Glendale Water and Power

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Report on Additional RCF Pilot Testing to Optimize Design

Task 19

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Final

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1. Executive Summary

The City of Glendale, in partnership with McGuire Malcolm Pirnie, tested six treatment technologies for hexavalent chromium, Cr(VI), in the 2003-2004 Phase II Pilot-scale study. One of the pilot-tested technologies – reduction with ferrous sulfate, coagulation/aeration, and filtration (RCF) – successfully removed Cr(VI) from 100 μg/L to less than 5 μg/L (and to less than 1 μg/L under some conditions). The purpose of the initial Phase II pilot testing was to demonstrate if the various technologies were effective at all. Essentially, Phase II was designed to test the proofs of the overall treatment concepts. Optimization of the process design for scale-up was not possible given the scope and budget of the Phase II project.

Further optimization was recommended as part of the Phase III demonstration effort to identify the most effective, and least costly, design of an RCF system. The key objectives of the additional RCF pilot testing were to determine the reduction time necessary, aeration time necessary, and the possibility of passive backwash water treatment and recycle.

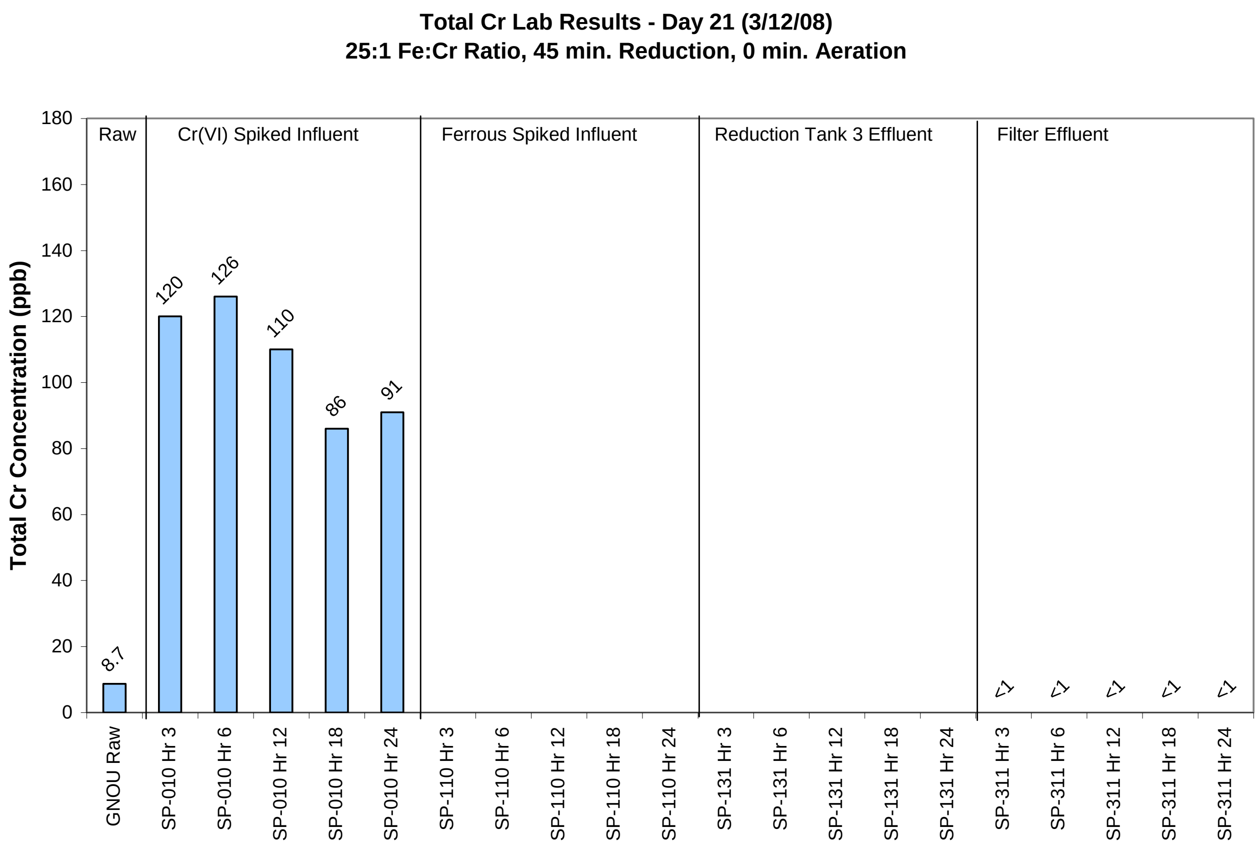
The additional RCF pilot testing included verification of system effectiveness (i.e., using conditions found to yield favorable results in Phase II pilot testing), longer time periods to test 24-hour filter runs, shorter reduction times (30 or 15 minutes compared with 45 minutes), shorter aeration times (12, 6, or 0 minutes compared to 18 minutes), and optimized combinations of effective reduction and aeration times. A modular approach was used in constructing the pilot testing system to allow for testing these multiple variables.

The removal of total Cr (and, thus, Cr(III)), rather than Cr(VI) alone, was critical to evaluate the success of the RCF drinking water treatment process. Cr(III) can be reoxidized to Cr(VI) in distribution systems by typical concentrations of free chlorine and chloramine secondary disinfectants. Therefore, reduction of Cr(VI) without removal of the total Cr was not a feasible treatment alternative for Glendale.

Phase III additional pilot testing results revealed that 45 minutes of reduction time (followed by filtration) was successful in consistently reducing Cr(VI) and removing total Cr to concentrations below 1 μg/L (i.e., the method reporting level) without the need for an aeration step (Figure 1-1). In addition, little pressure drop across the filters was observed during this 24-hour run, indicating that longer runs might be possible, further reducing the frequency of backwashing and the quantity of washwater produced.

Closer investigation of the RCF process provided evidence that full Cr(VI) reduction occurred within 15 to 30 minutes. Ferrous iron, Fe(II), oxidation required a detention time longer than 15 to 30 minutes or the presence of an aeration step. However, without aeration, ferrous iron was completely converted to ferric iron, Fe(III), and removed by the time the water reached the filter effluent, indicating that either additional contact time in the pilot plant piping between the ferrous iron and dissolved oxygen or air entrainment during the rapid mix/polymer addition step oxidized the remaining ferrous iron to ferric iron. With efficient particle removal in the granular media filters, total chromium concentrations less than 1 μg/L can be anticipated in the demonstration treatment facility.

Figure 1-1: Total Cr Concentrations Measured During the Optimized 24-Hour Run



Pilot testing revealed that clarified backwash water could be recycled to the treatment process influent without negatively impacting Cr(VI) treatment. Thus, backwash water recycle should be included in the design of the demonstration-scale facility to minimize water losses and reduce wastewater quantities. A passive means of filtration to dewater the backwash solids should also be included in the demonstration study design because it offers great cost savings over a filter belt press and was found to yield high quality filtrate in the pilot testing. Other design recommendations are included in Appendix A.

Based on these pilot test findings, we recommend that Glendale design an RCF system with 45 minutes of reduction time, polymer addition in a rapid mix tank after the reduction tanks, and dual-media granular filtration. No pH adjustment and no additional aeration (beyond that provided by the dissolved oxygen concentrations in the water) were necessary in the pilot testing, which will result in significant capital cost savings in the RCF system construction. However, during the design process physical space and hydraulic capacity should be included in the demonstration-scale plant design in case pH adjustment and aeration are needed at a later time.

2. Introduction and Objectives

In 2003-2004, the City of Glendale, in partnership with McGuire Malcolm Pirnie, conducted the Phase II Pilot-scale study of six treatment technologies for removing hexavalent chromium [Cr(VI)] from groundwater. One of the pilot-tested technologies – reduction with ferrous sulfate, coagulation/aeration, and filtration (RCF) – successfully removed Cr(VI) from 100 μg/L to less than 5 μg/L (and to less than 1 μg/L in under some conditions). The purpose of the initial Phase II pilot testing was to demonstrate if the various technologies were effective at all. Essentially, Phase II was designed to test the proofs of the overall treatment concepts. Optimization of the process design for scale-up was not possible given the scope and budget of the Phase II project.

In October 2007, an expert panel workshop was convened by Glendale to identify cost-effective Cr(VI) treatment technologies that were appropriate for further testing at demonstration scale. The expert panel members, including Bruce Macler, Pankaj Parekh, Sun Liang, Richard Sakaji, Mel Suffet, Laurie McNeill, Arup SenGupta, and Gary Amy, unanimously recommended the RCF process for demonstration-scale testing. Primary considerations for their recommendation included process effectiveness, a thorough understanding of the technology, and ease of permitting. Consequently, the City of Glendale intends to design and build a demonstration-scale RCF treatment facility to treat part or all of the water from two high-chromium wells from the North Operable Unit (GN-2 and GN-3).

As Glendale moves into the design phase for the RCF system, further optimization of the RCF system was required as part of the Phase III demonstration effort to identify the most effective, and least costly, design. Consequently, optimization pilot testing was conducted and is described in this report. Outstanding design issues considered included:

- **Reduction time needed for Cr(VI) reduction by ferrous sulfate.** Bench-testing literature[1] reported that as much as 45 minutes was needed to remove Cr(VI) from 55 to 5 μg/L using ferrous sulfate; consequently, the Phase II pilot test relied upon this information and found that 45 minutes was sufficient for Cr(VI) reduction. However, it has come to our attention that an operational RCF treatment system for a confidential client found that 10 minutes of in-pipe mixing followed by approximately 15 minutes of batch mixing (for a total of 25 minutes of reduction time) was sufficient. For a 1,000 gpm treatment system, the difference between 30 and 45 minutes of reduction time is approximately 20,000 gallons of tankage. Consequently, a modular approach for additional pilot-scale testing (i.e., 3 reactors in series, each providing 15 minutes of reaction time) was evaluated to determine how much reduction time should be built into the demonstration study design.

[1] Lee, G. and Hering, J. 2003. Removal of Chromium(VI) from Drinking Water by Redox-Assisted Coagulation with Iron(II). *Journal of Water Supply: Research and Technology – AQUA.* 52:5:319-332.

- **Need for aeration to accomplish coagulation.** To maximize the chances of removing particulate iron and chromium during pilot testing filtration, the Phase II pilot design included multiple aeration columns fitted with coarse bubble diffusers fed by an air compressor. However, the need for this step and the duration of aeration necessary had not been evaluated in any detail. This additional pilot testing evaluated the need for aeration and how much time would be required.

- **Filtration approach.** Granular media (anthracite and sand) filters were used in the Phase II pilot testing and proved to be highly effective at removing iron and chromium particles from the process water. However, extensive studies of filter performance over time were not conducted. Tests of different iron doses indicated that bed depth penetration of the particles may be linked to dosage. During the Expert Panel, Dr. Gary Amy recommended the possible use of microfiltration (MF) membranes to achieve consistent, effective particle removal. However, the MF option is considerably more costly than dual media filtration. The existing Cr(VI) RCF treatment facility for the confidential client mentioned previously is reported to have tubular Pall MF treatment. Due to budgetary restraints, Glendale decided to test dual-media filtration in this pilot test optimization but may consider MF for the demonstration-scale study.

- **Sludge dewatering.** Initial cost estimates for sludge dewatering included a filter belt press, which added significant capital costs to the design and complexity to the operations. Due to the small quantities of sludge produced by RCF, a more passive means of sludge dewatering (similar to the Flo Trend Systems, Inc. approach) may be an option for Glendale and was tested in this pilot test optimization.

- **Backwash water recycle.** In the Phase II pilot testing, backwash water was shown to be effectively settled using a relatively small dose of polymer 1.0 ppm). If settled backwash water is recycled to the head of the plant, possible impacts of this polymer on the process train may occur. This possibility was tested to determine any potential impacts on the process.

Due to the number and substance of outstanding design issues as well as the fact that this is a new treatment technology for Cr(VI) removal to low levels for drinking water applications (the operational RCF installation for the confidential client notwithstanding, since full design details are not available for that installation), this additional optimization pilot testing of the RCF system was necessary. **The key objectives of the pilot testing were to determine the reduction time necessary, aeration time necessary, and the possibility of passive backwash water treatment and recycle.**

3. RCF Process Description

3.1. General Conceptual Design for Demonstration-Scale Testing

In the RCF process, Cr(VI) is first reduced to Cr(III) with the addition of excess ferrous iron (Fe^{2+}), which is oxidized to ferric iron (Fe^{3+}) by the electron transfer during the reduction of Cr(VI) and by dissolved oxygen present in the water. Ferrous iron doses found to be acceptable in Phase II testing ranged from 1.5 to 2.5 mg/L for treating 100 μg/L of Cr(VI) to less than 5 μg/L. Cr(III) either precipitates, forms a co-precipitate with the ferric iron, or adsorbs onto the ferric floc. The ferric iron/Cr(III) particles form larger floc during the aeration and coagulation (with the use of a polymer) stages. Particles are then removed by filtration.

RCF is a mature treatment process for removing high concentrations of Cr(VI) from industrial wastewaters. RCF minus the reduction step (i.e., just coagulation/filtration) is an accepted technology for arsenic removal in drinking water treatment. Unfortunately, only limited studies have been conducted to examine the possibility of achieving low chromium treatment goals using the RCF process for drinking water. Some studies have demonstrated that ferrous sulfate effectively reduces Cr(VI), but that subsequent Cr(III) removal by filtration is not effective under all conditions. In Phase II testing, a pilot-scale RCF unit (approx. 2-gpm capacity) successfully removed total chromium to below detectable levels for an extended period (23 to 46 hrs).[1]

Based on the Phase II pilot test, a demonstration-scale RCF system was conceptually designed with a treatment capacity of 500 gpm (one of the likely configurations to treat a single well). According to a recent cost estimate by Malcolm Pirnie, the total capital cost for the 500-gpm RCF system was $3.05 million and the annual operations and maintenance (O&M) cost was estimated at $164,000. Due to limited funding availability, the treatment capacity for the demonstration-scale treatment unit may have to be reduced to 100 gpm.

The RCF demonstration-scale system will be located adjacent to the Glendale Water Treatment Plant (GWTP) to treat groundwater from Well Sites GN-2 and/or GN-3. These two wells have high levels of Cr(VI), which make them good candidates for the demonstration study.

3.2. Phase III RCF Pilot Testing

Phase III additional RCF pilot testing was conducted at the Glendale Water Treatment Plant on an empty concrete pad located within a containment area. Figure 3-1 shows a simplified schematic of the pilot-scale treatment process. Appendix B provides the final as-built process flow schematic for the RCF pilot testing system by AVANTech, the vendor who supplied the system. Appendix B also contains photos of the final as-built pilot plant.

[1] Qin, G.; McGuire, M.J.; Blute, N.K.; Seidel, C.J.; Fong, L. 2005. Hexavalent Chromium Removal by Reduction with Ferrous Sulfate, Coagulation, and Filtration: A Pilot-Scale Study. *Environ. Sci. Technol.* 39(16):6321-6327.

Raw water from the North Operable Unit was fed at a rate of 2 gpm to the pilot plant with in-line spiking of Cr(VI) to achieve a target concentration of 100 µg/L. Chromic acid (10% weight to volume--w/v) was diluted to 0.1% in the chemical day tank, which was used for spiking. The Cr(VI)-spiked water then entered an influent holding tank and was pumped out to the reduction tanks. Ferrous sulfate addition occurred in the pipeline from the influent holding tank to the first reduction tank. Ferrous sulfate was added to the spiked influent water at a dose of either 1.5 or 2.5 mg/L (as Fe) using ferrous sulfate solution (5% w/v) diluted to approximately 3% with distilled water. The diluted ferrous sulfate solution pH was still very low (approximately 2.96--compared with 2.57 in the 5% solution), which minimized any ferrous sulfate oxidation during each day's run.

Three reduction tanks with detention times of approximately 15 minutes each were piped in series, with the ability to bypass one or two tanks. Effluent from the final reduction tank flowed into a small tank where the water was pumped into three aeration columns in series. Water flowed into the tops of the aeration columns and a 10 Standard Cubic Feet per Minute (SCFM) countercurrent of air bubbles was provided using coarse bubble diffusers (connected to an air compressor) at the bottoms of each column. The pilot plant could be operated with aeration tanks either as 0, 1, 2, or 3 in series.

Sodium hydroxide chemical feed was built into the design of the pilot system between the final reduction tank and the first aeration column but was not used. This capacity was built into full-scale testing elsewhere for a confidential client to adjust the pH to greater than 7.7. As discussed in the Results section, pH adjustment was not necessary for complete ferrous iron oxidation in the water matrix tested during this pilot study.

Downstream of the aeration columns, polymer was added into a rapid mix tank for enhanced floc formation. Three different polymers were used during this testing. In Phase II pilot testing, Magnafloc Ciba E40 anionic polymer was used. Discussions with the Ciba vendor during this pilot testing revealed that the E40 product is not yet NSF-certified; consequently, a similar product (Magnafloc Ciba E38) was substituted and yielded similar floc formation. Experience at a full-scale treatment facility for a confidential client determined that Nalco 9901 anionic polymer formed a good floc to coagulate ferric iron in a Cr(VI) removal facility, so Nalco 9901 was also used in some pilot runs.

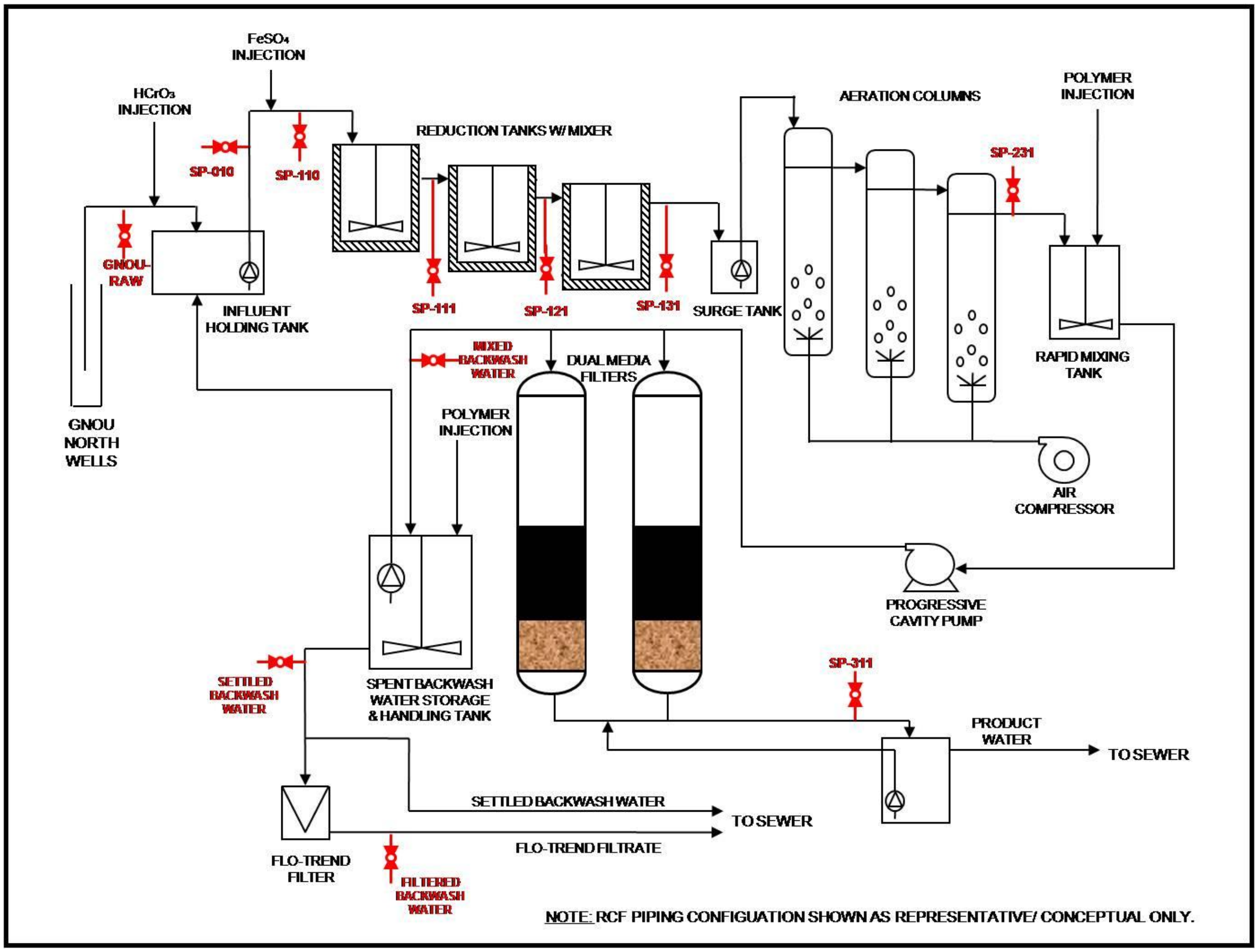
Early testing (February 4-7, 2008) included the use of a surge tank and sump pump after the rapid mix tank and before the filter columns, but this configuration caused dramatic break-up of the floc that had already formed. Starting on February 11th, the system was reconfigured to place the surge tank and sump pump upstream of the rapid mix tank, and the rapid mix tank was elevated to provide gravity flow to the filters. However, the additional head was not sufficient to allow for a run longer than 6 to 8 hours. In addition, more free board above the filter beds was found to be necessary to allow for better backwashing (incorporating air scour, which was not originally planned by AVANTech). Consequently, system modifications were made on February

17th and 18th to add a progressive cavity pump between the rapid mix and filter columns to permit pressurized filter column operation. Modifications also included the addition of five feet of free board above the filter beds to allow for more vigorous and efficient backwashing. Operations on and after February 19th represent the final system configuration.

The filtration media consisted of 26 inches of anthracite (1.0 to 1.25 mm diameter, uniformity of <1.5) and 14 inches of sand (0.5 to 0.6 mm silica sand), with a gravel (3/8 to 3/4 inch) support underdrain. Both anthracite and sand were purchased from an established supplier with AWWA certification. The parallel, dual media filters were operated at a hydraulic loading rate of approximately 3 gpm/sf throughout the testing period,

Filtered water was sent to an effluent tank prior to discharge to the sewer. This clean effluent was also used to backwash the filters at a rate of approximately 7.5 gpm per column (21 gpm/sf) for 5 minutes. Spent backwash water was piped to a separate holding tank for discharge to the sanitary sewer. A sample of the settled backwash solids was collected for processing through the Flo Trend Systems, Inc. material.

Figure 3-1: Simplified schematic of the RCF pilot system



4. Testing Periods and Methods

RCF treatment process optimization included testing periods to change single variables associated with the treatment process components and optimized process train testing. The sections below provide an overview of the data collection and study protocol used in the RCF pilot testing, including monitoring parameters, locations, frequency, and analytical approach. Results are provided in Section 5.

4.1. Testing Periods

The RCF pilot testing periods included verification of system effectiveness (i.e., using conditions found to yield favorable results in Phase II pilot testing), longer time periods to test 24-hour filter run times, shorter reduction times (30 or 15 minutes compared with 45 minutes), shorter aeration times (12, 6, or 0 minutes compared to 18 minutes), and other combinations of effective reduction and aeration times. Table 4-1 shows the breakdown of the testing periods during Phase III piloting.

Table 4-1.
Phase III RCF Testing Periods

	Date	Reduction time	Aeration time	Filter run time	Target Fe:Cr dose	Polymer
Day 1	4-Feb-08	45 min	18 min	6-8 hrs	15:1	Nalco 9901 - 0.2 ppm
Day 2	5-Feb-08	45 min	18 min	6-8 hrs	25:1	Nalco 9901 - 0.2 ppm
Day 3	6-Feb-08	45 min	18 min	6-8 hrs	25:1	Nalco 9901 - 0.2 ppm then Ciba E40 - 0.38 ppm
Day 4	7-Feb-08	-	-	-	-	-
Day 5	8-Feb-08	-	-	-	-	-
Day 6	11-Feb-08	45 min	18 min	6-8 hrs	25:1	Nalco 9901 - 0.2 ppm
Day 7	12-Feb-08	45 min	18 min	6-8 hrs	25:1	Ciba E40 - 0.28 ppm
Day 8	13-Feb-08	45 min	18 min	6-8 hrs	25:1	Ciba E40 - 0.28 ppm
Day 9	14-Feb-08	30 min	18 min	6-8 hrs	25:1	Ciba E40 - 0.26 ppm
Day 10	15-Feb-08	15 min	18 min	6-8 hrs	25:1	Ciba E40 - 0.26 ppm (a.m.), 0.1 ppm (p.m.)
Day 11	18-Feb-08	-	-	-	-	-
Day 12	19-Feb-08	45 min	12 min	6-8 hrs	25:1	Ciba E40 - 0.092 ppm
Day 13	20-Feb-08	45 min	6 min	6-8 hrs	25:1	Ciba E40 - 0.085 ppm
Day 14	21-Feb-08	30 min	6 min	6-8 hrs	25:1	Ciba E40 - 0.085 ppm
Day 15	22-Feb-08	15 min	12 min	6-8 hrs	25:1	Ciba E40 - 0.095 ppm
Day 16	25-Feb-08	45 min	0 min	6-8 hrs	25:1	Ciba E40 - 0.094 ppm
Day 17	26-Feb-08	45 min	18 min	6-8 hrs	25:1	Ciba E38 - 0.1 ppm
Day 18	27-Feb-08	45 min	18 min	24 hrs	25:1	Ciba E38 - 0.093 ppm
Day 19	28-Feb-08	45 min	18 min	24 hrs	25:1	Ciba E38 - 0.1 ppm
Day 20	29-Feb-08	45 min	No air	6-8 hrs	25:1	Ciba E38 - 0.1 ppm
Day 21	12-Mar-08	45 min	No air	24 hrs	25:1	Ciba E38 - 0.1 ppm

4.2. Monitoring Parameters

4.2.1. Water Quality Parameters

Table 4-2 shows the laboratory analyses that were conducted during the pilot testing. Cr(VI), total Cr [Cr(VI) plus Cr(III)], and total suspended solids (TSS) were measured by Montgomery Watson Harza (MWH) Laboratories at seven sampling points. Table 4-2 also contains the sampling point IDs corresponding to the locations shown in the P&ID drawing in Appendix B.

Table 4-3 lists the field analyses, including Cr(VI), total iron, ferrous iron, pH, temperature, turbidity, dissolved oxygen (DO), and oxidation reduction potential (ORP). Selected effluent samples were also filtered through a 0.2 micron filter to compare the total Cr results of membrane filtered and membrane unfiltered effluent.

In general, each day consisted of three sampling events timed to correspond with the beginning, middle, and end of the run. The first sampling event confirmed dosing and occurred approximately one to two hours into the run. The middle and end of the run samples were used to assess process efficiency. The middle samples were collected after approximately 3 to 4 hours of operation. End of the run samples were collected approximately 6 hours into operation. For 24-hour runs, total Cr and iron samples were collected after 3 hours, 6 hours, 12 hours, 18 hours, and 24 hours. Effluent turbidity samples were measured hourly during all sample runs as a proxy for iron and chromium breakthrough.

Supernatant from the settled backwash water was monitored twice after two 24-hour runs for Cr(VI), total Cr, total iron, pH, and turbidity. Filtrate water quality from the Flo Trend system was also measured for Cr(VI), total Cr, and total Fe.

The volume of solids generated during backwashing was estimated following the 24-hour runs. The backwash tank was first flushed and vacuumed to remove any water and solids before beginning the test. Water from a single backwash (both columns) was captured in the backwash tank, mixed, and two samples were collected. A 500 mL sample was analyzed for total suspended solids. A 1,000 mL sample was analyzed for settleable solids according to Standard Methods 2540F using an Imhoff cone.

Table 4-2.
Laboratory Analyses and Sample Locations for RCF Pilot Testing

	Lab Analyses		
Sampling Location	**Cr(VI)***	**Total Cr^**	**TSS**
SP-010 - Cr(VI) Spiked Influent	2 /day: • middle of run • end of run	2 /day: • middle of run • end of run	-
SP-131 - After Reduction Tank #3	1 /day: • middle of run	-	-
SP-231 - Aeration Process Effluent	1 /day: • middle of run	-	-
SP-311 - Filter Effluent	2 /day: • middle of run • end of run	2 /day: • middle of run • end of run	-
BW Tank - Settled Backwash Water	1 /week	1 /week	-
BW Tank - Mixed Backwash Water	1 /week	1 /week	1 / iron dose
Flo Trend Filtrate - Filtered Backwash Water	1 /pilot testing	1 / pilot testing	-

* Turnaround time of 5-days
^ Turnaround time of 24-hours

Table 4-3.
Field Analyses and Sample Locations for RCF Pilot Testing

	Field Analyses							
Sampling Location	**Cr(VI)**	**Total Iron**	**Ferrous Iron**	**pH/Temp**	**ORP**	**Turbidity**	**Dissolved Oxygen**	**Settleable Solids**
GNOU Raw Water (at sample tap)	1 / week	1/ week	1/ week	1/ week	1/ week	1/ week	1 / week	-
SP-010 - Cr(VI) Spiked Influent	2 /day: • beginning of run • middle of run	-	-	2 /day: • middle of run • end of run	1 /day: • middle of run	1/day: • end of run	2 /day: • middle of run • end of run	-
SP-110 - Fe-Spiked Influent	-	2 /day: • beginning of run • middle of run	2 /day: • beginning of run • middle of run	2 /day: • middle of run • end of run	1 /day: • middle of run	1/day: • end of run	-	-
SP-111 - After Reduction Tank #1	1 /day: • middle of run	-	-	-	-	-	-	-
SP-121 - After Reduction Tank #2	1 /day: • middle of run	-	-	-	-	-	-	-
SP-131 - After Reduction Tank #3	1 /day: • middle of run	2 /day: • middle of run • end of run	2 /day: • middle of run • end of run	2 /day: • middle of run • end of run	1 /day: • middle of run	-	2 /day: • middle of run • end of run	-
SP-231 - Aeration Process Effluent	-	2 /day: • middle of run • end of run	2 /day: • middle of run • end of run	2 /day: • middle of run • end of run	1 /day: • middle of run	-	2 /day: • middle of run • end of run	-
SP-311 - Filter Effluent	-	2 /day: • middle of run • end of run	2 /day: • middle of run • end of run	2 /day: • middle of run • end of run	-	8 /day: • hourly	-	-
BW Tank - Settled Backwash Water	-	1 /week	-	1 /week	-	1 /week	-	-
BW Tank - Mixed Backwash Water	-	-	-	-	-	-	-	1 / iron dose
Flo Trend Filtrate - Filtered Backwash Water	-	1 / pilot testing	-	-	-	-	-	-

4.2.2. Process Parameters

In addition to chemical and physical water quality analyses, process-related parameters were recorded to evaluate the operations of the RCF pilot system. The process-related parameters included flow rate and pressure buildup through the filter columns.

Backwash sediment samples were collected from the bottom of the backwash tank once during the pilot runs and filtered using material supplied by Flo Trend Systems, Inc. Filtrate quality was determined by monitoring for iron and chromium concentrations. In addition, the floc toughness after dewatering with the Flo Trend material was assessed by mixing the floc in a jar tester at 300 RPM to visually assess whether the floc stayed together or broke apart. The sludge was also visually inspected to determine the dryness (e.g., whether the sludge was wet and slimy or dry and matte in appearance).

Following testing, the piping and tanks were inspected to assess any scale formation from the ferric iron precipitates. The occurrence of scale on RCF process components has been reported for another full-scale RCF installation.

4.3. Monitoring Locations

Samples were collected from sample ports identified in Appendix B. Sample locations for the RCF pilot testing are highlighted in Table 4-2 and Table 4-3. For the pilot system, sampling locations included the raw Glendale North Operable Unit (GNOU) water (obtained from the combined transmission main from the North Operable Unit); Cr(VI) spiked influent water; ferrous sulfate-spiked influent water; after each of the three reduction tanks; the effluent from the aeration column(s); filter effluent from the granular media filters; settled backwash water from the backwash tank; and mixed water from the backwash tank. In addition, one sample was collected from the bottom of the backwash tank to test Flo Trend solids separation on a small scale.

4.4. Monitoring Frequency

4.4.1. Water Quality Parameters

The sampling frequency followed for chemical parameters are shown in Table 4-2 and Table 4-3. The selected frequency was based on treatment process design and the duration of pilot testing (four 5-day weeks).

4.4.2. Process Parameters

Flow rates were measured on a daily basis, and pressure buildup was recorded each hour through the 24-hour filter runs.

4.5. Analytical Approach

Analytical methods for the water quality parameters and treatment residuals conformed to EPA guidelines and recommended test methods for Cr(VI) and total Cr. Standard-tested Hach methods were used for field monitoring.

Total Cr and Cr(VI) were measured by ELAP-certified MWH Laboratories. The laboratory analyses of total chromium were performed by ICP-MS (EPA Method 200.8). Cr(VI) was analyzed using IC (EPA Method 218.6). TSS was measured gravimetrically using EPA Method 160.2. All other parameters were analyzed in the field using the methods shown in Table 4-4.

The Method Reporting Levels (MRLs) at MWH Labs for Cr(VI) and total Cr are 0.1 µg/L and 1 µg/L, respectively. Samples found to be less than these values were reported as "<MRL."

Table 4-4.
Analytical Methods, Locations of Analyses, and Detection Limits

Sample Analysis	Analytical Method	Analysis Location	Method Detection Level (MDL)	Method Reporting Level (MRL)
Cr(VI) – Lab	EPA 218.6 (IC)	MWH Labs	0.015 µg/L	0.1 µg/L
Total Cr	EPA 200.8 (ICP-MS)	MWH Labs	0.192 µg/L	1.0 µg/L
TSS	EPA 160.2 (Gravimetric)	MWH Labs	4 mg/L	4 mg/L
Cr(VI) – Field	Hach Method 8023 (Diphenylcarbohydrazide)	Field	10 µg/L	10 µg/L
Total Iron	Hach Method 8147 (FerroVer)	Field	0.02 mg/L	0.02 mg/L
Ferrous Iron	Hach Method 8146 (1,20-Phenanthroline)	Field	0.02 mg/L	0.02 mg/L
pH	SM 4500H+ B (Electrometric)	Field	N/A	N/A
Temperature	SM 2550 (Thermometric)	Field	N/A	N/A
ORP	Ag/AgCl Combination Electrode	Field	N/A	N/A
Turbidity	SM 2130 B	Field	0.02 NTU	0.02 NTU
Dissolved Oxygen	Hach Method 8166 (HRDO)	Field	0.3 mg/L	0.3 mg/L
Settleable Solids	SM 2540F (Volumetric)	MWH Labs	0.5 mL/L	0.5 mL/L

4.6. Quality Assurance/Quality Control Checks

QA/QC sampling in the field included duplicate samples and blanks. Field-collected duplicate samples were obtained for 10% of lab samples by collecting one sample after the other. Field-collected blanks were also collected using distilled water. Duplicates and blanks were not identified as QA/QC samples when sent to the laboratory.

Laboratory analyses were subjected to numerous procedures to assess QA/QC objectives. A combination of matrix spikes (MS), matrix spike duplicates (MSD), laboratory reagent blanks (LRB), instrument performance check samples (IPC) for Method 218.6 and continuing calibration verification (CCV) samples for Method 200.8, and laboratory control samples (LCS) were analyzed.

Accuracy (a combination of random and systematic error) in Cr(VI) and total Cr analyses was evaluated by determining percent recoveries in matrix spike samples. A matrix spike was performed on 10% of samples (or at least one sample per run; spike added in the laboratory), chosen at random. Spike recoveries between 90 and 110% of the expected value for Cr(VI) and between 70 to 130% for total Cr were acceptable. Accuracy was also tested at the beginning of the runs and after every 10 samples by sampling a mid-range IPC sample and a LRB. The acceptance criterion for the IPC sample was between 95 and 105%.

Precision (random error) was investigated by performing repeat analyses on the same analytical instruments. For every batch of twenty samples, LCS and MS samples were run. The acceptable ranges for these sample results were between 90 and 110% for Method 218.6 and 70 to 130% for Method 200.8. Laboratory duplicates or MSD samples were analyzed for every batch of twenty samples with an acceptance criteria of <20% Relative Percent Difference (RPD).

5. Results and Discussion

Due to the large amount of data collected during pilot testing, only the key findings are summarized and discussed in this report. All data are available in Appendix C.

5.1. Cr(VI) Reduction

In the RCF process, Fe(II) promotes the reduction of Cr(VI) to Cr(III). Pilot testing investigated the time required to accomplish full Cr(VI) reduction by sampling the end of the reduction process using 15, 30, or 45 minutes of reduction tank detention time. Figure 5-1 shows that Cr(VI) was significantly converted to Cr(III) after the first 15 minutes of reduction time. Two runs using 15 minutes of reduction time revealed Cr(VI) concentrations at the 15-minute reduction tank sampling point of 1.5 and 0.3 μg/L. After 30 minutes of reduction time in two other runs, the Cr(VI) concentrations remaining were 0.37 and 0.11 μg/L. Forty-five minutes of reduction time typically yielded Cr(VI) values of less than the MRL (0.1 μg/L). No reoxidation of Cr(VI) occurred in the aeration columns or filters.

Figure 5-1: Hexavalent Chromium Reduction

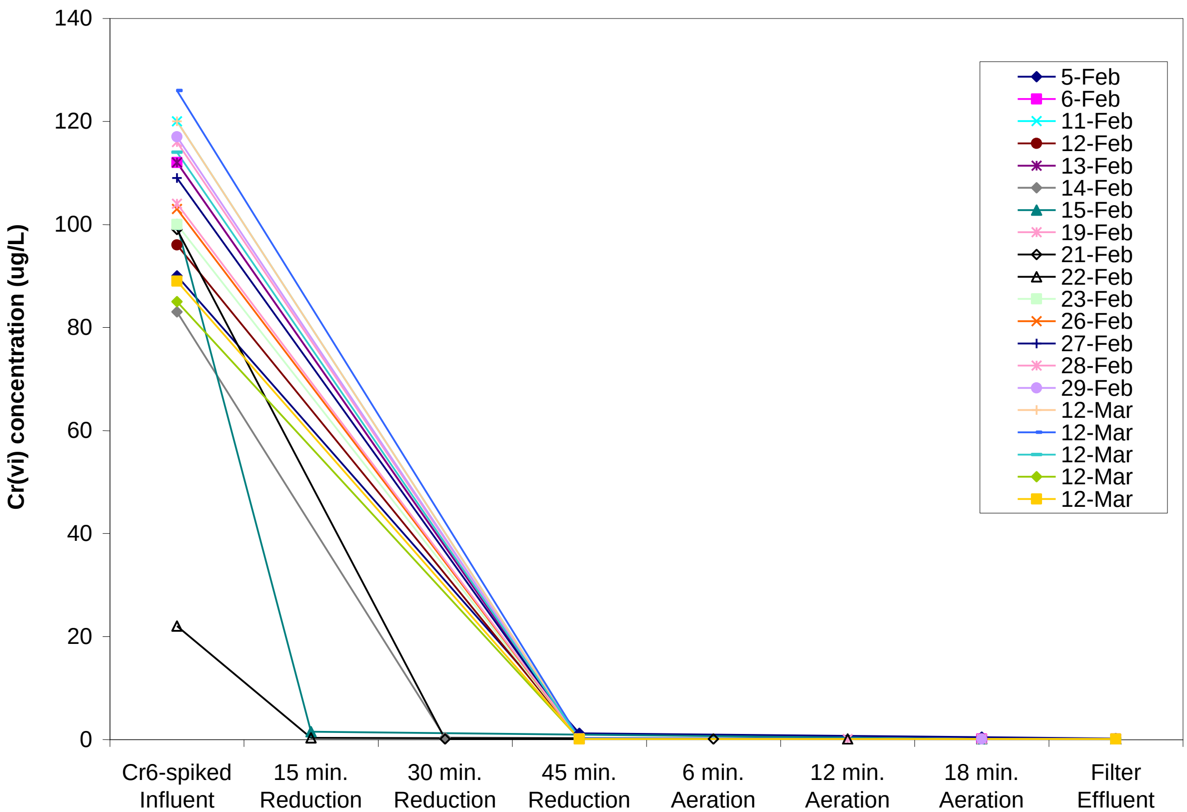
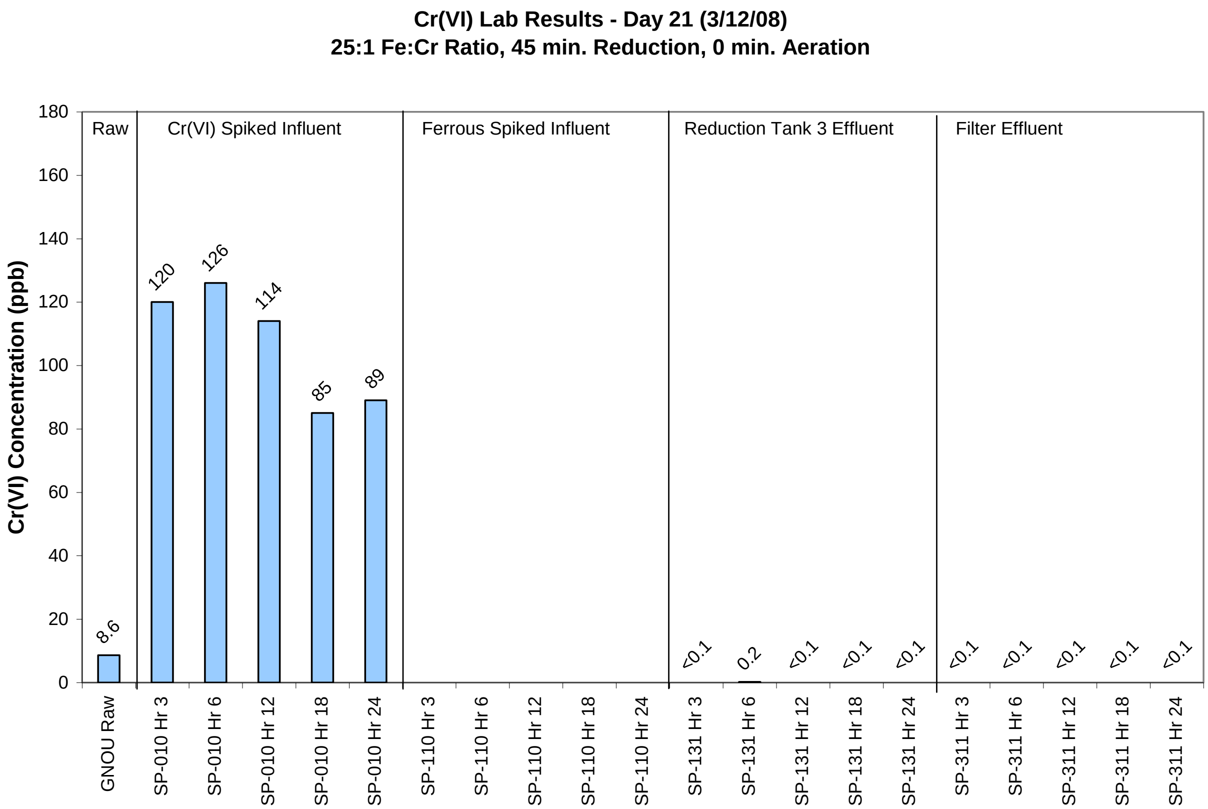


Figure 5-2 highlights the Cr(VI) reduction for the optimized case of 45-minutes reduction and 0 minutes of aeration on March 12th. As shown in this figure, all of the sampling times exhibited

Cr(VI) less than 0.2 µg/L after 45 minutes of reduction time. Filter effluent Cr(VI) concentrations were all less than 0.1 µg/L.

Figure 5-2: Hexavalent Chromium Reduction in the Optimized 24-Hour Run



5.2. Ferrous Iron Oxidation

Ferrous-spiked influent water was analyzed for both total iron and ferrous iron throughout pilot testing. According to the Hach field methods used for these analyses, ferrous iron comprised approximately 44% ± 12% of the total iron concentration in the spiked influent water. However, the total iron concentration was used to set the iron dose based on the desired iron-to-chromium ratio, since the successful Phase II testing also relied upon total iron rather than ferrous. The reason for the low percent ferrous concentration in the ferrous sulfate solution was unknown and occurred in spite of precautions taken to minimize ferrous oxidation (e.g., ensuring a low pH was maintained in the diluted stock solution and using distilled water as the diluent).

For the ferrous iron observed in the iron-spiked influent water, oxidation to ferric iron in the reduction tanks required at least 45 minutes. Figure 5-3 shows that runs testing 15 minutes or 30 minutes of reduction time resulted in measurably higher ferrous iron concentrations, in most cases, in water exiting the reduction tanks. On average, 15 minutes of reduction time resulted in 60±16% ferrous remaining in solution, 30 minutes of reduction time resulted in 26±12% ferrous remaining in solution, and 45 minutes of reduction time resulted in 21±10% ferrous remaining in solution.

Figure 5-3: Ferrous Iron Oxidation in the Reduction Tanks

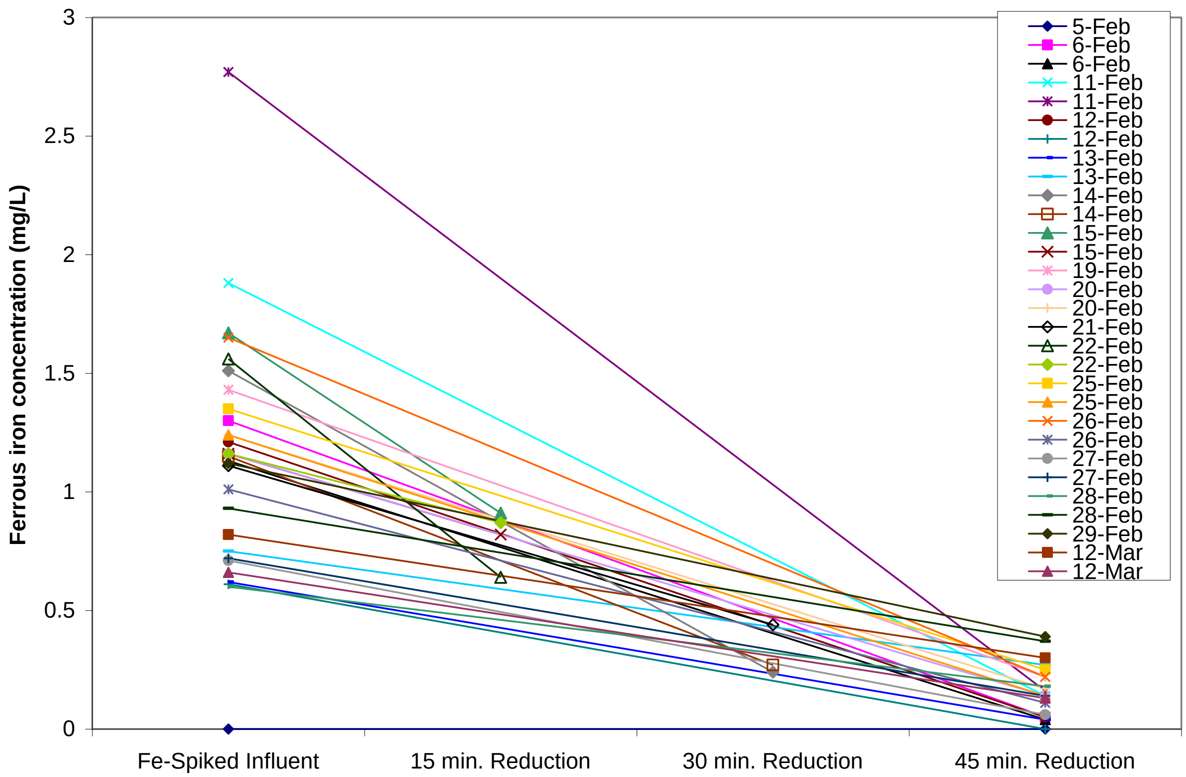


Figure 5-4 confirms that the remaining ferrous iron after the reduction step was oxidized to less than 0.1 mg/L in solution by the aeration step. Even the cases in which lower reduction times were used (Figure 5-5) and all of the ferrous iron was not oxidized in the reduction tanks, it was effectively oxidized during the aeration step.

Figure 5-4: Ferrous Iron Oxidation Through the RCF Process

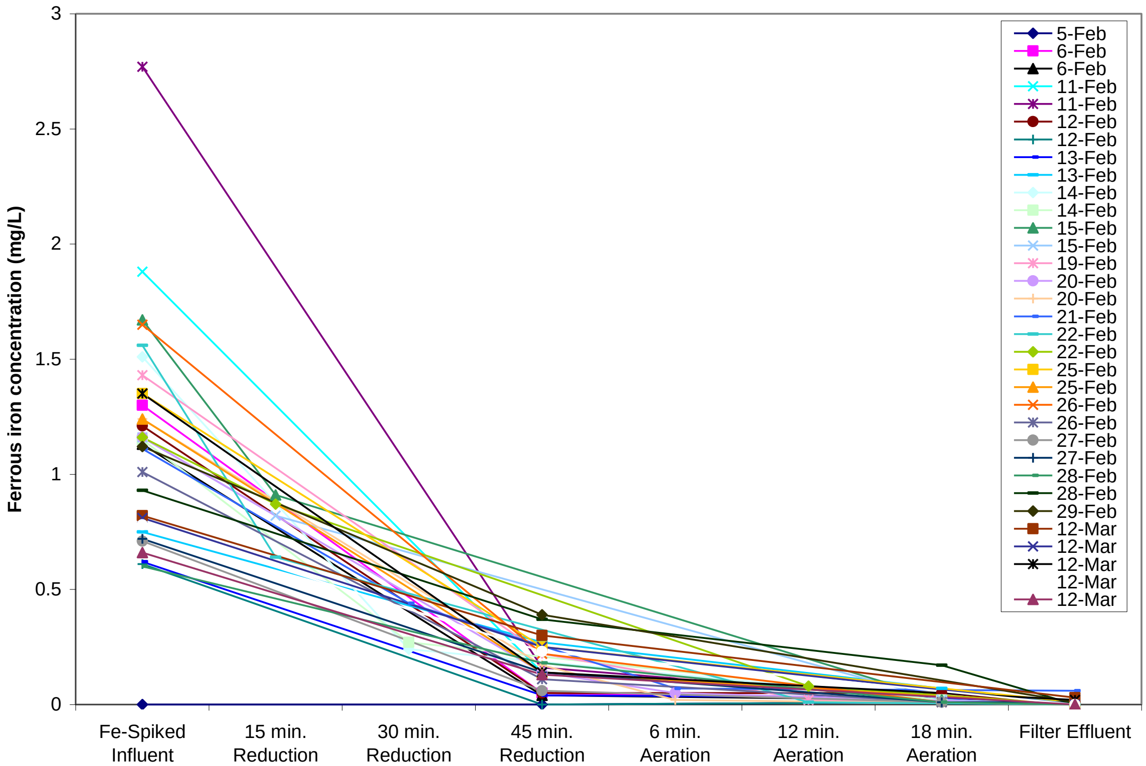
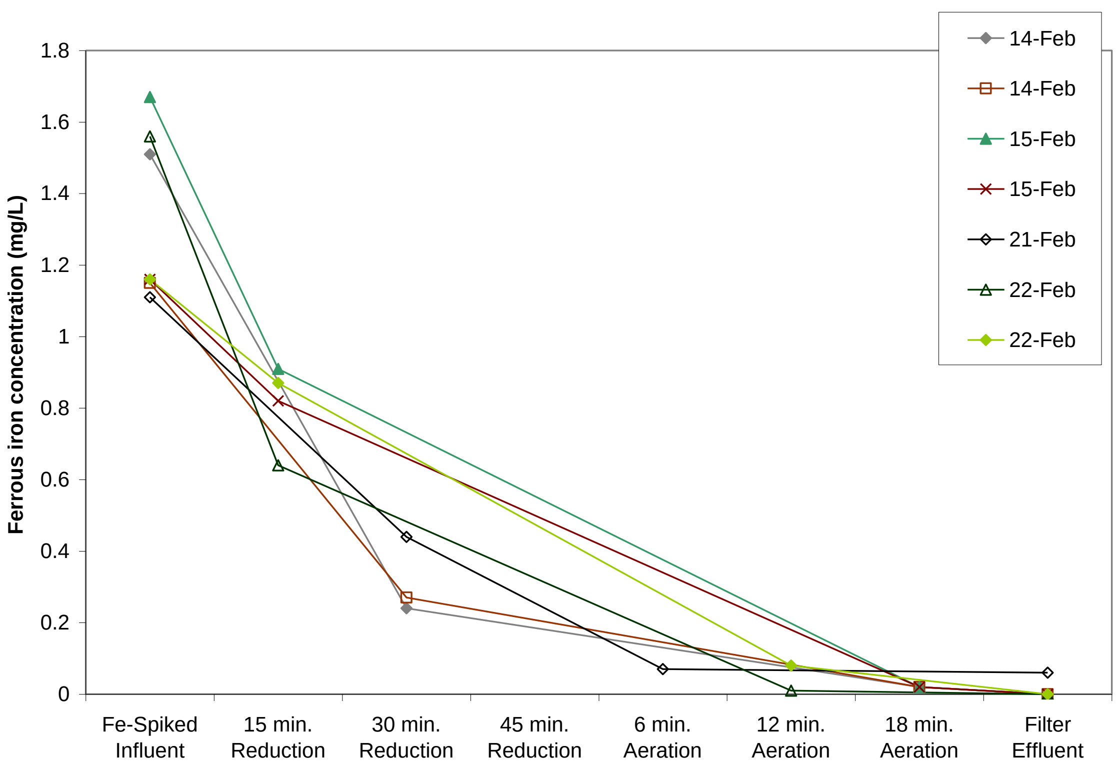


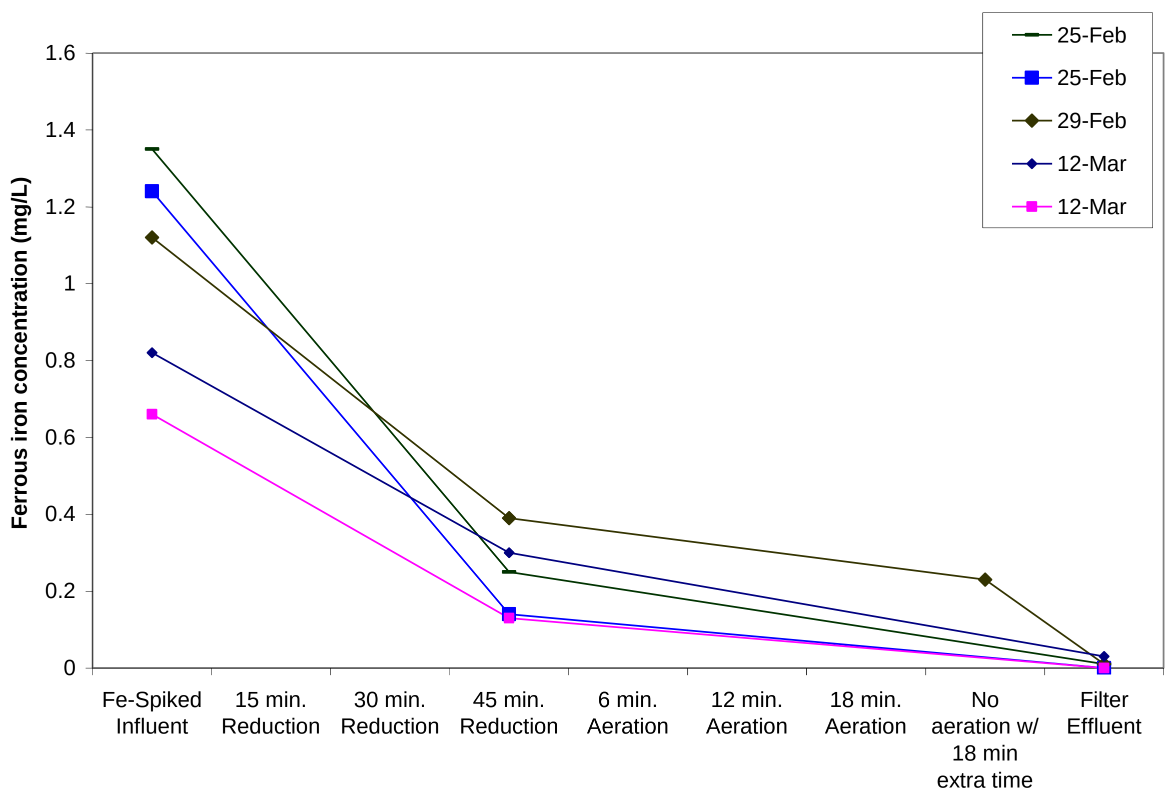
Figure 5-5: Ferrous Iron Oxidation by Aeration in Lower Reduction Time Runs



Three runs were conducted to determine if additional detention time without aeration could provide the conditions necessary to oxidize remaining ferrous iron (Figure 5-6). On February 25th and March 12th, the aeration columns were bypassed, resulting in only 5 minutes' detention time in the rapid mix plus 8 minutes' time in the filtration columns above the media (a total of 13 minutes after the last reduction tank). All samples collected on those days showed ferrous iron levels near the MRL after the water exited the filters, indicating that the remaining 0.13 to 0.30 mg/L ferrous iron present after the reduction tanks was oxidized and removed to achieve an effluent ferrous iron concentration of less than 0.03 mg/L. Without sufficient oxidation, the ferrous iron would not have been removed by the filters because ferrous iron is soluble in water.

On February 29th, water was routed through the aeration columns without the air compressor in use to provide additional detention time without active oxygen addition. Similar ferrous oxidation and removal by the filter effluent was observed in this run compared with the runs on February 25th and March 12th. These results indicated that additional detention time without active aeration oxidized all of the ferrous iron to ferric iron, likely due to the plentiful dissolved oxygen concentrations in the water or air entrainment during the rapid mix step.

Figure 5-6: Ferrous Iron Oxidation without Aeration

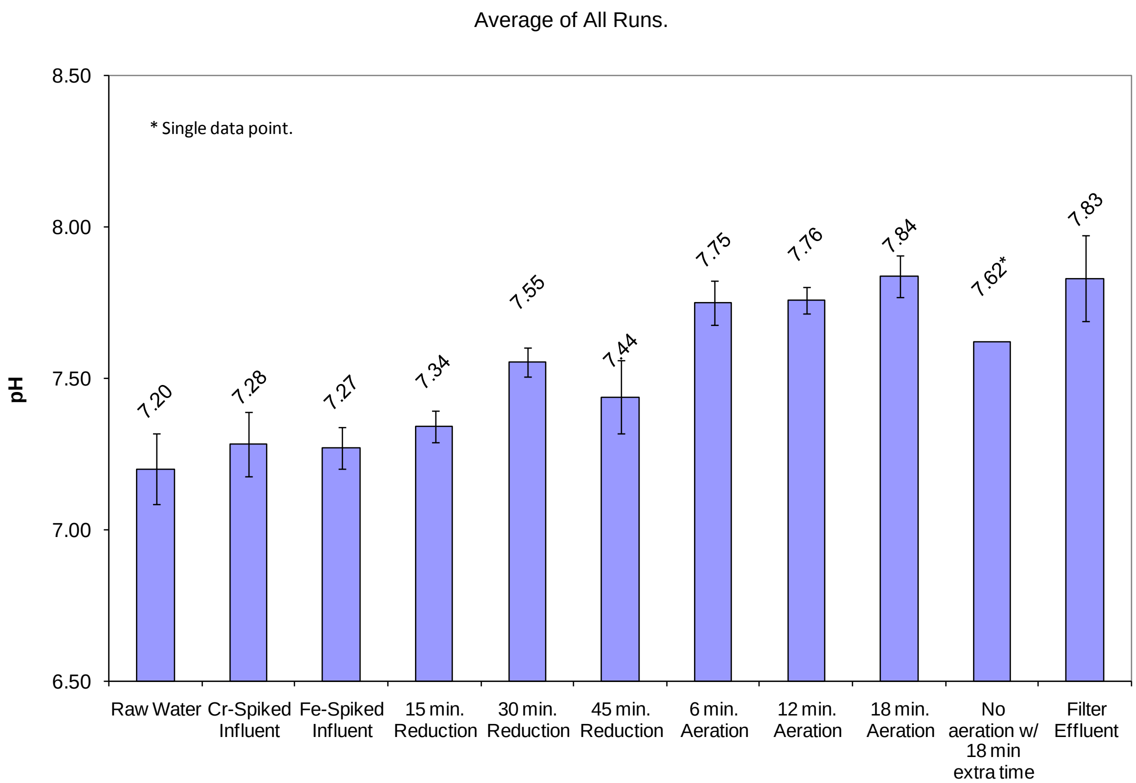


5.3. pH Changes

Figure 5-7 shows the increase in pH observed through the RCF process. No discernable difference from the ambient pH was observed after ferrous injection, while a slight increase in pH occurred with the reduction step. Aeration, however, caused a slightly greater pH due to stripping of carbon dioxide from the water. The ambient pH of approximately 7.3 to 7.5 in the reduction tanks increased to approximately 7.8 after aeration. Six, 12, and 18 minutes of aeration all showed a similar resultant pH. By comparison, lack of aeration resulted in pH levels that were 0.1 to 0.2 units lower than with aeration. Runs with and without aeration were both effective in achieving the total Cr goals, indicating that ambient pH values were sufficient for ferrous oxidation, floc formation, and particle removal.

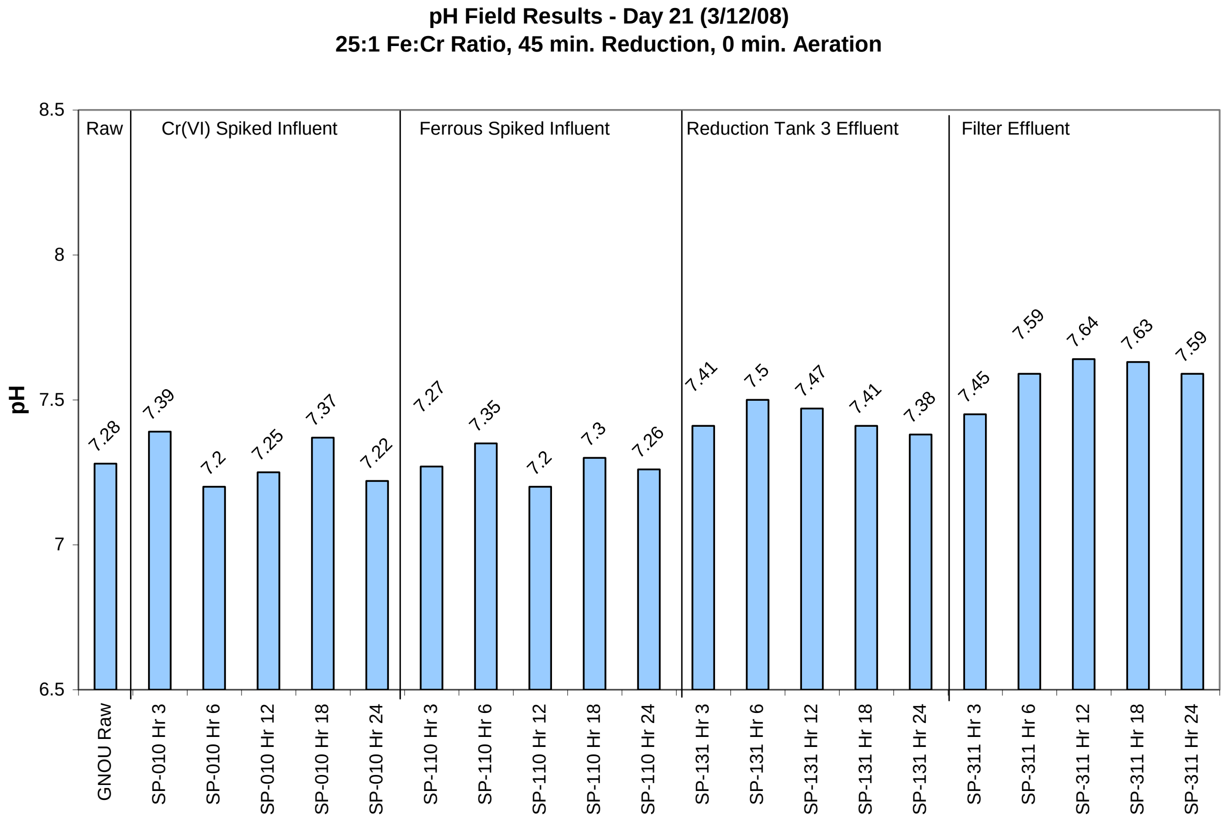
Although the ability to feed sodium hydroxide before the aeration columns was available in the pilot test, an increase in pH beyond ambient levels was not necessary for effective removal of the iron hydroxide particles. Similar findings were observed in the Phase II pilot testing.

Figure 5-7: pH Change Observed Through the RCF Process



For the optimized 24-hour run (45 min. reduction, 0 min. aeration), the pH change observed was less significant than for the average of all runs (Figure 5-8). The lack of aeration (and lower removals of CO_2) was responsible for the smaller change in pH. However, total Cr and total Fe results shown in Figure 5-13 indicate that the ambient pH conditions tested in this pilot were able to achieve target removal goals.

Figure 5-8: pH Change During the 24-Hour Optimized Run



5.4. Dissolved Oxygen and Oxidation-Reduction Potential

The average of dissolved oxygen measurements collected during RCF pilot testing are shown in Figure 5-9. The groundwater contained an average of 5.7 mg/L dissolved oxygen. Mixing/air equalization during the influent spiking and reduction process increased the DO by between 1 to 2.2 mg/L, and aeration increased the DO by an additional 0.7 to 1.7 mg/L. DO concentrations were approximately at the oxygen saturation limit at the measured temperatures (8.2 to 9.1 mg/L for temperatures ranging from 25 to 20°C) after the aeration step.

Figure 5-10 highlights the relatively constant DO values observed during the 24-hour run without aeration. DO measurements even without the aeration step were high throughout the RCF process, and accounted for the additional ferrous iron oxidation observed after the reduction tanks.

Figure 5-9: Dissolved Oxygen Concentrations in the RCF Process

Average of All Runs.

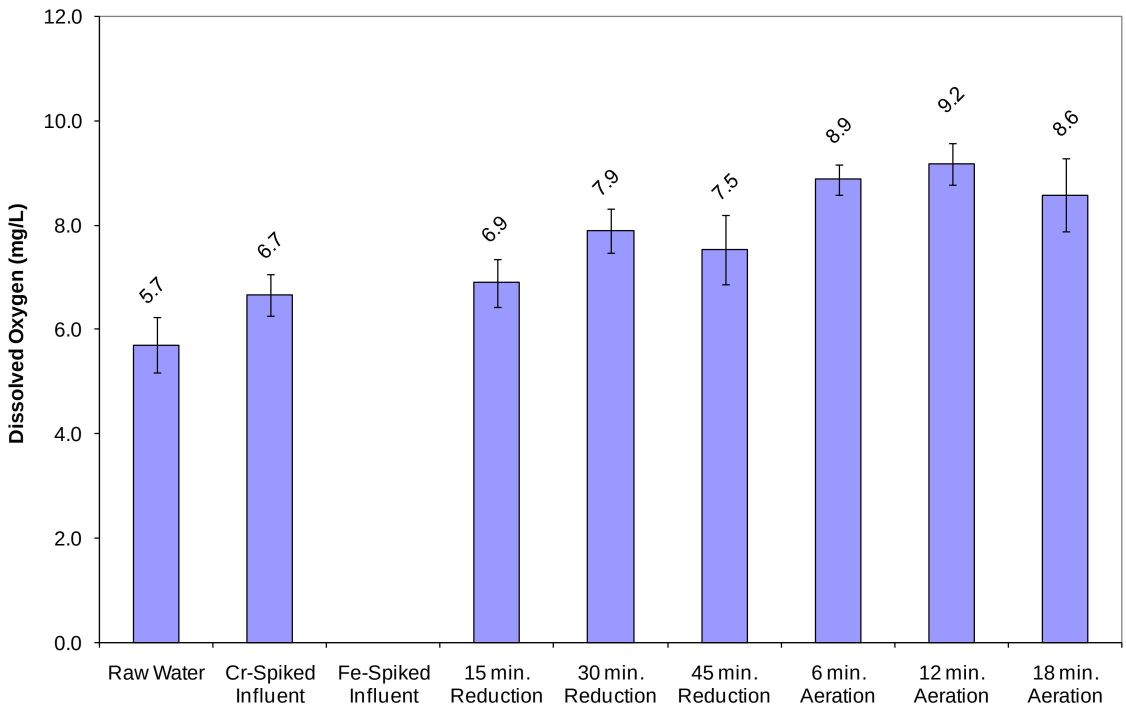
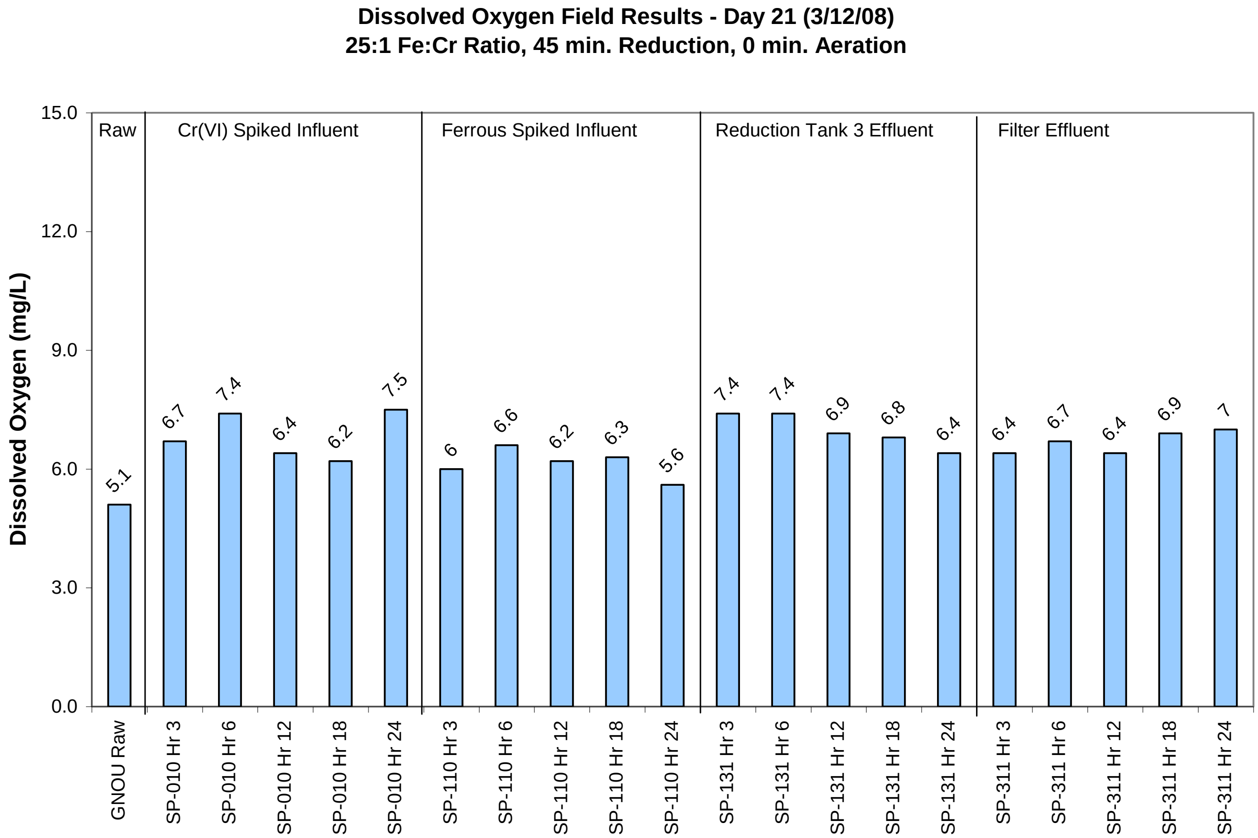


Figure 5-10: DO Concentrations in the RCF Process During the 24-Hour Optimized Run



Average ORP values through the RCF process are shown in Figure 5-11. The GNOU raw water was characterized by a relatively high ORP value, which decreased to a negative value with the addition of ferrous sulfate. ORP remained low in the three reduction tanks then increased with aeration. No discernable difference was observed between ORP values for the 6-, 12-, and 18-minute aeration steps, and no further increase in DO was apparent after 6 minutes of aeration (Figure 5-9).

Figure 5-12 provides the ORP values for the 24-hour optimized case run. Compared with the average of all runs, the final ORP (filter effluent) was lower for than the average ORP values leaving the aeration columns. The ORP increase between the final reduction tank and the filter effluent may have been due to air entrainment in the rapid mix/polymer addition tank.

Figure 5-11: ORP Values Through the RCF Process

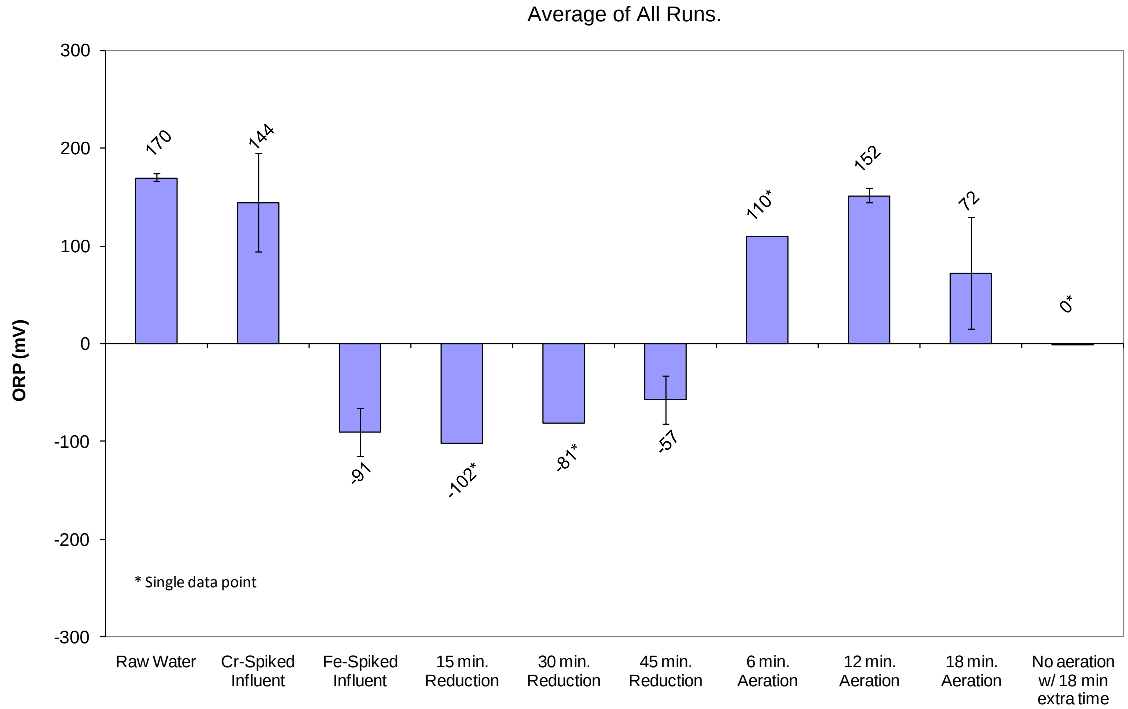
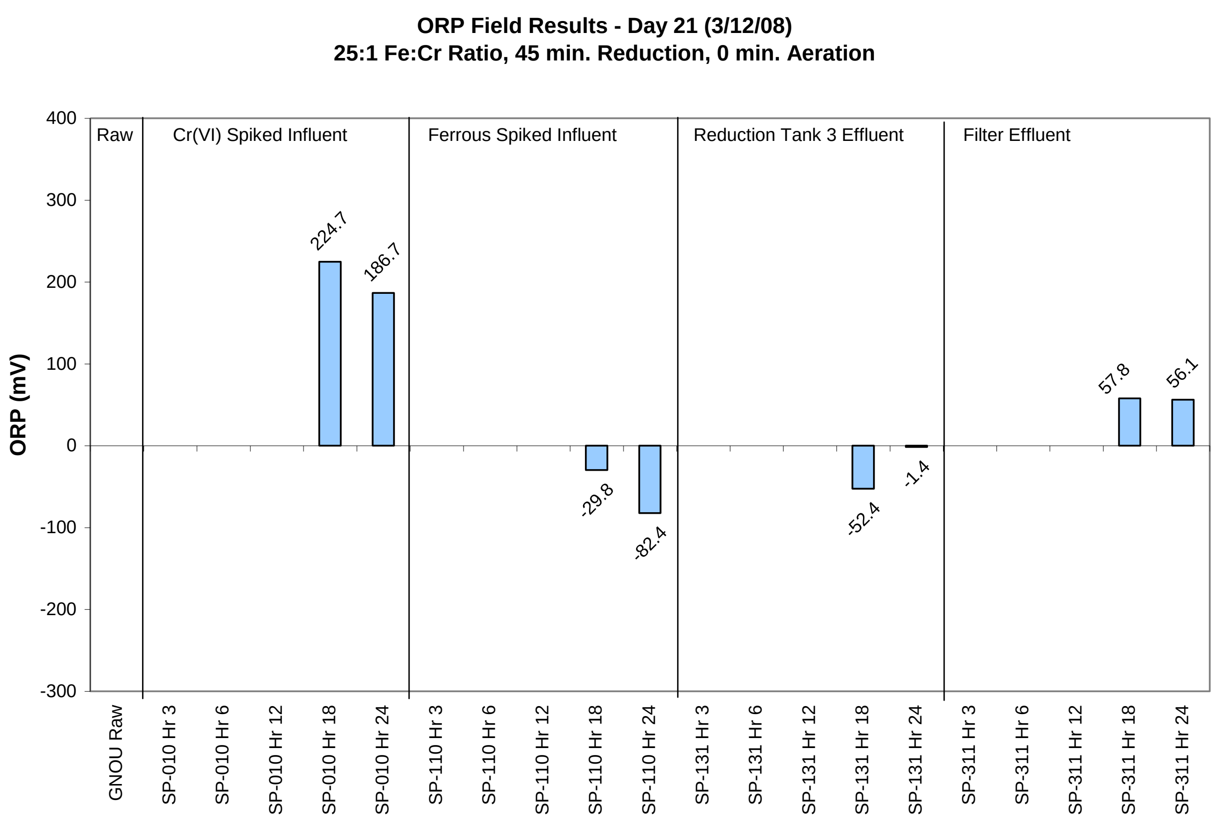


Figure 5-12: ORP Changes During the 24-Hour Optimized Run



5.5. Particle Removal

As discussed in Section 2.2, several modifications were made to the pilot unit to improve floc formation and filtration during testing. Figure 5-13 shows the improvement in effluent total iron and turbidities after removing the sump pump from between the rapid mix tank and the filters. Visible floc breakup after rapid mix/polymer addition was observed in the initial operation due to the sump pump. Both the gravity feed and progressive cavity pump filter operation yielded lower total iron effluent concentrations and turbidities compared with the original configuration. The pilot study demonstrated the importance of using progressive cavity pumps to lift water containing iron floc so that the floc structure would not be compromised. In general, total iron concentrations and turbidities were lower than 0.05 mg/L and 0.3 NTU, respectively, after the modifications.

Figure 5-13 shows evidence that particle removal was the key variable resulting in low total Cr effluent concentrations, as was observed in the Phase II RCF pilot testing. Although all three periods exhibited runs with total Cr concentrations less than 5 μg/L, all runs in the third period had effluent total Cr concentrations at or below 1 μg/L. The third period represents the optimum pilot filter configuration and use of the progressive cavity pump.

Figure 5-14 shows the results of two correlations: total Cr vs. turbidities and total Cr vs. total iron. While most results for total Cr were less than detectable, the detectable total Cr concentrations were generally observed when turbidities and/or iron concentrations were relatively high. There is much scatter in both correlations but it appears clear that removal of total Cr was strongly associated with these parameters. We know from previous work that the reduced Cr is attached to iron hydroxide particles that are removed by the granular media filters. There was no indication from any of the data that soluble Cr was breaking through the pilot filters.

Figure 5-13: Effluent Total Cr, Total Fe, and Turbidities After System Modifications

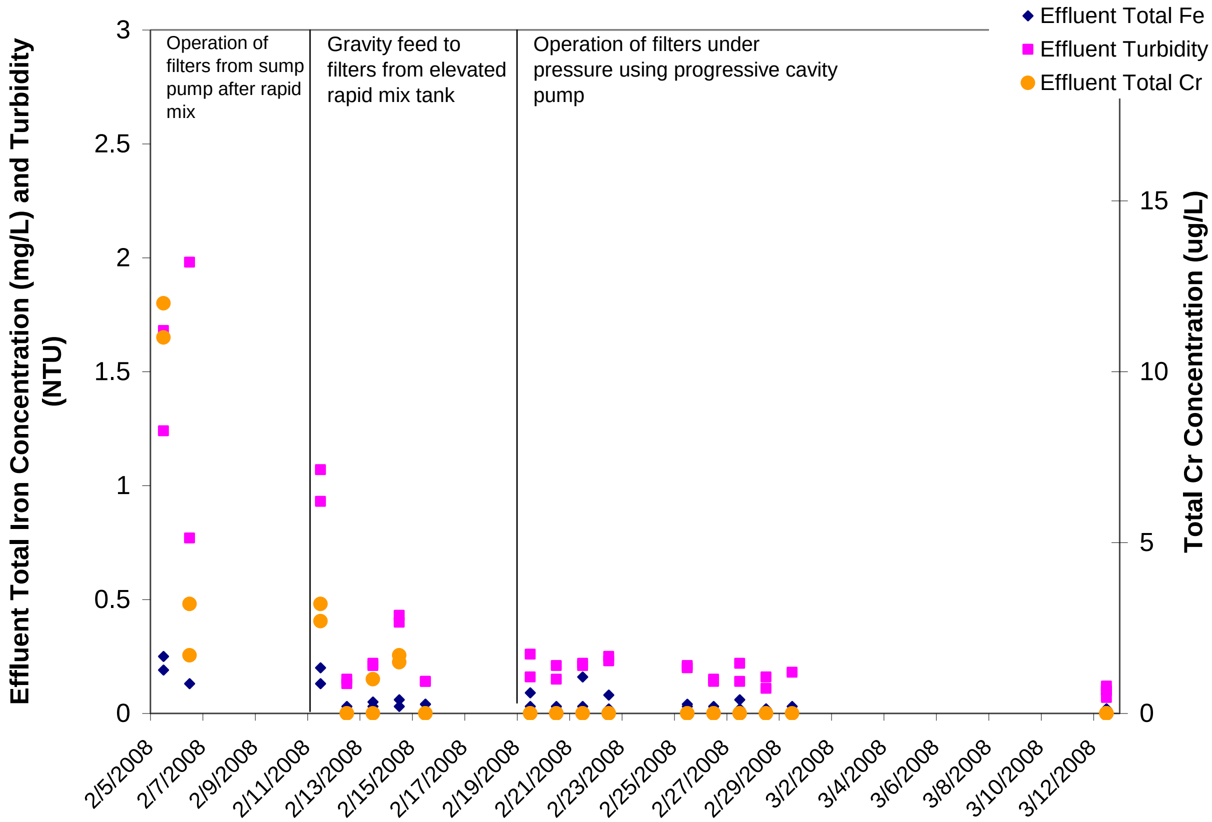
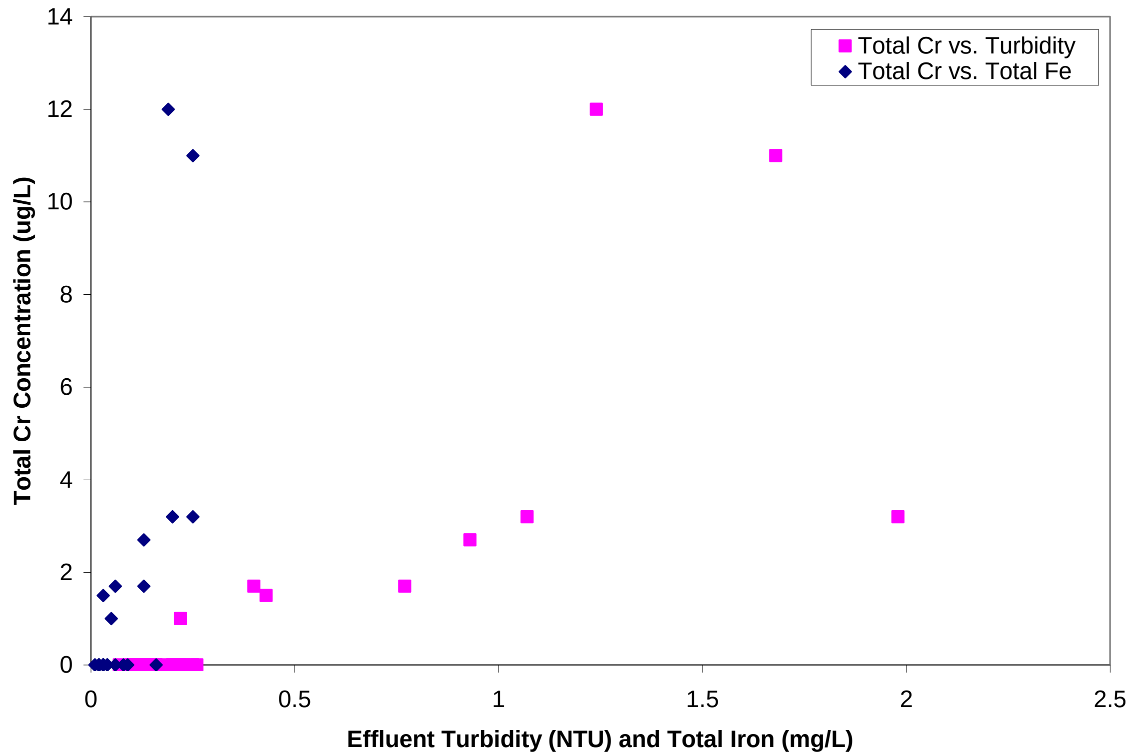


Figure 5-14: Effluent Total Cr Concentrations Compared with Total Iron and Turbidities



5.6. Total Cr Removal

The removal of total Cr, rather than Cr(VI) alone, is critical in evaluating the success of an RCF drinking water treatment process. Previous studies[1] demonstrated that Cr(III) can be reoxidized to Cr(VI) in distribution systems by typical concentrations of free chlorine and chloramine secondary disinfectants. Consequently, total Cr was closely measured in this RCF pilot testing to assess system performance.

Table 5-1 provides a summary of RCF pilot testing results. All except the first two runs achieved the total Cr effluent goal of less than 5 µg/L. Initial runs revealed that the Nalco 9901 polymer tended to form much larger floc than the Ciba polymer, which visually appeared to blind the filters and yield higher total Cr filter effluent concentrations. In addition, floc breakup may have occurred prior to February 19th due to use of a centrifugal pump after the rapid mix, rather than a progressive cavity pump.

After February 19th, all runs exhibited total Cr filter effluent concentrations of less than 1 µg/L with the exception of one sample collected on February 19th (effluent concentration of 1.4 µg/L). As shown in Table 5-1, 45 minutes of reduction time coupled with no aeration was effective in short 6 to 8 hour runs (Days 16 and 20) and also a 24-hour run (Day 21). Figure 5-15 provides

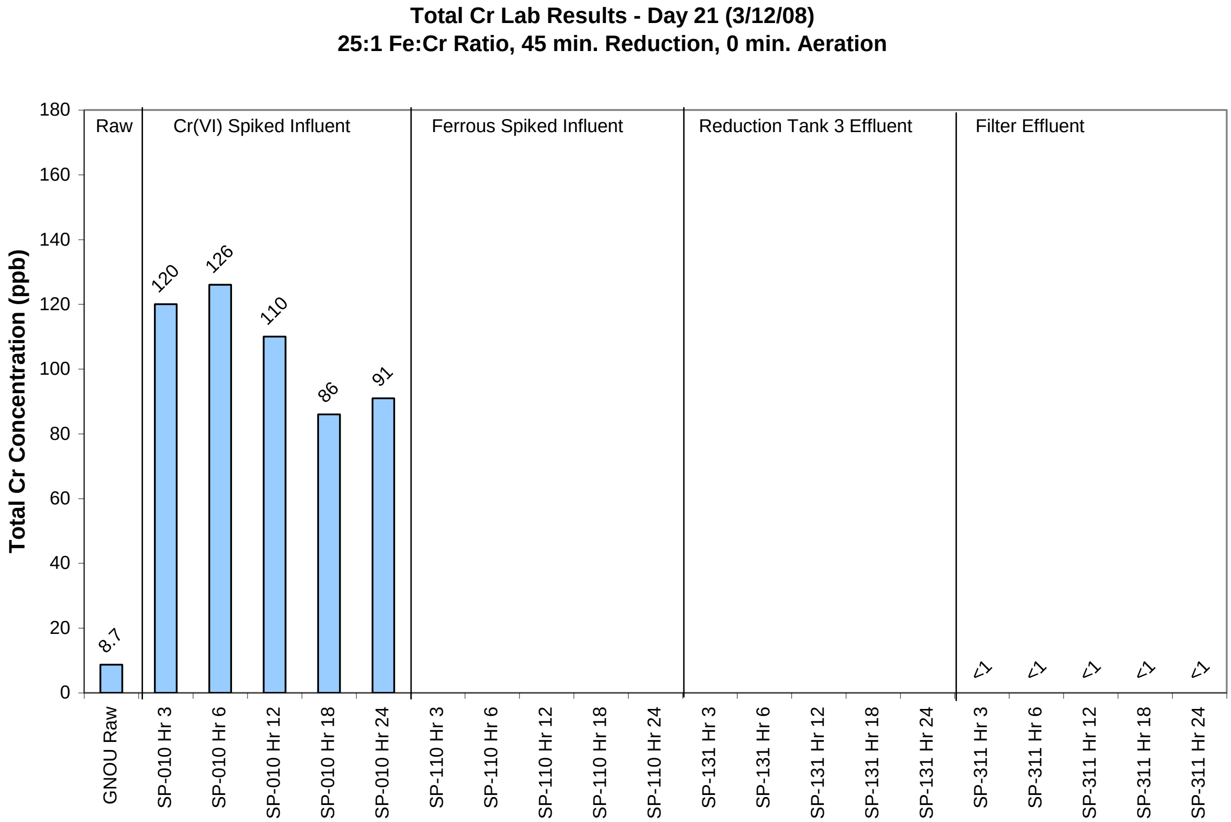
[1] Brandhuber, P. et al. 2005. Low-Level Hexavalent Chromium Treatment Options: Bench-Scale Evaluation. AwwaRF, Denver, CO.

the total Cr laboratory results throughout the 24-hour run, showing influent total Cr concentrations ranging from 86 to 126 µg/L and effluent total Cr concentrations below 1 µg/L. During this 24-hour run, only 0.5 psi of pressure buildup (14 inches of water) was observed in the filters, indicating that even longer runs may be achieved from a head loss perspective. Visible floc penetration and capture in the bed, however, extended to approximately 20-21 inches into the anthracite (out of 24 inches). No breakthrough of iron or turbidity was observed in the 24-hour run without aeration, indicating that the filter bed had sufficient capacity to remove the iron/chromium floc for at least 24 hours. Note, however, that the floc penetration in the 45-minute reduction/0 min aeration runs differed somewhat from the runs using 18 minutes of aeration time in which larger floc was sometimes formed and strained in the first few inches of the anthracite, resulting (in two instances) in pressure buildups of 4.9 to 5.1 psi (approximately 139 inches of water). Floc penetration into the filter beds was more a function of the polymer dose and flocculation of the particles in the rapid mix tank.

Table 5-1.
Summary Table of Results

	Date	Reduction time	Aeration time	Filter run time	Polymer	Total Cr Filter Effluent Results
Day 1	4-Feb-08	45 min	18 min	6-8 hrs	Nalco 9901 - 0.2 ppm	6.6 µg/L
Day 2	5-Feb-08	45 min	18 min	6-8 hrs	Nalco 9901 - 0.2 ppm	11 to 12 µg/L
Day 3	6-Feb-08	45 min	18 min	6-8 hrs	Nalco 9901 - 0.2 ppm then Ciba E40 - 0.38 ppm	3.2 µg/L (Nalco), <1 µg/L (Ciba)
Day 4	7-Feb-08	-	-	-	-	-
Day 5	8-Feb-08	-	-	-	-	-
Day 6	11-Feb-08	45 min	18 min	6-8 hrs	Nalco 9901 - 0.2 ppm	2.7 to 3.2 µg/L
Day 7	12-Feb-08	45 min	18 min	6-8 hrs	Ciba E40 - 0.28 ppm	< 1 µg/L
Day 8	13-Feb-08	45 min	18 min	6-8 hrs	Ciba E40 - 0.28 ppm	< 1 µg/L, 1 µg/L
Day 9	14-Feb-08	30 min	18 min	6-8 hrs	Ciba E40 - 0.26 ppm	1.5 to 1.7 µg/L
Day 10	15-Feb-08	15 min	18 min	6-8 hrs	Ciba E40 - 0.26 ppm (a.m.), 0.1 ppm (p.m.)	< 1 µg/L
Day 11	18-Feb-08	-	-	-	-	-
Day 12	19-Feb-08	45 min	12 min	6-8 hrs	Ciba E40 - 0.092 ppm	< 1 µg/L to 1.4 µg/L
Day 13	20-Feb-08	45 min	6 min	6-8 hrs	Ciba E40 - 0.085 ppm	< 1 µg/L
Day 14	21-Feb-08	30 min	6 min	6-8 hrs	Ciba E40 - 0.085 ppm	< 1 µg/L
Day 15	22-Feb-08	15 min	12 min	6-8 hrs	Ciba E40 - 0.095 ppm	< 1 µg/L
Day 16	25-Feb-08	45 min	0 min (Aeration columns bypassed)	6-8 hrs	Ciba E40 - 0.094 ppm	< 1 µg/L
Day 17	26-Feb-08	45 min	18 min	6-8 hrs	Ciba E38 - 0.1 ppm	< 1 µg/L
Day 18	27-Feb-08	45 min	18 min	24 hrs	Ciba E38 - 0.093 ppm	< 1 µg/L
Day 19	28-Feb-08	45 min	18 min	24 hrs	Ciba E38 - 0.1 ppm	< 1 µg/L
Day 20	29-Feb-08	45 min	0 min (but extra 18 min detention time in aeration columns)	6-8 hrs	Ciba E38 - 0.1 ppm	< 1 µg/L
Day 21	12-Mar-08	45 min	0 min (Aeration columns bypassed)	24 hrs	Ciba E38 - 0.1 ppm	< 1 µg/L

Figure 5-15: Total Cr Results Through the Process Treatment Train on the March 12th Run



5.7. Backwash Water and Solids Recovery

The initial setup for this RCF testing relied upon a backwash flow rate of approximately 7.5 gpm (21 gpm/sf, without air scour) to remove the iron particles captured on the granular media filters. However, increasingly larger iron particles agglomerated with anthracite media began to appear in the filters and were not removed by the backwash water flow alone. On February 19th, an air scour was instituted along with the backwash flow rate (and more filter freeboard to enable effective use of an air scour), which resulted in significantly improved breakup and removal of iron clumps in the filters.

The quantity of backwash water necessary to clean the filters was approximately 38 gallons per column (i.e., 7.5 gpm for 5 minutes). In order to collect enough backwash water for the RCF run incorporating backwash water recycle, the filters were backwashed for a few additional minutes to fill the 100-gallon backwash water holding tank.

As also observed in Phase II testing, an initial polymer dose of 0.2 mg/L did not rapidly clarify the backwash water (i.e., within 20 minutes, corresponding to an overflow rate of 0.125 gpm/sf). Instead, backwash water was effectively settled using a polymer dose of 1.0 mg/L (Magnafloc

Ciba E38). Based on recycle to the head of the plant comprising 4% of the influent flow, a backwash polymer dosage of 1.0 mg/L plus the 0.2 mg/L in the process flow would contribute a maximum of approximately 0.048 mg/L polymer to the influent (assuming none of the polymer is incorporated in the precipitates, which would be unlikely).

Total suspended solids and settleable solids were analyzed for two batches of collected backwash water following the 24-hour runs (February 27th and 28th). Following backwash, the backwash water in the holding tank was mixed using a portable mixer and TSS and settleable solids samples were collected. Physical-chemical results for the backwash water are shown in Table 5-2. The quantities of backwash water for February 27th and 28th runs were 90 and 100 gallons, respectively. After adding 1.0 mg/L of polymer to the tank and mixing for approximately 5 minutes, the backwash water was settled for 32 minutes on February 27th and 1 hour on February 28th. Total Cr and Cr(VI) samples were collected from the settled backwash water.

Table 5-2.
Backwash Water Characterization

Run Start Date	Backwash Water Qty. (gallons)	Mixed BW Water TSS (mg/L)	Settleable Solids (mL/L)	Total Cr (μg/L)	Cr(VI) (μg/L)	Total Iron (mg/L)
Feb. 27, 2008	90	124	3.5	23	<0.1	NA
Feb. 28, 2008	100	70	2.5	30	0.98	1.06

NA = Not analyzed.

During the 24-hour run on February 28th, clarified backwash water was recycled to the influent tank. Solids (and remaining liquid) from the bottom of the backwash tank were removed from the tank and sent through Flo-Trend filter material (Figure 5-16). Particles were captured in the Flo-Trend filter, and the resultant filtrate water had metal concentrations of 0.3 μg/L Cr(VI), 24 μg/L total Cr, and 0.06 mg/L total iron.

De-watered solids captured on the Flo-Trend filter (within an hour after solids separation) were generally characterized as wet and slimy in appearance rather than dry and matted, although solids retained in the upper part of the cone-shaped filter (i.e., given more time to dry) were more dry and matte in appearance. A subsample of the solids was tested for floc “toughness” by mixing the floc in a jar tester at 300 RPM for 5 minutes; the floc broke apart during the mixing and did not resettle within a 30-minute time period.

The volume of backwash water generated for 24-hour filter runs in this pilot testing was approximately 95 gallons (combined quantity arising from two parallel filter backwashes). The 24-hour run time at 2 gpm corresponds to 2,880 gallons of water treated; therefore, the backwash water volume was approximately 3.3% of the flow. Previous estimates of 4% backwash water volume[1] were considered similar, since longer backwashing periods than used in pilot testing may be desired to more thoroughly clean the filters in continuous operation.

Figure 5-16: Flo-Trend Solids Separation of Backwash Water Solids

Settleable solids generated in this testing revealed that approximately 3 mL/L were generated, representing 0.3% of the backwash water as settled sludge. By comparison, cost estimates were calculated using 0.58% as the percentage of backwash water as settled sludge, which provided a more conservative estimate of waste generated by the RCF process.

Solids production was estimated using the following equation[2]:

$$S = 8.34\ Q\ (2.9\ Fe)$$

where, S is the sludge produced (lb dry sludge per day), Q is the plant flow (mgd), and Fe is the iron concentration introduced (mg/L as Fe). This equation is used for the production of $Fe(OH)_3 \cdot 3H_2O$ solids. A 534 gpm RCF system, for example, would generate 47 lbs/day of dry sludge.

Previously[1], assumptions of 3% solids in (thickened) settled sludge and 80% filter press dewatering efficiency estimated the tonnage of solids produced (51 tons per year). Flo-Trend could not provide a dewatering efficiency[3], but indicated that filter presses generate a 2 to 5% drier cake compared with the Flo-Trend units. Assuming that the dewatering efficiency of 3% solid sludge by the Flo-Trend unit is 75%, the tonnage of solids produced will be approximately 64 tons per year.

[1] Used in O&M cost estimates for the RCF technology.
[2] Cornwell, D.A. 1999. Water Treatment Plant Residuals Management. In: *Water Quality and Treatment*, 5th ed.
[3] Conversation with Russ Caughman of Flo-Trend, March 10, 2008.

Alternately, if the Flo-Trend system generates a residual stream that is 8% solids without thickening (as is occurring in some of their arsenic treatment systems), the quantity of wet solids produced would be approximately 106 tons per year.

After the pilot study was terminated, inspection of the tanks and pipes showed only a moderate staining of the materials caused by ferric iron. No significant buildup of any scale was noted.

5.8. QA/QC Data

QA/QC samples for Cr(VI) and total Cr analyses included the following:

- Field-collected duplicate samples were collected to determine the representative nature of the samples and the degree to which the samples reflect actual field conditions
- Matrix spike samples that were used to assess the accuracy of measurements in the laboratory
- Matrix spike duplicates to ensure precision of laboratory measurements
- Laboratory reagent blank samples that are used to determine the PQL of the analytical procedure and to detect potential problems in the sample collection and preservation methods
- Laboratory control samples or continuing calibration verification samples to determine analytical precision and check for continuing instrument calibration

Table 5-3 shows the results of the field-collected duplicate samples for both total Cr and Cr(VI) with relative percent difference (RPD) values. Excellent agreement between the samples was observed in all cases. In summary, all other QA/QC results provided by the laboratory, including matrix spike duplicates, laboratory reagent blanks, and laboratory control samples or continuing calibration verification samples, were within acceptable ranges as noted in the laboratory reports.

Table 5-3.
Quality Control Sample Results During RCF Pilot Testing

Date	Sample ID	QC Sample ID	Total Cr			Cr(VI)		
			Sample Result	QC Sample Result	RPD (%)	Sample Result	QC Sample Result	RPD (%)
2/5/2008	SP-311-E01	A1	12	12	0	0.72	0.69	4.3
2/6/2008	SP-311-M02	A2	3.2	3.2	0	<0.1	<0.1	NA
2/11/2008	SP-311-E04	A3	2.7	2.7	0	<0.1	<0.1	NA
2/12/2008	SP-311-M05	A4	<1	<1	NA	<0.1	<0.1	NA
2/13/2008	Blank	A5	-	<1	NA	-	<0.1	NA
2/14/2008	SP-010-M07	A6	77	77	0	83	83	0
2/15/2008	SP-311-E08	A7	<1	<1	NA	<0.1	<0.1	NA
2/22/2008	SP-010-E12	A8	98	98	0	103	104	1.0
2/25/2008	Blank	A9		<1	NA		<0.1	NA
2/26/2008	SP-311-M14	A10	<1	<1	NA	<0.1	<0.1	NA
2/27/2008	SP-010-E15	A11	113	110	2.7	114	114	0
2/29/2008	SP-010-M17	A12	-	-	NA	117	115	1.7
3/12/2008	SP-311-6HR	A13	<1	<1	NA	<0.1	<0.1	NA
3/12/2008	Blank	A14	-	<1	NA	-	<0.1	NA

NA = Not applicable.

During the pilot study, unexplained high total Cr values in the filter effluents were reported by the contract laboratory. An investigation of potential sources of high total Cr led to the discovery that all of the high total Cr filter effluent values were spurious. MWH Labs determined that the water matrix being analyzed on one of their instruments resulted in a positive interference with total Cr analysis. Although the analytical issues were resolved in this study, researchers and system operators for the demonstration-scale study should be aware of the potential false positive total Cr results in this water matrix.

6. Summary and Recommendations

Additional RCF pilot testing was intended to determine if the RCF demonstration design could be modified to reduce or eliminate unnecessary process components. In fact, the pilot testing revealed that 45 minutes of reduction time (followed by filtration) was successful in reducing Cr(VI) and removing total Cr without the need for an aeration step. The elimination of the aeration process offers a significant cost savings for the RCF demonstration-scale design.

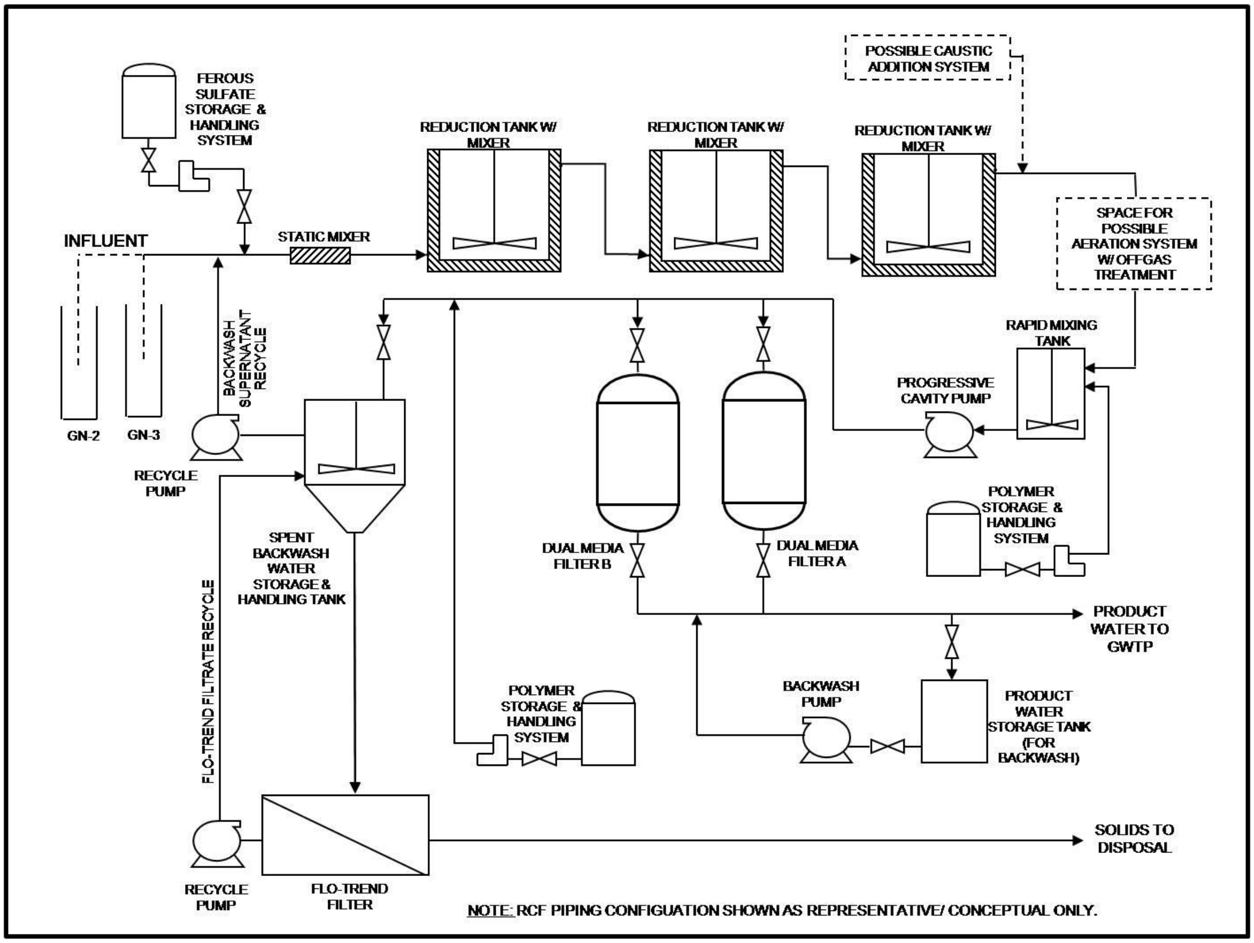
Pilot testing results also provided the following findings with respect to process performance:

- Ferrous sulfate reduced Cr(VI) concentrations from 100 μg/L to less than 1 μg/L within 15 to 30 minutes.
- In the reduction tanks, approximately 21±10% of the ferrous iron remained after 45 minutes of reduction time, whereas 60±16% of the ferrous iron was present after only 15 minutes of reduction time.
- Aeration effectively oxidized the majority of the ferrous iron; even 6 minutes of aeration lowered ferrous concentrations to less than 0.08 mg/L.
- Runs conducted without aeration resulted in filter effluent ferrous iron concentrations of less than 0.03 mg/L, indicating that either additional contact time of the ferrous iron with dissolved oxygen or air entrainment during the rapid mix/polymer addition step oxidized the remaining ferrous iron to ferric iron.
- Total Cr filter effluent concentrations greater than 5 μg/L were coupled with relatively high filter effluent turbidity values (greater than 1 NTU) and high total iron concentrations (greater than 0.19 mg/L).
- Filter run times of 24 hours resulted in a increase across the filter beds of only 0.5 psi (14 inches of water) through the optimized run (45 min. reduction time/0 min. aeration). Based on these results, filter run time to breakthrough for this optimized case would be more dependent on turbidity/iron (and hence, Cr) breakthrough rather than pressure buildup. By comparison, 24-hour runs with 18 minutes of aeration resulted in a much larger pressure increase of 4.9 to 5.1 psi (139 inches of water).
- Magnafloc Ciba E38 anionic polymer was effective in process floc formation (at a concentration of 0.1 ppm) as well as backwash water settling (at a dose of 1 mg/L). Nalco 9901 polymer formed a larger floc and did not effectively remove total Cr by the filters.
- Backwash water settling and recycle of the clarified water (corresponding to 4% of the flow) did not negatively impact the RCF process performance and offers a means of reducing water losses in the treatment process.
- Passive filtration using a technology akin to the Flo-Trend system was effective in dewatering the sludge and producing filtrate water quality low in total Cr and iron.
- No significant scale buildup in the pilot filter tanks and pipes was noted.

Based on these pilot test findings, we recommend that Glendale design an RCF system with 45 minutes of reduction time, polymer addition in a rapid mix tank after the reduction tanks, and dual-media granular filtration. Figure 6-1 shows a schematic of the proposed demonstration-scale

RCF treatment plant (at approximately 100 gpm). No pH adjustment and no additional aeration (beyond that provided by the dissolved oxygen concentrations in the water) were necessary in the pilot testing, which will result in significant capital cost savings in the RCF system construction. However, during the design process physical space and hydraulic capacity should be included in the demonstration-scale plant design in case pH adjustment and aeration are needed at a later time. Backwash water recycle should be included in the design to minimize water losses and wastewater quantities. A passive means of filtration should be included in the demonstration study since it offers great cost savings over a filter belt press and was found to yield high quality filtrate in the pilot testing. In addition, some specific design considerations for the demonstration-scale RCF system are recommended based on pilot plant operation and listed in Appendix A.

Figure 6-1: Flow schematic of the proposed demonstration-scale RCF treatment plant



7. Acknowledgments

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8. Appendices

Appendix A: Design Suggestions Based on Pilot Plant Operations
Appendix B: As-Built (Final) Process and Instrumentation Diagram and Photos
Appendix C: Data Summary Sheets

Appendix A: Design Suggestion Based on Pilot Plant Operation

Appendix A: Design Suggestions Based on Pilot Plant Operations

The following is a list of suggestions that design engineers may want to consider for the demonstration-scale RCF system. This list is based on the additional RCF pilot testing findings and review comments received for the “Report on Additional RCF Pilot Testing to Optimize Design.”

- Physical space and hydraulic capacity for caustic injection and aeration (with off-gas treatment) should be included in the design
- The design should consider if VOC treatment is necessary. If so, a passive vapor collection system should be designed to collect incidental VOC-bearing air streams from relevant RCF equipments
- The reduction step should take place in three completely stirred reactors (t_D = 15 minutes each) operated in series that are open to the atmosphere.
- Polymer addition should take place in a completely stirred tank open to the atmosphere (t_D = 5 minutes)
- All transfer pumps after the reduction step are recommended to be positive displacement type to help maintain integrity of Fe/Cr floc through the filtration process
- The construction material of the equipment and/or piping in contact with process liquids and/or sludge should be smooth to minimize precipitate build-up. PVC could be the material of choice due to its low surface roughness
- Iron precipitates are anticipated to accumulate throughout the treatment process. Consequently, each of the process equipment should plan for periodic precipitate removal. Cone-bottom reaction/reduction tanks are recommended for the precipitate removal activities
- The GAC effluent from GWTP (upstream of chlorination) might be used for backwashing the filters, thus eliminating backwash water storage tank and pump
- Filter design should include a vigorous backwash system (including air and water) with sufficient freeboard to expand and thoroughly clean the media. Periodic inspection of the media and sampling to detect “mudball” formation which means that access, observation and sampling ports should be included in the filter design.
- Hydraulic loading rate for the dual media filters should be 3 gpm/sf. A sufficient number of filters should be included in the final design so that the hydraulic rate for the filters does not exceed 3 gpm/sf when one of the filters is being backwashed.
- Backwash water recycle should be included in the design to minimize water losses and wastewater quantities.
- A passive means of filtration should be included in the demonstration study since it offers great cost savings over a filter belt press and was found to yield high quality filtrate in the pilot testing. In the preliminary design step, equipment manufactured by Flow Trend should be considered (http://www.flotrend.com/).

Appendix B: As-Built (Final) Process and Instrumentation Diagram and Photos

PIPING AND INSTRUMENTATION DIAGRAM

PILOT SCALE SYSTEM FOR
REDUCTION COAGULATION FILTRATION TESTING

GLENDALE, CA

REV	DATE	DESCRIPTION	DRAWN BY	CHECKED BY	APPROVED BY
2	02/29/08	TEST CONFIGURATION	DL	TB	N/A
1	01/25/08	AS BUILT	DL	TB	N/A
0	12/07/07	INITIAL RELEASE	DL	TB	N/A

CUSTOMER / PROJECT

PILOT SCALE R.C.F. SYSTEM
GLENDALE, CA

AVANTech INCORPORATED

PROCESS AND INSTRUMENTATION DIAGRAM
COVER PAGE

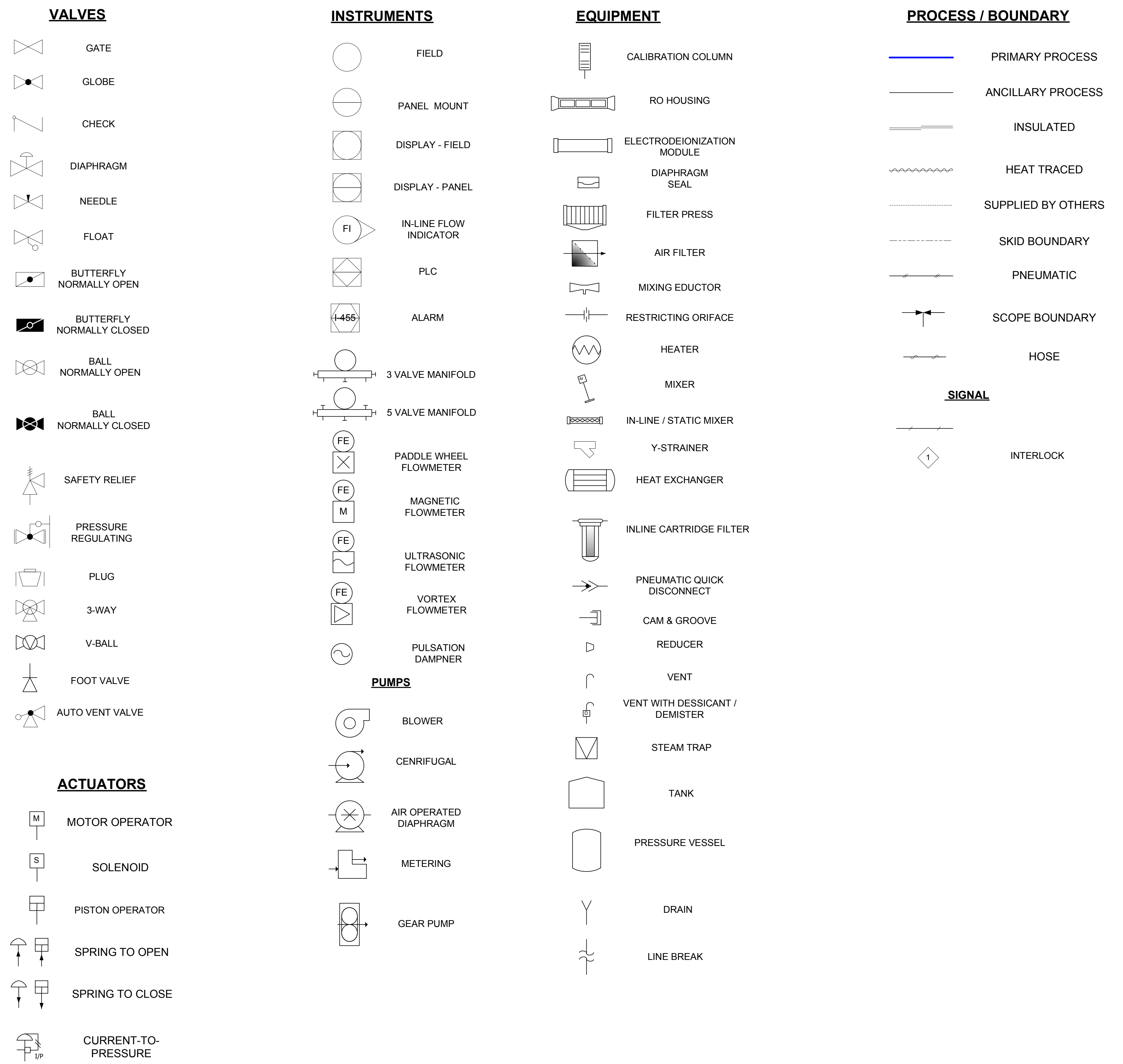
JOB NO. 07-12

FILE ID. 0G2000201-0712-D.VSD

DIMENSIONS IN INCHES UNLESS SPECIFIED

SIZE	DRAWING NUMBER	REV.
D	0G200-0712-D	2

SCALE: WT.: SHEET 1 OF 3



INSTRUMENT LETTER CODES

- A ANALYZER, ALARM, ANALOG
- C CONDUCTIVITY, CONTROL, CLOSED
- D CONCENTRATION, DENSITY, TURBIDITY, DIFFERENTIAL, DIGITAL, DISCRETE, FAULT, DRIVE
- E PRIMARY ELEMENT, VOLTAGE
- F FLOW, FLOW RATE
- G GAUGE, SITE GLASS
- H HAND SWITCH, HIGH, HIGH-HIGH
- I INDICATOR, ELECTRIC CURRENT, INPUT
- L LEVEL, PILOT LAMP, LOW, LOW-LOW
- O ORIFACE PLATE, OUTPUT, OPEN
- P PRESSURE / VACUUM
- Q QUANTITY, INTEGRATE, TOTALIZE
- R RESISTIVITY, RECORDER
- S SWITCH, SPEED, SOLENOID
- T TEMPERATURE, TRANSMIT, TEE
- V CONTROL DEVICE OR VALVE, VALVE, VIBRATION, VARIABLE
- W WEIGHT OR FORCE, WELL
- Y RELAY, EVENT
- Z ACTUATOR, POSITION, DIMENSION

EQUIPMENT ABBREVIATIONS

- A ACTUATOR
- AC AIR COMPRESSOR
- AV ACTUATED VALVE
- AVV AUTOMATIC VENT VALVE
- CF COALESCING FILTER
- M MOTOR
- MC MOTOR CONTROL
- PF PARTICULATE FILTER
- P PUMP
- PV PRESSURE VESSEL
- MV MANUAL VALVE
- PRV PRESSURE REGULATING VALVE
- SP SAMPLE POINT
- SRV SAFETY RELIEF VALVE
- TK TANK
- TS TRAVEL STOP
- VC VARIABLE SPEED CONTROLLER

NOTE: Except as noted, all automatic valves fail in their normal operating position.

REV	DATE	DESCRIPTION	DRAWN BY	CHECKED BY	APPROVED BY
2	02/29/08	TEST CONFIGURATION	DL	TB	N/A
1	01/25/08	AS BUILT	DL	TB	N/A
0	12/07/07	INITIAL RELEASE	DL	TB	N/A

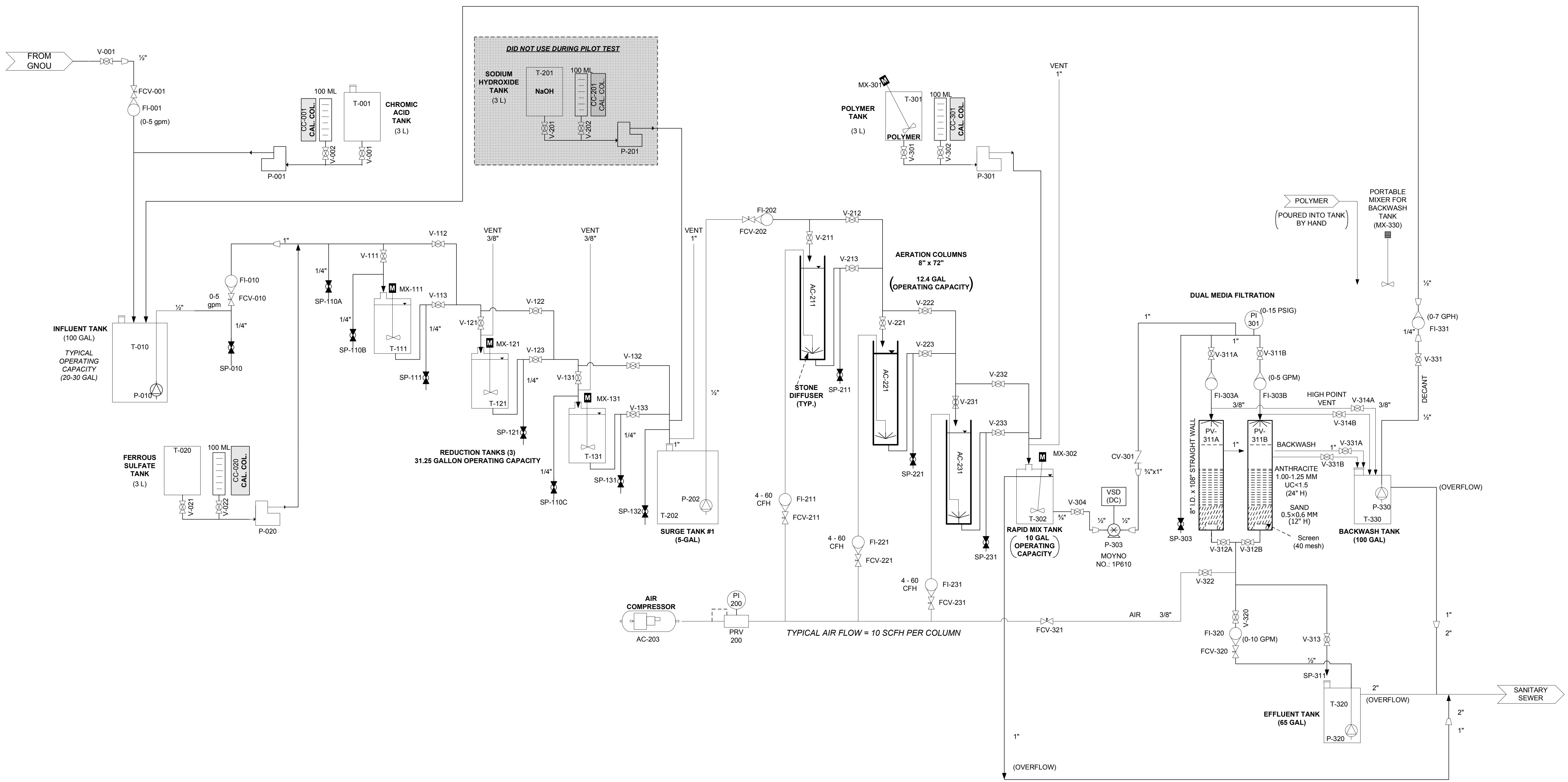
CUSTOMER / PROJECT
PILOT SCALE R.C.F. SYSTEM
GLENDALE, CA

JOB NO. 07-12
FILE ID. 0G2000202-0712-D.VSD
DIMENSIONS IN INCHES UNLESS SPECIFIED

AVANTech INCORPORATED

WATER TREATMENT SYSTEM LEGEND

SIZE: D | DRAWING NUMBER: 0G200-0712-D | REV. 2
SCALE: | WT.: | SHEET 2 OF 3



REV	DATE	DESCRIPTION	DRAWN BY	CHECKED BY	APPROVED BY
2	02/29/08	TEST CONFIGURATION	DL	TB	N/A
1	01/25/08	AS BUILT	DL	TB	N/A
0	12/07/07	INITIAL RELEASE	DL	TB	N/A

CUSTOMER / PROJECT

PILOT SCALE R.C.F. SYSTEM
GLENDALE, CA

JOB NO. 07-12

FILE ID. 0G2000203-0712-D.VSD

DIMENSIONS IN INCHES UNLESS SPECIFIED

AVANTech INCORPORATED

PROCESS AND INSTRUMENTATION DIAGRAM
WELL WATER TREATMENT SYSTEM

SIZE: D | DRAWING NUMBER: 0G200-0712-D | REV. 2

SCALE: | WT.: | SHEET 3 OF 3

Photos of the RCF Pilot Testing Equipment

Figure B-1. Chemical Feed Pumps

Figure B-2. Chemical Feed Day Tanks (White PVC columns)

Figure B-3. Cr(VI)-Spiked Influent Tank and Three Reduction Tanks in Series

Figure B-4. Three Aeration Columns in Series and Rapid Mix Tank

Figure B-5. Progressive Cavity Pump Between the Rapid Mix and Filter Columns

Figure B-6. Parallel Filtration Columns and Effluent Tank

Figure B-7. Floc Retention in the Granular Media Filter (24-hour run on 2/28/08)

Figure B-8. Start of Filter Backwashing (Overflow of backwash water)

Figure B-9. End of Filter Backwashing (Overflow of backwash water)

Figure B-10. Backwash Water Holding Tank

Appendix C: Data Summary Sheets

Date:	2/4/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	15:1
Reduction Time	45 min
Aeration Time	18 min
Polymer and Dose	Nalco 9901 - 0.2 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	N/A

			Lab Results			**Field results**								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI) (ppb)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning												
		SP-010 Middle												
		SP-010 End	104	98										
SP-110	Fe-spiked Influent	SP-110 Beginning												
		SP-110 Middle				0.001	1.15	0.49						
		SP-110 End					0.96	0.63						
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle												
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle												
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle	0.23											
		SP-131 End												
SP-231	Aeration Effluent	SP-231 Beginning												
		SP-231 Middle	<0.1											
		SP-231 End												
SP-311	Filter Effluent	SP-311 Beginning												
		SP-311 Middle												
		SP-311 End	<0.1	6.6										
		SP-311 Hr 1												
		SP-311 Hr 2												
		SP-311 Hr 3												
		SP-311 Hr 4												
		SP-311 Hr 5												
		SP-311 Hr 6												
		SP-311 Hr 7												
		SP-311 Hr 8												
BW Tank	Settled BW Water	BW Beginning												
		BW Middle												
		BW End												
BW Tank	Mixed BW Water	BW End												
Flo Trend Filtrate														

Date:	2/5/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1
Reduction Time	45 min.
Aeration Time	18 min.
Polymer and Dose	Nalco 9901 - 0.2 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	N/A

			Lab Results			**Field results**								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI) (ppb)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning				100								
		SP-010 Middle	90	110					7.20	21.4			6.5	
		SP-010 End	94	89					7.09	21.9		0.11	6.6	
SP-110	Fe-spiked Influent	SP-110 Beginning					2.24	1.52						
		SP-110 Middle					2.68		7.35	21.0				
		SP-110 End					1.80	0.96	7.15	21.9		2.27		
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle				11								
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle				7								
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle	1.2			0			7.32	21.2			7.8	
		SP-131 End					1.17	0.00	7.29	22.2			7.6	
SP-231	Aeration Effluent	SP-231 Beginning												
		SP-231 Middle	0.42						7.84	20.8			9.4	
		SP-231 End					1.23	0.01	7.80	22.6			8.7	
SP-311	Filter Effluent	SP-311 Beginning												
		SP-311 Middle	0.18	11			0.25	0.00	7.92	20.3				
		SP-311 End	0.72	12			0.19	0.01	7.89	22.8				
		SP-311 Hr 1										2.59		
		SP-311 Hr 2 (M)										1.94		
		SP-311 Hr 3										1.68		
		SP-311 Hr 4										1.24		
		SP-311 Hr 5 (E)										1.20		
		SP-311 Hr 6												
		SP-311 Hr 7												
		SP-311 Hr 8												
BW Tank	Settled BW Water	BW Beginning												
		BW Middle												
		BW End												
BW Tank	Mixed BW Water	BW End												
Flo Trend Filtrate														

Date:	2/6/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1
Reduction Time	45 min.
Aeration Time	18 min.
Polymer and Dose	Nalco 9901- 0.2 ppm (7:30-9:45am), Ciba E40 - 0.38 ppm (9:45am to end)

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	N/A

			Lab Results			**Field results**								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning				109								
		SP-010 Middle	112	100		117			7.38	20.8			7.4	
		SP-010 End	106	98					7.19	21.7		0.13	6.7	
SP-110	Fe-spiked Influent	SP-110 Beginning					2.81	1.30						
		SP-110 Middle					2.07	1.13	7.19	20.6				
		SP-110 End							7.23	21.5		3.07		
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle				3								
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle				4								
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle	<0.1			4	4.11	0.05	7.31	21.2			8.2	
		SP-131 End					3.34	0.04					7.7	
SP-231	Aeration Effluent	SP-231 Beginning												
		SP-231 Middle	<0.1				4.05	0.02	7.77	20.7			9.7	
		SP-231 End					3.31	0.02	7.82	22.1			8.6	
SP-311	Filter Effluent	SP-311 Beginning												
		SP-311 Middle	<0.1	3.2			0.25	0.00	7.84	20.5				
		SP-311 End	<0.1	<1			0.13	0.01	7.95	23.1				
		SP-311 Hr 1										2.28		
		SP-311 Hr 2 (M)										1.98		
		SP-311 Hr 3										0.51		
		SP-311 Hr 4										0.51		
		SP-311 Hr 5										0.95		
		SP-311 Hr 6 (E)										0.77		
		SP-311 Hr 7												
		SP-311 Hr 8												
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														

Date:	2/7/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1
Reduction Time	45 min.
Aeration Time	18 min.
Polymer and Dose	Nalco 9901 - 0.2 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	N/A

			Lab Results			**Field results**								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning				11	0.01	0.00	7.09	20.8	194.6	0.13	6.1	
		GNOU Raw Middle				118								
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning												
		SP-010 Middle												
		SP-010 End												
SP-110	Fe-spiked Influent	SP-110 Beginning					2.16	1.04						
		SP-110 Middle					3.03	1.45						
		SP-110 End												
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle												
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle												
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle												
		SP-131 End												
SP-231	Aeration Effluent	SP-231 Beginning												
		SP-231 Middle												
		SP-231 End												
SP-311	Filter Effluent	SP-311 Beginning												
		SP-311 Middle												
		SP-311 End												
		SP-311 Hr 1										1.20		
		SP-311 Hr 2										0.77		
		SP-311 Hr 3										0.83		
		SP-311 Hr 4										0.80		
		SP-311 Hr 5												
		SP-311 Hr 6												
		SP-311 Hr 7												
		SP-311 Hr 8												
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														

Date:	2/11/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1 ferrous target rather than usual total iron target
Reduction Time	45 min.
Aeration Time	18 min.
Polymer and Dose	Nalco 9901 - 0.2 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	2 (after 2.5 hrs); backwashed then

			Lab Results			Field results								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning				118								
		SP-010 Middle	120	117		130			7.32	21.5			6.5	
		SP-010 End							7.36	22.4		0.20	6.7	
SP-110	Fe-spiked Influent	SP-110 Beginning					3.45	1.88						
		SP-110 Middle					4.93	2.77	7.27	22.1				
		SP-110 End							7.23	22.4		4.39		
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle				0								
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle				0								
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle	<0.1			0	4.48	0.14	7.34	21.8			8.5	
		SP-131 End					3.94	0.16					7.8	
SP-231	Aeration Effluent	SP-231 Beginning												
		SP-231 Middle	<0.1				4.40	0.03	7.80	21.4			9.1	
		SP-231 End					3.88	0.02	7.84	23.5			9.1	
SP-311	Filter Effluent	SP-311 Beginning												
		SP-311 Middle	<0.1	3.2			0.20	0.01	7.88	21.1				
		SP-311 End	<0.1	2.7			0.13	0.00	7.92	24.2				
		SP-311 Hr 1										1.23		
		SP-311 Hr 2										0.99		
		SP-311 Hr 2.5(M)										1.07		
		SP-311 Hr 3.5										2.26		
		SP-311 Hr 4										1.37		
		SP-311 Hr 5										1.09		
		SP-311 Hr 6 (E)										0.93		
		SP-311 Hr 8												
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														

Date:	2/12/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1 total iron
Reduction Time	45 min.
Aeration Time	18 min.
Polymer and Dose	Magnafloc Ciba E40 - 0.28ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	0.5

			Lab Results			**Field results**								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning				127								
		SP-010 Middle	96	95		109			7.32	24.4			6.7	
		SP-010 End	94	93					7.31	24.4		0.07	5.9	
SP-110	Fe-spiked Influent	SP-110 Beginning					2.99	1.45						
		SP-110 Middle					2.73	1.21	7.39	24.9				
		SP-110 End					2.20	0.61	7.36	24.8		8.25		
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle												
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle												
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle	<0.1				2.82	0.05	7.48	24.9			7.4	
		SP-131 End					2.52	0.00					8.0	
SP-231	Aeration Effluent	SP-231 Beginning												
		SP-231 Middle	<0.1				2.72	0.05	7.83	24.4			8.8	
		SP-231 End					2.69	0.01	7.93	24.5			8.7	
SP-311	Filter Effluent	SP-311 Beginning												
		SP-311 Middle	<0.1	<1			0.03	0.00	7.97	24.4				
		SP-311 End	<0.1	<1			0.02	0.00	8.03	25.0				
		SP-311 Hr 1										0.32		
		SP-311 Hr 2										0.21		
		SP-311 Hr 3 (M)										0.16		
		SP-311 Hr 4										0.15		
		SP-311 Hr 5 (E)										0.13		
		SP-311 Hr 6												
		SP-311 Hr 7												
		SP-311 Hr 8												
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														

Date:	2/13/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1 total iron
Reduction Time	45 min.
Aeration Time	18 min.
Polymer and Dose	Magnafloc Ciba E40 - 0.26 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	

			Lab Results			**Field results**								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning				119								
		SP-010 Middle	112	105		101			7.34	22.5			6.6	
		SP-010 End	122	120					7.49	21.8		0.08	6.6	
SP-110	Fe-spiked Influent	SP-110 Beginning												
		SP-110 Middle					2.42	0.62	7.30	22.1				
		SP-110 End					2.28	0.75	7.30	21.9		12.3		
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle												
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle												
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle	0.13				2.45	0.04	7.48	22.3			7.9	
		SP-131 End					2.35	0.27					7.6	
SP-231	Aeration Effluent	SP-231 Beginning												
		SP-231 Middle	<0.1				2.65	0.03	7.86	22.3			8.9	
		SP-231 End					2.30	0.07	7.84	21.8			8.9	
SP-311	Filter Effluent	SP-311 Beginning												
		SP-311 Middle	<0.1	<1			0.03	0.00	7.93	22.5				
		SP-311 End	<0.1	1			0.05	0.00	7.93	22				
		SP-311 Hr 1										0.53		
		SP-311 Hr 2										0.49		
		SP-311 Hr 3										0.28		
		SP-311 Hr 4										0.22		
		SP-311 Hr 5										0.22		
		SP-311 Hr 6 (M)										0.21		
		SP-311 Hr 7 (E)										0.22		
		SP-311 Hr 8												
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														

Date:	2/14/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1 total iron
Reduction Time	30 min.
Aeration Time	18 min.
Polymer and Dose	Magnafloc Ciba E40 - 0.26 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	

			Lab Results			**Field results**								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning				123								
		SP-010 Middle	83	77		95			7.45	22.8	165.9		6.5	
		SP-010 End	85	79					7.25	23.0		0.11	6.3	
SP-110	Fe-spiked Influent	SP-110 Beginning												
		SP-110 Middle					2.33	1.51	7.32	23.3	-89.6			
		SP-110 End					2.52	1.15	7.18	23.1		7.82		
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle												
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle	0.37				2.23	0.24	7.58	23.4	-49.7		7.6	
		SP-121 End					2.47	0.27					7.5	
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle												
		SP-131 End												
SP-231	Aeration Effluent	SP-231 Beginning												
		SP-231 Middle	<0.1				2.25	0.02	7.94	22.8	151.1		8.8	
		SP-231 End					2.25	0.02	7.79	23.8			9.7	
SP-311	Filter Effluent	SP-311 Beginning												
		SP-311 Middle	<0.1	1.7			0.06	0.00	7.96	21.9				
		SP-311 End	<0.1	1.5			0.05	0.00	7.88	23.8				
		SP-311 Hr 1										0.65		
		SP-311 Hr 2										0.49		
		SP-311 Hr 3										0.39		
		SP-311 Hr 4 (M)										0.40		
		SP-311 Hr 5										0.37		
		SP-311 Hr 6 (E)										0.43		
		SP-311 Hr 7												
		SP-311 Hr 8												
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														

Date:	2/15/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1 total iron
Reduction Time	15 min.
Aeration Time	18 min.
Polymer and Dose	Magnafloc Ciba E40 - 0.26 ppm until 8:15; resumed at 1:30 pm - 0.1 ppm dose

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	

			Lab Results			Field results								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning	94	89		100								
		SP-010 Middle	100	96		106			7.2	23.8			6.8	
		SP-010 End	104	98										
SP-110	Fe-spiked Influent	SP-110 Beginning					2.85	1.67						
		SP-110 Middle					2.70	1.16	7.24	24.2				
		SP-110 End												
SP-111	After Red. Tank 1	SP-111 Beginning					2.65	0.91						
		SP-111 Middle	1.5				2.67	0.82	7.32	24.2			7.0	
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle												
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle												
		SP-131 End												
SP-231	Aeration Effluent	SP-231 Beginning					2.49	0.02						
		SP-231 Middle	<0.1				2.65	0.02	7.75	24.2			8.4	
		SP-231 End												
SP-311	Filter Effluent	SP-311 Beginning	<0.1	<1		7	0.03	0.00						
		SP-311 Middle	<0.1	<1			0.04	0.00	7.84	24.3				
		SP-311 End	<0.1	<1										
		SP-311 Hr 1										1.09		
		SP-311 Hr 2										0.19		
		SP-311 Hr 3										0.17		
		SP-311 Hr 4										0.15		
		SP-311 Hr 5 (M)										0.14		
		SP-311 Hr 6.5 (E)										0.11		
		SP-311 Hr 7												
		SP-311 Hr 8												
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														

Date:	2/19/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1 total iron
Reduction Time	45 min.
Aeration Time	12 min.
Polymer and Dose	Magnafloc Ciba E40 - 0.092 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	0

			Lab Results			Field results								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning				116								
		SP-010 Middle	116	110		125			7.28	22.5	155.6		6.9	
		SP-010 End	127	120					7.20	21.6			7.0	
SP-110	Fe-spiked Influent	SP-110 Beginning					2.24	0.97						
		SP-110 Middle					2.35	1.43	7.23	22.2	-84.2			
		SP-110 End					2.21	1.03	7.34	20.7				
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle												
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle												
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle	0.21				2.10	0.22	7.46	23.3	-58		7.9	
		SP-131 End					2.16	0.24					7.7	
SP-231	Aeration Effluent	SP-231 Beginning					2.23	0.02						
		SP-231 Middle	<0.1				1.99	0.02	7.79	22.6	145.1		9.3	
		SP-231 End					2.17	0.03	7.79	21.9			9.5	
SP-311	Filter Effluent	SP-311 Beginning					0.07							
		SP-311 Middle	0.12	1.4			0.09	0.00	7.89	22.0				
		SP-311 End	<0.1	<1			0.03	0.00	7.85	20.2				
		SP-311 Hr 1										0.30		
		SP-311 Hr 2										0.26		
		SP-311 Hr 3										0.19		
		SP-311 Hr 4 (M)										0.26		
		SP-311 Hr 5										0.22		
		SP-311 Hr 6										0.24		
		SP-311 Hr 7 (E)										0.16		
		SP-311 Hr 8										0.27		
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														

Date:	2/20/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1 total iron
Reduction Time	45 min.
Aeration Time	6 min.
Polymer and Dose	Magnafloc Ciba E40 - 0.085 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	1

			Lab Results			Field results								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning	115	100		136			7.37	23.1	155.1		7.0	
		SP-010 Middle				123								
		SP-010 End	109	96					7.18	22.1		0.11	6.8	
SP-110	Fe-spiked Influent	SP-110 Beginning					2.29	1.16	7.25	21.4	-77.1			
		SP-110 Middle												
		SP-110 End					1.88	1.24	7.27	22.3		5.63		
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle												
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle												
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning	0.28				2.04	0.14	7.57	22.8	-65.8		8.2	
		SP-131 Middle												
		SP-131 End					1.72	0.17					8.0	
SP-231	Aeration Effluent	SP-231 Beginning	0.21				2.01	0.05	7.86	23.1	150.4		8.8	
		SP-231 Middle					1.99							
		SP-231 End					1.72	0.02	7.73	23.1			8.7	
SP-311	Filter Effluent	SP-311 Beginning	<0.1	<1			0.09	0.00	7.90	21.5				
		SP-311 Middle					0.03							
		SP-311 End	0.21	<1			0.02	0.00	7.79	23.3				
		SP-311 Hr 1										0.35		
		SP-311 Hr 2										0.23		
		SP-311 Hr 3 (B)										0.19		
		SP-311 Hr 4												
		SP-311 Hr 5 (M)										0.21		
		SP-311 Hr 6										0.20		
		SP-311 Hr 7 (E)										0.15		
		SP-311 Hr 8												
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														

Date:	2/21/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1 total iron
Reduction Time	30 min.
Aeration Time	6 min.
Polymer and Dose	Magnafloc Ciba E40 - 0.085 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	<1

			Lab Results			Field results								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning				118								
		SP-010 Middle	99	115		120			7.19	22.1	118.8		6.6	
		SP-010 End	89	87					7.40	21.3		0.08	6.9	
SP-110	Fe-spiked Influent	SP-110 Beginning												
		SP-110 Middle					2.97	1.11	7.17	23.4	-98.9			
		SP-110 End					3.32	1.15	7.36	21.6		9.61		
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle												
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle												
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle	0.11				2.75	0.44	7.50	23.6	-81		8.1	
		SP-131 End					2.90	0.22	7.58	22.1			8.4	
SP-231	Aeration Effluent	SP-231 Beginning												
		SP-231 Middle	<0.1				2.86	0.07	7.71	24.0	110.2		8.7	
		SP-231 End					2.84	0.06	7.7	22.2			9.3	
SP-311	Filter Effluent	SP-311 Beginning												
		SP-311 Middle	<0.1	<1			0.03	0.06	7.81	23.5				
		SP-311 End	<0.1	<1			0.16	0.00	7.79	22.6				
		SP-311 Hr 1										0.45		
		SP-311 Hr 2										0.31		
		SP-311 Hr 3										0.30		
		SP-311 Hr 4												
		SP-311 Hr 5										0.21		
		SP-311 Hr 6 (M)										0.21		
		SP-311 Hr 7 (E)										0.22		
		SP-311 Hr 8												
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														
0.2 filtered SP-31	Filter Effluent	SP-311 End		<1										

Date:	2/22/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1 total iron
Reduction Time	15 min.
Aeration Time	12 min.
Polymer and Dose	Magnafloc Ciba E40 - 0.095 ppb

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	0

			Lab Results			Field results								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning				16	0.01	0	7.11	22.3	173.1	0.10	6.2	
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning				115								
		SP-010 Middle	22	21		20			7.31	22.9	165		6.4	
		SP-010 End	103	98		116			7.21	22.4		0.12	7.0	
SP-110	Fe-spiked Influent	SP-110 Beginning					3.21	1.56						
		SP-110 Middle					2.99	1.16	7.24	22.4	-121.9			
		SP-110 End					3.07	1.6	7.20	23.1		9.87		
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle												
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle												
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle	0.3				2.72	0.64	7.40	23.2	-102.2		6.4	
		SP-131 End					2.86	0.87	7.30	23.1			7.3	
SP-231	Aeration Effluent	SP-231 Beginning												
		SP-231 Middle	<0.1				2.54	0.01	7.75	23.3	159.5		8.6	
		SP-231 End					2.88	0.08	7.70	22.9			9.3	
SP-311	Filter Effluent	SP-311 Beginning												
		SP-311 Middle	<0.1	<1			0.08	0.00	7.85	23.3				
		SP-311 End	<0.1	<1			0.02	0.00	7.78	23.0				
		SP-311 Hr 1										0.46		
		SP-311 Hr 2										0.29		
		SP-311 Hr 3										0.26		
		SP-311 Hr 4 (M)										0.25		
		SP-311 Hr 5										0.24		
		SP-311 Hr 6										0.22		
		SP-311 Hr 7 (E)										0.23		
		SP-311 Hr 8												
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														
0.2 filtered SP-31	Filter Effluent	SP-311 End		<1										

Date:	2/25/2008		
Experimental Conditions:			
Fe:Cr Dose Ratio Target	25:1 total iron		
Reduction Time	45 min.		
Aeration Time	0 min. (columns bypassed)	Flow Rate (gpm):	2
Polymer and Dose	Magnafloc Ciba E40 - 0.094 ppm	Change in Pressure Over Run (psi):	0.5

			Lab Results			Field results								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning				102								
		SP-010 Middle	100	96		117			7.36	22.6	160.8		7.5	
		SP-010 End	107	100					7.22	23.8		0.14	6.6	
SP-110	Fe-spiked Influent	SP-110 Beginning					2.97	1.07						
		SP-110 Middle					2.87	1.35	7.26	22.3	-108.6			
		SP-110 End					3.05	1.24	7.16	23.7		10.4		
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle												
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle												
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle	<0.1				2.70	0.25	7.48	23.0	-80.2		8.2	
		SP-131 End					2.87	0.14	7.42	23.5			8.0	
SP-231	Aeration Effluent	SP-231 Beginning												
		SP-231 Middle												
		SP-231 End												
SP-311	Filter Effluent	SP-311 Beginning												
		SP-311 Middle	<0.1	<1			0.04	0.01	7.61	22.4				
		SP-311 End	<0.1	<1			0.03	0.00	7.55	23.3				
		SP-311 Hr 1										0.39		
		SP-311 Hr 2										0.27		
		SP-311 Hr 3 (M)										0.20		
		SP-311 Hr 4										0.19		
		SP-311 Hr 5										0.18		
		SP-311 Hr 6 (E)										0.21		
		SP-311 Hr 7												
		SP-311 Hr 8												
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														
0.2 filtered SP-31	Filter Effluent	SP-311 End		<1										

Date:	2/26/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1 total iron
Reduction Time	45 min.
Aeration Time	18 min.
Polymer and Dose	Magnafloc Ciba E38 (first day) - 0.1 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	1.1

			Lab Results			**Field results**								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning				110								
		SP-010 Middle	103	100		110			7.24	20.4	154.4		6.7	
		SP-010 End	110	104					7.26	23.5		0.10	6.5	
SP-110	Fe-spiked Influent	SP-110 Beginning					2.96	1.07						
		SP-110 Middle					2.66	1.65	7.19	24.5	-108.2			
		SP-110 End					2.66	1.01	7.25	24.3		8.94		
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle												
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle												
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle	<0.1				2.59	0.22	7.42	23.9	-84.7		7.7	
		SP-131 End					2.54	0.11	7.51	23.7			7.4	
SP-231	Aeration Effluent	SP-231 Beginning												
		SP-231 Middle	<0.1				2.60	0.01	7.85	23.8	137.9		8.6	
		SP-231 End					2.50	0.01	7.90	24.3			8.3	
SP-311	Filter Effluent	SP-311 Beginning												
		SP-311 Middle	<0.1	<1			0.02	0.00	7.90	23.8				
		SP-311 End	<0.1	<1			0.03	0.00	7.95	24.2				
		SP-311 Hr 1										0.25		
		SP-311 Hr 2										0.22		
		SP-311 Hr 3										0.17		
		SP-311 Hr 4 (M)										0.14		
		SP-311 Hr 5										0.13		
		SP-311 Hr 6 (E)										0.15		
		SP-311 Hr 7												
		SP-311 Hr 8												
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														
0.2 filtered SP-31	Filter Effluent	SP-311 Middle		<1										

Date:	2/27/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1 total iron
Reduction Time	45 min.
Aeration Time	18 min.
Polymer and Dose	Magnafloc Ciba E38 (first day) - 0.1 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	5.1

			Lab Results			Field results								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Hr 2				98								
		SP-010 Hr 3	109	104		81			7.45	22.8	154.8		6.2	
		SP-010 Hr 6	114	113		128			7.34	23.2			6.5	
		SP-010 Hr 12		110		133								
		SP-010 Hr 18		110		93								
		SP-010 Hr 24		100		124								
SP-110	Fe-spiked Influent	SP-110 Hr 2					2.81	0.79						
		SP-110 Hr 3					2.83	0.71	7.37	24.1	-91.8	0.16		
		SP-110 Hr 6					2.91	0.72	7.27	24.0		6.61		
		SP-110 Hr 12					2.92							
		SP-110 Hr 18					2.25							
		SP-110 Hr 24					2.46							
SP-131	After Red. Tank 3	SP-131 Hr 2												
		SP-131 Hr 3	<0.1				2.83	0.06	7.45	23.4	-43.8		7.5	
		SP-131 Hr 6					2.85	0.14	7.39	23.7			6.1	
		SP-131 Hr 12					2.93							
		SP-131 Hr 18					1.98							
		SP-131 Hr 24					2.38							
SP-231	Aeration Effluent	SP-231 Hr 2												
		SP-231 Hr 3	<0.1				2.57	0.01	7.85	23.2	36.7		8.1	
		SP-231 Hr 6					2.71	0.01	7.93	23.6			7.3	
		SP-231 Hr 12					2.73							
		SP-231 Hr 18					1.94							
		SP-231 Hr 24					2.38							
SP-311	Filter Effluent	SP-311 Hr 1										0.28		
		SP-311 Hr 2										0.22		
		SP-311 Hr 3	<0.1	<1			0.06	0.00	7.90	23.7		0.19		
		SP-311 Hr 4										0.18		
		SP-311 Hr 5										0.14		
		SP-311 Hr 6	<0.1	<1			0.02	0.01	7.99	23.9		0.13		
		SP-311 Hr 7										0.12		
		SP-311 Hr 8										0.11		
		SP-311 Hr 9										0.09		
		SP-311 Hr 10										0.11		
		SP-311 Hr 11										0.15		
		SP-311 Hr 12		<1			0.01			21.6		0.08		
		SP-311 Hr 13										0.09		
		SP-311 Hr 14										0.09		
		SP-311 Hr 15										0.11		
		SP-311 Hr 16										0.2		
		SP-311 Hr 17										0.23		
		SP-311 Hr 18		<1			0.01			20.4		0.16		
		SP-311 Hr 19										0.18		
		SP-311 Hr 20										0.21		
		SP-311 Hr 21										0.21		
		SP-311 Hr 22										0.18		
		SP-311 Hr 23										0.16		
		SP-311 Hr 24		<1			0.01					0.07		
BW Tank	Settled BW Water	Settled BW water		23										
BW Tank	Mixed BW Water	Mixed BW water			124									3.5
Flo Trend Filtrate		Flo Trend Filtrate												
0.2 filtered SP-31	Filter Effluent	SP-311 Hr 6		<1										

Date:	2/28/2008
Experimental Conditions:	Backwash water recycle
Fe:Cr Dose Ratio Target	25:1 total iron
Reduction Time	45 min.
Aeration Time	18 min.
Polymer and Dose	Magnafloc Ciba E38 - 0.1 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	4.9

			Lab Results			**Field results**								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle												
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Hr 2				126								
		SP-010 Hr 3	104	100		91			7.31	23.9	67.7		5.8	
		SP-010 Hr 6	101	103		117			7.06	22.3	68.3			
		SP-010 Hr 12		71		83								
		SP-010 Hr 18		67		80								
		SP-010 Hr 24	103	99		112								
SP-110	Fe-spiked Influent	SP-110 Hr 2					2.12	0.98						
		SP-110 Hr 3					2.29	0.60	7.40	24.5	-99.7			
		SP-110 Hr 6					2.72	0.93	7.30	22.6	-100.9			
		SP-110 Hr 12					1.77							
		SP-110 Hr 18					2.14							
		SP-110 Hr 24					2.78							
SP-131	After Red. Tank 3	SP-131 Hr 2												
		SP-131 Hr 3	0.13				2.26	0.18	7.51	24.6	-69.2		6.4	
		SP-131 Hr 6					2.65	0.37	7.27	22.8	-73			
		SP-131 Hr 12					2.43							
		SP-131 Hr 18					2.33							
		SP-131 Hr 24					2.68							
SP-231	Aeration Effluent	SP-231 Hr 2												
		SP-231 Hr 3	<0.1				2.15	0.01	7.91	24.6	41.6		7.0	
		SP-231 Hr 6					2.50	0.17	7.67	23.0	16.9			
		SP-231 Hr 12					2.36							
		SP-231 Hr 18					2.33							
		SP-231 Hr 24					2.55							
SP-311	Filter Effluent	SP-311 Hr 1										0.26		
		SP-311 Hr 2										0.16		
		SP-311 Hr 3	<0.1	<1			0.04	0.00	7.91	24.3		0.12		
		SP-311 Hr 4										0.12		
		SP-311 Hr 5										0.11		
		SP-311 Hr 6	<0.1	<1			0.02	0.00	8.00	23.6	35.6	0.14		
		SP-311 Hr 7										0.12		
		SP-311 Hr 8										0.1		
		SP-311 Hr 9										0.12		
		SP-311 Hr 10										0.15		
		SP-311 Hr 11										0.16		
		SP-311 Hr 12		<1			0.02					0.14		
		SP-311 Hr 13										0.12		
		SP-311 Hr 14										0.16		
		SP-311 Hr 15										0.15		
		SP-311 Hr 16										0.16		
		SP-311 Hr 17										0.18		
		SP-311 Hr 18		<1			0.00					0.19		
		SP-311 Hr 19										0.21		
		SP-311 Hr 20										0.19		
		SP-311 Hr 21												
		SP-311 Hr 22										0.11		
		SP-311 Hr 23										0.07		
		SP-311 Hr 24		<1			0.02					0.10		
BW Tank	Settled BW Water	Settled BW water	0.98	30			1.02							
BW Tank	Mixed BW Water	Mixed BW water			70									2.5
Flo Trend Filtrate		Flo Trend Filtrate	0.3	2.4			0.06							
0.2 filtered SP-31	Filter Effluent	SP-311 Hr 3		<1										

Date:	2/29/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1 total iron
Reduction Time	45 min.
Aeration Time	18 min.detention time but no air
Polymer and Dose	Magnafloc Ciba E38 - 0.1 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	0

			Lab Results			Field results								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning	5	4.9										
		GNOU Raw Middle	9.3	9.1		12	0.01	0.00	7.32	21.7	166.9	0.09	5.4	
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Beginning												
		SP-010 Middle	117	112		130			7.03	22.7	45		6.3	
		SP-010 End												
SP-110	Fe-spiked Influent	SP-110 Beginning												
		SP-110 Middle					2.96	1.12	7.30	22.5	-96.5	9.15		
		SP-110 End												
SP-111	After Red. Tank 1	SP-111 Beginning												
		SP-111 Middle												
		SP-111 End												
SP-121	After Red. Tank 2	SP-121 Beginning												
		SP-121 Middle												
		SP-121 End												
SP-131	After Red. Tank 3	SP-131 Beginning												
		SP-131 Middle	<0.1				2.92	0.39	7.41	22.5	-61	16.7	6.5	
		SP-131 End												
SP-231	Aeration Effluent	SP-231 Beginning												
		SP-231 Middle	<0.1				2.83	0.23	7.62	22.9	0.4	16.1	6.7	
		SP-231 End												
SP-311	Filter Effluent	SP-311 Beginning												
		SP-311 Middle	<0.1	<1			0.03	0.01	7.79	23.0	10.1			
		SP-311 End												
		SP-311 Hr 1												
		SP-311 Hr 2										0.32		
		SP-311 Hr 3										0.18		
		SP-311 Hr 4 (M)										0.18		
		SP-311 Hr 5												
		SP-311 Hr 6												
		SP-311 Hr 7												
		SP-311 Hr 8												
BW Tank	Settled BW Water	Settled BW Beginning												
		Settled BW Middle												
		Settled BW End												
BW Tank	Mixed BW Water	Mixed BW End												
Flo Trend Filtrate														

Date:	3/12/2008
Experimental Conditions:	
Fe:Cr Dose Ratio Target	25:1 total iron
Reduction Time	45 min.
Aeration Time	0 min (columns bypassed)
Polymer and Dose	Magnafloc Ciba E38 - 0.1 ppm

Flow Rate (gpm):	2
Change in Pressure Over Run (psi):	0.5

			Lab Results			Field results								
Sample Location		**Sample Time**	Cr(VI)	Total Cr	TSS	Cr(VI)	Total Fe	Ferrous Iron	pH	Temp	ORP	Turbidity	Dissolved Oxygen	Settleable Solids
GNOU Raw Water		GNOU Raw Beginning												
		GNOU Raw Middle	8.6	8.7			0.00	0.01	7.28	22.4		0.06	5.1	
		GNOU End												
SP-010	Cr(VI) Spiked Influent	SP-010 Hr 1				128								
		SP-010 Hr 3	120	120		132	0.04	0.02	7.39	22.2		0.07	6.7	
		SP-010 Hr 6	126	126		143			7.20	21.1		0.08	7.4	
		SP-010 Hr 12	114	110		131			7.25	22.0		0.08	6.4	
		SP-010 Hr 18	85	86		80			7.37	22.1	224.7	0.10	6.2	
		SP-010 Hr 24	89	91		100			7.22	23.7	186.7	0.08	7.5	
SP-110	Fe-spiked Influent	SP-110 Hr 1					2.76							
		SP-110 Hr 3					3.20	0.82	7.27	22.5		9.76	6.0	
		SP-110 Hr 6					2.53	0.81	7.35	21.8		6.94	6.6	
		SP-110 Hr 12					2.62	1.35	7.20	22.0		8.08	6.2	
		SP-110 Hr 18					2.44	0.78	7.30	22.8	-29.8	0.91	6.3	
		SP-110 Hr 24					2.65	0.66	7.26	24.0	-82.4	6.75	5.6	
SP-131	After Red. Tank 3	SP-131 Hr 1												
		SP-131 Hr 3	<0.1				3.44	0.30	7.41	22.4		17.9	7.4	
		SP-131 Hr 6	0.2				2.60	0.25	7.50	21.9		13.1	7.4	
		SP-131 Hr 12	<0.1				2.49	0.14	7.47	21.8		14.5	6.9	
		SP-131 Hr 18	<0.1				2.62	0.23	7.41	22.7	-52.4	11.8	6.8	
		SP-131 Hr 24	<0.1				2.47	0.13	7.38	23.8	-1.4	15.1	6.4	
SP-231	Aeration Effluent	SP-231 Hr 1												
		SP-231 Hr 3												
		SP-231 Hr 6												
		SP-231 Hr 12												
		SP-231 Hr 18												
		SP-231 Hr 24												
SP-311	Filter Effluent	SP-311 Hr 1										0.28		
		SP-311 Hr 2										0.15		
		SP-311 Hr 3	<0.1	<1			0.02	0.03	7.45	23.3		0.12	6.4	
		SP-311 Hr 4										0.11		
		SP-311 Hr 5										0.15		
		SP-311 Hr 6	<0.1	<1			0.02	0.00	7.59	21.9		0.10	6.7	
		SP-311 Hr 7										0.08		
		SP-311 Hr 8										0.08		
		SP-311 Hr 9										0.08		
		SP-311 Hr 10										0.08		
		SP-311 Hr 11										0.09		
		SP-311 Hr 12	<0.1	<1			0.02	0.02	7.64	21.9		0.10	6.4	
		SP-311 Hr 13										0.12		
		SP-311 Hr 14										0.22		
		SP-311 Hr 15										0.19		
		SP-311 Hr 16										0.08		
		SP-311 Hr 17										0.07		
		SP-311 Hr 18	<0.1	<1			0.01	0.00	7.63	22.9	57.8	0.07	6.9	
		SP-311 Hr 19										0.08		
		SP-311 Hr 20										0.07		
		SP-311 Hr 21										0.07		
		SP-311 Hr 22										0.08		
		SP-311 Hr 23										0.08		
		SP-311 Hr 24	<0.1	<1			0.01	0.00	7.59	24.1	56.1	0.10	7.0	
BW Tank	Settled BW Water	Settled BW water												
BW Tank	Mixed BW Water	Mixed BW water												
Flo Trend Filtrate		Flo Trend Filtrate												