in this report and also Figures 6-9 through 6-11 in EPA, 2003, which are also presented in GE, 2012c). However, since October 2006 the bicarbonate here has remained at nondetect levels.

The EPA (2003, Figure 6-8) also presented Stiff diagrams for ten Zone 3 wells based on October 2002 sampling (this figure was also presented in GE, 2012c). The following discussion refers to the Stiff diagrams shown in EPA’s (2003) Figure 6-8, while also providing updates on specific changes in water quality through October 2012.

The first chemical measurements in Well NBL 1 were made in August 2001 (Appendix B), when the calcium-sulfate type of water was representative of background water quality. Subsequently, early stage seepage impact was shown by the gradual reduction of the Ca/Mg ratio from 2001 through October 2005 (Appendix B) and the beginning of decreasing bicarbonate concentrations during approximately April 2004 (Appendix B, based on laboratory determinations of bicarbonate) and June 2004 (Table 11, based on field kit determinations of bicarbonate). Appendix B shows that starting in January 2010 NBL 1 has shown significant increases in cobalt (0.94 mg/L in October 2012), nickel (1.23 mg/L in October 2012), and aluminum (43.4 mg/L in October 2012); considered with the 2012 nondetects for bicarbonate and pH values frequently less than 4, these data indicate that the water quality here is strongly seepage-impacted (though ~ 100 ft to the south at PB 3, the water quality is notably better). These closely spaced, large

variations in groundwater quality are attributed to the effects of extraction well pumping in their vicinity, which causes variations in the proportion of seepage-impacted versus non-seepage-impacted water that reaches the wells. *Monitoring of the northernmost part of Zone 3 in Section 36 indicates that this area is a complex zone of mixing of background and seepage-impacted water, rather than a singular advancing plume edge with a “sharp line” boundary.*

Invariably, some wells (or certain time spans at some wells) are difficult to classify because their groundwater chemistry tends to be gradational. For example, the geochemistry associated with Well 420 has long been considered to be “borderline” between background and seepage-impacted water quality which is consistent with its location between the area of formerly perennial alluvial recharge and that of tailings seepage. Samples from this well, located along the western edge of the seepage-impacted area in Figure 35, indicate a calcium-sulfate type of background water. Combined radium in this well has fluctuated above and below the Site standard from 1989 through July 2007, after which it has persistently been above the standard – this may reflect the flux of geochemically heterogeneous background water or seepage-impacted water (e.g., N.A. Water Systems, 2005b). Over the one-year period from April 2006 to April 2007, bicarbonate dropped from 781 mg/L to 237 mg/L. Since October 2007, uranium has persistently been greater than 0.27 mg/L for the first time in this well’s monitoring history (which started in 1989; see Appendix B), and since January 2010 uranium exceeded the Site standard of 0.3 mg/L (although pH at this location does not indicate impact). The calculated UCL95 of the mean for background water uranium is 0.107 mg/L (range of 0.0007 to 0.38 mg/L), which is higher than the UCL95 of the mean calculated for the exposure point concentration (representing seepage-impacted water) of 0.043 mg/L for uranium (range of 0.0011 to 0.138 mg/L) (these values are from N.A. Water Systems (2008f) and (2008g), respectively). (UCL95 refers to the upper confidence limit on the mean at the 95% confidence level.) These observations are interpreted as indicating that the groundwater quality is “borderline” between background and seepage-impacted, that the seepage-impacted region is nearby, and that the groundwater quality may be degrading very gradually (though the magnesium concentrations have been approximately stable during the entire monitoring history).

Well 717, near the western edge of the seepage-impacted area in Figure 35, provides a third example of a calcium-sulfate type of water that was interpreted as predominantly background (largely non-seepage-impacted) in 2002, but has subsequently become increasingly impacted. Starting during 2006, exceedances for cobalt, nickel, and gross alpha have occurred. Bicarbonate concentrations attained a maximum of 740 mg/L in July 2002, and subsequently decreased to nondetect to present (Appendix B). This sharp decline is similar to that observed in Well EPA 14 (see Figure 40) and is interpreted to represent exhaustion of the local buffering capacity. The comparative water quality of 717 and EPA 14 are discussed further in Section 3.3.4.

The other seven wells depicted with Stiff diagrams (EPA, 2003, Figure 6-8) represent seepage-impacted magnesium-sulfate types of waters. For example, in October 2012 (see Appendix B) upgradient Well 613 (in the southwestern part of the seepage-impacted area shown in Figure 35)

showed a very high sulfate concentration, Ca/Mg ratio less than one, nondetect bicarbonate, chloride concentration 142 mg/L, pH 2.88, and exceedances for most parameters except several metals, lead, and some of the major ions.

3.3.3 Rate of Seepage Migration

Table 13 summarizes the key factors, locations, and criteria underpinning the past calculations of northward seepage travel times for Zone 3. As discussed in the 2006 annual report (N.A. Water Systems, 2007a), during that year the seepage-impact front was inferred to have receded from Well PB 4 to PB 2 as a consequence of pumping of RW 11, RW 12, RW 13, and PB 2. In 2007 (N.A. Water Systems, 2008a), the location of the northern edge of seepage impact was inferred to have remained unchanged. In 2008 (Chester Engineers, 2009a), the leading edge of impact was inferred to have migrated from PB 4 to PB 2; as Table 13 shows, this same specific advance had previously occurred from April 2003 to February 2004. Such a repeated advance, covering the same ground locations, reflects the pumping-related hydraulic “tug of war” occurring in the vicinity of the northern tracking wells. With the advent of pumping from the northern, NW-series extraction wells in February 2009, the older northern tracking wells became subject to influences from upgradient and downgradient extraction wells. The purpose of the upgradient wells (e.g., the RW-series wells) is primarily to dewater and recover contaminant mass, while the purpose of the downgradient wells (e.g., the NW-series) is to form a hydraulic barrier. The original purpose of calculating seepage-impact migration velocities for Table 13 equivalents, as a basis of predicting the progression of the impact reaction front, has been rendered moot by the designed actions of these extraction wells.

Since the beginning of field measurements in the PB-series northern tracking wells (October 2002), the inferred northern edge of full seepage impact had not shown a northward advance beyond Well PB 3 (refer to the related map depictions in Figure 35 the Annual Review Reports for 2002 through 2007) until 2009.

Figure 35 shows the location of the northern edge of the seepage-impact front during October 2012 at Well NBL 1, which is the same location depicted in 2011. As explained in the lower block of Table 13, full seepage impact has occurred at PB 4 since November 2008, but to the north of this well there is no unequivocal basis for selecting a single location representing the leading edge of moderate seepage impact. This reflects the influence of pumping. Table 13 explains the basis for selecting NBL 1 as the “end point well” of seepage impact shown in Figure 35. The time-space variations in groundwater quality, especially the key bicarbonate and pH parameters, indicate that over the last four years or more, there is no clearly defined northern edge of seepage impact that is consistently advancing northward. Rather, over this time period the northern area of seepage impact has been a mixing zone that is largely contained by the NW-series extraction.

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 groundwater

discharge associated with historical mining operations that ceased in 1986), 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.

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) an overall 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. Shutoff of the remaining Stage II wells in 2000 enhanced the effectiveness of the natural attenuation processes in many parts of the seepage-impacted area.

The impact of natural attenuation of seepage impacts by geochemical processes is discussed for individual constituents in Zone 3 (Table 14) below.

Sulfate and TDS

Figure 41 is a graph of sulfate concentrations from 1989 through 2012. Concentrations are relatively high closest to the tailings impoundment (i.e., Well 613 shown on Figure 35 as compared to every other Zone 3 well). As in the Southwest Alluvium, sulfate concentrations are controlled by geochemical equilibrium with gypsum (or anhydrite) and calcite. Although very high sulfate concentrations were present in the tailings fluids, such sulfate concentrations attenuate rapidly downgradient. Over the entire monitoring history since 1989, sulfate concentrations overall have remained steady. Moreover, there is a complete overlap between the range of sulfate concentrations in seepage-impacted and background water (except for Well 613). The marked stability of sulfate in all wells, throughout the duration of remedial pumping and in the absence of such pumping, demonstrates that sulfate concentrations are determined exclusively by the geochemical equilibria between natural minerals and waters rather than remedial operations.

Earth Tech (2002d, Figure 3-13) demonstrated that sulfate concentrations decreased by about 85 percent between the North Cell and the seepage-impacted water at Well 613 via precipitation of gypsum (the saturation index of virtually all water samples with respect to gypsum hovers around unity).

It necessarily follows that 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 (i.e., gypsum can dissolve as well as precipitate to maintain the equilibrium concentrations). TDS also will continue to exceed the Site standard because sulfate comprises most of the TDS (as in the Southwest Alluvium and Zone 1).

Metals and Basis for Request for Revision of ROD Background Concentrations

Figures 42A and 42B are time-series graphs of concentrations of metals that exceeded the Site standards in any Zone 3 well whether it represents background or seepage-impacted water.

Included are: aluminum, beryllium, cadmium, cobalt, manganese, molybdenum, and nickel (the metals uranium and vanadium are discussed later with the radionuclides). There were no arsenic exceedances during 2012, but an arsenic chart is included in Figure 42B because we have included it in previous years.

UNC supports the need to revise the ROD background concentrations for some of these constituents including arsenic, molybdenum, cobalt, and nickel (similar to the NRC revision in 1996 for the background standards for sulfate, nitrate, and TDS). The reasons are 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 (now seepage-impacted), while very low to nondetect concentrations are found in most seepage-impacted wells, including the most impacted well, Well 613 (see Table 14 and Figure 42B).

April 2010 through July 2011 sample results showed exceedances of arsenic in Well NBL 1. It was below the standard during all of 2012. Arsenic exceedances between approximately 0.5 and 1.0 mg/L from 2001 to 2004 were associated with background water – the more recent, seepage-impacted water quality in Well NBL 1 is better than non-seepage-impacted water in regard to arsenic concentrations. Well NBL 1 also exceeded the standard for molybdenum when it exhibited background water quality, but not after it exhibited seepage-impacted water quality.

UNC has calculated background concentrations as the 95th percentile upper prediction limits (UPL95s) for the constituents having NRC License GWPSs (UNC, 2012) and ROD cleanup standards (Chester Engineers, 2012e). UPL95s statistically represent an estimate of the background threshold values in the upper tail of the groundwater quality data distribution. A License amendment request to use UPL95s as the appropriate value by which to judge whether or not any given water analysis can be distinguished from the background population was submitted to NRC in April 2012 (UNC, 2012; GE, 2012b).

Metals in Seepage-Impacted Waters

Well 613 is located near the center of the seepage-impacted area, closest to the source area, where pH has ranged from 2.76 to 3.24 since this well was first monitored in 2000. This well shows the highest metals concentrations during October 2012 for cobalt, cadmium, beryllium, nickel, manganese, and aluminum.

Figure 43 is a map showing the extent of aluminum concentrations exceeding 5 mg/L based on October 2012 sampling. This map distribution pattern has been approximately constant over time, regardless of an active remedy or not. The map illustrates that the distribution of aluminum exceedances was largely restricted to the southwestern part of the seepage-impacted area. Two isolated outlying areas of elevated aluminum concentrations are depicted to the north near Wells PB 4 and PB 2, and NBL 1.

All wells sampled in October 2012 within the seepage-impacted area continued to show exceedances of manganese, cobalt, and nickel, except Well 420, which is near the northwestern edge of seepage impact (Figure 35) and shows borderline seepage-impacted/background water quality. Well NBL 2 did not show an exceedance of manganese, and cobalt and nickel were nondetects in this background well (Table 14).

The depletion of neutralization capacity has stabilized the concentrations of metals at higher levels in some wells. For example, concentrations of beryllium, cobalt, nickel, manganese, and aluminum stabilized at elevated levels in Well 717 between October 2008 and July 2009.. This commenced as bicarbonate concentrations approached nondetect levels in October 2008 (and remained nondetect after January 2009). The same process occurred earlier in Well EPA 14, which is 330 ft upgradient of Well 717. The concentrations of most metals increased in Well EPA 14 after May 2000, when bicarbonate concentrations declined precipitously (Figure 39). The concentrations of these metals stabilized after July 2006, when the neutralization capacity was exhausted (as evidenced by the absence of detectable bicarbonate).

Uranium, Vanadium, and Radionuclides

Figure 44A presents graphs of the concentrations of uranium, vanadium, combined radium, and thorium-230 from 1989 through 2012. Combined radium concentrations exceed the Site standard for Zone 3 (5 pCi/L) in the background water; consequently, radium concentrations in Zone 3 are never expected to reach the standard. Combined radium in Zone 3 background groundwater is estimated to have a mean (UCL95) concentration of 10.66 pCi/L. (N.A. Water Systems, 2008f, Table 5). This is exemplified by combined radium concentrations at well NBL 1 (Figure 44A). From its installation in 2001 through approximately July 2005, combined radium concentrations at NBL 1 were approximately steady and above the Site standard; this period is interpreted as representing mostly background water quality. Since that time and the onset of seepage impact, the overall trend had been increasing but in 2012 the range of fluctuation was very high (11.5 to 65 pCi/L). The October 2012 concentration (11.5 pCi/L) is the lowest value since January 2005.

Historically, uranium, vanadium, and thorium-230 are typically present above the standards in Well 613, which has almost always had the most acidic pH (2.88 in October 2012) and is closest to the source. Downgradient toward the northeast, natural attenuation reduces the concentrations of these three radionuclides in Well 708 (pH of 3.54 in October 2012). These radionuclides are attenuated by neutralization, adsorption, or possibly precipitation. Accordingly, much lower concentrations are reported where the pH is more neutral.

In October 2012, exceedances of standards for these three constituents were primarily in samples collected from Well 613 (though Well 420 exceeded for uranium and PB 4 exceeded for thorium-230 and uranium; see Table 14). The longer-term pattern of uranium at Well 613 has been a decreasing trend. The concentration in October 2012 (0.989 mg/L) was higher than the calculated UCL95 of the background mean (0.107 mg/L; N.A. Water Systems, 2008f). Downgradient from this well, uranium in seepage-impacted water attenuates quickly, and it

attenuates to concentrations that are within, or less than, the background water concentration range.

The geochemistry of the background water (of post-mining/pre-tailings age) that seeped into the ground was heterogeneous, and it is often inherently difficult to unequivocally infer that seepage-impacted water, rather than high-concentration-bearing background water, is responsible for the pattern of exceedances at many locations. The range of uranium concentrations in Zone 3 background water is higher than the range in seepage-impacted water (discussed further in Section 3.4).

Figure 44B shows uranium isoconcentration maps from October 2002 and October 2012. The contour pattern along the northwest part of the plume (approximately between Wells 717 and NBL 1) may be interpreted as due to background water being drawn in, from west to east, to seepage-impacted water, under the action of former and current pumping. NBL 1 had a higher uranium concentration in October 2002 (0.251 mg/L) when the water was background (seepage impact reached this well in January 2004) – in October 2012, under seepage-impacted conditions, the concentration was lower (0.189 mg/L). Well 420 has long been classified as having water quality transitional between seepage-impacted and background. In October 2002 the uranium concentration here (0.0779 mg/L) was significantly lower than the concentration in October 2012 (0.388 mg/L), and the contour pattern suggests that this higher concentration water did not migrate from northeasterly-directed flow. Instead, one may infer that the higher concentration was due to incursion of background water located to the west of this well.

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 seepage-impacted wells (except Well 613, which shows smaller fluctuations). The gross alpha Site standard of 15 pCi/L was not exceeded in October 2012 (Table 14 and Appendix B). Since October 2004, Well 719 has remained below the standard. EPA 14 showed exceedances in January and July of 2011. Well EPA 14 has demonstrated a distinctive pattern of gross alpha concentrations compared to all other seepage-impacted wells (see Appendix B). Since 1989, the values had 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 quarters 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 has been followed by the relatively large range in combined radium (Figure 44A). Background Well NBL 2 has shown persistent exceedances of combined radium.

Total Trihalomethanes (TTHMs)

TTHMs were detected above the Site standard in only Well 613 during October 2012 (see Figure 45). The concentrations in Well 613 have exceeded the TTHMs Site standard of 80 µg/L since October 2002, consistent with this well's proximity to the tailings source (see Figure 35). Well 613 concentrations have shown long-term fluctuations but increased by a factor of four from July

to October 2002. Since then the concentrations have shown relatively large fluctuations that are superimposed on an overall decreasing trend.

Detectable TTHMs are present, but below the GWPS, in Wells 517 (7.52 µg/L chloroform in October 2012), EPA 14 (0.66 µg/L in October 2012), and 717 (3.48 µg/L in October 2012). Well 717 first showed chloroform detection in July 2008, and it has shown 10 consecutive quarters of very low concentrations through 2012 (Appendix B). These are the first repeated detections of chloroform downgradient of Well EPA 14, and these observations support the inference that fully-seepage-impacted water has migrated downgradient from EPA 14 to 717. Well 518 also consistently showed chloroform detections until it ceased being sampled in 2000 (Appendix B). All other Zone 3 wells have shown historic nondetects for chloroform and, since the fourth quarter of 2006, TTHMs. This indicates that groundwater to the northeast of Well 517 rapidly attenuates chloroform by degradation, dispersion, and dilution, to levels that are generally nondetect but are otherwise always far below the Site standard (which is equivalent to the primary drinking water standard).

Pb-210

Table 14 shows that there were eight detections of Pb-210 during October 2012. The 2012 concentrations vary from 1.1 (Well 711) to 3.4 pCi/L (Well NBL 1). At least three issues are important to consider in the context of regulatory compliance with the NRC GWPS of 1 pCi/L:

- The quantitative analytical errors (reported as precision errors) associated with each sample's result indicate that some of the results are statistically not exceedances;
- The analytical results as reported have a confidence level (also called the combined standard uncertainty) of 2σ (2 standard deviations, equivalent to a 95 percent confidence level) and, as such, the results are tied to probability functions; and
- Accepting the results at face value indicates that they fall within the range of background water concentrations (provided just below).

Background water quality statistics for Pb-210 in Zone 3 have been presented by UNC (N.A. Water Systems, 2008f, Table 5). 186 laboratory results that were analyzed had the following statistical parameters:

Percent nondetects = 69.5%

Minimum detected = 1 pCi/L

Maximum detected = 11 pCi/L

Mean of detected = 2.549 pCi/L

Median of detected = 2 pCi/L

Upper Confidence Limit of the mean at the 95% confidence level of the sampled population (UCL95) = 1.618 pCi/L.

The October 2012 detections are not inherently indicative of impact from the tailings seepage; they fall within the lower third of the range of 1 to 11 pCi/L defined by the minimum and maximum values associated with background water. The highest detection in October 2012 (3.4 pCi/L in NBL 1) is greater than the mean concentration calculated for background water. As discussed earlier, the water quality in NBL 1 during October 2012 is fully seepage-impacted (Table 14; Appendix B).

3.4 Analysis of the Efficiency of Seepage-Impacted Groundwater Removal by Pumping

During the annual technical meeting in Albuquerque (May 15, 2012), one of the UNC presentations (Chester Engineers, 2012c) addressed remediation and water quality in Zone 3. This presentation included a new conceptual and quantitative analysis of the efficiency of groundwater removal from the area of seepage impact by pumping. This analysis is briefly summarized in this section, and it addresses considerations for the continuation of the pumping program.

A new metric for pumping system performance derives from analysis of the efficiency of seepage-impacted groundwater extraction. The pumping efficiency is less than 100% because some proportion of background groundwater, from outside the seepage-impact area, flows to the recovery wells. The efficiency may be calculated by determination of the groundwater volume reduction within the Zone 3 seepage-impacted area, which is then compared to the total volume pumped. The volume reduction within the seepage-impacted area is calculated knowing the related change in head, area, and porosity. The total volume pumped is determined from Site records.

The following example compares the volume reduction within the seepage-impacted area, to the volume pumped, from 2004 to 2011:

Dates	Impacted GW Volume Reduction (gal)	Impacted or Mixed GW Volume Pumped (Total Pumped in gal)	Ratio of Impacted GW Volume Change to Total Pumped
2004-2008	5,078,167	7,959,941	0.64
2008-2011	2,258,048	3,680,280	0.61
2004-2011	7,336,215	11,640,221	0.63

The pumping efficiency is declining with time, i.e., more background water is pumped over time. The most recent time period shown, 2008-2011, has the lowest pumping efficiency (61%). As Zone 3 pumping continues, more background water flows eastward to replace (and possibly mix with) the seepage-impacted water volume removed by pumping, resulting in a lower pumping efficiency. This process of inducing progressively more background water into the recovery system has had the additional effect of increasing the uranium concentrations in this northwestern part of the plume because the background water has higher uranium concentrations than the seepage-impacted water (background uranium the range is 0.0007 to 0.38 mg/L with a

UCL95 of the mean equal to 0.107 (N.A. Water Systems, 2008f) – for Zone 3 seepage-impacted water the range is 0.0011 to 0.138 mg/L with a UCL95 of the mean equal to 0.0431 mg/L (the value for the exposure point concentration; N.A. Water Systems, 2008g)). Figure 44B shows Zone 3 isoconcentration maps for uranium in October 2002 and October 2012. The October 2012 map shows the geochemical influence of background water that has migrated to the east, into the northwestern part of the seepage-impacted area, to the north of Well 717.

All Zone 3 pumping well capacities decline over time. One important cause is loss of saturated thickness. It will not be possible to pump out all of the seepage-impacted water. The approximate efficiency of seepage-impacted groundwater removal by pumping is 60%, and the efficiency is expected to decline with time. UNC proposes using the pumping efficiency metric as a potential quantitative threshold for terminating pumping in Zone 3 in the future.

Drawing in background water toward the extraction wells will lead to increased concentrations of other parameters in addition to uranium (for example, molybdenum is at significantly higher concentrations in background compared to seepage-impacted waters). UNC believes that overall conditions are such that active remedial operations in Zone 3 are reaching the limits of their effectiveness. As a result, continued operation will be met with diminishing returns, and/or will adversely affect groundwater quality in some ways as was seen a decade ago with the former pumping system.

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 had 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 recovery 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 is summarized in Table 15. The program consists of quarterly monitoring of water levels in 15 wells and water quality in eight wells and has been in effect since the second quarter of 2000. At the request of EPA, in October 2012 two additional wells that are not part of the monitoring program were sampled for laboratory analysis: 617 and 619, which are both in Section 2 and proximal to the northeastern edge of the Central Cell.

4.3.1 *Water Level Evaluation*

Historic water level data for Zone 1 wells through October 2012 are presented in Appendix C. Water levels for the fourth quarter of 2012 are shown on the potentiometric surface map in Figure 46. Water levels through time are shown on Figure 47. Saturated thicknesses calculated from the October 2012 measurements in Zone 1 are presented in Table 16. This table shows that the Zone 1 hydrostratigraphic unit remains completely saturated 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). However, during 2012, most of the wells continued to show overall decreasing piezometric elevations (usually with small fluctuations), indicating that the Zone 1 potentiometric field continues to lower as groundwater drains downdip into partially saturated parts of this bedrock stratigraphic unit.

Changes of potentiometric elevations in updip and downdip wells indicate the broad pattern of the shift in the potentiometric field caused by groundwater drainage to the northeast in Zone 1. Groundwater levels in Well 504 A have risen gradually and may become fully saturated as groundwater migrates to this portion of the confined Zone 1 hydrostratigraphic unit (see Table 16; Figures 46 and 47; and Appendix C). Similarly, the slowly rising groundwater levels at downdip Wells 142, 143, and 412 represent 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, are a response to the continued flow of groundwater downdip into partially saturated parts of the system. Figure 47 suggests that the potentiometric levels in Wells 142, 143, and 412 may have stabilized and are no longer increasing. Continued monitoring will clarify this issue.

Earlier groundwater flow in Zone 1 was approximately eastward, reflecting groundwater mounding and recharge from the borrow pits and the alluvium to the west. Since the dewatering of Borrow Pit No. 2 and termination of mine-dewatering groundwater discharge into Pipeline Arroyo, the former mounding has dissipated. Consequently, water levels in updip areas of Zone 1 have dropped significantly, though the rate of decline has reduced with the dissipation of recharge-induced mounding (see Figure 47). The rate of groundwater drainage is also limited by the unit's relatively low transmissivity, and the very low transmissivity of the underlying aquiclude.

UNC has submitted to NRC an ACL application for Zone 1 that presented a historic quantitative analysis of groundwater flow rates and directions (N.A. Water Systems, 2008h). In January 1983 the flow-direction azimuth (63°) had a strong easterly component. During later time periods the flow azimuth gradually rotated to the north, resulting in an azimuth of 24° during October 2007. This indicates that as the formerly higher groundwater mound has gradually continued to dissipate over the years, the northerly dip of the Zone 1 sandstone has exerted greater control on the flow direction. Darcy seepage velocities have gradually fallen through time. During January 1983, the groundwater velocity was 93 ft/yr, and by October 2007 the velocity had fallen to 40 ft/yr (a reduction of 57 percent).

EPA requested sampling of Wells 617 and 619 and the results are shown in Appendix Table C.1. Groundwater flow and transport are presently to the north in the vicinity of these wells. Multiple exceedances in 617 are consistent with its longstanding inclusion within the boundary of seepage impact. The water quality is somewhat better in 619, although this location showed October 2012 exceedances of manganese and nickel for only the second time (for each) since 1989, and the first exceedance of cobalt.

Both 617 and 619 are located relatively close to the northeastern margin of the Central Cell, and it is not surprising that they now show indications of impact. The most recent previous sampling of 619 was in January 2000, when the water quality was characteristic of background groundwater (N.A. Water Systems, 2008f). Comparing the October 2012 analytical results for Well 619, with the previous results from July 1989 to January 2000, shows that the October 2012 results have exceedances for cobalt (0.1 mg/L versus earlier, infrequent detections of ≤ 0.03

mg/L), manganese (4.91 mg/L versus ≤ 2.77 in the earlier time period), and nickel (0.27 mg/L versus only one earlier detection of 0.07 mg/L in January 1995). The October 2012 results for these three parameters may indicate that, between January 2000 and October 2012, seepage impact has migrated to this well location that was previously classified as having background water quality. In addition, the October 2012 pH in 619 (6.86 SU), the increasing alkalinity, and the increasing chloride are indicative of the well being in transition from background to seepage-impacted.

The seepage impact at 619 is likely to have been derived from the northeastern part of Borrow Pit 2 located approximately 375 ft to the southwest. However, flow is presently approximately northward and the seepage impacts are attenuated via reaction with the formation matrix. UNC has demonstrated (e.g., Chester Engineers, 2012g) that pre-mining (natural) groundwater in Zone 1 is encountered along the northern boundary of Section 36 in Wells (TWQ)-142 and (TWQ)-143; that this natural groundwater is overlain updip by post-mining/pre-tailings (background) water; and that the interface between these two types of groundwater is not migrating to the north. The natural and background waters would provide effective barriers to any potential Zone 1 COC transport to the north of Section 36.

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

The temporary saturation created by the infiltration of former mine-dewatering groundwater discharges is considered the background water for Zone 1 (EPA, 1988b; 1998). This anthropogenic groundwater was later seepage-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, and capping of the Central Cell), 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 2012. Table 17 summarizes the constituents detected in Zone 1 during October 2012.

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 ROD Site standard of 5 pCi/L (which NRC revised in 2006 to 9.4 pCi/L; NRC, 2006b). 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 degree of seepage impact is diminishing. Zone 1 seepage impacts have been delineated (Figure 48) by chloride concentrations greater than 50 mg/L (Earth Tech, 2000a). Well EPA 5 has shown a long-term, gradual reduction in chloride concentrations from a maximum of 289 mg/L

in April 1992 to 40 mg/L in October 2012 (and since April 2008, 18 of 19 values are less than 50 mg/L – refer to Appendix C).

The zone of seepage impact has migrated predominantly toward the northeast and the north-northeast. Further eastward components to migration are limited by the proximity of the eastern edge of saturation. The acidic “core” of the seepage-impacted zone is approximated by the area where pH is inferred to be less than 4.0 (orange area in Figure 48). Figure 49 shows historic field pH values for Zone 1 wells through October 2012. Well 604 has persistently shown the lowest pH; as discussed below, it also is the most highly seepage-impacted well. However, this well shows a long-term increasing trend in pH values (Figure 49). Figure 49 shows that starting in approximately 1990, acid neutralization and buffering resulted in substantial pH increases in Wells 515 A, 516 A, and EPA 7. However, during the last several years the water quality has been declining in 515 A (discussed below).

During October 2012 the following constituents continue to exceed the Site standards outside the property boundary in Section 1:

- TDS – Well EPA 7
- Sulfate – Wells EPA 4, EPA 5, and EPA 7
- Manganese – Well EPA 4

TDS, sulfate, and manganese are non-hazardous constituents. All of these constituents have generally exceeded standards at the cited wells since 1989. As discussed earlier, during August 2006 the NRC groundwater protection standard for combined radium in Zone 1 was revised to 9.4 pCi/L (NRC, 2006b). There were no exceedances of this standard in October 2012.

Within the Site property, the standards were exceeded for TDS, sulfate, and manganese (Table 17). Other constituents whose standards were exceeded onsite in October 2012 were: cobalt (Wells 604 and 619), nickel (Wells 515 A, 604, 617, and 619), and TTHMs (Well 515A and 614). During October 2012, Wells 515 A, 614, and 617 exceeded the chloride standard, as has frequently occurred at the first two locations since the start of monitoring during 1989.

The extent of seepage impacts, as delineated by a chloride concentration greater than 50 mg/L, has diminished gradually over time (e.g., compare 2008 annual report Figures 48 and 49, which show that the area of seepage impact contracted from 2007 to 2008). However, October 2012 sampling of Wells 617 and 619 (the first “spot” sampling here in many years) showed that both wells exceeded 50 mg/L and this has required modification of the boundary of seepage impact (Figure 48). The boundary now has been extended to the north by approximately 250 ft in order to include Well 619.

Many other aspects of water quality have continued to improve since shutoff, confirming that the degree of seepage impact is diminishing in both time and space. Natural attenuation processes include acid neutralization by:

- Reaction with the Zone 1 bedrock (which has a calcite (calcium carbonate) component of 0.03 percent (Canonie, 1987, Table 4.5));
- Mixing with the neutral background water;
- Precipitation of metals and radionuclides; and
- Adsorption of metals (excluding manganese) and radionuclides.

These processes attenuate pH, metals, and other seepage constituents. The relatively low transmissivity of Zone 1 slows migration and increases residence time for the attenuation processes.

Outside the UNC property boundary in Section 1, the post-pumping groundwater quality continues to improve overall (Tables 17 and 18).

During October 2012 there was one exceedance of a hazardous constituent outside the UNC property boundary: Well EPA 5 had a nickel concentration of 0.06 mg/L (the NRC License standard is 0.05 mg/L). This is the first exceedance at this location since October 2006. The exceedances of sulfate and TDS in Wells EPA 5 and EPA 7 reflect geochemical equilibrium of the groundwater with gypsum; these constituents are also non-hazardous. All of these constituents are discussed more below.

During the last several years the water quality has been degrading at Well 515 A. Field pH declined from 7.21 in January 2011 to 6.04 in October 2012; sulfate increased from 5060 mg/L in January 2011 to 6,160 mg/L in October 2012; and bicarbonate increased from 231 mg/L in July 2010 to 893 mg/L in October 2012 (a sharp increase). The increase in bicarbonate accompanied by the decrease in pH indicates that relatively acidic seepage-impacted water has moved through this location and the water is being buffered.

During October 2012 sampling of Well 619 both an unfiltered sample (collected by low-flow protocol) and a filtered sample were analyzed in the laboratory – the results for both samples are in the historic data Table C.1 in Appendix C. Both samples have very similar numeric results, indicating that the unfiltered sample collected using low-flow protocol is very representative of the filtered sample (the one exception are the results for aluminum which was nondetect (< 0.1 mg/L) in the filtered sample versus 0.5 mg/L in the unfiltered sample (the Site standard is 5 mg/L).

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-dewatering groundwater discharges), and the tailings fluids. The natural system is successfully attenuating the seepage impacts by the processes of neutralization, precipitation, adsorption, and a degree of passive mixing with the background waters. However, some constituents will remain at above-standard concentrations because of the inherent geochemical characteristics of the Zone 1 background water.

Table 18 shows the predicted geochemical performance of the Zone 1 natural attenuation system (revised from 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. Outside of Section 2, TTHMs have always met the Site standard and, based on trends, we fully expect that condition to continue. The individual constituents of concern are discussed below.

Sulfate and TDS

Sulfate concentrations exceed the Site standard in both the seepage-impacted water and the background water in Zone 1. Figure 50 shows historic sulfate concentrations through October 2012; Figure 51 shows the extent of sulfate exceedances during October 2012. The time-series indicate that the operation of extraction wells prior to July 1999 did not have a discernable influence on sulfate and TDS, because 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 (or elsewhere). As in the Southwest Alluvium and Zone 3, most of the TDS comprises sulfate (although other dissolved solids contribute significantly to the TDS in Wells 614 and EPA 7; see Appendix C)). Accordingly, TDS concentrations are not expected to meet the clean-up standards in Section 1 (or elsewhere), although they should gradually decrease to background levels. The UCL95 of the mean sulfate concentration in Zone 1 background water was determined to be 2,773 mg/L (N.A. Water Systems, 2008f); the ROD cleanup level is 2,160 (see multiple comparison values in op cit, Table 6).

Manganese

Manganese concentrations exceed the Site standard in both the seepage-impacted water and the background water (Well EPA 4) in Zone 1. Concentrations in the seepage-impacted water are usually 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 2012 are shown on Figure 52 and tabulated in Appendix C. The extent of manganese that exceeded the Site standard during October 2012 is shown on Figure 53. Figure 52 shows that the long-term decreasing trend in manganese in Well EPA 7, which started in January 1998, for the first time fell below the standard in 2006; in 2008 the concentrations began to slowly increase and small exceedances occurred but manganese remained below the standard during all four quarters of 2012 (concentration of 1.89 mg/L in October 2012). Well 604 continues to show a decreasing trend in manganese that started in January 2004, and Well 515 A has shown a sharp decline from 13.1 mg/L since July 2009 (Figure 52). In October 2012 the concentration in 515 A was 8.12 mg/L. This decline is very likely related to the substantial increase in bicarbonate concentrations at this location since July 2010.

Bicarbonate concentrations in seepage-impacted wells are related to the waters' degree of neutralization of acidic seepage. Figure 54 shows historic bicarbonate concentrations through October 2012. As discussed above regarding Zone 3, marked declines of bicarbonate concentration are indicative of (sometimes temporary) exceedance of the local buffering capacity of the natural geochemical system (i.e., the flux of acidity (temporarily) exceeds the rate of buffering). The plunge of bicarbonate concentration in Well EPA 5 from January 2000 to May 2000 is such an example. 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 trends is provided by Well EPA 7 (Figure 54), where formerly very low bicarbonate concentrations have increased step-wise beginning in July 1990, with additional upward steps in January 1994, again in October 1998, and again in May 2000. The rising concentrations indicated that the natural attenuation neutralization capacity has not been depleted. The historically highest bicarbonate concentration in EPA 7 was measured in April 2010 (680 mg/L); 2012 concentrations define an upward trend, suggesting that while there is tailings-impacted water reaching this location the buffering capacity has not been overcome by the amount of acidity reaching this location.

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 had a decrease in manganese concentration to below the standard. In contrast, seepage-impacted wells with lower bicarbonate concentrations, such as Wells 515 A, 604 and EPA 7, have historically had manganese exceedances (including 515 A and 604 in October 2012). However, even among these wells the effect of bicarbonate on manganese concentrations is well illustrated by EPA 7. Since July 1991, increasing bicarbonate concentrations in Well EPA 7 (in Section 1) have exceeded 500 mg/L (Figure 54), and the manganese concentration steadily declined through October 2008 (Figure 52) – since then the manganese concentrations have mostly been below the standard, as was the case in all four quarters of 2012, and the bicarbonate fluctuated within an overall stable trend. This geochemical behavior has previously been analyzed by Earth Tech (2000c). The recent increase in bicarbonate at 515 A correlates with decreasing manganese (Appendix C).

In contrast to seepage-impacted wells, long-term manganese exceedances at Well EPA 4 represent background water quality. Similarly, Well EPA 8, located beyond the tailings-impacted zone in background water to the east of EPA 4, also showed persistent manganese exceedances through the termination of groundwater quality monitoring in January 2000. Most of the other constituents at EPA 8 had been fluctuating to steady since 1989 (Appendix C).

In summary, exceedance of the manganese standard within the property boundary will continue except where there is sufficient neutralization capacity to reduce the manganese concentrations. It is also important to realize that manganese exceeds the standard in the background water quality. Manganese is a non-hazardous constituent in water. UNC agrees with NRC (1996) that manganese is not a useful indicator of seepage impacts or remediation success and it should be removed as a parameter of concern for all the reasons that have been discussed.

Cobalt and Nickel

During October 2012 there was only one exceedance of a metallic hazardous constituent outside the UNC property boundary: Well EPA 5 had a nickel concentration of 0.06 mg/L (the NRC License standard is 0.05 mg/L). This is the first exceedance at this location since October 2006. The extent of cobalt and nickel exceeding the Site standard during October 2012 is shown in Figure 56. Other metals are attenuated within the property boundary.

Nickel has shown a continuous decline in Well EPA 5 since January 2002 (Figure 55). After April 2007 there were no detections until January 2012 and April 2012, when the concentration equaled the standard. The October 2012 nickel concentration was 0.06 mg/L. Cobalt has shown a continuous decline in Well EPA 5 since April 2003 (Figure 55) and concentrations have been below the standard since October 2007.

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). For example, cobalt and nickel concentrations in Well EPA 7 historically have fluctuated around the Site standard as the pH has increased to above 6.0. Neutralization of tailings seepage in Well EPA 7 (pH rose steadily from the approximately 4 to 7 throughout the 1990s) has been the geochemical impetus for reductions in concentrations to levels below the standards for cobalt in April 2002, and nickel in January 2003. Empirically (Appendix C) it appears that a pH of approximately 6.0 may promote adsorption sufficient for reduction of concentrations to below the standards for both parameters.

The cobalt and nickel time series (Figure 55) empirically demonstrate that natural attenuation occurs in two senses: over time at a given location, and spatially downgradient of the eastern part of the Central Cell.

Combined Radium-226 and Radium-228

Similar to the metals, combined radium is attenuated by neutralization, precipitation, and adsorption. The highest concentrations of combined radium are within the property boundary where the pH is more acidic (Table 17). Historic concentrations for combined radium through October 2012 are presented in Figure 57. During October 2012, the NRC combined radium Zone 1 Site standard of 9.4 pCi/L (NRC, 2006b) was exceeded only in Well 619 (Table 17; Appendix C), which is not part of the formal performance monitoring program.

Total Trihalomethanes (TTHMs)

Exceedance of the Site standard (80 µg/L; see NRC, 2006b) for TTHMs in October 2012 occurred at Well 515 A (416 µg/L), which is within the property boundary and not a POC well, and at Well 614 (238 µg/L), which is also within the property boundary and is a POC well. UNC has submitted an ACL application for TTHMs in POC Well 614 and nickel in POC Well 604 (discussed below).

Pb-210

Table 17 shows that there were no detections of Pb-210 during October 2012. During the entire year there was one detection: 1.1 pCi/L in Well 604 during January (the first detection here since July 1999). At least three issues are important to consider in the context of regulatory compliance with the NRC GWPS of 1 pCi/L:

- The quantitative analytical errors (reported as precision errors) associated with each sample's result indicate that some of the results are statistically not exceedances;
- The analytical results as reported have a confidence level (also called the combined standard uncertainty) of 2σ (2 standard deviations, equivalent to a 95 percent confidence level) and, as such, the results are tied to probability functions ; and
- Accepting the results at face value indicates they fall within the range of background water concentrations.

Background water quality statistics for Zone 1 have been presented by UNC (N.A. Water Systems, 2008f, Table 5). 234 Pb-210 laboratory results had the following statistical parameters:

- Percent nondetects = 80.8%
- Minimum detected = 1.1 pCi/L
- Maximum detected = 9.1 pCi/L
- Mean of detected = 2.58 pCi/L
- Median of detected = 2.1 pCi/L
- Upper Confidence Limit of the mean at the 95% confidence level of the sampled population (UCL95) = 1.579 pCi/L.

The single 2012 detection is not inherently indicative of impact from the tailings seepage; it is equivalent to the minimum concentration detected in the background water.

4.4 Alternate Concentration Limits Application

During December 2008 UNC submitted to NRC an ACL application (N.A. Water Systems, 2008h) for TTHMs in POC Well 614 and nickel in POC Well 604. Both of these wells are located along the eastern property boundary in Section 2 (see Figure 48). This document followed NRC's guidance for organizational content and included sections addressing hazard assessment, exposure assessment, and corrective action assessment (including an As Low As Reasonably Achievable (ALARA) demonstration).

During 2011, NRC stated that this ACL application is unacceptable because the proposed POEs (Wells EPA 5 and EPA 7) are not located on UNC property. This proposal was made because there is no space for more wells to the east of the Central Cell in Section 2, such that there would be spatially separate POC wells (604 and 614) and POE wells. UNC is presently considering alternate approaches to address TTHMs and nickel in these two POC wells. Nonetheless, it is

important to understand the key issues related to UNC's ACL application from 2008, which are summarized next.

In developing the proposed ACLs, UNC had conducted concentration trend analyses from the final shutoff of Zone 1 pumping wells in July 1999 through July 2008. In addition, historic groundwater quality has been reviewed for all monitoring wells in Zone 1. Based on these observations, UNC proposed the ACL of 0.4 mg/L for nickel at POC Well 604, and the ACL of 0.3 mg/L for TTHMs at POC Well 614.

The NRC Source Materials License for the Site has a groundwater protection standard (GWPS) for nickel of 0.05 mg/L. The New Mexico Water Quality Control Commission (NMWQCC) standard for nickel is 0.2 mg/L.

The License GWPS for TTHMs is 0.08 mg/L; this is the same value as the federal MCL. The NMWQCC standard for TTHMs is 0.1 mg/L.

Since the termination of pumping, most constituent concentrations have progressively reduced through natural geochemical processes (as discussed in detail for all constituents in this 2012 Annual Review Report). Nickel and chloroform are being diluted or immobilized and will not migrate any further. The analysis presented in the ACL application confirms that the spatial extent of Zone 1 seepage impact is stable to diminishing, and that natural attenuation by neutralization (buffering) and adsorption is occurring for the metals (including nickel), and that attenuation by degradation, dilution, and dispersion is occurring for chloroform.

The 23-year history of continuous groundwater quality monitoring in Zone 1 (and Site-wide) provides a sound empirical basis for evaluating contaminant transport and attenuation. The key conclusions of the ACL application are summarized below:

- There was no nickel or chloroform at concentrations above standards in any Section 1 well (however, subsequent to this application Well EPA 5 had a nickel detection of 0.06 mg/L in October 2012, which was the first exceedance at this location since October 2006).
- The long monitoring history provides more than sufficient time to detect exceedances and to evaluate trends.
- Source area concentrations within Section 2 show decreasing long-term trends.
- Constituent concentrations progressively decrease downgradient.
- Hydraulic gradients and groundwater flow rates are diminishing over time.
- Groundwater quality is expected to continue its improvement at the proposed point-of-exposure (Wells EPA 5 and EPA 7) from levels which are very largely below Site standards.
- There are no Zone 1 exceedances of the License GWPS in Section 36 (UNC property) or Section 1 (Indian Trust Land property), nor are there exceedances of any hazardous

constituents within seepage-impacted water outside of Section 2. (However, note the statement about EPA 5 in the top bullet of this list.)

- A large part of Zone 1 in Section 1 is dry, and this hydrostratigraphic unit is physically and chemically non-viable for sourcing domestic or stock water supply wells. Treatment of either the seepage-impacted or background water, to potable quality, would be extremely expensive and is not feasible.
- The proposed Zone 1 remedy of No Further Action plus ACLs will be protective of human health and the environment.
- UNC has demonstrated ALARA conditions in Zone 1.

Section 5

Conclusions and Recommendations

This annual review evaluated the performance of the natural systems in all three Site hydrostratigraphic units and the active remediation in Zone 3. In the Southwest Alluvium and Zone 1, the natural systems have functioned as effectively as when active remediation took place. During 2012, part of Zone 3 underwent continued extraction well pumping that started during the hydrofracture program in 2005 and which was most recently supplemented, in 2009, with extraction started in the NW-series wells located along the northernmost area of impact. The injection of sodium bicarbonate-amended water into Zone 3 Well IW A, in the northern part of Section 36, was terminated on June 29, 2012 for a lack of sufficient capacity, ending a 15-month pilot test. The conclusions and recommendations of this report are provided below.

5.1 Conclusions

Below are some of the key conclusions of this report:

- An upward trend in TDS at Southwest Alluvium Well GW 2 appears to have stabilized starting in January 2010. The formerly upward trend can be explained by either declining saturation levels and/or continued dissolution of alluvium mineral salts. Heterogeneous distribution of the soluble alluvium minerals very likely affects the inter-well variations in concentrations of common dissolved ions.
- Concentrations of uranium in the Southwest Alluvium are an indicator that natural attenuation is at least as effective a remedy as pumping. With the exception of POC Well GW 3 and non-POC Well EPA 25, uranium concentrations and concentration time trends have either stabilized or shown decreasing trends since the pumps were turned off. The increasing trend of concentrations at GW 3 does not necessarily relate to the shutoff. During October 2012, the saturated thickness (water column height) in GW 3 was 3.3 ft and UNC has projected that this well will go dry in approximately seven years. Since approximately July 2007 there has been no covariance between this well's bicarbonate and uranium concentrations.
- Uranium concentrations in the Southwest Alluvium are not related to the migration of uranium in tailings fluids. The range of uranium concentrations in the background water has been empirically shown to be the same as the range within seepage-impacted water (GE, 2006). Uranium and bicarbonate concentrations are usually covariant in the Southwest Alluvium groundwater, i.e., when the concentration of the bicarbonate parameter changes, uranium changes with it provided that there is uranium available for dissolution or desorption in the sediments. This observation has held for most Southwest Alluvium wells for both the 11 years of active pumping and the 11.7 years of post-pumping monitoring, and is expected based on principles of aqueous chemistry.
- Mapping of bicarbonate isoconcentration contours is an important method of delineating seepage-impacted water in the Southwest Alluvium.

- At downgradient Well 624, in the Southwest Alluvium, the increase in bicarbonate to a chart plateau starting in May 2000 is attributed to the migration of the bicarbonate “front” associated with tailings seepage-impact. However, this well shows no covariance between the bicarbonate and uranium concentrations. At least two interpretations are possible: (1) at this well location there is little to no adsorbed or precipitated uranium (i.e., solid phase) within the alluvial sediments; and (2) aqueous uranium that originated from upgradient tailings seepage impact has been strongly attenuated during transport and it has not reached this location.
- Groundwater levels in the Southwest Alluvium continued to decline in 2012, indicating that the artificially recharged zone of saturation continues to become naturally dewatered as the groundwater drains down the arroyo. Groundwater to the north of the Nickpoint has become ponded and is no longer flowing to the southwest – this water is slowly infiltrating into the underlying bedrock.
- Hydraulic containment is not a necessary feature of the corrective action program in the Southwest Alluvium because of the geochemical attenuation that occurs naturally. The natural system is as effective as, or more effective than, pumping for controlling the migration of the constituents of concern.
- The non-hazardous constituents sulfate, TDS, and manganese exceed standards 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 seepage-impacted groundwater in the Southwest Alluvium. Background concentrations for sulfate and TDS ahead of the seepage migration front tend to exceed the standards but this reflects local geochemistry and is not related to seepage impact. Behind this migrating front, seepage-impacted groundwater quality tends to have sulfate and TDS levels approximately equal to, or lower than, those in the background water due to equilibration with the mineral gypsum.
- Locally increasing trends in concentrations of common dissolved ions are unrelated to tailings seepage; they derive from the reaction of the anthropogenic recharge water with natural alluvium materials.
- Evaluation and prediction of constituent concentrations in the Southwest Alluvium is predicated on understanding the geochemical evolution of both the background water quality and later changes associated with passage of the seepage-impact front. Hazardous constituents derived from seepage impact are effectively attenuated to acceptable concentrations within the Site boundary.
- Both onsite and offsite groundwater quality in the Southwest Alluvium meets or exceeds the NRC groundwater protection standards (GWPSs).
- Both the Southwest Alluvium and Zone 1 natural systems are at least as effective as the former active remediation systems in attenuating the seepage-impacted water. Acidic seepage is being neutralized, resulting in attenuation of metals and radionuclides. Natural

geochemical conditions related to gypsum equilibrium and bicarbonate availability will control sulfate and manganese concentrations in both hydrostratigraphic units, regardless of whether or not the extraction wells are operated.

- Groundwater elevations in Zone 1 continued to decline in 2012, causing the saturated thickness that accommodates groundwater flow and constituent migration to diminish in the updip parts of this bedrock stratigraphic unit.
- Outside the UNC property boundary in Zone 1, the post-pumping groundwater quality continues to improve overall (Tables 17 and 18). The exceedances of sulfate and TDS in Wells EPA 5 and EPA 7 reflect geochemical equilibrium of the groundwater with gypsum; these constituents are non-hazardous.
- With a single exception (a nickel detection of 0.06 mg/L at Well EPA 5), Zone 1 groundwater in Section 1 meets or exceeds the NRC GWPSs.
- The Zone 1 groundwater corrective action program has achieved success. Final closure and License transfer will require meeting the Site standards or Technical Impracticability waivers. It is likely that some standards will need to be revised.
- Groundwater levels in Zone 3 continued to decline in 2012, indicating that the artificially recharged zone of saturation continues to diminish as the groundwater drains down the dip of the bedrock layers. Pumping of extraction wells since 2005 has locally accelerated the rate of water level decline in Zone 3.
- Groundwater quality along the northern tracking wells in Zone 3 has been oscillating between degrading and improving trends over the last 10 years. Individual well water-quality trends of improvement and degradation have become collectively asynchronous since May 2007, which approximately coincides with an increase in the size and rapidity of water-quality oscillations. The variations in water quality indicate that there have been local and variable degrees of mixing of seepage-impacted water with background water drawn in from the west. This is interpreted to have been a consequence of the designed actions of extraction wells upgradient and, since February 2009, downgradient of the northern tracking wells.
- Pumping in the northernmost part of Zone 3 has created a mixing zone of background and seepage-impacted water, which makes a single-line plume boundary depiction in this area inappropriate. However, based on specific (though oscillating) water quality trends, fully seepage-impacted water has not advanced beyond NBL 1.
- UNC installed five new Zone 3 extraction wells (the NW-series) north of Well NBL 1 during September 2008. Pumping of three of these wells began in February 2009, and the pumping regime was adjusted during early November 2009 and during May and June of 2012. These extraction wells have provided significant containment of the northernmost seepage-impacted water in Section 36.

- UNC started injecting water amended with sodium bicarbonate at Zone 3 Well IW A during April 2011. The injection capacity at IW A has progressively declined from the original target rate of 1 gpm, and the injection rates became so low that injection was terminated on June 29, 2012. Subsequently, the July 2012 groundwater quality at nearby monitoring Well MW 6 showed (compared to July 2011) increased bicarbonate, sodium, and uranium. Though a uranium increase was expected with increased bicarbonate, the uranium increase was large enough that UNC would have then terminated the injection program (had it not already been terminated due to critically diminished capacity). October 2012 lab results from MW 6 showed significant reductions in bicarbonate, sodium, and uranium (and some other parameters, e.g., molybdenum).
- In the Southwest Alluvium and Zone 3 there are no exceedances of NRC groundwater protection standards for hazardous constituents outside the UNC property within seepage-impacted groundwater.
- There is no basis to infer that recent Pb-210 results reflect increasing concentrations in groundwater. With very few exceptions (e.g., Zone 3 Well NBL 1) the analytical results fall within the lower end of the range of background concentrations in each hydrostratigraphic unit. The results do not inherently reflect the impact of tailings seepage, given the background distributions. Background water Pb-210 concentrations define the following ranges: 1 to 14 pCi/L (Southwest Alluvium); 1 to 11 pCi/L (Zone 3); and 1 to 9 pCi/L (Zone 1).
- Technical issues set out in an email dated April 30, 2012 (EPA (2012b)) must be resolved before the SWSFS can proceed further.

5.2 Recommendations

1. Site groundwater protection standards should be revised to reflect newly calculated background threshold values (95th percentile of the upper prediction limits).
- UNC has previously requested deletion of Pb-210 from the Site standards, which NRC denied (Earth Tech, 2001b and 2001c; NRC, 2001). An additional 12 years of chemical analytical data have accrued, and the revised laboratory protocols and analytical results indicate that it is important to consider Pb-210 issues including sample-specific minimum detectable concentrations and analytical results, and the implications of Site background water quality statistics. Relevant background information is found in NRC (1980), U.S. Geological Survey (2008), and N.A. Water Systems (2008d). UNC (2012) submitted a License amendment request for NRC that proposes the revision of some Site groundwater protection standards to newly calculated background threshold values (95th percentile of the upper prediction limits).

2. A pumping efficiency metric should be developed as a potential quantitative threshold for terminating pumping in Zone 3 in the future.
 - A new metric for pumping system performance derives from analysis of the efficiency of seepage-impacted groundwater extraction. The pumping efficiency is less than 100% because background groundwater, from outside the seepage-impacted area, flows toward the pumping.
 - For some constituents the background water has higher concentrations than the seepage-impacted water.
 - All Zone 3 pumping well capacities decline over time. One important cause is loss of saturated thickness. It will not be possible to pump out all of the seepage-impacted water.

5.2.1 *Recommendations for Closure of Southwest Alluvium Remedial Action*

1. The 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:
2. Decommission the pumping wells and implement a No Further Action remedial alternative. Attenuation via natural geochemical processes has been shown to be at least as effective as pumping.
3. Change performance monitoring from quarterly to an annual basis because the seepage-impacted water quality is largely stable and migrating very slowly (estimated to be moving southwestward toward Well SBL 1 at an average rate of 11 ft per year, which should continue to diminish in the future). The offsite seepage-impacted water quality is not hazardous, and a yearly frequency is sufficient for tracking the migration of the seepage-impact front.
4. Sulfate, TDS and manganese should be waived as constituents of concern based on NRC's (1996) background water quality analysis report and multiple reports by UNC (many of which are summarized in the SWSFS Part I, N.A. Water Systems, 2007b; and Chester Engineers, 2009b). A Technical Impracticability waiver should be issued for sulfate and TDS.
5. EPA should consider adopting the background threshold values (UPL95 calculations) that UNC has proposed for the Southwest Alluvium (Chester Engineers, 2012e, draft Table 4) in the context of a future compliance monitoring program with "not to exceed" standards.
6. As first put forth by the NRC (1996), and further developed in several geochemistry (Earth Tech, 2000d and 2002c) and annual reports (Earth Tech, 2002d; N.A. Water Systems, 2004, 2005b, 2007a), there is quite simply no method to achieve the standards for sulfate, TDS and manganese – short of completely dewatering the alluvium, which is

technically infeasible. The last drop of water left in the alluvium would exceed the standards for these parameters. UNC once again requests approval of a TI Waiver for sulfate and TDS to the extrapolated, downgradient impact zone in the year 2204 shown in Figure 58. The ongoing development of a SWSFS will formally evaluate and prioritize the most appropriate remedial course of action; however, many of the actions required to meet closure are administrative and have been the subject of longstanding discussions.

5.2.2 Recommendations for Zone 3 Remedial Action

Consider terminating extraction pumping, which is tending to draw in background water from the west. Some constituents have higher concentrations in background water, compared to seepage-impacted water. All Zone 3 pumping well capacities decline over time. It will not be possible to pump out all of the seepage-impacted water, and over time the pumping is capturing more background water. The approximate efficiency of seepage-impacted groundwater removal by pumping is 60% (i.e., 60% of the pumped volume is seepage-impacted water and 40% is inferred to be background water), and the efficiency is expected to decline with time. UNC recommends using the pumping efficiency metric as a potential quantitative threshold for terminating Zone 3 pumping in the future.

Declining yields from the current extraction-well array indicate that hydraulic control is temporary. This has always been the case for pumping in Zone 3. Zone 3 saturated thicknesses are quite low (especially considering well losses), and any future pumping to reduce the pressure head will obtain only limited short-term results. Because the bedrock slope drives groundwater flow to the north, there is an irreducible elevation head that cannot be decreased by pumping. Counteracting this force is the reduction of effective porosity by the seepage-induced chemical alteration of feldspar to clay. This reduces the bedrock permeability, which retards the migration of the seepage. Eventually, a balance will develop between the irreducible elevation head and the trapping of the seepage-impacted groundwater due to the diminished bedrock permeability, retarding further migration of seepage-impacted water. Although the timing and location of such a balance cannot be predicted, such a development is likely. UNC recommends that consideration be given to other regulatory tools to manage the inherent physical limitations to the Zone 3 bedrock-groundwater system. As with Zone 1 and the Southwest Alluvium, the tools might include: ACLs, TI Waivers, MNA, and ICs.

EPA should consider revision of the ROD background concentrations for the following metals in Zone 3: arsenic, molybdenum, nickel, cobalt and manganese. Uranium should also be addressed and UNC recommends that EPA adopt the NRC standard for uranium.

Sulfate, TDS and manganese should be waived as constituents of concern based on NRC's (1966) background water quality analysis report.

EPA should consider adopting the background threshold values (UPL95 calculations) that UNC has proposed for Zone 3 (Chester Engineers, 2012e, draft Table 6) in the context of a future compliance monitoring program with "not to exceed" standards.

5.2.3 Recommendations for Closure of Zone 1 Remedial Action

The Zone 1 seepage-impacted area has attained ALARA goals. The predicted performance of the Zone 1 natural attenuation system is summarized on Table 18. Implement the following recommendations toward closure of the Zone 1 corrective action system:

1. EPA should consider adopting the background threshold values (UPL95 calculations) that UNC has proposed for Zone 1 (Chester Engineers, 2012e, draft Table 5) in the context of a future compliance monitoring program with “not to exceed” standards.
2. As first put forth by the NRC (1996), and further developed in several geochemistry (Earth Tech, 2000c) and annual reports (Earth Tech, 2000e; N.A. Water Systems, 2004, 2005b, 2007a), there is no method to achieve the standards for sulfate and TDS, which are exceeded in background groundwater. Zone 1 has already been dewatered to the extent that is feasible. It is not appropriate to tie remediation progress to sulfate or TDS concentrations which reflect geochemical equilibrium of the groundwater with gypsum. The EPA should approve a TI Waiver for sulfate and TDS in the TI zone shown in Figure 58. Remedial alternatives to be presented in the final, complete SWSFS should be closely coordinated with the necessary TI Waiver(s), ACL applications, ICs, and potentially appropriate changes in Site remediation standards (EPA, 2008b).

Section 6

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<p style="text-align: center;">TABLE 1A Chronology of Events June 1977 to December 2012 UNC Church Rock Mill Tailings Site, Church Rock, New Mexico</p>	
Event	Date
The UNC milling operations began.	June 1977
Dam on south tailings disposal cell is breached, releasing an estimated 93 million gallons of uranium mill tailings and pond water to Pipeline Canyon and the Rio Puerco. EPA Region 6 and New Mexico Environmental Improvement Division (NMEID) respond to release.	July 1979
New Mexico Environment Improvement Division orders UNC to implement discharge plan to control contaminated tailing seepage.	October 1979
UNC announces mill closing due to depressed uranium market.	May 1982
Site placed on the National Priorities List (NPL) of Superfund Sites due to off-site migration of radionuclides and chemical constituents in ground-water.	1983
EPA conducts Remedial Investigation (RI) field activities to determine the nature and extent of ground-water contamination in the three water-bearing formations at the Site.	March 1984- August 1987
In 1984, UNC blocked EPA access to the Church Rock facility, and EPA brought an action to compel site access. UNC counterclaimed seeking declaratory and injunctive relief. The U.S. District Court granted an EPA motion to dismiss the UNC counterclaims, and UNC provided access to the Site to EPA. <i>United States v. United Nuclear Corporation</i> , 610 F Supp. 527, 528 (D.N.M., 1985).	April 18, 1985
NMEID returns Uranium Mill Tailings Radiation Control Act (UMTRCA) federal regulatory program to the U.S. Nuclear Regulatory Commission (NRC).	June 1986
EPA and NRC sign MOU coordinating EPA's CERCLA ground-water remedial action with NRC's reclamation and closure activities under the Source Materials License.	August 26, 1988
EPA releases RI and Feasibility Study (FS) report along with proposed plan of action field sheet.	August 1988
EPA issues ROD for extraction of contaminated water and evaporation of the extracted water as the remedy for ground-water contamination outside of the Tailings Disposal Site.	September 30, 1988
NRC approves a UNC submitted closure plan for the reclamation of the mill site.	September 1988
UNC submits Remedial Design Report.	April 1989
Remedial action implemented in Zone 1 – Borrow Pit No. 2 dewatered.	April 1989
EPA issues Unilateral Administrative Order (UAO) Docket No. CERCLA 6-11-89 to UNC requiring UNC to implement the Site CERCLA ground-water operable unit remedy determined by the ROD.	June 29, 1989
Remedial action implemented in Zone 3 – 12 new extraction wells begin pumping.	August 1989
Remedial action implemented in Southwest Alluvium – 3 new extraction wells begin pumping.	October 1989
Ground Water Corrective Action Annual Review 1989 documents remedial action construction completion.	December 1989

<p style="text-align: center;">TABLE 1A Chronology of Events June 1977 to December 2012 UNC Church Rock Mill Tailings Site, Church Rock, New Mexico</p>	
United States had brought action against UNC in 1991 for response cost recovery under CERCLA; and in late 1992, the U.S. District Court issued an opinion and order granting a U.S. motion for partial summary judgment on the issue of costs and denying a UNC cross motion for summary judgment. <i>United States v. United Nuclear Corporation</i> , 814 F Supp. 1552 (D.N.M., 1992).	December 28, 1992
NRC issues a background-water quality study that recommends higher concentrations of background constituents than presented in the ROD.	1996
First Five-Year Review completed.	September 24, 1998
NRC, EPA, and NMED approve the decommissioning of 10 Zone 3 wells, 3 Zone 1 wells, and 1 Southwest Alluvium well because they meet the decommissioning criteria of producing less than 1 gallon per minute (gpm).	July 30, 1999
NRC approves eliminating the Section 1 portion of Zone 3 as a point of exposure.	September 16, 1999
UNC submits request to terminate all Zone 3 pumping and for Technical Impracticability waiver to EPA, NRC and NMED.	May 2000
All but three Zone 3 wells decommissioned in accord with criterion.	June 2000
EPA approves UNC's request to shut down remaining three Zone 3 wells to slow seepage migration rate.	November 2000
License Amendment No. 31 allows UNC to temporarily suspend the corrective action pumping in Zone 3.	December 29, 2000
License Amendment No. 32 approves the conversion of the Zone 3 Phase II extraction wells to monitoring wells.	March 8, 2001
UNC submits Draft Tribal Resolution and Environmental Right-of-Way to the Navajo Nation to form basis for ICs.	March 2001
EPA gives UNC approval to temporarily shut down Southwest Alluvium extraction wells and an 18-month Natural Attenuation Test is conducted.	February 2001 through July 2002
UNC submits Final Report and Technical Impracticability Evaluation – Southwest Alluvium Natural Attenuation Test to EPA, NRC and NMED.	November 2002
UNC submits proposal to conduct hydraulic fracturing pilot test.	May 21, 2003
UNC conducts the hydraulic fracturing pilot test in Zone 3.	June 2003
Second Five-Year Review completed.	September 18, 2003
Meeting between EPA, Bureau of Indian Affairs (BIA), and the Department of the Interior (DOI) to discuss access issues in connection with the Site ground-water monitoring program on Navajo Allotment lands.	December 5, 2003
UNC submits Final Report – Hydraulic Fracturing Pilot Test Results and Preliminary Full-Scale Design, United Nuclear Church Rock Facility.	December 2003
EPA comments on the Final Report – Hydraulic Fracturing Pilot Test Results and Preliminary Full-Scale Design and directs UNC to perform supplemental feasibility study (SFS) for Zone 3.	March 10, 2004 and March 19, 2004
EPA approves Final Report - Hydraulic Fracturing Pilot Test Results and Preliminary Full-Scale Design.	May 21, 2004
UNC conducts the Phase 1 full-scale hydraulic fracturing test in Zone 3.	September 2004
UNC installs well SBL-01 in Section 10, Southwest Alluvium.	October 2004

TABLE 1A
Chronology of Events
June 1977 to December 2012
UNC Church Rock Mill Tailings Site, Church Rock, New Mexico

UNC submits the draft SFS for Zone 3 for review.	October 27, 2004
EPA disapproves draft SFS for Zone 3 and directs UNC to perform a Site-wide SFS (SWSFS) consistent with the NCP.	June 24, 2005
Meeting between EPA, UNC, NRC, NMED, and Navajo Nation EPA (NNEPA) to discuss the SWSFS. UNC generally expresses its opposition to the feasibility study process.	August 17, 2005
Meeting between EPA, NNEPA, BIA and NMED in Window Rock, AZ, to discuss feasibility of ICs restricting the use of contaminated ground water.	January 18, 2006
Meeting between EPA and NNEPA in Dallas, TX, to continue discussions on ICs.	March 16, 2006
EPA approves in-situ alkalinity stabilization pilot study for Zone 3.	May 12, 2006
EPA directs UNC to perform the SWSFS in writing, stating that the feasibility study is appropriate and necessary.	June 23, 2006
Meeting between EPA, NNEPA, BIA, and NMED in Albuquerque, NM to continue discussions on ICs.	August 21, 2006
UNC submits the draft List of Preliminary Assembled Remedial Alternatives for the SWSFS.	September 2006
UNC begins the in-situ alkalinity stabilization pilot study in Zone 3. The study is completed in February 2007.	October 2006
UNC submits the draft SWSFS, Part 1, Church Rock Remediation Standards Update.	February 2007
UNC submits In-Situ Alkalinity Stabilization Pilot Study Report.	June 2007
EPA disapproves SWSFS, Part 1, Church Rock Remediation Standards Update and requires revision to address written comments.	January 2008
Meeting between EPA, State, NRC, NNEPA and UNC to discuss status of remedial activities. UNC notifies regulatory agencies that pumping of hydraulic fracture wells in Zone 3 was unsuccessful in stopping migration of seepage impacted ground-water. UNC proposes to submit a plan for additional extraction wells for Zone 3.	March 12, 2008
UNC submits summary of hydrogeologic analysis evaluation of groundwater flow and recommended plan for additional extraction wells for interception and recovery of seepage-impacted ground-water in Zone 3.	April 2008
UNC submits white paper on statistics to address some of EPA comments on the SWSFS, Part 1.	May 2008
EPA notifies NRC of approval of UNC's recommendation for additional extraction wells.	June 2008
UNC installs five new extraction wells (the NW-series) in northern Zone 3.	September 2008
EPA issues third Five-Year Review report for the UNC groundwater operable unit.	September 2008
UNC submits calculation of background statistics with comparison values.	October 2008
UNC submits calculation of estimated UCL95 statistics and exposure point concentrations in impacted groundwater.	December 2008
UNC submits to NRC an alternate concentration limits application for Zone 1.	December 2008

<p style="text-align: center;">TABLE 1A Chronology of Events June 1977 to December 2012 UNC Church Rock Mill Tailings Site, Church Rock, New Mexico</p>	
Pumping of the NW-series of extraction wells in northern Zone 3 begins. Later in the year the pumping scheme was reorganized to include three of the five wells.	February 2009 and November 2009
EPA issues comment letter on Site-Wide Supplemental Feasibility Part I (Church Rock Remediation Standards Update) and approves Part I (approval later effectively rescinded by EPA comments letters).	February 2009
UNC submits revised Site-Wide Supplemental Feasibility Study Part II.	July 2009
UNC submits hydrogeologic analysis of recent Zone 3 injection testing (new background well NBL-2) in northern Zone 3 and proposal to enhance remediation using one or more injection wells amended with sodium bicarbonate.	December 2009
UNC proposes the location for a pilot injection well in Zone 3.	April 2010
UNC submits a remedial design report on a conceptual approach to enhanced remediation in Zone 3 involving new injection wells combined with existing extraction wells.	May 2010
UNC submits a hydrogeologic analysis of injection testing of Zone 3 well IW-A during July 2010.	August 2010
EPA issues comments letter on revised Site-Wide Supplemental Feasibility Study Part II (UNC document from July 2009).	September 2010
UNC submits an updated baseline human health risk assessment.	March 2011
UNC submits revised Site-Wide Supplemental Feasibility Study Parts I and II.	April 2011
UNC starts injection at well IW-A of site Mill well water amended with alkalinity (sodium bicarbonate).	April 14, 2011
EPA issues comment letter on the draft updated human health risk assessment (March 2011).	July 2011
UNC submits a technical memorandum summarizing two previously submitted reports on Zone 3 tailings seepage sourcing and groundwater recharge, with an information update.	August 2011
EPA issues comment letter on the Site-Wide Supplemental Feasibility Study Part II (July 2009) (in fact, this comment letter addressed Parts I, II, and III).	October 2011
UNC submits provisional responses to EPA comment letter (July 2011) on the draft baseline human health risk assessment (March 2011).	October 2011
UNC submits hydrogeologic assessment of injection at Zone 3 well IW-A through September 2011.	November 2011
UNC submits a document requesting discussion and clarification about the EPA comment letter (October 14, 2011) addressing revised Site-Wide Supplemental Feasibility Study Parts I and II (April 2011).	November 2011
By email, UNC provides all agency stakeholders with revisions to the draft updated human health risk assessment (March 2011).	February 2012
EPA risk assessment specialist provides UNC with comments (by email) on the revised draft updated human health risk assessment (February 2012). Followup phone discussion between EPA risk specialist and UNC on April 27, 2012	March 2012 and April 27, 2012
GE submits to NRC a license amendment request for revised groundwater protection standards based on updated background concentrations (statistically called background threshold values). The three site hydrostratigraphic units are addressed individually.	April 2012

<p style="text-align: center;">TABLE 1A Chronology of Events June 1977 to December 2012 UNC Church Rock Mill Tailings Site, Church Rock, New Mexico</p>	
UNC presents the numeric groundwater hydraulic modeling (with focus on Zone 3) to all agency stakeholders at the annual technical meeting in Albuquerque.	May 14, 2012
UNC makes an operational adjustment of pumping in the northernmost part of Zone 3.	June 2012
UNC submits to EPA: Overview of Draft Attached Tables, Summary Comparisons of Upper Prediction Limits for Parameter Concentrations in Background Groundwater to Site Cleanup Standards and Potential ARARs for All Three Hydrostratigraphic Units at the Church Rock Mill Tailings Site.	June 2012
UNC has their laboratory reduce the reporting limits for beryllium and lead.	July 2012
UNC submits to EPA the Updated Baseline Human Health Risk Assessment – Final, Church Rock Site, Church Rock, New Mexico, United Nuclear Corporation, Gallup, New Mexico.	August 2012
EPA approves the final version of the Updated Baseline Human Health Risk Assessment (August 13, 2012).	September 2012
UNC notifies the agencies that injection of sodium bicarbonate-amended water, in Zone 3 well IW-A, was terminated on June 29, 2012.	October 2012
UNC submits the Groundwater Flow Model of the Church Rock Site and Local Area.	October 2012
UNC submits to NRC Supplemental Information Pertaining to License Amendment Request (April 2012) for Revised Groundwater Protection Standards.	November 2012
UNC sends the agencies an email with discussion of turbidity results from July 2012 and October 2012.	December 2012

TABLE 1B
Southwest Alluvium Performance Monitoring Program, 2012 Operating Year
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Well	Use ¹	Water Level	Water Quality	NRC POC	Purpose
509 D	Monitor	X	X	Y	Seepage extent
624	Monitor	X	X		Downgradient background, seepage extent
627	Monitor	X	X		Downgradient background, seepage extent
632	Monitor	X	X	Y	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	X			Water level only
808 ³	Pumping (idled)	X	X		Seepage extent
EPA 23	Monitor	X	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	X	X	Y	Seepage extent
GW 3	Monitor	X	X	Y	Downgradient background, seepage extent
Total		16	14		

Eliminated From Monitoring				Reason for Elimination
GW 4	X	X		Dry
EPA 22A			Y	Dry
29A				Dry
639				Dry
642				Dry
644				Dry
645				Dry
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 2012
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Chemical Name	Action Level	Unit	0509 D	0624	0627	0632	0801	0802	0803	0808	EPA 23	EPA 25	EPA 28	EPA 28 FD	GW 1	GW 2	GW 3	SBL-01
ALUMINUM	5	mg/l															0.2	0.2
AMMONIA (AS N)		mg/l	1.53			0.56	3.8 D		1.8 D	1.24	0.66				0.17	1.4 D		0.2 D
ARSENIC	0.05	mg/l																
BICARBONATE (HCO3)		mg/l	2580	1550	609	1890	1520	2010	1750	2150	1260	1240	811	674	1950	2230	1710	460
CALCIUM		pci/l	856	728	555	632	592	642	678	765	703	810	576	556	760	628	937	520
CHLORIDE	250	mg/l	364 D	212 D	39 D	247 D	211 D	193 D	160 D	193 D	104 D	115 D	126 D	122 D	248 D	219 D	177 D	89 D
COBALT	0.05	mg/l	0.01													0.01	0.01	0.02
GROSS ALPHA	15	mg/l	0.5	0.9		1.1	0.7	0.8	0.7							0.5		1.2
LEAD	0.05	mg/l						0.001	0.002	0.002								
LEAD-210	1	pci/l												1				
MAGNESIUM		mg/l	407	418	231	790	652	849	723	713	378	226	482	460	546	1130	284	1150
MANGANESE	2.6	mg/l	3.83	0.22	0.03	2.85	5.01	1.24	3.14	1.62	6.09	0.23	0.86	0.72	0.13	1.7	1.75	3.74
NICKEL	0.05	mg/l																0.08
NITRATE (NO3)	190	mg/l	7.6 D	72 D	89 D	66 D	20 D	110 D	38 D	57 D		72 D	26 D	23 D	86 D	15 D	87 D	39 D
PH (FIELD)		su	6.46	6.7	7.03	6.51	6.57	6.55	6.53	6.5	6.68	6.86	6.79	6.8	6.61	6.39	6.58	6.72
PH (LAB)		su	6.55 H	6.66 H	6.97 H	6.56 H	6.62 H	6.58 H	6.54 H	6.56 H	6.70 H	6.90 H	6.86 H	6.86 H	6.65 H	6.43 H	6.64 H	6.83 H
POTASSIUM		mg/l	13	6	7	11	14	6	14	7	11	8	12	12	7	17	9	15
RADIUM-226		pci/l	0.3	0.24	0.24	0.84	0.42	0.19			0.18		0.32	0.27	0.26	0.26		0.39
RADIUM-228		pci/l	1.9			2.2	2.5		1.3						1.3			
RADIUM 226 & 228	5	pci/l	2.2	0.24	0.24	3.04	2.92	0.19	1.3		0.18		0.32	0.27	1.56	0.26		0.39
SELENIUM	0.01	mg/l																
SODIUM		mg/l	403	285 D	443 D	402 D	352 D	350 D	283 D	349 D	145 D	191 D	231 D	242 D	408 D	382 D	328 D	297 D
SULFATE (SO4)	2125	mg/l	1830 D	2180 D	2280 D	3400 D	3270 D	3420 D	3300 D	3150 D	2310 D	1830 D	2810 D	2900 D	2740 D	4700 D	2280 D	5900 D
THORIUM-230	5	pci/l			0.2													
TOTAL DISSOLVED SOLIDS (LAB)	4800	mg/l	5420	5110	4510	6770	6120	7130	6590	6630	4540	4180	5120	4980	6230	8730	5330	8640
TOTAL TRIHALOMETHANES	80	ug/l				2.98	1.81	12.6	8	2.04					1.9	5.68		
URANIUM	0.3	mg/l	0.283	0.0351	0.0199	0.078	0.0387	0.121	0.0781	0.12	0.0283	0.12	0.047	0.0384	0.103	0.0865	0.295	0.012

TABLE 3

Southwest Alluvium Saturated Thickness, October 2012
United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

Well	Water Level Measurement Date	SW Alluvium Unsaturated Thickness	SW Alluvium Saturated Thickness	SW Alluvium Percentage Saturated
0509 D	10/8/2012	78.70	31.30	28%
0624	10/9/2012	51.89	23.11	31%
0627	10/9/2012	59.29	11.71	16%
0632	10/8/2012	44.55	22.45	34%
0801	10/8/2012	50.03	10.47	17%
0802	10/8/2012	47.88	33.62	41%
0803	10/8/2012	62.96	55.04	47%
0805	10/18/2012	50.25	69.75	58%
0807	10/18/2012	55.84	44.16	44%
0808	10/8/2012	49.53	82.47	62%
EPA 23	10/8/2012	53.90	66.10	55%
EPA 25	10/9/2012	52.40	17.60	25%
EPA 28	10/9/2012	61.80	16.20	21%
GW 1	10/8/2012	61.30	15.70	20%
GW 2	10/8/2012	55.09	34.91	39%
GW 3	10/9/2012	53.68	3.32	6%
SBL-01	10/9/2012	48.92	16.08	25%

TABLE 4
Summary of Operational Data
Southwest Alluvium Extraction Wells 1989 to 2001
United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

Well No.	Annual Average Pumping Rate (gallons per minute)												1990-2001
	1990 ⁽¹⁾	1991 ⁽²⁾	1992 ⁽³⁾	1993 ⁽⁴⁾	1994 ⁽⁵⁾	1995 ⁽⁶⁾	1996 ⁽⁷⁾	1997 ⁽⁸⁾	1998 ⁽⁹⁾	1999 ⁽¹⁰⁾	2000 ⁽¹¹⁾	2001 ⁽¹²⁾	
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⁾		10.0	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.

Source: Earth Tech, December 2002, Figure 2.1

TABLE 5

Southwest Alluvium Groundwater Velocities, October 2012
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Well Pair 805 and 624

Groundwater Elevations: 6859.80 (Well 805) and 6846.27 (Well 624) ft amsl
Separation Distance: 1902 ft
Average Linear Horizontal Hydraulic Gradient: 0.0071
Velocity 1 = 68 ft/yr
Velocity 2 = 52 ft/yr
Average Velocity = 60 ft/yr

Well Pair 805 and 627

Groundwater Elevations: 6859.80 (Well 805) and 6832.52 (Well 627) ft amsl
Separation Distance: 3203 ft
Average Linear Horizontal Hydraulic Gradient: 0.0085
Velocity 1 = 81 ft/yr
Velocity 2 = 62 ft/yr
Average Velocity = 72 ft/yr

Well Pair 624 and SBL 1

Groundwater Elevations: 6846.27 (Well 624) and 6845.61 (Well SBL 1) ft amsl
Separation Distance: 500 ft
Average Linear Horizontal Hydraulic Gradient: 0.0013
Velocity 1 = 12 ft/yr
Velocity 2 = 9 ft/yr
Average Velocity = 11 ft/yr

Darcy seepage velocity calculation input values:

Mean hydraulic conductivity used = 2.5×10^{-3} cm/s (based on groundwater flow model calibration for the Southwest Alluvium (Chester Engineers, 2012g)).

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

TABLE 6

Predicted Performance of Southwest Alluvium Natural Attenuation, 2012
 United Nuclear Corporation, Church Rock Site
 Church Rock, New Mexico

Constituent	Will Standards Be Met?			Remarks
	Section 2	Section 3	Section 10	
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 but Mn slightly above standard occasionally in background Well SBL 1 (see Table 2 and Table A.1 in Appendix A)
Sulfate	No	No	No	Seepage impact areas limited by calcium availability; background waters characterized by exceedances unrelated to seepage impact; highest sulfate concentrations occur in background Well SBL 1 (see Figures 9 and 16)
TDS	No	No	No	Governed by sulfate concentration; highest TDS concentrations occur in background Well SBL 1 and in impacted Well GW 2 (see Figure 17)
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 nickel in background Well SBL 1 continued during 2012 (see Table 2)
Radionuclides	Yes	Yes	Yes	Attenuation by neutralization and adsorption; single uranium exceedance in GW 3 (Section 3, July 2012) is associated with the smallest saturated thickness (October 2012 = 3.32 ft (6%)) in the Southwest Alluvium, and this well is projected to go dry in ~ 7 years
TTHMs	Yes	Yes	Yes	Attenuated by degradation, dilution, dispersion

TABLE 7
Change in Zone 3 Saturated Thickness from 1989 to 2012
United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

Well Number ¹	Saturated Thickness		Change (feet)	Change
	3rd Quarter 1989	4th Quarter 2012		
402	--	15.44	--	--
420	56.3	4.16	-52.1	-92.61%
424	--	15.69	--	--
446	--	6.82	--	--
504 B	40.1	0.00	-40.1	-100.00%
517	42.7	10.12	-32.6	-76.28%
613 ³	67.2	18.96	-48.2	-71.78%
EPA 09	8.1	3.73	-4.4	-53.88%
EPA 13	24.8	7.39	-17.4	-70.24%
EPA 14	76.3	23.65	-52.6	-69.00%
701	46.1	15.54	-30.6	-66.29%
702	24.1	8.36	-15.7	-65.31%
703	32.6	18.65	-13.9	-42.79%
705	--	--	--	--
706	--	15.53	--	--
707	58.8	11.21	-47.6	-80.94%
708	49.8	13.05	-36.7	-73.79%
709	56.1	11.33	-44.8	-79.81%
710	45.5	10.88	-34.6	-76.08%
711	43.7	18.05	-25.6	-58.70%
712	39.1	4.43	-34.7	-88.66%
713	34.2	8.31	-25.9	-75.71%
714 ⁴	50.1	14.56	-35.5	-70.95%
715 ⁴	47.6	8.88	-38.7	-81.34%
716 ⁴	58.3	15.49	-42.8	-73.44%
717 ⁴	57.6	18.07	-39.5	-68.62%
718 ⁴	51.1	13.88	-37.2	-72.84%
719 ⁴	39.9	5.78	-34.1	-85.50%
720 ⁴	33.1	0.00	-33.1	-100.00%
NBL-01 ⁵	--	10.56	--	--
501 B ⁶	20.2	--	--	--
411 ⁶	62.5	--	--	--
502 B ⁶	48.5	--	--	--
518 ⁶	37.2	--	--	--
EPA 01 ⁶	14.7	--	--	--
EPA 03 ⁶	8.3	--	--	--
EPA 11 ⁶	30.8	--	--	--
EPA 12 ⁶	10.7	--	--	--
EPA 15 ⁶	60.8	--	--	--
EPA 17 ⁶	1.4	--	--	--
EPA 18 ⁶	2.5	--	--	--
Average	39.5	11.33	-34.1	-75%

Notes:

- ¹ 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 was completed above the bottom of Zone 3. Measurements of saturated thickness in this well are less than actual conditions. 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 2000.
- 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 2001 and first water level measured in August 2001.
- ⁶ Wells are not currently monitored. See Table 9 for additional information regarding the status of each well. Shading indicates saturated thickness greater than 25 feet. "--" indicates that no data is available.

TABLE 8
Estimated Mass Removal by Extraction Well Pumping in Zone 3, December 2011 Through November 2012
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Well	Water Pumped (gallons)	SO4 (kg)	NO3 as N (kg)	Chloroform (g)	Al (kg)	As (g)	Be (g)	Co (g)	Pb (g)	Mn (kg)	Mo (g)	Ni (g)	U (g)	Total Radium (mci)	Pb-210 (mci)	Gross Alpha (mci)
RW-11	247,882	2,702	0.0	0.0	0.0	0	0	235	0	5	188	272	131	28	0.00	9
RW-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0
RW-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0
RW-15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0
RW-16	136,664	2,292	15.5	1.8	63	0.0	53	460	5	11	0	455	10.0	24	1.24	7
RW-17	214,730	3,397	0.00	0.0	0	0.0	0	252	0	5	81	317	2	15	0.00	4
PB-2	27,563	362	0.00	0.0	0	0.0	0	51	0	1	10	65	2	3	0.00	1
RW-A	161,749	1,702	0.00	0.0	0.0	0.0	0	165	0	3	61	190	57	20	0.00	7
NW-1	647	10	0.00	0.0	0.1	0.1	0	2	0	0	0	3	0	0	0.01	0
NW-2	399,005	6,434	0.00	0.0	65.5	48.3	59	1,420	112	10	0	1,858	285	17	5.13	8
NW-3	0	0	0.00	0.0	0.0	0.0	0	0	0	0	0	0	0	0	0.00	0
NW-4	39,286	633	0.00	0.0	6.5	4.8	6	140	11	1	0	183	28	2	0.51	1
NW-5	0	0	0.00	0.0	0.0	0.0	0	0	0	0	0	0	0	0	0.00	0
Total	1,227,526	17,532	16	2	135	53	118	2,725	128	36	341	3,342	517	109	7	36

Notes:

Wells are located on Figure 38 of the *2012 Annual Review Report*.

Wells RW-12, RW-13, and RW-15 were not pumped, because of negligible capacity.

Units for radionuclides (mci) are not mass units proper; mci are milli-Curies, or thousandths of Curies.

In developing this table, masses were estimated from analyses of October 2012 samples from RW-11 and RW-A. Masses for RW-16 and RW-17 were estimated from concentrations in samples from nearby wells 717 and 719. Masses in the NW-series wells were estimated from concentrations in the sample from NBL-01.

Nonradiological nondetects were assigned values of one-half the reporting limit.

Radiological results were assigned as reported (even if negative).

TABLE 9
 Zone 3 Performance Monitoring Program, 2012 Operating Year
 United Nuclear Corporation, Church Rock Site
 Church Rock, New Mexico

Well	Water Level	Water Quality	NRC POC	Purpose
Continue Monitoring				
420	X	X		Postmining-pretailings background, track plume.
711	X	X	Y	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			Water level only.
713	X			Water level only.
714	X			Water level only.
613	X	X	Y	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	Y	Added to program 2nd quarter 2001.
717	X	X		Water level. Water quality added 2nd quarter 2001.
719	X	X		Water level. Water quality added 2nd quarter 2001.
Additional Wells, Not Included In Original Performance Monitoring Program				
402	X			Long-term water level for migration path.
424	X			Long-term water level for migration path.
446	X			Long-term water level for migration path.
NBL-01	X	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

TABLE 10
 Zone 3 Saturated Thickness, October 2012
 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
0402	10/19/2012	47.56	15.44	25%
0420	10/16/2012	46.84	4.16	8%
0424	11/30/2012	57.31	15.69	21%
0446	10/18/2012	58.18	6.82	10%
0504 B	10/16/2012		<1.73 ¹	--
0517	10/15/2012	51.88	10.12	16%
0613	10/9/2012	49.04	18.96	28%
0701	10/18/2012	48.46	15.54	24%
0702	10/18/2012	72.64	8.36	10%
0703	10/18/2012	73.35	18.65	20%
0706	10/18/2012	62.47	15.53	20%
0707	10/18/2012	76.79	11.21	13%
0708	10/15/2012	71.95	13.05	15%
0709	10/18/2012	65.67	11.33	15%
0710	10/18/2012	70.12	10.88	13%
0711	10/15/2012	66.95	18.05	21%
0712	10/18/2012	81.57	4.43	5%
0713	10/18/2012	64.69	8.31	11%
0714	10/18/2012	23.44	14.56	38%
0715	10/18/2012	26.12	8.88	25%
0716	10/18/2012	48.51	15.49	24%
0717	10/16/2012	52.93	18.07	25%
0718	10/18/2012	33.12	13.88	30%
0719	10/16/2012	39.22	5.78	13%
EPA 09	10/15/2012	46.27	3.73	7%
EPA 13	10/15/2012	56.61	7.39	12%
EPA 14	10/9/2012	49.35	23.65	32%
MW-2	10/18/2012	49.83	10.60	18%
MW-3	10/19/2012	50.09	10.83	18%
MW-4	10/19/2012		<2 ¹	--
MW-5	10/19/2012		<2 ¹	--
MW-6	10/17/2012	40.90	6.81	14%
MW-7	10/16/2012	36.35	18.12	33%
NBL-01	10/16/2012	33.75	10.56	24%
NBL-02	10/16/2012	53.47	24.10	31%
NW-1	10/16/2012	40.51	3.78	9%
NW-2	10/16/2012	37.47	13.65	27%
NW-3	10/16/2012	35.22	22.59	39%
NW-4	10/16/2012	42.76	7.60	15%
NW-5	10/16/2012	35.09	22.92	40%
PB-02	10/16/2012	38.96	8.64	18%
PB-03	10/16/2012	34.52	12.45	27%
PB-04	10/16/2012	36.18	10.82	23%
RW-11	10/16/2012	49.91	11.93	19%
RW-15	10/18/2012		<4.9 ¹	--
RW-16	10/18/2012	59.68	3.42	5%
RW-17	10/18/2012	68.71	4.52	6%
RW-A	10/16/2012	55.72	12.15	18%
Z3 M-01	10/18/2012	43.13	2.71	6%
Z3 M-02	10/18/2012	43.89	2.38	5%
IW-A	10/15/2012	38.69	9.02	19%

¹Dry well

TABLE 11
 Zone 3 Field Parameter Measurements of Tracking Wells Through October 2012
 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

Date	Bicarbonate (mg/L)							Conductivity (umhos/cm)							pH (s.u.)							Chloride (mg/L)						
	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A
Oct-02	0	58	194	224	330			5,010	4,040	3,730	3,670	3,160			5.06	7.09	7.10	7.10	7.18			NA	25.3	23.8	113.0	NA		
Nov-02	0	41	188	299	285			4,930	3,080	2,860	2,510	3,120			5.30	5.95	6.47	6.60	6.51			14.0	26.5	24.3	23.8	21.0		
Dec-02	22.9	57	178	283	NA			5,040	4,120	3,950	3,330	NA			5.40	5.75	6.40	6.68	NA			22.9	26.2	23.2	25.7	NA		
Jan-03	0	34	148	239	311			5,180	3,930	3,716	3,460	3,300			5.54	4.97	6.92	6.41	6.43			NA	NA	22.9	22.8	NA		
Feb-03	0	58	193	324	328			3,620	2,910	2,660	2,570	2,300			3.52	5.57	6.96	6.92	6.53			26.7	30.1	30.4	28.5	21.5		
Mar-03	NA	60	188	311	326			4,000	3,090	2,890	2,680	2,500			3.49	5.59	6.71	6.95	6.73			26.4	30.1	29.7	29.7	22.1		
Apr-03	NA	34	172	310	321			4,210	4,460	4,220	3,820	2,650			5.14	5.46	5.94	6.26	6.87			26.6	30.5	30.0	30.1	21.6		
May-03	0	34	167	293	322			5,510	4,460	4,210	3,820	3,390			5.01	5.36	5.99	6.31	6.37			28.0	31.0	30.2	31.9	32.7		
Jun-03	0	21	129	267	316			5,470	4,480	4,060	3,820	3,380			4.28	5.15	6.17	6.20	6.36			27.7	30.8	29.6	30.6	28.0		
Jul-03	NA	32	126	257	311			5,480	4,560	4,330	3,920	3,500			5.35	5.28	5.85	6.32	6.29			26.5	30.6	29.7	31.1	25.8		
Aug-03	NA	5	100	234	307			5,210	4,280	3,960	3,630	3,230			5.14	5.18	5.76	6.18	6.28			27.0	30.4	29.7	31.1	23.1		
Sep-03	NA	7	91	218	295			5,260	4,400	4,160	3,770	3,340			4.68	5.23	5.79	6.28	6.39			28.0	30.5	29.3	31.5	26.7		
Oct-03	NA	0	65	211	295			5,360	4,450	4,210	3,860	3,410			5.48	5.18	5.81	6.34	6.41			27.7	21.0	30.0	32.7	26.8		
Nov-03	NA	0	73	197	285			5,290	4,510	4,210	3,880	3,490			5.09	5.25	5.81	6.24	6.42			27.3	30.6	30.2	32.1	24.8		
Dec-03	NA	NA	41	166	265			5,370	4,540	4,290	3,910	3,510			4.41	5.14	5.77	6.76	6.48			27.7	30.2	29.8	31.5	25.2		
Jan-04	NA	NA	73	194	327			5,340	4,610	4,310	4,030	3,550			5.39	5.16	5.82	7.51	6.50			32.5	30.5	29.5	32.6	26.8		
Feb-04	NA	NA	50	190	323			5,410	4,630	4,260	3,970	3,590			3.40	3.81	5.99	6.25	6.40			28.0	30.1	30.3	32.7	26.6		
Mar-04	NA	15	48	179	316			5,560	4,730	4,500	4,130	3,780			3.89	4.75	5.70	6.31	6.29			27.5	30.1	30.2	33.3	25.9		
Apr-04	NA	15	48	174	315			5,370	4,560	4,380	4,010	3,630			5.36	5.08	5.52	6.03	6.34			28.1	32.1	32.3	36.2	31.1		
May-04	NA	0	27	166	312			6,190	4,390	4,160	3,870	3,510			3.26	5.02	5.34	5.88	6.23			28.4	33.2	32.8	38.1	31.9		
Jun-04	NA	0	22	152	294			5,510	4,530	4,400	4,040	3,750			4.48	4.92	5.46	6.05	6.40			28.2	32.6	32.9	37.7	34.1		
Jul-04	NA	0	20	140	274			5,450	4,510	4,420	4,000	3,740			5.48	5.04	5.58	6.05	6.45			27.8	31.9	32.8	36.9	34.1		
Aug-04	NA	0	17	124	272			5,500	4,450	4,380	4,040	3,710			3.77	4.26	5.45	5.98	6.39			28.3	31.0	32.3	36.2	33.7		
Sep-04	0	0	20	117	251			5,480	4,500	4,430	4,030	3,790			4.04	4.46	5.48	6.05	6.45			28.5	30.9	32.5	36.0	34.0		
Oct-04	0	0	18	102	245			5,520	4,540	4,560	4,110	3,940			5.56	5.15	5.62	6.08	6.47			27.8	31.5	32.0	30.2	33.2		
Nov-04	0	0	17	98	245			5,370	4,400	4,340	3,950	3,840			4.46	4.23	5.47	5.99	6.37			28.8	31.4	32.3	35.6	32.0		
Dec-04	0	0	13	87	207			5,290	4,340	4,290	3,920	3,790			4.46	4.28	5.44	5.95	6.36			28.3	31.2	31.0	34.0	30.0		
Jan-05	11	0	32	79	198			5,700	4,610	4,520	4,110	4,080			5.31	3.92	5.46	6.03	6.29			29.1	31.3	31.3	33.8	34.2		
Feb-05	0	0	7	68	196			5,680	4,720	4,550	4,130	3,980			3.92	3.24	5.31	5.98	6.37			28.0	31.5	31.3	33.4	30.0		
Mar-05	0	0	0	60	169			5,540	4,510	4,350	3,990	3,960			3.84	3.72	5.32	5.93	6.27			24.5	31.3	32.0	33.7	35.2		
Apr-05	8	0	29	70	154			5,350	4,300	4,340	3,980	3,890			4.46	4.25	5.56	5.88	6.31			27.8	32.4	32.2	34.0	35.1		
May-05	0	0	0	67	150			5,300	4,290	4,170	3,840	3,810			4.33	3.78	4.53	5.85	6.30			28.5	32.6	30.6	33.4	34.6		
Jun-05	0	0	0	65	138			5,400	4,330	4,280	3,980	3,910			4.06	3.93	4.63	5.77	6.15			28.1	32.1	31.0	33.6	34.7		
Jul-05	0	0	0	67	123			5,020	4,150	4,100	3,780	3,640			5.10	3.55	4.04	5.58	5.88			27.9	31.2	31.9	33.1	34.3		
Aug-05	0	0	0	57	122			5,270	4,320	4,360	3,880	3,730			3.40	3.39	3.29	5.89	6.62			28.4	31.5	31.6	34.2	34.2		
Sep-05	0	NA	0	54	111			5,430	NA	4,230	3,920	3,830			3.58	NA	4.15	5.80	6.24			28.4	NA	31.3	33.2	34.1		
Oct-05	0	NA	0	51	107			5,630	NA	4,410	4,220	4,030			5.45	NA	4.99	6.00	6.26			28.3	NA	31.3	33.6	34.0		
Nov-05	0	NA	5	48	96			5,550	NA	4,180	4,080	3,940			3.75	NA	5.45	5.76	6.25			28.7	NA	33.0	34.2	34.2		
Dec-05	0	NA	22	44	77			5,670	NA	4,190	4,060	3,950			3.38	NA	5.92	5.97	6.43			33.3	NA	35.6	34.1	31.6		
Jan-06	0	NA	28	89	128			5,720	NA	4,110	4,330	4,250			5.22	NA	6.30	6.36	6.47			29.4	NA	45.0	35.2	32.2		
Feb-06	0	NA	101	117	126			5,670	NA	4,350	4,250	4,040			3.83	NA	6.19	6.14	6.38			27.5	NA	41.3	37.5	49.0		
Mar-06	0	NA	190	133	132			5,850	NA	4,290	4,310	4,060			4.14	NA	6.19	6.18	6.18			27.6	NA	43.7	39.9	38.8		
Apr-06	0	NA	244	139	119			5,710	NA	4,280	4,310	5,710			5.21	NA	6.24	6.17	6.10			28.9	NA	44.3	41.0	34.0		
May-06	0	NA	246	138	112			5,740	NA	4,180	4,290	4,130			4.12	NA	6.16	6.02	6.01			28.3	NA	45.1	42.0	33.9		
Jun-06	0	104	249	138	130			5,680	4,280	4,160	4,450	4,080			4.12	5.86	6.14	6.08	6.02			29.0	44.3	45.8	42.0	32.8		
Jul-06	0	134	230	217	138			5,140	4,020	3,750	4,060	3,810			5.06	5.90	6.13	6.14	6.06			29.4	40.7	45.0	50.5	37.0		
Aug-06	0	160	232	227	137			5,340	4,050	3,860	4,140	3,850			3.89	6.04	6.17	6.34	6.24			27.6	43.1	47.2	50.0	37.8		
Sep-06	0	137	235	278	155			5,350	3,960	3,740	3,980	3,870			3.41	6.00	6.16	6.45	6.49			27.8	38.7	27.8	50.5	41.2		
Oct-06	0	141	279	323	133			5,230	4,040	3,810	4,000	4,000			5.11	6.02	6.24	6.42	6.21			29.9	39.0	47.3	51.4	35.0		
Nov-06	0	159	229	304	155			5,390	4,180	3,840	4,020	4,020			3.64	6.01	6.96	6.46	6.59			27.8	38.7	46.2	53.1	44.0		

TABLE 11
 Zone 3 Field Parameter Measurements of Tracking Wells Through October 2012
 United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

	Bicarbonate (mg/L)							Conductivity (umhos/cm)							pH (s.u.)							Chloride (mg/L)						
Date	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A
Dec-06	0	151	233	328	183			5,680	4,290	4,090	4,230	4,360			3.42	6.18	7.05	6.67	6.44			28.6	38.8	47.1	54.0	48.3		
Jan-07	0	149	243	335	196			5,310	4,170	3,920	4,010	4,220			5.23	6.13	6.70	6.56	6.36			29.0	37.0	48.0	53.0	49.0		
Feb-07	0	144	205	272	178			5,340	4,150	3,800	3,900	4,160			4.16	6.50	6.64	6.62	6.43			28.0	37.0	49.0	53.0	51.0		
Mar-07	0	NA	258	310	210			5,500	NA	3,970	4,120	4,200			3.84	NA	6.99	6.92	6.56			29.0	NA	50.0	53.0	50.0		
Apr-07	0	161	302	345	217			5,210	3,990	3,830	3,950	4,060			5.25	6.01	6.33	6.44	6.18			28.0	38.0	46.0	44.0	52.0		
May-07	0	173	288	317	223			5,260	3,980	3,750	3,850	3,860			3.91	6.05	6.48	6.52	6.61			28.0	36.0	48.0	52.0	54.0		
Jun-07	0	169	310	311	191			4,200	3,230	3,020	2,980	3,030			3.38	6.03	6.86	6.85	6.44			28.0	35.0	50.0	51.0	52.0		
Jul-07	0	156	293	322	199			4,750	3,400	3,530	3,410	3,520			5.10	6.16	6.37	6.51	6.40			29.0	36.0	51.0	49.0	54.0		
Aug-07	0	171	293	306	150			4,860	3,770	3,550	3,570	3,650			3.92	5.91	6.45	6.41	6.06			28.0	36.0	53.0	52.0	55.0		
Sep-07	0	184	307	304	135			4,940	3,610	3,570	3,660	3,720			3.58	6.09	6.60	6.46	6.77			29.0	35.0	54.0	53.0	57.0		
Oct-07	20	161	329	307	185			4,630	3,300	3,170	3,200	3,350			3.29	6.39	6.51	6.64	6.20			29.0	36.0	55.0	52.0	50.0		
Nov-07	0	159	295	258	109			4,400	3,530	3,170	3,160	3,350			3.69	5.88	6.94	6.52	6.20			29	36	53	50	53		
Dec-07	0	148	316	290	55			5,440	3,990	3,890	3,980	4,110			3.49	6.04	6.80	6.65	6.05			29	34	51	51	53		
Jan-08	NA	NA	289	294	107	302	350	NA	NA	4,190	4,220	4,470	3,720	3,870	NA	NA	6.41	6.37	5.88	6.69	6.27	NA	NA	54	54	50	37	43
Feb-08	NA	NA	189	299	13	313	NA	NA	NA	3,900	4,050	4,280	3,710	NA	NA	NA	6.80	7.00	5.34	6.64	NA	NA	NA	57	49	53	36	NA
Mar-08	NA	143	139	323	0	312	602	NA	4,220	3,900	4,060	4,370	3,630	3,870	NA	6.20	6.45	6.82	5.16	6.92	6.30	NA	32	57	50	57	35	50
Apr-08	NA	116	156	362	96	306	NA	NA	3,800	3,590	3,680	3,840	3,260	NA	NA	5.86	6.18	6.58	5.83	6.51	NA	NA	32	58	50	49	36	NA
May-08	NA	NA	169	337	29	312	406	NA	NA	3,900	4,040	3,950	3,690	3,980	NA	NA	6.21	6.50	5.97	6.29	6.47	NA	NA	58	53	51	36	37
Jun-08	NA	0	293	287	133	302	453	NA	4,570	3,890	3,990	3,940	3,640	3,880	NA	3.84	6.40	6.53	6.12	6.26	6.15	NA	35	54	54	48	35	37
Jul-08	NA	0	268	302	162	313	228	NA	4,140	3,740	3,770	3,850	3,450	3,730	NA	5.94	6.39	7.28	6.33	6.54	6.38	NA	36	49	53	50	33	41
Aug-08	NA	99	201	289	208	316	349	NA	4,230	3,800	3,840	3,790	3,620	3,810	NA	5.83	6.42	6.88	6.46	6.50	6.35	NA	35	52	51	48	34	40
Sep-08	NA	106	211	290	244	310	327	NA	4,170	3,650	3,720	3,340	3,510	3,740	NA	5.86	6.89	7.18	7.09	6.39	6.32	NA	37	42	48	46	35	38
Oct-08	NA	98	84	301	294	321	337	NA	4,080	4,000	3,770	3,820	3,560	3,760	NA	5.74	5.85	6.69	6.31	6.54	6.37	NA	30	50	55	48	38	38
Nov-08	NA	80	50	127	246	335	338	NA	4,120	3,570	3,900	3,730	3,560	3,750	NA	5.55	5.87	6.16	6.41	6.43	6.24	NA	32	53	57	46	34	35
Dec-08	NA	85	39	79	268	351	346	NA	3,990	3,500	4,040	3,660	3,530	3,700	NA	6.05	5.68	5.76	6.86	6.48	6.26	NA	34	52	57	44	36	38
Jan-09	NA	63	10	15	295	351	344	4950	4,190	3,690	4,100	3,860	3,580	3,800	5.5	5.41	4.02	5.41	6.24	6.55	6.25	NA	30	50	57	43	40	39
Apr-09	NA	55	0	174	271	338	385	5110	4,010	4,960	3,900	3,560	3,600	3,710	5.59	5.31	2.88	6.21	6.80	6.43	6.36	NA	29	42	53	40	38	38
Feb-09	NA	74	0	16	268	344	361	NA	4,200	4,220	3,910	3,420	3,580	3,730	NA	5.64	3.03	5.00	6.55	6.43	6.35	NA	29	51	58	43	39	40
Mar-09	NA	89	12	0	306	343	351	NA	4,170	3,430	3,850	3,750	3,580	3,750	NA	5.74	4.56	4.87	7.29	6.44	6.30	NA	31	39	58	40	38	37
May-09	NA	83	0	205	258	337	332	NA	4,250	4,980	3,800	3,600	3,530	3,820	NA	5.80	2.51	6.35	6.99	6.41	6.31	NA	28	51	50	44	36	36
Jun-09	NA	83	0	287	235	334	318	NA	4,010	4,410	3,520	3,400	3,410	3,660	NA	5.60	2.52	7.32	6.98	6.43	6.30	NA	29	51	48	44	39	37
Jul-09	NA	77	0	244	227	328	308	4670	4,030	4,540	3,680	3,370	3,470	3,660	3.56	5.70	2.50	6.45	7.16	7.91	6.30	NA	29	>40	48	50	40	38
Aug-09	NA	50	0	226	85	312	293	NA	4,440	5,200	3,760	3,640	3,490	3,860	NA	5.33	2.51	6.62	6.64	6.58	6.21	NA	29	40	48	51	41	37
Sep-09	NA	65	NA	51	59	306	277	NA	4,370	NA	3,570	3,720	3,390	3,910	NA	5.40	NA	9.18	6.60	6.44	6.30	NA	29	NA	49	59	43	37
Oct-09	NA	94	NA	111	178	335	280	4860	3,980	NA	3,530	3,960	3,360	3,470	5.5	5.60	NA	6.26	5.65	6.41	5.80	NA	28	NA	42	48	41	36
Nov-09	NA	96	0	87	198	252	294	NA	4,260	2,230	3,500	3,970	3,260	3,760	NA	5.80	3.83	7.04	6.10	6.65	6.40	NA						

TABLE 11
Zone 3 Field Parameter Measurements of Tracking Wells Through October 2012
United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

	Bicarbonate (mg/L)							Conductivity (umhos/cm)							pH (s.u.)							Chloride (mg/L)						
Date	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A
Feb-11	NA	57	NA	234	16	390	246	NA	4,600	NA	3,510	3,750	3,530	3,850	NA	5.66	NA	7.35	4.94	6.91	6.30	NA	28	NA	26	36	45	35
Mar-11	NA	35	0	237	0	397	245	NA	4,680	5,220	3,430	3,790	3,520	3,860	NA	5.40	2.71	7.43	4.07	6.75	6.36	NA	28	28	27	36	48	36
Apr-11	NA	78	0	262	0	402	247	NA	4,720	5,390	3,490	4,060	3,490	3,940	NA	5.87	2.80	6.96	5.71	6.68	6.35	NA	30	28	29	36	50	37
May-11	NA	76	0	223	0	401	239	NA	4,110	5,390	3,470	3,830	3,550	3,920	NA	5.76	2.65	7.42	3.91	6.81	6.65	NA	30	NA	30	36	51	39
Jun-11	NA	67	0	223	0	412	241	NA	4,710	5,340	3,450	3,820	3,510	3,910	NA	5.52	2.59	7.61	3.74	6.87	6.36	NA	30	30	29	34	51	37
Jul-11	NA	65	0	272	0	405	248	NA	4,650	5,640	3,240	4,040	3,450	3,840	NA	5.48	2.70	7.28	5.47	6.51	7.12	NA	30	33	29	35	50	38
Aug-11	NA	294	0	235	0	405	243	NA	3,770	5,640	3,610	4,440	3,700	3,880	NA	6.42	2.70	7.74	3.17	6.78	6.43	NA	38	33	28	34	49	38
Sep-11	NA	85	0	267	0	400	243	NA	4,600	5,610	3,440	4,380	3,530	3,830	NA	5.87	2.51	6.52	2.83	6.58	6.41	NA	30	33	28	37	50	38
Oct-11	NA	79	0	251	0	414	244	NA	4,580	5,540	3,380	4,200	3,490	3,830	NA	5.73	2.56	7.35	2.88	6.80	6.40	NA	30	32	28	36	51	37
Nov-11	NA	88	0	236	0	406	245	NA	4790	5700	3530	4590	3600	3980	NA	5.9	2.49	6.68	2.86	6.75	6.46	NA	29	32	29	32	51	37
Dec-11	NA	77	0	234	0	408	243	NA	4800	5640	3560	4730	3640	3960	NA	6.06	2.67	6.62	2.99	6.78	6.42	NA	30	32	28	32	52	37
Jan-12	NA	63	NA	217	0	405	224	NA	4790	NA	3650	4680	3540	3940	NA	5.74	NA	6.57	2.91	6.76	6.39	NA	30	NA	29	40	52	37
Feb-12	NA	79	0	213	0	406	234	NA	4720	5580	3570	4800	3640	3980	NA	5.83	2.68	6.83	2.84	6.84	6.3	NA	29	33	28	33	52	37
Mar-12	NA	83	0	230	0	391	224	NA	4690	5300	3600	4830	3660	4010	NA	5.9	2.66	6.63	2.82	6.74	6.39	NA	29	33	28	34	50	37
Apr-12	NA	77	0	221	0	373	223	NA	4680	5420	3560	4810	3520	3990	NA	5.8	2.65	6.38	2.81	6.67	6.28	NA	30	33	28	34	50	36
May-12	NA	90	0	219	0	376	228	NA	4690	5420	3500	5350	3550	3980	NA	5.97	2.46	6.50	2.59	6.6	6.37	NA	30	34	27	35	50	36
Jun-12	NA	69	0	223	0	377	226	NA	4600	5830	3450	5420	3520	3900	NA	5.85	2.73	6.60	2.67	6.68	6.24	NA	29	33	27	32	48	37
Jul-12	NA	77	0	213	0	377	226	NA	4610	5630	3560	5130	3480	3950	NA	5.85	2.68	6.41	3.04	6.54	6.36	NA	30	31	27	31	47	35
Aug-12	NA	86	0	207	0	363	221	NA	4530	5580	3640	5550	3540	3890	NA	5.85	2.58	6.56	2.55	6.63	6.32	NA	30	31	27	31	47	35
Sep-12	NA	66	0	184	0	385	222	NA	4460	5660	3600	5150	3490	3870	NA	5.83	2.52	6.58	2.48	6.62	6.46	NA	30	32	27	31	49	36
Oct-12	NA	63	0	219	0	386	224	NA	4500	6080	3630	5110	3230	3930	NA	5.90	2.55	6.38	2.73	6.75	6.46	NA	30	33	27	31	49	35

Notes:
Parameter monitoring of wells NBL-2 and RW-A started in January 2008.
NA = not available (parameters not measured).

TABLE 12
Zone 3 Field Parameter Measurements of NW-Series Wells Through October 2012
United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

	Bicarbonate (mg/L)					Conductivity (umhos/cm)					pH (s.u.)					Chloride (mg/L)				
Date	NW-1	NW-2	NW-3	NW-4	NW-5	NW-1	NW-2	NW-3	NW-4	NW-5	NW-1	NW-2	NW-3	NW-4	NW-5	NW-1	NW-2	NW-3	NW-4	NW-5
Jun-09	137	351	484	196	502	4,170	3,640	3,350	4,270	3,450	5.93	6.27	6.52	6.15	6.52	26	39	40	31	45
Jul-09	127	333	483	212	577	4,270	3,660	3,380	4,400	3,440	6.25	6.15	6.40	6.64	6.30	27	39	37	32	45
Aug-09	106	319	458	220	563	4,460	3,820	3,530	4,460	3,670	5.91	6.16	6.40	6.30	6.51	26	37	36	33	46
Sep-09	112	328	457	232	511	4,420	3,850	3,570	4,530	3,650	6.00	6.35	6.51	6.55	6.88	26	37	37	32	46
Oct-09	146	341	490	243	597	4,060	3,480	3,250	4,080	3,340	7.01	6.73	6.91	6.59	7.15	25	36	36	29	48
Nov-09	117	380	475	154	604	4,330	3,670	3,390	4,270	3,560	6.50	6.34	6.70	5.96	6.70	27	39	38	30	52
Dec-09	124	402	502	167	612	4,320	3,560	3,520	4,260	3,600	6.11	6.38	6.52	6.13	6.89	26	41	39	30	52
Jan-10	123	432	524	167	591	4,310	3,820	3,680	4,230	3,680	6.68	6.26	6.33	6.10	6.35	26	43	41	29	53
Feb-10	119	428	554	173	590	4,280	3,620	3,630	4,150	3,400	6.57	6.47	6.55	6.28	6.76	26	45	45	29	53
Mar-10	127	415	546	192	595	4,260	3,540	3,650	4,080	3,640	6.90	6.52	6.88	6.36	6.97	26	43	46	29	54
Apr-10	123	404	569	173	589	4,560	3,930	3,950	4,260	3,960	5.72	5.96	6.22	5.76	6.32	26	42	47	30	50
May-10	128	400	573	174	597	4,520	3,890	4,210	4,440	3,830	6.16	6.33	6.61	6.09	6.88	26	42	49	29	54
Jun-10	126	395	606	168	584	4,210	3,540	3,720	4,020	3,540	6.11	6.36	6.63	6.09	6.86	26	43	50	30	53
Jul-10	160	389	561	168	590	4,200	3,630	3,690	4,030	3,590	6.12	6.46	6.69	6.17	6.71	26	43	49	30	53
Aug-10	121	402	563	172	501	4,190	3,530	3,680	3,990	3,490	6.13	6.50	6.63	6.11	6.19	26	42	49	30	47
Sep-10	129	401	533	177	597	4,160	3,500	3,680	3,970	3,560	6.10	6.42	6.60	6.05	6.52	25	40	47	28	53
Oct-10	134	399	508	163	585	4,190	3,540	3,690	4,040	3,630	6.17	6.50	6.49	6.12	6.84	25	41	44	28	53
Nov-10	132	390	488	155	567	4,220	3,600	3,680	4,080	3,650	5.94	6.31	6.56	5.92	6.62	24	41	44	28	52
Dec-10	138	390	490	175	563	4,340	3,650	3,860	4,120	3,760	6.30	6.43	6.68	6.05	6.85	24	40	45	27	51
Jan-11	141	395	511	169	610	4,350	3,750	3,860	4,210	3,690	6.49	6.65	6.83	6.20	7.10	25	39	46	27	51
Feb-11	151	391	490	171	622	4,180	3,630	3,750	4,090	3,640	6.37	6.52	6.69	6.19	6.94	25	40	45	28	51
Mar-11	150	409	489	171	627	4,200	3,620	3,770	4,070	3,670	6.70	6.57	6.77	6.26	6.90	25	41	47	28	52
Apr-11	155	395	489	168	557	4,280	3,700	3,820	4,190	3,620	6.36	6.52	6.85	6.20	6.91	25	43	48	30	51
May-11	133	377	465	173	549	4,330	3,730	3,800	4,200	3,650	6.18	6.50	6.81	6.27	6.83	26	43	49	30	50
Jun-11	135	399	468	158	545	4,280	3,700	3,790	4,170	3,640	6.17	6.35	6.75	6.01	6.91	26	43	48	29	49
Jul-11	140	398	445	162	544	4,160	3,670	3,780	4,120	3,600	6.64	6.84	6.50	6.81	6.89	26	42	50	29	50
Aug-11	141	393	435	162	582	4,130	3,590	3,530	4,050	3,520	6.58	6.56	6.80	6.21	7.05	26	42	48	29	50
Sep-11	145	367	437	139	583	4,120	3,630	3,630	3,950	3,480	6.59	6.65	6.94	6.14	7.10	28	43	46	30	50
Oct-11	266	368	399	163	591	3,880	3,630	3,620	4,090	3,540	6.60	6.53	6.98	6.30	7.00	35	42	46	28	52
Nov-11	157	379	417	170	583	4,260	3,750	3,800	4,330	3,620	6.49	6.65	6.95	6.49	7.00	25	43	46	29	52
Dec-11	155	362	423	163	569	4,410	3,840	3,830	4,320	3,720	6.74	6.79	6.75	6.41	7.18	26	42	44	29	53
Jan-12	123	347	401	151	491	4,300	3,760	3,760	4,380	3,370	6.61	6.55	6.77	6.28	6.94	26	42	42	29	48
Feb-12	212	368	406	158	490	4,280	3,790	3,760	4,350	3,400	6.75	6.52	6.67	6.12	6.97	25	42	43	29	45
Mar-12	161	344	385	157	492	4,210	3,780	3,750	4,380	3,700	7.01	6.51	6.75	6.23	6.99	24	40	42	28	47
Apr-12	132	327	385	149	484	4,240	3,810	3,730	4,370	3,720	6.54	6.36	6.54	5.90	6.95	26	40	42	29	47
May-12	182	341	396	126	478	4,250	3,830	3,750	4,370	3,750	6.70	6.47	6.79	6.05	7.00	23	40	39	29	46
Jun-12	180	251	380	134	446	4,080	3,750	3,760	4,280	3,780	6.67	6.53	6.61	6.00	6.98	23	39	39	28	45
Jul-12	180	245	360	133	417	4,100	3,690	3,560	4,340	3,740	6.61	6.50	6.66	6.03	6.91	23	39	39	29	45
Aug-12	178	296	373	135	418	3,860	3,730	3,650	4,240	3,810	7.05	7.27	6.57	6.11	6.91	23	38	39	28	44
Sep-12	225	222	382	118	417	3,840	3,630	3,550	4,190	3,740	7.43	6.97	6.95	6.20	7.10	22	40	39	28	45
Oct-12	225	238	389	116	401	3,890	3,960	3,610	4,230	3,810	7.07	6.35	6.78	6.20	7.02	22	39	38	28	44

TABLE 13
Zone 3 Seepage Migration Evaluation, 2012
United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

End Point Well	Starting Point	Distance Between Both Points (ft)	Time for Onset		Travel Time (ft/yr)	Basis for Determining Onset Date for Seepage Impacts At Selected Points
			Seepage Impacts at Starting Point (date)	Seepage Impacts at End Point (date)		
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	Apr-96	95	Bicarbonate concentration greater than 500 mg/L
PB 2	North Cell	3,080	1980	Oct-02	140	Bicarbonate concentrations first declining to 50 mg/L at Well PB 2
PB 2	504 B	630	Jul-92	Oct-02	61	Bicarbonate concentrations first declining to 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
PB 4	PB 2	52	Jan-08	Nov-08	58	Bicarbonate concentrations again declined to below 50 mg/L at each well
			Geometric Mean		92	

End Point Well	Starting Point Well	Distance Between Both Points (ft)	Time for Onset		Net Migration Distance (ft)	Basis for Determining Onset Date for Seepage Impacts At Selected Points
			Seepage Impacts at Starting Point (date)	Seepage Impacts at End Point (date)		
NBL 1	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	<p>Since December 2005, water quality in the northern tracking wells (including NBL 1) has varied significantly (for example, see the field bicarbonate measurements in Table 11 and the lab bicarbonate measurements shown in Figure 40). This reflects the influence of pumping systems (which have changed over time) and variable mixing of impacted water with background water drawn in from the west. Full seepage impact has occurred at PB 4 since Nov-08 (bicarbonate < 50 mg/L) or Jan-09 (pH < 5.0). To the north of this well, NBL 1 has shown strongly degraded water quality in terms of both bicarbonate and pH (Table 11) as well as other constituents (see laboratory analytical summary sheet for 2012 in Appendix B; e.g., elevated aluminum, cobalt, and nickel). Based on these data, the leading edge of the impacted water is shown as passing through NBL 1 in Figure 35. Between impacted wells PB 4 and NBL 1, the water quality at PB 3 significantly improved during 2010 and 2011 and has since been stable (Table 11 and Appendix B), indicating the high degree of geochemical variability, sometimes at very close spacing, in the northern part of Zone 3.</p>

TABLE 14
Detected Constituents in Zone 3, October 2012
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Chemical Name	Action Level	Unit	0420	0517	0613	0708	0711	0717	0717 FD	0719	EPA 13	EPA 14	MW-6	MW-7	NBL-01	NBL-02	NW-1	NW-2	NW-3	NW-4	NW-5	PB-02	PB-03	PB-04	RW-11	RW-A
ALUMINIUM	5	mg/l	0.2	12.9	566 D	36.7	0.3	122	120	0.1		70.8			43.4							0.4	0.2	132		
AMMONIA (AS N)		mg/l	0.1	10.4 D	206 D	1.3 D	0.42	59 D	58 D	0.7	0.26	24 D	0.42	1.1 D	0.7 D							0.67	0.9 D	0.27	1.9 D	2.5 D
ARSENIC	0.05	mg/l					0.004				0.015				0.032									0.011		
BERYLLIUM	0.017	mg/l		0.011	0.144	0.043	0.002	0.102	0.104		0.002	0.069			0.039									0.033		
BICARBONATE (HCO3)		mg/l	503							14	57		281	348		399	242	243	402	112	415	57	217		220	227
CADMIUM	0.01	mg/l		0.008	0.036			0.016	0.016			0.01														
CALCIUM		mg/l	718	456	442	460	500	486	504	536	532	470	508	673	531	654						555	596	504	594	595
CHLORIDE	250	mg/l	52 D	43 D	142 D	30 D	16 D	67 D	67 D	30 D	43 D	61 D	38 D	41 D	30 D	51 D	26 D	41 D	41 D	30 D	43 D	29 D	27 D	30 D	38 D	36 D
COBALT	0.05	mg/l	0.02	0.85	1.89	0.6	0.29	0.89	0.9	0.31	0.09	0.75	0.11	0.06	0.94	0.03						0.49	0.12	1.33	0.25	0.27
GROSS ALPHA	15	pci/l	5.2	7	14.5	11.2	4.3	13.2	14.5	4.5	5.2	4.8	3.5	7.7	5.1	5.7						14.2	7.6	3.3	9.8	10.7
LEAD	0.05	mg/l		0.014	0.007	0.004	0.003	0.01	0.01			0.006			0.074									0.022		
LEAD-210	1	pci/l		1.9	2.4	1.2	1.1	2.4	2.7			1.5			3.4											
MAGNESIUM		mg/l	144	480	693	604	462	508	510	674	896	480	383	229	368	190						508	288	457	373	346
MANGANESE	2.6	mg/l	1.43	10.7	51.1	13.8	5.02	22.1	21.2	6.04	7.68	15.1	3.83	3.77	6.61	1.66						6.21	4.19	9.8	5.12	4.91
MOLYBDENUM	1	mg/l	0.9				0.2			0.1	0.2		4.6	0.8		0.2						0.1	0.4	0.4	0.2	0.1
NICKEL	0.05	mg/l		1.07	1.9	0.82	0.27	0.88	0.9	0.39	0.23	0.71	0.15	0.1	1.23							0.62	0.17	2	0.29	0.31
NITRATE (NO3)	190	mg/l			3.4 D			30 D	30 D		0.1	12 D		0.7 D		9 D										
PH (FIELD)		su	6.72	3.56	2.88	3.54	5.07	4.22	4.21	5.76	6.05	4.29	6.88	6.61	2.73	6.75	7.07	6.35	6.78	6.20	7.02	5.90	6.38	2.55	6.25	6.46
PH (LAB)		su	7.14 H	3.09 H	2.97 H	2.91 H	3.78 H	4.07 H	4.06 H	5.18 H	6.35 H	4.24 H	6.61 H	6.73 H	2.73 H	6.71 H	7.20 H	6.25 H	6.74 H	6.12 H	6.98 H	5.76 H	6.89 H	2.50 H	6.22 H	6.43 H
POTASSIUM		mg/l	7	12	1	15	11	14	14	14	14	12	10	9	13	8						13	11	3	11	11
RADIUM-226		pci/l	4.4	6.6	13	7.6	3.4	12	12	3.4	4.1	8.1	2.6	7.5	6	6.2						12	7.1	6.8	9.7	12
RADIUM-228		pci/l	8.1	14		6	9.6	34	35	15	9.7	18	5.7	14	5.5	12						20	9.5		20	21
RADIUM 226 & 228	5	pci/l	12.5	20.6	13	13.6	13	46	47	18.4	13.8	26.1	8.3	21.5	11.5	18.2						32	16.6	6.8	29.7	33
SELENIUM	0.01	mg/l									0.001															
SODIUM		mg/l	156	151 D	248 D	130 D	103 D	186 D	181 D	149 D	171 D	170	213 D	150	138 D	157						150 D	135	140 D	145 D	149
SULFATE (SO4)	2125	mg/l	2070 D	3770 D	8630 D	4500 D	3280 D	4430 D	4410 D	4180 D	5030 D	4090 D	2840 D	2490 D	4260 D	2170 D						3470 D	2600 D	6400 D	2880 D	2780 D
THORIUM-230	5	pci/l		7.3	690					0.3					4.9							0.3		34.5		
TOTAL DISSOLVED SOLIDS (LAB)	4800	mg/l	3550	5470	11900	6270	4520	6120	6090	5900	7160	6080	4680	3900	5530	3580	4190	4100	3960	4830	4060	5140	4020	8300	4540	4460
TOTAL TRIHALOMETHANES	80	ug/l		7.52	88.8			3.48	6.4			0.66														
URANIUM	0.3	mg/l	0.388	0.124	0.989	0.108	0.0169	0.0194	0.0192	0.0029	0.0115	0.0078	0.129	0.165	0.189	0.195						0.0212	0.136	0.453	0.14	0.0936
VANADIUM	0.1	mg/l			1.8																					

TABLE 15

Zone 1 Performance Monitoring Program, 2012 Operating Year
 United Nuclear Corporation, Church Rock Site
 Church Rock, New Mexico

Well ¹	Water Level ²	Water Quality ²	NRC POC	Purpose
Continue Monitoring				
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	X	Y	Postmining-pretailings background water quality
EPA 5	X	X	Y	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 Performance Monitoring 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
Total	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:

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

TABLE 16
Zone 1 Saturated Thickness, October 2012
United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

Well	Water Level Measurement Date	Zone 1 Unsaturated Thickness	Zone 1 Saturated Thickness	Zone 1 Percentage Saturated
TWQ-142	10/16/2012	0.00	55.00	100%
TWQ-143	10/19/2012	0.00	52.00	100%
0412	10/19/2012	0.00	76.00	100%
0501 A	10/18/2012	10.38	54.62	84%
0502 A	10/18/2012	0.00	59.00	100%
0504 A	10/18/2012	7.56	60.44	89%
0505 A	10/18/2012	0.00	46.00	100%
0515 A	10/10/2012	28.55	12.45	30%
0604	10/10/2012	25.98	19.02	42%
0614	10/10/2012	23.67	21.33	47%
0617	10/10/2012	39.31	6.69	15%
0619	10/16/2012	26.90	38.10	59%
EPA 02	10/15/2012	21.32	28.68	57%
EPA 04	10/15/2012	19.01	35.99	65%
EPA 05	10/15/2012	30.05	18.95	39%
EPA 07	10/15/2012	30.60	52.40	63%
EPA 08	10/15/2012	27.73	38.27	58%

TABLE 17

Detected Constituents in Zone 1, October 2012
 United Nuclear Corporation, Church Rock Site
 Church Rock, New Mexico

Chemical Name	Action Level	Unit	0142	0515 A	0604	0614	0617	0619	EPA 02	EPA 02 FD	EPA 04	EPA 05	EPA 07
ALUMINUM	5	mg/l		1.4	1.6		1.9	0.5					0.2
AMMONIA (AS N)		mg/l	0.4	28 D		161 D	264 D	0.9 D	0.44	0.42	1.4 D	1.4	0.18
ARSENIC	0.05	mg/l			0.002								
BICARBONATE (HCO ₃)		mg/l	296	893	29	1370	1540	518	306	338	153	66	658
CALCIUM		mg/l	61	458	473	562	505	553	382	391	592	488	522
CHLORIDE	250	mg/l	18	383 D	62 D	269 D	263 D	119 D	22 D	21 D	39 D	40 D	241 D
COBALT	0.05	mg/l		0.02	0.15		0.01	0.11				0.04	0.03
GROSS ALPHA	15	pci/l	1.1	1.6	1.3	0.6	1.9	2.4	1.8	2.8	1.7	2.2	1.7
LEAD	0.05	mg/l		0.002		0.003	0.004	0.003				0.001	
MAGNESIUM		mg/l	31	1260	794	703	1560	652	161	169	380	486	967
MANGANESE	2.6	mg/l		8.12	5.36	0.82	2.1	4.94	1.24	1.39	2.76	0.9	1.89
NICKEL	0.05	mg/l		0.13	0.25		0.07	0.27				0.06	
NITRATE (NO ₃)	190	mg/l		39 D	68 D	139 D	98 D					2.1 D	131 D
PH (FIELD)		su	8.07	6.04	5.31	6.52	6.82	6.94	6.93	6.93	6.85	6.11	6.11
PH (LAB)		su	7.36 H	6.06 H	5.40 H	6.58 H	6.75 H	7.08 H	7.04 H	6.75 H	7.04 H	6.16 H	6.33 H
POTASSIUM		mg/l	4	20	13	17	26	14	7	7	9	6	9
RADIUM-226		pci/l	0.57	2	1.4	1.1	2.1	1.8	0.91	1.1	1.1	1.1	0.36
RADIUM-228		pci/l	0	3.3	4.6	3	6.9	9.4	2.4	3	3.6	2.3	1.8
RADIUM 226 & 228	5	pci/l	0.57	5.3	6	4.1	9	11.2	3.31	4.1	4.7	3.4	2.16
SELENIUM		mg/l		0.001	0.003		0.005						
SODIUM		mg/l	362	604 D	302 D	464 D	504 D	275 D	215	216	191 D	112 D	415 D
SULFATE (SO ₄)	2125	mg/l	697 D	6160 D	4620 D	3720 D	7340 D	3720 D	1800 D	1700 D	3010 D	3130 D	4490 D
THORIUM-230	5	pci/l								0.4			
TOTAL DISSOLVED SOLIDS (LAB)	4800	mg/l	1290	9870	6880	7170	11600	6200	2990	2820	4500	4790	7740
TOTAL TRIHALOMETHANES	80	ug/l		416	6.6	238	2.23						0.63
URANIUM	0.3	mg/l		0.0125	0.0004	0.0459	0.0811	0.0474	0.002	0.0022	0.0003	0.0006	0.0018

TABLE 18
 Predicted Performance of the Zone 1 Natural Attenuation System
 United Nuclear Corporation, Church Rock Site
 Church Rock, New Mexico

Constituent	Will Standards Be Met?		Remarks
	Section 1	Section 36	
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
TTHMs	Yes	No	dispersion. However, there have been long-term intermittent exceedances in 515 A and 614.