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TREATABILITY STUDIES ON F/H AREA GROUNDWATER COMPOSITE (U)

by

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**TREATABILITY STUDIES ON
F/H-AREA GROUNDWATER
COMPOSITE (U)**

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TO: S.D. FINK, 773-A

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**TREATABILITY STUDIES ON F/H AREA
"HOT SPOT" GROUNDWATER COMPOSITE (U)**

1.0 SUMMARY

The data found in this report were collected from laboratory experiments that were conducted to characterize the "hot spot" groundwater before and after pH adjustment, to describe the settling behavior and particle size of the precipitates resulting from pH adjustment, and to compare several methods of pH adjustment. Although Decontamination Factors (DFs) for all precipitating agents are similar, the best settling characteristics and most manageable precipitate were produced when 25 ppm Al^{3+} was introduced as $\text{Al}_2(\text{SO}_4)_3$ and pH adjustment was made from 6-8 with NaOH. The resulting precipitate will not be a hazardous secondary waste.

2.0 INTRODUCTION

The groundwater below the F- and H-Area seepage basins has become contaminated with radionuclides and hazardous ions, such as mercury, cadmium, and arsenic. Treatability studies have already been performed on a so-called RCRA (Resource Conservation and Recovery Act) composite sample¹ that represents water from a plume that contains the maximum volume of contaminated groundwater that might have to be treated to lower concentrations of RCRA constituents that are above maximum concentration limits. A second composite, prepared by blending groundwater drawn from wells that have historically produced water having the greatest concentrations of contaminants, has been studied to describe its behavior toward pH adjustment and solids separation. This study on the "hot spot" composite is of interest since that composite represents a smaller, but more concentrated, plume system that may be treated instead of the larger, RCRA plume. Treatment of either plume may include pH adjustment, solids removal, and reinjection of treated water.

3.0 EXPERIMENTAL PROCEDURE

3.1 Characterization of the Groundwater

Samples of the groundwater composite were obtained from Robin Baena of Environmental Restoration Technology (ERT). The wells sampled and the volumes of each groundwater mixed are listed in Table 1. The mixture of volumes represented in the groundwater composite was determined by Environmental Restoration (ER) personnel.

Table 1. Wells and Volumes Supplying F/H Groundwater "Hot Spot" Composite Sample

<u>Well</u>	<u>Volume</u>
FSB77	7.5 Liters
FSB78	7.5 Liters
FSB97D	7.5 Liters
FSB87C	10 Liters
FSB90C	10 Liters
FSB93C	10 Liters
FSB105C	10 Liters
HSB67	7.5 Liters
HSB101D	7.5 Liters
HSB103D	7.5 Liters
HSB104D	7.5 Liters
HSB105D	7.5 Liters
HSB106D	7.5 Liters
HSB107D	7.5 Liters
HSB108D	7.5 Liters

FSB = F-Area seepage basin

HSB = H-Area seepage basin

Samples of this composite groundwater were sent to Analytical Development Section (ADS) for the following "routine customer assisted" analyses²: ion chromatography for anions and NH_4^+ , tritium by liquid scintillation, alpha and beta scintillation, gamma pulse height analysis, inductively coupled plasma atomic emission spectrometry for metals, cold vapor atomic absorption for Hg, total inorganic and organic carbon content, total uranium, and conductivity. A 10-mL sample of the groundwater composite was

submitted for semi-quantitative analysis (approximate standard deviation $\pm 30\%$) across the full mass range using the VG Instruments Plasma Quad I Inductively Coupled Plasma/Mass Spectrometer (ICP/MS), Model 1. The results of these sets of analyses appear in Table 2. Spectra for each mass region analyzed in the ICP/MS appear in Figure 1.

Figure 1. Spectra of ICP/MS Analysis of Groundwater

3.2 Treatments With Various pH-adjusting and Precipitating Agents

Bench-scale treatability studies were performed using the additives for pH adjustment, precipitation, and flocculation that had shown the most promise in the study on the RCRA groundwater plume.¹ In each study, a 200-mL sample of the groundwater composite was pH adjusted to pH 6 through pH 8 using NaOH or $\text{Mg}(\text{OH})_2$. The maximum size of the sample was limited by Health Protection requirements, based on the tritium content of the solutions and the number of samples being addressed at a given time. Some samples were mixed with measured amounts of $\text{Al}_2(\text{SO}_4)_3$, FeSO_4 , or $\text{Fe}(\text{NO}_3)_3$ before pH adjustment. These salts were dissolved in groundwater samples to a concentration of 25 mg/L Al^{3+} , 50 mg/L Fe^{2+} , or 15 mg/L Fe^{3+} , respectively, before pH adjustment. These concentrations were arbitrarily selected based on knowledge of the amounts tested successfully in water treatment studies at the F/H Effluent Treatment Facility at SRS (Al and Fe^{3+}) and at Oak Ridge (Fe^{2+}). The FeSO_4 was added immediately before pH adjustment to prevent as much oxidation of ferrous ion as possible.

Other samples were treated with flocculating agents prior to pH adjustment. Two anionic polymers (A3010L and A3040L) and two cationic polymers (K122L and K144L) manufactured by Pollu-Tech, Inc. of Richboro, PA were used. Polymers were activated according to the manufacturer's instructions. First, homogeneity of the polymer solution was ensured by shaking vigorously for 20 minutes. Next, a beaker containing 100 mL of deionized water was placed on a magnetic stirrer and stirred such that a vortex was created in the water. Into the vortex, 200 μL of homogenized polymer was mixed and the resulting 0.2% by volume solution was stirred for another 20 minutes. Two hundred milliliters of groundwater were mixed with 20 μL of the polymer solution, to generate a 25 ppm polymer concentration. (On an industrial scale, 25 mL of the polymer solution prepared in this way is added to 100 gallons of wastewater.) The mixture was then pH adjusted with NaOH.

When the pH-adjusted mixtures were ready for each set of tests, they were placed on a Phipps and Bird Model 779-400 gang stirrer. The samples were stirred carefully such that the flocculant precipitate generated by pH adjustment was suspended but not broken into smaller flocs. The stirrer was then turned off and settling times for the suspended solids were determined using a calibrated stopwatch, #WP-555. The final volume of settled solids

HS Composite

Table 2. Analysis of F/H Groundwater "Hot Spot" Composite

SPECIES, units	Routine Analysis	ICP/MS Analysis

Ca, mg/L	11.903	
Cd, mg/L	0.017	0.010
Co, mg/L	0.150	0.156
Cu, mg/L	0.162	0.056
Mg, mg/L	3.104	8.150
Mn, mg/L	1.144	3.175
Pb, mg/L	<.200	0.048
Zn, mg/L	0.781	
Zr, mg/L	0.147	
Al, mg/L	15.635	
Ba, mg/L	0.247	0.440
Fe, mg/L	0.506	
La, mg/L	0.240	
Li, mg/L	0.158	0.039
Mo, mg/L	0.075	0.004
Na, mg/L	66.776	
Ni, mg/L	0.139	0.063
Sn, mg/L	0.120	
Sr, mg/L	0.073	0.127
Ti, mg/L	0.110	
V, mg/L	0.140	
B, mg/L	0.179	0.094
Cr, mg/L	<0.030	0.004
P, mg/L	0.274	
Si, mg/L	10.498	
U, mg/L	0.480	1.256
Hg, mg/L	<0.01	0.000
As, µg/L	<20	19.6
Gross B/g, d/m/ml	<50	
Gross a, d/m/ml	<5	
TIC	0.380	
TOC	0.960	
Tritium, µCi/ml	4.16E-03	
NO3	333.000	
Cl	3.020	
F	0.476	
NO2	Not Detected	
SO4	4.220	
NH4	1.740	
I		0.020
Cond., mmhos	0.478	
Gamma Scan	No Peaks Detected	

a = alpha
B = beta
g = gamma

was recorded. The mixture was filtered using a previously weighed 0.45 μm filter. The time needed to completely filter the 200-mL sample was recorded. Solids were air-dried to constant weight and then oven-dried to constant weight at 100°C. Filtrates were sent to ADS for the following "customer assisted analyses"; inductively coupled plasma atomic emission spectrometry for metals, total inorganic and organic carbon content, total uranium, and conductivity. Portions of the filtrates were also sent for ICP/MS scan. Behaviors of anions, NH_4^+ , Pu, tritium, and Hg were not tracked in the filtrates because they were either not present in the groundwater (Pu and Hg) or were expected to be unaffected by treatment (anions, NH_4^+ , and tritium).

Particle size analyses were done using a Brinkman Particle Size Analyzer, Model 2010. Samples containing precipitated solids in treated groundwater were placed in a stirred 4-mL cuvette for analysis by the instrument. The stirrer was set at the slowest stirring speed to try to prevent breakup of the precipitate. The filtrates, after filtration through a 0.45 μm filter, were examined on the particle size analyzer. In all cases, no particles were detected in the filtrate sample by the instrument. The minimum detection limit of the analyzer with the software program used (0.1-150 μm) was 0.1 μm .

Another sample of this groundwater (and one of the RCRA plume groundwater) was treated with a new product that has been highly touted by its manufacturer for removal of hazardous metals from dilute waste. The product is called TMT-15 and is manufactured by Degaussa Corporation. TMT-15 was recieved as a solution of the trisodium salt of trimercapto-S-triazine (Figure 2) in caustic.

Figure 2. TMT-15

Two hundred milliliters of each of the F/H groundwater composites, RCRA and "hot spot" plumes, were treated with 4 mL of TMT-15. The final pH of the mixture was adjusted to a value of 8. No precipitation occurred so the samples were heated gently. A fine, suspension formed in each sample. Gentle digestion for 2.5 hours was applied to induce precipitation. At the end of that time, peptization had been overcome. The mixtures were cooled, filtered through a 0.45 μm filter, and the filtrates were sent for ICPEs and total uranium analyses. The solids were collected on a weighed filter paper, air-dried to constant weight, and then oven-dried to constant weight at 100 °C.

3.3 Titration of Groundwater With Standard Base

A 10 mL sample of F/H composite groundwater representing the "hot spot" plume was titrated with 0.0995 M NaOH (Standard #RS60.5). Base was added in increments of 100 μL with stirring. The resulting pH was recorded on an Orion Model 701A digital pH meter that had been calibrated using current pH 4 and 7 buffers.

3.4 Analysis of Precipitate

A 1000-mL sample of groundwater was pH-adjusted to 7 with NaOH. The precipitate was collected on a weighed filter and oven-dried to constant weight. The precipitate was then dissolved in a minimum amount of concentrated nitric acid and the volume of the solution was brought to 10 mL in a volumetric flask with DI water. The dissolved precipitate was sent to ADS for ICPEs scan for metals, total U, Hg by cold vapor atomic absorption, and alpha counting.

A 200-mL sample of groundwater was mixed with 100 μL of a solution that was 54 $\mu\text{g/L}$ Al^{3+} , as $\text{Al}_2(\text{SO}_4)_3$. The mixture was pH-adjusted to 7 with NaOH. The precipitate was collected on a weighed filter and oven-dried to constant weight. The precipitate was then completely dissolved in a minimum amount of concentrated nitric acid and the volume of the solution was brought to 20 mL in a volumetric flask with DI water. The dissolved precipitate was sent to ADS for ICPEs scan for metals, total U, Hg by cold vapor atomic absorption, and alpha counting.

4.0 RESULTS

4.1 Elemental Analyses of Treated Waters

The results of elemental analyses for each pH adjustment procedure are collected in Tables 3-11 in Appendix 1. The ICP/MS data for

the same treated samples can be found in Tables 12-19 in Appendix 2. Where available, ICP/MS spectra are shown for treated water in Figures 3-8 in Appendix 2. Use of the ICP/MS information should be limited to the identification of isotopes still present in the treated and filtered groundwater. "Arbitrary Y" units on the Y axis are not useful in interpreting concentration directly. Calibration is performed by the computer software on the instrument relative to an internal In-155 standard and a blank. These are reported in the Tables 12-19. Peaks that are absent relative to the untreated groundwater are of interest, because their absences reflect the absences of elements, such as Hg, and Pu, in the groundwater. ICP/MS data were collected from the same instrument by two different researchers at times that differed by several months.

4.2 Titration of Groundwater with Standard Base

The results of the titration of untreated groundwater with standard NaOH are found in Figure 9. The initial pH was 3.8.

Figure 9. Titration Curve for Std. NaOH vs 10 mL
Untreated "Hot Spot" Groundwater Composite

4.3 Analysis of Groundwater Precipitates

The analyses of the precipitates formed on pH-adjusting untreated groundwater to a value of 7 with NaOH, with and without 25 mg/L Al^{3+} are given in Table 20. Local per cent distributions of particles of a recorded diameter for each of the precipitated solids are found in Tables 21-26 in Appendix 3. Settling times, settled solids volumes, and per cent water in dried solids are found in Tables 27-32 in Appendix 4.

Table 20. Analyses of Precipitates Formed with NaOH
25 mg/L Aluminum Ion Present and Absent

<u>ELEMENT, E</u>	<u>g E/g Precipitate</u> <u>Al Not Added</u>	<u>g E/g Precipitate</u> <u>Al Added</u>
Ca	1.97E-03	6.81E-03
Cd	2.37E-05	1.56E-05
Co	1.02E-04	1.98E-04
Cu	3.75E-04	2.92E-04
Mg	3.38E-04	1.29E-03
Mn	8.76E-04	3.86E-04
Pb	9.32E-04	3.13E-04
Zn	1.09E-03	5.05E-03
Zr	3.26E-04	4.92E-01
Al	2.13E-01	2.52E-02
Ba	7.61E-05	3.84E-04
Fe	6.31E-03	6.05E-03
La	7.75E-04	9.61E-04
Mo	7.38E-05	6.25E-05
Na	1.59E-03	1.18E-02
Ni	4.34E-05	3.60E-03
Sn	8.39E-05	1.09E-04
Sr	2.44E-06	3.13E-06
Ti	1.65E-04	9.84E-05
V	2.03E-04	7.81E-05
B	1.87E-05	6.30E-04
Cr	2.65E-05	6.25E-05
P	2.82E-03	2.84E-03
Si	5.29E-04	1.27E-02
U	7.37E-03	5.31E-03
Hg	5.42E-06	1.81E-07
gamma	not detected	not detected
<u>gross alpha</u>	5.82E+3 *	<3.55E+4 *

* Units are pCi/g

4.4 Precipitation with TMT-15

Precipitation of ions in the RCRA and "Hot Spot" composite groundwaters with a caustic solution of TMT-15, digestion with stirring at approximately 60°C, yielded treated waters (i.e., filtrate) of the following compositions.

Table 33. Water From the RCRA and "Hot Spot" Composites After Treatment With Degaussa TMT-15 and Removal of Solids

<u>Species*</u>	<u>Treated RCRA Water</u>	<u>Treated "hot spot" Water</u>
Ca	5.06	7.59
Cd	<0.010	<0.010
Co	<0.040	0.042
Cu	0.091	0.080
Mg	0.048	0.021
Mn	0.006	<0.003
Pb	0.445	0.457
Zn	1.12	1.29
Al	24.9	16.1
Ba	0.144	0.136
Fe	0.156	0.154
Na	1130	1014
Ni	0.156	0.279
Sn	0.163	0.160
Sr	0.073	0.059
Cr	0.053	<0.040
Si	12.0	10.3
U	0.31	0.32

* Units are all mg/L

Air-dried solids from the RCRA composite, precipitated using TMT-15, weighed 0.0817 g/200 mL of groundwater; oven-dried solids weighed 0.0052 g. There was 94% water in the air-dried solids from this precipitation.

Air-dried solids from the "hot spot" composite, precipitated using TMT-15, weighed 0.0809 g/200 mL of groundwater; oven-dried solids weighed 0.0044 g. There was 93% water in the air-dried solids from this precipitation.

5.0 CONCLUSIONS

° Heavy metals and arsenic can be removed from the "hot spot" groundwater by pH adjustment between 6 and 8 with caustic. The ICP/MS data is essentially qualitative but indicates that some of the iodine in solution can also be removed by precipitation. All precipitation tests that were done in this study removed all contaminant ions, including arsenate and iodide, from solution to below regulatory maximum concentration limits (MCLs).

° The ICP/MS data is important in that it shows no mercury or plutonium present in the composite sample. Furthermore, the uranium in solution in the groundwater composite is the natural U-238 isotope.

5.1 Precipitating Agents

° All precipitation tests yielded results that were very similar. Precipitation with NaOH after addition of 25 mg/L Al^{3+} as $Al_2(SO_4)_3$ to the groundwater gave a precipitate that was more compact and generally had a slightly larger particle size than that produced with other precipitating agents, though particles generated on pH adjustment with just NaOH were comparable. Settling times for precipitates generated when $Al_2(SO_4)_3$ was present indicate that about 45 minutes would be required for the solids to settle after pH adjustment.

° When precipitates formed by pH adjustment with NaOH, with and without aluminum ion, were dissolved and analyzed, it was evident that neither precipitate would be a hazardous waste due to heavy metals. If all of a 100 gram sample of either precipitate dissolved completely in 2000 mL of a pH5 acetic acid buffer (the ratio of mass of sample to the leaching agent in the standard Toxicity Component Leaching Procedure -TCLP- leach test³), none of the heavy metal ion concentrations would exceed allowable RCRA concentration limits.

° Precipitation using the TMT-15 is not recommended. The precipitate was too difficult to develop with this groundwater and removal of heavy metal ions was no better than with NaOH. In addition, Na concentrations in the treated groundwater are ten times greater with TMT-15 than with NaOH alone.

5.2 Titration of Groundwater

Determination of the inflection point in the titration curve shown in Figure 7 was made by calculating where the value of $\Delta pH^2 / \Delta^2 V$ is zero at the point where the first derivative is a maximum. Interpolation found that 0.157 mL of 0.0995 M NaOH, or 1.56 E-6 mole of NaOH, was needed to neutralize 10 mL of the "hot spot" composite water. Each liter of F/H groundwater would, then, require 1.56 E-3 moles or 6.24 E-2 grams of NaOH for neutralization. Stated in other units, 10,000 gallons of this groundwater would require 165 grams of NaOH for neutralization.

6.0 QUALITY ASSURANCE

All chemicals used in this study were of reagent grade. Nitric acid used to dissolve precipitates was Ultrex™ mercury-free, 16 M HNO₃. Data from this study can be found in WSRC-NB-90-345 and WSRC-NB-90-346. "Routine customer assisted" analyses were conducted by ADS using blanks and standard solutions made from standards traceable to NBS standards.

7.0 REFERENCES

1. BIELER, J.P., "Treatability Studies on F/H Area Groundwater Composite (U)", WSRC-RP-91-1030, October 29, 1991.
2. "Guide to Savannah River Laboratory Analytical Services Group (U)", WSRC-IM-90-29, Section C, "Analytical Methods".
3. 40CFR261 Appendix II, "Method 1311, Toxicity Characteristic Leaching Procedure".

APPENDIX 1

ELEMENTAL ANALYSES OF TREATED GROUNDWATER

Table 3. pH adjustment with NaOH.....	14-15
Table 4. pH Adjustment with NaOH/50 mg/L Fe as FeSO ₄	16
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Table 8. pH Adjustment with NaOH/25 ppm A3010L Anion Polymer..	20
Table 9. pH Adjustment with NaOH/25 ppm A3040L Anion Polymer..	21
Table 10. pH Adjustment with NaOH/25 ppm K122L Cation Polymer.	22
Table 11. pH Adjustment with NaOH/25 ppm K144L Cation Polymer.	23

Table 3. pH Adjustment With NaOH

SPECIES	COMPOSITE	pH 6 Filtrate	pH 6 DF	pH 6.5 Filtrate	pH 6.5 DF	pH 7 Filtrate	pH 7 DF
Ca	11.903	11.859	1	11.926	1	11.909	1
Cd	0.017	<0.010	>1	<0.001	>10	<0.001	>10
Co	0.150	<0.040	>3	<0.040	>3	<0.040	>3
Cu	0.162	<0.010	>16	<0.010	>16	<0.010	>16
Mg	3.104	3.067	1	3.120	1	3.163	1
Mn	1.144	1.041	1	1.021	1	0.899	1
Pb	<0.200	<0.200		<0.020		<0.200	
Zn	0.781	1.469		0.991		0.666	1
Zr	0.147	<0.020	>7	<0.020	>7	<0.020	>7
Al	15.635	<0.100	>150	<0.100	>150	<0.100	>150
Ba	0.247	0.049	5	0.051	5	0.051	5
Fe	0.506	<0.020	>25	<0.020	>25	<0.020	>25
La	0.240	<0.030	>8	<0.030	>8	<0.030	>8
Li	0.158	<0.008	>20	<0.008	>20	<0.008	>20
Mo	0.075	<0.040	>1	<0.040	>1	<0.040	>1
Na	66.776	107.610		111.470		115.750	
Ni	0.139	<0.005	>25	<0.005	>25	<0.005	>25
Sn	0.120	<0.070	>1	<0.07	1	<0.070	
Sr	0.073	0.003	24	0.005	12	<0.002	>35
Ti	0.110	<0.001	>100	<0.010	>100	<0.010	>100
V	0.140	<0.010	>14	<0.010	>14	<0.01	>14
B	0.179	<0.040	>4	<0.040	>4	<0.040	>4
Cr	<0.030	<0.040		<0.040		<0.040	
P	0.274	<0.100	>250	<0.01	>250	<0.010	>250
Si	10.498	3.093	3	2.608	3	1.937	5
U	0.480	<0.010	>48	<0.01	>48	0.020	24
TIC	0.380	0.438		0.632		1.360	
TOC	0.960	2.540		1.870		2.250	
Cond., mahos	0.478	0.500		0.492		0.508	
H-3, µCi/mL	8.33E-03	8.55E-03		9.23E-03		1.00E-02	

DF values have no units.

Concentrations are in mg/L unless otherwise noted.

Table 3. pH Adjustment With NaOH, Continued

SPECIES	COMPOSITE	pH 7.5 Filtrate	pH 7.5 DF	pH 8 Filtrate	pH8 DF	pH 8.5 Filtrate	pH 8.5 DF
Ca	11.903	11.779	1	11.391	1	11.382	1
Cd	0.017	<0.010	>17	<0.010	>17	<0.010	>17
Co	0.150	<0.040	>3	<0.040	>3	<0.040	>3
Cu	0.162	<0.010	>16	<0.010	>16	<0.010	>16
Mg	3.104	3.109	1	3.031	1	3.047	1
Mn	1.144	0.900	1	0.666	16	0.620	16
Pb	<0.200	<0.200		<0.200		<0.200	
Zn	0.781	0.667	1	0.567	1	0.563	
Zr	0.147	<0.020	>2	<0.020	>7	<0.020	>7
Al	15.635	<0.001	>150	<0.001	>150	<0.001	>150
Ba	0.247	0.026	10	<0.004	>60	<0.004	>60
Fe	0.506	<0.020	>25	<0.020	>25	<0.020	>25
La	0.240	<0.030	>8	<0.030	>8	<0.030	>8
Li	0.158	<0.008		<0.008	>20	<0.008	>20
Mo	0.075	<0.040	>1	<0.040	>1	<0.040	>1
Na	66.776	113.200		115.150		118.090	
Ni	0.139	<0.005	>25	<0.005	>25	<0.005	>25
Sn	0.120	<0.070	>1	<0.070	>1	<0.070	>1
Sr	0.073	<0.010	>35	<0.020	>3	<0.020	>3
Ti	0.110	<0.001	>100	<0.001	>100	<0.001	>100
V	0.140	<0.01	>14	<0.01	>14	<0.01	>14
B	0.179	<0.040	>40	<0.040	>40	<0.040	>40
Cr	<0.030	<0.040		<0.040		<0.040	
P	0.274	<0.100		<0.100	>250	<0.100	>250
Si	10.498	1.802	5	1.399	7	0.813	12
U	0.480	0.010	48	0.020	24	0.040	12
TIC	0.380	0.799		1.230		1.740	
TOC	0.960	1.930		1.620		1.950	
Cond., mmoles	0.478	0.512		0.516		0.528	
H-3, µCi/mL	8.33E-03	1.01E-02		1.02E-02		9.74E-03	

Concentrations are in mg/L unless otherwise noted.

DF values have no units.

Table 4. pH Adjustment With NaOH/50 mg/L Fe as Ferrous Sulfate Present

SPECIES	COMPOSITE	pH 6 Filtrate	pH 6 DF	pH 7 Filtrate	pH 7 DF	pH 8 Filtrate	pH 8 DF
*****	*****	*****	*****	*****	*****	*****	*****
Ca	11.903	12.540		12.477		12.314	
Cd	0.017	<0.010	>1	<0.010	>1	<0.010	>1
Co	0.150	<0.040	>3	<0.040	>3	<0.040	>3
Cu	0.162	<0.010	>16	<0.010	>16	<0.010	>16
Mg	3.104	3.823	1	3.465	1	3.313	1
Mn	1.144	1.220	1	1.202	1	1.118	1
Pb	<0.200	<0.020	>10	<0.020	>10	<0.200	>10
Zn	0.781	1.988		1.302		1.043	
Zr	0.147	<0.020	>70	<0.020	>70	<0.020	>50
Al	15.635	<0.100	>150	<0.100	>150	<0.100	>150
Ba	0.247	0.153	1	0.165	1	0.163	1
Fe	50.506*	54.340	-	46.817	1	4.083	10
La	0.240	0.030	8	0.032	8	0.057	>4
Li	0.158	<0.008	>18	0.029	5	0.019	>1
Mo	0.075	<0.040	>	0.060	1	<0.040	>1
Na	66.776	142.570		200.960		240.030	
Ni	0.139	<0.050	>2	<0.050	>2	<0.050	>2
Sn	0.120	<0.070	>1	<0.070	>1	<0.070	>1
Sr	0.073	0.039	2	0.044	2	0.052	1
Ti	0.110	<0.010	>11	<0.010	>11	<0.010	>11
V	0.140	<0.010	>14	<0.010	>14	<0.010	>14
B	0.179	<0.040	>3	0.061	>4	<0.040	>4
Cr	<0.030	<0.040		<0.040		<0.040	
P	0.274	<0.01	2	0.107	>40	<0.10	>2
Si	10.498	7.002	3	4.007	1	1.743	6
U	0.480	0.130	>3	0.050	>9	<0.01	>48
TIC	0.380	0.367	1	0.335	1	0.129	2
TOC	0.960	2.690		1.480		1.780	
Cond., μ mhos	0.478	0.942		0.906		1.000	

* Original concentration plus 50 mg/L (not analyzed)
Concentrations are in mg/L unless otherwise stated.
DF values have no units.

Table 5. pH Adjustment With NaOH/15 mg/L Fe as Ferric Nitrate Present

SPECIES	COMPOSITE	pH6 Filtrate	pH 6 DF	pH7 Filtrate	pH 7 DF	pH 8 Filtrate	pH 8 DF
Ca	11.903	12.180	1	11.855	1	10.660	1
Cd	0.017	<0.010	>1	0.012	1	<0.010	>1
Co	0.150	0.043	3	<0.040	>3	<0.040	>3
Cu	0.162	<0.010	>16	<0.010	>16	<0.010	>16
Mg	3.104	3.262	1	2.922	1	2.922	1
Mn	1.144	1.057	1	0.280	4	0.280	4
Pb	<0.200	<0.020		<0.200		<0.200	
Zn	0.781	1.306		0.735	1	0.735	1
Zr	0.147	<0.020	>7	<0.020	>7	<0.020	>7
Al	15.635	<0.100	>150	<0.100	>150	<0.100	>150
Ba	0.247	0.175	2	0.138	2	0.163	2
Fe	15.506*	<0.020	>775	<0.020	>775	4.083	4
La	0.240	0.041	6	0.047	6	0.057	6
Li	0.158	0.138	1	0.095	1	0.019	8
Mo	0.075	0.104	1	0.080	1	<0.040	>1
Na	66.776	154.920		158.300		240.030	
Ni	0.139	<0.050	>2	<0.050	>2	<0.050	>2
Sn	0.120	<0.010	>12	<0.010	>12	<0.010	>12
Sr	0.073	0.051	1	0.050	1	0.052	1
Ti	0.110	<0.010	>11	<0.010	>11	<0.010	>11
V	0.140	<0.010	>14	<0.010	>14	<0.010	>14
B	0.179	0.286		0.228		<0.040	
Cr	<0.030	<0.040		<0.040		<0.040	
P	0.274	<0.100	>2	<0.100	>2	<0.100	>2
Si	10.498	2.751	4	1.839	3	1.743	6
U	0.480	<0.01	>48	<0.01	>48	<0.01	>48
TIC	0.380	0.773		1.170		1.580	
TOC	0.960	1.140		1.460		1.200	
Cond., μ mhos	0.478	0.688		0.698		0.702	

* Original concentration plus 15 mg/L (not analyzed)
Concentrations are in mg/L unless otherwise stated.

DF values have no units.

Table 6. pH Adjustment With NaOH/25 mg/L Al as Aluminum Sulfate

SPECIES	COMPOSITE	pH 6 Filtrate	pH 6 DF	pH 7 Filtrate	pH 7 DF	pH 8 Filtrate	pH 8 DF
Ca	11.903	11.926	1	11.746	1	11.302	1
Cd	0.017	<0.010	>1	<0.010	>1	<0.010	>1
Co	0.15	<0.040	>3	<0.040	>3	<0.040	>3
Cu	0.162	<0.010	>16	<0.010	>16	<0.010	>16
Mg	3.104	3.067	1	3.008	1	3.876	1
Mn	1.144	1.023	1	0.964	1	0.13	9
Pb	<0.200	<0.200		<0.200		<0.200	
Zn	0.781	1.058		0.942		1.005	
Zr	0.147	<0.020	>7	<0.020	>7	<0.020	>7
Al	40.635*	<0.100	>450	<0.100	>450	<0.100	>450
Ba	0.247	0.031	8	0.006	40	0.12	2
Fe	0.506	<0.020	>25	<0.020	>25	<0.020	>25
La	0.24	<0.030	>8	<0.030	>8	<0.030	>8
Li	0.158	<0.008	>19	<0.008	>19	<0.008	>19
Mo	0.075	<0.040	>1	<0.040	>1	<0.040	>1
Na	66.776	116.2		120.2		283.08	
Ni	0.139	<0.050	>2	<0.050	>2	<0.050	>2
Sn	0.12	<0.070	>1	<0.070	>1	<0.070	>1
Sr	0.073	<0.002	<30	<0.002	<30	<0.002	<30
Ti	0.11	<0.010	>11	<0.010	>11	<0.010	>11
V	0.14	<0.010	>14	<0.010	>14	<0.010	>14
B	0.179	<0.040	>4	<0.040	>4	<0.040	>4
Cr	<0.030	<0.040		<0.040		<0.040	
P	0.274	<0.010	>27	<0.01	>27	<0.100	>27
Si	10.498	2.791	4	1.405	7	2.233	5
U	0.48	<0.01	>48	<0.01	>48	<0.01	>48
TIC	0.38	0.075	5	0.645		1.137	1
TOC	0.96	1.84		1.47		0.672	1
Cond., μ mhos	0.478	0.560		0.575		0.57	

* Original plus 25 mg/L added (not analyzed as such)
Concentrations are in mg/L unless otherwise noted.

DF values have no units.

Table 7. pH Adjustment With Magnesium Hydroxide

SPECIES	COMPOSITE	PH 6 Filtrate	PH 6 DF	PH 7 Filtrate	PH 7 DF	PH 8 Filtrate	PH 8 DF
Ca	11.903	12.318		12.872		12.75	
Cd	0.017	<0.010	>1	<0.010	>1	<0.010	>1
Co	0.15	<0.040	>3	<0.040	>3	<0.040	>3
Cu	0.162	<0.010	>16	<0.010	>16	<0.010	>16
Mg	3.104	24.312		28.166		27.79	
Mn	1.144	1.064	1	1.007	1	0.535	2
Pb	<0.200	<0.200		<0.200		<0.200	
Zn	0.781	0.802		0.632		0.535	
Zr	0.147	<0.020	>7	<0.020	>7	<0.020	>7
Al	15.635	<0.010	>150	<0.010	>150	<0.010	>150
Ba	0.247	0.052	4	0.055	4	<0.004	4
Fe	0.506	<0.020	>25	<0.020	>25	<0.020	>25
La	0.24	<0.030	>8	<0.030	>8	<0.030	>8
Li	0.158	<0.008	>19	<0.008	>19	<0.008	>19
Mo	0.075	<0.040	2	<0.040	2	<0.040	2
Na	66.776	70.575		72.886		72.785	
Ni	0.139	<0.050	>2	<0.050	>2	<0.050	>2
Sn	0.12	<0.070	>1	<0.070	>1	<0.070	>1
Sr	0.073	0.006	12	0.013	12	0.015	12
Ti	0.11	<0.010	>11	<0.010	>11	<0.010	>11
V	0.14	<0.010	>14	<0.010	>14	<0.010	>14
B	0.179	<0.040	>4	<0.040	>4	<0.040	>4
Cr	<0.030	<0.040		<0.040		<0.040	
P	0.274	<0.100	>2	<0.100	>2	<0.100	>2
Si	10.498	2.969	3	2.29	3	2.374	3
U	0.48	0.02	24	<0.01	24	0.01	24
TIC	0.38	0.531		1.39		2.96	
TOC	0.96	3.02		2.69		2.12	
Cond., mmhos	0.478	0.544		0.577		0.577	

Concentrations are in mg/L unless otherwise stated. DF values have no units.

Table 8. pH Adjustment With NaOH/25 ppm A3010L Anionic Polymer

SPECIES	COMPOSITE	pH 6 Filtrate	pH 6 DF	pH 7 Filtrate	pH 7 DF	pH 8 Filtrate	pH 8 DF
Ca	11.903	12.160	1	12.257	1	11.500	1
Cd	0.017	0.010	2	0.016	1	<0.010	>1
Co	0.150	0.071	2	0.054	3	0.094	2
Cu	0.162	0.010	16	<0.010	>16	0.021	8
Mg	3.104	3.169	1	3.111	1	3.027	1
Mn	1.144	1.079	1	1.010	1	0.741	2
Pb	<0.200	<0.200		<0.200		<0.200	
Zn	0.781	1.708	0	1.360	1	1.130	1
Zr	0.147	0.027	5	0.043	3	0.041	4
Al	15.635	0.283	55	0.495	32	0.666	23
Ba	0.247	0.198	1	0.195	1	0.157	2
Fe	0.506	0.022	23	0.039	13	0.057	9
La	0.240	0.117	2	0.190	1	0.190	1
Li	0.158	0.117	1	0.129	1	0.130	1
Mo	0.075	0.080	1	0.051	1	<0.040	>1
Na	66.776	113.700		114.640		117.770	
Ni	0.139	0.050	3	<0.050	>2	0.120	1
Sn	0.120	0.083	1	0.121	1	<0.070	>1
Sr	0.073	0.028	3	0.063	1	0.065	1
Ti	0.110	0.010	11	0.036	3	0.034	3
V	0.140	0.010	14	<0.010	>14	0.037	4
B	0.179	0.307		0.108		0.103	2
Cr	<0.030	<0.040		<0.040		<0.010	
P	0.274	<0.100	>2	<0.010		<0.100	
Si	10.498	4.793	2	14.112		3.171	3
U	0.480	<0.01	>48	<0.01	>48	0.020	24
TIC	0.380	0.336		0.677		1.078	
TOC	0.960	2.504		1.369		1.385	
cond., mmhos	0.478	0.535		0.524		0.533	

Concentrations are in mg/L unless otherwise stated. DF values have no units.

Table 9. pH Adjustment With NaOH/25 ppm A3040L Anionic Polymer

SPECIES	COMPOSITE	pH 6	Filtrate	pH 6	DF	pH 7	Filtrate	pH 7	DF	pH 8	Filtrate	pH 8	DF
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
Ca	11.903	12.374	1	11.935	1	11.125	1	11.125	1	11.125	1	11.125	1
Cd	0.017	<0.010	>1	<0.010	>1	<0.010	>1	<0.010	>1	<0.010	>1	<0.010	>1
Co	0.150	0.134	1	0.063	2	<0.040	2	<0.040	>3	<0.040	>3	<0.040	>3
Cu	0.162	0.043	4	<0.010	>16	<0.010	>16	<0.010	>16	<0.010	>16	<0.010	>16
Mg	3.104	3.198	1	3.103	1	2.955	1	2.955	1	2.955	1	2.955	1
Mn	1.144	1.12	1	0.956	1	0.427	3	0.427	3	0.427	3	0.427	3
Pb	<0.200	0.256		<0.020		<0.200		<0.200		<0.200		<0.200	
Zn	0.781	1.076		0.952	1	0.468	2	0.468	2	0.468	2	0.468	2
Zr	0.147	0.09	2	0.042	4	<0.020	>7	<0.020	>7	<0.020	>7	<0.020	>7
Al	15.635	0.778	20	0.442	35	<0.100	>150	<0.100	>150	<0.100	>150	<0.100	>150
Ba	0.247	0.23	1	0.191	1	<0.004	>60	<0.004	>60	<0.004	>60	<0.004	>60
Fe	0.506	0.073	7	0.061	8	<0.020	>25	<0.020	>25	<0.020	>25	<0.020	>25
La	0.240	0.215	1	0.174	1	<0.030	>8	<0.030	>8	<0.030	>8	<0.030	>8
Li	0.158	0.135	1	0.102	2	<0.030	>5	<0.030	>5	<0.030	>5	<0.030	>5
Mo	0.075	0.086	1	0.075	1	<0.040	>1	<0.040	>1	<0.040	>1	<0.040	>1
Na	66.776	116.67	1	118.59	1	126.27	1	126.27	1	126.27	1	126.27	1
Ni	0.139	0.052	3	0.092	2	<0.050	>2	<0.050	>2	<0.050	>2	<0.050	>2
Sn	0.120	<0.070	>1	<0.070	>1	<0.070	>1	<0.070	>1	<0.070	>1	<0.070	>1
Sr	0.073	0.072	1	0.063	1	0.012	6	0.012	6	0.012	6	0.012	6
Ti	0.110	0.066	2	0.031	4	<0.010	>11	<0.010	>11	<0.010	>11	<0.010	>11
V	0.140	0.043	3	0.015	9	<0.010	>14	<0.010	>14	<0.010	>14	<0.010	>14
B	0.179	0.136	1	<0.040	>3	<0.040	>3	<0.040	>3	<0.040	>3	<0.040	>3
Cr	<0.030	<0.020	>1	<0.040	>1	<0.040	>1	<0.040	>1	<0.040	>1	<0.040	>1
P	0.274	<0.100	>2	<0.100	>2	<0.100	>2	<0.100	>2	<0.100	>2	<0.100	>2
Si	10.498	4.974	2	3.762	3	1.458	7	1.458	7	1.458	7	1.458	7
U	0.480	<0.01	>48	0.02	24	0.07	7	0.07	7	0.07	7	0.07	7
TIC	0.380	0.847	0	2.106		2.636		2.636		2.636		2.636	
TOC	0.960	1.62		1.226		1.373		1.373		1.373		1.373	
cond., mmhos	0.478	0.53		0.546		0.538		0.538		0.538		0.538	

Concentrations are in mg/L unless otherwise stated.

DF values have no units.

Table 10. pH Adjustment With NaOH/25 ppm K122L Cationic Polymer

SPECIES	COMPOSITE	pH 6 Filtrate	pH 6 DF	pH 7 Filtrate	pH 7 DF	pH 8 Filtrate	pH 8 DF
Ca	11.903	12.693	1	12.142	1	11.950	1
Cd	0.017	<0.010	>1	<0.010	>1	<0.010	>1
Co	0.150	<0.040	>3	<0.040	>3	<0.040	>3
Cu	0.162	0.050	3	0.038	4	<0.010	>16
Mg	3.104	3.007	1	3.093	1	3.085	1
Mn	1.144	0.611	2	1.057	1	0.832	1
Pb	<0.200	0.538		0.371		<0.200	
Zn	0.781	1.054	1	1.537	1	1.171	
Zr	0.147	0.182	1	0.149	1	<0.020	>7
Al	15.635	1.406	11	1.261	12	<0.100	>150
Ba	0.247	0.143	2	0.215	1	<0.004	>60
Fe	0.506	0.133	4	0.125	4	<0.020	>25
La	0.240	0.352	1	0.413	1	<0.030	>8
Li	0.158	0.043	4	0.060	3	<0.008	>18
Mo	0.075	0.095	1	0.086	1	<0.040	>1
Na	66.776	117.560	1	112.720	1	116.010	
Ni	0.139	0.177	1	0.105	1	<0.050	>2
Sn	0.120	0.106	1	<0.070	>1	<0.070	>1
Sr	0.073	0.056	1	0.056	1	<0.002	>35
Ti	0.110	0.128	1	0.105	1	<0.010	>11
V	0.140	0.058	2	0.038	4	<0.010	>14
B	0.179	<0.040	>4	0.090	2	<0.040	>4
Cr	<0.030	<0.040		<0.040		<0.040	
P	0.274	0.110	2	<0.100	>2	<0.100	>2
Si	10.498	3.110	3	4.177	3	2.129	5
U	0.480	0.010	48	0.020	24	0.050	10
TIC	0.380	1.402		1.981		2.746	
TOC	0.960	1.459		1.193		1.737	
cond., mmhos	0.478	0.523		0.526		0.515	

Concentrations are in mg/L unless otherwise stated.

DF values have no units.

Table 11. pH Adjustment With NaOH/25 ppm K144L Cationic Polymer

SPECIES	COMPOSITE	PH 6 Filtrate	PH 6 DF	PH 7 Filtrate	PH 7 DF	PH 8 Filtrate	PH 8 DF
Ca	11.903	11.700	1	12.317	1	11.984	1
Cd	0.017	0.018	1	<0.010	>1	<0.010	>1
Co	0.150	0.060	3	<0.040	>3	<0.040	>3
Cu	0.162	0.013	12	<0.010	>16	<0.010	>16
Mg	3.104	3.090	1	3.093	1	3.079	1
Mn	1.144	0.682	2	1.072	1	0.893	1
Pb	<0.200	<0.200		<0.200		<0.020	
Zn	0.781	0.820	1	1.555		1.269	1
Zr	0.147	0.057	3	<0.020	>7	<0.020	>7
Al	15.635	0.636	25	0.277	56	<0.100	>150
Ba	0.247	0.143	2	0.168	1	0.097	3
Fe	0.506	<0.020	>25	0.032	16	<0.020	>25
La	0.240	0.161	1	0.210	1	0.170	1
Li	0.158	0.087	2	<0.008	>18	<0.008	>18
Mo	0.075	<0.040	>1	<0.040	>1	0.060	1
Na	66.776	123.030		112.250		113.650	1
Ni	0.139	<0.050	>2	0.069	>2	0.054	3
Sn	0.120	<0.070	>1	<0.070	>1	<0.070	>1
Sr	0.073	0.062	1	0.056	>1	<0.002	>35
Ti	0.110	0.034	3	0.035	3	0.012	9
V	0.140	0.031	5	<0.010	>14	<0.010	>14
B	0.179	0.122	1	0.084	2	<0.040	>4
Cr	<0.030	<0.040		<0.040		<0.040	
P	0.274	0.119	2	<0.100	>2	<0.100	>2
Si	10.498	2.914	4	4.198	3	3.535	3
U	0.480	<0.01	>48	0.010	48	0.020	24
TIC	0.380	0.908		1.053		1.481	
TOC	0.960	1.459		1.197		1.234	
cond., mmhos	0.478	0.521		0.518		0.532	

Concentrations are in mg/L unless otherwise stated. DF values have no units.

APPENDIX 2

ICP/MS DATA FOR TREATED WATER

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ICP/MS Spectrum of Treated Water-Precipitate With NaOH

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Table 12. ICP/MS Data for Precipitation With NaOH

Element	Initial Conc.		Treated Water Conc.					
	ppb (a)	pH 6 ppb (a)	pH 6.5 ppb (a)	pH 7 ppb (a)	pH 7.5 ppb (a)	pH 8 ppb (a)	pH 8 ppb (a)	
V-51	47							
Cr-52	5.6							
Mn-55	3175	2604	2596	2122	1989	1451		
Fe-57	156	51	49	31	29	13		
Co-59	63	21	19	11	10	4.2		
Ni-60	56	5.7	1.9	1.0	0.73	0.4		
Ga-69	22							
Ge-72	11							
As-75	20							
Se-77	0.36							
Rb-85	19	8.4	9.2	8.2	8.3	7.3		
Sr-88	128	60	58	57	54	47		
Y-89	658	30	3.2	0.21	0.18	0.015		
Zr-90	0.229							
Ru-99	1.2							
Rh-103	0.01							
Pd-106	0.16							
Ag-107	0.017							
Cd-111	10	5.5	4.4	2.4	2.0	0.56		
Sn-120	0.045	0.52	0.41	0.44	0.70	0.36		
Sb-121	0.33							
I-127	12							
Te-128	1.4							
Cs-133	2.8	2.3	2.5	2.5	2.7	1.7		
Ba-138	440	281	284	236	240	170		
La-139	162	49	10	0.39				
Au-197	0.4							
Tl-205	0.52	0.50	0.44	0.50	0.55	0.45		
Pb-208	48	27	3.1	0.53	0.37			
U-238	1256	18	23	23	15	38		

(a) Run by F. Kinard with an internal standard
(b) Run by J. Gemmill without an internal standard--data normalized by F. Kinard

Figure 3. ICP/MS Spectra for Groundwater After pH-Adjusting to 6.0 (JPL2P60) and 6.5 (JPL2P65) with NaOH

Figure 3 (cont'd). ICP/MS Spectra for Groundwater After pH-Adjusting to 6.0 (JPL2P60) and 6.5 (JPL2P65) with NaOH

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Figure 4 (cont'd). ICP/MS Spectra for Groundwater After pH-Adjusting to 7.0 (JPL2P70) and 7.5 (JPL2P75) with NaOH

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Figure 5 (cont'd). ICP/MS Spectra for Groundwater After pH-Adjusting to 8.0 (JPL2P80) and 8.5 (JPL2P85) with NaOH

Table 13. ICP/MS Data for Precipitation With NaOH
50 mg/L Fe Present as Ferrous Sulfate

Element	Initial Conc.	Treated Water Conc.		
	ppb (a)	pH 6 ppb (b)	pH 7 ppb (b)	pH 8 ppb (b)
V-51	47			
Cr-52	5.6			
Mn-55	3175	1214	1041	1083
Fe-57				
Co-59	156	62	51	38
Ni-60	63	33	22	15
Cu-65	56	4.7	3.1	0.6
Zn-66		187	117.0	138.0
Ga-69	22	5.3	3.6	2.8
Ge-72	11	7.5	3.8	0.49
As-75	20	0.032	0.268	
Rb-85	19	7.8	6.8	8.8
Sr-88	128	46	41	45
Y-89	658	185	82	12
Zr-90	0.229	0.016	0.82	0.018
Ru-102	1.2	0.024	0.23	0.028
Rh-103	0.01			0.026
Pd-106	0.16	0.67	0.65	0.225
Ag-107	0.017		0.10	
Cd-111	10	3.8	5.0	1.6
Sn-120	0.045	0.85	0.46	0.36
Sb-121	0.33	0.007	0.54	0.051
I-127	12	3.5	4.1	2.2
Te-128	1.4	0.049	2.1	0.627
Cs-133	2.8	24	7	17
Ba-138	440	112	95	69
La-139	162	54	27	3.7
Au-197	0.4	0.005	0.09	0.003
Hg-202		1.1	0.77	0.282
Tl-205	0.52	0.16	0.16	0.20
Pb-208	48	0.24	0.53	
U-238	1256	113	50	4.5

(a) Run by F. Kinard with an internal In-155 standard
(b) Run by J. Gemmill with an internal In-155 standard

Table 14. ICP/MS Data for Precipitation With NaOH
15 mg/L Fe Present as Ferric Nitrate

Element	Initial Conc.	Treated Water Conc.		
	ppb (a)	pH 6 ppb (b)	pH 7 ppb (b)	pH 8 ppb (b)
V-51	47			
Cr-52	5.6			
Mn-55	3175	974	809	367
Fe-57				
Co-59	156	38	16	3.7
Ni-60	63	15	7.4	2.0
Cu-65	56	0.55	1.2	1.9
Zn-66		126	133.0	115.0
Ga-69	22	5.6	5.3	3.3
Ge-72	11	7.5		
As-75	20	0.021	0.001	
Rb-85	19	6.3	8.1	8.9
Sr-88	128	44	46	44
Y-89	658	1.1	0.567	0.23
Zr-90	0.229	0.016	0.02	0.02
Ru-102	1.2	0.024		0.005
Rh-103	0.01		0.001	
Pd-106	0.16	0.10		
Ag-107	0.017			
Cd-111	10	1.4	0.35	0.17
Sn-120	0.045	0.48	2.2	2.4
Sb-121	0.33			0.05
I-127	12	1.4	2.0	3.1
Te-128	1.4	0.24	0.20	0.59
Cs-133	2.8	2.8	18	14
Ba-138	440	165	137	91
La-139	162	1.3	0.5	0.32
Au-197	0.4	0.004	0.01	0.002
Hg-202		0.019	0.09	1.4
Tl-205	0.52	0.20	0.15	0.13
Pb-208	48	0.19	0.04	6.3
U-238	1256	1.6	2.8	6.1

(a) Run by F. Kinard with an internal In-155 standard

(b) Run by J. Gemmill with an internal In-155 standard

Table 15. ICP/MS Data for Precipitation With NaOH
25 mg/L Al Present as Aluminum Sulfate

Element	Initial Conc.	Treated Water Conc.		
	ppb (a)	pH 6 ppb (b)	pH 7 ppb (b)	pH 8 ppb (b)
V-51	47			
Cr-52	5.6			
Mn-55	3175	1081	977	721
Fe-57				
Co-59	156	48	38	15
Ni-60	63	19	13	5.1
Cu-65	56	4.7	4.6	3.9
Zn-66		150	103	90
Ga-69	22	5.7	5.2	3.9
Ge-72	11	0.70	0.12	0.023
As-75	20	0.063	0.025	0.008
Rb-85	19	7.6	6.9	7.2
Sr-88	128	46	42	42
Y-89	638	41	3.7	1.5
Zr-90	0.229	0.16	0.01	
Ru-102	1.2	0.02		0.013
Rh-103	0.01	0.01	0.001	
Pd-106	0.16	0.20	0.11	0.054
Ag-107	0.017			
Cd-111	10	3.7	2.30	0.86
Sn-120	0.045	0.76	3.5	1.8
Sb-121	0.33	0.007	0.17	0.094
I-127	12	2.3	2.6	2.7
Te-128	1.4	0.25		
Cs-133	2.8	27	10	8.0
Ba-138	440	182	156	120
La-139	162	41	5.7	2.1
Au-197	0.4		0.003	0.001
Hg-202		0.68	0.12	0.03
Tl-205	0.52	0.10	0.15	0.12
Pb-208	48	6.8	0.76	0.22
U-238	1256	9.8	5.5	11

(a) Run by F. Kinard with an internal In-155 standard
(b) Run by J. Gemmill with an internal In-155 standard

Table 16. ICP/MS Data for Precipitation With NaOH
25 mg/L A3010L Anion Polymer Present

Element	Initial Conc.	Treated Water Conc.		
	ppb (a)	pH 6 ppb (b)	pH 7 ppb (b)	pH 8 ppb (b)
V-51	47			
Cr-52	5.6			
Mn-55	3175	1131	1119	695
Fe-57				
Co-59	156	52	42	13
Ni-60	63	21	17	5.4
Cu-65	56	2.62	1.3	0.8
Zn-66				
Ga-69	22	9.5	8.7	5.7
Ge-72	11	0.51	0.16	0.05
As-75	20	0.06	0.01	0.01
Rb-85	19	7.5	7.8	7.3
Sr-88	128	47	49	42
Y-89	658	22.6	1.26	0.11
Zr-90	0.229	0.02		
Ru-102	1.2	0.1	0.06	0.06
Rh-103	0.01			
Pd-106	0.16	0.53	0.07	0.05
Ag-107	0.017	0.02	0.01	
Cd-111	10	2.72	1.83	2.72
Sn-120	0.045			
Sb-121	0.33	0.04	0.07	0.07
I-127	12	3.79	4.7	4.12
Te-128	1.4	0.15		
Cs-133	2.8	24	12	2.4
Ba-138	440	176	174	106
La-139	162	29.2	1.3	0.06
Au-197	0.4			
Hg-202		0.01		0.03
Tl-205	0.52	0.17	0.27	0.15
Pb-208	48	2.1	0.84	0.06
U-238	1256	13.87	14.4	20

(a) Run by F. Kinard with an internal In-155 standard

(b) Run by J. Gemmill with an internal In-155 standard

Table 17. ICP/MS Data for Precipitation With NaOH
25 mg/L 3040L Anion Polymer Present

Element	<u>Initial Conc.</u>	<u>Treated Water Conc.</u>		
	ppb (a)	pH 6 ppb (b)	pH 7 ppb (b)	pH 8 ppb (b)
V-51	47			
Cr-52	5.6			
Mn-55	3175	795	902	698
Fe-57				
Co-59	156	22	32	13
Ni-60	63	8.3	12	5.1
Cu-65	56	0.67	0.90	0.90
Zn-66				
Ga-69	22	5.3	6.6	5.1
Ge-72	11		0.01	0.03
As-75	20		0.01	0.02
Rb-85	19	6.1	6.3	7.0
Sr-88	128	37	41	41
Y-89	658	0.27	0.58	0.13
Zr-90	0.229			
Ru-102	1.2	0.02	0.06	0.06
Rh-103	0.01			
Pd-106	0.16	0.04	0.03	0.01
Ag-107	0.017			
Cd-111	10	0.89	0.1	0.46
Sn-120	0.045			
Sb-121	0.33	0.09	0.02	0.04
I-127	12	4.5	3.6	4.3
Te-128	1.4	0.36	0.49	0.59
Cs-133	2.8	19	2.7	3.1
Ba-138	440	120	141	99
La-139	162	0.32	0.70	0.13
Au-197	0.4			
Hg-202				
Tl-205	0.52	0.19	0.19	0.20
Pb-208	48	0.03	0.01	0.03
U-238	1256	25	27	74

(a) Run by F. Kinard with an internal In-155 standard

(b) Run by J. Gemmill with an internal In-155 standard

Table 18. ICP/MS Data for Precipitation With NaOH
25 mg/L K122L Cation Polymer Present

Element	Initial Conc.	Treated Water Conc.		
	ppb (a)	pH 6 ppb (b)	pH 7 ppb (b)	pH 8 ppb (b)
V-51	47			
Cr-52	5.6			
Mn-55	3175	1053	1009	614
Fe-57				
Co-59	156	46	38	9.3
Ni-60	63	18	14	3.5
Cu-65	56	1.6	1.4	0.60
Zn-66				
Ga-69	22	7.7	7.5	4.0
Ge-72	11	0.17	0.10	0.03
As-75	20			0.01
Rb-85	19	6.6	7.9	7.0
Sr-88	128	41	53	40
Y-89	658	6.6	2.3	0.11
Zr-90	0.229			
Ru-102	1.2	0.03	0.02	0.01
Rh-103	0.01	0.02	0.10	0.05
Pd-106	0.16	0.12	0.05	
Ag-107	0.017			
Cd-111	10	3.1	2.0	0.20
Sn-120	0.045			
Sb-121	0.33	0.04	0.11	0.03
I-127	12	4.4	4.8	5.2
Te-128	1.4	0.26		0.47
Cs-133	2.8	12	4.8	2.0
Ba-138	440	160	164	90
La-139	162	14	4.8	0.08
Au-197	0.4			
Hg-202		0.01	0.01	
Tl-205	0.52	0.19	0.12	0.18
Pb-208	48	0.7		0.23
U-238	1256	9.7	14	63

(a) Run by F. Kinard with an internal In-155 standard

(b) Run by J. Gemmill with an internal In-155 standard

Table 19. ICP/MS Data for Precipitation With NaOH
25 mg/L K144L Cation Polymer Present

Element	<u>Initial Conc.</u>	<u>Treated Water Conc.</u>		
	ppb (a)	pH 6 ppb (b)	pH 7 ppb (b)	pH 8 ppb (b)
V-51	47			
Cr-52	5.6			
Mn-55	3175	986	889	593
Fe-57				
Co-59	156	16	11	10
Ni-60	63	16	12	4.1
Cu-65	56	1.6	0.6	0.60
Zn-66				
Ga-69	22	6.7	5.8	0.0
Ge-72	11	0.22		
As-75	20			0.01
Rb-85	19	6.9	6.5	6.6
Sr-88	128	41	41	38
Y-89	658	5.1	0.23	0.04
Zr-90	0.229			
Ru-102	1.2	0.05	0.03	0.02
Rh-103	0.01			
Pd-106	0.16	0.07	0.02	
Ag-107	0.017			
Cd-111	10	2	1.0	0.28
Sn-120	0.045			
Sb-121	0.33	0.07	0.07	0.05
I-127	12	4.65	5.0	0.63
Te-128	1.4	0.51		0.25
Cs-133	2.8	1.03	16	5.8
Ba-138	440	154	135	97
La-139	162	12	0.4	0.03
Au-197	0.4			
Hg-202			0.01	
Tl-205	0.52	0.17	0.18	0.17
Pb-208	48	0.37		1.07
U-238	1256	13	15	29

(a) Run by F. Kinard with an internal In-155 standard
(b) Run by J. Gemmill with an internal In-155 standard

Figure 6. ICP/MS Spectra for Groundwater After Treatment With NaOH and Polymer-K144L (pH 6) and K122L (pH 6,7,8)

Figure 6 (Cont'd). ICP/MS Spectra for Groundwater After Treatment With NaOH and Polymer-K144L (pH 6) and K122L (pH 6, 7, 8)

Figure 7. ICP/MS Spectra for Groundwater After Treatment With NaOH and Polymer-K144L (pH 7,8) and A3040L (pH 6,8)

Figure 7 (Cont'd). ICP/MS Spectra for Groundwater After Treatment With NaOH and Polymer-K144L (pH 7,8) and A3040L (pH 6,8)

Figure 8. ICP/MS Spectra for Groundwater After Treatment With NaOH and Polymer-A3040L (pH 7) and A3010L (pH 6,7,8)

Figure 8 (Cont'd). ICP/MS Spectra for Groundwater After Treatment With NaOH and Polymer-A3040L (pH 7) and A3010L (pH 6,7,8)

APPENDIX 3

PARTICLE SIZE ANALYSES OF PRECIPITATES

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Table 21. Particle Size - Local % of NaOH Precipitated
Particles in a Range of Diameters

Range, μm	pH 6	pH 6.5	pH 7	pH 7.5	pH 8	pH 8.5
0.0-1.0	38.89	48.60	42.72	44.87	47.23	41.58
1.0-2.0	28.65	23.40	25.23	26.92	24.55	32.46
2.0-3.0	11.39	11.08	12.56	11.31	11.37	10.85
3.0-4.0	8.62	7.24	8.30	7.27	7.37	6.24
4.0-5.0	5.60	4.42	2.61	4.57	4.49	4.08
5.0-6.0	2.91	2.37	1.29	2.31	2.30	2.12
6.0-7.0	1.76	1.28	0.67	1.27	1.20	1.15
7.0-8.0	0.72	0.54	0.44	0.53	0.54	0.43
8.0-9.0	0.42	0.29	0.24	0.30	0.27	0.31
9.0-10.0	0.25	0.20	0.56	0.18	0.19	0.20
10.0-20.0	0.68	0.51	0.05	0.43	0.45	0.53
20.0-30.0	0.08	0.06	0.01	0.04	0.03	0.06
30.0-40.0	0.02	0.01	0.01	0.01	0.00	0.01
40.0-50.0	0.01	0.01	0.00	0.00	0.00	0.00
50.0-60.0	0.00	0.00	0.00	0.00	0.00	0.00
60.0-70.0	0.00	0.00	0.00	0.00	0.00	0.00
70.0-80.0	0.00	0.00	0.00	0.00	0.00	0.00
80.0-90.0	0.00	0.00	0.00	0.00	0.00	0.00
90.0-100.0	0.00	0.00	0.00	0.00	0.00	0.00
100.0-150.0	0.00	0.00	0.00	0.00	0.00	0.00
mean diameter, μm	2.04	1.81	1.95	1.81	1.79	1.78

Table 22. Particle Size - Local % of Precipitated
Particles in a Range of Diameters -
Ferrous Sulfate/NaOH

Range, μm	pH 6	pH 7	pH 8
*****	*****	*****	*****
0.0-1.0	74.11	53.89	80.02
1.0-2.0	22.09	33.30	11.53
2.0-3.0	1.59	4.95	2.98
3.0-4.0	0.75	2.56	1.90
4.0-5.0	0.60	1.70	1.12
5.0-6.0	0.27	1.03	0.66
6.0-7.0	0.22	0.65	0.36
7.0-8.0	0.09	0.37	0.23
8.0-9.0	0.06	0.26	0.20
9.0-10.0	0.04	0.19	0.12
10.0-20.0	0.16	0.85	0.63
20.0-30.0	0.03	0.15	0.14
30.0-40.0	0.00	0.05	0.05
40.0-50.0	0.00	0.02	0.02
50.0-60.0	0.00	0.02	0.01
60.0-70.0	0.00	0.02	0.01
70.0-80.0	0.00	0.00	0.00
80.0-90.0	0.00	0.00	0.00
90.0-100.0	0.00	0.00	0.00
100.0-150.0	0.00	0.00	0.00
mean diameter, μm	1.01	1.49	1.21

Table 23. Particle Size - Local % of Particles
Precipitated by NaOH - Ferric Nitrate Present

Range, μm	pH 6	pH 7	pH 8
*****	*****	*****	*****
0.0-1.0	91.38	89.44	48.67
1.0-2.0	5.72	5.53	37.17
2.0-3.0	1.50	1.63	7.53
3.0-4.0	0.71	1.39	2.96
4.0-5.0	0.34	0.77	1.74
5.0-6.0	0.15	0.40	0.59
6.0-7.0	0.07	0.25	0.38
7.0-8.0	0.04	0.12	0.13
8.0-9.0	0.02	0.10	0.12
9.0-10.0	0.02	0.06	0.07
10.0-20.0	0.04	0.26	0.45
20.0-30.0	0.00	0.03	0.12
30.0-40.0	0.00	0.00	0.03
40.0-50.0	0.00	0.00	0.03
50.0-60.0	0.00	0.00	0.01
60.0-70.0	0.00	0.00	0.01
70.0-80.0	0.00	0.00	0.01
80.0-90.0	0.00	0.00	0.00
90.0-100.0	0.00	0.00	0.00
100.0-150.0	0.00	0.00	0.00
mean diameter, μm	0.98	1.46	1.10

Table 24. Particle Size - Local % of Precipitated
Particles in a Range of Diameters -
Aluminum Sulfate/NaOH

Range, μm	pH 6	pH 7	pH 8

0.0-1.0	46.17	75.23	64.66
1.0-2.0	37.37	14.06	19.84
2.0-3.0	8.96	4.67	7.00
3.0-4.0	4.45	2.57	3.94
4.0-5.0	1.67	1.54	2.28
5.0-6.0	0.78	0.80	1.08
6.0-7.0	0.26	0.44	0.50
7.0-8.0	0.14	0.19	0.22
8.0-9.0	0.07	0.12	0.14
9.0-10.0	0.05	0.10	0.09
10.0-20.0	0.07	0.26	0.21
20.0-30.0	0.00	0.02	0.02
30.0-40.0	0.00	0.00	0.00
40.0-50.0	0.00	0.00	0.00
50.0-60.0	0.00	0.00	0.00
60.0-70.0	0.00	0.00	0.00
70.0-80.0	0.00	0.00	0.00
80.0-90.0	0.00	0.00	0.00
90.0-100.0	0.00	0.00	0.00
100.0-150.0	0.00	0.00	0.00
mean diameter, μm	1.40	1.18	1.34

Table 25. Local % of Particles Precipitated by NaOH/Anion Polymers
in a Range of Diameters

Range, μm	A3040L			A3010L		
	pH 6	pH 7	pH 8	pH 6	pH 7	pH 8
0.0-1.0	76.17	70.05	59.92	68.91	59.96	64.10
1.0-2.0	15.68	22.59	28.71	19.42	22.60	26.82
2.0-3.0	4.13	3.13	6.43	5.34	7.77	5.15
3.0-4.0	1.81	1.76	2.41	2.88	4.45	2.15
4.0-5.0	1.13	1.08	1.14	1.73	2.67	0.88
5.0-6.0	0.46	0.50	0.59	0.77	1.22	0.40
6.0-7.0	0.26	0.31	0.30	0.40	0.60	0.20
7.0-8.0	0.12	0.16	0.16	0.19	0.25	0.08
8.0-9.0	0.06	0.08	0.08	0.10	0.16	0.06
9.0-10.0	0.05	0.06	0.05	0.07	0.09	0.04
10.0-20.0	0.13	0.23	0.16	0.16	0.21	0.10
20.0-30.0	0.01	0.04	0.04	0.02	0.01	0.02
30.0-40.0	0.00	0.01	0.01	0.01	0.00	0.00
40.0-50.0	0.00	0.00	0.00	0.00	0.00	0.00
50.0-60.0	0.00	0.00	0.00	0.00	0.00	0.00
60.0-70.0	0.00	0.00	0.00	0.00	0.00	0.00
70.0-80.0	0.00	0.00	0.00	0.00	0.00	0.00
80.0-90.0	0.00	0.00	0.00	0.00	0.00	0.00
90.0-100.0	0.00	0.00	0.00	0.00	0.00	0.00
100.0-150.0	0.00	0.00	0.00	0.00	0.00	0.00
mean diameter, μm	1.08	1.13	1.24	1.22	1.41	1.15

Table 26. Local % of Particles Precipitated by NaOH/Cation Polymers
in a Range of Diameters

Range, μm	K144L			K122L		
	pH 6	pH 7	pH 8	pH 6	pH 7	pH 8
0.0-1.0	47.15	59.39	56.92	72.44	81.63	81.50
1.0-2.0	29.51	27.85	24.12	17.22	11.25	11.02
2.0-3.0	10.29	6.45	8.05	5.08	3.37	3.67
3.0-4.0	6.17	3.41	4.87	2.73	1.66	2.05
4.0-5.0	3.30	1.52	2.90	1.33	0.90	0.78
5.0-6.0	1.63	0.72	1.35	0.65	0.43	0.38
6.0-7.0	0.78	0.32	0.74	0.23	0.25	0.23
7.0-8.0	0.35	0.13	0.34	0.09	0.13	0.12
8.0-9.0	0.21	0.07	0.24	0.07	0.08	0.06
9.0-10.0	0.15	0.03	0.11	0.05	0.05	0.06
10.0-20.0	0.42	0.11	0.35	0.11	0.20	0.11
20.0-30.0	0.03	0.01	0.02	0.01	0.03	0.01
30.0-40.0	0.00	0.00	0.00	0.00	0.01	0.00
40.0-50.0	0.00	0.00	0.00	0.00	0.00	0.00
50.0-60.0	0.00	0.00	0.00	0.00	0.00	0.00
60.0-70.0	0.00	0.00	0.00	0.00	0.00	0.00
70.0-80.0	0.00	0.00	0.00	0.00	0.00	0.00
80.0-90.0	0.00	0.00	0.00	0.00	0.00	0.00
90.0-100.0	0.00	0.00	0.00	0.00	0.00	0.00
100.0-150.0	0.00	0.00	0.00	0.00	0.00	0.00
mean diameter, μm	1.64	1.49	1.27	1.15	1.05	1.04

APPENDIX 4

SETTLING TIMES, SETTLED SOLIDS VOLUME, AND % WATER IN SOLIDS

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Table 27. Precipitate Behavior on pH-Adjustment With NaOH

Approximate pH	Measured pH	Settling Time, min	Final Solids Volume, mL	Air-dried solids, g	Oven-dried H ₂ O in air- solids, g dried solids settled solids	g solids/mL
6	5.95	20	8	0.0148	0.0114	23 1.43E-03
6.5	6.49	51	8	0.0919	0.0125	86 1.56E-03
7	7.04	39	5	0.0896	0.0121	86 2.42E-03
7.5	7.5	31	7	0.0904	0.0131	86 1.87E-03
8	7.95	29	8	0.0933	0.0135	86 1.69E-03
8.5	8.42	23	10	0.0926	0.0133	86 1.33E-03

Table 28. Precipitate Behavior on pH-Adjustment With NaOH and 50 ppm Fe as Ferrous Sulfate

Approximate pH	Measured pH	Settling Time, min	Final Solids Volume, mL	Air-dried solids, g	Oven-dried H ₂ O in air- solids, g dried solids settled solids	g solids/mL
6	5.91	45.5	14	0.0365	0.0305	16 2.18E-03
7	6.96	73.5	19	0.0645	0.0567	12 2.98E-03
8	7.99	63	25	0.0814	0.0702	14 2.81E-03

Table 29. Precipitate Behavior on pH-Adjustment
With NaOH and 15 ppm Fe as Ferric Nitrate

Approximate pH	Measured pH	Settling Time, min	Final Solids Volume, mL	Air-dried solids, g	Oven-dried %H ₂ O in air- dried solids, g	g solids settled solids
6	6	23	15	0.0319	0.0266	16.6 1.77E-03
7	6.93	48	13	0.0326	0.0279	14.4 2.15E-03
8	7.91	40	13	0.0320	0.0269	15.9 2.07E-03

Adjustment With NaOH and 25 ppm Al as Aluminum Sulfate

Approximate pH	Measured pH	Settling Time, min	Final Solids Volume, mL	Air-dried solids, g	Oven-dried %H ₂ O in air- dried solids, g	g solids settled solids
6	5.94	35	10	0.0199	0.0164	17.6 1.64E-03
7	6.96	39	10	0.0198	0.0155	21.7 1.55E-03
8	7.97	45	10	0.0187	0.0156	16.6 1.56E-03

Table 31. Precipitate Behavior on pH-Adjustment With Magnesium Hydroxide

Approximate pH	Measured pH	Settling Time, min	Final Solids Volume, mL	Air-dried solids, g	Oven-dried %H ₂ O in air- dried solids, g	g solids settled solids
6	5.97	39	1	0.0305	0.0278	8.9 2.78E-02
7	7.02	112	5	0.0220	0.0207	5.9 4.14E-03
8	7.77	128	5	0.02572	0.02540	1.2 5.08E-02

Table 32. Precipitate Behavior on pH-Adjustment With NaOH and Four Polymer Flocculating Agents

A3040L Anionic Polymer

Approximate pH	Measured pH	Settling Time, min	Final Solids Volume, mL	Air-dried solids, g	Oven-dried solids, g	H ₂ O in air- dried solids	g solids/ mL settled solids
6	5.96	19.5	8	0.0163	0.0143	12.3	1.79E-03
7	7.05	52	8	0.0141	0.0113	19.9	1.41E-03
8	8	34	9	0.0147	0.0123	16.3	1.37E-03

A3010L Anionic Polymer

Approximate pH	Measured pH	Settling Time, min	Final Solids Volume, mL	Air-dried solids, g	Oven-dried solids, g	H ₂ O in air- dried solids	g solids/ mL settled solids
6	5.98	22.5	9	0.0131	0.0103	21.4	1.14E-03
7	6.96	61	9	0.0144	0.0109	24.3	1.21E-03
8	8	36	10	0.0136	0.0118	13.2	1.18E-03

K122L Cationic Polymer

Approximate pH	Measured pH	Settling Time, min	Final Solids Volume, mL	Air-dried solids, g	Oven-dried solids, g	H ₂ O in air- dried solids	g solids/ mL settled solids
6	6.03	22	9	0.0173	0.0138	20.2	1.53E-03
7	7.03	34	9	0.0172	0.0145	15.7	1.61E-03
8	8.01	28	10	0.0184	0.0157	14.7	1.57E-03

K144L Cationic Polymer

Approximate pH	Measured pH	Settling Time, min	Final Solids Volume, mL	Air-dried solids, g	Oven-dried solids, g	H ₂ O in air- dried solids	g solids/ mL settled solids
6	6.01	37	10	0.0166	0.0135	18.7	1.35E-03
7	6.93	64	10	0.0166	0.0133	19.9	1.33E-03
8	8	46	10	0.0174	0.0146	16.1	1.46E-03

S.D. FINK
F/H "HOT SPOT"GROUNDWATER TREATABILITY

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August 30, 1993
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