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APPENDIX

1. PURPOSE/SCOPE OF REPORT

During the spring of 2010, the arsenic treatment system at Well 4 had several instances where the finished water exceeded the Maximum Contaminant Level (MCL) of arsenic at 10 µg/L (ppb). The New Mexico Environment Department (NMED) issued official Notices of Violation to Bernalillo on two occasions, one each for wells 3 and 4, and the agency required a corrective plan to be developed. Thus, the Town of Bernalillo implemented a Corrective Action Plan (CAP) that was proposed to and accepted by NMED for investigations and corrective actions at the water treatment facilities of Wells 3 & 4.

The purpose of this report is to summarize the CAP and the results of the investigations, and to make recommendations for improvements to the water treatment system especially pertaining to the arsenic treatment facilities. This report will include the following components:

a. Purpose/Scope of the report
b. Description of Corrective Action Plan
c. Results of the Investigations
d. Recommendations for future improvements

2. DESCRIPTION OF CORRECTIVE ACTION PLAN

The CAP is included in the Appendix information of this report. In summary, the CAP included the following recommendations for investigations:

a. Augment or replace electro-flocculation system (aluminum coagulant) with ferric chloride as a coagulant for removing arsenic.
b. Replace the media at Well 3 from the zeolite material back to the original sand/anthracite media.
c. Remove the backwash water from the process stream.

3. INVESTIGATIONS IMPLEMENTED

a. Augment/Replace electroflocculation system with ferric chloride

Corrective measures were started following approval of the CAP by NMED on March 29, 2010. The first of which was to augment the electro-flocculation system with ferric chloride to act as a coagulant for removing arsenic. The ferric chloride was injected using a chemical metering pump into the untreated well water. The methodology for improving arsenic removal was to gradually increase the dose of ferric chloride while reducing the amperage of the electro-flocculation system. The dosage of ferric chloride and the electro-flocculation amperage for well 4 investigations is presented in Table 1. A picture of the ferric chloride injection port and pump at well 4 is shown in Figure 1.

Table 1: Sampling Dates with Ferric Chloride Dose and Electro-flocculation Amperage

Stage	Date	FeCl Dose (mg/L)	Electro-flocculation Amperage
1	4/12/10	1.9	130
2	4/21/10	4.5	10
3	4/30/10	3.2	0
4	5/6/10	2.5	0
5	5/24/10	3.2	0
6	6/1/10	2.5	0

Figure 1: Ferric Chloride Injection Port and Pump at Well 4

Data and samples were obtained at about 2 hour intervals for varying amounts of time. The filter runs were initially set at 260,000 gallons between backwashes, as per the previous operations using the ARS equipment. The change to ferric chloride treatment has been shown to allow longer filter runs, greater than 1,000,000 gallons, than previously demonstrated using the electro-flocculation system. Use of ferric chloride-based coagulant has been reported to produce floc particles which are less reactive and more compact than when a ferric-based coagulant is used (Crittenden et. al., 2005). Thus, a process using an aluminum-based coagulant would likely exhibit more rapid breakthrough and be less effective at removing arsenic than a similar process using ferric-based coagulant.

Data was taken for several filtration runs beginning 4/17 and going through 6/1. The results of this investigation at Well 4 are presented in the following section. Several of the sampling results in April and early May were found to be very difficult to explain. After an operational change was made, results were found to follow a more consistent and predictable pattern. All test results are presented below, even those early results which were inconsistent.

4. RESULTS OF INVESTIGATIONS

Well 4: 4/12/10 Sampling

The first water testing event was carried out by WCI on April 17th using stage 1 conditions from Table 1. The arsenic, iron, and aluminum concentrations for the filter influent and effluent over time are shown in Figure 2, Figure 3, and Figure 4, respectively. Arsenic concentrations were reduced from 12.4 ppb to between 4.2 and 10 ppb with an average concentration of 6.6 ppb. After blending 1:1, the arsenic concentration would be about 9.5 ppb. Interestingly, iron concentrations were tightly correlated with arsenic concentrations in the influent water to the pressure filters. Iron was not consistently removed by the pressure filters to concentrations below the maximum contaminant level (MCL) standard of 0.3 ppb. Aluminum concentrations were higher than the MCL standards and were similar in the influent to and the effluent from both pressure filters. A sharp spike occurred in both the iron and arsenic influent concentrations at the end of the testing while backwash water decant was used.

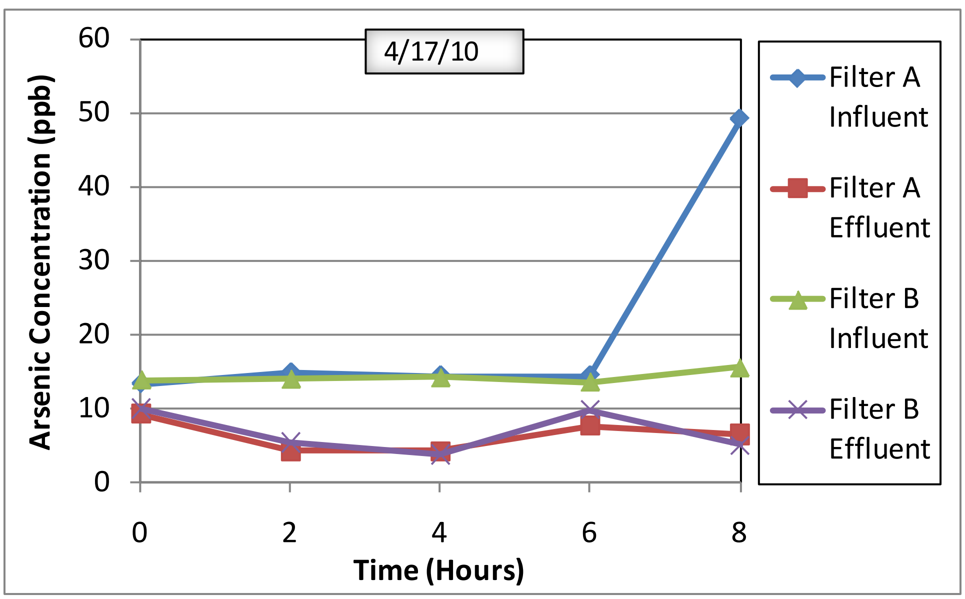


Figure 2: Arsenic Concentration over time for 4/17 Run with Electro-flocculation set at 130 amps and a Ferric Chloride dose of 1.89 mg/L

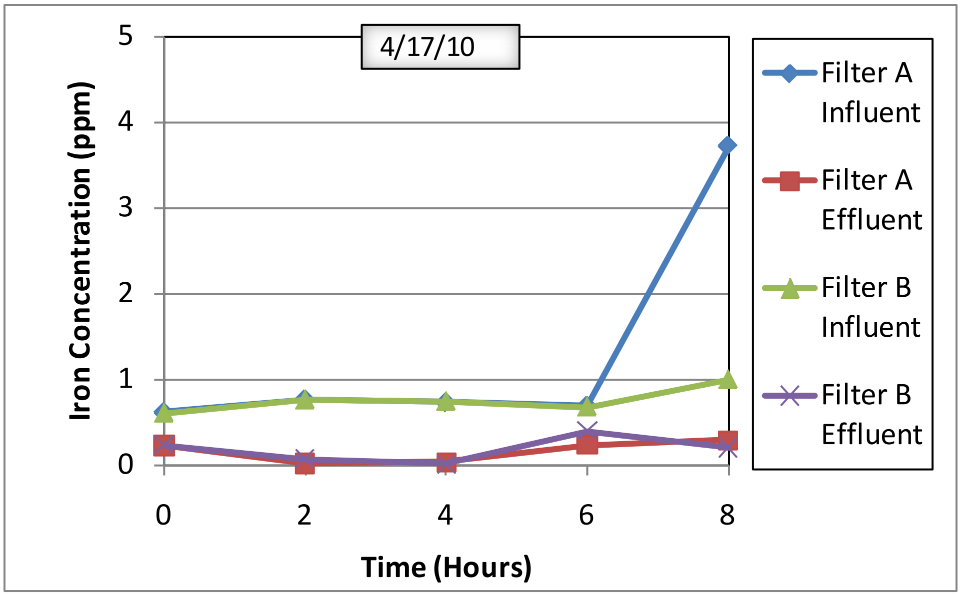


Figure 3: Iron Concentration over time for 4/17 Run with Electro-flocculation set at 130 amps and a Ferric Chloride dose of 1.89 mg/L

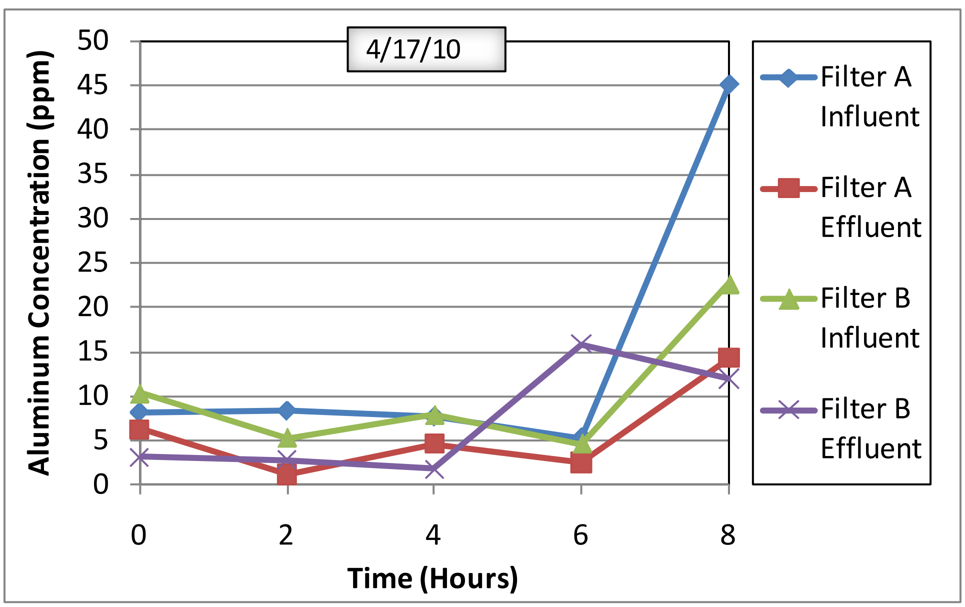


Figure 4: Aluminum Concentration over time for 4/17 Run with Electro-flocculation set at 130 amps and a Ferric Chloride dose of 1.89 mg/L

Well 4: 4/21/10 Sampling

The second water testing event was conducted on April 21st using stage 2 conditions from Table 1. The arsenic, iron, and aluminum concentrations for the filter influent and effluent over time are shown in Figure 5, Figure 6, and Figure 7, respectively. The arsenic concentrations in the filter effluent ranged between 1.15 and 16.1 ppb with an average concentration of 5.3 ppb. As in the previous test, a tight correlation was observed between the influent iron and arsenic concentrations. The sharp spike in both iron and arsenic concentrations at the beginning of the test occurred when backwash decant water was being used. Aluminum concentrations were observed above MCL standards, but were on average approximately 50% lower than the previous test at 130 amps and 1.9 mg/L ferric chloride. Three of the effluent water samples had iron concentrations surpassing the MCL standard.

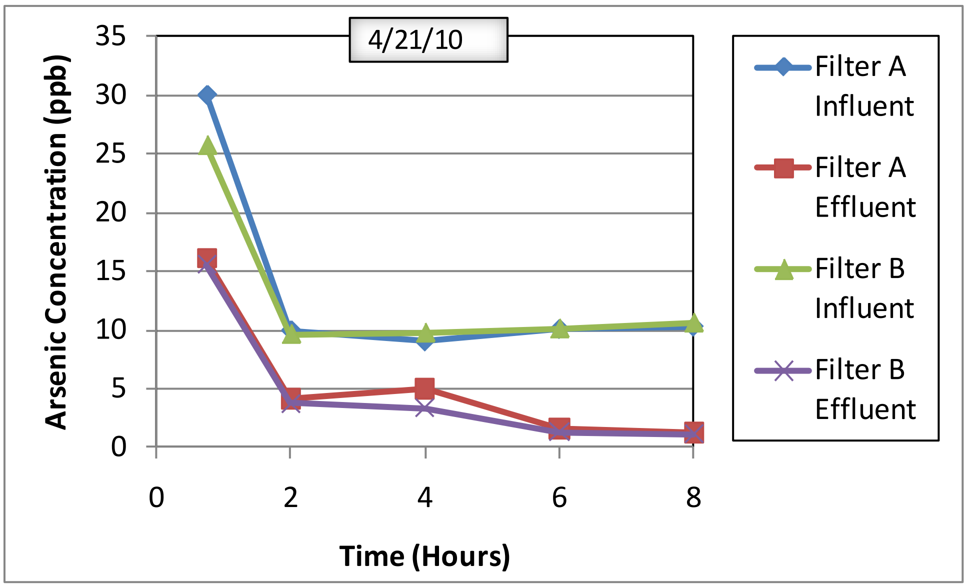


Figure 5: Arsenic Concentration over time for 4/21 Run with Electro-flocculation set at 10 amps and a Ferric Chloride dose of 4.5 mg/L

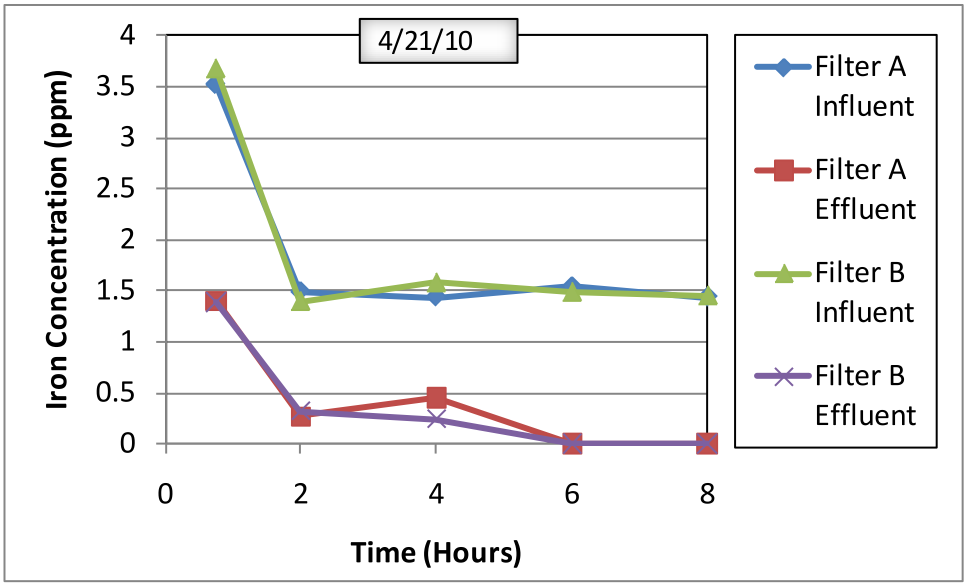


Figure 6: Iron Concentration over time for 4/21 Run with Electro-flocculation set at 10 amps and a Ferric Chloride dose of 4.5 mg/L

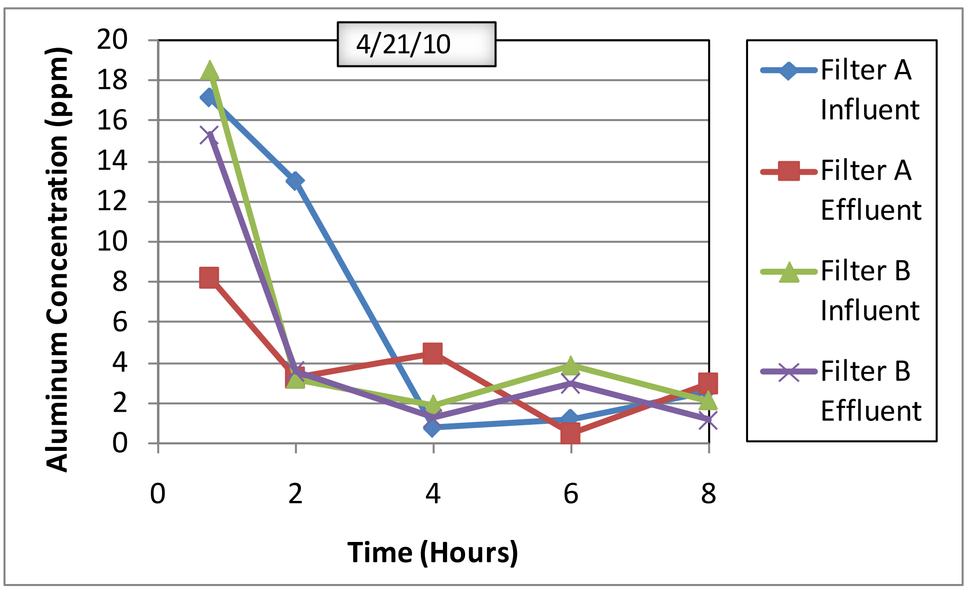


Figure 7: Aluminum Concentration over time for 4/21 Run with Electro-flocculation set at 10 amps and a Ferric Chloride dose of 4.5 mg/L

Well 4: 4/30/10 Sampling

The third water testing event was undertaken on April 30th using stage 3 conditions from Table 1. Power to the electro-flocculation units was completely cut off by turning the amperage to the units to zero on the control panel and turning the breaker to each unit off. For this test, metal concentrations were analyzed with respect to volume of water treated since the last backwash instead of time elapsed since well pumps turned on. The arsenic, iron, and aluminum concentrations for the raw water, filter influent and effluent over volume of water treated are shown in Figure 8, Figure 9, and Figure 10, respectively. Effluent water iron and arsenic concentrations remained below MCL standards until after 450,000 gal treated. Sporadic peaks in aluminum concentration occurred throughout the filter run. These instances of high aluminum concentrations were likely due to residual aluminum hydroxide sloughing off of either the electro-flocculation tanks and/or the piping. After 450,000 gallons treated, spikes in arsenic, iron, and aluminum concentrations were observed in both the filter influent and effluent. These large spikes occurred when backwash decant water was first introduced into the system, as had transpired previously. Because there was never an increase in effluent arsenic and iron concentrations without a corresponding increase in influent iron and arsenic concentrations, filter breakthrough was not shown to have occurred.

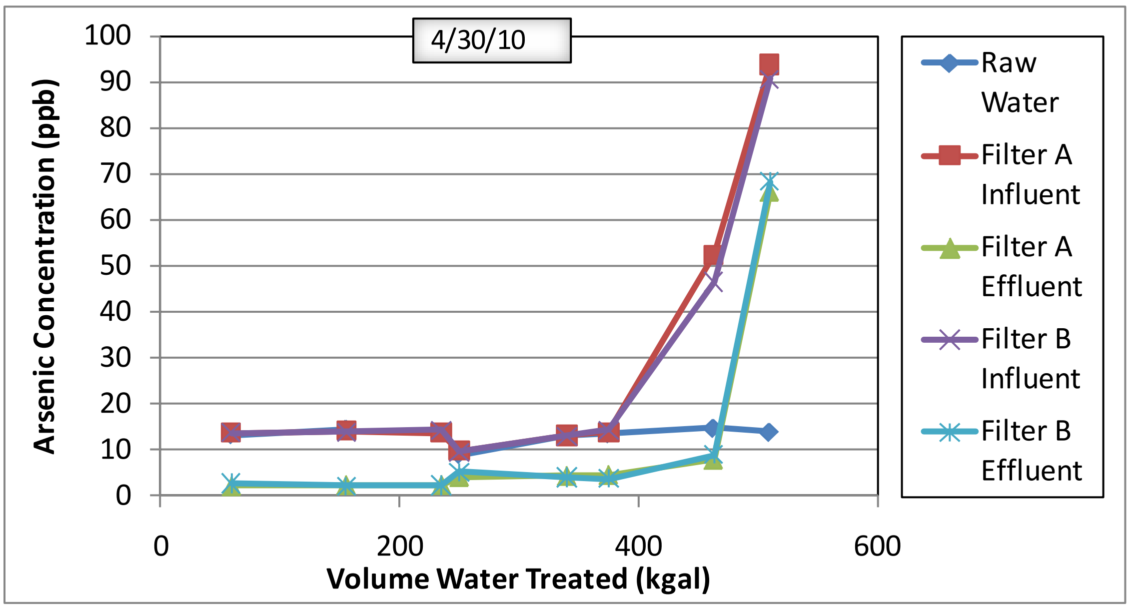


Figure 8: Arsenic Concentration over time for 4/30 Run with no Electro-flocculation and a Ferric Chloride dose of 3.2 mg/L

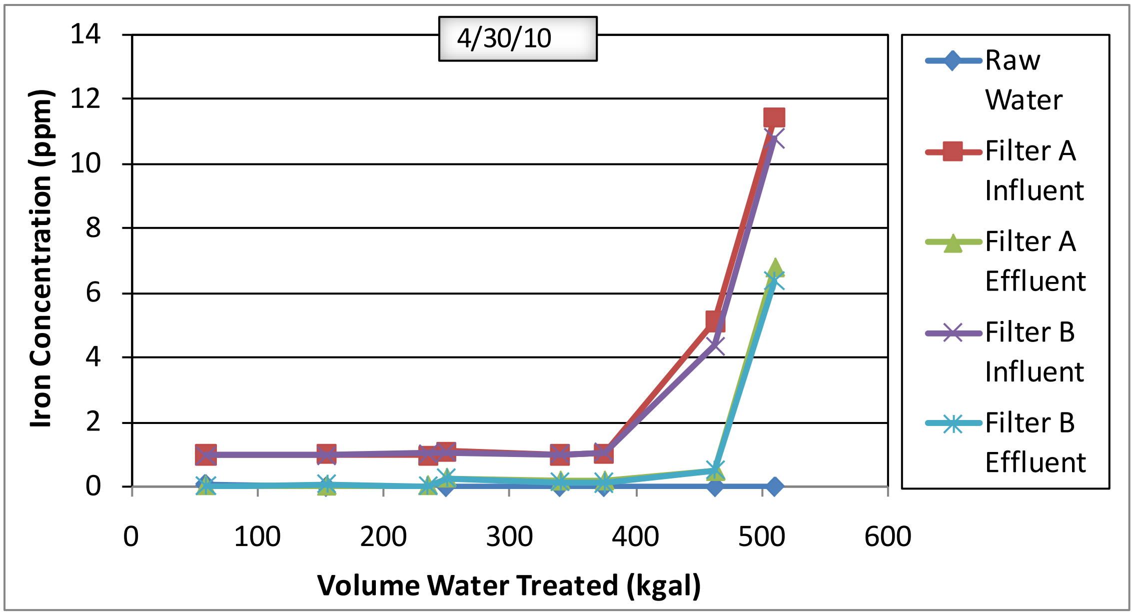


Figure 9: Iron Concentration over time for 4/30 Run with no Electro-flocculation and a Ferric Chloride dose of 3.2 mg/L

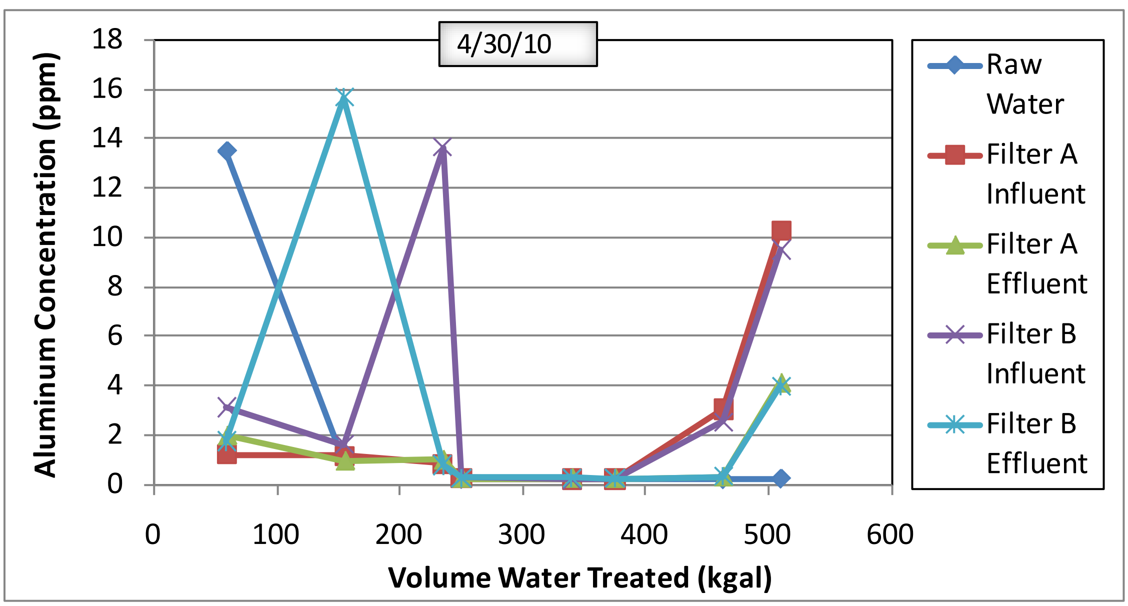


Figure 10: Aluminum Concentration over time for 4/30 Run with no Electro-flocculation and a Ferric Chloride dose of 3.2 mg/L

Well 4: 5/6/10 Sampling

The fourth water testing event happened on May 6th using stage 4 conditions from Table 1. This run was a repetition of the third water testing run, but was run longer to determine when breakthrough occurs during the filter run. The arsenic, iron, and aluminum concentrations for the raw water, filter influent and effluent over volume of water treated are shown in Figure 11,

Figure 12, and Figure 13, respectively. A large spike in arsenic and iron concentrations was measured in the filter influent water, but not in the raw water after 222,000 gallons treated. This corresponded with the introduction of backwash decant water to the system. Another smaller spike in influent iron and arsenic concentration occurred after 600,000 gallons treated. A larger spike was observed in aluminum concentration over this same period. An increase in the pressure drop across the filters was recorded concurrently with a measured increase in arsenic, iron, and aluminum concentrations, indicating filter breakthrough. Due to the consistency in correlation between increased arsenic, iron, and aluminum concentrations in the influent and effluent water samples and backwash decant water use, large concentrations of these metals were suspected in the backwash decant water. Therefore, backwash decant water samples were collected and analyzed along with the influent, effluent, and raw water samples at each time point. Results showed, as expected, that the backwash decant water was many times more concentrated than the raw water in terms of arsenic, iron, and aluminum concentration, especially when first being used in each filter run. One backwash decant water sample had concentrations of 191 ppm iron, 1915 ppb arsenic, and 34 ppm aluminum. Relative to the NMED MCL regulations, that is 637 times greater iron, 192 times greater arsenic, and 113 times greater aluminum.

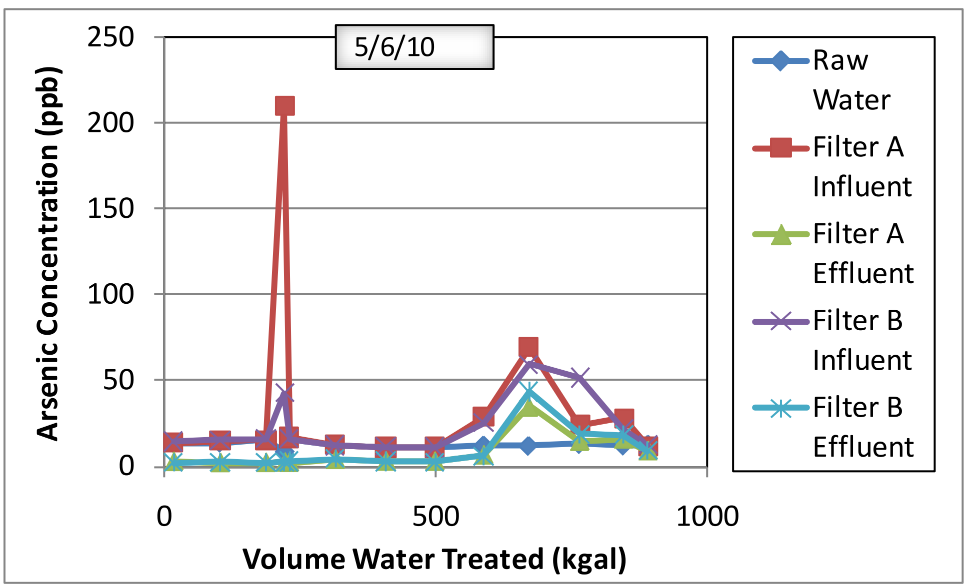


Figure 11: Arsenic Concentration over time for 5/6 Run with no Electro-flocculation and a Ferric Chloride dose of 3.2 mg/L

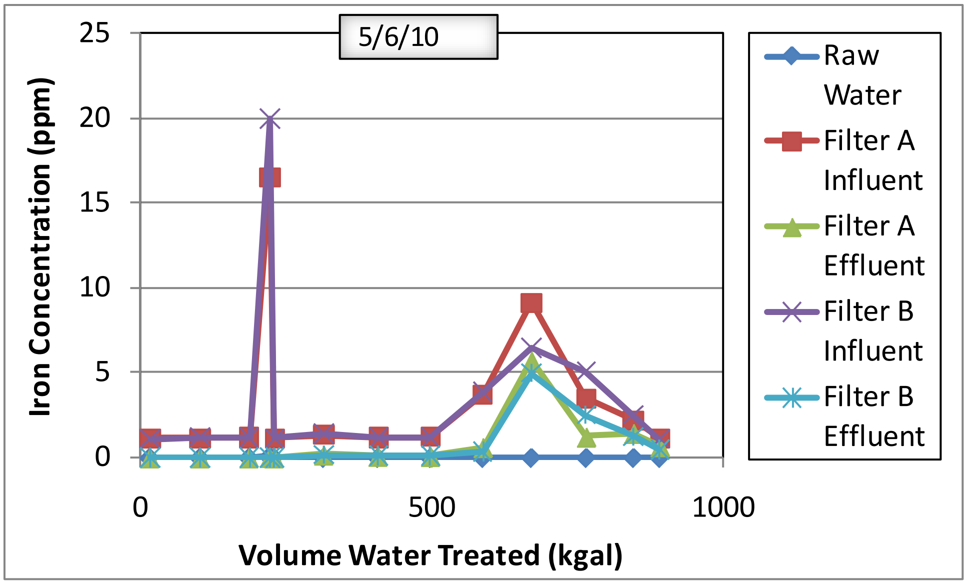


Figure 12: Iron Concentration over time for 5/6 Run with no Electro-flocculation and a Ferric Chloride dose of 3.2 mg/L

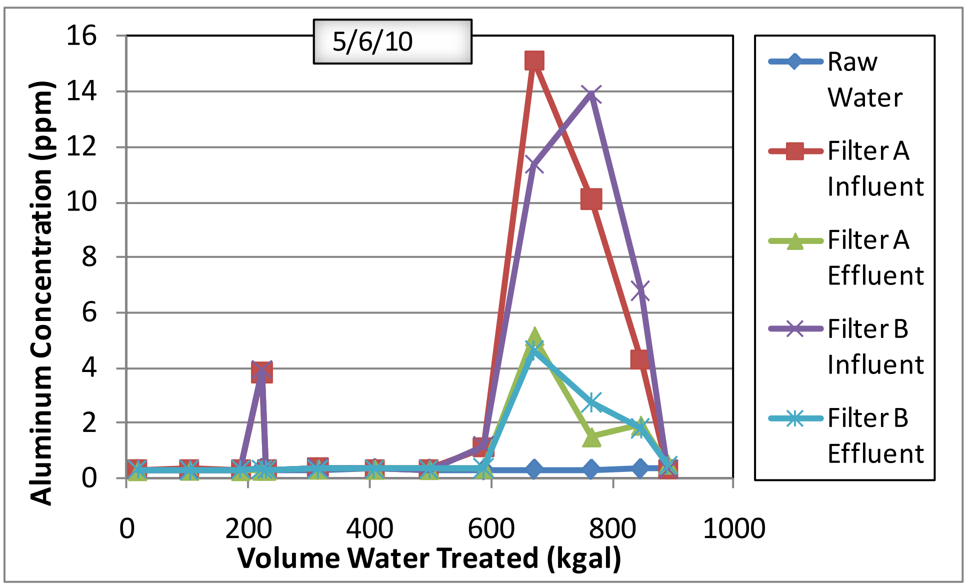


Figure 13: Aluminum Concentration over time for 5/6 Run with no Electro-flocculation and a Ferric Chloride dose of 3.2 mg/L

Backwash

An investigation was done on the backwash system due to the unexpected periodic elevated concentrations observed of all parameters tested. Reuse of backwash decant water is common practice to reduce water waste for water conservation. Given enough time for floc settling, iron and arsenic concentrations in the backwash decant water should be low. The settling time before backwash decant water was used at the Well 4 site was within industry standards. This prompted an investigation of the plant operations, which involved a review of the available plant schematics and discussions with the plant operators. The valve to the bottom of the backwash tank which allowed the settled floc, or sludge, to be pumped to the Sludge Mate trailers for solids disposal was always left open. The valve that allowed the decant water to be gravity fed to a sump inside of the plant which allowed the backwash decant water to be reintroduced to the system was only opened during sludge removal, but closed during normal operations. Thus, the sludge and the decant water were being collected into the Sludge Mate trailers for solids disposal, but only the sludge, and not the decant water, was being reintroduced to the system once the floc had been allowed to settle. This issue was corrected, the plant operators were informed of correct operating procedures with regards this issue, and a protocol was written for operations instruction so the issue would not recur. The sludge removal procedure and process diagram are shown in the appendix. After the plant was operated correctly for one week, another water testing was undertaken at the same ferric dose as the last water testing run, as described below. Removal of the backwash water was thus no longer considered necessary.

Well 4: 5/24/10 Sampling

Once backwash operations were corrected, the fifth water testing event was conducted on May 24th using stage 5 conditions from Table 1. The arsenic, iron, and aluminum concentrations for the raw water, filter influent and effluent over volume of water treated are shown in Figure 14, Figure 15, and Figure 16, respectively. Effluent iron concentrations were always below the detection limit. Effluent arsenic was consistently reduced to between 1.3 and 2.1 ppb with an average of 1.7 ppb. Aluminum concentrations were below the MCL, averaging 0.12 ppm. After blending, the arsenic concentration was about 7.1 ppb, which is well below the MCL of 10 ppb. Even after 900,000 gallons treated, filter breakthrough did not occur nor had the differential pressure across the filter (programming set at 10 psi) been exceeded.

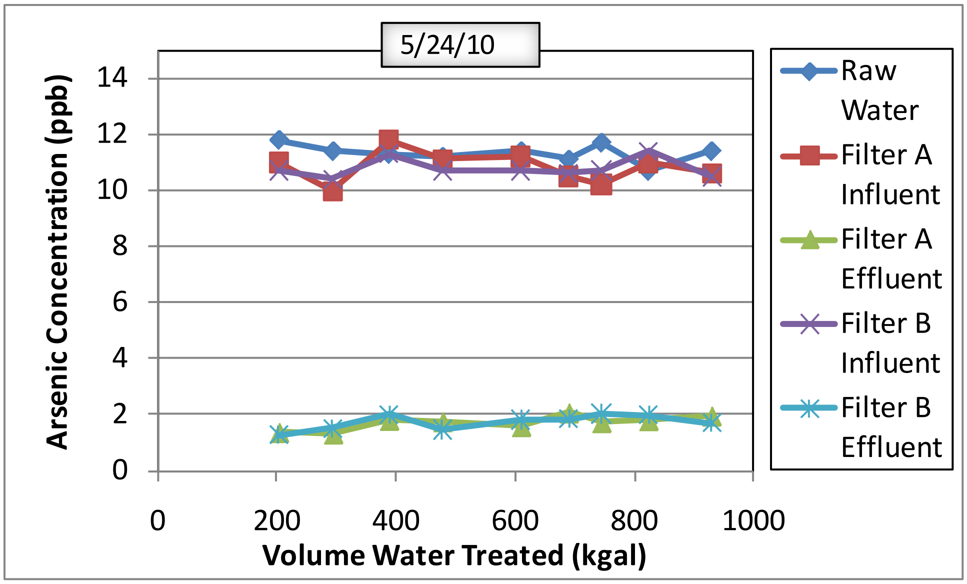


Figure 14: Arsenic Concentration over time for 5/24 Run with no Electro-flocculation and a Ferric Chloride dose of 3.2 mg/L

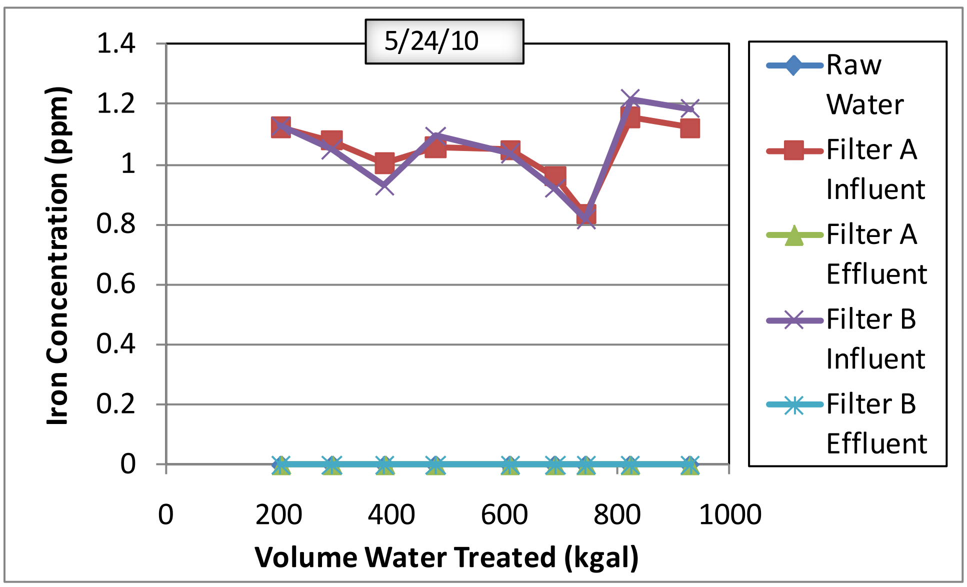


Figure 15: Iron Concentration over time for 5/24 Run with no Electro-flocculation and a Ferric Chloride dose of 3.2 mg/L

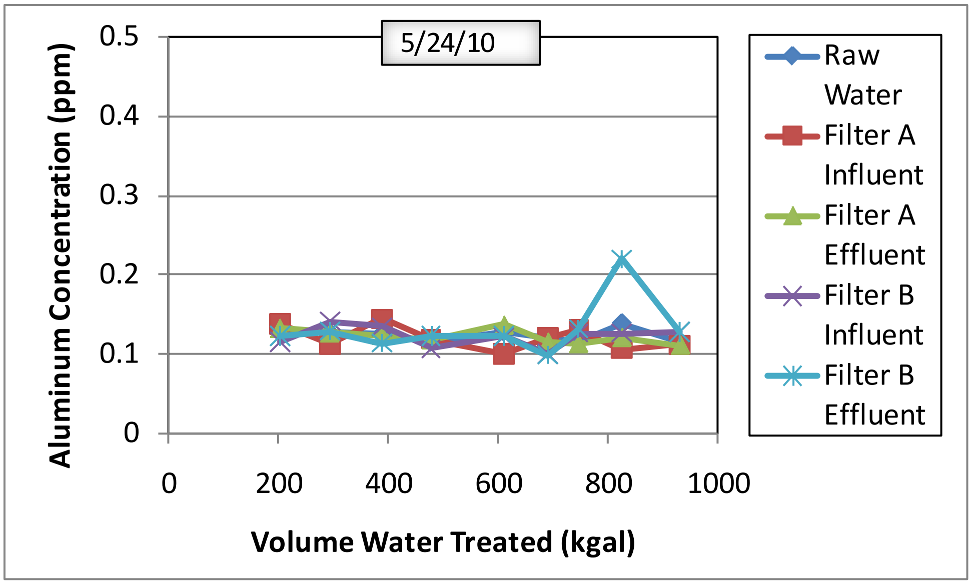


Figure 16: Aluminum Concentration over time for 5/24 Run with no Electro-flocculation and a Ferric Chloride dose of 3.2 mg/L

Well 4: 6/1/10 Sampling

The sixth water testing event was on June 1st using stage 6 conditions from Table 1. The arsenic, iron, and aluminum concentrations for the raw water, filter influent and effluent over volume of water treated are shown in Figure 17, Figure 18, and Figure 19, respectively. Effluent arsenic concentrations ranged from 2.8 to 5.4 ppb, with an average of 3.7 ppb. Effluent iron concentrations remained below the detection limit. Aluminum concentrations were consistently below 0.2ppm, which is safely below the secondary limit. What aluminum was within the system was not a part of the treatment operation since the Electro-flocculation system had been turned off for several months. During the 1.1 million gallon filter run, filter breakthrough did not appear to have occurred.

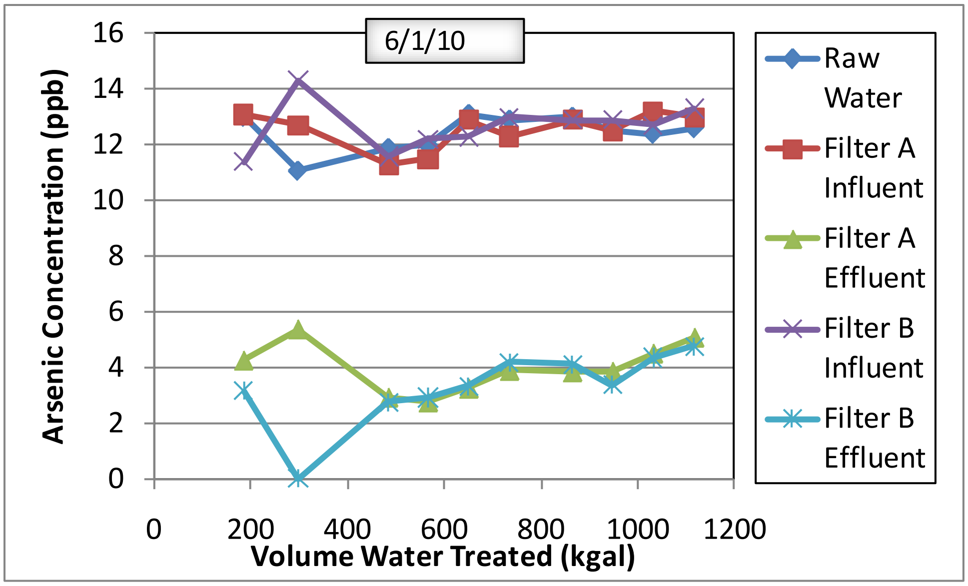


Figure 17: Arsenic Concentration over time for 6/1 Run with no Electro-flocculation and a Ferric Chloride dose of 2.5 mg/L

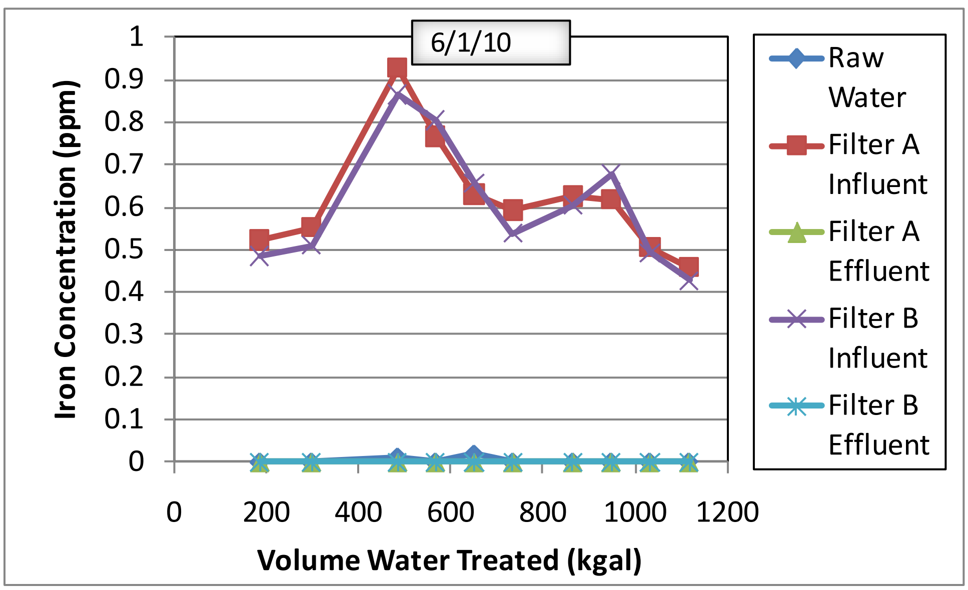


Figure 18: Iron Concentration over time for 6/1 Run with no Electro-flocculation and a Ferric Chloride dose of 2.5 mg/L

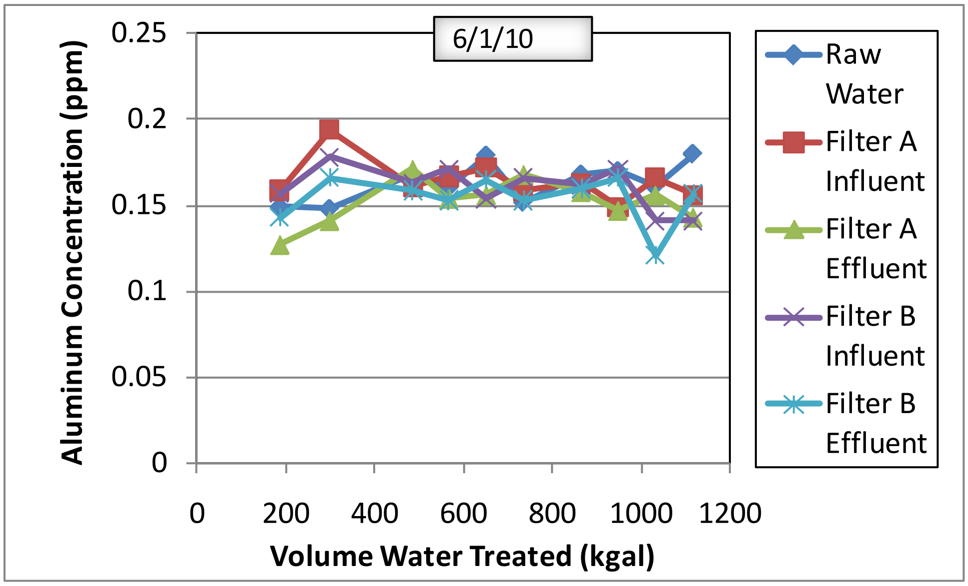


Figure 19: Aluminum Concentration over volume of treated water for 6/1 Run with no Electro-flocculation and a Ferric Chloride dose of 2.5 mg/L

Results of the Investigations at Well 3

The existing well flow rate is approximately 550 GPM and was split between the two pressure filters. Unlike arsenic treatment at Well 4, all of the well water is treated at Well 3. The total volume treated in a run, between backwashes, was set for 200,000 gallons. Unlike Well 4, Well 3 had to be run manually to collect samples.

As the filter runs progressed, the pressure drop across the pressure filters increased more rapidly in Filter B than Filter A, and the flow through filter B was lower than through filter A. By the end of each filter run, the volume through Filter A was therefore greater than through Filter B. The electro-flocculation system was turned off over the duration of all water testing. White precipitate, likely aluminum from when the electro-flocculation system was online, was observed at the bottom of all of the electro-flocculation tanks. Water sampling began on September 8th and continued through September 15th. Water sampling was delayed until this time due to some issues with some of the valves and pumps and a broken chlorine injection regulator. The operator informed WCI of some difficulties with backwashing, possibly due to problems with the pneumatic tank. Between the two sampling runs conducted, an automatic backwash was observed, and no issues were observed.

Well 3: 9/8-9/13 Sampling

The first water testing event was on September 8th through 13th. The ferric chloride dose was set for 2.9 mg/L. The well pump at Well 3 was turned to "hand" mode starting Wednesday September 8th, on Friday September 10th, and again on Monday September 13th. When initially turned on for testing, 95,000 gallons of well water had been treated since the previous backwash. Well 3 was run for a total of 8 hours, during which 100,000 gallons were treated and three sets of samples were collected for analysis. The arsenic, iron, and aluminum concentrations for these samples are presented in **Figure 20**, **Figure 21**, and **Figure 22**, respectively. The average arsenic concentration in the raw water was 20 ppb. After ferric chloride treatment, the arsenic concentration was brought below 10 ppb, with an average of 6.1 ppb. Iron was effectively removed from the ferric chloride treated influent water by the pressure filters to levels near the raw water concentration and below the limit of 0.3 ppm. Aluminum concentrations were consistently lower than the 0.2 mg/L (ppm) limit, and were never measured above 0.01 ppm. However, the aluminum concentrations in the influent and effluent samples were typically higher than the raw water concentrations, for one sample, even three times the concentration of the raw water. This indicates that some of the aluminum previously deposited in the system is being reintroduced into the treated water.

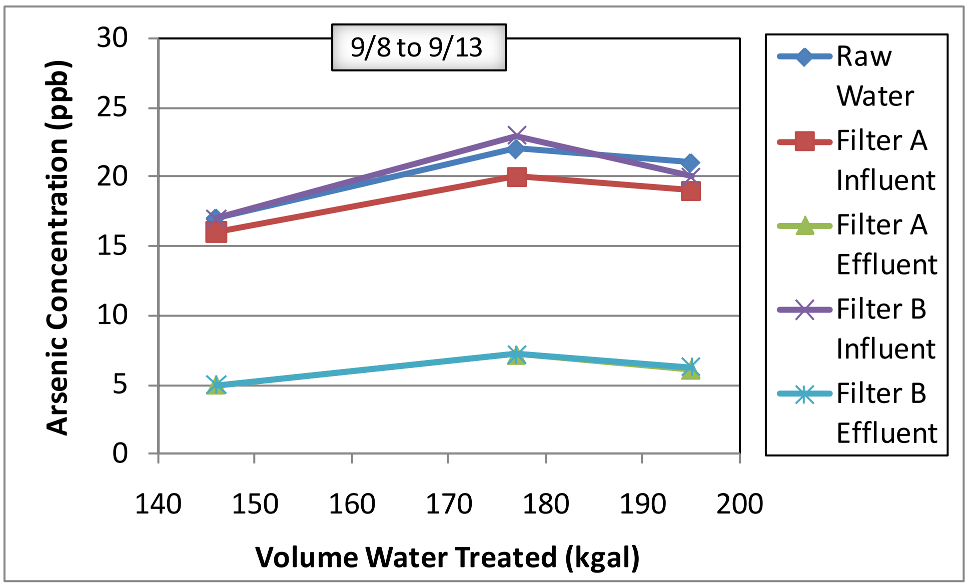


Figure 20: Arsenic Concentrations over Volume of Water Treated for September 8th through 13th with a Ferric Chloride dose of 2.9 mg/L

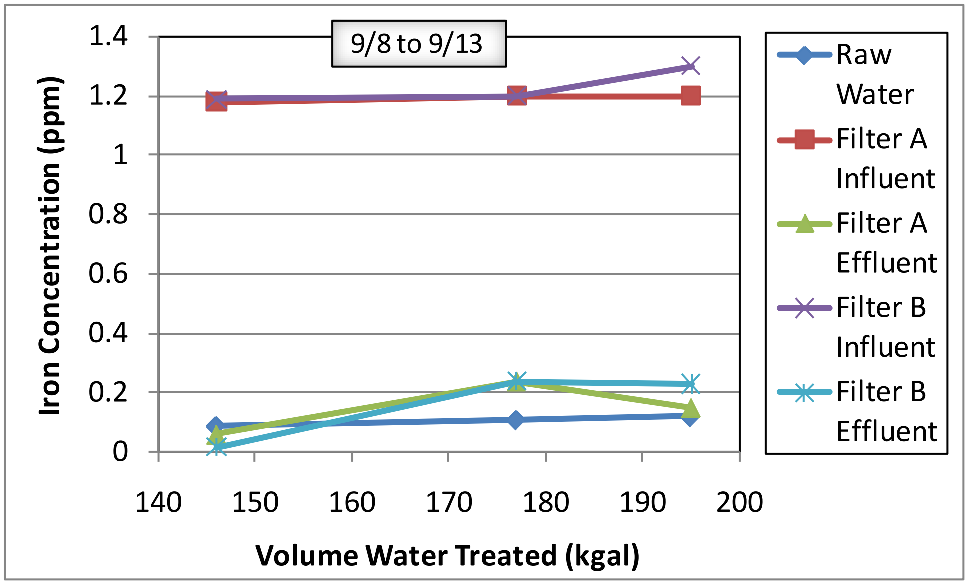


Figure 21: Iron Concentration over Volume of Water Treated for September 8th through 13th with a Ferric Chloride dose of 2.9 mg/L

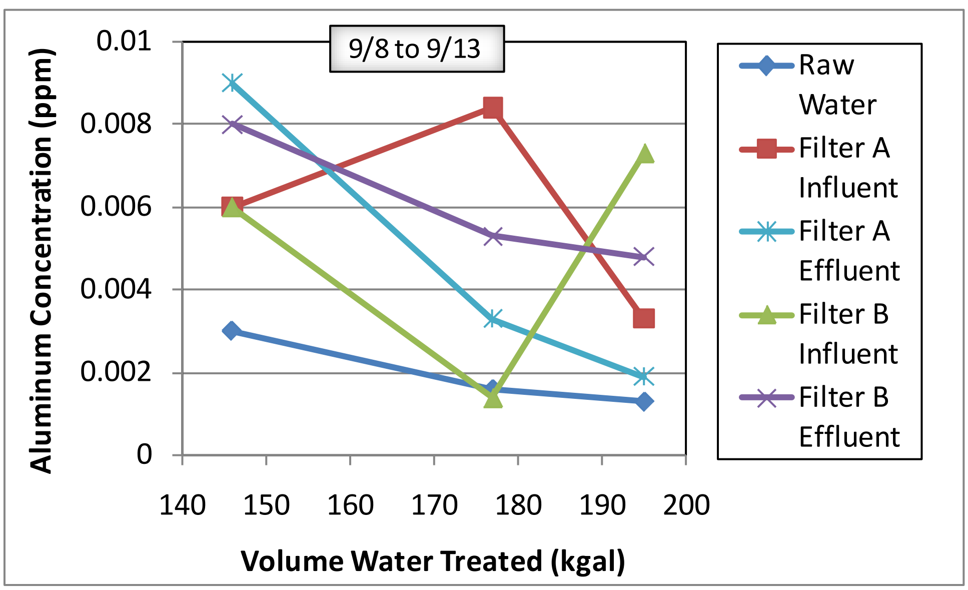


Figure 22: Aluminum Concentration over Volume of Water Treated for September 8th through 13th with a Ferric Chloride dose of 2.9 mg/L

Well 3: 9/14-9/15 Sampling

The second water testing event was on September 14th and 15th. The ferric chloride dose was set for 3.5 mg/L. The well pump at Well 3 was turned to "hand" mode starting Tuesday

September 14th, and again on Wednesday September 15th. When initially turned on for testing, 7,000 gallons of well water had been treated since the previous backwash, according the total volume treated display. Well 3 was run for a total of 10.5 hours, during which 168,000 gallons were treated, according to the total volume treated display, and four sets of samples were collected for analysis. The arsenic, iron, and aluminum concentrations for these samples are presented in **Figure 23**, **Figure 24**, and **Figure 25**, respectively. The average arsenic concentration in the raw water was 20 ppb. After ferric chloride treatment, the arsenic concentration was brought below 10 ppb, with an average of 2.7 ppb. Iron was effectively removed from the ferric chloride treated influent water by the pressure filters to levels below the raw water concentration and below 0.1 ppm, which is 30 percent lower than the iron concentration limit of 0.3 ppm. Aluminum concentrations were consistently lower than the 0.2 ppm limit, and were never measured above 0.03 ppm.

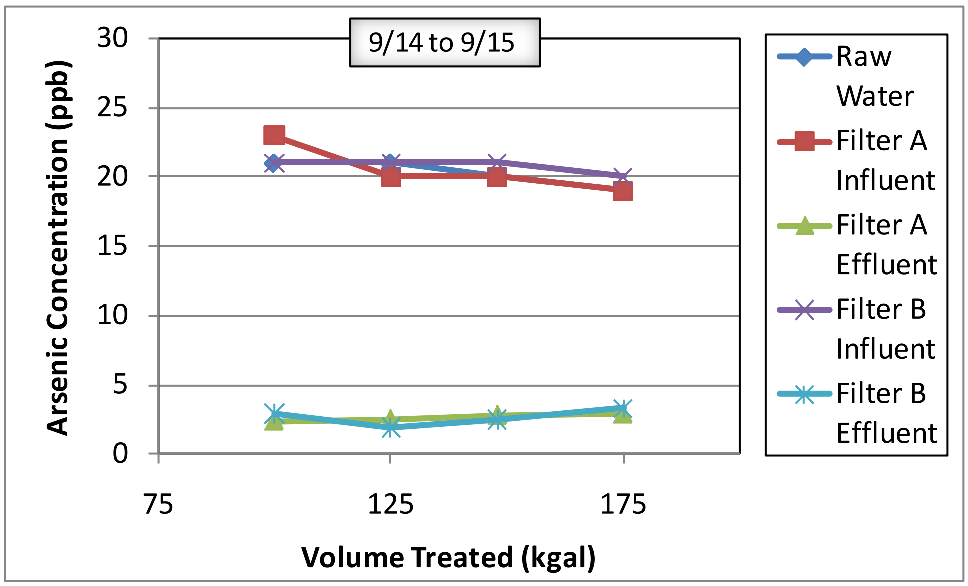


Figure 23: Arsenic Concentrations over Volume of Water Treated for September 14th through 15th with a Ferric Chloride Dose of 3.5 mg/L

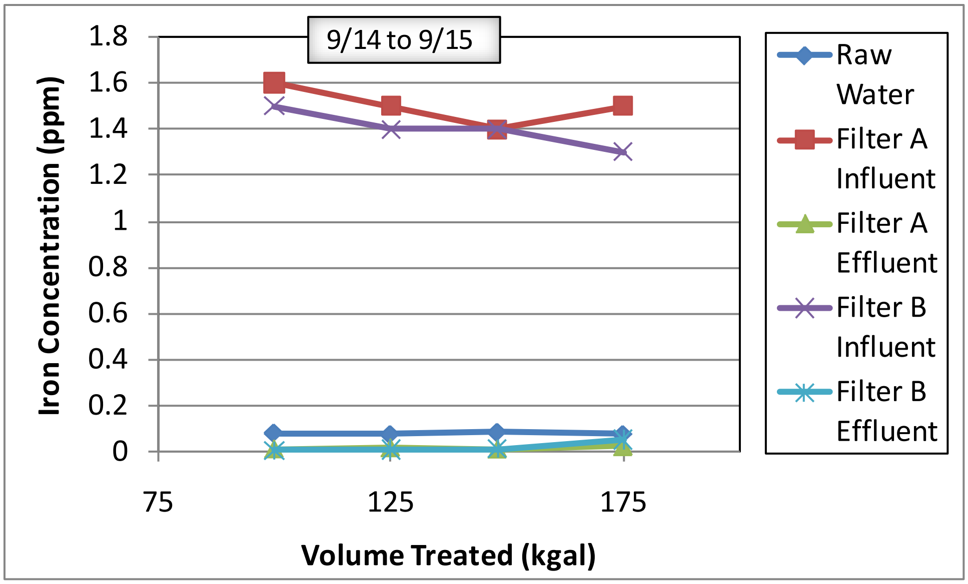


Figure 24: Iron Concentrations over Volume of Water Treated for September 14th through 15th with a Ferric Chloride dose of 3.5 mg/L

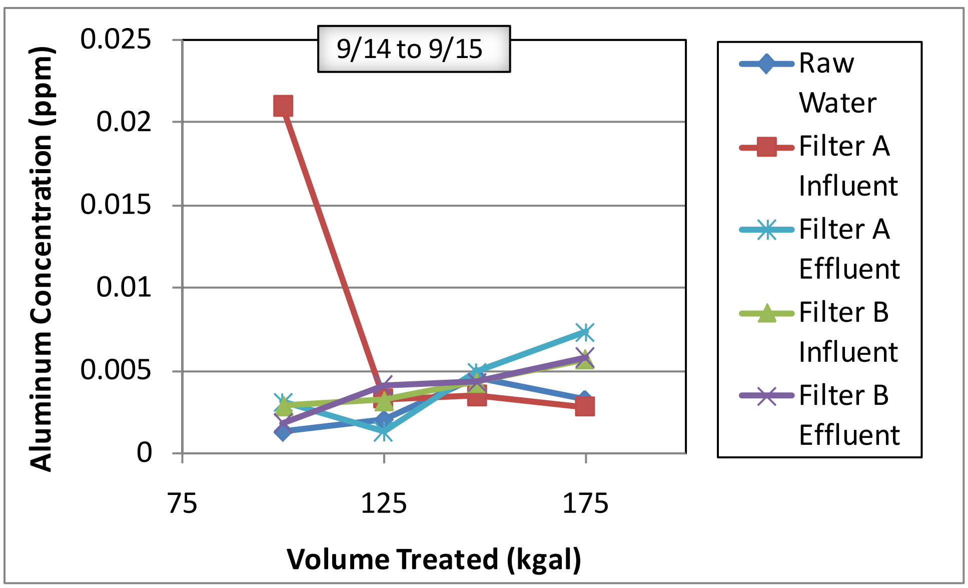


Figure 25: Aluminum Concentrations over Volume of Water Treated for September 14th through 15th with a Ferric Chloride dose of 3.5 mg/L

b. Replace the media at Well 3 from the zeolite material back to the original sand/anthracite media.

The zeolite material was removed and replaced with the original sand/anthracite media at Well 3 was done in early June.

c. Remove the backwash water from the process stream.

Removal of the backwash water from the process stream was suggested when introduction of backwash water decant lead to spikes of all water quality parameters tested. After investigations into the backwash water system revealed operational issues, a process diagram and procedure were made to correct the issues. Once the correct sludge removal procedure was instituted, the backwash water was consistently low with regard to all water quality parameters tested. Removal of the backwash water from the process stream was thus considered unnecessary.

5. CONCLUSIONS OF THE TESTING

The following conclusions were determined after the test results were completed at Well 4 and then verified with operations at Well 3.

1. Ferric Chloride is an effective coagulant for removal of arsenic from well water.
    a. Initially several test runs at Well 4 displayed widely varied results which were difficult to understand. However, after operational changes were made, arsenic removal below the primary drinking water standard was accomplished uniformly and consistently.
    b. Testing at a 2-hour interval demonstrated consistent results through ever-increasing filter runs, up to 1 million gallons treated.
    c. Testing was confirmed with operations at Well 3, which has a slightly different operational configuration and slightly higher raw arsenic amount.

2. Removal of the backwash water from reintroduction to the process flow is not necessary.
    a. Operational changes in manually closing the backwash sludge pump isolation valves eliminated the problem of inconsistent results.
    b. While cumbersome to complete during the testing period, addition of a solenoid valve can make opening of the valves during sludge removal easier. The backwash will therefore not be re-introduced into the process flow.

6. RECOMMENDATIONS FOR FUTURE IMPROVEMENTS

The following recommendations are made for permanent changes at Well 4 and Well 3. These are pertinent to completion of the CAP as well as operations changes within the water facilities in general.

In addition, during the course of testing, the SCADA system, installed for Wells 3 & 4 was found to have lost the Input/Output terminal capabilities due to inoperable components. This must be replaced in order to have communication capabilities with the wells and tanks. These modifications will be verified as the future design unfolds.

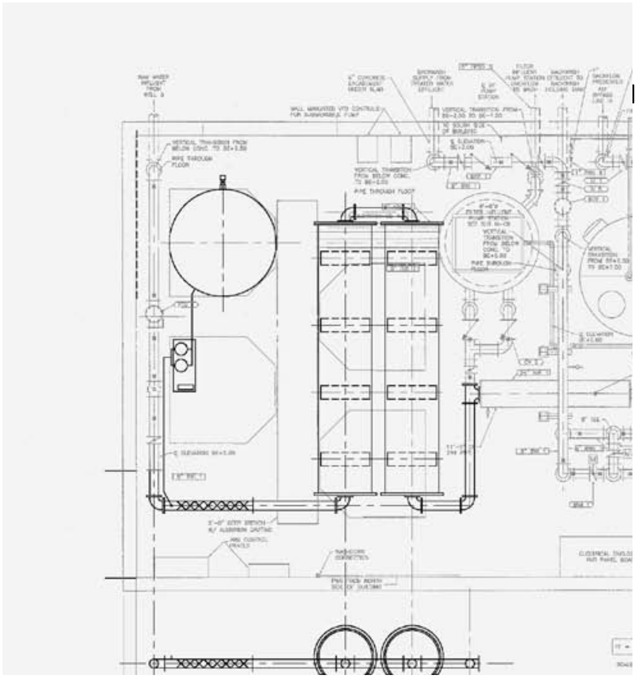
A third recommendation is a re-institution of tank rehabilitation that was to be part of the previous Wells 1 & 2 Arsenic Treatment Project. This work was cancelled earlier in 2010 when the Archer Western Construction contract was cancelled. The tank rehabilitation work is necessary to provide additional storage tank capacity firstly for fire flow storage but secondly for redundancy in tank capacity. At the present time, only Tank 3 is in operation and cannot be removed for repair without jeopardizing the entire water distribution system operation. With Tank 1 (500,000 gallons) or Tank 2 (1 million gallons) or both in service, they can provide backup to Tank 3 (1.9 million gallons) if/when it needs to be removed from service for repair. While there would be potential short-term savings to only rehabilitate one of the two tanks, eventually both tanks are necessary to provide the overall water storage for fire protection necessary for the Town. The rehabilitation requirements are taken directly from the plans (C-16 and C-17) for the above project and are presented below.

1. Recommended changes to arsenic treatment facilities at Wells 3 & 4:
    a. Remove Electro-flocculation facilities
    b. Install permanent ferric chloride chemical feed system and bulk chemical feed tank.
    c. Provide associated piping, including large diameter piping for detention of flocculated water upstream of pressure filters.
    d. Incorporate electrical and control changes in order to incorporate changes to chemical feed system.
    e. A sketch layout is shown below.

2. Renovate the existing SCADA control system between all wells (3, 4, and eventually 1 & 2) and the master control station at the Water Department office. This will include modifications to PLC units at both wells and receiving system at the master control station.

3. Tank Rehabilitation
    a. Tank 1
        i. Minor structural repairs – foundation, tank floor plate, center column.
        ii. New interior ladder, safety climb rod.
        iii. Lead paint abatement, sand blast and recoat all interior components.
        iv. Sand blast and recoat exterior components, including new Town of Bernalillo logo.
        v. Replace water level indicator, shell manway gasket, Cathodic protection system.
        vi. Allowance items (may vary in cost/complexity) – remove/replace approximately 15 of the 30 corroded rafters; remove scab marks and weld spatter.
    b. Tank 2
        i. Replace shell manway gasket, Cathodic protection system.
        ii. Lead paint abatement, sand blast and recoat all interior components.
        iii. Sand blast and recoat exterior components, including a new Town of Bernalillo logo.
        iv. Allowance items (may vary in cost/complexity) – remove/replace approximately 20 of the 48 corroded rafters; remove scab marks and weld spatter.

4. Flush the entire water system, including all tanks.
    a. Tanks 1 & 2 have been off line for many years. Prior to being placed in service, these tanks need to be flushed of debris.
    b. When either Tank 1 or 2 (or both) is on line, Tank 3 should be taken off line and flushed for debris.
    c. When tanks are flushed and online, begin a waterline flushing program of all dead-end lines to remove debris.



uipment – Well 4 site shown as typical.

Figure 26: Proposed Arsenic Treatment System Changes, Well 4

7. ESTIMATED COSTS OF IMPROVEMENTS

The following opinion of probable costs are estimated as follows:

1.	Well 4		
a.	Ferric Chloride Chemical Feed System – 0-10 gph, duplex, installed		$ 35,000
b.	Well 4, Ferric Chloride Storage Tank – 8,000 gallon, fiberglass construction		$ 40,000
c.	Well 4, Miscellaneous Piping Modifications		$ 20,000
	Subtotal Well 4	$ 95,000	
2.	Well 3		
a.	Ferric Chloride Chemical Feed System – 0-10 gph, duplex, installed		$ 35,000
b.	Well 4, Ferric Chloride Storage Tank – 8,000 gallon, fiberglass construction		$ 40,000
c.	Well 4, Miscellaneous Piping Modifications		$ 20,000
	Subtotal Well 3	$ 95,000	
3.	SCADA Modifications		
a.	Well 4 – PLC replacement, programming, incorporation into overall controls		$ 20,000
b.	Well 3– PLC replacement, programming, incorporation into overall controls		$ 20,000
c.	Master Control Station – PLC replacement, programming		$ 40,000
	Subtotal SCADA	$ 80,000	
4.	Tank Modifications/Rehabilitation		
a.	Tank 1 – Rehabilitations per Archer Western Bid dated 1-12-10		
	Tank Rehab, Surface Prep, Paint, Structural Improvements		$216,000
	Steel Tank Allowance Items		$ 40,000
b.	Tank 2 – Rehabilitations per Archer Western Bid dated 1-12-10		
	Tank Rehab, Surface Prep, Paint, Structural Improvements		$305,000
	Steel Tank Allowance Items		$ 40,000
	Subtotal Tank Rehab	$601,000	
	Total Project		**$871,000**

The flushing program is not included in this estimate. It is assumed that this work would be completed with Town staff.

Reference

Crittenden, J.C.; Trussel, R.R.; Hand, D.W.; Howe, K.J.; Tchobanoglous, G.T. Water Treatment: Principles and Design. Hoboken, New Jersey: John Wiley & Sons, 2005.

APPENDIX