Memorandum

To: File

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Date: August 6, 2009

Subject: Bench-Scale Testing Summary Report

TESTING DESCRIPTION

Bench-scale pilot testing was performed at Sandoval County Well #6 on Saturday, June 13 and Tuesday, June 16, 2009. Bench scale pilot testing was performed prior to the full-scale pilot testing program to determine the recommended chemical dosages to reduce hardness, alkalinity, TDS, and the concentration of specific contaminants. Qualitative observations of water quality, chemical dosage requirements, and well water behavior were made in the field during bench-scale testing. Laboratory analysis of samples taken in the field will be used to verify field observations. As a result of the bench scale testing and water quality analysis, stripping of carbon dioxide, followed by hot lime softening is envisioned as being the preferred method of reducing the hardness and alkalinity of the raw water before it is treated by an RO system to remove dissolved solids.

Prior to conducting the bench testing, the necessary testing equipment and chemicals were collected, ordered, prepared and packaged. Equipment and chemicals used during the bench scale testing were:

- Six-paddle Phipps & Bird Jarstirrer
- Six B-Ker2 jars
- Hach pH meter, turbidimeter, and alkalinity/hardness test strips for field water quality analysis
- Sodium hydroxide (NaOH) and lime ($Ca(OH)_2$) for pH adjustment and softening
- Ferric chloride ($FeCl_3$), aluminum chlorhydrate (PAC300), and cationic coagulant (Magnifloc368) for coagulation

Field preparation included flushing the water column of the well (approximately 28,400 gallons), setting up the jar test apparatus, ensuring that adequate power for the apparatus was available from the inverter power supply, and calibrating equipment. Initial and final totalizing flow meter readings were used to confirm that one full well volume was flushed from the well bore space before any water samples were collected.

Seven bench scale tests were conducted over the course of the two field test dates.

Testing Process

Bench scale testing focused on increasing the pH of the raw water and softening the raw water and determining the dosages of coagulants to reduce hardness and TDS. Activities conducted each day of the bench scale pilot testing were:

- First day- Confirm dosages of caustic soda and lime to achieve target pH ranges and provide softening via the precipitation of divalent cations and to observe the increase of pH of the raw water via rapid mixing to simulate the stripping of carbon dioxide (CO_2)

- Second day- Evaluate coagulant performance. Using the dosages of lime and caustic soda determined in the first day of testing to achieve the target pH values, coagulants were added to further precipitate dissolved materials. Floc formation and settling rates were observed to refine pH target dosages.

Coagulation experiments included varying dosages of ferric chloride, aluminum chlorhydrate (ACH), and cationic polymer and observing floc formation, settling rates, and the quality of settled materials and supernatant water. Water quality samples were collected from select experiments for laboratory analysis.

Stripping of carbon dioxide (CO_2) to raise the pH of the water was evaluated in four of the seven tests. CO_2 stripping was achieved via rapid mixing of the test jars at 300 RPM and observing pH and temperature changes.

DETAILED TEST DISCUSSION AND FIELD OBSERVATIONS

In Test 0, raw well water was collected in jars and stirred rapidly at 300 RPM to simulate stripping of CO_2. A timer was set and the pH and temperature of the water were recorded at regular intervals for approximately 20 minutes and measurements were made until the raw water pH equalized. CO_2 stripping is not expected to take 20 minutes at the pilot- or full-scale process. During testing, raw water pH raised from 6.58 at t=0 to 7.79 at t=17 min. Water temperature decreased from 49.5°C to 42.9°C at t=17 min and further dropped throughout testing. Subsequent CO2 stripping experiments were conducted to provide test water for later tests.

In Test 1, either sodium hydroxide or lime was added to raw well water to achieve target pH values of 10, 10.5, and 11.0 for the sodium hydroxide and 10 and 10.5 for the lime. Dosages to achieve these target pH values were 2625 mg/L, 2875 mg/L, and 3125 mg/L respectively for sodium hydroxide and 2875 and 3125 mg/L respectively for the lime. Settling characteristics for this test were all within 5-8 minutes, with no noticeable difference in settling rates or floc formation. General water quality lab analysis samples were collected.

Test 1-Precipitation Without CO2 Stripping					
Jar No.	Chemical Used	Dose mg/L	Initial pH	Target pH	Final pH
1	NaOH	2,625	6.45	10.0	10.31
2	NaOH	2,875	6.45	10.5	10.64
3	NaOH	3,125	6.45	11.0	11.18
4	Ca(OH)2	2,875	6.45	10.5	10.66
5	Ca(OH)2	3,125	6.45	11.0	11.29

In Test 2, lime was added to CO_2 stripped water to achieve target pH values of 9.5, 10, 10.3, 10.6, and 11.0. CO_2 stripping was conducted for 10 min and the pH increased from 6.51 at t=0 to 7.22 at t=10 min. Following stripping, lime addition was performed and dosages of lime ranged from 1500 mg/L to 2200 mg/L to achieve the target pH values. Settling was fastest in the pH 11.0 jar while the slowest was in the pH 10.3 jar. Floc formation was consistently 0.1mm pin floc for all jars. General water quality lab analysis samples were collected including two samples for arsenic speciation.

Test 2-Lime Precipitation with CO2 Stripping						
Jar No.	Chemical Used	Dose mg/L	Initial pH	Target pH	Final pH	Settling Time, min
1	Ca(OH)2	1500	7.4	9.5	9.69	5
2	Ca(OH)2	1750	7.4	10.0	10.27	6
3	Ca(OH)2	1940	7.4	10.3	10.43	8+
4	Ca(OH)2	2025	7.4	10.6	10.67	5
5	Ca(OH)2	2215	7.4	11.0	11.02	2

In Test 3, the CO_2 stripped water from Test 0 was used. Caustic soda was added to increase the pH to target pH values of 9.5, 10, 10.5 and 11. Chemical dosages to achieve these pH targets were between 875, 1065, 1375, and 1500 mg/ respectively. Settling time was approximately 4 minutes to achieve complete settling. General water quality lab analysis samples were collected including one sample for arsenic speciation.

Test 3-Caustic Soda Precipitation with CO2 Stripping						
Jar No.	Chemical Used	Dose mg/L	Initial pH	Target pH	Final pH	Settling Time, min
1	NaOH	13	7.5			NA
2	NaOH	65	7.5			NA
3	NaOH	875	7.5	9.5	9.55	4
4	NaOH	1065	7.5	10.0	10.1	4
5	NaOH	1375	7.5	10.5	10.6	4
6	NaOH	1500	7.5	11.0	10.9	4

In Test 4, ferric chloride was added to CO_2 stripped water at dosages ranging from 0 to 50 mg/L. Visible floc formed in the 25 mg/L, 35 mg/L and 50 mg/L jars, with the 50mg/L jar settling fastest, but the settling time was still nearly 20 minutes. No lab samples were analyzed for this test as this was not a productive experiment for hardness removal as the pH was not increased to promote precipitation softening.

Test 4-Ferric Chloride Coagulation with CO2 Stripping					
Jar No.	Chemical Used	Dose, mg/L	Initial pH	Final pH	Settling Time, min
1	FeCl3	0	7.08	7.26	NA
2	FeCl3	10	7.08	7.16	>20
3	FeCl3	25	7.08	7.22	20
4	FeCl3	35	7.08	7.1	<20
5	FeCl3	50	7.08	6.94	<20

In Test 5, ferric chloride and ACH were added to raw well water (non-CO_2 stripped). No floc formation or settling was observed at the initial dosages of 25 and 50 mg/L of ferric chloride or at dosages of 10 to 50 mg/L of ACH. Dosages were increased to 50 mg/L of each coagulant then the pH of the ACH sample was adjusted to approximately 9.0 (750 mg/L NaOH). A full suite of lab samples were collected for the ACH test.

Test 5- Ferric Chloride Coagulation without CO2 Stripping						
Jar No.	Chemical Used	Dose mg/L	Initial pH	Intermediate pH	Target and Final pH	Chemical and Dose, mg/L
1	FeCl3	25	6.55	6.81	NA	--
2	FeCl3	50	6.55	6.67	NA	--
3	ACH	10	6.55	6.91	NA	--
4	ACH	25	6.55	6.85	NA	--
5	ACH	50	6.55	6.92	9.0	NaOH, 750

In Test 6, the cationic coagulant (M368) was added to raw well water (not CO_2 stripped) at dosages ranging from 10-40 mg/L. Observed settling was best at 30 mg/L so a 6L sample was prepared at this dose and pH adjusted to approximately 10.4 (NaOH dose of 1,750 mg/L). This combination of chemicals and pH provided a readily settleable floc with a precipitate that was stable and easy to decant. Lab samples were collected for full analysis.

Test 6- Magnifloc Coagulation without CO2 Stripping						
Jar No.	Chemical Used	Dose mg/L	Initial pH	Intermediate pH	Final pH	Chemical and Dose, mg/L
2	M358	10	6.58	6.64		--
3	M358	20	6.58	6.65		--
4	M358	30	6.58	6.64	10.4	NaOH, 750
5	M358	40	6.58	6.62		--

In Test 7, a two stage chemical addition scheme was evaluated. First, 10 mg/L of M368 and a NaOH dose of 1,250 mg/L were added to achieve a target pH between 9.5 and 10.0. This sample was mixed and allowed to settle, and then the clarified water was decanted from the precipitate into clean mixing jars. 50 mg/L of ferric chloride was then added, mixed and allowed to settle. Noticeable floc was formed and settling in both stages was complete within 5-8 minutes. A lab sample was collected for full analysis.

Test 7-Two-Stage Precipitation and Coagulation, with CO2 Stripping								
Jar No.	Chemical Used	Dose mg/L	Initial pH	Intermediate pH	Chemical Used	Dose, mg/L	Final pH	Settling Time
1	M358 NaOH	10 1250	6.58	9.80, with NaOH addition	FeCl3	50	9.55	5-8 min

PRELIMINARY CONCLUSIONS

The bench scale pilot testing showed that stripping CO_2 from the raw well water is very effective at increasing pH and may be a necessary step for hardness removal if lime softening is used. Bench scale testing also showed that adding a coagulant aid polymer (M358) while increasing pH with caustic soda produced an excellent floc that settled rapidly and formed a dense precipitate, which are both beneficial to chemical precipitation.

The quantities of lime and caustic soda required to achieve target pH values were greater than previously predicted in an aqueous geochemistry (pHREEQ) software model. The discrepancy may be due to interfering ions and less than expected increase in pH through CO_2 stripping.

Bench testing also showed that ferric chloride was very effective in forming precipitates that can be removed via filtration. Aluminum chlorhydrate, however, was not effective at floc formation at the dosages and pH ranges that were evaluated.

WATER QUALITY EVALUATION

Samples were collected in the field and sent to a laboratory for water quality analysis to supplement and confirm field observations. The following parameters were tested in the laboratory:

- Metals: Calcium, magnesium, arsenic (including speciation), iron, and silica (measured as silicon)
- Anions: Sulfate
- General Parameters: Alkalinity (including bicarbonate and carbonate) and total dissolved solids(TDS)
- Radionuclides: U-238, gross alpha particles, gross beta emmiters, Ra-226, Ra-228

These parameters were selected because they represent the major treatment objectives for pilot testing for this project. The change in these water quality parameters based on variations in chemical dosage during jar testing will help to determine starting dosages for the pilot- scale experiments. Laboratory analysis results are presented below. The quality of the raw water is also presented as a reference.

Laboratory analysis of water quality parameters- Bench testing 6/13 and 6/16/2009

Sample ID	Test Description	Date	Time	Lab ID	Sulfate mg/L	Alk, total mg/L as CaCO3	Carbonate mg/L as CaCO3	Bicarbonate mg/L as CaCO3	Hydroxide mg/L as CaCO3	TDS mg/L	Ca mg/L	Mg mg/L	As, tot mg/L	As(III) mg/L	As(V) mg/L	Fe mg/L	Si mg/L	U-238 ug/L	Gross Alpha pCi/L	Precision (+/-)	Gross Beta pCi/L	Precision (+/-)	Ra-226 pCi/L	Precision (+/-)	Ra-228 pCi/L	Precision (+/-)
	Typical Well 6 Raw Water (11/20/07)				4400	1800	0	1800		12000	450	97	0.634			3.3	15	0.002	209	14.8	166	30	35.9	2.2	49.1	1.9
T1J1	NaOH to pH 10.3	6/13/2009	7:00	0906292-01	4300	3600	3200	360		14000	58.3	58.6	0.467			0.17	14.3									
T1J2	NaOH to pH 10.6	6/13/2009	7:00	0906292-02	4100	3600	3500	98		14000	25	23.4	0.27			0.18	9.1									
T1J3	NaOH to pH 11.2	6/13/2009	7:00	0906292-03	4200	4000	3800	ND	290	15000	6.1	4.1	0.188			ND	8.2									
T1J4	CaOH2 to pH 10.6	6/13/2009	7:00	0906292-04	4000	460	450	ND		11000	15.9	22.6	0.319			0.06	13.4									
T1J5	CaOH2 to pH 11.3	6/13/2009	7:00	0906292-05	4000	410	230	ND	180	10000	14.4	1.9	0.307			0.05	12.6									
T2J1	CaOH2 to pH 9.7 CO2 Stripped	6/13/2009	4:40	0906292-06	4100	650	430	230		11000	22.1	65.9	0.453	0.346	0.107	0.1	17.8									
T2J2	CaOH2 to pH 10.3 CO2 Stripped	6/13/2009	4:40	0906292-07	4200	530	460	70		11000	26	39.3	0.304			0.22	12.9									
T2J3	CaOH2 to pH 10.4 CO2 Stripped	6/13/2009	4:40	0906292-08	4200	460	420	45		11000	27	27.4	0.274	0.241	0.032	0.06	11.4									
T2J4	CaOH2 to pH 10.7 CO2 Stripped	6/13/2009	4:40	0906292-09	4300	410	400	ND		11000	13.8	12.6	0.229			0.39	12.5									
T2J5	CaOH2 to pH 11.0 CO2 Stripped	6/13/2009	4:40	0906292-10	4000	390	310	ND	82	11000	11	2.7	0.234			0.04	12.3									
T3J3	NaOH to pH 9.5 CO2 Stripped	6/13/2009	1:30	0906292-11	4200	1800	850	950		13000	39.3	88.2	0.493			0.36	17.6									
T3J4	NaOH to pH 10.0 CO2 Stripped	6/13/2009	1:30	0906292-12	4300	2000	1500	480		13000	39.2	85.8	0.529			0.92	17.9									
T3J5	NaOH to pH 10.5 CO2 Stripped	6/13/2009	1:30	0906292-13	4300	2200	2000	190		12000	21	69.7	0.465	0.329	0.135	0.05	16.5									
T3J6	NaOH to pH 11.0 CO2 Stripped	6/13/2009	1:30	0906292-14	4200	2400	2400	60		14000	32.1	26.4	0.264			0.06	10.4									
T4J1	Raw Water, CO2 Stripped	6/16/2009	11:40	0906344-01	4400	1800	ND	1800		13000	441	94.4	0.645	0.366	0.28	2.97	16.2									
T5J2	FeCl3 at 50 mg/L, pH 6.7	6/16/2009	13:45															ND	-11.29	20.1	92.7	22.9	16.7	3.69	4.26	0.998
T5J5	ACH at 50 mg/L, pH 9.0	6/16/2009	14:45	0906344-07	4300	1700	380	1300		13000	30.7	90.3	0.451	0.241	0.209	1.13	16	ND	1.07	16.6	48	17.9	3.01	1.03	0.984	0.423
T6J4	M358 at 30 mg/L, pH 10.4	6/16/2009	16:30	0906344-08	4300	2600	2000	560		13000	58.9	65.5	0.415			0.09	14.4	ND	-2.958	17.8	74	19.7	1.38	0.718	0.435	0.311
T7J1	M358 at 10 mg/L, FeCl3 at 50 mg/L, pH 9.55	6/16/2009	17:30	0906344-09	4200	1900	700	1200		13000	17.3	65.1	0.173	0.095	0.078	1.18	9	ND	-3.751	21.4	58.8	18.1	0.533	0.425	0.483	0.348

GENERAL CHEMISTRY RESULTS

Sulfate was not significantly reduced in the softening process. This was expected as sulfate is a divalent anion that would typically be reduced in an ion exchange process or in the RO process. Raw water sulfate is 4,400 mg/L and the lab samples following bench testing were in the range of 4,000-4,400 mg/L.

As expected, TDS was also not significantly reduced during bench testing. Minor reductions in TDS were observed in lime softening experiments at the highest pH range, due to the significant reduction in alkalinity and carbonates. However, reduction of TDS was not an objective of bench testing.

Alkalinity was reduced significantly when lime was used to increase the solution pH. Adding lime reduced the alkalinity from 1800 mg/L to 400-600 mg/L. Caustic soda was used to increase pH; however, it also increased alkalinity to 3600-4,000 mg/L. For reducing alkalinity, lime softening was more effective than precipitation with caustic soda, which actually increased alkalinity.

Hardness, as indicated by concentration of calcium and magnesium ions, was reduced significantly with an increase in pH. The concentration of calcium in the raw water is approximately 450 mg/L and was reduced to within a range of 6-60 mg/L. The most effective doses were adding caustic soda to a pH of 11.2 to reduce the concentration to 6.1 mg/L Ca in T1J3 and adding lime to a pH of 11.0 reduced the concentration to 11 mg/L Ca in T2J5. Magnesium concentration in the raw water is approximately 97 mg/L, treated water was in the range of 2-90 mg/L Mg. The most effective Mg removal was lime addition to pH exceeding 11.0 as shown in T1J5 and T2J5.

ARSENIC REMOVAL RESULTS

Arsenic concentration was reduced from 0.63 mg/L in the raw well water to a range of 0.17 to 0.53 mg/L. The most effective arsenic removal was achieved with coagulation using M358 and ferric chloride, and then pH adjustment to 9.5 with caustic soda in T7J1. Caustic soda was slightly more effective than lime for reduction of arsenic; however there was only a small improvement. On average, 50% of the arsenic was removed by precipitation with caustic soda or lime softening. Approximately 75% of the arsenic was removed by precipitation followed by coagulation with ferric chloride. While precipitation/ softening was effective for the reduction of arsenic, additional steps will be necessary to further lower arsenic to the 0.01 mg/L drinking water standard.

SILICA REMOVAL RESULTS

The reduction of silica (measured as elemental silicon) in bench scale testing was less dramatic than arsenic reduction, showing only 10-40% reductions in silicon concentration. Silica reduction was most effective at the highest pH, with caustic soda being slightly more effective than lime. Raw water silicon concentration is 15 to 16 mg/L. Caustic soda addition to a pH endpoint of 11.2 reduced silicon to 8.2 mg/L in T1J3; while lime addition to a pH endpoint of 11.3 only reduced the silicon to 12.6 mg/L in T1J5. Use of M358 coagulant aid and ferric chloride, then adjusted to a pH endpoint of 9.5 in T7J1, resulted in a silicon concentration of 9.0 mg/L. Silicon reduction is not essential ahead of RO if the RO is operated at a high pH, where silica solubility is highest, however, when operating RO at a pH less than 8, silica concentrations could become a limiting factor for recoveries greater than 90 percent.

RADIONUCLIDE REMOVAL RESULTS

Uranium is not present at elevated levels in the raw water and was not detected in the lab samples from the bench scale testing. Specific treatment consideration for uranium will not be required.

Gross alpha particle removal was extremely effective (99%) during bench testing with the concentration in the raw water of 209±14.9 pCi/L being reduced to 0±17 pCi/L. Ra-226 and Ra-228 are the primary forms of alpha particles and the reduction in concentration of these isotopes during bench testing was 60-

98% for Ra -226 and 90-99% for Ra-228. The ACH was less effective than ferric chloride and the M358 specialty coagulant for reduction of these isotopes. Lab results indicate that coagulation using ferric chloride or M358 will reduce alpha particle and radium isotope concentrations to below drinking water standards.

Beta particle emitters were also reduced during bench testing, however the removal rate was only 30-60%. The concentration in the raw water was reduced from 166 ± 30 pCi/L to a range of 48 to 93 ± 20 pCi/L. Beta particle reduction was most effective using ACH, but the multistage test using both M358 and ferric chloride was nearly as effective. Radium isotopes are also representative of beta particles, however beta particles are a much smaller and less harmful form of radiation, and as such are not regulated under drinking water standards. Reduction of the radium isotopes concentration, as shown in the lab results from bench testing, will also reduce beta particles.

PILOT TREATMENT RECOMMENDATIONS

The jar testing procedures and lab analysis provided guidance to the chemical dosing strategy including chemical types and approximate dosages. As discussed in the preceding paragraphs, for the softening process to be used in pilot testing, stripping of CO_2 reduced the required dosages of lime and caustic soda and also reduced the alkalinity slightly more than water that was not stripped of CO_2. Lime addition reduced alkalinity considerably while the addition of caustic soda increased the alkalinity. Calcium and magnesium hardness were reduced with both lime and caustic soda, as was arsenic. As a result of these observations, lime is the preferred precipitation chemical, with a recommended target pH of 10.5.

Coagulant addition reduced arsenic concentrations by nearly 75% and reduced silica by 40%. Maginfloc358 was more effective than aluminum chlorhydrate when used alone. However, a combination of M358 and ferric chloride were most effective for arsenic and radionuclide reduction. Alpha particles and radium isotopes were reduced to levels less than 50% of drinking water MCLs with coagulation using ferric chloride and M358 and the increase in pH from softening. As a result, the pilot will consider separate removal of arsenic and radio nuclides ahead of the softening process.

The softening process recommended for pilot testing is lime softening to a pH endpoint of 10.5 and coagulation using a low (<10 mg/L) dose of cationic coagulant aid polymer such as Magnifloc358 and ferric chloride at a dose of 50 mg/L. Coagulant doses can be further refined during pilot scale testing to determine the most efficient chemical use.