

Section 3

Zone 3

3.1 Corrective Action Summary

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

While operating, the corrective action system in Zone 3 performed as designed to enhance dewatering of the seepage-impacted area and remove constituent mass. Historic corrective action in Zone 3 consisted of pumping the three sets of extraction wells shown on Figure 35: (1) Northeast Pump-Back System (green triangles), (2) Stage I Remedial Action System (filled blue squares), and (3) Stage II Remedial Action System (empty black squares). The Northeast Pump-Back wells started operation in 1983; the Stage I and II wells were added later as part of the Remedial Action Plan (UNC, 1989b) implemented in 1989.

The numbers of operating extraction wells were reduced as Zone 3 dewatering caused sustainable pumping rates to drop below 1 gpm. The number and pumped volumes of the former extraction wells, during the period of Zone 3 corrective action from 1989 through 2000, have been summarized in Earth Tech (2002d, Figure 3-2). Pumping from the last three extraction wells ceased in 2000. The NRC amended the License (with approval from NMED and EPA) to shut off the three remaining wells (716, 717, and 718) in December 2000. This decision included a provision for UNC to submit a modified corrective action plan, an application for ACLs, or an alternative to the specific requirements of 10 CFR Part 40, Appendix A, if the License standards are not achievable.

3.1.2 2004 Supplemental Feasibility Study

At the request of the EPA (2004b), UNC conducted a Supplemental Feasibility Study (SFS) to evaluate all appropriate remedial options for Zone 3. Prior to reporting the SFS (MWH, 2004), UNC submitted (2004) a Technical Memorandum including a chronology of events that led to UNC's initiative to aggressively develop remedy modifications or enhancements that might improve the performance of the remedy in Zone 3. The SFS report presented (1) groundwater modeling of the Zone 3 sandstone unit and the locally overlying alluvium, (2) pilot-hole hydrofracturing study results, (3) a remedial alternatives analysis, and (4) conclusions and recommendations for enhancing or optimizing remedies for Zone 3. The hydraulic modeling indicated that for most of the alternative remedies to be effective (excluding Alternative 6 – Cutoff/Containment Wells), the recharge from the alluvium to Zone 3 should be reduced or eliminated.

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

3.1.3 *In-Situ Alkalinity Stabilization Pilot Study*

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

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

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

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

Extraction of impacted groundwater from a new array of wells in the northern part of Zone 3 in Section 36 was tested in April 2005 as part of the Phase I (i.e., post-pilot) hydrofracture program (MACTEC, 2006). Continuous pumping of these wells began in May 2005. Phase I ended in January 2006; however, as discussed later in this section of the report, the pumping has been continued and supplemented by the installation of additional extraction wells. The locations of the Phase I pumping wells (RW 11, RW 12, RW 13, RW 15, RW 16, RW 17, and PB 2) are shown on Figure 37 and Figure B-1 in Appendix B. Also shown is the location of a newer extraction well, RW A, which started pumping on September 24, 2007. Due to fouling and/or insufficient yield, RW 12, RW 13, and RW 15 have been taken off-line and are no longer

pumping. Of this group, the pumping wells that were operational during 2011 are PB 2, RW 11, RW 16, RW 17 and RW A.

Based on UNC's hydrogeologic analysis and recommended pumping system design (N.A. Water Systems, 2008c), five new extraction wells to intercept and recover impacted water were installed during September 2008. These well locations are shown on Figure 35 and Figure B-1 (in the front of Appendix B) – they are designated NW-1, NW-2, NW-3, NW-4, and NW-5. After an initial test period to determine that all five wells were pumping properly, three of the wells started pumping during February 2009 (NW-1, NW-2, and NW-3). NW-2 and NW-3 were each pumping at approximately 1 gpm and NW-1 at 0.1 gpm. Yields have since declined at all of the wells and most dramatically at NW-1, which has a very low recharge rate and shallow saturated thickness. As discussed in the next section, the pumping scheme was reoptimized during November 2009. The average yields from wells pumped during 2011 were 0.006 gpm from NW-1 (the pump must cycle on and off), 0.49 gpm from NW-2, and 0.18 gpm from NW-4. NW-3 and NW-5 were not pumped to minimize the potential of drawing impacted groundwater to the northwest.

Approximately 12,914,018 gallons of groundwater have been pumped from this new Zone 3 extraction well network from January 2005 through the end of November 2011, and piped to the evaporation pond.

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

Twenty-two years of remedial pumping have resulted in significant dewatering of Zone 3. One effect of this is that once the saturated thickness falls to approximately 25 ft or less, well efficiency declines and pumping rates fall to less than 1.0 gpm (Earth Tech, 2001). Table 7 presents the reductions in saturated thickness for Zone 3 monitoring wells between the third quarter of 1989 and the fourth quarter of 2011. Values of saturated thickness greater than 25 ft are shaded.

The saturated thickness measured in Zone 3 wells has declined by 73 percent on average since the third quarter of 1989. Only one well, EPA 14, had a saturated thickness greater than 25 ft in October 2011. Figure 35 shows that between 1989 and the fourth quarter of 2011, a very large portion of the Zone 3 Remedial Action Target Area has been desaturated (effectively dewatered). The eastern limit of Zone 3 saturation has shifted to the west-northwest over this time period (from the location of the wavy blue line, showing the saturation limit in 1989, to the dashed brown line showing the approximate October 2011 “zero” saturation limit).

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

The in-situ alkalinity stabilization study unexpectedly found that the seepage-induced alteration of feldspathic minerals is reducing the bedrock permeability. This will tend to restrict the

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

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

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

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

Groundwater quality in Zone 3 started to sharply degrade between May and December 2007 in several of the northern tracking wells (N.A. Water Systems, 2008b). Groundwater quality along the northern tracking wells has been oscillating between degrading and improving trends over the last 9 years. Individual well water-quality trends of improvement and degradation have become collectively asynchronous since May 2007.

UNC measures monthly field parameters in all five NW-series wells, and the alkalinity concentrations indicate the following: NW-1 is the most impacted and has the least saturated thickness; NW-4 shows lesser impact; NW-2 shows little to no impact; and NW-3 and NW-5 (not pumped in 2011) are predominantly background water and have the greatest saturated

thicknesses. Note that NW-1 and NW-4 are the easternmost of these five new wells, and NW-3 and NW-5 are the westernmost. These observations are consistent with our general understanding that the seepage-impacted water is most prevalent towards the eastern limit of saturation; moving westward the prevalence of non-seepage-impacted water increases as does the formation's saturated thickness.

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

- NW-1 was left pumping at the current, maximum rate.
- NW-2 pumping rate was reduced by one-half to ~ 0.5 gpm.
- NW-3 was turned off.
- NW-5 remains off.
- NW-4 pumping was started at the maximum practicable rate.

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

3.1.6 Injection Well Feasibility Testing and Pilot Study

On October 27 and November 4, 2009, UNC conducted injection testing in background well NBL 2 (the results and analysis were reported in Chester Engineers, 2009d). The primary objective of this test was to empirically assess the amount of water a well in the non-impacted, northern part of Zone 3 can accommodate by injection. A secondary objective was to determine an additional estimate of the hydraulic conductivity in this area.

The purpose of this test was to evaluate the potential for creating a hydraulic (or possibly an alkalinity) barrier, using multiple injection wells, to limit further northward advance of the seepage-impacted groundwater in the northern part of Section 36. This potential remedial option was retained in the SWSFS Part II (Chester Engineers, 2009b and 2011c) with a caveat that the formation may not accept sufficient quantities of fluid to practicable, as occurred in the Zone 3 in-situ alkalinity stabilization test (ARCADIS BBL, 2007). The NBL 2 injection test was located outside the influence of tailings seepage where secondary permeability restrictions, due to reaction of the bedrock with acidic tailings, are less likely. The two tests conducted (falling-head followed by stepped-head) showed average injection rates of ~ 8 gpm.

Based on the results of this injection test, UNC proposed (Chester Engineers, 2009d) enhancement and testing of the potential remedial alternative comprising the injection of alkalinity-amended water through an array of new injection wells located to the north of the NW-series of extraction wells and south of the Section 36 property boundary. The first phase of the injection program would comprise a pilot phase with the installation of one new injection well (at a location suitable for the new well array) to be subjected to injection testing similar to that conducted at well NBL 2. Chester Engineers (2010b) proposed the pilot injection well location at IW A, to which the agencies agreed; this location was incorporated into the Remedial Design Report (Chester Engineers, 2010c).

This program was approved by the agencies and in May and June 2010, UNC installed three new wells: IW A (the pilot injection well), and, nearby, MW 6 and MW 7 (to monitor the reaction of Zone 3 to the water injection). The locations of the pilot test well and nearby extraction wells (NW-prefix) are shown in Figures 37 and 38. Two injection tests were conducted in Well IW A. During the first test on July 1, 2010, 800 gallons of water were injected at a constant rate of ~ 3 gpm. The second test, on July 14, 2010, involved injection of 1235 gallons of water at rates incremented in steps of approximately 1 gpm, 3 gpm, and 5 gpm. The water was obtained from the Site's Mill Well, which taps the same water source (Westwater Canyon Formation) that was used for the previous in-situ alkalinity stabilization pilot test and the injection tests of Well NBL 2.

The injection tests at Well IW A have been described and analyzed by Chester Engineers (2010d). The estimates of hydraulic conductivity based on water level recovery data from IW A were lower by factors of ~ 0.06 to 0.2 from other estimates for the northern portion of Zone 3 made from the injection test of Well NBL 2 and from broadly based flow data. However, those newest estimates are applicable only to the formation immediately surrounding Well IW A. It was expected that response data from longer-term pilot testing will provide a more representative basis for estimating the influence of injection on hydraulic heads in Zone 3 and nearby wells.

The IW A injection tests indicated that there is sufficient injection capacity to meet the expected results for further pilot testing, following the proposed plan in the Remedial Design 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) provide a hydraulic barrier to the northerly advance of impacted groundwater. The sodium bicarbonate was added to water in a mixing tank at the concentration of 2 grams per liter (equivalent to 16.6 pounds per 1,000 gallons of water). Prior to injection the water level at this location was approximately 191 ft below ground. During injection the operations staff has varied the injection rate causing water levels to vary from approximately 12 ft to 50 ft below ground. On October 31, 2011 the top of the injection mound was approximately 20 ft below ground.

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). So far there has been no measurable hydraulic response (i.e., water level rise) in nearby wells, nor have the nearby wells showed the geochemical effects of the alkalinity injection (i.e., increased bicarbonate concentrations or increased pH). The mass transport of the sodium bicarbonate may require more time. More details on the injection and nearby pumping are provided in Chester Engineers (2011h).

3.2 *Mass of Chemical Constituents Removed*

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

As previously discussed, a relatively recent phase of extraction well pumping that originated with the hydrofracture program has continued to present. Table 8 shows the estimated mass removal by this pumping from December 2010 through November 2011 (the similar Table 8 in the 2010 Annual Report showed data through November 2010); the RW-series extraction wells (and converted pumping well PB 2), and the NW-series extraction wells, are shown on Figure 37 and Figure B-1 in Appendix B. The recovered masses were estimated by multiplying the volume of groundwater pumped by the estimated concentration of each constituent in the pumped water. The constituent concentrations were estimated from concentrations measured in groundwater samples taken from the extraction wells and nearby monitoring wells during October 2011.

3.3 *Performance Monitoring Evaluation*

The current Zone 3 performance monitoring program is summarized in Table 9 and comprises quarterly monitoring of water levels in 23 wells and water quality in 11 wells. This program went into effect in the second quarter of 2000 and was modified in the second quarter of 2001, at the request of the NRC, to include the following additional components:

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

The location of Well NBL 1 (see Figure 35) was selected to both bound the downgradient extent of the impacted water and function as a tracking well.

To supplement the performance monitoring program, four monitoring wells were installed (June 2002) between Wells 504 B and NBL 1: from south to north they are PB 1, PB 2, PB 4, and PB 3 (Figure 35). Drilling logs and well completion forms are included in Earth Tech (2002d, Appendix B). These wells serve to track the advance of the northernmost seepage-impact boundary. Well PB 1 was installed within impacted water and was thence excluded from monitoring of the advancing front.

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

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

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

Two piezometers were installed in July 2004 to the base of Zone 3 just north of the northeastern boundary of the Central Cell (see Figure 35, piezometers Z3M-1 and Z3M-2). These installations were made following recommendations in UNC's investigation (USFilter, 2004b) of the potential for the covered tailings cells to continue to source seepage impact and recharge to the updip part of the Zone 3 hydrostatigraphic unit. The first two quarters of water-level monitoring showed that both piezometers were dry (excluding small amounts of drilling fluid). Water levels were measured in these piezometers, starting in October 2004 and at an annual or greater frequency since 2008. On each occasion too little water was found to be sampled and what was found was interpreted to be residual drilling fluid stored at the bottom of each well. On the basis of these findings it was concluded that the area of the former borrow pits 1 and 2 was not an ongoing source of measurable quantities of recharge or tailings seepage (USFilter, 2004b).

Minor differences of the measured depths to water over time at Z3M-2 (standard deviation of 0.08 ft) appear to be random measurement error. The height of the water measured in Z3M-1 has ranged from 0.15 ft to 1.0 ft. This amount of variation is greater than expected from measurement error. This raises the possibility that the measurements are representative of transient resaturation at the base of Zone 3 in this locality (Chester Engineers, 2011e). During July 2011, UNC installed pressure transducers in both of these piezometers in order to obtain

more frequent water level measurements. During October 2011, the height of the water column in Z3M-1 was 0.20 ft and Z3M-2 was dry (Table 10).

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

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

Though not a formal part of the performance monitoring program, to improve our understanding of the groundwater quality along the northern front of the 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. Field parameter measurements and laboratory measurements are generally in good agreement (though field pH tends to be more accurate than laboratory measurements of pH).

3.3.1 Water Level Evaluation

Water level data from 1989 through the fourth quarter of 2011 are presented in Appendix B. Water levels from October 2011 are shown on the potentiometric surface map in Figure 37. These potentiometric contour lines indicate groundwater flows toward the north and northeast, approximately parallel with the eastern limit of Zone 3 saturation. This potentiometric field is similar to, though lowered from, those depicted for the fourth quarters of 2001 (Earth Tech, 2002a), 2002 (Earth Tech, 2002d), 2003 (USFilter, 2004a), 2004 (N.A. Water Systems, 2004), 2005 (N.A. Water Systems, 2005b), 2006 (N.A. Water Systems, 2007a), 2007 (N.A. Water Systems, 2008a), 2008 (Chester Engineers, 2009a), 2009 (Chester Engineers, 2010a), and 2010 (Chester Engineers, 2011a).

Figure 37 shows the locations of wells pumped during October 2011, and monitoring wells. Measured groundwater elevations were used to develop this potentiometric map, which shows a 5-ft contour interval. The pumping in Wells RW A, RW 16, and PB 2 are associated with southwestward deflection of the contour lines, and a cone of depression is suggested by the contours around RW 16 and RW A. The closed contours around injection well IW A suggest a

mound of impression. The discrepancy between the posted groundwater elevation at IW A (6977.05 ft amsl) and the surrounding, closed contour at 6810 ft amsl discounts more than half of the well-bore surcharge as being due to well inefficiency.

Mine water discharge into Pipeline Arroyo ceased in 1986. Since then, Zone 3 groundwater flow directions became more generally north-northeasterly as recharge from, and groundwater mounding within, the alluvium to the southwest and west has decreased. The earlier east-to-northeast flow direction caused the distribution of groundwater impacts that was the original basis for delineation of the Zone 3 Remedial Action Target Area, as shown on Figure 35. Effects on the potentiometric surface from alluvium recharge (mine water discharge) have largely dissipated, and rates of water level change in Zone 3 are mostly very slow (excluding the influence of recent pumping and injection). Variations from the depicted direction of groundwater flow are unlikely, except where flow may be locally redirected by the new pumping and injection configuration. Since cessation of mine water discharge, water levels have been declining. Pumping of extraction wells prior to January 2001 temporarily accelerated the local rates of water level decline until the saturated thickness was reduced to less than ~ 25 ft, after which the decline in levels slowed to natural rates of drainage. In October 2011, the collective average saturated thickness for all measured Zone 3 wells (Table 7) has reduced to 12 feet.

Contours of saturated thickness during the fourth quarter of 2011 (Figure 38) show the combined effects of former pumping, current pumping, injection, and natural drainage on Zone 3. This map was developed by evaluating the differences between two interpolated surfaces: the base of Zone 3 and the potentiometric surface for October 2011. The eastern extent of saturation has contracted to the west, so that the current boundary of saturation is approximately where the 25-ft saturated thickness contour was located in 1989 (for comparison, see Earth Tech, 2002d, Figure 3-1). Also, the wells located to the west, closer to the former recharge area, have lost substantial saturation. For example, Well EPA 14 had 76 ft of saturation in 1989 and 25.1 ft in the fourth quarter of 2011 (a 67 percent reduction in the saturated thickness; see Table 7). Table 10 shows the saturated thickness in each Zone 3 well during October 2011. From 2002 through 2011, most wells have shown overall decreasing groundwater elevations (usually with small fluctuations), indicating that the Zone 3 potentiometric field that drives groundwater flow and constituent migration continues to become lower as the groundwater further drains away. Pumping has removed almost 13 million gallons from 2005 through 2011.

The southwest part of Figure 35 shows the approximate contact area between the alluvium and the top of Zone 3. Former versions of this figure have shown an inferred area of saturation along this contact area (e.g., see Figure 35 in the 2008 annual report). The following lines of evidence suggest that this contact area is no longer saturated and no longer recharging Zone 3:

- N.A. Water Systems' (2008c) analysis of the groundwater flow through Zone 3 indicated little or no contribution from other sources (e.g., alluvium) than the ongoing self-drainage. There was very little flow crossing the southern, east-west directed cross section line near Well 613 (op cit, Figure 7), which is 1,642 ft long: the flux here in January 2005 was estimated to be 723 gallons per day (0.5 gpm).

- The elevation of the top of Zone 3 in the area of its contact with the alluvium is between 6910 and 6930 ft amsl. The closest alluvium well is 509 D (Figure 2) which had a water table elevation of 6870 ft amsl in October 2011, which is below the elevation of the relevant Zone 3 subcrop. Alluvium Well GW 4 (Figure 2) is much closer to the area of interest; this well went dry after July 1999 when it had a water elevation of 6909 ft amsl (which is very close to the well bottom). The alluvium groundwater then was very close to the lower part of the Zone 3 subcrop, suggesting that most of the alluvium/Zone 3 contact area was dry.
- Figure 35 shows that Wells 714 and 715 are not far downgradient from the alluvium/Zone 3 contact area. Table 7 indicates that in October 2011 these wells had saturated thicknesses of 14.6 ft and 9.5 ft, respectively. Compared to their saturated thicknesses in 1991 (when the wells were installed), the October 2011 values represent decreases of -35.5 ft (-71%) and -38.1 ft (-80%), respectively. These reductions do not prove the absence of updip recharge from the alluvium, but they are consistent with the inference that little or no such recharge is occurring.
- Chester Engineers (2011e) recently summarized the evidence that no discernable recharge is occurring into Zone 3.

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

The temporary saturation caused by the mine water discharge is considered the background water for Zone 3 (EPA, 1988a; 1988b; 1998). This background water was later impacted by acidic seepage from tailings in the North Cell. These seepage fluids contained elevated concentrations of metals, radionuclides, and major ions including sulfate and chloride. Source control (neutralizing and later dewatering of the North Cell), neutralization of the seepage by natural attenuation, and mixing with the background water have reduced constituent concentrations.

Seepage-impacted water, some of which exceeds Site standards, is contained within the property boundary in Section 36. The portion of the impacted water that extends off the property into Section 1 (Figures 6 and 35) was eliminated as a point-of-exposure (POE) because of limited saturation. The decision to eliminate this area as a Zone 3 POE is documented in a letter from the NRC (1999b).

It is important to recognize that exceedances of Site standards in some Site wells represent background water quality. For example, exceedances of the combined radium and sulfate standards in Well EPA 14 significantly pre-date the beginning of strong seepage impacts that were first observed at that well during 2000 (the water quality history of this well is discussed below). From 1989 through 1997, Well 411 showed long-term background exceedances in combined radium, cobalt, molybdenum, nickel, and sulfate. Background water quality is discussed further in the natural attenuation system performance evaluation. Statistical analysis of Site background water quality, using EPA's preferred ProUCL software, has been presented by UNC (N.A. Water Systems, 2008f) during revisions to Part I of the SWSFS.

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

- pH < 5 and bicarbonate < 100 and > 500 mg/L are useful (but not always definitive) indicators of seepage impact (see the Technical Memorandum (GE, 2000)). N.A. Water Systems (2008f, Figure 1) presented box-and-whiskers plots of bicarbonate and pH for the background wells. Impacted water with a pH < 5.0 has not yet migrated far enough to reach equilibrium, or to react sufficiently, with carbonate minerals in the Zone 3 strata (Canonie, 1987, Table 4-5 indicates a measured CaCO₃ content of 0.02 percent in the Zone 3 bedrock). A pH > 5.0 indicates either no seepage impact, or acid neutralization to varying degrees (usually a function of residence time and migration distance).

In non-impacted areas, background water has approximately reached equilibrium with the carbonate minerals resulting in bicarbonate concentrations ranging from approximately 100 to 500 mg/L. These threshold values reflect sequential chemical reactions. When acidic seepage-impacted water first entered Zone 3, it lacked bicarbonate. Once the seepage water migrates a short distance from its point of entry, bicarbonate is generated by reaction with calcite in the alluvium and/or bedrock. With increasing time of neutralization at a given location, the bicarbonate typically shows a gradual increase to levels above background (generally > 500 mg/L). Eventually, the neutralization capacity is exceeded and bicarbonate values may reduce to near zero. Further discussion of bicarbonate concentration trends is provided below.

- Time-series of these two indicator parameters are very helpful (sometimes essential). See N.A. Water Systems (2008f, Appendix A) for time-series of pH and bicarbonate for the background wells.
- The spatial context of well locations within the overall area impacted by seepage (e.g., see Figure 35).
- Time trends in the concentrations of major ions; in particular, decreasing ratios of Ca/Mg are associated with degrading groundwater quality (see Appendix B; e.g., Well EPA 14).
- Time trends in the concentrations of many metals and radionuclides will usually increase as the water quality degrades in Zone 3 (see Appendix B; e.g., Well EPA 15).

Invariably, some wells (or certain time spans at some wells) are difficult to classify because their groundwater chemistry tends to be gradational. For example, the geochemistry associated with Well 420 has long been considered to be “borderline” between background and impacted water quality.

Seepage-impact extent is primarily based on evaluation of pH and bicarbonate concentrations over time in (1) seepage-impacted wells (e.g., Wells 613, 518, and 517), (2) background and former background wells (e.g., Wells EPA 1 and 411), and (3) the northern tracking wells. Table 11 presents the monthly field parameter measurements for the northern tracking wells (from south to north: Wells RW A, PB 2, PB 4, PB 3, and NBL 2 and NBL 1). (The quarterly

laboratory analytical results are provided in the back part of Appendix B.) Table 12 presents the monthly field parameter measurements for the newer NW-series of wells (these measurements started in June 2009).

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

Historic groundwater quality data (see Appendix B) from fully impacted wells indicate that it takes from one to three years, from the onset of geochemical changes associated with the arrival of seepage-impacted groundwater, for full seepage-impact to develop (unless the constituent transport is effected by pumping). In discussing Table 11 in the 2005 annual report, it appeared that the development of full-stage seepage impact was imminent at Well PB 3 (i.e., it appeared likely that bicarbonate would very soon fall to levels persistently below 50 mg/L, accompanied by a subsequent decrease of pH to below 5.0). This is shown on the bicarbonate time-series charts in Figures 39 and 40 (it should be noted that the bicarbonate values plotted in these charts are those derived from *laboratory* analyses of the quarterly monitoring samples; see the laboratory analytical summary sheets in the back of Appendix B). The northern limit of seepage impact on Figure 35 of the 2005 Annual Report was shown passing through Well PB 3, because of the duration of bicarbonate decrease at this location, culminating with the bicarbonate value of 51 mg/L in October 2005. Subsequently (see Table 11, which includes the monthly *field* bicarbonate measurements from the northern tracking wells), bicarbonate at this location decreased during November and December 2005, but then started to increase during January 2006 – it continued to increase to October 2007, and since then it has very strongly fluctuated. The sharp increase starting in January 2006 represents an abrupt reversal of the long-term declining bicarbonate concentrations at this location since well monitoring started in October 2002 (Table 11). During 2011 the bicarbonate concentrations have been relatively stable (251 mg/L in October).

Since the beginning of the new Zone 3 pumping scheme in May 2005, bicarbonate in PB 2 started to decline in September 2007 and fell to 0 mg/L in January 2008. The bicarbonate level here quickly recovered and was 79 mg/L in October 2011.

Since October 2007, Well NBL 1 has shown unusually large variations in bicarbonate concentrations. From the most recent high of 198 mg/L during November 2009, the bicarbonate concentration fell to 0 mg/L in April 2010, and this concentration persisted through October 2010 (when a very small increase to 4 mg/L occurred). A similar range in bicarbonate concentrations in Well PB 3 occurred over this same time frame (though the large variations were sometimes asynchronous to those in NBL 1). In NBL-1 the level jumped to 103 mg/L in January 2011 but has been nondetect since March 2011 (see Table 11 and Figure 40).

Field pH values confirm the presence of strongly impacted water quality along Wells NBL 1 (2.88 during October 2011) and PB 4 (2.56 during October 2011). However, between these two well locations, along Well PB 3 the pH has remained relatively elevated (7.35 during October 2010) – see the posted pH values in Figure 35.

Collectively, these bicarbonate measurements in the northern tracking wells indicate that the groundwater quality is highly heterogeneous on the local scale of the related well array. The noted asynchronous changes of bicarbonate concentrations in the northern tracking wells indicates the seepage-impact front is proximal to the wells, and the geochemistry is dynamic due to the effects of pumping PB 2 (starting in September 2005), RW A (starting in September 2007), and NW-1, NW-2, and NW-3 (starting in February 2009), and then with NW-4 pumping replacing NW-3 in November 2009.

Field parameter measurements in the NW-series of wells provide some of the northernmost information on water quality. Table 12 presents the monthly field measurements of bicarbonate and pH. These data (inception in June 2009) so far have not shown any of the sharp and large fluctuations noted just to the south in the older tracking wells. With the exception of a few measurements, all of the pH values range between 6 and 7. Within individual wells, bicarbonate concentrations so far have shown only relatively small variations over time. These data indicate relative geochemical stability at these wells (though, as noted earlier, the bicarbonate concentrations indicate the most impacted waters are at the two easternmost wells, NW-1 and NW-4).

Figure 35 shows the location of the northern edge of the seepage-impact front during October 2011 at Well NBL 1. Table 13 explains the basis for selecting NBL 1 as the “end point well” of full seepage impact shown in Figure 35.

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

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

The acidic “core” of the impacted water is shown in Figure 35 with the closed dashed red lines indicating the pH value of 4.0. The other red line shows the approximate location where the pH values are 5.0. Note that the pH shown for Well PB 2 (5.73) is significantly higher than that shown a short distance to the north for PB 4 (2.56); and a short distance to the north of PB 4, Well PB 3 had a pH of 7.35 in October 2011. To the north of PB 3, the pH again drops off sharply to 2.88 at NBL 1. This relatively large pH variation over short distances is inferred to be

another effect of the pumping. That effect is interpreted to be the capacity of pumped wells to locally draw background quality groundwater into areas of seepage impact.

Well EPA 14 is fully impacted by tailings seepage (see Appendix B and Table 14). The EPA's Second Five-Year Review Report (EPA, 2003, Figure 6-7) presented Stiff diagrams for Well EPA 14 in annual "snapshots" of water quality from October 1998 through October 2002. Before October 2000, the calcium-to-magnesium (Ca/Mg) ratio was greater than one and the bicarbonate concentrations were elevated; from October 2000 to October 2002, the Ca/Mg ratio was less than one and bicarbonate was depleted. Modest exceedances of the aluminum and cobalt standards in Well EPA 14 began in 2000, when the bicarbonate concentration decreased suddenly and sharply. Figure 40 shows that the bicarbonate at this location fell sharply to nondetect (zero) in July 2001, then increased to 188 mg/L in October 2004, and then fell to nondetect again in October 2006. When the bicarbonate "comes off the floor" for either a short or extended period of time, this indicates flux in the geochemical conditions and a temporary (or extended) recovery in the groundwater systems' buffering capacity. However, since October 2006 the bicarbonate here has remained at nondetect levels.

The EPA (2003, Figure 6-8) also presented Stiff diagrams for ten Zone 3 wells based on October 2002 sampling. The following discussion refers to the Stiff diagrams shown in EPA's (2003) Figure 6-8, while also providing updates on specific changes in water quality through October 2011.

The first chemical measurements in Well NBL 1 were made in August 2001 (Appendix B), when the calcium-sulfate type of water was interpreted as representative of background water quality. Subsequently, early stage seepage impact was shown by the gradual reduction of the Ca/Mg ratio from 2001 through October 2005 (Appendix B) and the beginning of decreasing bicarbonate concentrations during approximately April 2004 (Appendix B, based on laboratory determinations of bicarbonate) and June 2004 (Table 11, based on field kit determinations of bicarbonate). Appendix B shows that starting in January 2010 NBL 1 has shown significant increases in cobalt (0.72 mg/L in October 2011), nickel (0.85 mg/L in October 2011), and combined radium (32 pCi/L in October 2011); considered with the 2011 nondetects for bicarbonate and pH values frequently less than 4, these data indicate that the water quality here is strongly impacted (though ~ 100 ft to the south at PB 3, the water quality is notably better). These closely spaced, large variations in groundwater quality are attributed to the effects of extraction well pumping in their vicinity, which causes variations in the proportion of seepage-impacted versus non-impacted water that reaches the wells. *Monitoring of the northernmost part of Zone 3 in Section 36 indicates that this area is a complex zone of mixing of background and impacted water, rather than a singular advancing plume edge with a "sharp line" boundary.*

Samples from Well 420, located along the western edge of the impacted area in Figure 35, indicate a calcium-sulfate type of background water. Combined radium in this well has fluctuated above and below the Site standard from 1989 through July 2007, after which it has persistently been above the standard – this may reflect the flux of geochemically heterogeneous background water or impacted water (e.g., N.A. Water Systems, 2005b). Over the one-year

period from April 2006 to April 2007, bicarbonate dropped from 781 mg/L to 237 mg/L. Since October 2007, uranium has persistently been greater than 0.27 mg/L for the first time in this well's monitoring history (which started in 1989; see Appendix B), and since January 2010 uranium exceeded the Site standard of 0.3 mg/L (although pH at this location does not indicate impact). The calculated UCL95 of the mean for background water uranium is 0.107 mg/L, which is higher than the UCL95 of the mean calculated for the exposure point concentration (representing impacted water) of 0.043 mg/L for uranium (these values are from N.A. Water Systems (2008f) and (2008g), respectively). (UCL95 refers to the upper confidence limit on the mean at the 95% confidence level.) These observations are interpreted as indicating that the groundwater quality is "borderline" between background and impacted, that the seepage-impacted region is nearby, and that the groundwater quality may be degrading very gradually (though the magnesium concentrations have been approximately stable during the entire monitoring history).

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

The other seven wells depicted with Stiff diagrams (EPA, 2003, Figure 6-8) represent impacted magnesium-sulfate types of waters. For example, in October 2011 (see Appendix B) upgradient Well 613 (in the southwestern part of the impacted area shown in Figure 35) showed a very high sulfate concentration, Ca/Mg ratio less than one, nondetect bicarbonate, chloride concentration 135 mg/L, pH 3.05, and exceedances for most parameters except several metals, lead, and some of the major ions. Notably, few detections or exceedances of Pb-210 have been measured in Well 613, which otherwise is the most impacted Zone 3 well. Although some of the downgradient wells show significant impacts (e.g., Wells 708 and 719), they also show indications that neutralization accompanies migration from the waters' source area.

3.3.3 Rate of Seepage Migration

Table 13 summarizes the key factors, locations, and criteria underpinning the past calculations of northward seepage travel times for Zone 3. As discussed in the 2006 annual report (N.A. Water Systems, 2007a), during that year the seepage-impact front was inferred to have receded from Well PB 4 to PB 2 as a consequence of dilution from pumping of RW 11, RW 12, RW 13, and PB 2. In 2007 (N.A. Water Systems, 2008a), the location of the northern edge of seepage impact was inferred to have remained unchanged. In 2008 (Chester Engineers, 2009a), the leading edge of impact was inferred to have migrated from PB 4 to PB 2; as Table 13 shows, this same specific advance had previously occurred from April 2003 to February 2004. Such a repeated advance, covering the same ground locations, reflects the pumping-related hydraulic "tug of

war” occurring in the vicinity of the northern tracking wells. With the advent of pumping from the northern, NW-series extraction wells in February 2009, the older northern tracking wells became subject to influences from upgradient and downgradient extraction wells. The purpose of the upgradient wells (e.g., the RW-series wells) is primarily to dewater and recover contaminant mass, while the purpose of the downgradient wells (e.g., the NW-series) is to form a hydraulic barrier. The original purpose of calculating seepage-impact migration velocities for Table 13 equivalents, as a basis of predicting the progression of the impact reaction front, has been rendered moot by the designed actions of these extraction wells.

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

Figure 35 shows the location of the northern edge of the seepage-impact front during October 2011 at Well NBL 1, which is the same location depicted in 2010. As explained in the lower block of Table 13, full seepage impact has occurred at PB 4 since November 2008, but to the north of this well there is no unequivocal basis for selecting a single location representing the leading edge of moderate seepage impact. This reflects the influence of pumping. Table 13 explains the basis for selecting NBL 1 as the “end point well” of seepage impact shown in Figure 35. The time-space variations in groundwater quality, especially the key bicarbonate and pH parameters, indicate that over the last three years or more, there is no clearly defined northern edge of seepage impact that is consistently advancing northward. Rather, over this time period the northern area of seepage impact has been a mixing zone that is largely contained and/or treated by the NW-series extraction and the IWA injection.

3.3.4 *Natural Attenuation System Performance Evaluation*

The Zone 3 natural attenuation system comprises the hydro-geochemical interactions between the bedrock matrix, the anthropogenic background waters (derived from former mine water discharge), and the tailings fluids. The natural system is attenuating the seepage impacts by the processes of neutralization, precipitation, adsorption, and mixing with the background waters.

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

A summary of constituents detected in Zone 3 in October 2011 is provided in Table 14. Historic data are provided in Appendix B. These data indicate that the following constituents exceeded the Site standards in Zone 3 (in many cases in Well 613):

- Sulfate and TDS;
- Metals (aluminum, beryllium, cadmium, cobalt, manganese, and nickel);
- Radionuclides (uranium, combined radium-226 and -228, thorium, vanadium, Pb-210, and gross alpha); and
- Total trihalomethanes (of which only chloroform was detected).

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

Sulfate and TDS

Figure 41 is a graph of sulfate concentrations from 1989 through 2011. Concentrations are relatively high where seepage impacts have been greatest. However, as in the Southwest Alluvium, sulfate concentrations are controlled by geochemical equilibrium with gypsum (or anhydrite) and calcite. Although very high sulfate concentrations were present in the tailings fluids, such “primary” sulfate impact very rapidly attenuated downgradient. For example, compare the relatively elevated sulfate concentration in upgradient Well 613 (upper right, light blue line in Figure 41) with the much lower concentrations in all the other Zone 3 wells (grouped together in the lower part of Figure 41). Over the entire monitoring history since 1989, sulfate concentrations overall have remained within a range of approximately 5,000 to 1,800 mg/L (excluding Well 613). Background water quality analysis (N.A. Water Systems, 2008f, Table 8) shows that, excluding Well 613, there is substantial overlap between the range of sulfate concentrations in impacted and background water. Moreover, the marked stability of sulfate in all wells, throughout the duration of remedial pumping and in the absence of such pumping, demonstrates that sulfate concentrations are determined exclusively by the geochemical equilibria between natural minerals and waters rather than remedial operations.

Natural attenuation has reduced sulfate concentrations substantially from those reported in the tailings source area. Earth Tech (2002d, Figure 3-13) demonstrated that sulfate concentrations decreased by about 85 percent between the North Cell and the seepage-impacted water at Well 613. A similar comparison can be made using October 2011 sample data from the current northern portion of the impacted area: sulfate concentrations decrease 64 percent from Well 613 (9,300 mg/L) to the leading edge of the fully impacted water at Well NBL 1 (3,340 mg/L).

However, neither natural attenuation nor active remediation will reduce sulfate concentrations below the Site standard because the concentrations are controlled by groundwater equilibrium with the mineral gypsum (as in the Southwest Alluvium and Zone 1). For example, from 1989 through 1997, Well EPA 1 consistently had sulfate concentrations in the range of 2,500 mg/L to 3,000 mg/L. This well is located approximately 800 ft downgradient of the current northeastern edge of the seepage-impacted water (see Figure 35) and showed background water quality until

this part of Zone 3 lost saturation. TDS also will continue to exceed the Site standard because sulfate comprises most of the TDS (as in the Southwest Alluvium and Zone 1).

Metals and Basis for Request for Revision of ROD Background Concentrations

Figures 42a and 42b are graphs of metals concentrations (from 1989 through 2011) that exceeded the Site standards: aluminum, arsenic, beryllium, cadmium, cobalt, manganese, molybdenum, and nickel (the metals uranium and vanadium are discussed later with the radionuclides). Arsenic, beryllium, and cadmium have MCLs under the federal Safe Drinking Water Act; aluminum and manganese have SMCLs; and cobalt, molybdenum, and nickel have neither MCLs nor SMCLs.

UNC requests revision of the ROD background concentrations for constituents including arsenic, molybdenum, cobalt, and nickel (similar to the NRC revision in 1996 for the background standards for sulfate, nitrate, and TDS). The bases for this request are discussed below.

Arsenic and molybdenum exceed Site standards primarily in the background water. These two constituents have historically shown elevated concentrations in background Wells EPA 1 (now dry) and NBL 1 (now impacted), while very low to nondetect concentrations are found in most impacted wells, including Well 613 (see Table 14 and Figure 42b). Molybdenum has also shown long-term exceedances in impacted Well 504 B, but such occurrences may represent the local influence of background water that is mixed with impacted water.

April 2010 through July 2011 showed exceedances of arsenic in Well NBL 1 (though it was nondetect in October 2011). However, arsenic exceedances between approximately 0.5 and 1.0 mg/L from 2001 to 2004 were associated with background water – the seepage-impacted water quality here is better than non-impacted water in regard to arsenic concentrations.

It is important to realize that background water quality is associated with metals exceedances. For example, from installation in August 2001 through mid-2004 (a period of background water quality), tracking Well NBL 1 exceeded the standards for molybdenum, nickel, and manganese. N.A. Water Systems (2008f) calculated background concentrations for all chemical parameters in all three hydrostratigraphic units through October 2007. For Zone 3 background arsenic, the UCL95 of the mean is 0.175 mg/L (the existing Site standard is 0.05 mg/L), based on 186 total data showing a range from nondetect to a maximum of 1.01 mg/L.

For Zone 3 background molybdenum, the UCL95 of the mean is 17.43 mg/L (the existing site standard is 1 mg/L), based on 184 total data points showing a range from nondetect to a maximum of 75 mg/L. For Zone 3 background manganese, the UCL95 of the mean is 3.436 mg/L (the existing Site standard is 2.6 mg/L), based on 186 total data showing a range from nondetect to 7.5 mg/L. For Zone 3 background nickel, the UCL95 of the mean is 0.14 mg/L (the existing EPA Site standard is 2 mg/L, and the NRC standard is 0.05 mg/L), based on 186 total data points showing a range from nondetect to 0.67 mg/L (the background UPL95 [see next paragraph] for nickel is 0.569 mg/L). For Zone 3 background cobalt, the UCL95 of the mean is 0.0877 mg/L (the existing Site standard is 0.05 mg/L), based on 186 total data points showing a

range from nondetect to 0.53 mg/L). The metals exhibit a consistent pattern of higher concentrations in wells such as 613, 517, 719, and NBL 1, which have an acidic pH, and much lower concentrations where the pH is more neutral. This difference in concentrations is due to attenuation as the acidic seepage is neutralized along many groundwater flow paths.

In addition to UCL95s, UNC has calculated background concentrations as the 95th percentile upper prediction limits (UPL95) for the constituents having NRC License GWPSs. UPL95s statistically represent an estimate of the background threshold values in the upper tail of the groundwater quality data distribution. UNC will use UPL95s as the appropriate value by which to judge whether or not any given water analysis lies within the background population. A License amendment request to accomplish this is under preparation.

Metals in Impacted Waters

Well 613 is located near the center of the impacted area, closest to the source area, where pH has ranged from 2.76 to 3.24 since this well was first monitored in 2000. This well shows the highest metals concentrations during October 2011 for cobalt, cadmium, beryllium, nickel, manganese, and aluminum.

Figure 43 is a map showing the extent of aluminum concentrations exceeding 5 mg/L based on October 2011 sampling. The map illustrates that the distribution of aluminum exceedances was largely restricted to the southwestern part of the impacted area (this is a long-term distribution pattern). Three isolated outlying areas of elevated aluminum concentrations are depicted near Wells 504 B, PB 4 and PB 2, and NBL 1.

All wells sampled in October 2011 within the seepage-impacted area continued to show exceedances of manganese, cobalt, and nickel, except Well 420, which is near the northwestern edge of seepage impact (Figure 35) and shows borderline impacted/background water quality.

Attenuation has stabilized the metals concentrations in some wells. For example, the groundwater quality in Well 717 showed stabilization of concentrations, from approximately 2009 to 2011, in beryllium, cobalt, nickel, and aluminum. The bicarbonate concentrations here have been falling sharply since July 2003 (Figure 39) and reached nondetect levels in January 2009. Well 717 is 330 ft to the northeast of, and downgradient of, Well EPA 14, which started to show sharply degrading groundwater quality in 2000. Figure 39 shows that the rates of the sharp declines in bicarbonate concentrations are quite similar in both wells. In EPA 14 the sharp bicarbonate decline started during October 1999 (746 mg/L); in 717 it started in July 2003 (737 mg/L).

Uranium, Vanadium, and Radionuclides

Figure 44 presents graphs of the concentrations of uranium, vanadium, combined radium, and thorium-230 from 1989 through 2011. Combined radium concentrations exceed the Site standard for Zone 3 (5 pCi/L) in the background water; consequently, radium concentrations in Zone 3 are never expected to reach the standard. Combined radium in Zone 3 background groundwater is estimated to have a mean (UCL95) concentration of 10.66 pCi/L. (N.A. Water Systems, 2008f, Table 5). This is exemplified by combined radium concentrations at well NBL 1 (Figure 44). From its installation in 2001 through approximately July 2005, combined radium concentrations at NBL-1 were approximately steady and above the Site standard; this period is interpreted as representing mostly background water quality. Since that time and the onset of seepage impact, the overall trend had been increasing but it may have stabilized during 2010 and 2011.

The License amendment request to change the combined radium standards (UNC, 2006), and the related NRC License amendment (NRC, 2006b), addressed only the Southwest Alluvium and Zone 1. However, the central fact underpinning the statistical analysis of background and impacted water quality (N.A. Water Systems, 2006a; technical analysis report in support of the License amendment request) is that background water, derived from the former mine water discharge into the alluvium, frequently exceeds the Site standard for radium. This fact also applies to Zone 3 (N.A. Water Systems, 2008f), which derived its background quality groundwater from the same source. UNC is presently drafting a License amendment request to revise some of the NRC groundwater protection standards to new calculated values of the UPL95 background concentrations.

Historically, uranium, vanadium, and thorium-230 are typically present above the standards in Well 613, which has almost always had the most acidic pH (3.05 in October 2011). Downgradient toward the northeast, natural attenuation reduces the concentrations of these three radionuclides in Well 708 (pH of 3.54 in October 2011); however, since installation of this well in 1991 the concentration of uranium has been very gradually increasing. Much lower concentrations are reported where the pH is more neutral. These reductions are due to attenuation by neutralization, adsorption, or possibly precipitation. In October 2011, exceedances of these three constituents were primarily in samples collected from Well 613 (though 420 exceeded for uranium and PB 4 exceeded for thorium-230; see Table 14). The longer-term pattern of uranium at Well 613 has been fluctuating to approximately steady concentrations above the standard. The concentration in October 2011 (0.942 mg/L) was higher than the calculated UCL95 of the background mean (0.107 mg/L; N.A. Water Systems, 2008f).

No Zone 3 wells other than 613 had 2011 samples with vanadium detections.

Two wells, 613 and 420, had one or more samples with uranium concentrations greater than the standard in 2011. In Well 420, uranium had been increasing very gradually since 1989, but the concentrations stepped up in October 2007 and exceedances have occurred in all quarters since January 2010 (Figure 44).

Two Zone 3 wells had 2011 samples with thorium-230 concentrations above the standard of 5 pCi/L. These were 613 (during all four quarters; 710 pCi/L in October) and PB 4 (25.7 pCi/L in October).

The historic amounts of gross alpha within the Zone 3 groundwater indicate that this parameter tends to fluctuate by approximately one order of magnitude in most of the impacted wells (except Well 613, which shows smaller fluctuations). The gross alpha Site standard of 15 pCi/L was exceeded in October 2011 in the following wells: 613 (long-term fluctuations), 717, PB 2, and PB 4 (Table 14 and Appendix B). Since October 2004, Well 719 has remained below the standard. EPA 14 showed exceedances in January and July of 2011. Well EPA 14 has demonstrated a distinctive pattern of gross alpha concentrations compared to all other impacted wells (see Appendix B). Since 1989, the values had consistently been below the standard until the last two quarters of 2003, when the values spiked upward by a factor of approximately ten. During these same two last quarters of 2003, the combined radium concentrations in this well also showed sharp upward spikes. The unusual (and singularly large) value for uranium in this well during July 2003 has been followed by the relatively large range in combined radium (Figure 44). The geochemistry of the background water (of post-mining/pre-tailings age) that seeped into the ground was heterogeneous, and it is often inherently difficult to unequivocally infer that impacted water, rather than high-concentration-bearing background water, is responsible for the pattern of exceedances at many locations. Background Well NBL 2 showed an exceedance (0.3285 mg/L) of the uranium standard during its first monitoring event in July 2008; this location has also shown persistent exceedances of combined radium.

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

Total Trihalomethanes (TTHMs)

The Site standard is no longer for chloroform per se, but rather for TTHMs pursuant to NRC License amendment 37 (NRC, 2006b). TTHMs (comprising only chloroform in all Site groundwater analyses) were detected above the Site standard in only Well 613 during October 2011 (see Figure 45). The concentrations in Well 613 have exceeded the TTHMs Site standard of 80 µg/L since October 2002, consistent with this well's proximity to the North Cell (see Figure 35). Well 613 concentrations have shown long-term fluctuations but increased by approximately four times from July to October 2002 (166 µg/L). Since then the concentrations have shown relatively large fluctuations that are superimposed on an overall decreasing trend.

The only other Zone 3 locations with detected TTHMs are Wells 517 (1.30 µg/L chloroform in October 2011), EPA 14 (1.30 µg/L in October 2011), and 717 (4.16 µg/L in October 2011). Well 717 first showed chloroform detection in July 2008, and it showed detections during all four quarters of 2011 (Appendix B). These are the first repeated detections of chloroform downgradient of Well EPA 14, and these observations once again support the inference that highly impacted water has migrated downgradient from EPA 14 to 717. Well 518 also

consistently showed chloroform detections until it ceased being sampled in 2000 (Appendix B). All other Zone 3 wells have shown historic nondetects for chloroform and, since the fourth quarter of 2006, TTHMs. This indicates that groundwater to the northeast of Well 517 rapidly attenuates chloroform by degradation, dispersion, and dilution, to levels that are generally nondetect but are otherwise always far below the Site standard (which is equivalent to the primary drinking water standard).

Pb-210

Table 14 shows that there were five detections of Pb-210 during October 2011. The 2011 concentrations vary from 1.7 (Well NBL 1) to 12.7 pCi/L (Well PB 4). At least three issues are important to consider in the context of regulatory compliance with the NRC GWPS of 1 pCi/L:

- 1) The quantitative analytical errors (reported as precision errors) associated with each sample's result indicate that some of the results are statistically not exceedances;
- 2) The analytical results as reported have a confidence level (also called the combined standard uncertainty) of 2σ (2 standard deviations, equivalent to a 95 percent confidence level) and, as such, the results are tied to probability functions; and
- 3) Accepting the results at face value indicates that, with the exception of PB 4, they fall within the range of background water concentrations.

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

- Percent nondetects = 69.5%
- Minimum detected = 1 pCi/L
- Maximum detected = 11 pCi/L
- Mean of detected = 2.549 pCi/L
- Median of detected = 2 pCi/L
- Upper Confidence Limit of the mean at the 95% confidence level of the sampled population (UCL95) = 1.618 pCi/L.

Excluding Well PB 4, the October 2011 detections are not inherently indicative of impact from the tailings seepage; they fall within the lower half of the range of 1 to 11 pCi/L defined by the minimum and maximum values associated with background water. The highest detection in October 2011 (12.7 pCi/L in PB 4) is greater than the mean concentration calculated for background water. As discussed earlier, the water quality in PB 4 during October 2011 is highly impacted (Table 14; Appendix B).

Section 4

Zone 1

4.1 *Corrective Action Summary*

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

4.2 *Mass of Chemical Constituents Removed*

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

4.3 *Performance Monitoring Evaluation*

The Zone 1 performance monitoring program is summarized in Table 15. The program consists of quarterly monitoring of water levels in 15 wells and water quality in eight wells and has been in effect since the second quarter of the 2000 operating year.

4.3.1 *Water Level Evaluation*

Historic water level data for Zone 1 wells through October 2011 are presented in Appendix C. Water levels for the fourth quarter of 2011 are shown on the potentiometric surface map in Figure 46. Water levels through time are shown on Figure 47. Saturated thicknesses calculated from the October 2011 measurements in Zone 1 are presented in Table 16. This table shows that the Zone 1 hydrostratigraphic unit remains completely saturated in most of the downdip wells: 505 A, 502 A, and 412 (in Section 36), and (TWQ)142 and (TWQ)143 (along the northern boundary of Section 36) (see Figure 46). However, during 2011, most of the wells continued to show overall decreasing piezometric elevations (usually with small fluctuations), indicating that the Zone 1 potentiometric field continues to lower as groundwater drains downdip into partially saturated parts of this bedrock stratigraphic unit.

Changes of piezometric elevations in updip and downdip wells indicate the broad pattern of the shift in the potentiometric field caused by groundwater drainage to the northeast in Zone 1. Groundwater levels in Well 504 A have risen gradually and may become fully saturated as

groundwater migrates to this portion of the confined Zone 1 hydrostratigraphic unit (see Table 16; Figures 46 and 47; and Appendix C). Similarly, the slowly rising groundwater levels at downdip Wells 142, 143, and 412 represent increasing potentiometric levels within these 100-percent saturated parts of the fully confined Zone 1 hydrostratigraphic unit. Long-term decreasing water levels updip to the south-southwest, at locations under less than fully saturated conditions, are a response to the continued flow of groundwater downdip into partially saturated parts of the system.

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

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

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

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

Source remediation (neutralization and subsequent dewatering of the borrow pit, and capping of the Central Cell), continued neutralization of the seepage by natural geochemical processes, and mixing with the background water have reduced concentrations of most constituents below the Site clean-up standards. However, as discussed below, exceedances of some constituents still occur in Zone 1. Appendix C provides historic constituent concentration data through October 2011. Table 17 summarizes the constituents detected in Zone 1 during October 2011.

It is important to realize that exceedances of Site standards in some wells represent background water quality. For example, since 1989 background Well EPA 4 (in Section 1) has persistently shown exceedances of sulfate, has generally shown exceedances of manganese, and has shown concentrations of combined radium that have fluctuated above and below the former Site

standard of 5 pCi/L (revised in 2006 to 9.4 pCi/L; NRC, 2006b). Background water quality is discussed further in the subsequent section entitled Natural Attenuation System Performance Evaluation.

Water quality has continued to improve since shutoff of the pumping wells, indicating that the degree of seepage impact is diminishing. Zone 1 seepage impacts have been delineated (Figure 48) by chloride concentrations greater than 50 mg/L (Earth Tech, 2000a). Well EPA 5 has shown a long-term, gradual reduction in chloride concentrations from a maximum of 289 mg/L in April 1992 to 40 mg/L in October 2011 (and since April 2008, 14 of 15 values are less than 50 mg/L – refer to Appendix C).

The zone of seepage impact has migrated predominantly toward the northeast. Further eastward components to migration are limited by the proximity of the eastern edge of saturation. The acidic “core” of the impacted zone is approximated by the area where pH is inferred to be less than 4.0 (orange area in Figure 48). Figure 49 shows historic field pH values for Zone 1 wells through October 2011. Well 604 has persistently shown the lowest pH; as discussed below, it also is the most highly impacted well. However, this well shows a long-term increasing trend in pH values (Figure 49). Figure 49 shows that starting in approximately 1990, acid neutralization and buffering resulted in substantial pH increases in Wells 515 A, 516 A, and EPA 7.

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

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

TDS, sulfate, and manganese are non-hazardous constituents. All of these constituents have generally exceeded standards at the cited wells since 1989. As discussed earlier, during August 2006 the NRC groundwater protection standard for combined radium was revised to 9.4 pCi/L (NRC, 2006b). There were no exceedances of this standard in October 2011.

Within the Site property, the standards were exceeded for TDS, sulfate, and manganese (Table 17). Other constituents whose standards were exceeded onsite in October 2011 were: cobalt (Well 604), nickel (Wells 515 A and 604), and TTHMs (Well 515A). During October 2011, Wells 515 A and 614 exceeded the chloride standard, as has frequently occurred at these locations since the start of monitoring during 1989.

The extent of seepage impacts, as delineated by a chloride concentration greater than 50 mg/L has diminished gradually over time (e.g., compare 2008 annual report Figures 48 and 49). Many other aspects of water quality have continued to improve since shutoff, confirming that the degree of seepage impact is diminishing in both time and space. Natural attenuation processes include acid neutralization by:

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

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

Outside the UNC property boundary in Section 1, the post-pumping groundwater quality continues to improve overall (Tables 17 and 18). *During October 2011 there are no exceedances of hazardous constituents outside the UNC property boundary within seepage-impacted groundwater – in fact and more broadly, this is the case for all three hydrostratigraphic units.* The exceedances of sulfate and TDS in Wells EPA 5 and EPA 7 reflect geochemical equilibrium of the groundwater with gypsum; these constituents are also non-hazardous. All of these constituents are discussed more below.

4.3.3 Natural Attenuation System Performance Evaluation

The Zone 1 natural attenuation system comprises the hydro-geochemical interactions between the bedrock matrix, the anthropogenic background waters (derived from former mine water discharge), and the tailings fluids. The natural system is successfully attenuating the seepage impacts by the processes of neutralization, precipitation, adsorption, and mixing with the background waters. However, some constituents will remain at above-standard concentrations because of the inherent geochemical characteristics of the Zone 1 background water.

Table 18 shows the predicted geochemical performance of the Zone 1 natural attenuation system (revised from Earth Tech, 2002d). In summary, sulfate and TDS concentrations are not expected to meet Site standards because gypsum equilibrium in the groundwater prevents any further reduction in sulfate concentration. Manganese may meet the Site standards if sufficient bicarbonate is available for attenuation. The remaining metals and radionuclides are expected to meet the standards through attenuation by neutralization and adsorption. Outside of Section 2, TTHMs will meet the standard through attenuation by degradation, dilution, and dispersion. The individual constituents of concern are discussed below.

Sulfate and TDS

Sulfate concentrations exceed the Site standard in both the seepage-impacted water and the background water in Zone 1. Figure 50 shows historic sulfate concentrations through October 2011; Figure 51 shows the extent of sulfate exceedances during October 2011. The time-series indicate that the operation of extraction wells prior to July 1999 did not have a discernable influence on sulfate and TDS, because sulfate concentrations in Zone 1 are controlled by the system's equilibrium with gypsum. Based on the overall stable concentrations and the results of the geochemical investigation presented by Earth Tech (2000a), sulfate is not expected to meet the clean-up standards within Section 1. As in the Southwest Alluvium and Zone 3, most of the TDS comprises sulfate (although other dissolved solids contribute significantly to the TDS in Wells 614 and EPA 7; see Appendix C)). Accordingly, TDS concentrations are not expected to meet the clean-up standards in Section 1, although they should gradually decrease to background levels. The UCL95 of the mean sulfate concentration in Zone 1 background water was determined to be 2,773 mg/L (N.A. Water Systems, 2008f); the ROD cleanup level is 2,160 (see multiple comparison values in op cit, Table 6).

Manganese

Manganese concentrations exceed the Site standard in both the seepage-impacted water and the background water (Well EPA 4) in Zone 1. Concentrations in the seepage-impacted water are usually higher. These concentrations have decreased over time as the acidic seepage has been neutralized, but the magnitude of the decrease is largely controlled by the bicarbonate concentrations (Earth Tech, 2000a). Historic manganese concentrations through October 2011 are shown on Figure 52 and tabulated in Appendix C. The extent of manganese that exceeded the Site standard during October 2011 is shown on Figure 53. Figure 52 shows that the long-term decreasing trend in manganese in Well EPA 7, which started in January 1998, for the first time fell below the standard in 2006; in 2008 the concentrations began to slowly increase and small exceedances occurred during all four quarters of 2011 (concentration of 2.66 mg/L in October 2011). Well 604 continues to show a decreasing trend in manganese that started in January 2004, and Well 515A has shown a sharp decline since July 2009 (Figure 52).

Bicarbonate concentrations in impacted wells are related to the waters' degree of neutralization of acidic seepage. Figure 54 shows historic bicarbonate concentrations through October 2011. As discussed above regarding Zone 3, marked declines of bicarbonate concentration are indicative of (sometimes temporary) exceedance of the local buffering capacity of the natural geochemical system (i.e., the flux of acidity (temporarily) exceeds the rate of buffering). The plunge of bicarbonate concentration in Well EPA 5 from January 2000 to May 2000 is such an example. By contrast, Well 614 (Figure 54) has never shown such a falloff in bicarbonate concentrations, which is consistent with its side-gradient location with respect to former Borrow Pit No. 2. A third example of historic bicarbonate trends is provided by Well EPA 7 (Figure 54), where formerly very low bicarbonate concentrations have increased step-wise beginning in July 1990, with additional upward steps in January 1994, again in October 1998, and again in May 2000. The rising concentrations indicated that the natural attenuation neutralization capacity has

recovered in a similar step-wise manner at this location. The historically highest bicarbonate concentration in EPA 7 was measured in April 2010 (680 mg/L), and since then the overall trend is decreasing.

Recent bicarbonate increases in Well 515 A are noteworthy (Figure 54). From a bicarbonate concentration of 198 mg/L in January 2010, the concentration increased to 727 mg/L in October 2011. This is a large change and this well will be closely monitored in the coming year.

The seepage-impacted wells that have had bicarbonate concentrations greater than 1,000 mg/L (Wells 614, 516 A, and EPA 5) either have never had manganese exceedances or have had a decrease in manganese concentration to below the standard. In contrast, impacted wells with lower bicarbonate concentrations, such as Wells 515 A, 604 and EPA 7, have historically had manganese exceedances (including 515 A and 604 in October 2011). However, even among these wells the effect of bicarbonate on manganese concentrations is well illustrated by EPA 7. Since July 1991, increasing bicarbonate concentrations in Well EPA 7 (in Section 1) have exceeded 500 mg/L (Figure 54), and the manganese concentration steadily declined through October 2008 (Figure 52) – since then the relationship reversed, i.e., both the bicarbonate and the manganese concentrations have increased. The recent increase in bicarbonate at 515 A apparently correlates with decreasing manganese (Appendix C),.

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

In summary, exceedance of the manganese standard within the property boundary will continue except where there is sufficient neutralization capacity to reduce the manganese concentrations. It is also important to realize that manganese exceeds the standard in the background water quality. Manganese is a non-hazardous constituent.

Cobalt and Nickel

Excluding manganese, there are no exceedances of metals outside the property boundary in Section 1. Other metals are attenuated within the property boundary. Exceedances of cobalt and nickel are now limited to the area within the property boundary where the acidic seepage has not been fully neutralized. Historic concentrations for these two constituents through October 2011 are presented graphically in Figure 55. The extent of cobalt and nickel exceeding the Site standard during October 2011 is shown in Figure 56.

Nickel has shown a continuous decline in Well EPA 5 since January 2002 (Figure 55). Since April 2007, the concentrations have been nondetects. Cobalt has shown a continuous decline in Well EPA 5 since April 2003 (Figure 55) and concentrations have been below the standard since October 2007.

Cobalt and nickel typically do not adsorb sufficiently to reduce their concentrations below their standards until the pH is approximately 6.5 or more (Earth Tech, 2002d). For example, cobalt and nickel concentrations in Well EPA 7 historically have fluctuated around the Site standard as the pH has increased to above 6.0. Continued neutralization in Well EPA 7 has been the geochemical impetus for reductions in concentrations to levels below the standards for cobalt in April 2002, and nickel in January 2003. Empirically (Appendix C) it appears that a pH of approximately 6.0 may promote adsorption sufficient for reduction of concentrations to below the standards for both parameters.

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

Combined Radium-226 and Radium-228

Similar to the metals, combined radium is attenuated by neutralization, precipitation, and adsorption. The highest concentrations of combined radium are within the property boundary where the pH is more acidic (Table 17). Historic concentrations for combined radium through October 2011 are presented in Figure 57. During October 2011, the NRC combined radium Zone 1 Site standard of 9.4 pCi/L (NRC, 2006b) was not exceeded in any well (Table 17; Appendix C).

Total Trihalomethanes (TTHMs)

The sole exceedance of the Site standard (80 µg/L; see NRC, 2006b) for TTHMs in October 2011 occurred at Well 515 A (83.6 µg/L), which is within the property boundary and not a POC well. TTHMs exceedances have occurred here since April 2010 (Appendix C). UNC has submitted an ACL application for TTHMs in POC Well 614 and nickel in POC Well 604 (discussed below).

Pb-210

Table 17 shows that there were no detections of Pb-210 during October 2011. During the entire year there were two detections: 1.4 pCi/L in Well EPA 4 during April, and 1.6 pCi/L in Well EPA 5 during April. EPA 4 is a background quality well. At least three issues are important to consider in the context of regulatory compliance with the NRC GWPS of 1 pCi/L:

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

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

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

The 2011 detections are not inherently indicative of impact from the tailings seepage; they fall at the low end of the range of 1 to 11 pCi/L defined by the minimum and maximum values associated with background water. The two detections are less than the mean concentration calculated for background water. It is important to note that Well EPA 4 is a background well. The previous detection here was in January 2008 (4.4 pCi/L), and the detection previous to that was in January 1999 (1.5 pCi/L). Regarding impacted Well EPA 5, the previous detection here was in July 1999 (2.2 pCi/L). For both of these wells, the history of laboratory analytical results suggests Pb-210 is either not persistently present, or if it is, over time it has been difficult to detect because of factors tied to low concentrations and/or laboratory methods.

4.4 Alternate Concentration Limits Application

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

During 2011, NRC has stated that this ACL application is unacceptable because the proposed POEs (Wells EPA 5 and EPA 7) are not located on UNC property. This proposal was made because there is no space for more wells to the east of the Central Cell in Section 2, such that there would be spatially separate POC wells (604 and 614) and POE wells. UNC is presently considering alternate approaches to address TTHMs and nickel in these two POC wells. Nonetheless, it is important to understand the key issues related to UNC's ACL application from 2008, which are summarized next.

In developing the proposed ACLs, UNC has conducted concentration trend analyses from the final shutoff of Zone 1 pumping wells in July 1999 through October 2007 (with the groundwater analytical data from the first three quarters of 2008 integrated into the analyses). In addition,

historic groundwater quality has been reviewed for all monitoring wells in Zone 1. Based on these observations, UNC proposes the ACL of 0.4 mg/L for nickel at POC Well 604, and the ACL of 0.3 mg/L for TTHMs at POC Well 614.

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

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

Since the termination of pumping, constituent concentrations have progressively reduced through natural geochemical processes (as discussed in detail for all constituents in this 2011 Annual Review Report). Nickel and chloroform are being diluted or immobilized and will not migrate any further. The analysis presented in the ACL application confirms that the spatial extent of Zone 1 seepage impact is stable to diminishing, and that natural attenuation by neutralization (buffering) and adsorption is occurring for the metals (including nickel), and that attenuation by degradation, dilution, and dispersion is occurring for chloroform.

The 22-year history of continuous groundwater quality monitoring in Zone 1 (and Site-wide) provides a sound empirical basis for evaluating contaminant transport and attenuation. The key conclusions of the ACL application are summarized below:

- There is no nickel or chloroform at concentrations above standards in any Section 1 well.
- The long monitoring history provides more than sufficient time to detect exceedances and to evaluate trends.
- Source area concentrations within Section 2 show decreasing long-term trends.
- Constituent concentrations progressively decrease downgradient.
- Hydraulic gradients and groundwater flow rates are diminishing over time.
- Groundwater quality is expected to continue its improvement at the proposed point-of-exposure (Wells EPA 5 and EPA 7) from levels already below Site standards.
- There are no Zone 1 exceedances of the License GWPS in Section 36 (UNC property) or Section 1 (Indian Trust Land property), nor are there exceedances of any hazardous constituents within impacted water outside of Section 2.
- A large part of Zone 1 in Section 1 is dry, and this hydrostratigraphic unit is physically and chemically non-viable for sourcing domestic or stock water supply wells. Treatment of either the impacted or background water, to potable quality, would be extremely expensive and is not feasible.
- The proposed Zone 1 remedy of No Further Action plus ACLs will be protective of human health and the environment.
- UNC has demonstrated ALARA conditions in Zone 1.

Section 5

Conclusions and Recommendations

This annual review evaluated the performance of the natural systems in all three Site hydrostratigraphic units and the active remediation in Zone 3. In the Southwest Alluvium and Zone 1, the natural systems have functioned as effectively as when active remediation took place. During 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, injection of water amended with sodium bicarbonate began in Well IW A in the northern part of Zone 3 in Section 36. The conclusions and recommendations of this evaluation are provided below.

5.1 Conclusions

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

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

The MDC analytical results are generally very low concentrations. For example, of the 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. Quantitative analytical errors (precision errors) indicate that some of the results are, statistically not exceedances.

The current Site standard for Pb-210 is 1 pCi/L (NRC Source Materials License), which was the idealized lower limit of detection 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 (95th percentile of the upper prediction limits). With NRC concurrence, the Pb-210 background threshold values will be 5.9 pCi/L (Southwest Alluvium), 5.7 pCi/L (Zone 3), and 4.7 pCi/L (Zone 1). Application of these values will render most Pb-210 values as being in compliance. Background water Pb-210 concentrations define the following ranges: 1 to 14 pCi/L (Southwest Alluvium); 1 to 11 pCi/L (Zone 3); and 1 to 9 pCi/L (Zone 1).

Below are some of the key conclusions of this report:

- *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 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.)

5.2 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 (95th percentile of the upper prediction limits).

5.2.1 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 95th percentile on the mean in N.A. Water Systems, 2008f, and as 95th 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.

5.2.2 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 dewater 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.

5.2.3 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).

Section 6

References

- ARCADIS BBL, 2007, In-Situ Alkalinity Stabilization Pilot Study, UNC Church Rock Site, Gallup, New Mexico. June.
- BBL, 2006, UNC Church Rock Site In-Situ Alkalinity Stabilization Pilot Study, United Nuclear Corporation, Gallup, New Mexico. Revised June 2006.
- Canonie Environmental Services Corp., 1995, EPA Remedial Action and NRC Ground Water Corrective Action, Five-Year Review (1989-1994). January.
- Canonie Environmental Services Corp., 1993, Ground Water Corrective Action, Annual Review - 1993, Church Rock Site, Gallup, New Mexico. December.
- Canonie Environmental Services Corp., 1992, Ground Water Corrective Action, Annual Review - 1992, Church Rock Site, Gallup, New Mexico. December.
- Canonie Environmental Services Corp., 1991, Ground Water Corrective Action, Annual Review - 1991, Church Rock Site, Gallup, New Mexico. December.
- Canonie Environmental Services Corp., 1990, Ground Water Corrective Action, Annual Review - 1990, Church Rock Site, Gallup, New Mexico. December.
- Canonie Environmental Services Corp., 1989a, Remedial Design Report, Church Rock Site, Gallup, New Mexico. April.
- Canonie Environmental Services Corp., 1989b, Ground Water Corrective Action, Annual Review - 1989, Church Rock Site, Gallup, New Mexico. December.
- Canonie Environmental Services Corp., 1987, Geohydrologic Report, Church Rock Site, Gallup, New Mexico. May.
- Chester Engineers, 2011a, Annual Review Report – 2010 – Groundwater Corrective Action, Church Rock Site, Church Rock, New Mexico. January 26, 2011.
- Chester Engineers, 2011b, Updated Baseline Human Health Risk Assessment, Church Rock Site, Church Rock, New Mexico. March 16, 2011.
- Chester Engineers, 2011c, Revised Site-Wide Supplemental Feasibility Study Parts I and II, Church Rock Site, Church Rock, New Mexico. April 26, 2011.
- Chester Engineers, 2011d, UNC Presentations at the Site Technical Meeting, May 24, 2011, Albuquerque, New Mexico: (1) Zone 3 Groundwater Model Status; (2) Update on Injection in Zone 3; (3) Revised SWSFS Parts I and II – Short Look at Process and Findings; and (4) Lead-210 – Data Overview, Interpretations, Background Concentrations, and Action Items. May 24, 2011.

- Chester Engineers, 2011e, Technical Memorandum Summarizing Two Reports on Zone 3 Tailings Seepage Sourcing and Groundwater Recharge, with Information Update, United Nuclear Corporation's Church Rock Tailings Site, Gallup, New Mexico. August 18, 2011.
- Chester Engineers, 2011f, ACL Risk Assessment Questions/Comments/Strategy. August 30, 2011.
- Chester Engineers, 2011g, Provisional UNC Responses to EPA Comment Letter (July 8, 2011) on the Draft Baseline Human Health Risk Assessment (March 2011) for the UNC Church Rock Mill Superfund Site, Gallup, New Mexico. October 28, 2011.
- Chester Engineers, 2011h, Hydrogeologic Assessment of Injection at Zone 3 Well IW-A Through September 2011, United Nuclear Corporation's Church Rock Tailings Site, Gallup, New Mexico. November 1, 2011.
- Chester Engineers, 2011i, UNC Requests Discussion and Clarification Regarding EPA Comment Letter of October 14, 2011 – Revised SWSFS Parts I and II (UNC, April 2011). November 15, 2011.
- Chester Engineers, 2010a, Annual Review Report – 2009 – Groundwater Corrective Action, Church Rock Site, Church Rock, New Mexico. January 28, 2010.
- Chester Engineers, 2010b, Email from Mark Jancin (for UNC) to Mark Purcell (EPA), Yolande Norman (NRC), Earle Dixon (NMED), Eugene Esplain (NNEPA), Roy Blickwedel (GE), and Larry Bush (UNC); Subject: Proposed Location Pilot Injection Well Zone 3. April 1, 2010.
- Chester Engineers, 2010c, Remedial Design Report – Conceptual Approach to Enhanced Remediation in Zone 3, New Injection Wells Combined with Existing Extraction Wells, UNC Church Rock Tailings Site, Gallup, New Mexico. May 17, 2010.
- Chester Engineers, 2010d, Hydrogeologic Analysis of Injection Testing of Zone 3 Well IW-A, July 2010, UNC Church Rock Tailings Site, Gallup, New Mexico. August 30, 2010.
- Chester Engineers, 2010e, Email from Mark Jancin (for UNC) to Katrina Higgins-Coltrain (EPA), Mark Purcell (EPA), Yolande Norman (NRC), Lifeng Guo (NRC), Earle Dixon (NMED), Eugene Esplain (NNEPA), Roy Blickwedel (GE), and Larry Bush (UNC); Subject: UNC's Questions and Requested Clarifications Regarding EPA Comment Letter of September 2, 2010, Concerning Revisions to Site-Wide Supplemental Feasibility Study (SWSFS) Part II – for Participants in Conference Call on November 5, 2010. November 4, 2010.
- Chester Engineers, 2009a, Annual Review Report – 2008 – Groundwater Corrective Action, Church Rock Site, Church Rock, New Mexico. January 28, 2009.

- Chester Engineers, 2009b, Revised Submittal: Site-Wide Supplemental Feasibility Study Part II, UNC Church Rock Tailings Site, Church Rock, New Mexico. July 10, 2009.
- Chester Engineers, 2009c, Email from Mark Jancin (for UNC) to Mark Purcell (EPA), Buddy Parr (EPA), Yolande Norman (NRC), Earle Dixon (NMED), Roy Blickwedel (GE), and Larry Bush (UNC); Subject: Re-optimization of Pumping in Northern Zone 3. October 8, 2009.
- Chester Engineers, 2009d, Hydrogeologic Analysis of Recent Zone 3 Injection Testing and Proposal for Enhanced Remediation, UNC Church Rock Tailings Site, Gallup, New Mexico. December 17, 2009.
- Earth Tech, Inc., 2002a, Ground Water Corrective Action, Annual Review - 2001, Church Rock Site, Gallup, New Mexico. January.
- Earth Tech, 2002b, Presentation – “Status Update for Southwest Alluvium, Zone 1 and Zone 3 Remedial Action.” Presented to EPA, NRC, NMED and Navajo Superfund. Santa Fe, New Mexico. March 7, 2002.
- Earth Tech, 2002c, Final Report and Technical Impracticability Evaluation – Southwest Alluvium Natural Attenuation Test, Church Rock Site. Prepared for United Nuclear Corporation. November.
- Earth Tech, 2002d, Annual Review Report – 2002 – Groundwater Corrective Action, Church Rock Site, Gallup, New Mexico. December.
- Earth Tech, 2001a, “Technical Memorandum – Change in Zone 3 Saturated Thickness, United Nuclear Church Rock Site, Gallup, New Mexico.” April.
- Earth Tech, 2001b, “White Paper, Lead-210 Exceedances, United Nuclear Church Rock Site, Gallup, New Mexico. April 2, 2001.
- Earth Tech, 2001c, Supplemental Analytical Data Submitted in Support of: “White Paper, Lead-210 Exceedances, United Nuclear Church Rock Site, Gallup, New Mexico. May 7, 2001.
- Earth Tech, 2000a, Letter to John J. Surmeier, Subject: “Source Materials License SUA-1475, Technical Support for Proposed License Amendments.” January 13, 2000.
- Earth Tech, 2000b, Letter to Greg Lyssy, Subject: “Response to Agency Comments on the January 13, 2000, Letter titled ‘Source Materials License SUA-1475, Technical Support for Proposed License Amendments’, for United Nuclear Corporation Church Rock Site.” April 26, 2000.
- Earth Tech, 2000c, Zone 1 Groundwater Geochemistry, Church Rock Site, Gallup, New Mexico. May.
- Earth Tech, 2000d, Southwest Alluvium Groundwater Geochemistry Report, Church Rock Site, Gallup, New Mexico. June.

- Earth Tech, Inc., 2000e, Ground Water Corrective Action, Annual Review - 2000, Church Rock Site, Gallup, New Mexico. December.
- Earth Tech, Inc., 1999, Ground Water Corrective Action, Annual Review - 1999, Church Rock Site, Gallup, New Mexico. December.
- Earth Tech, Inc., 1998, Ground Water Corrective Action, Annual Review - 1998, Church Rock Site, Gallup, New Mexico. December.
- General Electric Corporation, 2009, Letter from Roy Blickwedel (for UNC) to Yolande Norman (U.S. NRC): Church Rock, Source Materials License no. SUA-1475 [letter listing technical impediments to eventual site closure at the Church Rock mill]. May 20, 2009.
- General Electric Corporation, 2006, Regulatory Significance of the Occurrence and Distribution of Dissolved Uranium in Groundwaters of the Southwest Alluvium, Church Rock Site, New Mexico. March 10, 2006.
- General Electric Corporation, 2000, "Technical Memorandum – Support for Shutting Off Remaining Zone 3 Pumping Wells." May.
- MACTEC Engineering and Consulting, Inc., 2006, Phase I Full Scale Hydraulic Fracturing Final Report, United Nuclear Church Rock Facility, New Mexico. June.
- MWH, 2004, Supplemental Feasibility Study, Zone 3 Hydrostratigraphic Unit, Church Rock, Uranium Mill Tailing Site. October 2004.
- N.A. Water Systems, 2008a, Annual Review Report 2007 – Groundwater Corrective Action, Church Rock Site, Church Rock, New Mexico. January 29, 2008.
- N.A. Water Systems, 2008b, UNC Presentation at Annual Technical Meeting, Santa Fe, New Mexico – Zone 3 Remediation Outlook. March 12, 2008.
- N.A. Water Systems, 2008c, Recommendations and Summary of Hydrogeologic Analysis – Evaluation of Groundwater Flow in Zone 3 for the Design of a Pumping System to Intercept and Recover Impacted Groundwater, UNC Church Rock Tailings Site, Gallup, New Mexico. April 25, 2008.
- N.A. Water Systems, 2008d, Letter from Mark Jancin (for UNC) to Mark Purcell (EPA) and Myron Fliegel (NRC): Notification that UNC's Groundwater Analytical Laboratory is Modifying the Reporting and Sampling Protocol for Radiologic Parameters, UNC Church Rock Tailings Site, Gallup, New Mexico. August 14, 2008.
- N.A. Water Systems, 2008e, Email from James Ewart (for UNC) to Mark Purcell (EPA), Earle Dixon (NMED), Diana Malone (NNEPA), Dennis Beal (SAIC for EPA), Larry Bush (UNC), and Roy Blickwedel (GE) – Example Decision Tree for Objective 1 Statistics Work for the Site-Wide Supplemental Feasibility Study. September 30, 2008.

- N.A. Water Systems, 2008f, Revised Submittal – Calculation of Background Statistics with Comparison Values, UNC Church Rock Mill & Tailings Site, Church Rock, New Mexico. October 17, 2008.
- N.A. Water Systems, 2008g, Revised Submittal – Estimated UCL95 Statistics and EPCs in Impacted Groundwater, UNC Church Rock Mill & Tailings Site, Church Rock, New Mexico. December 5, 2008.
- N.A. Water Systems, 2008h, Alternate Concentration Limits Application, Zone 1 of the Lower Gallup Sandstone, UNC Church Rock Site, Church Rock, New Mexico. December 29, 2008.
- N.A. Water Systems, 2007a, Annual Review Report 2006 – Groundwater Corrective Action, Church Rock Site, Church Rock, New Mexico. January 9, 2007.
- N.A. Water Systems, 2007b, Site-Wide Supplemental Feasibility Study, Part I, Church Rock Remediation Standards Update, Church Rock Site, Church Rock, New Mexico. February 19, 2007.
- N.A. Water Systems, 2006a, Technical Analysis Report in Support of License Amendment Request for Changing the Method of Determining Exceedances of the Combined Radium Groundwater Protection Standard in Source Materials License SUA-1375 (TAC LU0092), Groundwater Corrective Action Program, Church Rock Site, Church Rock, New Mexico. Revised February 2006.
- N.A. Water Systems, 2006b, Preliminary Proposed Content, Site-Wide Supplemental Feasibility Study, UNC Mill Tailings Site, Church Rock, New Mexico. July 27, 2006.
- N.A. Water Systems, 2006c, List of Preliminary Assembled Remedial Alternatives, Site-Wide Supplemental Feasibility Study, UNC Mill Tailings Site, NM. September 25, 2006.
- N.A. Water Systems, 2005a, Presentation: 2004 Corrective Action, Keypoints and Rationale for Changes to Standards; Meeting at Church Rock, May 5, 2005.
- N.A. Water Systems, 2005b, Annual Review Report 2005 – Groundwater Corrective Action, Church Rock Site, Church Rock, New Mexico. December 28, 2004.
- N.A. Water Systems, 2004, Annual Review Report 2004 – Groundwater Corrective Action, Church Rock Site, Church Rock, New Mexico. December 30, 2004.
- New Mexico Environment Department, 1998, Letter to Greg Lyssy (EPA) from Maura Hanning, Subject: “Revision of Postmining, Pretailings Concentrations at the UNC Church Rock Site.” January 6, 1998.
- Nuclear Regulatory Commission, 2007, Approval of Administrative License Amendment Requests, Source Materials License SUa-1475 – Amendment 39 (TAC J00513. April 23, 2007.

- Nuclear Regulatory Commission, 2006a, Environmental Assessment Related to Issuance of a License Amendment for United Nuclear Corporation, Church Rock, New Mexico Project; Source Materials License SUA-1475, Docket No. 40-8907. July. (Related Finding of No Significant Impact from the requested licensing action published in the Federal Register on August 2, 2006 (vol. 71, no. 148, p. 43822-43823).)
- Nuclear Regulatory Commission, 2006b, Amendment 37 to United Nuclear Corporation's Church Rock, New Mexico, Source Materials License No. SUA-1475 (TAC LU0117). August 9, 2006.
- Nuclear Regulatory Commission, 2001, Letter to UNC, Subject: "Deletion of Lead-210 from Church Rock Site Standards." October 12, 2001.
- Nuclear Regulatory Commission, 1999a, Letter to Roy Blickwedel from John Surmeier, Subject: "Discontinuing of Pumping of Selected Wells at Church Rock Site, Materials License SUA-1475." July 30, 1999.
- Nuclear Regulatory Commission, 1999b, Letter to Roy Blickwedel from John Surmeier, Subject: "Consideration of Temporary Saturation of a portion of Zone 3 at the Church Rock Site." September 16, 1999.
- Nuclear Regulatory Commission, 1996, Evaluation of the Statistical Basis for Establishing Background Levels and Remediation Standards at the United Nuclear Corporation Church Rock Uranium Mill Tailings Disposal Facility, Gallup, New Mexico. June.
- Nuclear Regulatory Commission, 1980, Radiological Effluent and Environmental Monitoring at Uranium Mills; Regulatory Guide 4.14, Revision 1. April 25, 1980.
- Rust Environment and Infrastructure, 1997, Ground Water Corrective Action, Annual Review - 1997, Church Rock Site, Gallup, New Mexico. December.
- Smith Technology Corporation, 1996, Ground Water Corrective Action, Annual Review - 1996, Church Rock Site, Gallup, New Mexico. December.
- Smith Technology Corporation (Smith Environmental Technologies Corporation), 1995, Ground Water Corrective Action, Annual Review - 1995, Church Rock Site, Gallup, New Mexico. December.
- United Nuclear Corporation, 2006, Letter Submittal to Gary Janosko (NRC), "Revised License Amendment Request for Changing Ground Water Protection Standard for Radium in Source Materials License SUA-1475 (TAC LU0092) Groundwater Corrective Action Program." April 7, 2006 (Revision of February 22, 2006 Submittal).
- United Nuclear Corporation, 2005, Letter Submittal to Gary Janosko (NRC), "Revised License Amendment Request for Changing the Chloroform Ground Water Protection Standard in Source Materials License SUA-1475 (TAC LU0092) Groundwater Corrective Action Program." July 14, 2005 (Revision of May 26, 2005 Submittal).

- United Nuclear Corporation, 1989a, Corrective Action Plan, Church Rock Uranium Mill Tailings Facility. April.
- United Nuclear Corporation, 1989b, Remedial Action Plan, Church Rock Uranium Mill Tailings Facility. April.
- U.S. Environmental Protection Agency, 2011a, Comments on the Draft Updated Baseline Human Health Risk Assessment Dated March 2011 for the UNC Church Rock Mill, Gallup, New Mexico Superfund Site and Related Source Materials License. July 8, 2011.
- U.S. Environmental Protection Agency, 2011b, Comments on the Site-Wide Supplemental Feasibility Study Revised Parts 1 and 2 Document Dated April 2011 for the UNC Church Rock Mill Superfund Site Located in Gallup, New Mexico, and Related Source Materials License. October 14, 2011.
- U.S. Environmental Protection Agency (EPA), 2010, Comments on the Site-Wide Supplemental Feasibility Study Part 2, Document Dated July 2009, for the UNC Church Rock Mill, Gallup, New Mexico. September 2, 2010.
- U.S. Environmental Protection Agency (EPA), 2009, Letter from Mark Purcell (EPA) to Larry Bush (UNC): Site-Wide Supplemental Feasibility Study – Phase II [sic], Church Rock Remediation Standards Update, UNC Superfund Site [letter approving SWSFS Part I]. February 11, 2009.
- U.S. Environmental Protection Agency (EPA), 2008a, Comments Letter to Larry Bush (UNC) from Mark Purcell (EPA): Site-Wide Supplemental Feasibility Study, Part 1, Church Rock Remediation Standards Update, United Nuclear Corporation Superfund Site. January 25, 2008.
- U.S. Environmental Protection Agency (EPA), 2008b, Third Five-Year Review Report for the United Nuclear Corporation Ground Water Operable Unit, Church Rock, McKinley County, New Mexico. September 2008.
- U.S. Environmental Protection Agency (EPA), 2006a, Letter on “Supplemental Feasibility Study, UNC Superfund Site, Church Rock, NM, Administrative Order (Docket No. CERCLA 6-11-89).” June 23, 2006.
- U.S. Environmental Protection Agency (EPA), 2006b, Letter on “N.A. Water Systems List of Preliminary Assembled Remedial Alternatives, United Nuclear Corporation Superfund Site, Administrative Order (Docket No.: CERCLA 6-11-89).” November 22, 2006.
- U.S. Environmental Protection Agency (EPA), 2004a, EPA Comments on the Technical Impracticability Evaluation and Southwest Alluvium Natural Attenuation Test, United Nuclear Corporation Church Rock Superfund Site. February 13, 2004.
- U.S. Environmental Protection Agency (EPA), 2004b, Letter on “Hydraulic Fracturing for Zone 3 and Supplemental Feasibility Study, United Nuclear Corporation Church Rock

- Superfund Site, Administrative Order (Docket No. CERCLA 6-11-89).” March 10, 1994, with additional comments on March 19, 2004.
- U.S. Environmental Protection Agency (EPA), 2003, Five-Year Review Report – Second Five-Year Review Report. September.
- U.S. Environmental Protection Agency (EPA), 1998, Five-Year Review Report. September.
- U.S. Environmental Protection Agency (EPA), 1992, Secondary Drinking Water Regulations: Guidance for Nuisance Chemicals; EPA 810/K-92-01. July 1992.
- U.S. Environmental Protection Agency (EPA), 1988a, United Nuclear Corporation Church Rock Site, Operable Unit Feasibility Study, Gallup, New Mexico. August.
- U.S. Environmental Protection Agency (EPA), 1988b, Record of Decision, United Nuclear Corporation, Ground Water Operable Unit, McKinley County, New Mexico. U.S. Environmental Protection Agency, Region VI, Dallas, Texas, September.
- U.S. Geological Survey, 2008, Interpreting and Reporting Radiological Water-Quality Data; Book 5, Laboratory Analysis; Section B, Methods of the National Water Quality Laboratory; Chapter 6.
- USFilter, 2004a, Annual Review Report 2003 – Groundwater Corrective Action, Church Rock Site, Church Rock, New Mexico; January 14, 2004.
- USFilter, 2004b, Rationale and Field Investigation Work Plan to Evaluate Recharge and Potential Cell Sourcing to the Zone 3 Plume, Church Rock Site, Gallup, New Mexico. January 19, 2004.