



The bench tests were performed to assess in practice, the theoretical rationale behind the approach to effect the geochemical changes, anticipated to occur by injecting alkaline-rich solutions into an area of seepage impacts. The remainder of this Tech Memo describes the execution of and results from the bench tests, along with discussion of how the results demonstrate that the field-testing portion of the Pilot Test should proceed as originally proposed.

## **BENCH TESTS: METHODS AND RESULTS**

### **Methods**

The bench tests consisted of a series of laboratory batch-mixing experiments, designed to evaluate potential geochemical reactions likely to occur during the field portion of the Pilot Test. The approach included reacting mixtures of groundwater from well 517, located within the seepage-impacted target zone, with non-impacted, alkalinity-rich alluvial groundwater from well NA-02, (i.e. the fixiviant). Groundwater samples were collected (unfiltered) from these two wells and transported to ACZ Laboratories, Inc. of Steamboat Springs, Colorado, who performed the batch-testing, and chemical analyses of aqueous samples collected during and after the tests.

Table 1 presents the materials and mixing ratios evaluated through the batch-testing procedure. Mixtures included various ratios of the two end-member solutions from well Na-02 and well 517, including: 0.1 to 0.9 Batch #3; 0.5 to 0.5, Batch #5; and 0.9 to 0.1, Batch #7. In addition to these aqueous mixtures, batch tests were also performed using the same liquid ratios along with solids from weathered outcrop samples of the Zone 3 Gallup Sandstone collected at the site (Batch #4, #6 and #8). The solid materials were crushed to sand-size and smaller particles, and mixed with water-rock ratios consistent with porosity values characteristic of Zone 3. These batch tests, identified as Batch #1 through #8 in Table 1, represent those contemplated originally in BBL's October 2005 report.

In response to potential issues raised during discussion with representatives from USEPA, NRC, and NMED, two additional batch studies were performed. These tests, identified as Batch #9 and #10 in Table 1, involved diluting the proposed NA-02 fixiviant with high-purity deionized water (DI water), and mixing with rock and target-zone solutions from well 517. Adding the DI water to dilute the fixiviant was designed to simulate potential reactions occurring if the alluvium groundwater were to be pre-treated by reverse osmosis (RO) or comparable method to lower salinity prior to injection into Zone 3.

Aqueous and aqueous/rock mixtures identified in Table 1 were placed in closed carboys and subjected to periodic mild agitation for a one-week period. Aqueous subsamples from the mixtures were collected routinely during the week for analysis of pH and specific conductance. Upon completion of the one-week period, filtered (0.45mm) aliquots were analyzed for the constituents identified in Table 2, which correspond to ones analyzed as part of the on-going monitoring program at the site. Solid materials present within the aqueous-only mixtures (Batch #3, #5 and #7) were analyzed via X-ray diffraction (XRD) to identify crystalline mineral phases. Tables 2 through 6 present information pertaining to the results of the bench tests. Laboratory reports from the bench tests are presented in Appendix A.

## Results

### *Aqueous-Only Mixtures*

Table 2 presents analytical results for the Batch tests consisting of aqueous mixtures. It should be noted that although these are considered "aqueous" mixtures, the original groundwater solutions, which were not filtered during sample collection, did contain some solid particulates entrained during the sampling procedure. Analytical results for the aqueous mixtures are identified in the column labeled "Observed ### Aqueous" in Table 2. The columns labeled "Calculated ### Aqueous" represent proportional mixtures of NA02 and 517 based on the observed analytical results for each sample alone. These calculated values are compared with the observed aqueous values within the columns labeled "Difference Observed - Calculated Aqueous", expressed as percentages of the calculated values. Negative differences imply that the specific constituent may have precipitated and/or adsorbed on to solids or the sample container during the test, while positive values imply possible dissolution of solid phases (turbidity) included in the samples. Of course, the differences, particularly minor percentages, may simply reflect analytical uncertainty.

The first point to be made about data presented in Table 2 involves the concentration reductions in constituents of concern (COCs) for mixtures containing higher percentages of the fixiviant, NA-02. Exceedances of applicable groundwater criteria for COCs are highlighted in yellow in this and accompanying tables. For Batch #7, which contains 90% fixiviant, observed concentrations of nickel (Ni), cobalt (Co), and gross alpha exceed the groundwater standards. For Ni and Co, however, this is not surprising, since these constituents slightly exceed applicable standards in NA-02. Results for gross alpha are somewhat meaningless, considering the high analytical error associated with the result, which is essentially equal to the reported concentrations. Large analytical errors are typically associated with highly saline samples (observed TDS value = 9140 mg/L). Furthermore, gross alpha measurements are designed to be more of a screening tool, to determine whether additional isotopic analyses are warranted, for constituents that undergo radioactive alpha decay like  $^{226}\text{Ra}$ ,  $^{230}\text{Th}$ , and  $^{232}\text{Th}$ . Concentrations of these radioactive species reported for the Batch #7 sample are all well below applicable groundwater criteria, indicating that the gross alpha results are a non-issue.

Lack of increased concentrations of COCs, observed within aqueous mixtures containing higher concentrations of fixiviant are not surprising, since likely mechanisms to cause such increases would be dissolution/desorption of entrained solids, and/or leaching from the sample containers. At the slightly basic to neutral pH values characteristic of the fixiviant, such reactions are not expected to occur.

Table 3 presents the results for XRD analyses of solid materials collected from the aqueous mixtures. Of the materials reported from the analyses, only gypsum (hydrated calcium sulfate) and amorphous phases may have actually formed during the time frame involved, which includes sample collection through the end of the testing. Other phases detected, such as quartz, feldspars, hematite, and clay minerals, would not form under the low temperature conditions and short time period. These other phases simply reflect the type of suspended solids contained within the original samples.

Detection of gypsum in samples from Batch #3 and #5 may reflect precipitation of this phase before and/or during the experiments. Presented near the bottom of Table 2 are equilibrium saturation indices (SI) for calcite (calcium carbonate), gypsum, and rhodochrosite (manganese carbonate) calculated using the geochemical program PHREEQCI, developed by the United States Geological Survey (USGS). Positive saturation indices indicate oversaturation, negative

ones indicate undersaturation, and zero values would represent equilibrium. The indices reflect a logarithmic scale; consequently, slight deviations at or near equilibrium are not very meaningful, and one typically can equate values near zero indicative of equilibrium conditions with respect to those phases.

Saturation indices near zero for gypsum, combined with its detection in Batch # 3 and #5, and its absence from Batch #7 along with its apparent undersaturated conditions (SI = -0.19) reflect the importance of gypsum in influencing groundwater geochemistry and concentrations of calcium, sulfate, and TDS at the site. Calcite was not detected via XRD analyses, and appears to be oversaturated only for the sample from Batch #7 (SI = 0.52). The absence of calcite in the oversaturated sample is not too surprising, considering the time period involved. Its oversaturation, however, particularly since it involves the sample with the highest proportion of fixiviant, does indicate the potential for it to precipitate in the field given enough time. This in turn is significant because calcite precipitation will serve to immobilize COCs such as Ra species, and perhaps others via co-precipitation reactions. Additionally, calcite precipitation, along with gypsum, may create fouling issues with injection and recovery wells, the assessment of which is a component of the proposed field portion of the Pilot Test. The longer time frame (one to several months) anticipated for the field test should provide additional information regarding potential for calcite precipitation to occur. Oversaturation calculated with respect to rhodochrosite for samples containing the proposed fixiviant indicates the potential for manganese (Mn) concentrations to decrease over time due to precipitation of this mineral phase.

#### *Mixtures with Added Solids from Zone 3*

Additional information regarding the geochemical behavior of phases like calcite, gypsum, and various COCs is provided from the batch test results involving mixtures with added solids. Table 4 presents results for the batch tests involving mixtures of the proposed fixiviant with added solids (Batch #4, #6 and #8), along with results for aqueous only mixtures at the same ratios (Batch #3, #5 and #7). Columns labeled "Difference Observed w/Rock - Observed Aqueous" compares the difference between concentrations measured in solutions containing added rock and those containing aqueous only mixtures. Values are expressed as a percentage relative to the aqueous only result. Negative values indicate decreases in solution composition, reflecting adsorption and/or precipitation of constituents, while positive values suggest dissolution/desorption from solids. For nitrogen species, principally nitrate and ammonia, the data suggest a combination of transformation of ammonia to nitrate plus ammonia adsorption.

Many important points about the geochemical influence of the proposed fixiviant on the target COCs are apparent from the results presented in Table 4. The first one can be seen by comparing the results for the 90/10 ratio of fixiviant/impacted mixtures shown in the three columns at the right of Table 4. These three columns probably contain the most important data, because they reflect the greatest influence of the fixiviant on the targeted seepage impacts. Recall the point made above regarding Ni and Co concentrations observed for the aqueous only mixtures, and how the fixiviant concentrations were slightly in excess of the groundwater criteria. Results for the mixtures containing added solids demonstrate that these COCs are strongly adsorbed to aquifer solids, indicated by essentially complete (-100%) sorption for Co and extensive (-83%) sorption for Ni. Similar strong adsorption is apparent for COC species like cadmium (Cd, -83%), Mn (-45%), ammonia (-45%), and to a lesser extent <sup>226</sup>Ra (-13%). These results demonstrate that the approach to use the alkalinity rich alluvium groundwater is effective in neutralizing the acidic conditions within areas of seepage impact, and immobilizing, or reducing the migration of targeted COCs.

Constituents that show concentration increases for the 90/10 mixture containing added solids (positive percentages) include calcium (Ca, +43%), chloride (+34%), sodium (+30%), sulfate (+24%) and alkalinity (+15%). Such increases indicate cation exchange reactions and dissolution of calcite, gypsum, possibly halite (NaCl) if present, and/or other complex salts typically occurring in near-surface desert environments.

Uranium (U) is another constituent showing relatively large percentage concentration increases within the added solids batch tests, compared to the aqueous mixtures for all batches. These results indicate that a U source occurs within Zone 3 Gallup sandstone, which produces aqueous concentrations that slightly exceed (approximately double) the groundwater criteria of 0.03 mg/L. The presence of slightly soluble U within Zone 3 materials is not surprising, evidenced by U concentrations observed at NBL-01, a non-seepage-impacted well in Zone 3, which have trended from about 0.3 to 0.1 mg/L during the period of monitoring performed at the site.

#### *Mixtures with Diluted Fixiviant*

Table 5 presents results for the additional batch tests (Batch #9 and #10) performed to evaluate reactions associated with modification of the proposed fixiviant, by diluting the original solution with de-ionized (DI) water. Results are compared with those for the 90/10 mixtures (Batch #7 and #8), since they involve comparable ratios of fixiviant to seepage-impacted solution. Batch tests involving aqueous-only mixtures were not performed for the modified fixiviant; consequently, results are compared to concentrations calculated from the observed concentrations for well NA-02 and well 517 samples, and assuming the DI water is equilibrated with atmospheric concentrations of carbon dioxide and oxygen but contains no other detectable constituents.

Results presented in Table 5 indicate that geochemical reactions involving the modified fixiviant are comparable to those occurring with the proposed unmodified solution. Uranium concentrations also exceed the groundwater criteria, and result in U concentrations (approximately 0.04 to 0.045 mg/L) greater than those within the unmodified fixiviant prior to application to the Zone 3 solids of approximately 0.01 mg/L.

Important characteristics of the modified (diluted) fixiviant compared to that proposed for the Pilot Test concern pH and alkalinity. The modified fixiviant contains no alkalinity, and pH values are calculated to be 4.4 (Batch #9) and 4.6 (Batch #10). These solutions are also undersaturated with respect to gypsum and calcite. Such data illustrate how modification of the proposed fixiviant will require additional treatment following RO or other salinity-reduction approach in order to raise the pH and provide sufficient alkalinity to obtain the desired neutralization/immobilization of the targeted COCs.

Table 6 displays results for the 90/10, added-solid mixtures, along with the end-member aqueous concentrations. This table provides for a more direct comparison of only concentrations of the constituents detected, rather than information about likely geochemical reactions provided in previous tables. The comparison suggests that for the primary, targeted COCs, such as heavy metals (Cd, Co, Ni) and radionuclides, there appears to be little to be gained by modifying the alluvium groundwater proposed for the fixiviant. For some constituents, such as lead (Pb) and <sup>226</sup>Ra, resulting concentrations are actually greater with the modified fixiviant compared to the original. The bench test results demonstrate that it is highly unlikely, if not impossible, for a modified fixiviant to result in groundwater concentrations that would meet drinking-water standards for constituents like TDS, sulfate, and possibly Mn. Lowering the salinity of alluvium

groundwater via RO or similar method will require addition of materials to raise pH and increase alkalinity, which will raise the salinity to higher values than occurring after RO treatment.

The batch test results suggest that TDS concentrations, and those of major inorganic constituents (Ca, Mg, Na, Cl, SO<sub>4</sub>), plus Mn, may be lower using modified alluvium groundwater as a fixiviant, rather than the unmodified alluvial groundwater originally proposed. Exactly how much lower, however, remains uncertain at this point, owing to the short time frame for the tests, combined with results from the batch tests for Batch #9 and #10. Undersaturation with respect to gypsum (SI = -0.21), indicated for the Batch #10 test, indicates that equilibrium with the added solids was not achieved during this week-long test containing the most diluted fixiviant. These results suggest that aqueous concentrations of TDS, SO<sub>4</sub>, and other major inorganic constituents would likely increase over time in the field compared to results for the batch testing, and compared to the proposed fixiviant.

It is also important to consider that the added solids consisted of weathered Zone 3 outcrop material, which has been exposed to meteoric solutions over many years. Weathering processes would likely make such materials less susceptible to leaching of constituents and concomitant salinity increases when exposed to dilute solutions. The alluvial groundwater, in contrast, has been in direct contact with native deposits for many years, and appears to have equilibrated with solid phases (principally gypsum) that strongly influence groundwater chemistry. Furthermore, batch test results with the diluted fixiviant still generate solutions that exceed groundwater criteria, implying that resulting groundwater would be unfit for direct consumption even with pretreatment/modification of the proposed fixiviant.

## CONCLUSIONS

Bench tests, performed to evaluate geochemical reactions anticipated to occur during the field portion of the proposed Pilot Test, indicate that alluvial groundwater can serve as a suitable fixiviant to retard and/or immobilize target COCs. Results of the testing indicate that the alkaline-rich solutions should prove effective in neutralizing the acidity within the areas of seepage impacts. Neutralization reactions will promote precipitation/adsorption of target COCs, especially heavy metals and radium, consistent with the rationale applied when designing the Pilot Test. Overall, results from the bench tests provide evidence that the Pilot Test can proceed as originally proposed without resulting in adverse groundwater impacts, and in fact will improve overall groundwater quality where seepage impacts exist.

Data indicate that the modified fixiviant will be no more effective than that proposed in addressing target COCs, and may actually be less effective for several constituents. In addition, batch tests performed with modified (i.e. diluted) fixiviant suggest that marginal improvement will be achieved in resulting groundwater quality, compared to using unmodified alluvial groundwater. Although batch tests with diluted fixiviant result in lower concentrations of TDS, sulfate, and other major inorganic chemical species, the value of pre-treating the fixiviant to a more dilute solution is diminished because formation solids naturally dissolve and the major ion concentrations essentially get replenished once the fixiviant reacts with formation material. We expect that this phenomenon will be even more pronounced in practice than it was in the batch tests because:

1. added rock samples used during the batch tests were collected from surface outcrop exposed to surficial weathering processes. Such weathered material may be less reactive than underlying, saturated Zone 3 strata; and
2. experiments with the most dilute fixiviant suggest that equilibrium conditions were not reached during the week-long test, indicating a likelihood that salinity and concentrations of major inorganic species will be greater in the field than observed from the batch tests. This is especially true over time as equilibration between the formation and the solutions is more closely approached.

Other important points to consider with respect to bench-test results, the proposed field test, and the efficacy of using modified versus unmodified fixiviant include:

- Although the diluted fixiviant appears to result in lower salinity and concentrations of major inorganic species like Ca, Mg, Na, Cl, and SO<sub>4</sub>, resulting groundwater concentrations will still exceed primary drinking water standards for the non-target COCs.
- The proposed fixiviant (unmodified alluvial groundwater) contains lower concentrations of TDS, SO<sub>4</sub>, other inorganic ions, and has comparable Mn concentrations, compared to regions with the greatest degree of seepage impacts (such as well 613), located slightly upgradient of the Pilot Test area.
- Issues with manganese concentrations within the alluvial groundwater in excess of applicable groundwater criteria have been cited as a reason to require dilution/modification of the proposed fixiviant. Batch test results demonstrate significant Mn adsorption (approximately 50%), and oversaturation with respect to rhodochrosite (MnCO<sub>3</sub>) occurs during the week-long tests. Historical monitoring results within the alluvium document an order-of-magnitude reduction in Mn concentrations, starting with concentrations comparable to those reported for the proposed fixiviant, indicating that Mn concentrations will decrease over time when the proposed fixiviant is injected in the field. Based on the results of the bench scale tests and historical monitoring, the concentration of manganese in solution appears to be dictated more by natural solid-fluid equilibria than by whether or not the solutions are made more or less dilute prior to injection.
- Alluvium groundwater is ideal for use as a fixiviant because it is properly “aged” with regard to native materials and equilibrated with ambient conditions. Such aging is important with respect to potential fouling issues, and the ability to get the solutions into the rock to neutralize the seepage-impacted groundwater.
- One must keep in mind that alluvial groundwater recharges the Zone 3 formation naturally, and that the Pilot Test approach essentially expedites a natural process, which simultaneously reduces/eliminates potential risks associated with seepage impacts.

- It seems to be an imprudent use of resources to pretreat (i.e. dilute) the proposed fixiviant. Pretreatment via RO or similar method will necessitate re-injection of alkalinity removed during the process, and much of the constituents removed, particularly relatively innocuous inorganic constituents, will be returned to groundwater solutions via predictable, common reactions between the fixiviant and native host rock.

Considering the results from the bench tests, in combination with a desire to expedite improvement in groundwater quality within the area of seepage impacts at the site, BBL recommends that the field-portion of the Pilot Test be implemented as originally proposed.

PMS/ams

**TABLE 1  
UNC CHURCH ROCK  
CHURCH ROCK, NEW MEXICO**

**BENCH TESTS FOR IN-SITU ALKALINITY PILOT STUDY**

**BATCH-TESTING MIXTURES**

<b>Batch Test #</b>	<b>Impacted Volume Well 517 (Liters)</b>	<b>Fixiviant Volume Well NA-02 (Liters)</b>	<b>Mixing Ratio Fixiviant/Impacted</b>	<b>Mass Zone 3 Gallup SS (kg)</b>
1	0	4.5	∞	0
2	4.5	0	0	0
3	4.05	0.45	10/90	0
4	10.125	1.125	10/90	27.2
5	2.25	2.25	50/50	0
6	5.625	5.625	50/50	27.2
7	0.45	4.05	90/10	0
8	1.125	10.125	90/10	27.2
9	1.125	5.0625 + 5.0625 DI Water	90/10	27.2
10	1.125	1.688 + 8.438 DI Water	90/10	27.2

**Notes:**

1. DI = Deionized water.
2. kg = Kilograms.
3. SS = Sandstone.

TABLE 2  
 UNC CHURCH ROCK  
 CHURCH ROCK, NEW MEXICO

BENCH TESTS FOR IN-SITU ALKALINITY PILOT STUDY

RESULTS FOR PROPOSED FIXVANT - AQUEOUS MIXTURES

	Units	Groundwater Standard	NA-02	517	Observed 10/90 Aqueous	Calculated 10/90 Aqueous	Difference Observed - Calculated Aqueous	Observed 50/50 Aqueous	Calculated 50/50 Aqueous	Difference Observed - Calculated Aqueous	Observed 90/10 Aqueous	Calculated 90/10 Aqueous	Difference Observed - Calculated Aqueous
BATCH TEST NUMBER			1	2	3			5			7		
ANALYTE													
Aluminum, dissolved	mg/L	5		4.0	1.2	1.5							
Arsenic, dissolved	mg/L	0.01											
Beryllium, dissolved	mg/L	0.004											
Cadmium, dissolved	mg/L	0.005	0.0040	0.0068	0.0068	0.0068	0%	0.0044	0.0054	-19%	0.0039	0.0043	-9%
Calcium, dissolved	mg/L		518	475	489	488	0%	510	497	3%	505	514	-2%
Cobalt, dissolved	mg/L	0.05	0.14	0.82	0.73	0.74	-1%	0.42	0.48	-13%	0.18	0.21	-13%
Lead, dissolved	mg/L	0.05	0.0018	0.0010	0.0009	0.0009	-1%		0.0014	-100%	0.0011	0.0017	-36%
Magnesium, dissolved	mg/L		1020	508	510	510	0%	748	764	-2%	941	969	-3%
Manganese, dissolved	mg/L	2.6	65.20	9.10	14.20	13.69	4%	36.60	37.15	-1%	58.70	60	-1%
Molybdenum, dissolved	mg/L	1	0.001	0.001									
Nickel, dissolved	mg/L	0.2	0.28	0.71	0.85	0.85	-1%	0.48	0.50	-8%	0.35	0.33	5%
Potassium, dissolved	mg/L		44	10	14	14	3%	27	27	0%	39	41	-4%
Selenium, dissolved	mg/L	0.05	0.005										
Sodium, dissolved	mg/L		489	156	188	185	2%	328	323	2%	446	456	-2%
Uranium, dissolved	mg/L	0.03	0.0116	0.0400	0.0283	0.0295	-4%	0.0187	0.0258	-28%	0.0141	0.0144	-2%
Vanadium, dissolved	mg/L												
Gross Alpha	pCi/L	15	2+/-28	65+/-29	53+/-27	54	-2%	22+/-23	34	-34%	34+/-33	8	310%
Gross Beta	pCi/L		57+/-30	65+/-24	48+/-24	48		29+/-29	61		45+/-33		
Radium 226	pCi/L	5	0.28+/-0.28	9.2+/-0.68	8.7+/-0.57	7.0	-4%	1.8+/-0.3	4.7	-62%	0.75+/-0.21	1.17	-36%
Radium 226, total	pCi/L		0.68+/-0.63	8.6+/-1.2	8+/-0.79	5.4	-7%	6.4+/-0.86	4.6	38%	2.7+/-0.84	1.5	83%
Thorium 228	pCi/L		-0.07+/-0.19	0.72+/-0.29	0.15+/-0.22			0.12+/-0.21			0.1+/-0.21		
Thorium 230	pCi/L	15	-0.17+/-0.47	0.3+/-0.34	-0.21+/-0.4			-0.15+/-0.42			-0.28+/-0.42		
Thorium 232	pCi/L		-0.14+/-0.41	-0.03+/-0.34	0.03+/-0.39			-0.06+/-0.38			-0.03+/-0.41		
Bicarbonate as CaCO3	mg/L		671					242			573		
Carbonate as CaCO3	mg/L												
Chloride	mg/L		214	40	59	57	3%	139	127	9%	224	197	14%
Hydroxide as CaCO3	mg/L												
Nitrate as N, dissolved*	mg/L	190	1.34	0.05	0.05	0.05	0%	0.55	0.70	-21%	0.97	1.21	-20%
Nitrate/Nitrite as N, dissolve	mg/L		1.55					0.57			1.03		
Nitrite as N, dissolved	mg/L		0.21					0.02			0.06		
Nitrogen, ammonia	mg/L		348	8.00	48.9	44.8	9%	207	177	17%	390	312	25%
pH	units		7.2	4.0	3.8			6.7			7.0		
pH measured at	C		21.0	21.0	21.0			21.0			21.0		
Residue, Filterable (TDS) @180	mg/L	4800	9530	5360	5520	5504	0%	7380	7445	-1%	9140	9113	0%
Sulfate	mg/L	2125	4070	3560	3710	3695	0%	3920	3815	3%	3270	4019	-19%
Total Alkalinity	mg/L		671					242			573		

Calcite Saturation Index	0.77	-7.67	-8.06					-0.13			0.52		
Gypsum Saturation Index	-0.12	-0.03	-0.01					-0.05			-0.19		
			60% Gypsum XRD					5% Gypsum XRD			No Gypsum XRD		
Rhodochrosite (MnCO3) Saturation Index	1.70	-7.55	-7.77					0.56			1.44		

Notes:

- \*Nitrate in 517 samples assumed = 0.05 mg/L for calculations; corresponds to one-half PCL.
- Observed ## Aqueous identifies the analytical results for the aqueous mixture.
- Calculated ## Aqueous represent the proportional mixtures of NA-02 and 517 based on the observed analytical results for each sample alone.
- mg/L = milligrams per liter.
- pCi/L = picocuries per liter.
- Results that are shaded indicate that the concentration of the constituent is greater than the groundwater protection standard.

TABLE 3

UNC CHURCH ROCK  
CHURCH ROCK, NEW MEXICO

BENCH TESTS FOR IN-SITU ALKALINITY PILOT STUDY

X-RAY DIFFRACTION (XRD) RESULTS FOR AQUEOUS MIXTURES

	10/90 Aqueous	50/90 Aqueous	90/10 Aqueous
BATCH TEST NUMBER	3	5	7
PHASE	%	%	%
Quartz	12	33	36
K-Feldspar		5	5
Plagioclase		7	6
Smectite		<3*	16
Mica/Illite			3
Amorphous	16	17	
Gypsum	60	5	
Hematite	<2*	<2*	
Kaolin	8	29	31
Unaccounted	<5	<5	<5

Notes:

1. Analyses performed by DCM Science Laboratory, Inc., Wheat Ridge, CO.
2. \* Asterisk indicates doubt in identification and/or concentrations of phase.

TABLE 4  
UNC CHURCH ROCK  
CHURCH ROCK, NEW MEXICO

BENCH TESTS FOR IN-SITU ALKALINITY PILOT STUDY

RESULTS FOR PROPOSED FIXMIANT – AQUEOUS/ADDED SOLID MIXTURES

BATCH TEST NUMBER	Units	Groundwater Standard	NA-02	517	Observed 10/90 Aqueous	10/90 Observed w/Rock	50/50 Observed w/Rock	Observed 50/50 Aqueous	50/50 Observed w/Rock	Difference Observed w/Rock - Observed Aqueous	Observed 90/10 Aqueous	90/10 Observed w/Rock	Difference Observed w/Rock - Observed Aqueous
			1	2	3	4		5	6		7	8	
ANALYTE													
Aluminum, dissolved	mg/L	5		4.0	1.2								
Arsenic, dissolved	mg/L	0.01											
Beryllium, dissolved	mg/L	0.004											
Cadmium, dissolved	mg/L	0.005	0.0040	0.0068	0.0068			0.0044	0.0006	-86%	0.0039	0.0006	-85%
Calcium, dissolved	mg/L		518	475	489	722	48%	510	726	42%	505	724	43%
Cobalt, dissolved	mg/L	0.05	0.14	0.82	0.73		-100%	6.42	0.08	-86%	0.18		-100%
Lead, dissolved	mg/L	0.05	0.0018	0.0010	0.0009		-100%				0.0011	0.0006	
Magnesium, dissolved	mg/L		1020	508	510	478	-6%	746	671	-10%	941	899	-4%
Manganese, dissolved	mg/L	2.6	65.20	9.10	14.20	6.39	-55%	36.60	19.60	-46%	58.70	32.40	-45%
Molybdenum, dissolved	mg/L	1	0.001	0.001									
Nickel, dissolved	mg/L	0.2	0.29	0.71	0.65		-100%	0.46	0.07	-85%	0.35	0.06	-83%
Potassium, dissolved	mg/L		44	10	14	13	-7%	27	29	7%	39	39	0%
Selenium, dissolved	mg/L	0.05	0.005			0.009			0.007			0.010	
Sodium, dissolved	mg/L		489	156	188	356	89%	326	410	25%	446	579	30%
Uranium, dissolved	mg/L	0.03	0.0116	0.0400	0.0283	0.0548	94%	0.0187	0.0559	199%	0.0141	0.0612	334%
Vanadium, dissolved	mg/L												
Gross Alpha	pCi/L	15	2+/-28	65+/-29	53+/-27	51+/-26	-4%	22+/-23	22+/-32	0%	34+/-33	15+/-27	-58%
Gross Beta	pCi/L		57+/-30	65+/-24	46+/-24	38+/-23	-17%	29+/-29	48+/-30	0.855172414	45+/-33	60+/-36	33%
Radium 226	pCi/L		0.28+/-0.26	0.2+/-0.68	0.7+/-0.57	0.48+/-0.19	-93%	1.8+/-0.3	0.65+/-0.21	-64%	0.75+/-0.21	0.65+/-0.2	-13%
Radium 228, total	pCi/L	5	0.68+/-0.63	8.6+/-1.3	5+/-0.79	0.24+/-0.54	-95%	6.4+/-0.86	3.6+/-0.74	-44%	2.7+/-0.64	2.6+/-0.9	-4%
Thorium 228	pCi/L		-0.07+/-0.19	0.72+/-0.29	0.15+/-0.22	0.17+/-0.22		0.12+/-0.21	0.07+/-0.21		0.1+/-0.21	0.12+/-0.21	
Thorium 230	pCi/L	15	-0.17+/-0.47	0.3+/-0.34	-0.21+/-0.4	-0.27+/-0.45		-0.15+/-0.42	-0.47+/-0.4		-0.28+/-0.42	-0.23+/-0.38	
Thorium 232	pCi/L		-0.14+/-0.41	-0.03+/-0.34	0.03+/-0.39	-0.21+/-0.4		-0.06+/-0.38	-0.07+/-0.42		-0.03+/-0.41	-0.09+/-0.35	
Bicarbonate as CaCO3	mg/L		671			286		242	407		573	660	
Carbonate as CaCO3	mg/L												
Chloride	mg/L		214	40	59	197	234%	139	220	58%	224	300	34%
Hydroxide as CaCO3	mg/L												
Nitrate as N, dissolved*	mg/L	190	1.34	0.05	0.05	19.2	38300%	0.55	13.8	2409%	0.97	24.2	2395%
Nitrate/Nitrite as N, dissolve	mg/L		1.55			19.9		0.57	14.9		1.03	25.1	
Nitrite as N, dissolved	mg/L		0.21			0.67		0.02	1.07		0.06	0.94	
Nitrogen, ammonia	mg/L		348	8.00	48.9	23.8	-51%	207	137	-34%	390	240	-38%
pH	units		7.2	4.0	3.8	7.3		6.7	7.3		7.0	7.3	
pH measured at	C		21.0	21.0	21.0	21.0		21.0	21.0		21.0	21.0	
Residue, Filterable (TDS) @160	mg/L	4800	9530	5360	5520	6100	11%	7380	7510	2%	9140	9250	1%
Sulfate	mg/L	2125	4070	3560	3710	3620	-2%	3920	4060	4%	3270	4060	24%
Total Alkalinity	mg/L		671				286	242	407	68%	573	660	15%

Calcite Saturation Index	0.77	-7.67	-8.06	0.69				-0.13	0.61		0.52	1.01	
Gypsum Saturation Index	-0.12	-0.03	-0.01	0.11				-0.05	0.10		-0.19	-0.01	
Rhodochrosite (MnCO <sub>3</sub> ) Saturation Index	1.70	-7.55	-7.77	0.48	60% Gypsum XRD	5% Gypsum XRD		0.56	1.07		No Gypsum XRD	1.44	1.50

Notes:

- \*Nitrate in 517 samples assumed = 0.05 mg/L for calculations; corresponds to one-half PQL
- Observed ## Aqueous identifies the analytical results for the aqueous mixture.
- Calculated ## Aqueous represent the proportional mixtures of NA-02 and 517 based on the observed analytical results for each sample alone.
- mg/L = milligrams per liter.
- pCi/L = picocuries per liter.
- Results that are shaded indicate that the concentration of the constituent is greater than the groundwater protection standard.

**TABLE 5**  
**UNC CHURCH ROCK**  
**CHURCH ROCK, NEW MEXICO**

**BENCH TESTS FOR IN-SITU ALKALINITY PILOT STUDY**

**RESULTS FOR PROPOSED AND DILUTED FIXMANT - AQUEOUS/ADDED SOLID MIXTURES**

	Units	Groundwater Standard	NA-02	517	Observed / 90/10 Aqueous	90/10 Observed w/Rock	Difference Observed w/Rock - Observed Aqueous	1:1 ratio DI/NA2 Observed w/Rock	Calculated 1:1 Aqueous	Difference Observed w/Rock - Calculated Aqueous	5:1 ratio DI/NA2 Observed w/Rock	Calculated 5:1 Aqueous	Difference Observed w/Rock - Calculated Aqueous
BATCH TEST NUMBER			1	2	7	8		9			10		
ANALYTE													
Aluminum, dissolved	mg/L	5		4.0					0.0				
Calcium, dissolved	mg/L		518	475	505	724	41%	550	281	96%	417	125	233%
Cobalt, dissolved	mg/L	0.05	0.14	0.82	0.18		-100%	0.02	0.145	-86%	0.01	0.10	-90%
Lead, dissolved	mg/L	0.05	0.0018	0.0010	0.0011	0.0006	-65%	0.0016	0.0009	76%	0.0013	0.0004	251%
Magnesium, dissolved	mg/L		1020	508	941	899	-7%	439	510	-14%	158	204	-22%
Manganese, dissolved	mg/L	2.6	65.20	9.10	58.70	32.40	-46%	11.7	30.3	-61%	1.69	10.7	-84%
Nickel, dissolved	mg/L	0.2	0.29	0.71	0.35	0.06	-82%	0.02	0.2015	-90%	0.01	0.11	-91%
Potassium, dissolved	mg/L		44	10	39	39	-4%	21.7	20.8	4%	11.5	7.60	51%
Selenium, dissolved	mg/L	0.05	0.005			0.010		0.011	0.0023	389%	0.006	0.0008	700%
Sodium, dissolved	mg/L		489	156	446	579	27%	370	236	57%	195	89	119%
Uranium, dissolved	mg/L	0.03	0.0116	0.0400	0.0141	0.0612	324%	0.0449	0.0092	387%	0.0392	0.0057	583%
Gross Alpha	pCi/L	15	2+/-28	65+/-29	34+/-33	15+/-27	81%	39+/-25	7	427%	25+/-16	7	268%
Gross Beta	pCi/L		57+/-30	65+/-24	45+/-33	60+/-36		59+/-24	32	84%	43+/-13	15	186%
Radium 226	pCi/L	5	0.28+/-0.28	9.2+/-0.88	0.75+/-0.21	0.65+/-0.2	-45%	1.3+/-0.28	1.0	24%	1.3+/-0.24	0.96	35%
Radium 228, total	pCi/L		0.68+/-0.63	8.6+/-1.2	2.7+/-0.64	2.6+/-0.9	77%	2.6+/-0.79	1.2	123%	2.7+/-0.83	0.96	181%
Thorium 228	pCi/L		-0.07+/-0.19	0.72+/-0.29	0.1+/-0.21	0.12+/-0.21		0.2+/-0.23			0.15+/-0.22		
Thorium 230	pCi/L	15	-0.17+/-0.47	0.3+/-0.34	-0.26+/-0.42	-0.23+/-0.38		-0.22+/-0.37			0.03+/-0.44		
Thorium 232	pCi/L		-0.14+/-0.41	-0.03+/-0.34	-0.03+/-0.41	-0.09+/-0.35		-0.09+/-0.34	-0.0700	29%	0.12+/-0.41	0	-614%
Bicarbonate as CaCO3	mg/L		671		573	660		459	302	52%	275	112	146%
Chloride	mg/L		214	40	224	300	53%	282	100	181%	158	36	338%
Nitrate as N, dissolved*	mg/L	190	1.34	0.05	0.97	24.2	1898%	23.6	0.61	3782%		0.21	
Nitrate/Nitrite as N, dissolve	mg/L		1.55	0.05	1.03	25.1		24.5	0.70	3388%			
Nitrogen, ammonia	mg/L		346	8.00	390	240	-23%	92.4	157	-41%	21.6	52.7	-59%
pH measured at	units		7.2	4.0	7.0	7.3		7.8	4.4		7.8	4.6	
pH measured at	C		21.0	21.0	21.0	21.0		21.0			22		
Residue, Filterable (TDS) @180	mg/L	4800	9530	5360	9140	9250	2%	5910	4825	22%	3010	1966	53%
Sulfate	mg/L	2125	4070	3560	3270	4060	1%	3470	2188	59%	1700	967	76%
Total Alkalinity	mg/L		671		573	660		459	0		275	0	
Calcite Saturation Index			0.77	-7.67	0.52	1.01		1.26	-4.58		1.07	-4.74	
Gypsum Saturation Index			-0.12	-0.03	-0.19	-0.01		0.00	-0.4		-0.21	-0.83	
					No Gypsum XRD								

**Notes:**

- \*Nitrate in 517 samples assumed = 0.05 mg/L for calculations; corresponds to one-half PQL
- Observed ## Aqueous identifies the analytical results for the aqueous mixture.
- Calculated ## Aqueous represent the proportional mixtures of NA-02 and 517 based on the observed analytical results for each sample alone.
- mg/L = milligrams per liter.
- pCi/L = picocuries per liter.
- Results that are shaded indicate that the concentration of the constituent is greater than the groundwater protection standard.

TABLE 6

UNC CHURCH ROCK  
CHURCH ROCK, NEW MEXICO

BENCH TESTS FOR IN-SITU ALKALINITY PILOT STUDY

PROPOSED AND DILUTED FIXIVANT COMPARISON

	Units	Groundwater Standard	NA-02	517	90/10 Observed w/Rock	1:1 ratio DI/NA2 Observed w/Rock	5:1 ratio DI/NA2 Observed w/Rock
BATCH TEST NUMBER			1	2	8	9	10
ANALYTE							
Aluminum, dissolved	mg/L	5		4.0			
Arsenic, dissolved	mg/L	0.01					
Beryllium, dissolved	mg/L	0.004					
Cadmium, dissolved	mg/L	0.005	0.0040	0.0068	0.0006		
Calcium, dissolved	mg/L		518	475	724	550	417
Cobalt, dissolved	mg/L	0.05	0.14	0.82		0.02	0.01
Lead, dissolved	mg/L	0.05	0.0018	0.0010	0.0006	0.0016	0.0013
Magnesium, dissolved	mg/L		1020	508	899	439	158
Manganese, dissolved	mg/L	2.6	65.20	9.10	32.40	11.7	1.69
Molybdenum, dissolved	mg/L	1	0.001	0.001		0.02	0.02
Nickel, dissolved	mg/L	0.2	0.29	0.71	0.06	0.02	0.01
Potassium, dissolved	mg/L		44	10	39	21.7	11.5
Selenium, dissolved	mg/L	0.05	0.005		0.010	0.011	0.006
Sodium, dissolved	mg/L		489	156	579	370	195
Uranium, dissolved	mg/L	0.03	0.0116	0.0400	0.0612	0.0449	0.0392
Vanadium, dissolved	mg/L						
Gross Alpha	pCi/L	15	2+/-28	65+/-29	15+/-27	39+/-25	25+/-16
Gross Beta	pCi/L		57+/-30	65+/-24	60+/-36	59+/-24	43+/-13
Radium 226	pCi/L		0.28+/-0.28	9.2+/-0.68	0.65+/-0.2	1.3+/-0.28	1.3+/-0.24
Radium 228, total	pCi/L	5	0.68+/-0.63	8.6+/-1.2	2.6+/-0.9	2.6+/-0.79	2.7+/-0.83
Thorium 228	pCi/L		-0.07+/-0.19	0.72+/-0.29	0.12+/-0.21	0.2+/-0.23	0.15+/-0.22
Thorium 230	pCi/L	15	-0.17+/-0.47	0.3+/-0.34	-0.23+/-0.38	-0.22+/-0.37	0.03+/-0.44
Thorium 232	pCi/L		-0.14+/-0.41	-0.03+/-0.34	-0.09+/-0.35	-0.09+/-0.34	0.12+/-0.41
Bicarbonate as CaCO3	mg/L		671		660	459	275
Carbonate as CaCO3	mg/L						
Chloride	mg/L		214	40	300	282	158
Hydroxide as CaCO3	mg/L						
Nitrate as N, dissolved*	mg/L	190	1.34	0.05	24.2	23.6	
Nitrate/Nitrite as N, dissolve	mg/L		1.55	0.05	25.1	24.5	
Nitrite as N, dissolved	mg/L		0.21		0.94	0.86	0.01
Nitrogen, ammonia	mg/L		346	8.00	240	92.4	21.6
pH	units		7.2	4.0	7.3	7.8	7.8
pH measured at	C		21.0	21.0	21.0	21.0	22
Residue, Filterable (TDS) @180	mg/L	4800	9530	5360	9250	5910	3010
Sulfate	mg/L	2125	4070	3560	4060	3470	1700
Total Alkalinity	mg/L		671		660	459	275

Calcite Saturation Index	0.77	-7.67	1.01	1.26	1.07
Gypsum Saturation Index	-0.12	-0.03	-0.01	0.00	-0.21
Rhodocrosite Saturation Index	1.70	-7.55	1.50	1.38	0.48

## Notes:

1. kg = Kilograms.