



**Annual Review Report – 2011**  
**Groundwater Corrective Action**  
**Church Rock Site, Church Rock, New Mexico**

**United Nuclear Corporation**  
**Gallup, New Mexico**

**January 2012**







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January 28, 2012

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Ms. Katrina Higgins-Coltrain  
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USEPA Superfund (6SF-RL)  
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Re: Executive Summary  
2011 Groundwater Corrective Action Annual Review Report  
Materials License No. SUA-1475  
United Nuclear Corporation's Church Rock Tailings Site, Gallup, New Mexico

Dear Mr. McConnell and Ms. Higgins-Coltrain:

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 2011 operating year and represents the period from January 2011 through October 2011. 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 2011, remediation in this same area was enhanced by injection of water amended with sodium bicarbonate in well IW A. The conclusions and recommendations of this annual report are provided below.

### **Conclusions**

The current Site standard for Pb-210 is 1 pCi/L (NRC Source Materials License), which was the idealized lower limit of detection 30 years ago (see NRC, 1980). UNC is presently preparing a License amendment request for NRC to revise some of the groundwater protection standards to newly calculated background values as background threshold values (95<sup>th</sup> 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).

- *Excluding detections of Pb-210, there are no exceedances of hazardous constituents outside the UNC property within seepage-impacted groundwater – this is the case for all three hydrostratigraphic units.*
- *Excluding detections of Pb-210, Zone 1 groundwater offsite in Section 1 meets or exceeds the NRC groundwater protection standards.*
- *Excluding detections of Pb-210, both onsite and offsite groundwater quality meets or exceeds the NRC groundwater protection standards in the Southwest Alluvium.*
- Groundwater levels in the Southwest Alluvium continued to decline in 2011, indicating that the artificially recharged zone of saturation continues to become naturally dewatered as the groundwater drains down the arroyo. However, groundwater to the north of the Nickpoint apparently 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. Furthermore, prior pumping of extraction wells did not contain the constituents and would not do so in the future.
- Mapping of bicarbonate isoconcentration contours is the most meaningful method of delineating seepage-impacted water in the Southwest Alluvium.



- 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.
- Sulfate, TDS, and manganese are non-hazardous constituents that exceed standards outside the Site boundary in both seepage-impacted and background wells. Sulfate (the primary component of TDS) tends to temporarily fall below the standard in the migrating reaction zone associated with the front and northwestern flank of the migrating seepage-impacted groundwater in the Southwest Alluvium. Ahead of this migrating front, background concentrations for sulfate and TDS tend to exceed the standards but this water quality is unrelated to seepage impact and application of the Site standards is inappropriate. Behind this migrating front, impacted groundwater quality offsite will tend to have sulfate and TDS levels approximately equal to, or lower than, those in the background water due to equilibration with the mineral gypsum. Ahead of the current seepage-impact front, downgradient background well SBL 1 has shown very high sulfate and TDS and minor exceedances of manganese, cobalt, and nickel that are not due to seepage impact. Similarly, background waters in the other two hydrostratigraphic units also have shown exceedances of Site standards. For example, in Zone 3, Well NBL 1 has shown background exceedances of arsenic, cobalt, molybdenum, nickel, and combined radium. In Zone 1, Well EPA 4 has shown background exceedances of sulfate, manganese, combined radium, and Pb-210 (see Appendices A, B, and C).
- An upward trend in TDS at 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 (e.g., Wells GW 1 and GW 2) or shown decreasing trends (e.g., Well 802) since the pumps were turned off. The gradual increasing trend of concentrations at GW 3 post-dates, for the most part, the shutoff. However, this does not necessarily indicate a causal relationship. For example, nearby Southwest Alluvium 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. Many Southwest Alluvium wells have shown that variously



gradual to steep uptrends and downtrends in uranium are typical, whether they occur during pumping or in the absence of pumping. For example, from October 2008 to October 2010, POC Well 509 D showed a sharp uptrend in uranium; since then it has shown a sharp downtrend.

- Uranium concentrations in the Southwest Alluvium are not related to the migration of uranium in tailings fluids. In fact, tailings solutions are far more depleted in uranium than are background solutions. This is an important consideration for the Site-Wide Supplemental Feasibility Study (SWSFS) because it means the uranium in tailings-impacted water is not degrading the water quality. The range of uranium concentrations in the background water has been empirically shown to be the same as the range within 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 both the 11 years of active pumping and the 10.7 years of post-pumping monitoring, and is theoretically expected based on principles of aqueous chemistry.
- At downgradient Well 624 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.
- 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 levels in Zone 3 continued to decline in 2011, 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 nine 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 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.

- UNC installed five new 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 re-optimized during early November 2009. UNC started injecting water amended with sodium bicarbonate at Well IW A during April 2011, just north of the NW-series of extraction wells. These remedy enhancements in Zone 3 are meant to direct, intercept and extract impacted groundwater, and to locally buffer the water. The injection program was assessed in November 2011 (Chester Engineers, 2011h) and the injection at IW A will continue.
- Full seepage impact has occurred at Well PB 4 since November 2008 (based on bicarbonate concentrations  $< 50$  mg/L) or January 2009 (based on pH  $< 5.0$ ). To the north of this well, there is no unequivocal basis for picking a single location representing the leading edge of moderate seepage impact. Pumping in the northernmost part of Zone 3 has created a mixing zone of background and impacted water, which makes a single-line plume boundary depiction in this area inappropriate. However, based on specific (though oscillating) water quality trends, the northernmost edge of full impact is diagrammatically located along Well NBL 1 – bicarbonate and pH measurements just to the north, in the NW-series of wells and Wells MW-6 and MW-7, suggest that fully impacted water has not advanced beyond NBL 1.
- The degree of seepage impact in Zone 1 is diminishing. Groundwater elevations in Zone 1 continued to decline in 2011, 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.
- In Zone 1, the continuing improvement in offsite water quality, combined with the stability of onsite concentrations, leads to the conclusion that the Zone 1 groundwater corrective action program has achieved success. Final closure and License transfer will require meeting the Site standards, and it is likely that some standards will need to be revised.



- UNC submitted an updated baseline human health risk assessment during 2011 (Chester Engineers, 2011b). Based on written comments from EPA and a conference call with all the agencies, UNC is presently revising the risk assessment as a final draft.
- UNC submitted Revised SWSFS Parts I and II during 2011 (Chester Engineers, 2011c). Based on EPA written comments and a conference call with all the agencies, UNC is presently revising Parts I and II and developing Part III. (Part I = remediation standards update; Part II = development and screening of remedial alternatives; and Part III = detailed analysis of remedial alternatives.)

### ***Recommendations***

UNC has previously requested deletion of Pb-210 from the Site standards, which NRC denied (Earth Tech, 2001b and 2001c; NRC, 2001). An additional 11 years of chemical analytical data have accrued, and the recent laboratory protocols and results indicate that it is important to consider Pb-210 issues including (1) sample-specific minimum detectable concentrations and analytical results, and (2) 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 is preparing a License amendment request for NRC that proposes the revision of some Site groundwater protection standards to newly calculated background threshold values (95<sup>th</sup> percentile of the upper prediction limits).

### ***Recommendations for Closure of Southwest Alluvium Remedial Action***

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:

1. Decommission the pumping wells. Attenuation via natural geochemical processes has been shown to be at least as effective as pumping. Implement a No Further Action remedial alternative.
2. Change performance monitoring from quarterly to an annual basis because the seepage-impacted water quality is largely stable, the offsite impacted water quality is not hazardous, and a yearly frequency is sufficient for tracking the migration of the seepage-impact front (estimated to be moving southwestward toward Well SBL 1 at an average rate of 16 ft per year).
3. EPA should consider adopting the revised NRC standards (NRC, 2006b) for chloroform (revised to a total trihalomethanes (TTHMs) Site-wide standard of 80 µg/L) and combined radium (revised to 5.2 pCi/L standard for the Southwest Alluvium). EPA should also consider (a) revising their current ROD uranium standard of 5 mg/L and adopting the NRC Site-wide standard of 0.3 mg/L (based on the review of dissolved



uranium occurrences in the Southwest Alluvium presented by UNC (GE, 2006)), and (b) adopting the NRC's (1996) proposed standards for sulfate, TDS, and nitrate (throughout all three Site hydrostratigraphic units). 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).

4. The Southwest Alluvium meets or exceeds the NRC groundwater protection standards. EPA's longstanding reluctance to issue a TI Waiver for sulfate and TDS is confusing because there are no known groundwater analyses anywhere in the Southwest Alluvium, seepage-impacted or not, that meet the New Mexico Standards for sulfate and TDS. In lieu of eliminating sulfate and TDS concentrations as ARARs, a TI Waiver for sulfate and TDS could best be applied in a non-traditional sense in that there would not be a classic TI zone. Instead, UNC proposes that the projected 200-year seepage front (as extrapolated during 2004) be used, which we understand to be compatible with NRC guidance. Background water quality has shown modest exceedances of manganese, cobalt, Pb-210, and nickel; it is appropriate that the EPA consider revising the ROD to recognize the historic background water quality for these constituents in the Southwest Alluvium. We now have available statistically derived background concentrations for all constituents (data permitting) in all three hydrostratigraphic zones (both as upper confidence levels at the 95<sup>th</sup> percentile on the mean in N.A. Water Systems, 2008f, and as 95<sup>th</sup> percentile upper prediction limits (background threshold values) in the pending NRC License amendment request).
5. 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 dewatering the alluvium. 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*

Continue Zone 3 remediation using the natural system to stabilize the seepage impacts, in conjunction with the current pumping system that provides capture of most or all of the downgradient migration of seepage-impacted water, and dewateres the hydrostratigraphic unit.



Continue the injection of water amended with sodium bicarbonate in Well IW A in the northern area of Zone 3 in Section 36.

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, there will be a balance developed between the irreducible elevation head and the trapping of the seepage-impacted groundwater due to the diminished bedrock permeability. 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.

#### *Recommendations for Closure of Zone 1 Remedial Action*

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:

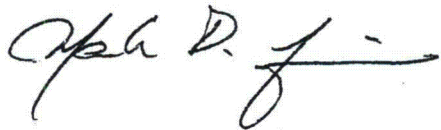
1. EPA should consider adopting the current NRC Site-wide groundwater protection standard of 80 µg/L for TTHMs (this group of compounds includes chloroform). This value is the current MCL.
2. EPA should consider adopting the current NRC standard of 9.4 pCi/L for combined radium in Zone 1. This value is based on background water quality statistical analysis that was done for NRC in 2006 (N.A. Water Systems, 2006a), as part of an approved License amendment.
3. The Zone 1 seepage-impacted area has attained ALARA goals.
4. 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, and Zone 1 has already been dewatered to the extent that is feasible (the final pumping wells were decommissioned in 1999 because their yields were less than the decommissioning limit). It is not appropriate to tie remediation progress to sulfate or TDS concentrations. Even the last drop of water left in Sections 1 and 2 of Zone 1 would exceed the standards for these parameters. 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).

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

Sincerely,



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

MDJ: 11-6209-SC-113

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

cc with enclosure:     Yolande Norman, Nuclear Regulatory Commission (2 copies)  
                             Earle Dixon, New Mexico Environment Department  
                             Eugene Esplain, Navajo Nation Environmental Protection Agency  
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United Nuclear Corporation  
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January 2012

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Approved by: Robinson P. Khosah, Ph.D.

Project No.: 11-6209-SC-113





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# List of Acronyms and Abbreviations

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ACL	alternate concentration limit
ALARA	as low as reasonably achievable
ARARs	applicable or relevant and appropriate requirements
COPCs	constituents of potential concern
EPA	U.S. Environmental Protection Agency
FS	feasibility study
ft/yr	feet per year
gpm	gallons per minute
GWPS	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 <sup>th</sup> 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 is the 23rd in the series and includes groundwater quality analyses and groundwater elevations for the first quarter of 2011 through the fourth quarter of 2011.

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) and by the approvals to decommission or temporarily shut off the three corrective action 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. 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 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. This report 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 re-optimization of the pumping scheme described in Chester Engineers, 2009c); 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, 2010d; 2011h). 22 years of active remediation of Zone 3 by the extraction of impacted groundwater and constituent mass resumed with the Phase I hydrofracture study in 2005 and continued through 2011.

UNC submitted an alternate concentration limit (ACL) application (N.A. Water Systems, 2008h) to the U.S. Nuclear Regulatory Commission (NRC). This focused ACL application proposed changing the NRC License groundwater protection standards in two Point-of-Compliance (POC) wells in Zone 1 within Section 2: Wells 604 (for nickel) and 614 (for total trihalomethanes [TTHMs]). During 2011 NRC informally indicated that UNC's proposed Points-of-Exposure (POEs), located off-site in Section 1, will not be acceptable. This application is discussed further in this annual report in Section 4.

At the request of the NRC, UNC submitted to NRC a list of technical impediments (GE, 2009) to eventual Site closure at the Church Rock mill. 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.

EPA has directed UNC (EPA, 2006a) to provide a Site-Wide Supplemental Feasibility Study (SWSFS). Toward that objective, UNC submitted a statement of the preliminary proposed content of the SWSFS (N.A. Water Systems, 2006b) and a list of preliminary assembled remedial alternatives (N.A. Water Systems, 2006c). The latter document has been addressed by EPA comments (EPA, 2006b) developed with input from the NRC, the New Mexico Environment Department (NMED), and the Navajo Nation Environmental Protection Agency (NNEPA).

UNC and the agencies held a conference call on November 30, 2006 and agreed on the next step toward developing the SWSFS: UNC would reassess the provisional site cleanup goals (preliminary remediation goals, remedial action objectives, and Applicable or Relevant and Appropriate Requirements (ARARs)), following the original site Feasibility Study (EPA, 1988a) and the EPA Record of Decision (EPA, 1988b). The results of this work were reported to EPA during February 2007 as Part I of the SWSFS (N.A. Water Systems, 2007b). This submittal was the subject of EPA comments (EPA, 2008a) that included the requirement that UNC conduct extensive statistical analyses of the background and impacted waters. These analyses were completed and submitted in 2008 (N.A. Water Systems, 2008e; 2008f; 2008g). EPA approved these revised components of the SWSFS Part I and indicated that this first part of the SWSFS has been satisfactorily completed (EPA, 2009).

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. EPA (2010) provided comments to UNC on revised Part II with guidance about the pending development of Part III (the detailed analysis of remedial alternatives); this document also included comments from NRC and NMED. UNC provided responses (Chester Engineers, 2010e) that were the subject of a conference call with all the stakeholders on November 5, 2010.

UNC submitted the Revised Site-Wide Supplemental Feasibility Study Parts I and II during April 2011 (Chester Engineers, 2011c), for which EPA has provided comments (EPA, 2011b). Follow-up discussion between UNC and the agency stakeholders (Chester Engineers, 2011i) has clarified specific issues that will allow UNC to proceed with further revision of SWSFS Parts I and II and development of Part III.

During 2011, EPA has decided that the Northeast Church Rock Mine (inactive) spoil piles are going to be moved and deposited on the tailings cells for final disposal. At the request of the stakeholders at the May 24 technical meeting, UNC prepared a report (Chester Engineers, 2011e) summarizing previous reports, and new information, related to Zone 3 tailings seepage sourcing and groundwater recharge.

At the request of EPA (EPA, 2010), UNC has submitted an updated baseline human health risk assessment (HHRA, Chester Engineers, 2011b). The objective of a human health risk assessment is to evaluate the likelihood of adverse effects occurring in human populations



potentially exposed to contaminants in the environment. EPA's site-specific objectives for preparing the baseline HHRA for the UNC Church Rock tailings Site were the following:

1. Update the risk estimates for the Site using current risk assessment methods and information;
2. Support the reassessment of remediation levels;
3. Provide a basis for comparing remedial alternatives.

EPA provided comments on the baseline HHRA (EPA, 2011a), for which UNC developed responses (Chester Engineers, 2011g) that were the subject of a conference call with all the agencies on December 9, 2011. UNC is presently revising the risk assessment to address those comments and responses.

Risk assessment methods are also used to ensure that regulatory decisions made at NRC-licensed facilities are protective of human health and the environment. For example, risk assessment methods are used in support of the establishment of site-specific ACLs to demonstrate that the constituents will not pose a substantial present or potential hazard to human health or the environment, as long as the ACLs are not exceeded. The regulatory approaches and guidance for risk assessments are somewhat different for EPA and NRC, and during 2011 UNC has significantly advanced risk-related issues with each agency (e.g., Chester Engineers, 2011b, and 2011f).

One principal difference between the methods used for a baseline HHRA prepared for EPA and a risk assessment evaluation for NRC is the treatment of background concentrations of constituents of potential concern (COPCs). For an EPA baseline HHRA, the risk calculations will typically include all constituents of potential concern (COPCs) that are present at concentrations above screening levels in the impacted area, regardless of whether the COPCs are present in background at similar or higher concentrations. The risk associated with background COPC concentration may be then distinguished from that associated with Site impacts at a later stage in the risk management process. For NRC, risk assessment methods are typically used to identify the excess risk related to the NRC-licensed facility (i.e., the risk above the existing background conditions) and therefore only those COPCs that are present in impacted areas at concentrations above background would be included in the risk assessment.

Another difference is that the NRC risk assessment process incorporates the concept of contaminant attenuation between a defined POC, the location at which a standard must be met, and a POE at which COPC concentrations must be protective of human health and the environment. The POE-POC concept is not part of the EPA baseline HHRA; however, the ultimate goal of the EPA risk management process, i.e., protectiveness at the point of exposure, is the same.



### 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, and 2011a).

### 1.2 Corrective Action Systems

The corrective action systems for tailings seepage remediation were installed and began operating during the summer and fall of 1989. These systems have been decommissioned or, in the case of the Southwest Alluvium, temporarily shut off, and performance monitoring is ongoing. The Zone 1 system was decommissioned in July 1999 in accordance with the letter from the NRC dated July 30, 1999 (NRC, 1999a).

In Zone 1 during April 2011 there were sporadic concentrations of lead-210 (Pb-210) above the GWPS in two POC wells: background Well EPA 4 (Section 1) and Well EPA 5 (Section 1). Except for these results (discussed more below), offsite groundwater quality for all NRC-regulated constituents in all Zone 1 wells in Section 1 meet or exceed the NRC groundwater protection standards. Pb-210 is a regulated constituent for the Site NRC License but not for the EPA ROD.

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 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 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 2011 (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 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 almost 13 million gallons from 2005 through 2011. 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 eight years. Individual well water-quality trends of improvement and degradation have become collectively asynchronous since May 2007. During 2009, two of these wells (NBL 1 and PB 3) showed highly variable groundwater quality reflecting mixing of impacted and background waters that accompanies pumping; during 2010 and 2011, the water quality improved in PB 3 but degraded in NBL 1 (these two wells are 110 ft apart). The groundwater quality in the northern part of Zone 3 is discussed further in Section 3 of this report.

On April 14, 2011 injection of water amended with sodium bicarbonate started at Zone 3 Well IW A (Chester Engineers, 2011h). 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 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 impacted groundwater. Through November 30, 2011 a total of 281,933 gallons has been injected at an average rate of approximately 0.87 gpm (equivalent to 52 gallons per hour and 1,253 gallons per day). The injection performance is discussed further in Section 3 of this report.

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 2011 groundwater quality has met or exceeded all NRC groundwater protection standards in the Southwest Alluvium.



### 1.3 Performance Monitoring and Supplemental Sampling

#### 1.3.1 Performance Monitoring

The groundwater performance monitoring plan is described by the Corrective Action Plan (UNC, 1989a), Remedial Design Report (Canonie, 1989a) and Remedial Action Plan (UNC, 1989b), and has been approved by the NRC and EPA. 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, and 2011a), to adjust the monitoring requirements as the corrective action has progressed. The NRC and EPA have approved all modifications.

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

The field and laboratory data collected from the fourth quarter of 1989 through the fourth quarter of 2011 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, 2011c, Table 15, which includes updated values for several of the current health-based criteria).

Quarterly laboratory analytical data sheets for the 2011 operating year are included at the end of each appendix.

#### 1.3.2 Supplemental Sampling

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.

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 2011 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 impacted for many years (see Table 11), and since January 2011 water levels there have become too low to allow sampling. 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, 2010d). 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, 2011h). Monthly field parameter monitoring at these two wells started in August 2011.

Though not a formal part of the performance monitoring program, to improve our understanding of the groundwater quality along the northern front of the impacted water in Zone 3 the following additional wells were sampled in 2011 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.

### *1.3.3 Lead-210 Analytical Results*

During 2010 an unexpectedly high frequency of Pb-210 detections and exceedances were found across the entire ~ 8,000 ft length of the Site, in all three hydrostratigraphic units. For example, during the nine years from 2001 through 2009, there were a total of 23 detections of Pb-210 across the Site. By comparison, during 2010 alone there also were 23 detections with 14 of them clustered into the October 2010 sampling event. During 2011 there were 21 detections. Changes in laboratory analytical and reporting protocol (started during April 2008; see N.A. Water Systems, 2008d) apparently are related to the sudden increase in detections, combined with Energy Laboratory's more recent change to using a new liquid-scintillation counter in Texas. Virtually all the detections were exceedances of the NRC License standard of 1 pCi/L. An analysis of the Pb-210 results was provided by UNC during a presentation at the Albuquerque technical meeting (Chester Engineers, 2011d), which is briefly summarized below.

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 has 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 at the new Texas location). 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 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.

The MDC analytical results are generally very low concentrations. For example, of the 21 Pb-210 detections during 2011, the highest result was 12.7 pCi/L (Zone 3 Well PB 4, which is highly impacted); the next highest result was 3.1 pCi/L (Zone 3 Well 708, which is highly impacted); all other results are less than 3 pCi/L. For results of duplicate samples, the relative percent differences tend to be skewed toward low or high values (the relative percent difference is defined as the numeric difference between the two concentrations, divided by the average concentration times 100). For example, during January 2011 the relative percent difference for Zone 1 Well EPA 4 is 67% (background well in Zone 1); for NBL 1 it is 52%; and for SBL-1 it is 138% (background well in the Southwest Alluvium). During the entire year for 2011, only one well had detections in all four quarters: Zone 3 Well EPA 14 (which is highly impacted as discussed in Section 3 of this report). Only one well had detections in three of the four quarters: Zone 3 Well 717 (impacted). For most of the other Site wells the very low detected concentrations, distributed in one to two of the four quarters, indicate that the Pb-210, if actually present, is very close to the MDCs and beneath background values. Quantitative analytical errors (precision errors) indicate that some of the results are, at face value, statistically not exceedances.

The Site License standard was apparently originally designated as 1 pCi/L because this represented the idealized lower limit of detection approximately 30 years ago (and this value is still sometimes used as the benchmark for evaluating analytical results); see NRC (1980). As such, this standard is unrelated to the reference frame of the background water quality. In later sections of this report, we will review the Pb-210 analytical results in comparison to the background water statistics for each hydrostratigraphic unit.

The appropriateness of the Site standard of 1 pCi/L, including the relevance of Pb-210 statistics associated with the background water quality, is being reevaluated as part of a License amendment request that is in preparation. Background water Pb-210 concentrations (N.A. Water Systems, 2008f) 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).

### 1.4 Southwest Alluvium

Active remediation of the Southwest Alluvium was suspended when the former extraction wells ceased being pumped in January 2001; those wells have remained idle while natural attenuation continues to be monitored. The NA test involved temporarily shutting off the pump-back wells and monitoring the water quality and water levels on a monthly basis. The results were presented in a “final” report submitted in November 2002 (Earth Tech, 2002c). The effectiveness of NA in the Southwest Alluvium was discussed by N.A. Water Systems in the 2004, 2005, 2006, and 2007 annual reports; in the 2008, 2009, and 2010 annual reports (Chester Engineers, 2009a, 2010a, and 2011a); and in a presentation (2005a) at the annual, multi-agency meeting that was held at UNC’s offices at Church Rock on May 5, 2005. This annual report presents a continuing assessment of the effectiveness of natural attenuation in the Southwest Alluvium.

### 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

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### *Southwest Alluvium*

#### **2.1 *Corrective Action Summary***

The Southwest Alluvium corrective action pumping system remained idle in 2011. Attenuation via natural geochemical processes has been shown to be at least as effective as pumping, and the data from this year continue to corroborate this finding. Excluding the exceedances of Pb-210 (discussed below), no hazardous constituents exceed Site standards outside the UNC property boundary.

#### **2.2 *Mass of Chemical Constituents Removed***

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

#### **2.3 *Performance Monitoring Evaluation***

The current performance monitoring program in the Southwest Alluvium is summarized in Table 1 and comprises quarterly monitoring of water levels in 16 wells and water quality in 14 wells. The monitoring well locations are shown on Figure 2 and Figure A-1 (Appendix A). A summary of constituents detected in the Southwest Alluvium in October 2011 is provided in Table 2. Historic groundwater quality and groundwater elevation data through October 2011 are provided in Appendix A (Table A.1).

##### **2.3.1 *Water Level Evaluation***

Groundwater in the Southwest Alluvium in the vicinity of the tailings impoundments was created by the infiltration of pumped mine water that was discharged to the Pipeline Arroyo. This water percolated into the alluvium and created temporary saturation in the vicinity of the tailings impoundments. This temporary saturation caused by discharged mine water is the recognized Southwest Alluvium background water (EPA, 1988a; 1988b; 1998; 2008b). The level of saturation has been declining since the mine water discharge ceased in 1986. As a result, the flanks of the alluvial valley and the northern property boundary alluvium have completely de-saturated and, by 2000, a 31 percent saturation loss had been observed further to the south (Earth Tech, 2000d). The October 2011 saturated thickness for each well in the performance monitoring program is provided in Table 3. During 2011, 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 23 percent since 1989.

The Southwest Alluvium potentiometric surface map for October 2011 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 2011. 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) over most of the chart. 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, 2011c); 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 unexpected exceedances of Pb-210 during October 2011, 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 22 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 fluids 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 425 ft into the north-central portion of adjacent Section 10. The total length of the area is approximately 6,065 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 2011 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 2011 as in all previous quarters, this well had the highest sulfate concentration of any well in the Southwest Alluvium (including all historic measurements of 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 4,950 mg/L in October 2011). 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 very likely to be a significant factor affecting the intra-well variations in concentrations of common dissolved ions.*

Figure 8 is a bicarbonate isoconcentration map of the Southwest Alluvium during October 2011. 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 ( $\text{CaCO}_3$ ) in the alluvium that is available for buffering: Canonie (1987, Table 4.4) reported measured alluvium  $\text{CaCO}_3$  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 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 ( $\text{Mg-SO}_4$ ) type water while Well 624 contains a calcium-sulfate ( $\text{Ca-SO}_4$ ) 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  $\text{HCO}_3$ ) 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-SO<sub>4</sub> (as anhydrite or gypsum), magnesium-carbonate (Mg-CO<sub>3</sub>, as magnesite or dolomite), and calcium-carbonate (CaCO<sub>3</sub>, 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 try to maintain constant 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-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 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. 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 2011. 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 ( $\text{HCO}_3$ ) 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.

The quality of both the seepage-impacted water and non-seepage-impacted water does not meet New Mexico water quality standards for TDS. There is a shift in the composition of the dissolved solids in each case, with magnesium and sulfate in higher concentrations in the non-seepage-impacted water and calcium and bicarbonate being higher in seepage-impacted water (Figure 9). There is no situation that can be envisioned in which the quality of alluvium background groundwater can be degraded by the migration of seepage-impacted water. In some respects, particularly regarding sulfate concentrations, the seepage-impacted water may be viewed as an improvement. Groundwater quality within the Southwest Alluvium is further discussed in Section 2.3.4.

Two other constituents are present at concentrations that 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 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 2010 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-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 3.57 mg/L in October 2011 (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 impacted water is nearly neutral. Consequently, there are no exceedances of the metals or radionuclides standards within the seepage-impacted water, with the exception of some exceedances of manganese (a non-hazardous constituent) located well within the property boundary (Table 2), and the first-time exceedance of the uranium standard in Well 509 D during October 2010 (subsequent to which all measurements have been below the uranium standard).

The non-impacted background water at downgradient Well SBL 1 showed October 2011 exceedances of nickel (0.09 mg/L) and manganese (3.57 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 2011 analytical results showed no detections of Pb-210 within the Southwest Alluvium (Table 2; Appendix A; see discussion in Section 1 of this report), and there were no detections during the entire year of 2011.



### 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 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. Using chemical trends and estimates of hydraulic conductivity, hydraulic gradient, and effective porosity, Earth Tech calculated an average migration rate of 77 ft/yr beyond Well 624. Their transport rate was applied to the updated depiction of the inferred, southern edge of the impacted water during October 2003 (Figure 3 in USFilter, 2004a).

Subsequently, new groundwater velocity calculations have been made to estimate the rate of downgradient seepage-impact transport. These estimates are Darcy seepage velocities equal to the product of the hydraulic conductivity and the hydraulic gradient, divided by the effective porosity. The resultant groundwater velocities are upper-bound estimates of constituent transport velocities because no retardation or attenuation factors are applied.

Table 5 shows Southwest Alluvium groundwater velocities determined using hydraulic gradients based on the October 2011 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  $3.69 \times 10^{-3}$  cm/sec formerly used by Earth Tech (2002c) results in the prediction that seepage impact should already have arrived at Well SBL 1, which is not the case. The hydraulic conductivity value used in this annual report is  $2 \times 10^{-3}$  cm/sec, which was determined to be an appropriate mean value based on an extensive review of relevant site reports (USFilter, 2004b). This same mean alluvium hydraulic conductivity value was used in the groundwater modeling accomplished as part of the Zone 3 Supplemental Feasibility Study (MWH, 2004).

The average calculated groundwater velocity from Well 624 to Well SBL 1 is 16 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). It is also 23% lower than the velocity calculated for October 2010 because the water level at 624 is approximately one-half foot lower in October 2011. The downgradient limit (“nose”) of the 1,000 mg/L bicarbonate isoconcentration contour shown in Figure 8 is 16 ft farther to the southwest than it was in the comparable figure in the 2010 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 (15 years prior to October 2011). Using the updated average groundwater flow rate from Wells 624 to SBL 1 of 16 ft/yr, and accepting the inferred location of the plume “nose” near SBL 1 in Figure 8 (with a



separation distance of 88 ft), it may take approximately 5.5 years for the seepage-impact front to reach SBL 1. This estimate assumes a constant seepage velocity, and it is a maximum estimate because saturation levels and gradients will continue to decline. There are also uncertainties in the hydraulic parameters used to make this estimate. Therefore, the timing of the arrival of seepage impacts at SBL 1 is not subject to precise prediction.

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 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, the start of future possible gradual increases in the bicarbonate and chloride levels in Well SBL 1 may be imminent. 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-impacted background concentrations, which are nonetheless greater than Site standards. Physical and geochemical processes that reduce the tailings-impacted groundwater concentrations to background (or lower than background) concentrations have operated since mine water discharge began. This is demonstrated by the sulfate concentrations from impacted wells that contain constituent concentrations equivalent to, or variously higher or lower than, the non-impacted background concentrations. (See Figures 7 and 8; compare background Wells 627, EPA 28, and SBL 1 with wells located within the area impacted by tailings seepage.) The same is true of TDS, for which historic concentrations are shown in Figure 12. Background Well 627 has fluctuated about the Site standard (4,800 mg/L); background Well EPA 28 has persistently exceeded the standard; and background (post-mining/pre-tailings) Well SBL 1 had the highest concentration of any well



during October 2011 (8,720 mg/L). The sharply increasing TDS trend for 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. However, 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. The concepts demonstrated above require a non-traditional view of a TI Waiver zone as it would apply to the Southwest Alluvium. 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 193 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 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 2011 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. Post-shutoff uptrends in GW 3 stabilized in approximately January 2003 and in GW 2 in approximately April 2005. GW 1 has shown a relatively steeply increasing trend post-shutoff to April 2010 when the maximum concentration was measured. Very gradual increases have occurred at EPA 23, EPA 25, and EPA 28 through April 2010, at which time the maximum concentrations were measured. These observations indicate that neutralization and geochemical attenuation have been occurring naturally, and that alluvial mineral salts dissolve into the alluvium groundwater. Bicarbonate concentrations in Wells GW 2 and GW 3 may have achieved a “plateau” level of relatively constant values. We conclude that the system has largely attained a new steady-state following the termination of alluvial groundwater extraction with respect to the groundwater chemistry.

### *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 2011; 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 impacted waters than within non-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.



### *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 2011. 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 non-hazardous constituent. 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).

Figure 11 presents manganese concentrations from 1999 through October 2011. 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.

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 2011 that were below the standard. Nearby, Well 632 maintained a very gradual increasing concentration trend that started in December 2001, with the last four measurements slightly exceeding 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 continues effectively in much of the seepage-impacted waters. 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, modest exceedances may continue at Well 801.

Since its initial installation and sampling in 2004, background Well SBL 1 has shown exceedances of the manganese standard (Table 2 and Figure 11). Well SBL 1 has also shown



nickel exceedances and relatively high concentrations of magnesium (Table 2; Figure 9; Appendix A). These characteristics do not reflect the presence of seepage-impacted water at this location. Rather, as explained earlier in Section 2.3.2, the geochemistry of groundwater at SBL 1 reflects background conditions that are believed to be related to the dissolution of soluble alluvium minerals associated with the flux of discharged mine waters.

### *Uranium*

The statistics 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 orally indicated that they are considering the adoption of the current MCL for uranium as their standard at Church Rock, although they have not yet proposed a formal modification to their current standard in the ROD (5 mg/L). Figures 18 through 34 (discussed below) show that most of both the impacted and background wells have long-term uranium concentrations exceeding 0.03 mg/L.

The concentration of dissolved uranium in seepage-impacted water is often a function of the bicarbonate concentration, and uranium has been empirically found to lie within the same concentration range as the background (post-mining/pre-tailings) water. The typical covariance of uranium and bicarbonate concentrations is an important observation for which some examples are provided below.

Graphs of uranium concentrations in all fourteen wells comprising the Southwest Alluvium water-quality performance monitoring program, through October 2011, are included as multi-well plots in Figures 18 and 19. These plots cover the period from April 1999 through October 2011, thus providing a visually expanded time (horizontal) scale spanning shutoff. Figure 18 shows only the seven POC wells; Figure 19 shows other select wells, including background water quality.

Historically, there have been only two 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; and (2) the October 2010 concentration of 0.312 mg/L in Well 509 D. The latter 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.

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 then ended in October 2010. 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 – the October 2011 value of 0.119 mg/L is the lowest measured since July 2000.
- **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. There is no discernible advantage to pumping based on well 803.
- **Well GW 1** (Figure 24): The uranium concentrations in Well GW 1 began to increase in 1999, well before the NA test, and therefore cannot be attributed to the cessation of pumping. Post-shutoff concentrations continued to increase at an accelerated rate through July 2002 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 2011 the two values were, respectively, 0.104 mg/L and 1,830 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 0.22 mg/L in October 2011, defining a linear rate of increase of +0.015 mg/L per year over this period of 10.7 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.
- **Well 624** (Figure 27): Post-shutoff concentrations have been stable at the lower end of the historic range. There is no discernible advantage to pumping based on Well 624. 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). There is no discernible advantage to pumping based on Well 632.
- **Well 627** (Figure 29): Post-shutoff concentrations have been stable along the historic trend that is associated with a low range. There is no discernible advantage to pumping based on Well 627.
- **Well 808** (Figure 30): This well was installed in conjunction with the planned shutoff of the extraction well system; it has no pre-shutoff history. The post-shutoff uranium concentration showed a large upward spike through September 2001; since then the trend 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. There is no discernible advantage to pumping based on Well EPA 23.
- **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. There is no discernible advantage to pumping based on Well EPA 28.
- **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 exceedance of uranium in Well 509 D during October 2010, 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 improving 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 groundwater 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).

However, the potential heterogeneity of adsorbed uranium (of non-tailings origin) within the Southwest Alluvium sediments may inherently limit the degree to which one can 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 2011 (a period of 9.5 years) the bicarbonate concentration in this well increased by +730 mg/L while the uranium concentration increased by +0.002 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, 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.

#### *Pb-210*

During 2011 there were no detections of Pb-210 in the Southwest Alluvium. During October 2010 the first detection of Pb-210 (1.8 pCi/L) occurred in background Well SBL 1. Background water quality statistics for the Southwest Alluvium have been presented by UNC (N.A. Water Systems, 2008f, Table 3). 391 laboratory results that were analyzed had the following statistical parameters:

- Percent nondetects = 78.3%
- Minimum detected = 1 pCi/L
- Maximum detected = 14.2 pCi/L
- Mean of detected = 2.845 pCi/L
- Median of detected = 2.2 pCi/L
- Upper Confidence Limit of the mean at the 95% confidence level of the sampled population (UCL95) = 1.153 pCi/L.