Well 29 Pilot Study Report
Madison Water Utility

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

Appendix

EXECUTIVE SUMMARY

A pilot study for iron (Fe) and manganese (Mn) removal was completed at Well 29 in Madison, Wisconsin. The Fe and Mn raw water concentrations and treatment objectives are provided in Table ES-1.

TABLE ES-1
MN AND FE CONCENTRATIONS

	Raw Water	Treatment Objective
Fe (milligrams per liter (mg/L))	0.4	< 0.1
Mn (mg/L)	0.18	< 0.01

Field Fe sampling was adequate to determine the performance of the filters; however, field Mn testing was on average 0.007 mg/L higher than lab Mn testing. Therefore, field Mn samples were evaluated on a corrected treatment objective to account for the variation.

Three oxidation processes were evaluated as listed in Table ES-2. The preferred oxidation processes is chlorination alone and is shown in red in Table ES-2.

TABLE ES-2
OXIDATION RESULTS

System	Performance	Present Worth
Chlorine Oxidation	• Meets treatment objectives • Easy to use • Recommended chlorine dose 1.3 mg/L for dual media, greensand and GSR. Recommended chlorine dose of 1.5 mg/L for pyrolusite • Capital Cost: $35,000 • O&M Cost: $10,600 for 1.3 mg/L dose • O&M Cost $12,100 for 1.5 mg/L dose	$147,300 at 1.3 mg/L $163,200 at 1.5 mg/L
Aeration with Chlorine Oxidation	• Meets treatment objectives • Recommended chlorine dose 1.12 mg/L • Capital Cost: $96,000 • O&M Cost: $10,300 for 1.12 mg/L dose • O&M Cost $11,800 for 1.32 mg/L dose	$205,100 at 1.12 mg/L $221,000 at 1.32 mg/L
Permanganate Oxidation	• Mn concentrations did not meet the treatment objectives • Potential for pink water if overfed and for excessive Mn if underfed	Not Viable Treatment Option

Five filtration strategies were evaluated in the pilot study. The results of each of the systems are provided in Table ES-3.

TABLE ES-3
SYSTEM TREATMENT RESULTS

System	Performance
Dual Media Filtration with Chlorine Oxidation	• Meets treatment objectives • Filter loading rate 5.0 gpm/ft^2 for run time of 48 hours • Terminal headloss 15 feet
Greensand Filtration with Chlorine Oxidation	• Meets treatment objectives • Filter loading rate 4.9 gpm/ft^2 for run time of 42 hours • Terminal headloss 15 feet
GSR Plus Filtration with Chlorine Oxidation	• Meets treatment objectives • Filter loading rate 5.0 gpm/ft^2 for run time of 72 hours • Terminal headloss 15 feet
Pyrolusite Filtration with Chlorine Oxidation	• Meets treatment objectives • Filter loading rate 12.0 gpm/ft^2 for run time of 24 hours • Terminal headloss 35 feet
Membrane Filtration with Chlorine Oxidation	• Preliminary results indicate membrane filtration does not meet treatment objectives • More challenging to use

A cost estimate was created for each of the viable systems to determine the most cost effective alternative. The costs are provided in Table ES-4.

TABLE ES-4
ORDER OF MAGNITUDE COST ESTIMATES

System	Capital Cost	O&M Cost	Present Worth
Dual Media with Chlorine Oxidation	$2,545,000	$40,200	$2,971,000
Greensand with Chlorine Oxidation	$2,525,000	$44,300	$2,994,000
GSR Plus Filtration with Chlorine Oxidation	$2,575,000	$46,300	$3,066,000
Pyrolusite Filtration with Chlorine Oxidation	$2,093,000	$47,700	$2,598,000
Membrane Filtration with Chlorine Oxidation	> $3,000,000	$379,500	$7,020,000

The recommended treatment strategy is chlorine oxidation with pyrolusite pressure filtration and is shown in red on Table ES-4. Pyrolusite is the lowest cost alternative that meets the treatment objectives and provides the added benefits of reduced sand retention on the filter media. The anticipated average Fe and Mn concentrations are 0.016 and 0.0024, respectively. The range of Fe anticipated in the treated water is “below detection limit” to 0.037 mg/L. The range of Mn anticipated in the treated water is 0.0002 to 0.0050 mg/L. The full scale treatment facility results may vary; however, it is anticipated that the full scale system will consistently meet the treatment objectives.

The design parameters for pyrolusite filtration with chlorine oxidation are as follows:

Chlorine Feed Dose:	1.0 mg/L
Chlorine Residual:	0.2 to 0.3 mg/L
Pyrolusite Flow Rate:	12 gpm/ft^2
Pyrolusite Media Depth:	36 inches
Filter Run Time:	24 hours
Maximum Filter Headloss:	35 feet
Backwash Rate:	25 to 30 gpm/ft^2
Backwash Duration:	5 minutes

The modifications required for Fe and Mn treatment include:

- Upgrade chlorine feed equipment.
- Install additional chlorine residual analyzer.
- Modify chemical room for additional equipment and chlorine cylinders.
- Construct a 28-foot x 44-foot addition to house filtration equipment.
- Construct 2 - 37,500-gallon backwash waste tanks.
- Update SCADA as necessary.
- Install one 10-foot diameter x 20-foot long multi-cell pressure vessel.
- Install 36-inch deep pyrolusite media and 10-inch support gravel.
- Install air wash system including blower, grid, and piping.
- Install air compressor.
- Install control panel.
- Modify existing well pump to optimize pump curve and replace existing motor and variable speed drive as design requires.
- Install piping from well to filtration system and back to storage reservoir.
- Install backwash recycle pumping system.
- Complete site work.
- Complete existing facility modifications including access to new addition.

The order of magnitude costs for the recommended pyrolusite filtration process with chlorine oxidation are:

Capital Costs: $2,093,000
Operational and Maintenance Costs: $47,700

1.0 INTRODUCTION

Madison Water Utility (MWU) Well 29 began operation in 2005 and operated for approximately one year. Its operation was discontinued because excessive iron (Fe) and manganese (Mn) were present in the water supply. MWU is evaluating the possible construction of a 2,200-gallon per minute (gpm) water treatment plant to remove the Fe and Mn from the water before it enters the distribution system. The Well 29 water treatment plant is planned to be operational by third quarter 2008.

The Fe and Mn concentrations exceed United States Environmental Protection Agency (EPA) and Wisconsin Department of Natural Resources (WDNR) Secondary Drinking Water Standards of 0.3 milligrams per liter (mg/L) and 0.050 mg/L, respectively. MWU's treatment goals for this pilot study are 0.10 mg/L Fe and 0.010 mg/L Mn.

A pilot study was completed to evaluate alternative water treatment processes and collect design data to allow for the design of a water treatment plant for MWU Well 29.

1.1 PURPOSE

This report provides a summary of the findings of the pilot study and recommendations for a treatment facility. The purpose of the pilot study was to:

- Identify whether one or more treatment process will meet MWU's water quality goals of 0.1 mg/L Fe and 0.010 mg/L Mn.
- Determine the efficiencies for each treatment process for Fe and Mn removal.
- Obtain information to be used in the design of a water treatment plant
- Identify operational requirements for treatment processes meeting MWU's goals

Data collected from the pilot study was used to develop "Order of Magnitude" costs for:

- Operational costs
- Capital costs
- Net present value for 20 year life expectancy

1.2 SCOPE

This report:

- Describes the processes piloted.
- Compiles the data and information from the pilot study.
- Recommends filter loading rates, chemical feed rates, backwash requirements, and other design criteria.
- Provides order of magnitude cost estimates for a treatment facility.

2.0 PILOT SYSTEM SETUP

The following section summarizes the equipment and methods used to complete the pilot study.

2.1 FE AND MN REMOVAL CHEMISTRY

The most common practice employed for the removal of Fe and Mn from drinking water supplies can be summed up as chemical oxidation followed by physical separation. In its simplest form, Fe is oxidized from soluble Fe^{+2} to less soluble Fe^{+3}, and Mn is oxidized from soluble Mn^{+2} to less soluble Mn^{+4}. The insoluble Fe^{+3} and Mn^{+4} are removed from the water through filtration. Additional information on Fe and Mn oxidation chemistry is provided in Appendix A.

2.2 EQUIPMENT DESCRIPTION

Granular media and membrane filtration equipment were utilized in the pilot study. The granular media pressure filter pilot equipment was provided by Siemens Water Technologies. The unit includes the following unit processes:

- Retention tanks
- Four vertical pressure filters, 12-inch diameter
- Four chemical feeders
- Four chemical storage containers with mixers and motors

Photo 1: Pilot Study Trailer

Photo 1 shows the outside of the trailer that housed three of the pressure filters. The trailer was setup outside the well house and water was provided thru a hose run through a temporary service door to the well discharge inside the well house. Figure 1 is a flow schematic of the equipment provided on the trailer. The fourth filter was located in the well house.

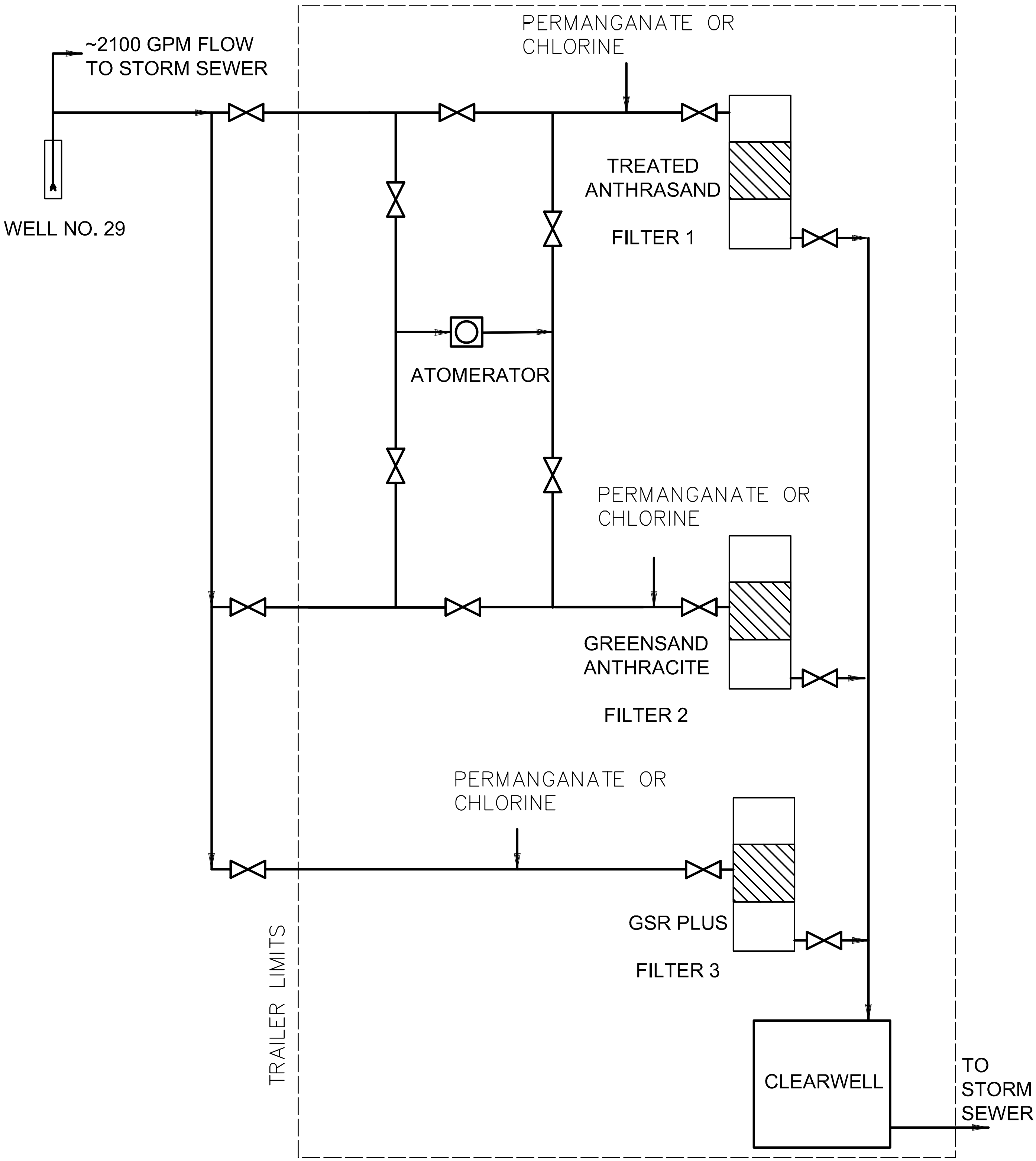
Photo 2 illustrates the setup of the fourth filter within the well house. Figure 2 is a flow schematic of the fourth vessel. Also visible in Photo 2 is the discharge header used to connect the water supply from the well to the individual filtration vessels

Photo 2: Filter 4 - Pyrolusite

The membrane filtration equipment was provided by GE Water Processes - Zenon. The membrane system was also located in the well house and is illustrated in Photo 3 to the right. Figure 3 is the flow schematic for the membrane system. The membrane system is further discussed in Section 2.3.

Oxidants evaluated during the pilot study included oxygen, chlorine, and potassium permanganate.

Photo 3: Membrane Pilot System



EARTH TECH

FIGURE 1

PILOT PLANT FLOW SCHEMATIC
PRESSURE FILTERS 1, 2, & 3

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MARCH 2007

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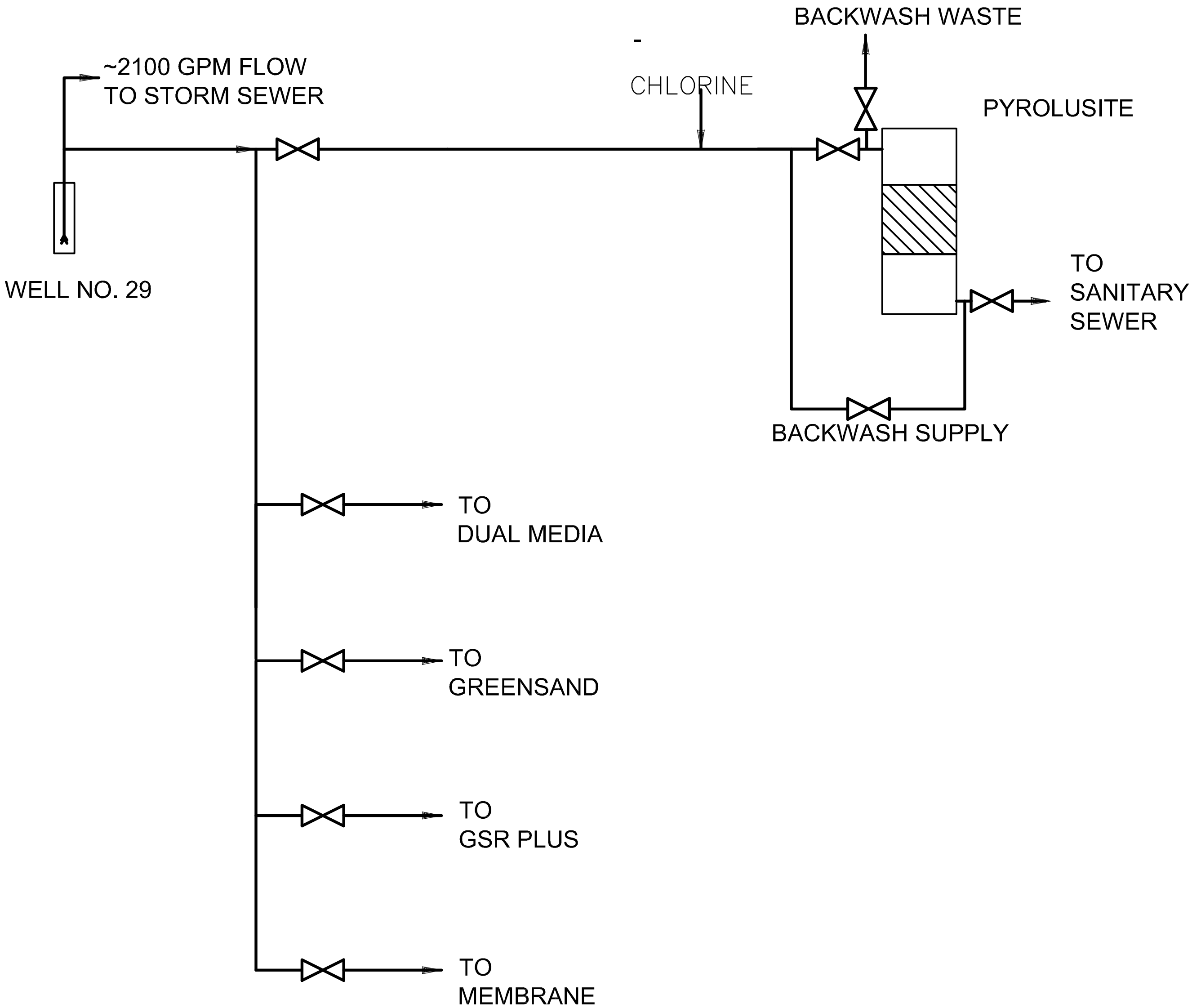

EARTH TECH

FIGURE 2

PILOT PLANT FLOW SCHEMATIC
PRESSURE FILTER 4

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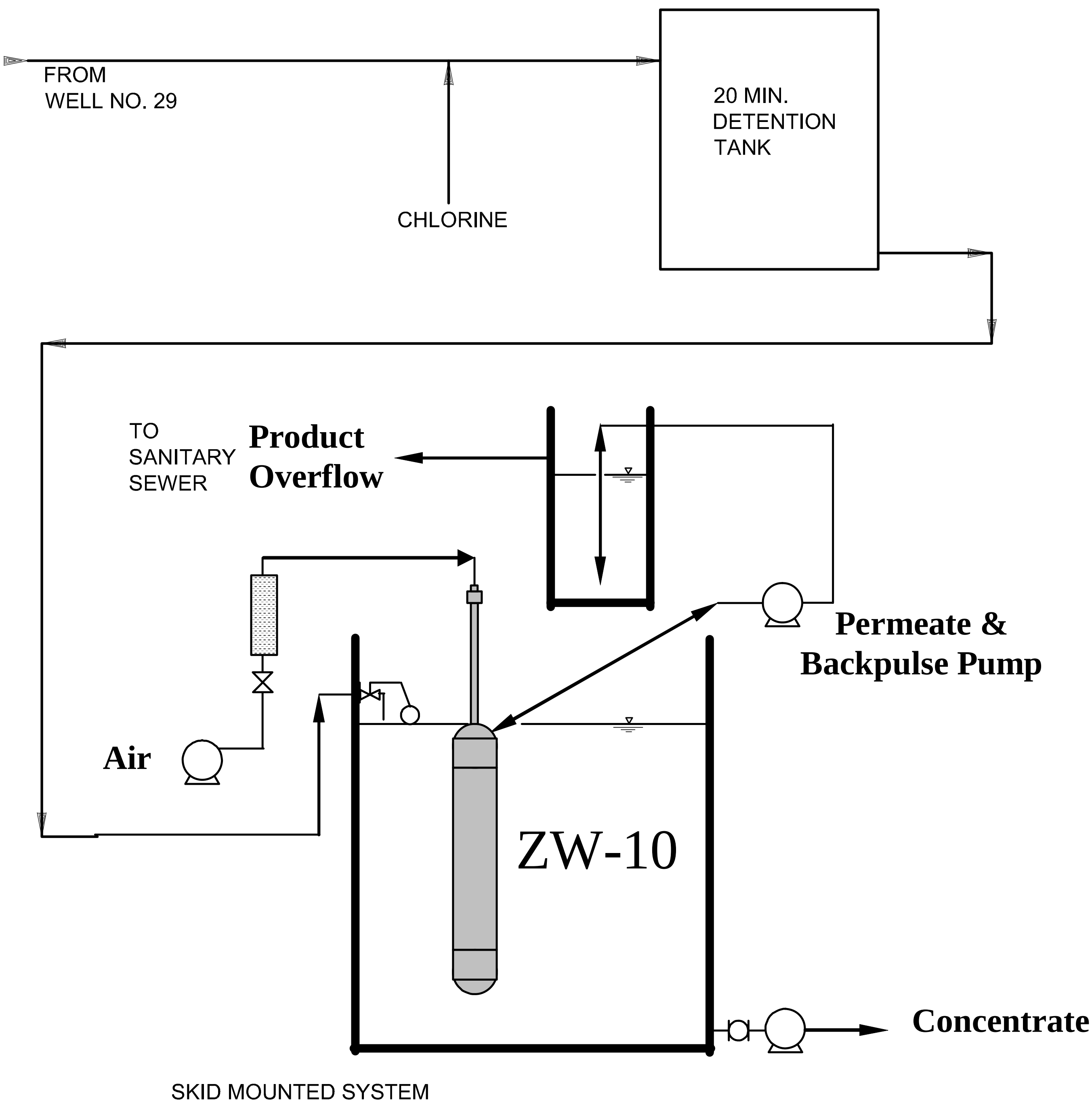
MADISON, WISCONSIN

MARCH 2007 98102



EARTH TECH

FIGURE 3

PILOT PLANT FLOW SCHEMATIC
MEMBRANE SYSTEM
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MARCH 2007 98102

2.2.1 Aeration

The process of adding oxygen to water for chemical oxidation is aeration. Aeration can be an effective oxidation process for Fe removal, but if used alone, it is generally not effective for oxidation of Mn, because the oxidation reactions are too slow to be practical. The time to complete the Mn oxidation using aeration can exceed two hours; however, the rate of Fe oxidation is less than five minutes. As a result, aeration can be used as an effective first step in Fe and Mn water treatment plants. Aeration was evaluated in the pilot studies to determine whether cost savings may be achieved by lower chemical dosages of other oxidizing chemicals.

Photo 4: Pressure Aeration Unit - Atomerator

An atomerator was utilized in the pilot study to aerate the water. Compressed air is forced into the water through a diffusion stone in the atomerator. The atomerator is shown in Photo 4 to the right. The benefit of the atomerator over gravity aeration devices is that the pressure is maintained through the unit, and subsequent pumping is not required.

2.2.2 Chlorine

Traditionally, Fe and Mn were controlled using chlorine alone or combined with potassium permanganate. Mn oxidation is much slower than Fe oxidation with chlorine; however, in the presence of Mn dioxide coated media, chlorine can be a very effective oxidant.

For the pilot study 6 percent sodium hypochlorite (household bleach) was diluted and pumped into the water. Bleach was used for the pilot study due to the availability, safety, and ease of use in the pilot scale system. Well 29 currently uses gas chlorine for disinfection prior to distribution. Regardless of the oxidant chosen for Fe and Mn removal, chlorine will continue to be used for disinfection and to provide a residual disinfectant into the distribution system.

The pumps used in the pilot system for both chlorine addition and permanganate addition were peristaltic pumps as shown in Photo 5 below. These pumps transferred the chemicals from the chemical tanks and into the inlet of the pressure vessels or the detention tank on the membrane system.

2.2.3 Potassium Permanganate

Photo 5: Filters 1, 2, and 3 Chemical Feed Pumps and Tanks

Although more expensive than chlorine, potassium permanganate has the added benefit of rapid oxidation of both Fe and Mn. Mn oxidation by permanganate has been shown to occur within 60 seconds over wide pH and temperature ranges[1].

The use of potassium permanganate must be precisely optimized, and the applied permanganate must completely

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[1] Casale, Robin and LeChevallier, Mark. Manganese Control and Related Issues. AWWARF 2002.

oxidize the source water without allowing excess permanganate to be present in the finished water. If excess permanganate is present in the finished water, it will give the finished water a pink color and eventually reduce to Mn^{+4} and precipitate in the distribution system.

2.3 FILTER MEDIA

Four granular media filters and one membrane filter were utilized in the pilot study. A brief description of the media is provided below. Detailed information on the media is provided in Appendix B.

It is common practice in Fe and Mn treatment to use a filter media with Mn oxide coating on the surface of the media. The coating assists in the oxidation and removal of Mn and Fe. The coating is continuously regenerated by the oxidized Mn adsorbing onto the surface of the filter media. Backwashing removes excess oxidized Mn and Fe that has been trapped within the filter.

The filter media evaluated in the pilot study include:

- Treated Dual Media (Mn oxide coated anthracite and silica sand)
- Mn Greensand (with Mn oxide coating)
- Pyrolusite (mined Mn oxide)
- CalMedia™ GSR Plus (Mn oxide bonded to silica)
- Ultrafiltration

Table 1 summarizes the filter media characteristics from the pilot study.

TABLE 1
FILTER MEDIA

	Column No. 1	Column No. 2	Column No. 3	Column No. 4	UF Membrane
	Dual Media	Mn Greensand	CalMedia™ GSR Plus	Pyrolusite	
Filter Loading Rate, gpm/ft²	2.5, 3, 4, 5, 6, 8	3, 4, 5	4, 5, 7	10, 12, 15, 18	NA
Specific Gravity, g/cm3	2.6 - Sand 1.6 - Anthracite	2.4-2.9 - Greensand 1.6 - Anthracite	2.0	3.8 - 4.0	NA
Bulk Density, lb/ft³	120- Sand 50 - Anthracite	85- Greensand 50 - Anthracite	45	125	NA
Effective Size, mm	0.45-0.55 - Sand 0.8-1.2 - Anthracite	0.3-0.35 - Greensand 0.8-1.2 - Anthracite	0.43	0.51	Ultrafiltration - 0.02 micron
Uniformity Coefficient	1.62 - Sand 1.65 - Anthracite	1.3 - Greensand 1.65 - Anthracite	2.0	1.7	NA
Media Depth	18-in Sand 12-in Anthracite	18-in Greensand 12-in Anthracite	30-in	36-in	NA
Backwash Rate	10 gpm/ft²	7.6 gpm/ft²	12.7 gpm/ft²	22 gpm/ft²	Same as forward flow
Aeration	Yes	No	No	No	No - air used to clean vessel
Chemical Feed	Permanganate Chlorine	Permanganate Chlorine	Permanganate Chlorine	Chlorine	Chlorine
Pre-filter Detention Time	Not Used				20 minutes

Typical dual media filters consist of 24 inches anthracite and 12 inches silica sand[2]. For this pilot study 18 inches of sand and 12 inches of anthracite were used. The dual media was treated prior to installation with permanganate to create Mn dioxide coating on the media. The typical flow rates for dual media filters range between 2.5 and 6 gallons per minute per square foot (gpm/ft^2). Higher loading rates have been demonstrated to be successful, although the filter run times are shorter for the higher filtration rates due to early breakthrough. The pilot study evaluated loading rates from 2.5 to 8 gpm/ft^2.

Mn greensand is a granular filter medium processed from glauconite sand. The glauconite sand is coated with a thin layer of Mn oxide resulting in a distinct green color, giving it its name. In order to improve hydraulics, an anthracite cap was provided. The anthracite was pre-treated to add Mn oxide coating to the media prior to installation. Greensand filters are generally best applied when the combined Fe and Mn concentrations are below 5 mg/L. Hydraulic loading rates were within the typical ranges of between 3 and 5 gpm/ft^2, and the backwash rate utilized matched the typical backwash rate of 8 gpm/ft^2. It is recommended that the maximum pressure drop across the media should be maintained at less than 8 pounds per square inch (psi) to avoid degradation of the greensand.[3]

CalMedia™ GSR Plus is a proprietary granular Mn dioxide filtering media manufactured by Calgon Carbon Corporation. It supports an active Mn dioxide coating to oxidize and precipitate soluble Fe and Mn. Typical bed depths are 24 to 36 inches deep and 30 inches was used in this study. Filter loading rates are typically 3 to 5 gpm/ft^2; however, intermittent applications as high as 10 gpm/ft^2 are possible. The pilot study evaluated loading rates of 4 to 7 gpm/ft^2; however, 5 gpm/ft^2 was considered the maximum design due to manufacturer's recommendations. Manufacturer's literature suggests backwash flow rates as low as 8 to 10 gpm/ft^2 are required to achieve a 20 to 40 percent bed depth expansion. The backwash rate for the pilot study was 12.7 gpm/ft^2.

Pyrolusite is the common name for naturally occurring Mn dioxide and is available in the United States, United Kingdom, South America, and Australia. It is distributed under brand names such as LayneOx, Pyrolox, Filox-R, and MetalEase. For this study, LayneOx brand pyrolusite was used. It is a mined ore consisting of 40 to 85 percent Mn dioxide by weight. The various configurations of pyrolusite provide extensive surface sites available for oxidation of soluble Fe and Mn. Pyrolusite media operates at a comparatively higher filtration rate than other filter media. Generally, filtration rates for pyrolyusite of 10 to 15 gpm/ft^2 have been achieved and flow rates of 10 to 18 were analyzed in this pilot study. The increased filtration rate reduces the filter size and overall construction costs.[6] Backwash is critical for proper operation. Attrition or friction from rubbing the media, during backwash can be a benefit, as it exposes more surface sites for oxidation of soluble Fe and Mn. The required backwash rate is 20 to 30 gpm/ft^2 which will fluidize the bed, scrub the media, and redistribute the media throughout the bed. Bed expansion of 30 percent is recommended. The backwash rate during the pilot study was 22 gpm/ft^2 which is within the recommended range. Daily backwashing is recommended to maintain the effectiveness of the media for oxidizing and removing Fe and Mn; therefore, daily backwashing was utilized for majority of the filter runs.

[2] Water Quality & Treatment, A Handbook of Community Water Supplies, American Water Works Association, 5th Ed., p. 8.19
[3] Occurrence of Manganese in Drinking Water and Manganese Control, AwwaRF, 2006, p. 40

Ultrafiltration (UF) has been used successfully in surface water treatment applications. One of the challenges to achieving low Fe and Mn concentrations in the treated water is that the oxidation process may form colloidal Mn that passes through traditional granular media filters.[4] UF systems have the ability to remove fine particles. The small particle size separation of membrane filtration may prove to efficiently remove Fe and Mn to below the MWU goals of 0.1 mg/L Fe and 0.01 mg/L Mn.

This pilot study will only determine the treatment performance of a membrane system. A long-term evaluation would be necessary prior to design of a membrane system. The long-term membrane evaluation will determine the impact of fouling, membrane recovery following cleaning, and selection of the proper membrane. A complete UF pilot study should occur over at least two clean-in-place cycles or approximately three months in order to obtain sufficient design information.

The membrane used in this pilot was sensitive to permanganate and therefore, only chlorine was used as an oxidant with the membrane. One concern with the use of membranes is that the Fe and Mn in the water must be completely oxidized before reaching the membranes. If the Mn oxidation kinetics are too slow, the Mn will not be removed. To provide additional time for the oxidation of Mn with chlorine, the pilot system utilized a minimum of 20 minutes of detention time before the membrane filter.

2.4 PILOT SYSTEM OPERATIONAL PROCEDURES

Experimental procedures were developed in the pilot study plan to define design information necessary for full-scale water treatment plant design. The experimental design was intended to provide preliminary information to make initial assessments whether a particular process should be continued for further evaluation.

Chemical analysis was completed using field laboratory analysis procedures as outlined in Appendix C. Select samples were submitted to the Madison City Lab to confirm the field results.

Testing included the following:

- Full Water Quality Testing on Raw Water
- Chlorine Demand Testing
- Process Optimization
- Filter Run Test
- Membrane Test
- Scale Formation Potential Evaluation

The purpose of the full water quality testing on the raw water is to ensure that no significant changes in the water quality have occurred. Significant changes in water quality can change the decision to continue with treatment.

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[4] Morgan, J.J and Stum, W., “Colloidal Chemical Properties of Manganese Dioxide,” Journal of Colloidal Science, 1964

The chlorine demand test allows for more accurate analysis of chlorine dose applied to the raw water versus the chlorine residual after oxidation of the water.

The process optimization test evaluated the use of different oxidants to determine what oxidant works best and what treatment scheme is necessary to meet the treatment objectives.

The filter run test utilized the best treatment scheme determined during the process optimization. Various filter loading rates were tested until filter breakthrough or backwash became necessary. The optimum filter loading rate was tested for a minimum of 3 filter runs to ensure adequate performance of the media.

The membrane test evaluated the performance of the membrane system by modifying the flux rate and backwash frequency to determine the best treatment performance of the system.

The scale formation potential evaluation reviewed the water quality to determine the potential for scale formation that could plug filter distribution headers or the potential for corrosive water that would result in copper and lead leaching from pipes in homes and into the drinking water.

3.0 RESULTS

The following chapter summarizes the results from the pilot testing completed and MWU Well 29. Pilot testing was conducted from January 22, 2007, through March 29, 2007.

3.1 RAW WATER QUALITY

MWU Well 29 was used throughout the duration of the pilot study. During the pilot study, the well was typically operated at 90 percent capacity or roughly 2,000 gpm, producing an average well drawdown of approximately 200 feet. Table 2 summarizes the inorganic water chemistry for MWU Well 29. In general, MWU Well 29 water quality, with the exception of Fe and Mn, meets the requirements for a municipal water supply. Removal of the Fe and Mn to the MWU treatment goals, 0.10 mg/L Fe and 0.01 mg/L Mn, from the water supply will provide aesthetically acceptable water for the residents of Madison.

TABLE 2
WELL 29 INORGANIC ANALYSIS

Parameter	Well 29	Units	MCL	SMCL	LOD
Alkalinity	324	mg/L			10.000
Aluminum	ND	µg/L			14.60
Antimony	ND	µg/L	6		2.00
Arsenic	ND	µg/L	10		1.00
Barium	59	µg/L	2,000		0.52
Beryllium	ND	µg/L	4		0.15
Cadmium	ND	µg/L	5		0.20
Calcium	72	mg/L			0.018
Chloride	2.06	mg/L			1.200
Chromium	ND	µg/L	100		0.35
Conductivity	578	umhos/cm			3.00
Copper	2.9	µg/L			1.20
Cyanide	ND	mg/L			0.004
Fluoride	0.171	mg/L	4		0.12
Hardness total (CaCO3)	328	mg/L			0.127
Fe	0.358	mg/L		0.3	0.003
Lead	ND	µg/L	15		1.00
Magnesium	36	mg/L			0.020
Mn	202	µg/L		50	0.20
Mercury, AA cold vapor	ND	µg/L			0.03
Nickel	1.41	µg/L	100		1.93
Nitrogen - Ammonia	ND	mg/L			0.025
Nitrogen-Nitrate	0.146	mg/L	10		0.120
Nitrogen-Nitrate & Nitrite	ND	mg/L			0.180
Nitrogen-Nitrite	ND	mg/L	1		0.060
Selenium	ND	µg/L	50		1.00
Silver	ND	mg/L			2.59
Sodium	2.8	mg/L		250	0.025
Sulfate	4.12	mg/L		250	1.20
Thallium , AA Furnace	ND	µg/L	2		0.40
Total solids	318	mg/L			6.00
Turbidity	<1.0	NTU			1.0
Zinc	1.8	µg/L			0.66
Total Organic Carbon	0.50	mg/L			0.30

Notes:
LOD = Limit of Detection
umhos/cm = micromho per centimeter

Throughout the pilot study the raw water Fe, Mn, pH, and temperature were analyzed. The raw water data is presented in Appendix D. Table 3 summarizes the raw water analytical results.

TABLE 3
RAW WATER FE AND MN CONCENTRATIONS

	Fe		Mn		pH	Temp
	Field	Lab	Field	Lab		
Average	0.352	0.387	0.189	0.179	7.32	13.4
Maximum	0.68	0.426	0.273	0.205	7.93	15.0
Minimum	0.30	0.352	0.143	0.134	7.15	12.7

The maximum lab Mn concentration occurred on the first day of well operation for the pilot test (January 23, 2007) when the well pump was started after prolonged shutdown. The maximum lab and field raw water Fe concentration and the minimum lab raw water Mn concentration occurred when the well was first restarted on January 29, 2007, after having been shutdown for a weekend. Figure 4 illustrates the raw water analytical Fe and Mn results throughout the pilot period. The Fe concentration continues to increase over time, suggesting the Fe concentration in the raw water may vary during full-scale production. The Fe concentration at the end of the pilot study appeared to begin stabilizing at or slightly above 0.40 mg/L. For the purposes of this report 0.40 mg/L raw water Fe concentration will be used.

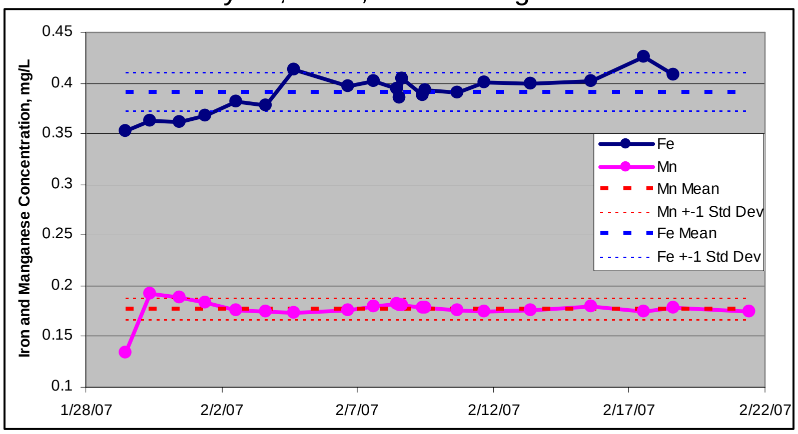

Figure 4: Raw Water Fe and Mn

The Mn concentration was stable throughout the pilot testing period; therefore, the average Mn concentration will be used as the raw water Mn concentration. To summarize the raw water concentrations:

- Fe: 0.4 mg/L
- Mn 0.18 mg/L

During the pilot study, lower flows at 50, 60, 70, and 80 percent of well pumping capacity were evaluated. Each pumping rate was continued for one hour prior to sampling for Fe and Mn to determine if raw water Fe and Mn concentrations would change. The raw water Fe and Mn concentrations at the various well flow rates are presented in Table 4.

TABLE 4
RAW WATER FE AND MN CONCENTRATIONS AT MODIFIED FLOW RATES

Percent Speed	Fe		Mn		pH	Temp	Drawdown (ft)
	Field	Lab	Field	Lab			
50%	0.36	0.394	0.185	0.181	7.20	13.3	184
60%	0.35	0.385	0.183	0.181	7.24	13.8	184
70%	0.35	0.405	0.189	0.178	7.34	13.3	191
80%	0.36	0.388	0.184	0.178	7.39	13.0	194
90%	0.35	0.387	0.189	0.179	7.32	13.4	200

The variation between the highest and lowest Fe and Mn laboratory analytical result was 0.02 mg/L and 0.003 mg/L respectively, which was not considered to be significant.

3.2 FIELD AND LAB COMPARISON

Water samples were collected and analyzed by both field and laboratory analytical procedures. Throughout the pilot study, lab analytical results for Fe and Mn were completed to provide a comparison with the field analytical results. The lab and field Fe and Mn analytical data is presented in Appendix E. HACH® Fe and Mn field analysis procedures were used throughout this pilot study. The analytical detection limits are presented in Table 5.

TABLE 5
ANALYTICAL DETECTION LIMITS, mg/L

	Mn		Fe	
	Field	Lab	Field	Lab
Analytical Detection Limit	0.002	0.00022	0.03	0.002

Figure 5 portrays the difference between the field and laboratory Fe analytical results. The x-axis represents time throughout the pilot test period and the y-axis is the difference between the field and laboratory results. The average Fe field analytical result was lower than the average lab result with a deviation of -0.0045 mg/L. The average deviation is less than the detection level for either field and laboratory analytical procedures; therefore, the field analytical procedures are considered to be an accurate portrayal of laboratory analyzed Fe concentration in the water.

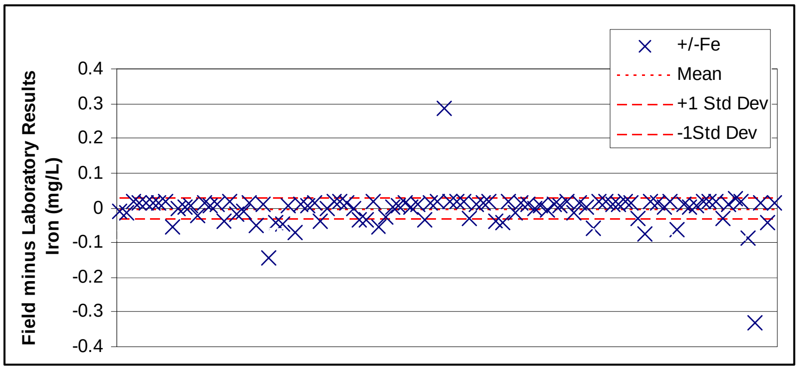

Figure 5: All Water Fe Deviation of Field Analytical Compared to Certified Laboratory Results (Field Fe minus Lab Fe)

A similar analysis was completed for the Mn results. The deviation between field and lab results is represented in Figure 6. The field results average +0.007 mg/L above the lab analytical results. This means that half of all field analytical results less than 0.017 mg/L would result in a laboratory analytical result less than the MWU goal of 0.010 mg/L. Further, it is noted that all laboratory analysis are less than the field analysis. For the purposes of this pilot study, field Mn results less than 0.017 mg/L are assumed to meet the MWU goal of 0.010 mg/L.

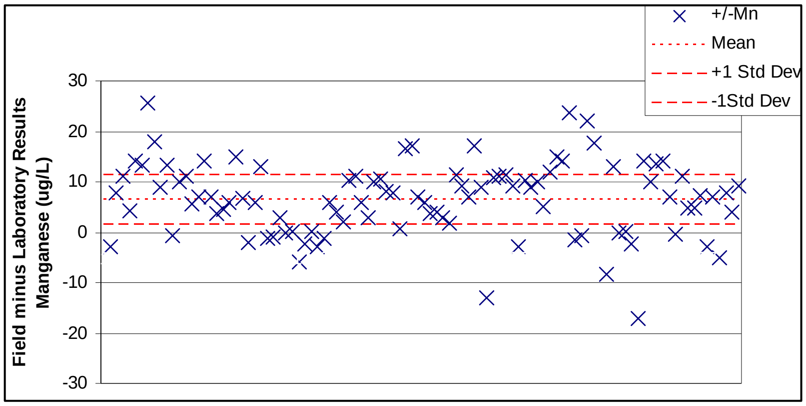

Figure 6: All Water Mn Deviation of Field Analytical Compared to Certified Laboratory Results (Field Mn minus Lab Mn)

3.3 CHLORINE DEMAND TEST

Photo 6: Chlorine Field Test Equipment

A chlorine demand test was completed on the raw water. The test compares the chlorine added to a sample of raw water with the free chlorine residual after a period of detention time. The test results are provided in Appendix F. Photo 6 illustrates the field equipment used to evaluate the chlorine residual in the water samples.

At the optimum chlorine residual of 0.2 mg/L, the chlorine feed dose was roughly 0.9 mg/L. The chlorine demand is the difference between the feed dose and the chlorine residual, which is 0.7 mg/L. The theoretical chlorine demand to oxidize the Fe and Mn in the raw water is 0.76 mg/L. The bench scale test results are very similar to theoretical results.

3.4 DUAL MEDIA FILTER

This section summarizes the results of the dual media (coated anthracite and coated silica sand) filter pilot test.

3.4.1 Optimization

Initial tests were conducted to optimize the chemical feed requirements for chlorine, potassium permanganate, and chlorine plus aeration at the typical flow loading rate of 3.9 gpm/ft^2.

Chlorination dosage of 1.3 mg/L resulted in a 0.3 mg/L free chlorine residual following filtration. The chlorine dosage is 0.3 mg/L greater than the chlorine demand test previously noted. Contact with the anthracite and Mn oxide coating are the probable cause of the additional chlorine demand.

Similarly, potassium permanganate was added to the filter influent at dosage rates ranging from 0.3 to 1.0 mg/L. The results demonstrated that the filtered water Mn concentration exceeded 0.020 mg/L at all dosage rates. Since potassium permanganate feed was not able to reduce the filtered water Mn concentration below the MWU treatment goals, its use was no longer evaluated.

Chlorination along with aeration was evaluated to determine the reduction in the chlorine dosage required. Aeration reduced the chlorine dosage by 0.18 mg/L. An economic evaluation of installing aerator compared to the costs of operating with chlorine alone will be evaluated later in this report.

The dual media optimization test data are presented in Appendix G.

3.4.2 Long-Term Test

Long-term tests were conducted to evaluate the differences in filter loading rates compared to Fe and Mn removal. Breakthrough for Fe was defined as field analytical results exceeding 0.100 mg/L. Breakthrough for Mn was defined as field analytical results exceeding 0.017 mg/L.

The dual media filter was operated between 2.9 and 9.2 gpm/ft^2 until breakthrough of either Fe or Mn or 72 hours of filter run time was exceeded. The results for the long-term filter runs are presented in Appendix G. If the treated water from the dual media filter met the treatment objectives for Fe and Mn at a given filter loading rate, then a higher filter loading rate was evaluated. The optimum filter loading rate was 5.0 gpm/ft^2 which was used over multiple filter runs.

Figure 7 illustrates the filtered water Fe concentrations. Fe was consistently treated to below the MWU treatment objective of 0.100 mg/L at flow rates less than 8.1 gpm/ft^2 and was typically below the level of detection of the field analytical procedures.

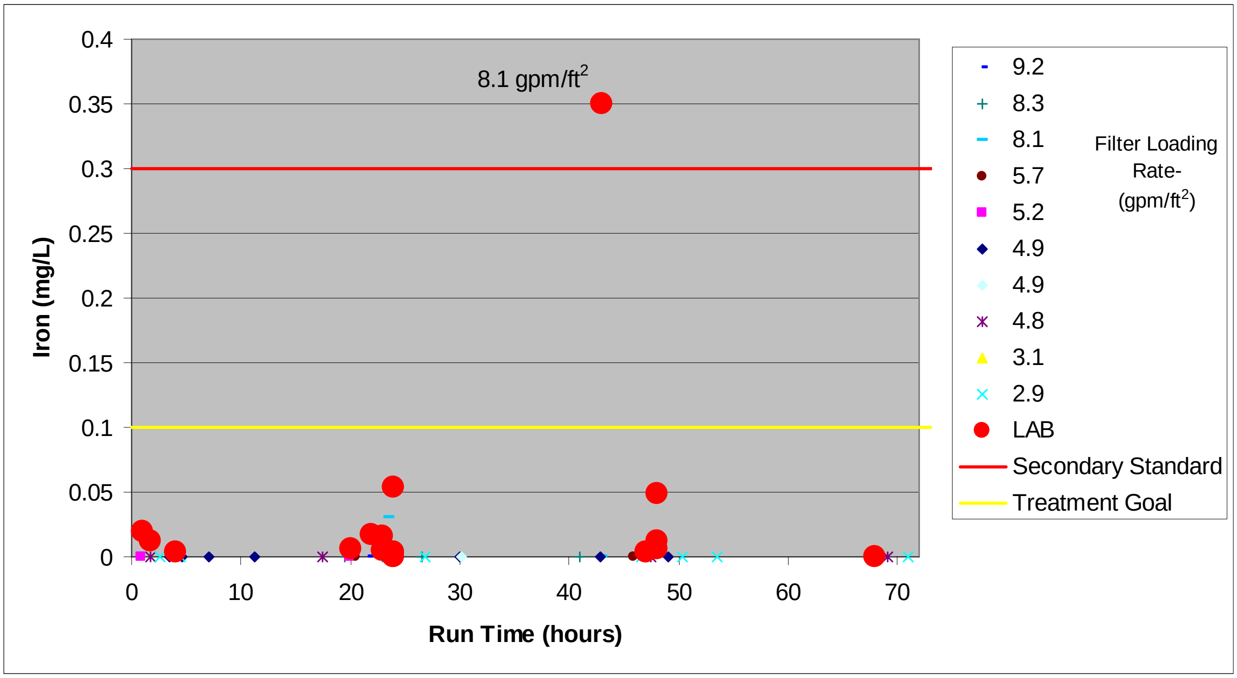

Figure 7: Dual Media – Fe Results

Figure 8 illustrates the treated water Mn concentrations with respect to filter run time for various flow rates. The higher flow rates resulted in higher treated water Mn concentrations.

The Mn analytical results exceeding the treatment objective were typically collected at the end of high rate filtration rates or considered to be data anomalies. Data was considered to be an anomaly when only one analytical result was not consistent with the rest of the filter run data. These anomalies were discounted when considering the filter run times.

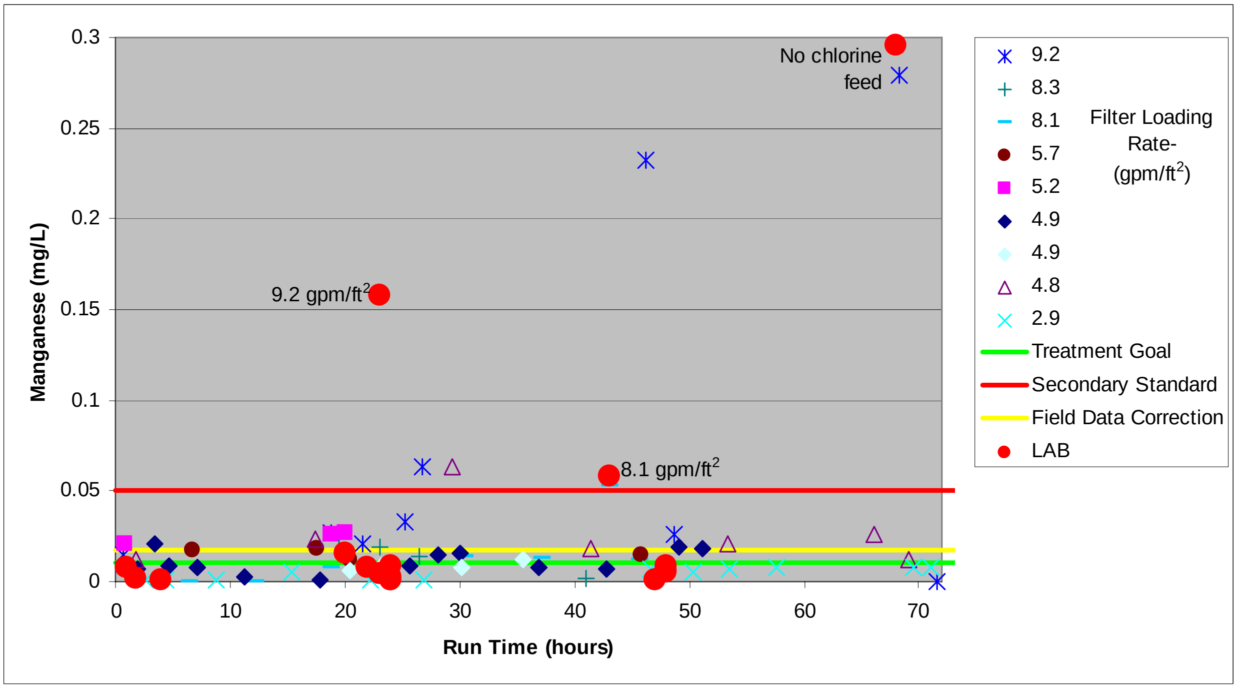

Figure 8: Dual Media – Mn Results

Filter run times are a function of the flow rate. Figure 9 illustrates the change in filter run time with respect to filter loading rate. Filter run time is defined as the time immediately before two consecutive Mn analytical results exceeded 0.017 mg/L. The arrows on the bars indicate that the filter run was terminated before Fe or Mn breakthrough occurred, indicating the filter run could have been extended.

These pilot results demonstrate that a dual media filter will meet the MWU's water quality objectives. The recommended design filtration rate is 5 gpm/ft^2 for a 48-hour filter run time. The pilot study suggests it may be possible to exceed the 48-hour filter run time.

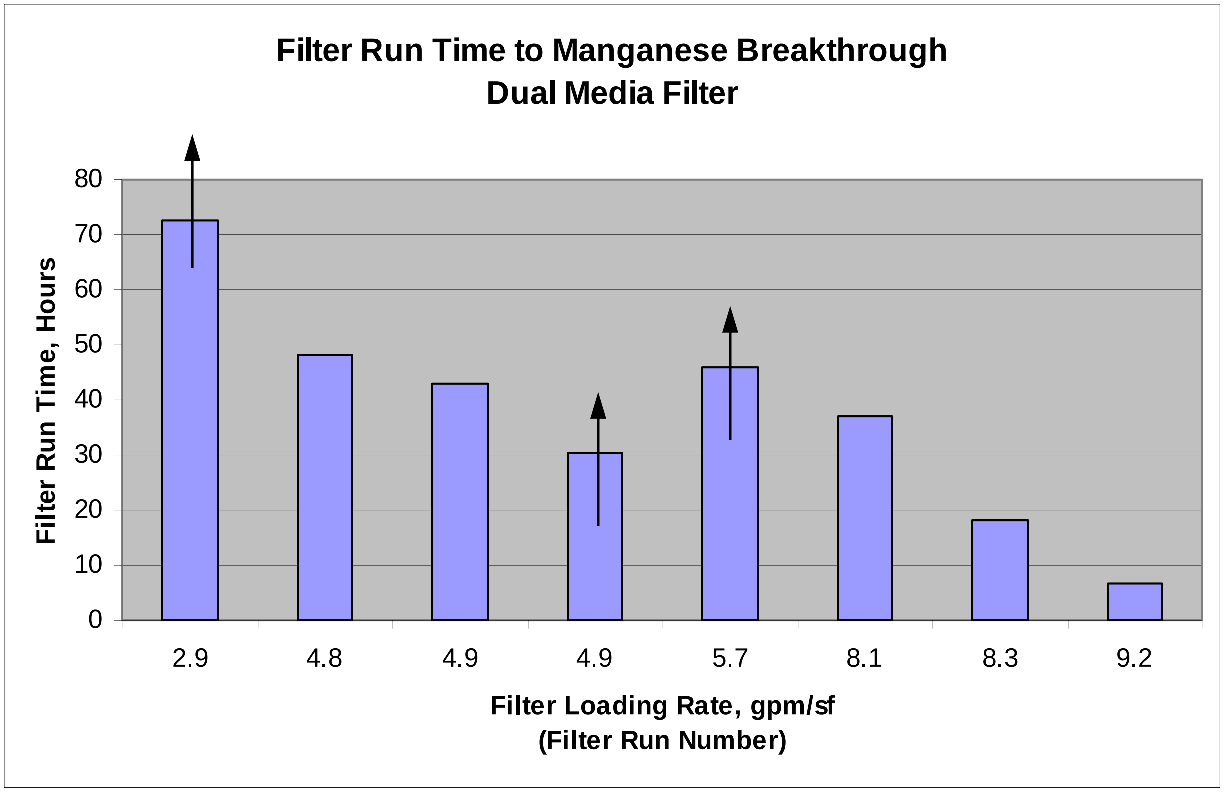

Figure 9: Dual Media – Filter Run Time to Mn Breakthrough

Figure 10 illustrates the headloss observed at various filter loading rates. At the recommended loading rate of 5 gpm/ft^2 and run time of 48 hours the anticipated maximum headloss is 12 feet.

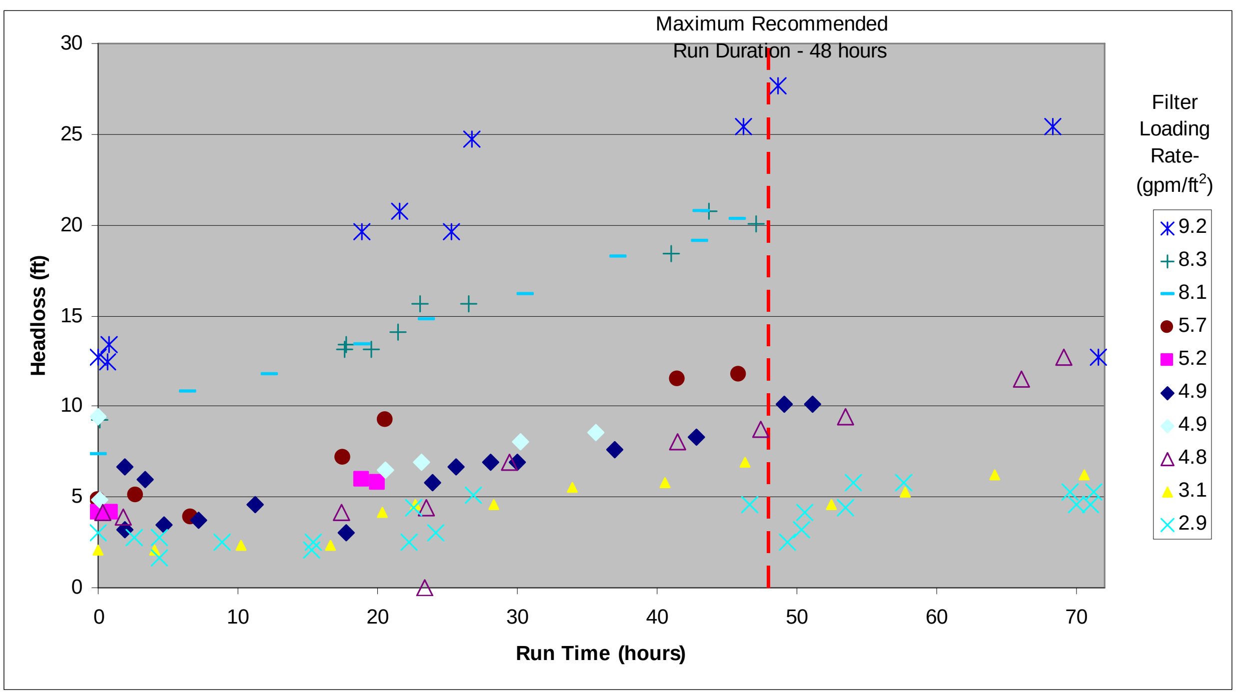

Figure 10: Dual Media - Headloss

3.4.3 Filter Backwash

The dual media filter was backwashed at a backwash rate of 10 gpm/ft^2 for 10 minutes. Observations throughout the filter backwash cycle indicated that the backwash water consistently became clear after 6 minutes. Backwashing was continued for the full 10 minutes to ensure the media was properly cleaned.

Backwash water composite samples were obtained by collecting a grab sample of the backwash water every 30 seconds over the 10 minute backwash cycle. The individual grab samples were composited in a 5-gallon pail to observe the time required for the solids to settle simulating backwash water being collected in a backwash recycle basin.

After one hour settling time, a sludge blanket developed at approximately the 50 percent mark o of the pail. After allowing the sample to settle for more than 8 hours, the sludge blanket was near the bottom of the pail. The supernatant liquid above the sludge was transparent but had a slight yellow color suggesting Fe particles remained in suspension.

Photo 7: Dual Media After Testing – Sand at Surface

At the completion of the long-term test, the media was inspected. A trace amount of sand was present at the top of the media as shown in Photo 7. Well 29 pumps sand from the aquifer into the filter units. The sand is collected on the top of the filter media. It is estimated that sand particles less than 0.099 mm diameter will be removed from the filter during backwash. Larger sand particles will be retained and will blend with the filter media, eventually resulting in increased filter headloss.

3.4.4 Operational Observations

The following are some observations made during the pilot testing of dual media filtration.

- Fe removal is effective to below the MWU goal of 0.100 mg/L at loading rates below 8.1 gpm/ft^2.
- Mn removal is effective to the MWU goal of 0.010 mg/L at a flow rate of 5 gpm/ft^2 and 48-hour filtration time.
- Headloss ranges between 3 to 12 feet. Recommended design terminal headloss is 15 feet.
- The chlorine dosage of 1.3 mg/L provided effective Fe and Mn treatment and provided a treated water chlorine residual of 0.30 mg/L.
- Chlorine with aeration resulted in effective Fe and Mn treatment and provided a reduced chlorine dose of 0.18 mg/L.
- Sand particles greater than 0.10 mm are expected to be retained within the filter bed.

3.5 GREENSAND FILTER

This section details the results of the greensand (coated anthracite and manufactured Mn greensand) media filter pilot test.

3.5.1 Optimization

The greensand media required regeneration with permanganate during start-up. After regeneration, permanganate was used as the oxidant for the reduction of Fe and Mn. During initial optimization testing, the greensand filter was operated at the typical filtration loading rate of 4 gpm/ft^2. The testing results are provided in Appendix H.

The optimum permanganate dose resulted in treated water Mn concentrations near 0.20 mg/L, greater than the MWU treatment objective and was not considered acceptable. Therefore, permanganate was no longer evaluated.

A chlorine dosage of 1.3 mg/L resulted in a 0.3 mg/L free chlorine residual following filtration. The chlorine dosage is 0.3 mg/L greater than the chlorine demand test previously noted. Contact with the Mn oxide coating is the probable cause of the additional chlorine demand. The treated water Mn concentration averaged 0.012 mg/L in field analysis. Chlorine oxidation was continued through the long-term testing which resulted in meeting the MWU treatment objectives.

3.5.2 Long-Term Test

Long-term tests were conducted to evaluate the differences in filter loading rates compared to Fe and Mn removal. The long-term test data for the greensand media filter is provided in Appendix H. The following section summarizes the results.

The greensand filter was operated between 3 and 4.9 gpm/ft^2. Fe was consistently treated to below the treatment objective of 0.100 mg/L at all flow rates and was typically below the level of detection of the field analytical procedures, see Figure 11.

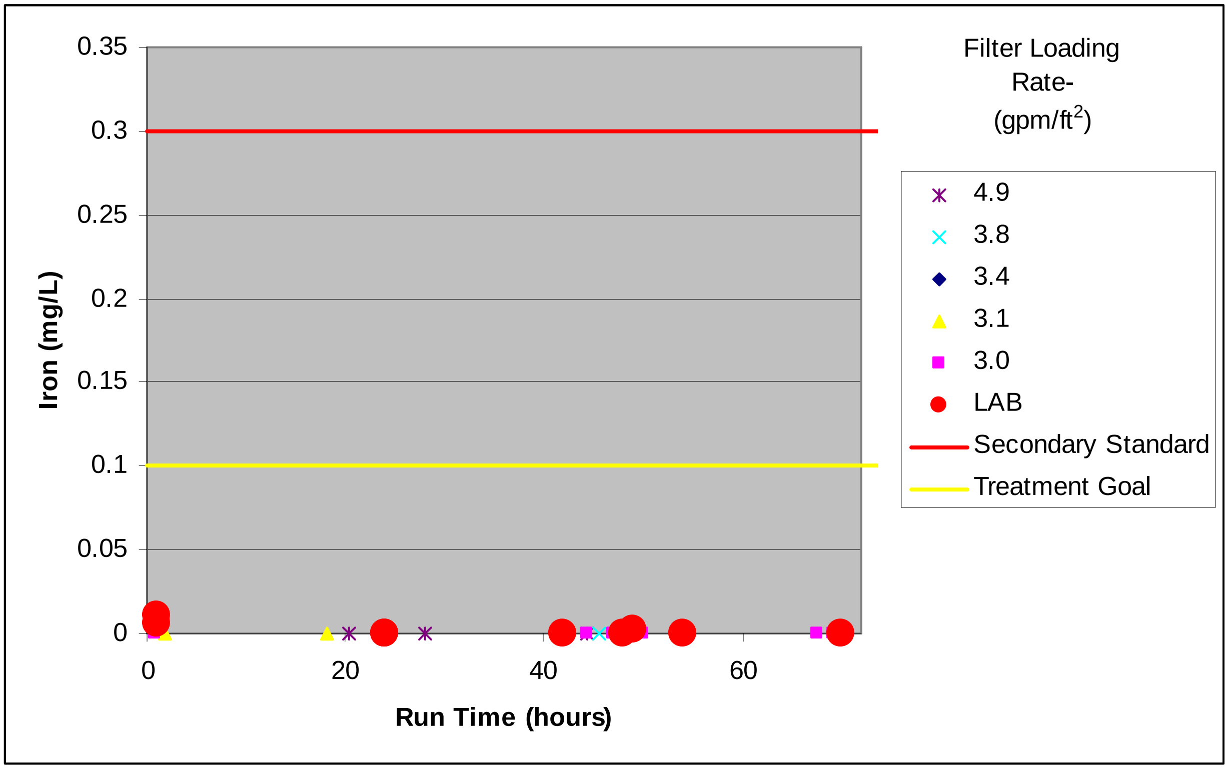

Figure 11: Greensand – Fe Results

Figure 12 illustrates the treated water Mn concentrations compared to filter run time for the greensand filter at various filter loading rates. Field analytical results were generally within the treatment objective for Mn. Results exceeding the MWU treatment objective were observed during the initial startup prior to realizing that the media required additional preparation prior to operation. Other analytical results exceeding the treatment objective represent periods when potassium permanganate oxidation was being used or when backup operators were performing the analysis.

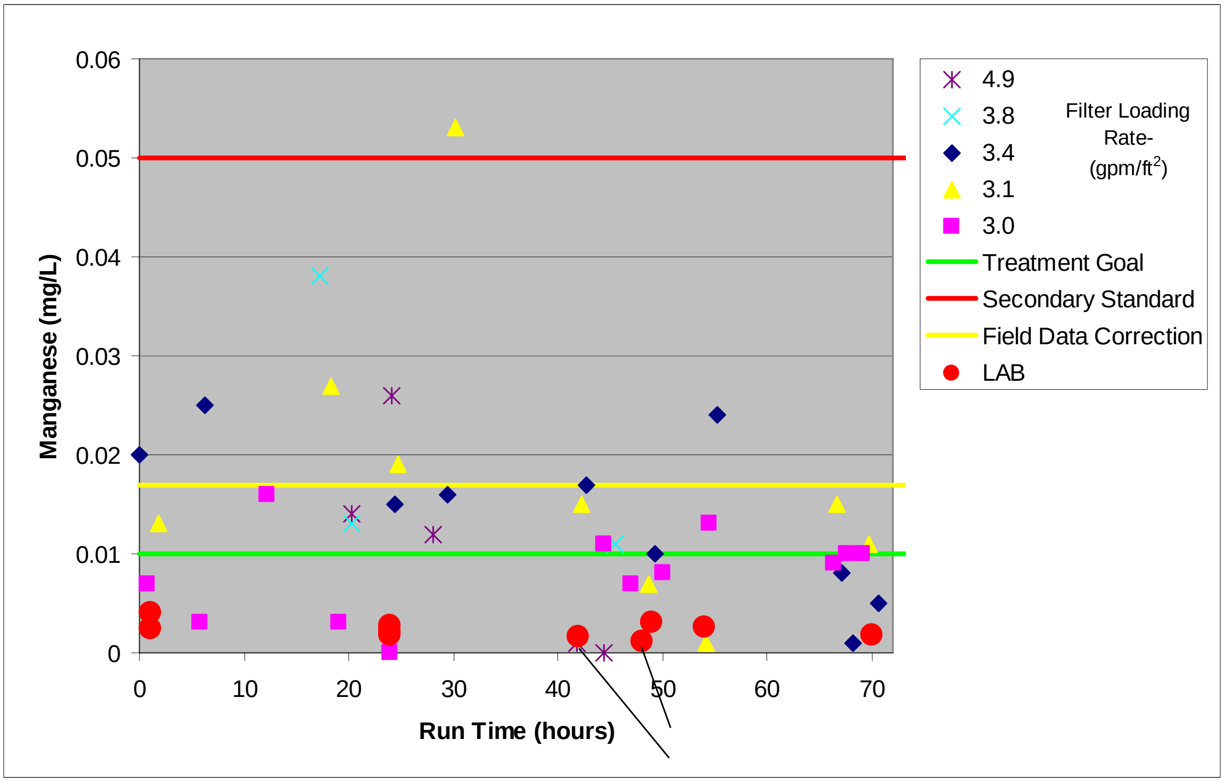

Figure 12: Greensand – Mn Results

The filter run times are presented in Figure 13. Filter run time is defined as the time immediately before two consecutive Mn analytical results exceeded 0.017 mg/L. The arrows on the bars indicate that the filter run was terminated before Fe or Mn breakthrough occurred, indicating the filter run could have been extended. Mn greensand filtration will remove Fe and Mn to below the MWU treatment objectives with 42-hour filter runs at filter loading rates up to 4.9 gpm/ft^2.

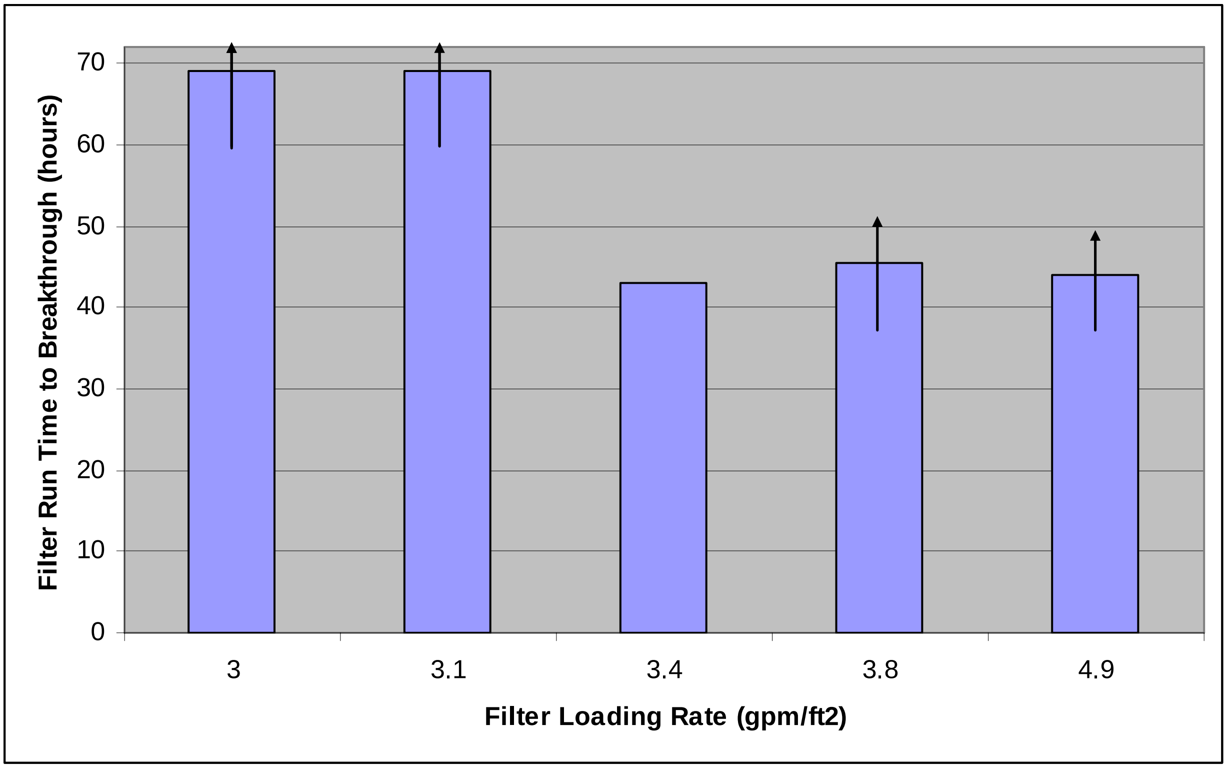

Figure 13: Greensand – Filter Run Time to Mn Breakthrough

Figure 14 shows the headloss observed at the various filter loading rates evaluated. The terminal headloss at 4.9 gpm/ft^2 loading rate was 9.7 feet after 42 hours filter run time.

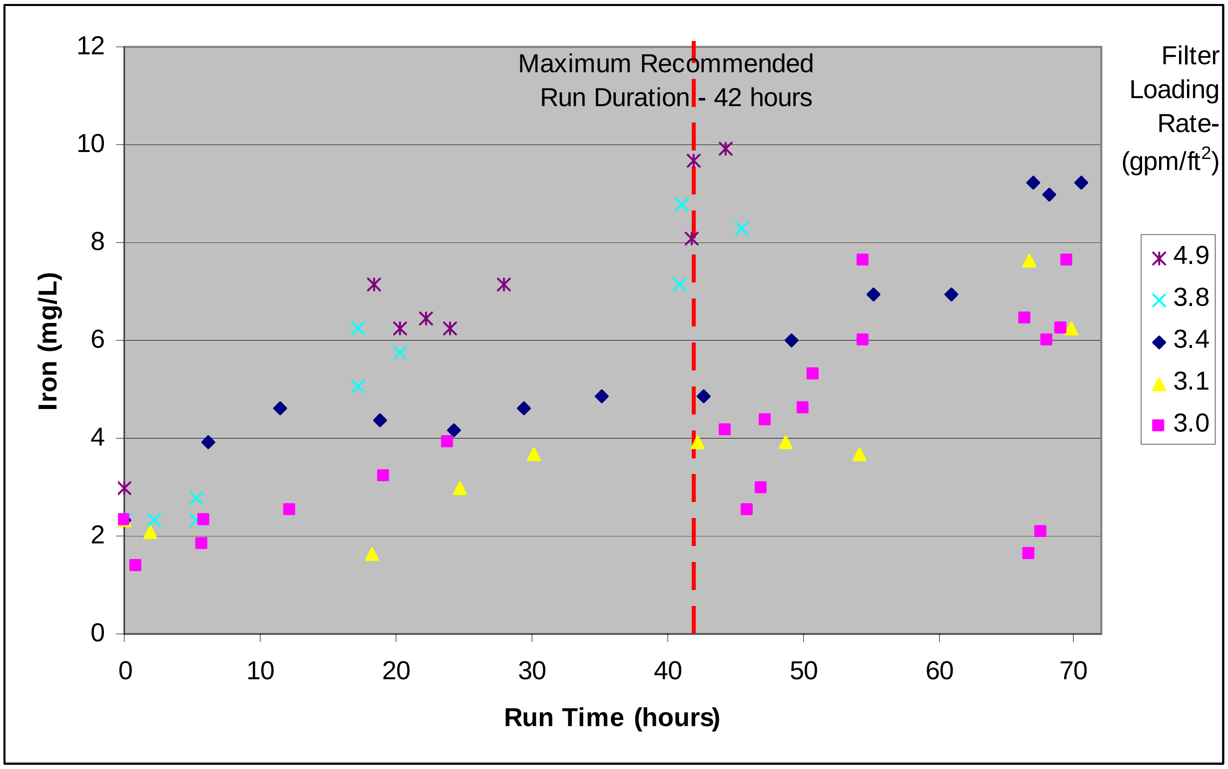

Figure 14: Greensand – Headloss

3.5.3 Backwash

Backwash was operated at 7.6 gpm/ft^2 for 10 minutes. Observations of the backwash water indicate that the backwash water cleared after 6 to 6.5 minutes backwash; however backwash was continued for the full 10 minutes to ensure appropriate cleaning of the filter media between filter runs.

Backwash water composite samples were obtained by collecting a grab sample of the backwash water every 30 seconds over the 10 minute backwash cycle. The individual grab samples were composited in a 5-gallon pail to observe the time required for the solids to settle simulating backwash water being collected in a backwash recycle basin.

After two hour settling time, only a trace amount of solids were present on the bottom and the supernatant was clear.

At the completion of the long-term test, the media was backwashed and then inspected. A trace amount of sand was present at the top of the media as shown in Photo 8. It is estimated that sand particles greater than 0.083 mm diameter will be retained within the filter. The larger retained sand will mix with the filter media. Over time this will result in additional media depth and increased filter headloss.

Photo 8: Greensand after Testing – Sand at Surface

3.5.4 Operational Observations

The following are some observations made during the pilot testing of greensand media filtration.

- Fe is removed to below the MWU treatment goal of 0.100 mg/L under all operating conditions.
- Mn is removed to below the MWU treatment goal of 0.010 mg/L at flow rate of 4.9 gpm/ft^2 and below for at least 42 hours operation using chlorine oxidation.
- Headloss ranges between 2 to 11 ft. Recommended design terminal headloss is 15 ft.
- Potassium permanganate oxidation did not meet the treatment objective for Mn. The optimum treated water Mn concentration using potassium permanganate was 0.022 mg/L.
- Chlorine dosage of 1.3 was required to achieve the required level of Mn treatment.
- When using chlorine as the oxidant, the treated water chlorine residual of 0.30 mg/L was maintained.
- Sand particles greater than 0.08 mm are expected to be retained within the filter bed.

3.6 CALMEDIA GSR FILTER

This section summarizes the results of the Cal Media GSR (GSR) media filter pilot test.

3.6.1 Optimization

Initial tests were conducted to optimize the chemical feed requirements for chlorine and potassium permanganate. The GSR media filter was operated at the typical operating loading rate of 4 gpm/ft^2. The optimization testing results are presented in Appendix I.

Potassium permanganate dosages ranged from 0.65 to 0.75 mg/L. The stoichiometric dosage for potassium permanganate is 0.70 mg/L. The filtered water Fe concentrations were 0.01 mg/L or less and the Mn concentrations ranged from 0.022 to 0.070 mg/L. Since no potassium permanganate dosage was observed to result in filtered water Mn concentrations less than the MWU treatment objective, potassium permanganate alone was no longer considered viable.

Chlorine dosage of 1.3 mg/L resulted in a free chlorine residual in the filtered water of 0.3 mg/L. The treated water Fe concentrations were 0.01 mg/L or less and the Mn concentration ranged from “no detect” to 0.002 mg/L Mn.

Chlorine and potassium permanganate together resulted in filtered water concentrations of “no detect” for Fe and 0.012 to 0.014 mg/L for Mn. Since chlorine alone provided greater Mn removal than chlorine and potassium permanganate together, only chlorine alone was continued for further evaluation.

3.6.2 Long-Term Test

The long-term test reviewed the treatment performance of the GSR filter media at various filter loading rates. The filter was operated a minimum of 48 hours at each loading rate to determine the treatment performance. The GSR filter media was tested at loading rates from 3.8 to 6.9 gpm/ft^2. Detailed long-term test data for the GSR media filter is provided in Appendix I.

Fe was well below the treatment objective of 0.1 mg/L and was typically below the level of detection of the field analytical instrument (<0.03 mg/L). Treated water Fe concentrations are provided in Figure 15.

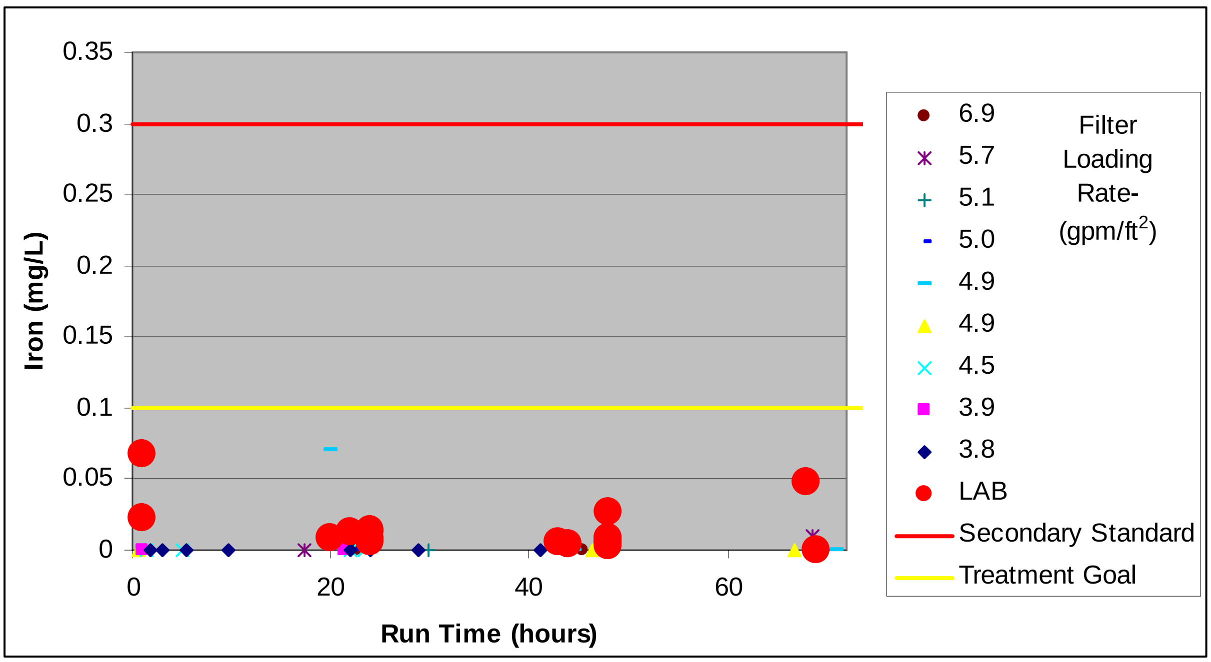

Figure 15: GSR Fe Results

Figure 16 illustrates the treated water Mn concentrations throughout the pilot test as the GSR media was operated at various flow rates.

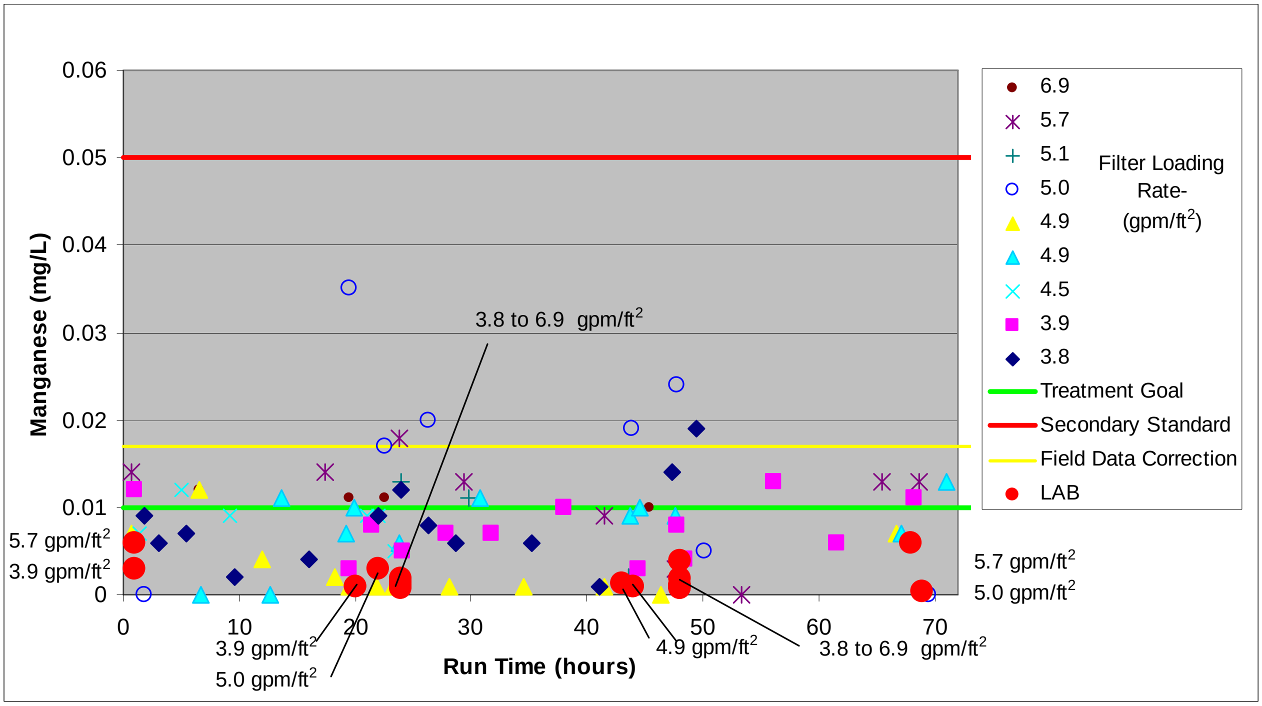

Figure 16: GSR Mn Results

Unlike the dual media and greensand, GSR did not have any field data greater than the SDWA Secondary Standard for Mn. As noted earlier, the field results were typically higher than the lab results. No lab results were above the treatment goal. One field result is above the field correction line; however, this was the first test completed by an alternate operator and is considered to be an outliner.

Figure 17 illustrates the change in filter run time with respect to filter loading rate. Filter run time is defined as the time immediately before two consecutive Mn analytical results exceeded 0.017 mg/L. The arrows on the bars indicate that the filter run was terminated before Fe or Mn breakthrough occurred, indicating the filter run could have been extended.

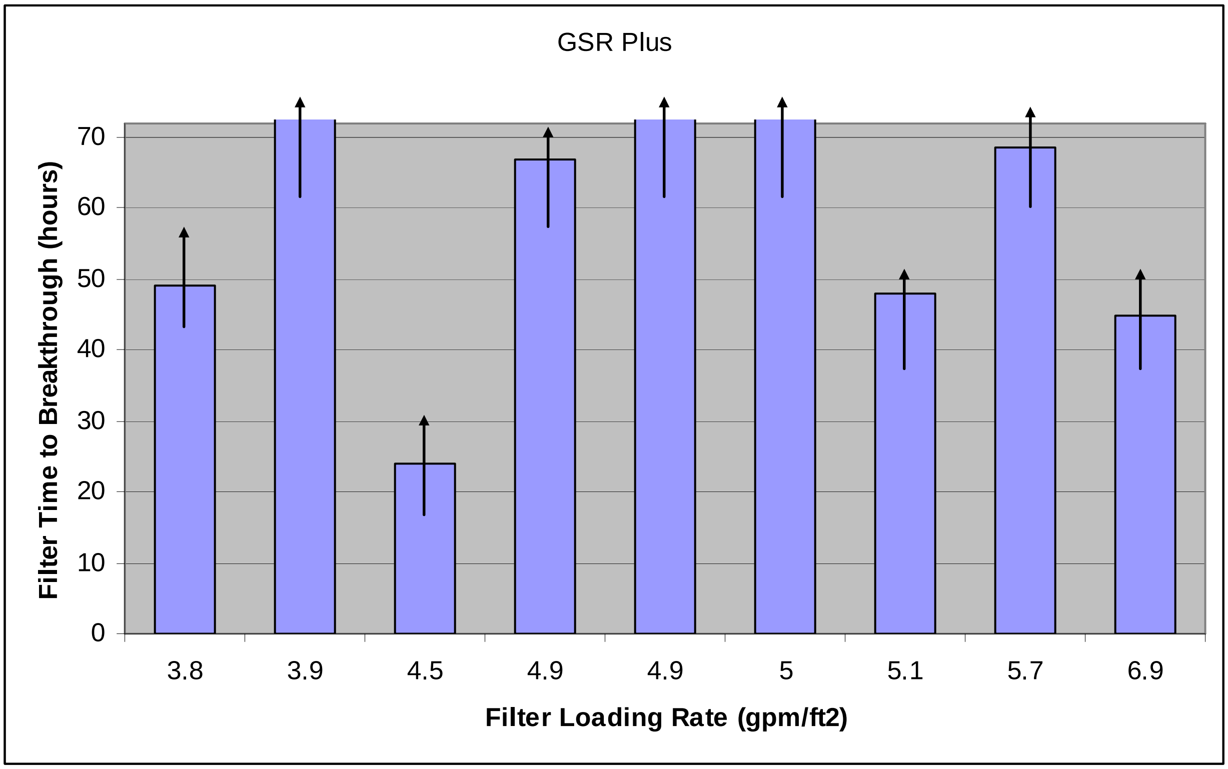

Figure 17: GSR Filter Run Times

These pilot results demonstrate that a GSR filter will meet the MWU's water quality objectives at all filter loading rates up to 6.9 gpm/ft^2 for at least 48 hours filter run time. The media manufacturer recommends a maximum flow rate of 5.0 gpm/ft^2. Although the unit performed well at higher flow rates, the recommended flow rate is 5.0 gpm/ft^2. The design filter run time is 72 hours. The pilot study suggests it may be possible to exceed the 72-hour filter run time.

Figure 18 illustrates the headloss observed over time at various filter loading rates. At the recommended loading rate of 5.0 gpm/ft^2 and run time of 72 hours the anticipated maximum headloss is 15 feet.

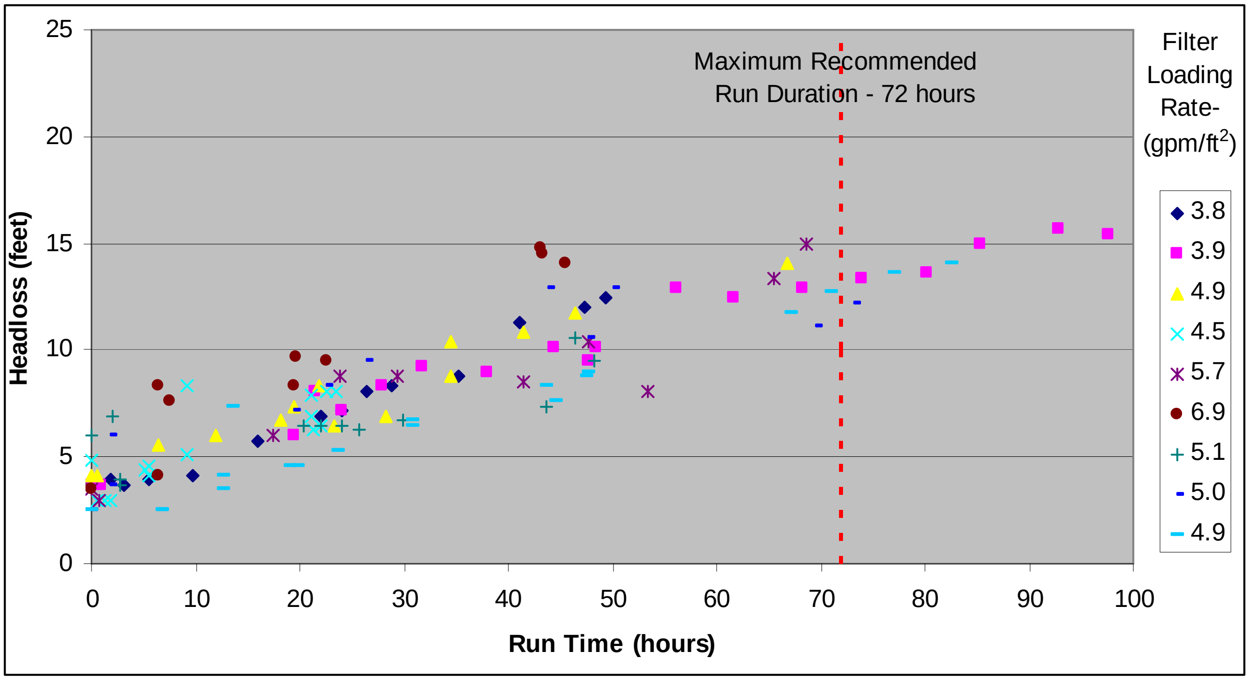

Figure 18: GSR Headloss

The unit continued to meet the treatment objectives immediately after backwash and after restarting the unit.

Chlorine feed was discontinued for four hours. During this period Mn removal continued with filtered water Mn concentrations at 0.003 mg/L.

3.6.3 Backwash

The GSR filter was backwashed at 12.7 gpm/ft^2 for 10 minutes. Observations throughout the filter backwash cycle indicated that the backwash water became clear between 5 to 8 minutes. Backwashing was continued for the full 10 minutes to ensure the media was properly cleaned.

Backwash water composite samples were obtained by collecting a grab sample of the backwash water every 30 seconds over the 10 minute backwash cycle. The individual grab samples were composited in a 5-gallon pail as shown in Photo 9 to observe the time required for the solids to settle simulating backwash water being collected in a backwash recycle basin.

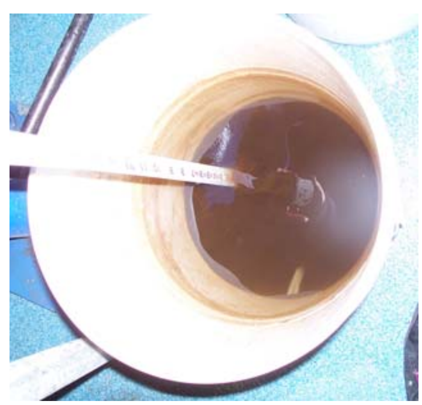

Photo 9: Composite Backwash Wastewater Sample

After a 2-hour settling time, only trace amounts of solids were present on the bottom and the supernatant was clear.

An additional settling test was completed to evaluate the potential for recycling backwash water, additional composite samples were collected over three filter runs. Following each filter run, water was allowed to settle and the clear supernatant was decanted. During the following filter backwash cycle additional 30 second grab samples were added to continue creating the composite sample. This second composite sample was allowed to settle and the supernatant also decanted. The same procedure continued for the third backwash cycle.

After the three filter runs the solids were allowed to settle. Approximately 97 percent of the total composite backwash water composite sample was decanted, suggesting that more than 90 percent of backwash water may reasonably be recycled through the filter, leaving 10 percent of the backwash water to be discharged to the sanitary sewer.

At the completion of the long-term test, the media was inspected. The filter was not backwashed prior to inspection. A trace amount of sand was present at the top of the media. It is estimated that sand particles greater than 0.108 mm diameter will be retained in the filter. Larger sand particles are retained and are mixed with the filter media. Over time this can result in additional media depth and increased headloss.

3.6.4 Operational Observations

The following are some observations made during the pilot testing of GSR filtration.

- Fe removal is effective to below the MWU goal of 0.100 mg/L at all loading rates evaluated.
- Mn removal is effective to the MWU goal of 0.010 mg/L at a flow rate of 5.0 gpm/ft^2 and 72-hour filtration time.
- Headloss ranges between 3 to 15. Recommended design terminal headloss is 15 feet.
- The chlorine dosage of 1.3 mg/L provided effective Fe and Mn treatment and provided a treated water chlorine residual of 0.30 mg/L.
- When oxidant addition is stopped, the unit will continue to meet the treatment objectives for at least 4 hours.
- Sand particles greater than 0.11 mm diameter are expected to be retained within the filter bed.

3.7 PYROLUSITE FILTER

This section details the results of the pyrolusite (coated mined Mn oxide ore) media filter pilot test.

3.7.1 Optimization

Initial testing to determine the optimum chlorine dosage was completed at a filter loading rate of 10 gpm/ft^2. Chlorine dosage of 1.3 mg/L resulted in treated water chlorine residual of 0.4 mg/L. Filter water Fe concentrations were “no detect” and the Mn concentrations ranged from “no detect” to 0.003 mg/L. The optimization testing results are presented in Appendix J.

3.7.2 Long-Term Test

Long-term tests were conducted to evaluate the differences in filter loading rates compared to Fe and Mn removal. The loading rates evaluated for the pyrolusite media were between 10.0 and 17.3 gpm/ft^2. Breakthrough for Fe and Mn was based on the treated water Fe and Mn concentrations exceeding 0.100 mg Fe/L and 0.017 mg Mn/L (field analysis). Long-term test results for the pyrolusite media filter is provided in Appendix J.

During the long-term test the chlorine dosage was further optimized. After multiple runs the chlorine dosage of 1.5 mg/L resulted in a treated water chlorine residual of 0.3 mg/L.

Figure 19 illustrates the effluent Fe concentrations throughout the pilot testing period. Only one Fe sample field analytical result exceeded the MWU treatment objective of 0.100 mg/L. Immediately following backwashing with raw water a sample was taken for lab analysis that resulted in Fe concentration above the treatment objective. All other results at that flow rate indicated the Fe concentrations were below the level of detection of the analytical instrument (<0.03 mg/L).

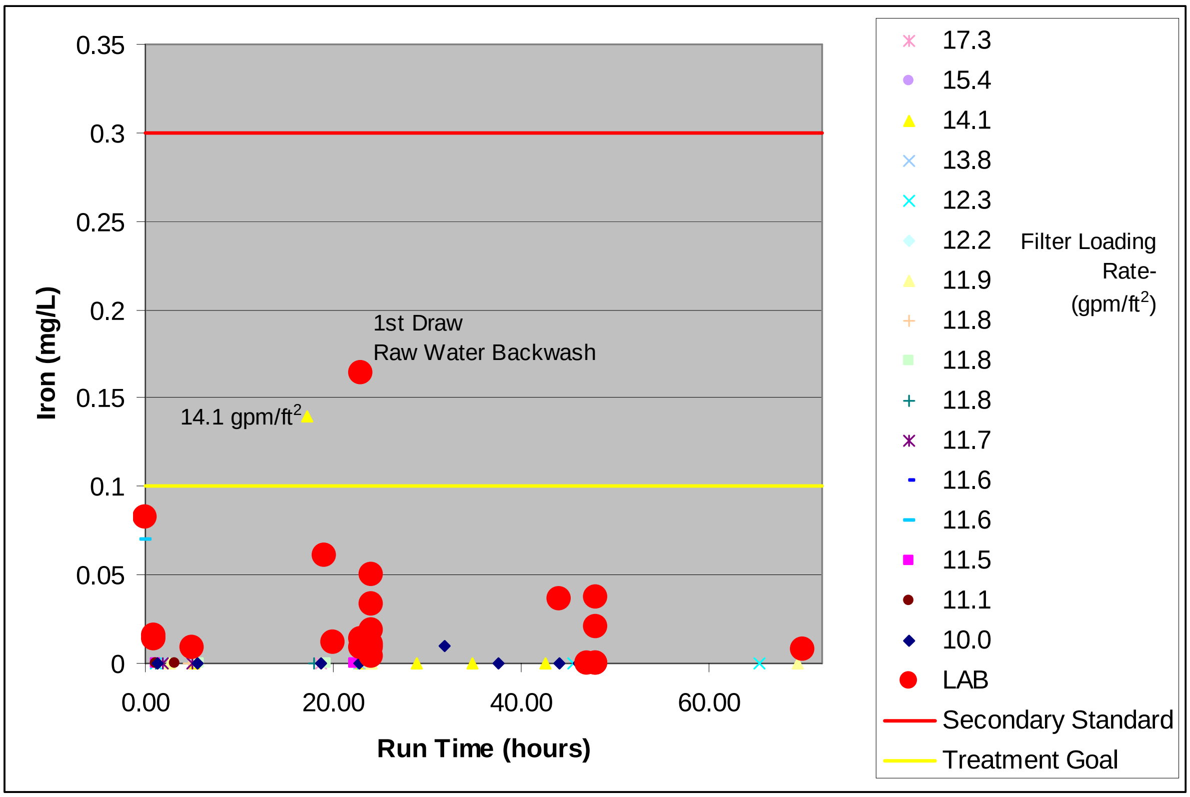

Figure 19: Pyrolusite Fe Results

Figure 20 illustrates the treated water Mn concentrations over time as the pyrolusite was operated at various flow rates.

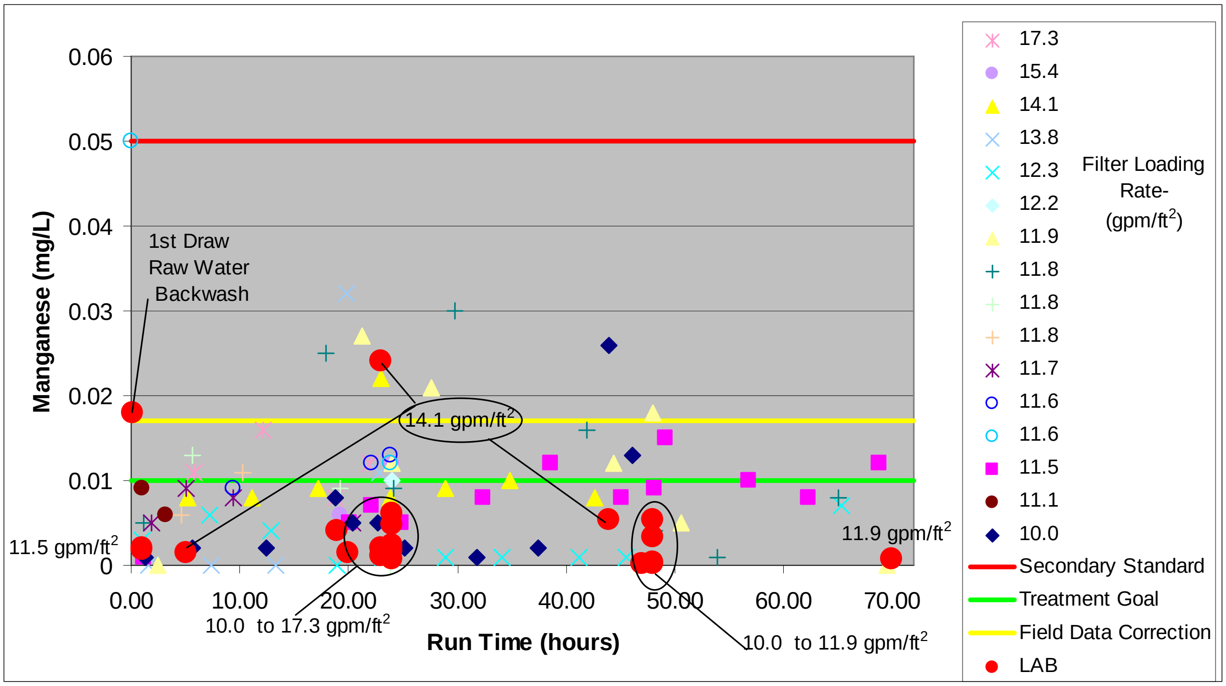

Figure 20: Pyrolusite Mn Results

Two lab results were above the treatment objective of 0.010 mg/L Mn. The first lab result was immediately following backwash with raw water. The Mn in the raw water used during backwash was reduced from 0.18 mg/L to 0.018 mg/L when discharged.

The second lab result above the treatment objective is at 24 hours at a flow rate of 14 gpm/ft^2. It is recommended that the flow rate through the unit be less than 14 gpm/ft^2. The laboratory Mn concentration at 11.6 gpm/ft^2 flow rate is 0.002 mg/L and the average Fe concentration is 0.011 mg/L.

Figure 21 illustrates the change in filter run time with respect to filter loading rate. The media manufacturer recommends a maximum run time of 24 hours prior to backwash. Although the pilot unit successfully removed Fe and Mn at longer run times, the backwash frequency will be 24 hours.

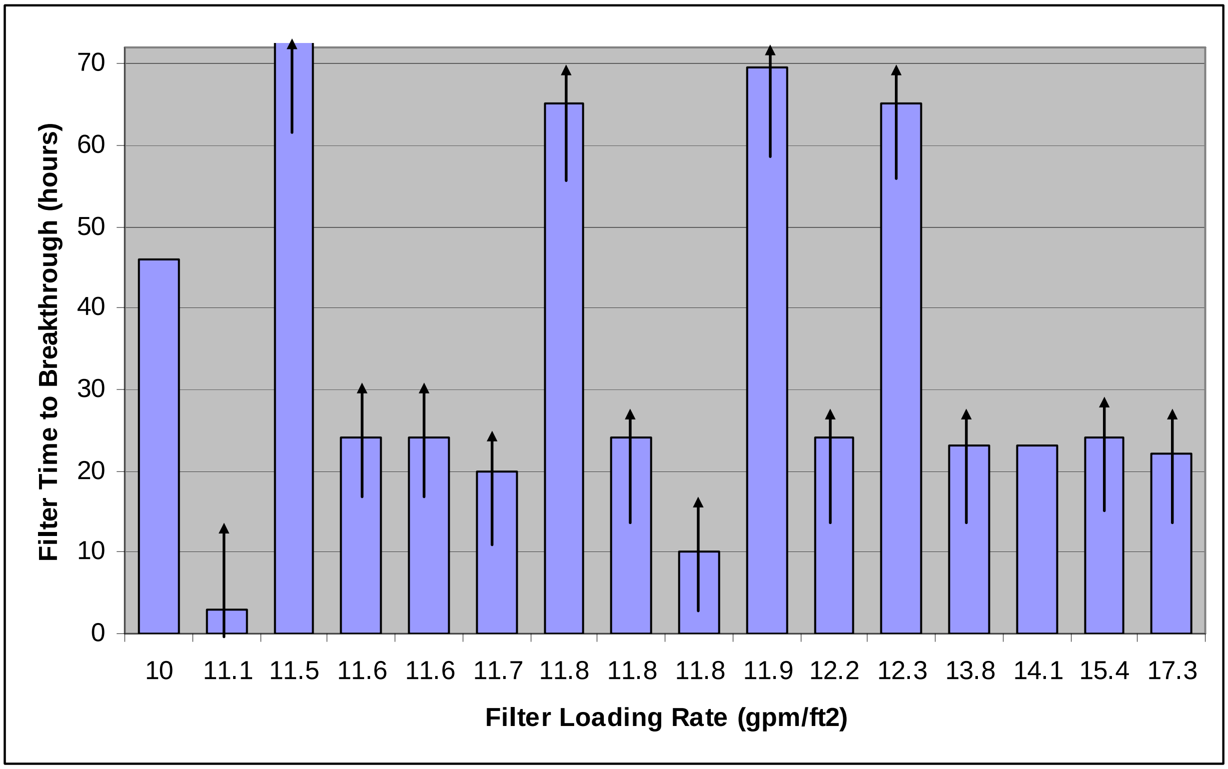

Figure 21: Pyrolusite - Filter Run Time to Mn Breakthrough

The headloss over time at the various flow rates is illustrated in Figure 22.

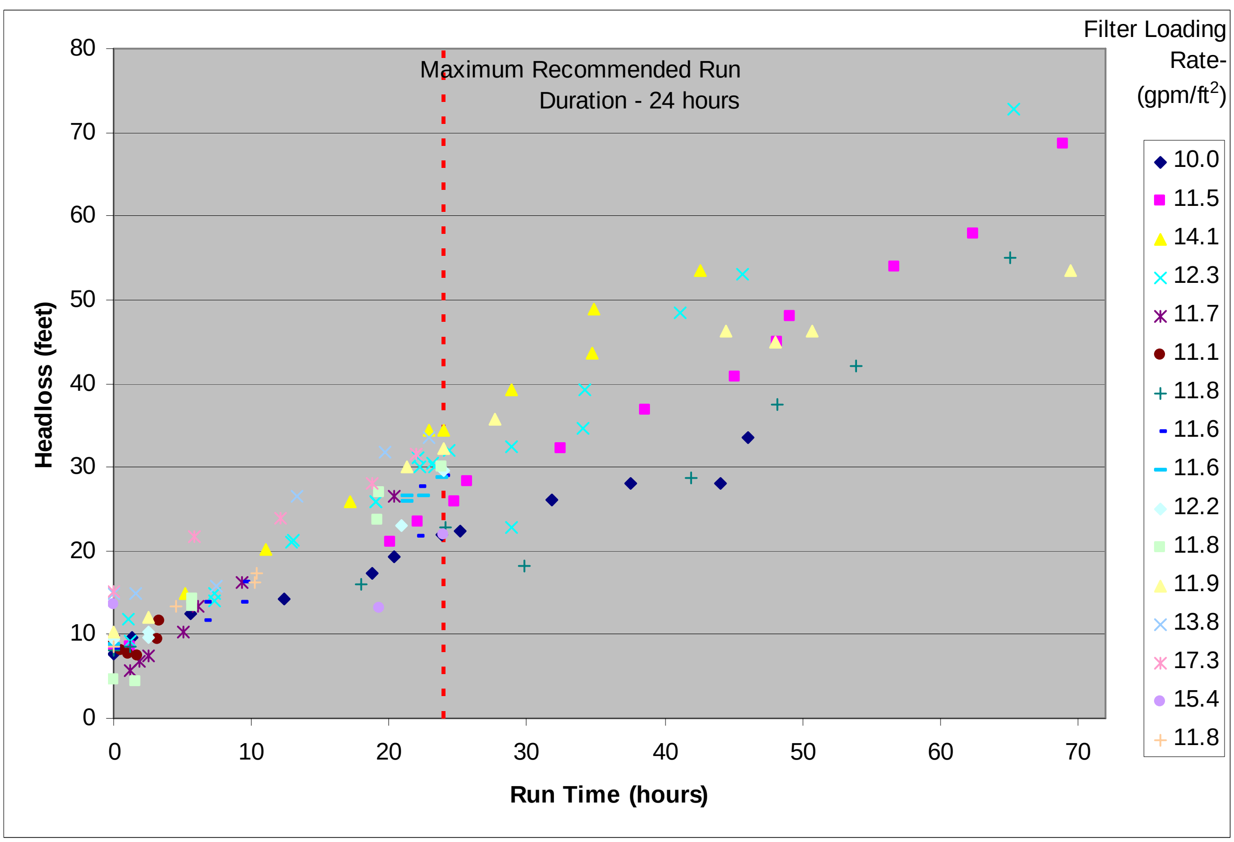

Figure 22: Pyrolusite Headloss

The maximum headloss at the recommended filter run time of 24 hours and at a flow rate of roughly 11.6 gpm/ft^2 is 29 feet.

Once during the study, the pilot filter was started quickly. A slug of Mn and Fe was pushed through the filter. This was caused by the fast filling of the unit. Treatment facility design should include slow startup and shutdown of the filter vessels to prevent this from occurring.

Chlorine feed was discontinued for six hours. During this period Fe and Mn removal remained below the treatment objectives.

3.7.3 Backwash

The pyrolusite filter was backwashed at 23 gpm/ft^2 for 5 minutes as recommended by the media manufacturer. Observations throughout the filter backwash cycle indicated that the backwash water consistently became clear after 3 minutes. Backwashing was continued for the full 5 minutes to ensure the media was properly cleaned.

Backwash water composite samples were obtained by collecting a grab sample of the backwash water every 30 seconds over the 5 minute backwash cycle. The individual grab samples were composited in a 5-gallon pail to observe the time required for the solids to settle simulating backwash water being collected in a backwash recycle basin.

After a 2-hour settling time, only trace amounts of solids were present on the bottom and the supernatant was clear.

An additional settling test was completed to evaluate the potential for recycling backwash water, additional composite samples were collected over three filter runs. Following each filter run, water was allowed to settle and the clear supernatant was decanted. During the following filter backwash cycle additional 30 second grab samples were added to continue creating the composite sample. This second composite sample was allowed to settle and the supernatant also decanted. The same procedure continued for the third backwash cycle. Faster settling was observed when more solids were present.

Photo 10: Settling Test

Imoff cone settling tests were completed on the backwash water. Photo 10 illustrates the settling test on backwash wastewater after 30 minutes. The sample to the left is the composite sample and to the right is the 3 minute grab sample. The settleability of the composite sample resulted in 200 mL/L and the 3 minute grab sample resulted in 20 mL/L.

At the conclusion of the pilot studies, the filter surface was observed to have sand present. This observation was completed prior to backwashing. Sufficient sand was not available for size distribution analysis, nor observable throughout the filter media. It is estimated that sand particles greater than 0.157 mm will be retained following the backwash of the pyrolusite filter media. Pyrolusite is more likely to remove the sand from the filter during backwash then the other media due to the higher backwash rate.

3.7.4 Operational Observations

The following are some observations made during the pilot testing of dual media filtration.

- Fe removal is effective to below the MWU goal of 0.100 mg/L at loading rates below 14.1 gpm/ft^2.
- Mn removal is effective to the MWU goal of 0.010 mg/L at a flow rate of 12 gpm/ft^2 and 24-hour filtration time.
- Headloss ranges between 5 to 33. Design terminal headloss should be 35 feet.
- The chlorine dosage of 1.5 mg/L provided effective Fe and Mn treatment and provided a treated water chlorine residual of 0.30 mg/L.
- When oxidant addition is stopped, the unit will continue to meet the treatment objectives for at least six hours.
- Sand particles greater than 0.16 mm diameter are expected to be retained within the filter bed.

3.8 MEMBRANE FILTER

3.8.1 Treatment Capacity

The membrane demonstration filter was provided by GE/Zenon. It is capable of providing permeate quality representative of full-scale modules; however, the demonstration filter is not designed to evaluate filtration variables such as flux, pressure, and energy requirements. If the permeate water quality is desirable, further pilot testing will be required to determine the water treatment design parameters.

Photo 11: Initial and Replacement Membranes

The membrane demonstration filter was evaluated using 20 minutes of detention time prior to the membranes to adequately oxidize the Fe and Mn.

The integrity of the initial membrane provided with the membrane demonstration filter was not known; therefore, the results of the initial membrane are not included in the review. A replacement membrane was installed and the new membrane Photo 11 illustrates the coloration of membranes before and after use for Fe and Mn removal. The original membrane is obviously stained with Fe and Mn. Long-term operation and cleaning procedures will need to be evaluated during future pilot studies.

The membrane results to March 16, 2007, indicate that the system does not meet treatment objectives for Mn removal. Treated water Fe was below the laboratory detection limits throughout the testing. The treated water Mn on the replacement membrane is 0.144 mg/L. The initial membrane was evaluated at detention times exceeding 1 hour. At the high detention time the Mn in the effluent was reduced to 0.034 mg/L on average. The membrane will continue to be tested until March 29, 2007.

3.9 SCALE FORMATION POTENTIAL

The scale formation and corrosion potential of the water were evaluated to determine the potential long-term effects of scale buildup or corrosion on the water treatment equipment and in the distribution system. Alkalinity, conductivity, pH, and calcium concentrations are used to calculate the Langliler's Index (LI), calcium carbonate precipitation potential (CCPP), copper solvency (CuII), and lead solvency (PbII). Table 6 presents the water quality data and resulting indices.

The Langelier Index provides an indication for the corrosiveness for steel and cast iron pipe as well as a tendency for calcium carbonate precipitation. A positive LI indicates non-corrosive water; conversely a negative LI suggests the water is corrosive toward steel and cast iron pipe. The LI for all filtered water is slightly positive. A positive LI less than 0.2 is considered stable and has minimal scaling tendencies.

CCPP is a measure of the development of calcium carbonate scale on piping in distribution systems. In a filtration system, scale buildup can lead to clogged distribution headers within the filtration vessels. Typical recommended CCPP is 4 to 10 mg/L. The CCPP values are within or below the recommended range; therefore, it can be assumed that some scale may buildup over time; however, the interval is the same as at other filtration locations.

CuII and PbII is the theoretical equilibrium between the water and raw metal copper and lead, with which it is in contact. The values are used as a relative value for comparison within and between water supply systems. Solvency is used to estimate relative changes in lead and copper corrosion resulting from Pb/Cu treatment techniques.

TABLE 6
CORROSION AND SCALE INDICES

	Recommended	Raw Water	Dual Media		Pyrolusite		GSR	
			Pre-Filter	Post-Filter	Pre-Filter	Post-Filter	Pre-Filter	Post-Filter
Alkalinity		268	284	284	280	286	284	273
pH		7.32	7.28	7.28	7.26	7.32	7.28	7.32
Calcium		85.6	70.4	69.6	69.6	69.6	65.2	68.0
TDS		347	347	347	347	347	347	347
Temperature		13.4	14.1	15.1	15.1	16.1	14.5	14.1
LI	>0	0.13	0.04	0.05	0.02	0.11	0.1	0.05
CCPP	4 - 10 mg/L	11.51	3.9	4.71	2.5	9.31	1.47	4.26
CuII	0	5.1	5.7	5.3	5.5	4.5	5.5	5.0
PbII	0	0.16	0.16	0.16	0.16	0.17	0.16	0.16

3.10 SUMMARY

Findings from the pilot study include:

A. The raw water Fe and Mn concentrations are 0.4 mg/L and 0.18 mg/L respectively.

B. Field analytical results for Fe are representative of the laboratory analytical Fe results.

C. Field analytical results for Mn are typically higher than lab analytical Mn results with an average difference of +0.007 mg/L.

D. A chlorine dose of 1.3 mg/L is necessary for dual media, greensand, and GSR filters. A chlorine dose of 1.5 mg/L is necessary for pyrolusite.

E. Chlorine use during the pilot study varied with the changes in flow rates and changes in the Fe and Mn concentrations in the raw water. It is recommended that the treatment facility design include a control loop that will automatically adjust the chlorine feed rate based on the chlorine residual post-filter. This control loop will ensure that the proper chlorine residual is maintained through the filter and into the distribution system.

F. Potassium permanganate feed consistently resulted in higher filtered water Mn concentrations than chlorine oxidation. The Mn treatment objectives were not achieved using potassium permanganate. Potassium permanganate was successful at oxidizing Fe.

G. Fe removal was quickly realized with all the treatment processes.

H. Mn removal below 0.010 mg/L was obtained throughout the pilot test for all filter media.

I. Sand is being pumped from the well and is captured on the filtration media.

    1. Most sand is assumed to be removed during the backwash cycle for pyrolusite.

    2. Some sand is believed to be retained within the other media; dual media, greensand, and GSR.

    The amount and gradation of the sand was not quantifiable, so a quantifiable impact on the filter media is not available. Buildup of sand in the media will result in higher headloss and more frequent replacement of the filter media.

J. Backwash wastewater settles quickly and 90 percent may be recycled.

K. Pyrolusite and GSR continued removing Fe and Mn to below the MWU treatment objectives after oxidant feed was discontinued.

    1. Pyrolusite continues performance for over six hours.
    2. GSR continues performance for over four hours.

L. Fe and Mn removal did not result in corrosive water.

M. Scale formation is not a concern for the facility.

Table 7 is a summary of the treatment processes and the performance of each.

TABLE 7
SYSTEM TREATMENT RESULTS

System	Performance	Viable System
Chlorine Oxidation	• Meets treatment objectives • Easy to use • Recommended chlorine dose 1.3 mg/L for dual media, greensand, and GSR. Recommended chlorine dose of 1.5 mg/L for pyrolusite	Yes
Permanganate Oxidation	• Mn concentrations did not meet the treatment objectives • Potential for pink water if overfed and for excessive Mn if underfed	No

Dual Media Filtration	• Meet treatment objectives
	• Filter loading rate 5.0 gpm/ft^2 for run time of 48 hours
	• Terminal headloss 15 feet
	• Aeration with Chlorine Oxidation
	  • Meets treatment objectives
	  • Recommended chlorine dose 1.12 mg/L
		Yes

Greensand Filtration	• Meets treatment objectives • Filter loading rate 4.9 gpm/ft^2 for run time of 42 hours • Terminal headloss 15 feet	Yes
Pyrolusite Filtration	• Meets treatment objectives • Filter loading rate 12.0 gpm/ft^2 for run time of 24 hours • Terminal headloss 35 feet	Yes
GSR Plus Filtration	• Meets treatment objectives • Filter loading rate 5.0 gpm/ft^2 for run time of 72 hours • Terminal headloss 15 feet	Yes
Membrane Filtration	• Preliminary results indicate membrane filtration does not meet treatment objectives • More challenging to use	Pilot Testing Incomplete

WDNR must approve all treatment processes prior to construction. Although treatment performance has been proven in the pilot study, this does not guarantee WDNR approval of the treatment process. Prior to design of the treatment facility WDNR should be contacted to review the design parameters and this pilot study report.

4.0 COST ANALYSIS

The following chapter summarizes the cost analysis for the various treatment options. In order to develop costs, the following unit costs were used:

Operational Cost: \$34.50/hour and \$44.00/hour
Electrical Costs: \$0.076/KWH
Building Addition Cost: \$175/ft^2
Sanitary Disposal Cost: \$1.1335/1,000 ft^3 and \$0.17/pound solids
Backwash Tank Cost: \$1.33/gallon

Operational costs were based on operating at an average of 75 percent capacity throughout the year, producing a total of 867 million gallons (MG).

4.1 OXIDATION COMPARISON

Chlorine was determined to be the best oxidant for all treatment alternatives. Aeration reduces the total chlorine requirement by assisting in the oxidation process. The chlorine dose reduction with aeration is 0.18 mg/L. This section summarizes cost effectiveness evaluations to determine the cost benefits of adding aeration.

4.1.1 Chlorination

This section reviews the upgrades required to the existing chlorine feed equipment. The filtration facility currently utilizes gas chlorine. The existing chlorine feed equipment has sufficient capacity to provide chlorine for Fe and Mn oxidation; however, it is recommended that the feed equipment be upgraded to include a chlorine feed instrumentation loop to maintain the filtered water chlorine residual. Also, another chlorine residual monitor will be needed for post-filter chlorine analysis. It is anticipated that the existing chlorine injection point will be used and that no further modifications to the chlorination system will be necessary.

The capital cost for chlorination equipment is provided in Table 8. Operational and maintenance costs are provided in Tables 9 and 10 for 1.3 mg/L and 1.5 mg/L chlorine dose, respectively.

TABLE 8
CHLORINE EQUIPMENT CAPITAL COSTS

Equipment	Capital Cost
Upgrade chlorine dosing system	\$25,000
Chemical feed room modifications	\$2,000
Chlorine residual monitor	\$8,000
Total	\$35,000

TABLE 9
CHLORINE OPERATIONAL AND MAINTENANCE COSTS AT 1.3 MG/L

Item	Unit Cost	Quantity	Annual Cost
Chlorine Gas at 1.3 mg/L	\$1.00/pound	9,400 pounds	\$9,400
Tank change	\$34.50/hour	0.5 hours/week	\$900
Preventative Maintenance	\$34.50/hour	8 hours	\$300
Total			\$10,600

TABLE 10
CHLORINE OPERATIONAL AND MAINTENANCE COSTS AT 1.5 MG/L

Item	Unit Cost	Quantity	Annual Cost
Chlorine Gas at 1.5 mg/L	$1.00/pound	10,900 pounds	$10,900
Tank change	$34.50/hour	0.5 hours/week	$900
Preventative Maintenance	$34.50/hour	8 hours	$300
Total			$12,100

4.1.2 Chlorination and Aeration

This section evaluates the costs of adding aeration to reduce the chlorine costs and evaluates the cost effectiveness of including aeration in the final design. Chlorination and aeration capital costs are presented in Table 11. Pressure aerators are the selected option, because they will work under pressure, eliminating the need for additional pumping after aeration.

TABLE 11
CHLORINE AND AERATION EQUIPMENT CAPITAL COSTS

Equipment	Capital Cost
Chlorination Equipment (see Table 8)	$35,000
Pressure Aerators - 3 units and air compressor	$50,000
Building Space - 60 ft^2	$11,000
Total	$96,000

The pressure aerators require maintenance every six months that includes removing the aerator from service and soaking it in a cleaning solution to remove buildup of Fe and Mn. The use of aeration will reduce the chemical cost for chlorine. The aerator will reduce the chlorine dose to 1.12 mg/L and 1.32 mg/L. The resulting operational and maintenance costs are provided in Tables 12 and 13.

TABLE 12
CHLORINE AND AERATION OPERATIONAL AND MAINTENANCE COSTS AT 1.12 MG/L

Item	Unit Cost	Quantity	Annual Cost
Chlorine gas at 1.12 mg/L	$1.00/pound	8,100 pounds	$8,100
Tank change	$34.50/hour	0.5 hour/week	$900
Preventative maintenance - chlorine system	$34.50/hour	8 hours	$300
Preventative maintenance - aerators	$34.50/hour	24 hours	$900
Preventative maintenance - air compressor	$34.50/hour	3 hours	$100
Total			$10,300

TABLE 13
CHLORINE AND AERATION OPERATIONAL AND MAINTENANCE COSTS AT 1.32 MG/L

Item	Unit Cost	Quantity	Annual Cost
Chlorine gas at 1.32 mg/L	$1.00/pound	9,600 pounds	$9,600
Tank change	$34.50/hour	0.5 hour/week	$900
Preventative maintenance - chlorine system	$34.50/hour	8 hours	$300
Preventative maintenance - aerators	$34.50/hour	24 hours	$900
Preventative maintenance - air compressor	$34.50/hour	3 hours	$100
Total			$11,800

4.1.3 Comparison of Options

Table 14 summarizes the capital, operating, and net present value cost for the two chlorination options.

TABLE 14
CHLORINE AND AERATION COST COMPARISON

Item	Chlorine Only (1.3 mg/L / 1.5 mg/L)	Chlorine Plus Aeration (1.12 mg/L / 1.32 mg/L)
Capital Cost	$35,000	$96,000
Operating Cost	$10,600/$12,100	$10,300/$11,800
Net Present Worth (7% 20 years)	$147,000 / $163,000	$205,000 / $221,000

The increase in capital cost from chlorination alone to chlorination and aeration is $61,000. The operational cost savings with aeration is $300 per year. The life expectancy of the aeration equipment is 20 years. At 7 percent interest, the capital cost will not be recovered in operational cost savings; therefore, chlorination only is the recommended alternative.

4.2 FILTRATION COMPARISON

Order of magnitude cost estimates were developed for each filtration alternative. The cost estimates are based on using horizontal pressure filters. Horizontal pressure filters were selected, because they provide a greater filter surface area per vessel compared to vertical pressure vessels. A typical pressure filter is 10 feet in diameter as shown in Photo 12, with lengths varying to meet the filter loading rates. Each pressure filter is designed with partitions and piping to allow backwash of one filter cell using the filtered water from the other filter cells. Figures 23 and 24 are flow schematics illustrating the existing and future major equipment for the filtration alternatives.

Photo 12: Horizontal Pressure Filter

Modifications to the existing Well 29 facilities include adding one stage to the well pump. The motor and variable frequency drives may be undersized to meet the increased headloss in the filtration system. It is assumed that 30 feet of headloss will be realized in the system piping and 15 or 35 feet (media dependant) terminal headloss will occur through the filtration media. The current motor is 250 hp. During final design the pumping requirements will be reevaluated. For cost estimating purposes, it was assumed that a new motor and variable frequency drive are required.

Building construction for all alternatives is assumed to be masonry block construction matching the existing Well 29 construction. Site work is minimal, as the filter building will abut the existing wellhouse to the immediate east. The backwash waste tank is a concrete structure below the filter operating floor with access hatches. Backwash recycle pumps are assumed to be submersible pumps designed to recycle decanted backwash water to the head of the filter at a flow rate of 10 percent or less compared to the raw water feed.

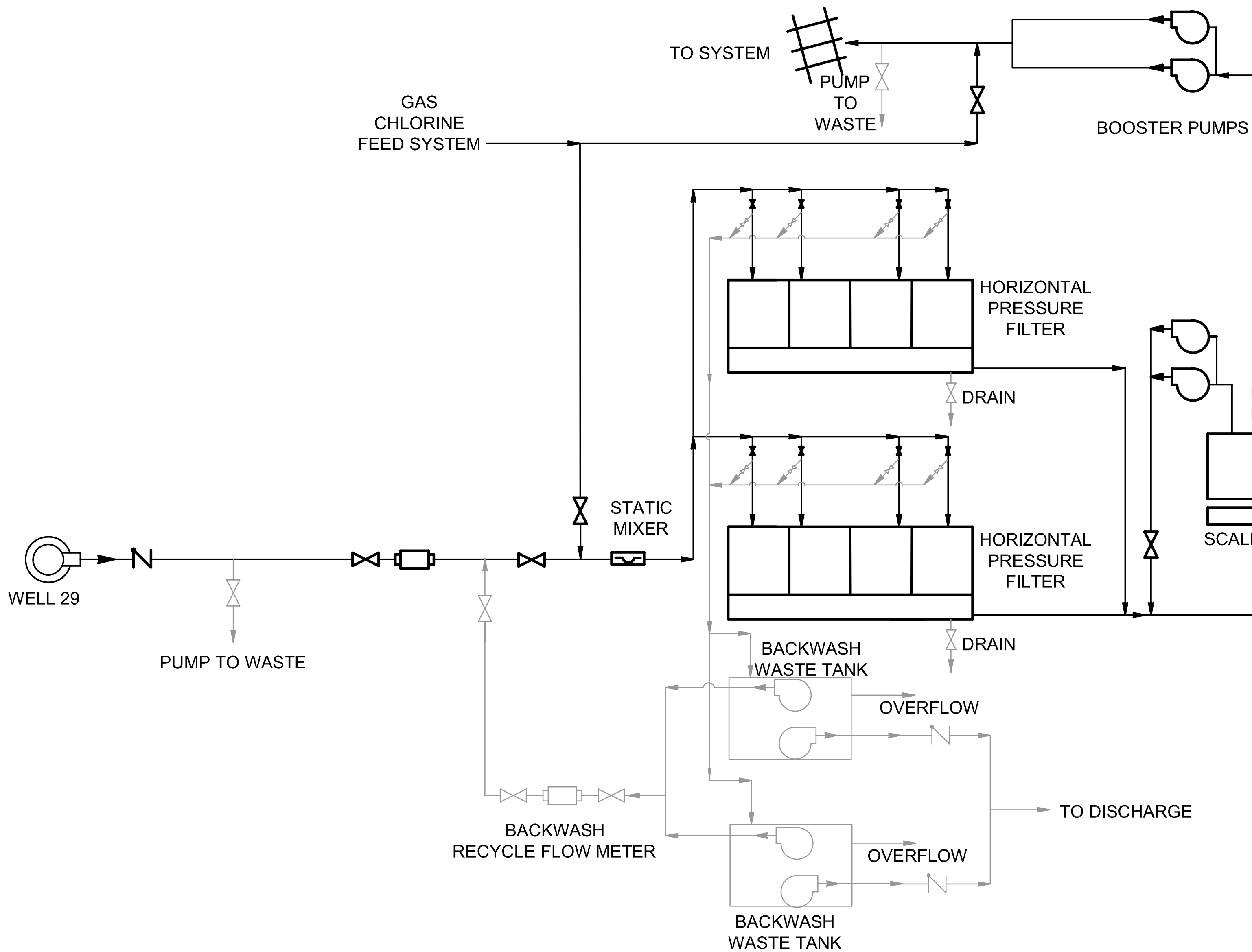

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FIGURE 23
DUAL MEDIA, GREENSAND, AND GSR FLOW DIAGRAM
WELL 29 PILOT STUDY REPORT
MADISON, WISCONSIN
MARCH 2007
98102

PSLtscale: 1 Ltscale: 1
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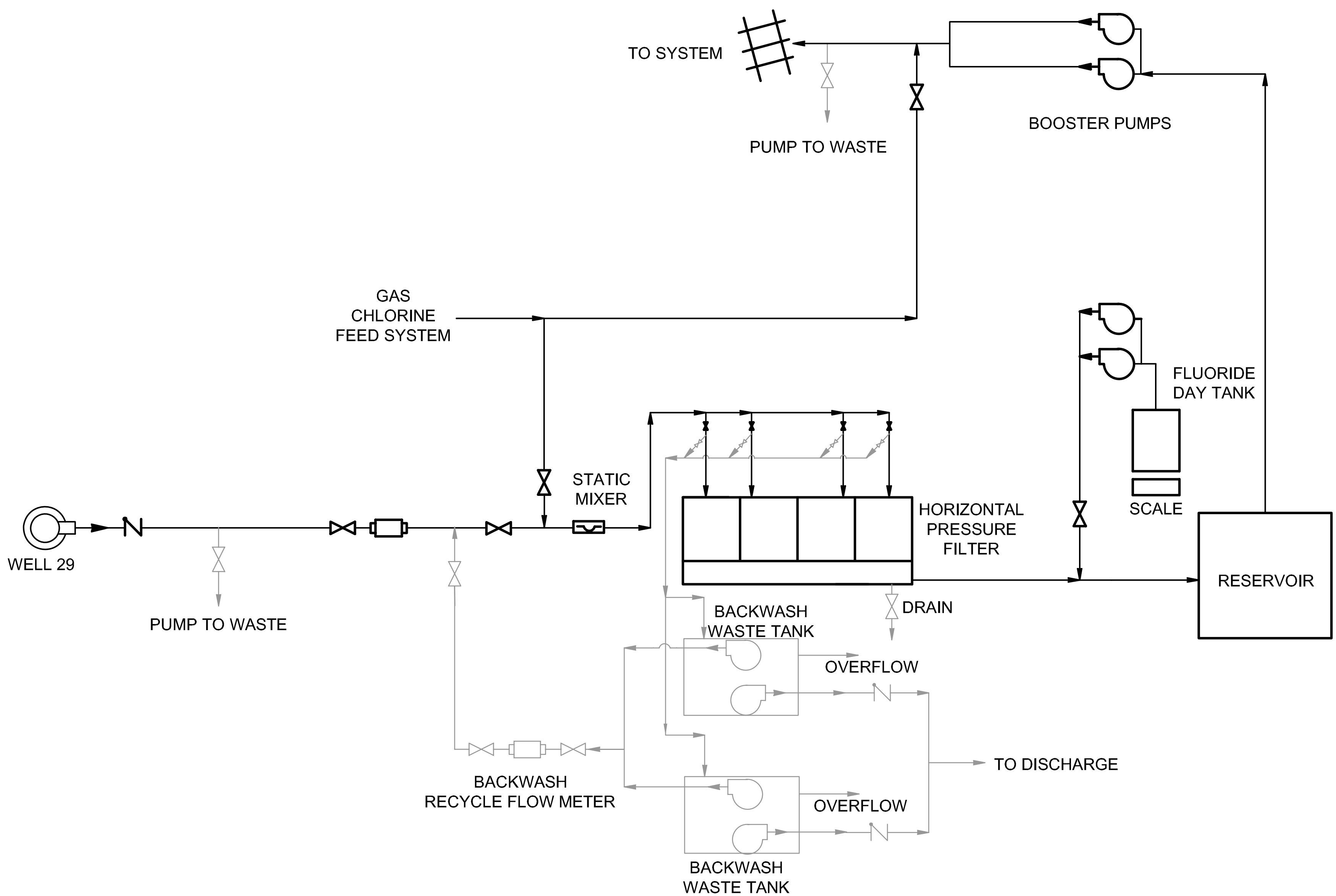

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FIGURE 24
PYROLUSITE FLOW DIAGRAM

WELL 29 PILOT STUDY REPORT
MADISON, WISCONSIN
MARCH 2007
98102

Tables 15, 16, 17, and 18 provide order of magnitude cost estimates for the capital costs associated with pressure filtration for dual media, greensand, GSR, and pyrolusite, respectively. The capital costs for pressure filtration include pressure filtration equipment, building construction, SCADA and electrical upgrades, well pump and motor modifications, process piping, backwash waste tanks, backwash recycle system, site work, and existing facility modifications.

TABLE 15
DUAL MEDIA CAPITAL COSTS

Equipment	Capital Cost
Pressure Filtration Equipment - Two 10 ft diameter by 24 ft long multi-cell filtration vessels Air wash blower, grid, and piping Face pipe and valves Air compressor for valves Control panel 18 inches treated sand and 12 inches treated anthracite 10 inches support gravel Does not include installation	$459,000
Building Construction - 2,500 ft^2 Masonry construction to match existing Set to north of existing building Space provided for lab area Access to backwash waste tank	$438,000
SCADA and Electrical Upgrades - Add filtration panel to main SCADA system Building electrical connections. Security system upgrades	$75,000
Well Pump Modifications - Replace current motor and VFD with 300 hp. Modify bowls to optimize pump curve	$155,000
Process Piping - Install pressure filtration equipment Connection for existing piping to new filtration system Connection from filtration system to tank	$380,000
Backwash Waste Tank - 50,000 gallons for two 10 min backwashes at 10 gpm/ft^2 plus freeboard Designed for backwash recycle	$67,000
Backwash Recycle System - Two pumps Controls Flow meter Pump removal system	$17,000
Site Work	$50,000
Existing Facility Modifications	$20,000
Chlorination Equipment from Section 4.1	$35,000
Subtotal	$1,696,000
Engineering - 20%	$340,000
Contingency - 30%	$509,000
Total	$2,545,000

TABLE 16
GREENSAND CAPITAL COSTS

Equipment	Capital Cost
Pressure Filtration Equipment - Two 10 ft diameter by 24 ft long multi-cell filtration vessels Air wash blower, grid, and piping Face pipe and valves Air compressor for valves Control panel 18 inches greensand 12 inches anthracite 10 inches support gravel Does not include installation	$459,000
Building Construction - 2,500 ft^2 Masonry construction to match existing Set to north of existing building Space provided for lab area Access to backwash waste tank	$438,000
SCADA and Electrical Upgrades - Add filtration panel to main SCADA system Building electrical connections. Security system upgrades	$75,000
Well Pump Modifications - Replace current motor and VFD with 300 hp. Modify bowls to optimize pump curve	$155,000
Process Piping - Install pressure filtration equipment Connection for existing piping to new filtration system Connection from filtration system to tank	$380,000
Backwash Waste Tank - 40,000 gallons for two 10 min backwashes at 13 gpm/ft^2 plus freeboard Designed for backwash recycle	$54,000
Backwash Recycle System - Two pumps Controls Flow meter Pump removal system	$17,000
Site Work	$50,000
Existing Facility Modifications	$20,000
Chlorination Equipment from Section 4.1	$35,000
Subtotal	$1,683,000
Engineering - 20%	$337,000
Contingency - 30%	$505,000
Total	$2,525,000

TABLE 17
GSR CAPITAL COSTS

Equipment	Capital Cost
Pressure Filtration Equipment - Two 10 ft diameter by 24 ft long multi-cell filtration vessels Air wash blower, grid, and piping Face pipe and valves Air compressor for valves Control panel 30 inches media 10 inches support gravel Does not include installation	$459,000
Building Construction - 2,500 ft^2 Masonry construction to match existing Set to north of existing building Space provided for lab area Access to backwash waste tank	$438,000
SCADA and Electrical Upgrades - Add filtration panel to main SCADA system Building electrical connections. Security system upgrades	$75,000
Well Pump Modifications - Replace current motor and VFD with 300 hp. Modify bowls to optimize pump curve	$155,000
Process Piping - Install pressure filtration equipment Connection for existing piping to new filtration system Connection from filtration system to tank	$380,000
Backwash Waste Tank - 65,000 gallons for two 10 min backwashes at 13 gpm/ft^2 plus freeboard Designed for backwash recycle	$87,000
Backwash Recycle System - Two pumps Controls Flow meter Pump removal system	$17,000
Site Work	$50,000
Existing Facility Modifications	$20,000
Chlorination Equipment from Section 4.1	$35,000
Subtotal	$1,716,000
Engineering - 20%	$344,000
Contingency - 30%	$515,000
Total	$2,575,000

TABLE 18
PYROLUSITE CAPITAL COSTS

Equipment	Capital Cost
Pressure Filtration Equipment - 10 ft diameter by 20 ft long multi-cell filtration vessel Air wash blower, grid, and piping Face pipe and valves Air compressor for valves Control panel 36-inches pyrolusite media 10-inches support gravel Does not include installation	$360,000
Building Construction - 1,250 ft^2 Masonry construction to match existing Set to north of existing building Space provided for lab area Access to backwash waste tank	$219,000
SCADA and Electrical Upgrades - Add filtration panel to main SCADA system Building electrical connections Security system upgrades	$75,000
Well Pump Modifications - Replace current motor and VFD with 300 hp. Modify bowls to optimize pump curve	$155,000
Process Piping - Install pressure filtration equipment Connection for existing piping to new filtration system Connection from filtration system to tank	$380,000
Backwash Waste Tank - 63,000 gallons for two 5 min backwashes at 25 gpm/ft^2 plus freeboard Designed for backwash recycle	$84,000
Backwash Recycle System - Two pumps Controls Flow meter Pump removal system	$17,000
Site Work	$50,000
Existing Facility Modifications	$20,000
Chlorination Equipment from Section 4.1	$35,000
Subtotal	$1,395,000
Engineering - 20%	$279,000
Contingency - 30%	$419,000
Total	$2,093,000

Operational costs for a pressure filtration system include backwash wastewater disposal, electrical costs, media replacement, building upkeep, and water testing. Media replacement is estimated at eight years based on conversations with manufacturers. Media replacement frequency may be shorter depending on the buildup of sand on the filter media. The costs provided are only additional costs associated with the pressure filtration system. Current well pumping costs and operation and maintenance costs are not included. The order of magnitude cost estimates for the operational and maintenance costs associated with pressure filtration for dual media, greensand, GSR, and pyrolusite are provided in Tables 19, 20, 21, and 22, respectively.

TABLE 19
DUAL MEDIA OPERATIONAL AND MAINTENANCE COSTS

Item	Unit Cost	Annual Quantity	Annual Cost
Backwash Wastewater Disposal - Backwash once per day, recycle 90%	\$1.1335/1,000 ft^3 \$0.17/lb	117,000 ft^3 4,200 lb	\$847
Electrical Costs - Additional pumping of 8 feet headloss through filter and 30 feet headloss through piping	\$0.076/KWhr	104,000 KW/yr	\$7,900
Media Replacement - Replaced once every 8 years	\$9/ft^3	1200 ft^3	\$1,400
Building Upkeep - Heat - \$0.18/ft^2 Lights - \$1.34/ft^2 Maintenance - 0.5 hours/week	\$1.52 \$34.50	2500 ft^2 26 hours	\$4,700
Lab Water Testing Weekly - Collect 0.5 hours Transport 0.5 hours Sample cost \$12 each	\$34.50/hour \$12	52 hours 52 samples	\$2,500
Operation and Maintenance - Daily walkthrough and water test – 0.5 hours Monthly data review for 1 hour Monthly backwash inspection for 1.5 hour Preventative maintenance 2 hours per month	 \$34.50 \$44.00 \$44.00 \$34.50	 182.5 12 18 24	\$8,500
Chlorine Costs for 1.3 mg/L feed			\$10,600
Subtotal			\$36,500
Contingency – 10%			\$3,700
Total			\$40,200

TABLE 20
GREENSAND OPERATIONAL AND MAINTENANCE COSTS

Item	Unit Cost	Annual Quantity	Annual Cost
Backwash Wastewater Disposal - Backwash once per day, recycle 90%	\$1.1335/1,000 ft^3 \$0.17/lb	94,000 ft^3 4,200 lb	\$821
Electrical Costs - Additional pumping of 6 feet headloss through filter and 30 feet headloss through piping.	\$0.076/KWhr	98,000 KW/yr	\$7,500
Media Replacement - Replaced once every 8 years	\$38/ft^3	1200 ft^3	\$5,700
Building Upkeep - Heat - \$0.18/ft^2 Lights - \$1.34/ft^2 Maintenance - 0.5 hours/week	\$1.52 \$34.50	2500 ft^2 26 hours	\$4,700
Lab Water Testing Weekly - Collect 0.5 hours Transport 0.5 hours Sample cost \$12 each	\$34.50/hour \$12	52 hours 52 samples	\$2,500
Operation and Maintenance - Daily walkthrough and water test – 0.5 hours Monthly data review for 1 hour Monthly backwash inspection for 1.0 hour Preventative maintenance 2 hours per month	 \$34.50 \$44.00 \$44.00 \$34.50	 182.5 12 18 24	\$8,500
Chlorine Costs for 1.3 mg/L feed			\$10,600
Subtotal			\$40,300
Contingency – 10%			\$4,000
Total			\$44,300

TABLE 21
GSR OPERATIONAL AND MAINTENANCE COSTS

Item	Unit Cost	Annual Quantity	Annual Cost
Backwash Wastewater Disposal - Backwash once per day, recycle 90%	$1.1335/1,000 ft^3 $0.17/lb	130,000 ft^3 4,200 lb	$861
Electrical Costs - Additional pumping of 9 feet headloss through filter and 30 feet headloss through piping	$0.076/KWhr	106,000 KW/yr	$8,100
Media Replacement - Replaced once every 8 years	$45/$ft^3$	1200 ft^3	$6,800
Building Upkeep - Heat - $0.18/$ft^2$ Lights - $1.34/$ft^2$ Maintenance - 0.5 hours/week	$1.52 $34.50	2500 ft^2 26 hours	$4,700
Lab Water Testing Weekly - Collect 0.5 hours Transport 0.5 hours Sample cost $12 each	$34.50/hour $12	52 hours 52 samples	$2,500
Operation and Maintenance - Daily walkthrough and water test – 0.5 hours Monthly data review for 1 hour Monthly backwash inspection for 1.0 hour Preventative maintenance 2 hours per month	 $34.50 $44.00 $44.00 $34.50	 182.5 12 18 24	$8,500
Chlorine Costs for 1.3 mg/L feed			$10,600
Subtotal			$42,100
Contingency – 10%			$4,200
Total			$46,300

TABLE 22
PYROLUSITE OPERATIONAL AND MAINTENANCE COSTS

Item	Unit Cost	Annual Quantity	Annual Cost
Backwash Wastewater Disposal - Backwash once per day, recycle 90%	$1.1335/1,000 ft^3 $0.17/lb	122,000 ft^3 4,200 lb	$852
Electrical Costs - Additional pumping of 19 feet headloss through filter and 30 feet headloss through piping	$0.076/KWhr	134,000 KW/yr	$10,200
Media Replacement - Replaced once every 8 years	$85/$ft^3$	600 ft^3	$6,400
Building Upkeep - Heat - $0.18/$ft^2$ Lights - $1.34/$ft^2$ Maintenance - 0.5 hours/week	$1.52 $34.50	1,250 ft^2 26 hours	$2,800
Lab Water Testing Weekly - Collect 0.5 hours Transport 0.5 hours Sample cost $12 each	$34.50/hour $12	52 hours 52 samples	$2,500
Operation and Maintenance - Daily walkthrough and water test – 0.5 hours Monthly data review for 1 hour Monthly backwash inspection for 1.0 hour Preventative maintenance 2 hours per month	 $34.50 $44.00 $44.00 $34.50	 182.5 12 18 24	$8,500
Chlorine Costs for 1.5 mg/L feed			$12,100
Subtotal			$43,400
Contingency – 10%			$4,300
Total			$47,700

4.2.1 Backwash Recycling

The above cost estimates assume backwash wastewater recycling. If all the backwash wastewater were disposed to the sanitary sewer, the costs would be as shown in Table 23.

TABLE 23
BACKWASH WASTEWATER DISPOSAL COSTS

Item	Unit Cost	Annual Quantity	Annual Cost
Backwash Wastewater Disposal - Dual Media 100% to Sanitary	$1.1335/1,000 ft^3$ $0.17/lb	1,170,000 ft^3 4,200 lb	$2,040
Backwash Wastewater Disposal - Greensand 100% to Sanitary	$1.1335/1,000 ft^3$ $0.17/lb	940,000 ft^3 4,200 lb	$1,779
Backwash Wastewater Disposal - GSR Plus 100% to Sanitary	$1.1335/1,000 ft^3$ $0.17/lb	1,300,000 ft^3 4,200 lb	$2,188
Backwash Wastewater Disposal - Pyrolusite 100% to Sanitary	$1.1335/1,000 ft^3$ $0.17/lb	1,220,000 ft^3 4,200 lb	$2,097

The capital cost savings by not including backwash wastewater recycling is $15,000 by saving the cost of two backwash waste pumps. The backwash wastewater tanks would still be required for providing equalization of the wastewater into the sanitary sewer.

The additional cost for operation and maintenance by discharging the wastewater to the storm sewer is between $900 and $1,300 depending on the filter media selected. Assuming 7 percent interest rates and 20-year life expectancy of the backwash pumping equipment, the capital cost for the equipment would not be recovered through operation and maintenance cost savings.

Recycling the wastewater will reduce the loading on the wastewater utility and reduces the environmental impact of the treatment process.

4.3 MEMBRANE FILTRATION

The membrane filtration facility would include 20 minutes of pretreatment detention, chemical storage for clean-in-place systems, and additional pumps. Membrane filtration systems have cost over $1 per gallon treated. For Well 29, the cost for membrane treatment would exceed $3,000,000.

Operation and maintenance costs for membranes presented in Table 24. The costs are based on 2006 bid prices for a 2,300 MG per year operating facility. The bid prices were modified to reflect the lower operational costs for an 867 MG per year facility.

TABLE 24
MEMBRANE OPERATIONAL AND MAINTENANCE COSTS

Item	Unit Cost	Annual Quantity	Annual Cost
Backwash Wastewater Disposal – 5% of total treated volume wasted	$1.1335/1,000 ft^3	580,000 ft^3	$657
Electrical Costs Additional pumping of 9 feet headloss through filter and 30 feet headloss through piping.	$0.076/KWhr	191,000 KW/yr	$14,500
Membrane Replacement – Replaced once every 10 years Includes labor for replacement	$174,000 for total membrane change out	1/10th of total	$17,400
Chemical Costs – Acid, Sodium Hydroxide, Sodium Hypochlorite, Sodium Bisulfite	TBD	TBD	$268,500
Lab Water Testing Weekly – Collect 0.5 hours Transport 0.5 hours Sample cost $12 each	$34.50/hour $12	52 hours 52 samples	$2,500
Operation and Maintenance – Daily walkthrough and water test – 2 hours Monthly data review for 1 hour Preventative maintenance 5.3 hours per month Membrane repair 7 hours /month	$34.50 $44.00 $34.50 $34.50	730 hours 12 hours 64 hours 84 hours	$30,800
Chlorine Costs for 1.3 mg/L feed			$10,600
Subtotal			$345,000
Contingency – 10%			$34,500
Total			$379,500

4.4 SUMMARY

Table 25 summarizes the costs for the five filtration alternatives. The order of magnitude capital costs range from $2,093,000 for the pyrolusite filter alternative to $3,000,000 for membrane filtration. The estimated cost for the pyrolusite is a 17 percent lower capital cost than the manganese greensand filter alternative, the second lowest capital cost. The primary reason for the lower cost is that the pyrolusite filter alternative requires only one horizontal pressure filter, 10-foot diameter and 20 feet long. The three other granular media filter alternatives require two horizontal pressure filters, 10-foot diameter and 24 feet long each. As a result, the building size for the pyrolusite is approximately one-half the area required for the other three alternatives. The dual media filter alternative is the lowest operating cost. This is primarily due to the lower head required through the media, therefore, lower power consumption and long filter run time and the lower media cost for media replacement. Of the granular media filter alternatives, the pyrolusite alternative is the highest operation and maintenance cost due to the higher power consumption.

The net present value comparison of the alternatives shows that the pyrolusite alternative is the lowest overall cost alternative. The increase in operation and maintenance costs associated with headloss through the filter media is not enough to offset the difference in capital costs

TABLE 25
COST SUMMARY

Comments	Capital Cost (x1000)	Additional Yearly O&M (x1000)	Present Worth Analysis[1] (x1000)
Dual Media Pressure Filtration With chlorine oxidation	$2,545	$40.2	$2,971
Greensand Pressure Filtration With chlorine oxidation	$2,525	$44.3	$2,994
GSR Plus Pressure Filtration With chlorine oxidation	$2,575	$46.3	$3,066
Pyrolusite Pressure Filtration With chlorine oxidation	$2,093	$47.7	$2,598
Membrane Filtration With chlorine oxidation	>$3,000	$379.5	$7,020
Footnote: [1] Present worth analysis: 7% interest for 20 years.			

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5.0 RECOMMENDATIONS

The recommended alternative is also the lowest cost alternative: chlorine oxidation with pyrolusite filtration. The pyrolusite filtration alternative has a higher operating cost that the other alternatives primarily due to the additional pumping cost associated with the higher filter loading rates, which create greater headloss through the filter; however, the additional operating costs do not offset the lower capital costs when compared at 7 percent for 20 years.

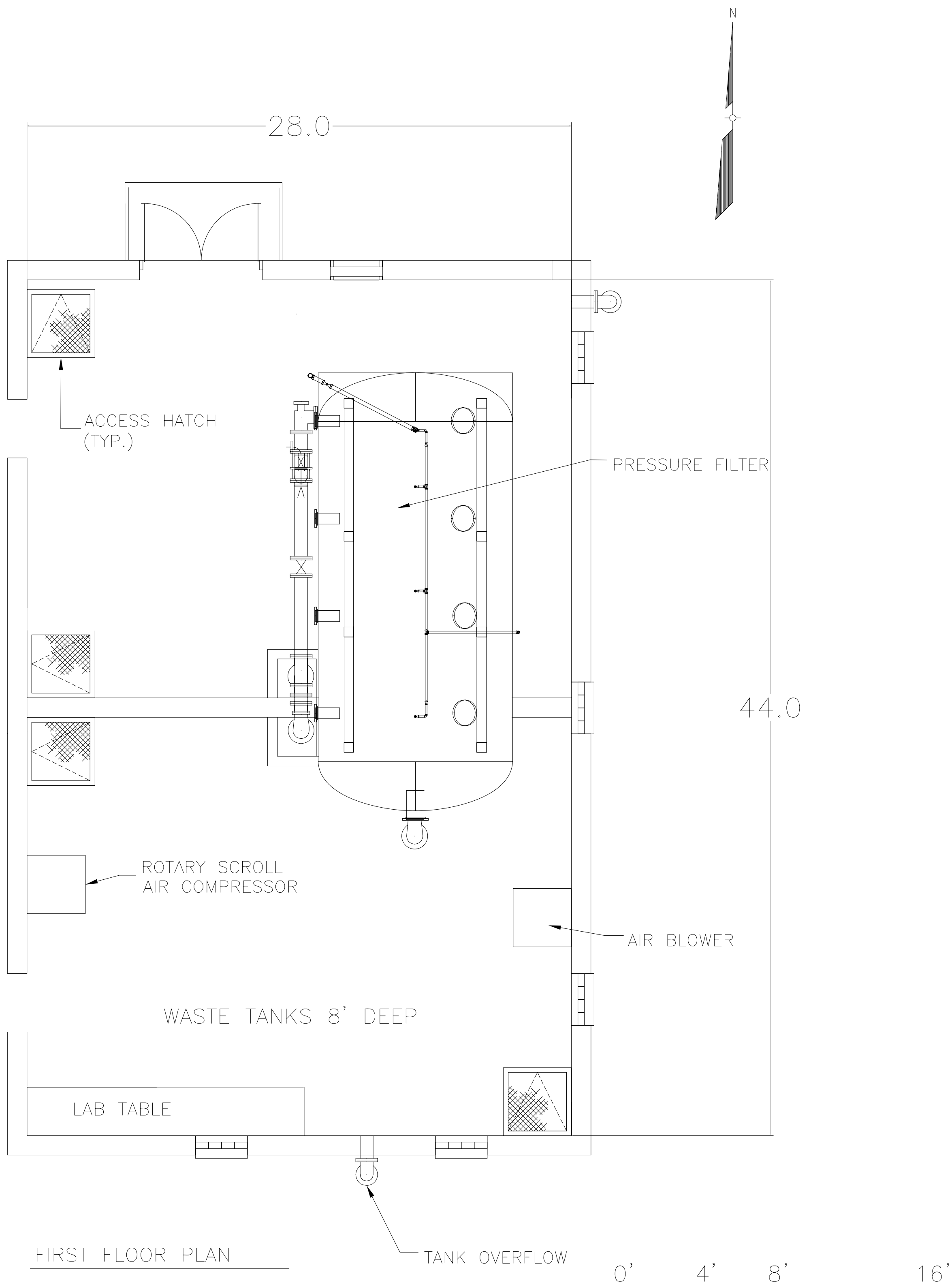
The order of magnitude capital cost for the pyrolusite filtration alternative is $2,093,000. Annual operation and maintenance costs are estimated to be $47,700 per year.

The filter loading rate for the pyrolusite filter is recommended to be 12 gpm/ft^2. With this loading rate, only one 10-foot diameter by 20-foot long horizontal pressure filter will be required. Since this filter loading rate is more than twice that recommended for other filter alternatives, the overall size of the filter building is approximately one-half the size required for other alternatives.

Figure 24 is a flow schematic for the pyrolusite filter. Figure 25 is the proposed layout for the filtration building located immediately east of the existing well building.

The pyrolusite filter operating with chlorine oxidation was able to produce filtered water below the MWU treatment goals of 0.100 mg/L Fe and 0.010 mg/L Mn. The average filtered water Fe and Mn concentrations were demonstrated to be 0.016 and 0.0024 mg/L, respectively.

An added benefit for using the pyrolusite filter is that more sand produced from Well 29 entering the filter will be backwashed out. The backwash flow rate is recommended to be 25 gpm/ft^2. At this flow rate, all sand particles less than 0.16 mm in diameter will theoretically be washed away. Other filters with lower backwash flow rates will retain more sand.



Earth Tech
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FIGURE 25

PRELIMINARY LAYOUT – PYROLUSITE IRON AND MANGANESE TREATMENT

WELL 29 PILOT STUDY REPORT
MADISON, WISCONSIN

MARCH 2007

98102

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APPENDIX A

FE AND MN REMOVAL CHEMISTRY

APPENDIX A
FE AND MN REMOVAL CHEMISTRY

The most common practice employed for the removal of Fe and Mn from drinking water supplies can be summed up as chemical oxidation followed by physical separation. In its simplest form, Fe is oxidized from soluble Fe^{+2} to insoluble Fe^{+3}, and Mn is oxidized from soluble Mn^{+2} to insoluble Mn^{+4}. The insoluble Fe^{+3} and Mn^{+4} are able to be removed from the water through filtration. Commonly used chemical oxidants in water treatment include oxygen, chlorine, and potassium permanganate. Other potential oxidants include ozone and chlorine dioxide.

The ability of an oxidant to effectively convert Fe and Mn from its dissolved to insoluble oxidation state depends on a variety of factors. Table 3 summarizes the various factors that influence the rate of oxidation and what the affect will be on MWU Well 29.

TABLE 3
FACTORS AFFECTING THE RATE OF Fe AND Mn OXIDATION
RELATING SPECIFICALLY TO MWU WELL 29 PILOT STUDY

Factor	Influence	MWU Well 29
Total Oxidant Demand	Competitive oxidizing species, such as sulfite, nitrate, ammonia and organic compounds, consume the oxidant, slowing oxidant efficiency.	Additional analysis, along with oxidant demand testing, will be completed to determine overall impact of oxidant demand.
Temperature	Warmer water temperatures speed the chemical reaction.	The groundwater for Well 29 is expected to be constant over time. No adjustment is recommended.
Detention Time	Sufficient reaction time determines how to complete the reaction.	Evaluated during the pilot study.
pH	Low pH slows the oxidation reaction; pH less than 6.0 for Fe and less than 9.5 for Mn.	pH adjustment is not practical for MWU Well 29, because the buffer capacity of the raw water is great and pH adjustment above 8.2 will begin to precipitate calcium carbonate also.
Presence of Anionic Complexing Compounds	Compounds such as chloride, nitrate, and phosphate complex with Fe and Mn increase the solubility of Fe and Mn.	Minimal concentrations of chloride (2.6 mg/L) and nitrate (0.17 mg/L). Phosphate was not evaluated and will be included in the initial analysis.
Catalytic Effects	Compounds such as copper, aluminum, and Mn dioxide tend to accelerate the oxidation reactions.	Well 29 raw water copper and aluminum concentrations are below the LOD. Mn dioxide will be produced during Mn oxidation, accelerating the oxidation reactions, reducing the impact oxidant requirement.
Ionic Strength	Increasing ionic strength decreases the oxidation rate. This is generally believed to be a result of the presence of high Cl^- and SO_4^{-2} complexes with Fe^{+2}.	Well 29 has relatively low ionic strength and does not adversely impact the treatment process.

Since Fe only exists in two oxidation states, as divalent ferrous or as trivalent ferric form, the chemistry is relatively simple. Mn, however, can exist at any oxidation state from 0 to +7. Naturally occurring Mn, as found in typical groundwater, is commonly found only as +2, +3, and +4.[1] Mn in the +7 oxidation state (permanganate) is a common oxidant used in the removal of Fe and Mn from source waters.

The following sections describe the chemical oxidation methods that available. Each method outlines its applicability for use at MWU Well 29.

A.1 Chemical Oxidation by Oxygen (Aeration)

The process of adding oxygen to water for chemical oxidation is aeration. Aeration can be an effective oxidation process for Fe removal, but if used alone, it is generally not effective for oxidation of Mn. The chemical reaction between Fe and oxygen is a first order reaction in waters with a pH value above 5.5 and no naturally organic material (NOM). The following is the typically reported chemical reaction.

$$Fe^{+2} + \frac{1}{2}O_2(aq) + 5H_2O \rightarrow 2Fe(OH)_3(s) + 4H^+$$ [2]

eq. 1[3]

The stoichiometric ratio of oxygen to Fe is 0.14 mg O_2/mg Fe.

The oxidation of Mn by oxygen alone is a slow process at the pH values generally encountered in water treatment practice. The following equations depict the 3-step reaction process for the oxidation of Mn in water. This reaction is neither a first- nor second-order reaction, but rather an autocatalytic reaction.

$$Mn^{+2} + O_2 \rightarrow MnO_2(s)$$

eq. 2[4]

$$Mn^{+2} + MnO_2(s) \rightarrow Mn^{+2} \bullet MnO_2$$

eq. 3

$$Mn^{+2} \bullet MnO_2 + \frac{1}{2}O_2 \rightarrow 2MnO_2(s)$$

eq. 4

Aeration alone is ineffective for Mn oxidation, because the reactions above are too slow to be practical. The time to complete the above reactions can exceed two hours; however, the rate of Fe oxidation is less than five minutes. As a result, aeration is often used as an effective first step in Fe and Mn water treatment plants. Aeration will be evaluated in the pilot studies to determine whether cost savings may be achieved by lower chemical dosages of other oxidizing chemicals.

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[1] Bell, G.R., "Removal of Manganese by Controlled Precipitation and Filtration," Journal of American Water Works Association, 57, 655-662, 1965.
[2] Water Treatment: Principles and Design, MWH, 2005, p. 1572
[3] Alternative Oxidants for the Removal of soluble Iron and Manganese, AwwaRF, 1990, p. 4
[4] Occurrence of Manganese in Drinking Water and Manganese Control, AwwaRF, 2006, p. 34

A.2 Chemical Oxidation by Chlorine

Traditionally, Fe and Mn were controlled using chlorine alone or combined with potassium permanganate. Mn is much less efficiently oxidized than Fe. The following reactions are generally accepted theoretical expressions:

$$2Fe^{+2} + HOCl + 5H_2O \rightarrow 2Fe(OH)_3(s) + Cl^- + 5H^+$$ *eq. 5*[3]

$$Mn^{+2} + HOCl + H_2O \rightarrow MnO_2(s) + Cl^- + 3H^+$$ *eq. 6*[4]

The stoichiometric ratio for chlorine to Fe and to Mn is 0.64 mg Cl_2/MG Fe and 1.29 mg Cl_2/mg Mn, respectively; therefore, the theoretical chlorine dosage to oxidize both Fe and Mn at MWU Well 29 is 0.50 mg/L as free chlorine. Because of the total chlorine demand of the water and/or anionic complexing constituents in the water, the required chlorine dosage is generally greater than the stoichiometric ratios. In addition, chlorine is generally used for disinfection, so it is common practice to maintain a fixed chlorine residual through the filtration process.

Chemical oxidation by chlorine will be considered as part of the pilot studies, possibly in combination with aeration.

A.3 Chemical Oxidation by Potassium Permanganate

Potassium permanganate was recognized in the 1960s as being a general and economical solution to the Fe and Mn removal problem. Typical potassium permanganate dosages range from 0.5 to 2.0 mg/L depending on the oxidant demand of the source water and available contact time. Although more expensive than chlorine, potassium permanganate has the added benefit of rapid oxidation of both Fe and Mn. Mn oxidation by permanganate has been shown to occur within 60 seconds over wide pH and temperature ranges.

The reactions of permanganate with soluble ferrous (Fe+2) and manganous (Mn+2) ions are:

$$5Fe^{+2} + MnO_4^- + 8H^+ \rightarrow Mn^{+2} + 5Fe^{+3}(s) + 4H_2O$$ *eq. 7*

and

$$3Mn^{+2} + 2MnO_4^- + 2H_2O \rightarrow 5MnO_2(s) + 4H^+$$ *eq. 8*[5]

Stoichiometrically, one part potassium permanganate will oxidize 1.06 parts soluble ferrous (Fe^{+2}) Fe or 0.52 parts of manganous (Mn^{+2}) Mn to their respective insoluble oxidation states. The theoretical potassium permanganate dosage for MWU Well 29 is 0.74 mg/L.

Practical experience shows that the stoichiometric permanganate requirement is usually in excess of the actual amount required to oxidize Fe and Mn. This is attributed to the secondary oxidation reactions in which insoluble Mn sesquioxide ($Mn_2O_3 \cdot x\ H_2O$) and mangano-manganic

[5] Fine, L.W. Chemistry, Meredith Corporation, New York, 1972

oxide ($Mn_3O_4 \cdot x\ H_2O$) are formed; the oxidation to these secondary reactions requires half the permanganate as the above chemical equations suggest[6]. In addition, there is also evidence that MnO_2 acts as a catalyst, increasing the rate at which the redox reactions occur.

Permanganate, like other oxidants, is consumed by a variety of compounds in the water. Increased organic carbon concentrations in the water supply consume the permanganate, requiring greater doses of permanganate to oxidize Fe and Mn[7]. For these reasons, it is necessary to use empirical procedures, permanganate demand test, to determine the proper dosage.

The use of potassium permanganate must be precisely optimized, and the applied permanganate must completely oxidize the source water without allowing excess permanganate to be present in the finished water. If excess permanganate is present in the finished water, it will eventually reduce to insoluble Mn^{+4} and precipitate in the distribution system. Optimization is made easer with the use of Mn oxide coated filter media.

A.4 Chemical Oxidation by Ozone

Ozone used in pre-oxidation for water treatment processes allows the removal of inorganic compounds such as Fe and Mn. The extremely fast kinetics of Fe oxidation result in the oxidation of uncomplexed Fe^{+2} over Mn^{+2}. Although ozone may be used for Fe and Mn oxidation, ozonation is not frequently practiced due to greater capital costs than other available methods. Ozonation also provides the risk of completely oxidizing the Mn^{+2} to permanganate (Mn^{+7}) with a result of pink effluent water, which will later reduce to Mn^{+4} and precipitate in the distribution system.

In some reported applications where ozone oxidation of Mn has been used, the oxidized Mn formed small pin floc particles that do not settle well and are difficult to remove by filtration. The application of ozone alone may not always result in the removal of soluble Mn to acceptable levels.

Because of the high capital cost, the risk of completely oxidizing Mn+2 to permanganate, and the difficulty to settle or remove by filtration the pin floc particles, ozone is not considered for further evaluation within this pilot study.

A.5 Chemical Oxidation by Chlorine Dioxide

Chlorine dioxide can be used to oxidize both Fe and Mn. Chlorine dioxide reacts with the soluble forms of Fe and Mn to form precipitates that can be removed through sedimentation and filtration. Chlorine dioxide reduces to chlorite ion in this reaction. About 1.2 mg/L of chlorine dioxide is required to remove 1.0 mg/L of Fe, and 2.5 mg/L of chlorine dioxide are required to remove 1.0 mg/L of Mn. For high concentrations of Fe and Mn, the use of chlorine dioxide is limited to the 1.0 mg/L chlorite/chlorate ion byproduct, as described before. Ferrous Fe may be added prior to conventional coagulation to chemically reduce chlorite ion (to chloride ion).[8]

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[6] Bell, G.R., "Removal of Manganese by Controlled Precipitation and Filtration," Journal of American Water Works Association, 655-662, 1965.
[7] Removal of Soluble Manganese from Water by Oxide-Coated Filter Media, AwwaRF, 1990, p. 7
[8] EPA Guidance Manual, Alternative Disinfectants and Oxidants, April 1999, p. 4-14.

The Stage 1 Disinfection/Disinfection Byproduct (D/DBP) Rule sets an MCL for chlorite at 1.0 mg/L. Based on the Fe and Mn concentrations at MWU Well 29 (0.406 mg/L and 186 µg/L, respectively), the chlorite production will be 0.94 mg/L. Because of the potential for the plant to exceed the chlorite MCL, chlorine dioxide is not considered for further evaluation in the pilot study.

APPENDIX B

PHYSICAL SEPARATION

APPENDIX B
PHYSICAL SEPARATION

Once solid Fe and Mn have been formed, it must be removed by physical separation processes. Initially, anthracite, sand, or dual media (anthracite and sand) filters were employed; however, it has been found that Mn removal less than 0.05 mg/L (50 µg/L) has been difficult at best. As a result, the primary methods for separating Fe and Mn from water have evolved into using a combination of adsorption followed by physical separation. Conditioning a filter media with permanganate to form an Mn oxide coating on the surface of the media allows the Mn^{+2} and Fe^{+2} to readily adsorb onto the media. Oxidation just prior to filtration can be used to oxidize the adsorbed Mn^{+2} and Fe^{+2} to their insoluble oxidation states.

The following sections describe the various filter media commonly employed in Fe and Mn removal plants. In addition, membrane technologies have been developed that may prove to be economically viable in the Fe and Mn applications.

2.3.1 Filter Media

It is common practice in Fe and Mn treatment to use a filter media conditioned with permanganate to form a Mn oxide coating on the surface of the media. The soluble Mn^{+2} and Fe^{+2} readily adsorb onto the media. Oxidation then takes place on the media surface, and the insoluble Mn^{+4} and Fe^{+3} are retained within the filter media matrix as a solid. Backwashing removes oxidized Mn and Fe from the filter.

The filter media to be evaluated in the pilot study include Dual Media (Mn oxide coated anthracite and silica sand), manganese greensand, pyrolusite, and CalMedia™ GSR Plus. Table 4 summarizes the filter media characteristics for each of the media discussed.

Selection of filter media needs to consider filter loading rate, headloss, filter run time (time to breakthrough) and backwash rates, time, and quality. Headloss is a function of filtration rate, water temperature, media size, and media depth. Filter headloss and backwash rates are calculated for each media described below. The assumed water temperature is 48 degrees Fahrenheit (9 degrees Celsius). Tables 5 and 6 present the calculated data. The pilot study will confirm these variables, and observations of the others will be made.

2.3.1.1 Dual Media; Mn Oxide Coated Anthracite and Silica Sand

Significant capacity exists for the adsorptive removal of Mn^{+2} by Mn oxide solids. The adsorption capacity of an oxide-coated filter media is a function of both surface oxide concentration and the pH of the applied solution. Alkaline pH conditions can yield a significant increase in observed adsorption capacity, whereas mildly acidic (pH less than 6.5) solution conditions can significantly reduce the adsorption capacity of the oxide surface; however, the addition of an oxidant promotes efficient Mn^{+2} removal under slightly acidic (pH 6.0 to 6.2) conditions[1]. The pH at MWU Well 29 is 7.36, which is high enough to expect appropriate adsorption.

[1] Removal of Soluble Manganese from Water by Oxide-Coated Filter Media, AwwaRF, 1990, p. 103.

Addition of an oxidant, free chlorine and potassium permanganate, into the water prior to filtration promotes the oxidation of previously adsorbed Mn^{+2} directly on the oxide surface. This reaction continually regenerates the Mn^{+2} adsorption sites, resulting in a highly efficient continuous Mn^{+2} removal system. Without continuous oxidant feed prior to the Mn oxide coatings, the media becomes exhausted as the available adsorption sites become saturated with Mn^{+2}.

The physical characteristics of filter media with regard to the effective size, uniformity coefficient, or density of the media do not significantly affect the presence of Mn oxide coating. The theoretical dose rate for free chlorine and potassium permanganate are is 0.50 mg/L and 0.74 mg/L, respectively, at MWU Well 29.

TABLE 4
FILTER MEDIA CHARACTERISTICS[2]

Media	Color	Filter Rate (gpm/ft^2)	Specific Gravity (g/cm^3)	Bulk Density (lb/ft^3)	Effective Size (mm)	Uniformity Coefficient	Mesh Size	Chemical Regeneration	pH	Air Scouring	Backwash Rate (gpm/ft^2)	Backwash Bed Expansion (% of bed depth)	Freeboard (% of bed depth)
MnO_X Coated Anthracite	Black	3.0-5.0	1.6	50	0.8-1.2	< 1.65	Varying	Not required	Inert	Not required	12-20	50	50
Silica sand	Light brown	3.0-5.0	2.6	120	0.45-0.55	1.62	16 x 50	Not required	Inert	Not required	10-20	30-35	50
Manganese greensand	Black	3.0-5.0	2.4-2.9	85	0.30-0.35	1.3	16 - 60	1.5-2.0 oz (by weight) of $KMnO_4$ per ft^3	6.2-8.5	Required	10-12	40	50
Pyrolusite	Black	10-15	3.8 - 4.0	125	0.51	1.7	8X20 20X40	Not required	6.5-9.0	Recommended	25 - 30	15 - 30	40
CalMedia™ GSR Plus[3]	Dark Brown	3.0-5.0	2.0	45	0.43	2.0	14X40	1.5-2.0 oz (by weight) of $KMnO_4$ per ft^3	6.2-8.5	Not Required	8 - 10	20 - 40	50

Notes:
gpm/ft^2 = gallons per minute per square foot
mm = millimeters

[2] Design Manual, Removal of Arsenic from Drinking Water Supplies by Iron Removal Processes, EPA/600/R-06/030, April 2006
[3] CalMedia™ GSR Plus, Data Sheet, Calgon Carbon Corporation, 2005

Typical flow rates for dual media filters range between 3 and 6 gallons per minute per square foot (gpm/sf). Both higher loading rates have been demonstrated to be successful, although the filter run times are shorter due to early breakthrough. For the purposes of the pilot study, a dual media filter should be operated between 3 and 8 gpm/sf.

The MWU Well 29 pilot study will evaluate a dual media filter: Mn oxide coated anthracite and sand. Typical dual media filters consist of 24 inches anthracite and 12 inches silica sand[4].

2.3.1.2 Manganese Greensand

Manganese greensand is a granular filter medium processed from glauconite sand. The glauconite sand is coated with a thin layer of Mn oxide resulting in a distinct green color, giving it its name.

The process for removing Fe and Mn is the same as for the dual media (Mn oxide coated anthracite and silica sand) discussed previously. The soluble Fe and Mn adsorb onto greensand particles, and the oxidant converts the soluble Fe and Mn to the insoluble Fe^{+3} and Mn^{+4} oxidation states where it is trapped within the media matrix and removed by backwashing. Both chlorine and potassium permanganate are used in this process. If chlorine is the only oxidant, sufficient Mn must be available in the raw water to provide continual regeneration of the filter media.

When potassium permanganate is used in combination with chlorine, the chlorine is fed first, with sufficient detention time to allow the chlorine, the cheaper chemical, to oxidize the Fe. Then the potassium permanganate is fed to oxidize the Mn and maintain the Mn dioxide coating on the greensand. The theoretical dosages are 0.26 mg/L chlorine and 0.35 mg/L potassium permanganate.

Typical Mn greensand filters consist of filter particles with an effective size of 0.3 to 0.35 mm and a UC of 1.60 or less, giving the media excellent filtration characteristics.[5] The recommended minimum bed depth is 18 to 20 inches.[8] In order to improve hydraulics, an anthracite cap is commonly included to the filter. The typical manganese greensand filter includes 18 inches manganese greensand and 12 inches anthracite. The pilot study will operate with 18 inches Mn greensand and 12 inches anthracite.

Greensand filters are generally best applied when the combined Fe and Mn concentrations are below 5 mg/L. The hydraulic loading rates should be between 3 and 5 gpm/sf and typical backwash velocities of 8 gpm/sf. The maximum pressure drop across the media should be maintained at less than 8 pounds per square inch (psi) to avoid degradation of the greensand.[6]

2.3.1.3 Pyrolusite

Pyrolusite is the common name for naturally occurring Mn dioxide and is available in the United States, United Kingdom, South America, and Australia. It is distributed under brand names

[4] Water Quality & Treatment, A Handbook of Community Water Supplies, American Water Works Association, 5th Ed., p. 8.19
[5] How to Operate and Maintain Manganese Greensand Treatment Units, National Drinking Water Clearing Hours, West Virginia University
[6] Occurrence of Manganese in Drinking Water and Manganese Control, AwwaRF, 2006, p 40

such as LayneOx, Pyrolox, Filox-R, and MetalEase. It is a mined ore consisting of 40 to 85 percent Mn dioxide by weight. The various configurations of pyrolusite provide extensive surface sites available for oxidation of soluble Fe and Mn. Removal rates of Fe in excess of 20 mg/L are achievable.

Pyrolusite is a coarse oxidizing media available in 8 by 20 and 20 by 40 mesh, with a high specific gravity of about 4.0.[7] Pyrolusite media operates at a comparatively higher filtration rate than other filter media. Generally, filtration rates for pyrolyusite of 10 to 15 gpm/sf have been achieved. The increased filtration rate reduces the filter size and overall construction costs.[6]

Backwash is critical for proper operation. Attrition during backwash can be a benefit, as it exposes more surface sites for oxidation of soluble Fe and Mn. The specific gravity of pyrolusite is 3.8 to 4.0, requiring a backwash rate of 20 to 30 gpm/ft^2 to fluidize the bed, scrub the media, and redistribute the media throughout the bed. Bed expansion of 30 percent is recommended. Daily backwashing is recommended to maintain the effectiveness of the media for oxidizing and removing Fe and Mn.

2.3.1.4 CalMedia™ GSR Plus

CalMedia™ GSR Plus is a proprietary granular Mn dioxide filtering media manufactured by Calgon Carbon Corporation. It supports an active Mn dioxide coating to oxidize and precipitate soluble Fe and Mn. The precipitates are filtered out in the granular bed and removed by backwashing.

The media consists of a granular core with a coating of Mn dioxide. It requires either intermittent or continuous regeneration to maintain its oxidizing capacity. For continuous regeneration, a solution of potassium permanganate or combination of chlorine and potassium permanganate are pre-fed to oxidize the soluble Fe and Mn and maintain the media coating.

Typical CalMedia™ consists of dark brown particles with an effective size of 0.43 mm, UC of 2.0, and specific gravity of 2.0. Typical bed depths are 24 to 36 inches deep. Filter loading rates are typically 3 to 5 gpm/sf; however, intermittent applications as high as 10 gpm/sf are possible. Manufacturer's literature suggests backwash flow rates as low as 8 to 10 gpm/sf are required to achieve a 20 to 40 percent bed depth expansion.

2.3.2 Membrane Filtration

Microfiltration (MF) and ultrafiltration (UF) technologies have been used successfully in surface water treatment applications. This is primarily due to the ability of the membrane filters to remove fine particles from drinking water applications. One of the challenges to achieving low Fe and Mn concentrations in the treated water is that the oxidation process may form colloidal Mn that passes through traditional granular media filters.[8] MF and UF systems have the ability to remove fine particles. MF membranes are capable of removing particles with sizes down to 0.04 microns. Some UF processes have a lower cutoff rating of 0.002 to 0.01 microns.[9] The

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[7] Design Manual, Removal of Arsenic from Drinking Water Supplies by Iron Removal Processes, EPA/600/R-06/030, April 2006
[8] Morgan, J.J and Stum, W., "Colloidal Chemical Properties of Manganese Dioxide," Journal of Colloidal Science, 1964
[9] Tech Brief Ten; Membrane Filtration, A National Drinking Water Clearinghouse Fact Sheet, March 1999

small particle size separation of membrane filtration may prove to efficiently remove Fe and Mn to below the MWU goals of 0.1 mg/L Fe and 10 µg/L Mn. The long-term membrane evaluation will be to determine the impact of fouling and the membrane recovery following cleaning. Selection of the proper membrane is also necessary, because some membranes are damaged in the presence of chlorine and potassium permanganate.

Membrane filtration is considered a viable physical separation process using chlorine and/or potassium permanganate as a pre-oxidant. The duration of this pilot study will only allow for the determination that membranes remove sufficiently more Fe and Mn, thus superior water quality than other alternatives. A complete MF/UF pilot study should occur over at least two clean-in-place cycles or approximately three months in order to obtain sufficient design information.

APPENDIX C

FIELD ANALYTICAL TESTING PROCEDURES

APPENDIX C
FIELD ANALYTICAL TESTING PROCEDURES

The following field analytical procedures will be followed throughout the duration of the pilot study.

- Alkalinity: HACH® Digital Titration Method
- Conductivity: Hanna Instruments Conductivity Meter
- Total and Calcium Hardness: HACH® Digital Titration Method
- Total Fe: HACH® 1,10 Phenanthroline Method
- Total Mn: HACH® PAN Method
- ORP: Hanna Instruments OPR Meter
- pH: Hanna Instruments pH Meter with temperature correction
- Free Chlorine: HACH® DPD Method

APPENDIX D

RAW WATER TESTS

APPENDIX D
Raw Water Tests
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

Iron							
Date	Iron		Manganese		pH	Temp	ORP
	Field	Lab	Field	Lab			
1/24/2007 14:47		0.359		0.205	7.27	15	
1/24/2007 9:45	0.35		0.208		7.23	14	-32
1/25/2007 12:20	0.36		0.143				
1/26/2007 10:30	0.33	0.352	0.19	0.2			
1/29/2007 10:42	3.3	3.31	0.273	0.134			
1/29/2007 11:02	0.63		0.216				
1/29/2007 11:47	0.31		Error in Mn sample				
1/29/2007 20:25	0.32		0.196		7.23	13.2	38
1/30/2007 9:00	0.34	0.353	0.189	0.192	7.15	13.5	-10
1/31/2007 11:10	0.31	0.363	0.206	0.188			
2/1/2007 9:28	0.3	0.362	0.193	0.183	7.22	13.4	-14
2/1/2007 14:10	0.33		0.2				
2/1/2007 14:40	Well to 95% Flow Drawdown at 200.0 ft						
2/1/2007 15:20	0.33		0.19				
2/2/2007 13:13	0.33	0.368	0.19	0.176			
2/2/2007 14:33	Well back to 90% flow drawdown from 201.8 to 199.4						
2/3/2007 15:20	0.33	0.382	0.189	0.174			
2/4/2007 15:45	0.33	0.378	0.186	0.173	7.22	13.2	219
2/5/2007 12:00		0.386		0.174			
2/6/2007 15:17	0.34	0.413	0.175	0.176			
2/7/2007 14:00	0.36	0.397	0.173	0.179	7.21	13.4	30
2/8/2007 11:00	0.4	0.402	0.188	0.182			
2/8/2007 12:23	80% Presure 32 psi						
2/8/2007 12:33	70% Pressure 26/27 psi						
2/8/2007 12:44	60% Pressure 20 psi						
2/8/2007 12:51	50% pressure 15 psi Drawdown 189.0 ft to 183.7 ft						
2/8/2007 13:23	0.36	0.394	0.185	0.181	7.2	13.3	-13
2/8/2007 14:00	Change to 60% Drawdown 184 feet to 184.3 ft						
2/8/2007 15:42	0.35	0.385	0.183	0.181	7.24	13.8	56

Raw Water Tests
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

Iron							
Date	Iron		Manganese		pH	Temp	ORP
	Field	Lab	Field	Lab			
2/8/2007 17:38	Change to 90%						
2/9/2007 9:32	Change to 70% Drawdown 197 to 191 ft						
2/9/2007 10:00	0.35	0.405	0.189	0.178	7.38	13.3	98
2/9/2007 10:39	Change to 80% drawdown 194 ft						
2/9/2007 11:27	0.36	0.388	0.184	0.178	7.39	13	61
2/9/2007 12:20	Change to 90% 195 ft drawdown						
2/10/2007 16:10	0.68	0.393	0.183	0.176			
2/11/2007 16:10	0.36	0.391	0.178	0.175			
2/13/2007 9:30	0.36	0.401	0.193	0.176	7.22	12.8	262
2/14/2007 13:40	0.35		0.184		7.93	12.7	124
2/15/2007 14:30	0.34	0.4	0.193	0.179			
2/16/2007 14:10	0.34		0.17		7.33	13.3	256
2/17/2007 13:05	0.34	0.402	0.189	0.175	7.79	13.5	229
2/18/2007 15:10	0.35	0.426	0.191	0.178	7.33		160
2/19/2007 15:55	0.35		0.155		7.28	13.2	212
2/20/2007 10:45	0.36		0.187		7.26	13.5	123
2/21/2007 10:20	0.32	0.408	0.182	0.175	7.24	13.3	137
2/22/2007 12:00	0.32		0.185		7.32		147

AVERAGE	0.352	0.387	0.189	0.179	7.32	13.41	109.63
MEDIAN	0.34	0.392	0.189	0.178	7.25	13.3	123
MAXIMUM	3.3	3.31	0.273	0.205	7.93	15	262
MINIMUM	0.3	0.352	0.143	0.134	7.15	12.7	-32

APPENDIX E

LAB AND FIELD TEST RESULTS

APPENDIX E
Lab and Field Test Results
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

		Lab		Field	
	Sample Description	Mn	Fe	Mn	Fe
		mg/L	mg/L	mg/L	ppm
1/29/2007 10:47	Raw Well 29-1st Draw 1/29	0.134	3.31	0.273	>3.3
1/30/2007 9:00	Raw Well 29-1/30	0.192	0.353	0.189	0.34
1/30/2007 9:20	Dual Media-24 hr 3.9gpm	0.0023	<0.002	0.01	<0.02
1/30/2007 11:15	GSR Plus 24 hr	0.0008	0.006	0.012	<0.02
1/30/2007 13:40	Pyrolusite 24 hr 7.9 gpm	0.0007	0.004	0.005	<0.02
1/31/2007 10:28	Dual Media-48 hr 3.9 gpm	0.0048	0.006	0.019	<0.02
1/31/2007 10:40	GSR-48 hr 3.1 gpm	0.0007	0.004	0.014	<0.02
1/31/2007 10:55	Pyrolusite-48 hr 7.9 gpm	0.0003	<0.002	0.026	<0.02
1/31/2007 11:10	Raw Well 29	0.188	0.363	0.206	0.31
1/31/2007 14:53	GSR-1 hr 3.1 gpm	0.003	0.023	0.012	<0.02
1/31/2007 15:08	Dual Media-1 hr 3.9 gpm	0.0076	0.019	0.021	<0.02
1/31/2007 14:30	Pyrolusite-1 hr 9.4 gpm	0.0018	0.014	0.001	<0.02
2/1/2007 9:28	Raw Well 29	0.183	0.362	0.193	0.34
2/1/2007 11:07	Dual Media 3.9 gpm 20 hr	0.016	0.006	0.027	<0.02
2/1/2007 11:27	Pyrolusite 9.3 gpm 20 hr	0.0014	0.012	0.007	<0.02
2/1/2007 11:18	GSR-3.1 gpm 20 hr	0.001	0.009	0.008	<0.02
2/2/2007 13:13	Raw Well 29	0.176	0.368	0.19	0.33
2/2/2007 13:35	GSR ~48hr	0.0009	0.003	0.008	<0.02
2/2/2007 13:25	Pyrolusite ~ 48hr - 9.3gpm	0.0054	0.037	0.009	<0.02
2/3/2007 15:30	Pyrolusite	0.0045	0.029	0.009	<0.02
2/3/2007 15:55	GSR - 3.1 - 74 hour	0.001	0.004	0.007	<0.02
2/3/2007 15:20	Raw Well 29	0.174	0.382	0.189	0.33
2/3/2007 21:30	Pyrolusite 11.1 gom - 5 hour	0.0014	0.009	0.008	<0.02
2/4/2007 15:15	Pyrolusite - 11.7 gpm 23 hour	0.024	0.164	0.022	<0.02
2/4/2007 15:35	GSR-3.1-97 hour	0.0092	0.062	0.015	0.02
2/4/2007 15:45	Raw Well 29	0.173	0.378	0.186	0.33
2/6/2007 15:06	Pyrolusite	0.0021	0.014	0.001	<0.02
2/6/2007 15:17	Raw Well 29	0.176	0.413	0.175	0.34
2/6/2007 15:45	Greensand - 2.5 - 1 hr	0.0041	0.011	0.007	<0.02
2/6/2007 15:55	GSR - 3.9 - 24 hr	0.001	0.012	0.001	<0.02
2/6/2007 16:05	Dual Media - 2gpm - 4 hour	0.0009	0.004	0.001	<0.02
2/7/2007 14:00	Raw Well 29	0.179	0.397	0.173	0.36
2/7/2007 14:10	Pyrolusite 9.9 gpm-48hr	0.0034	0.021	0.001	<0.02
2/7/2007 14:30	Dual Media 2.5 gpm-24 hr	0.0008	0.003	0.001	<0.02
2/7/2007 14:58	Greensand 2.5 gpm-24 hr	0.0028	<0.002	0	<0.02
2/7/2007 15:00	GSR-3.9 gpm-48hr	0.0012	0.005	0	<0.02
2/8/2007 11:00	Raw Well 29	0.182	0.402	0.188	0.4
2/8/2007 13:23	Raw Well 29-50%	0.181	0.394	0.185	0.36
2/8/2007 15:42	Raw Well 29-60%	0.181	0.385	0.183	0.35
2/8/2007 21:10	Greensand	0.0026	<0.002	0.013	<0.02
2/9/2007 10:00	Raw Well 29-70%	0.178	0.405	0.189	0.35
2/9/2007 11:27	Raw Well 29-80%	0.178	0.388	0.184	0.36
2/9/2007 17:12	Pyrolusite-9.4-1hr	0.0021	0.016	0.005	<0.02
2/9/2007 17:35	Dual Media	0.0021	0.012	0.012	<0.02
2/9/2007 17:13	Greensand-2.4-1hr	0.0025	0.006	0.013	<0.02
2/9/2007 17:23	GSR-4.7gpm-1hr	0.0059	0.067	0.014	0.07
2/10/2007 15:45	White-Pyrolusite	0.0012	0.009	0.009	<0.02
2/10/2007 15:45	Red-Dual Media	0.0084	0.054	0.009	<0.02

APPENDIX E
Lab and Field Test Results
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

		Lab		Field	
	Sample Description	**Mn**	**Fe**	**Mn**	**Fe**
2/10/2007 3:45	Yellow-GSR	0.0014	0.007	0.018	<0.02
2/10/2007 15:45	Blue-Greensand	0.002	<0.002	0.019	<0.02
2/10/2007 16:10	Raw Water	0.176	0.393	0.183	0.68
2/11/2007 15:15	Red-Dual Media	0.003	0.003	0.009	<0.02
2/11/2007 15:15	White-Pyrolusite	0.0002	<0.002	0.004	<0.02
2/11/2007 16:00	Blue-Greensand	0.003	0.002	0.007	<0.02
2/11/2007 16:10	DW Raw Water	0.175	0.391	0.178	0.36
2/11/2007 16:25	Yellow-GSR	0.0012	0.009	0.003	<0.02
2/12/2007 12:55	Dual Media 3.9	0.0007	0.004	0.012	<0.02
2/12/2007 13:05	Greensand	0.0017	<0.002	0.011	<0.02
2/12/2007 13:15	GSR	0.0059	0.048	0.013	0.01
2/13/2007 9:30	Raw Well 29	0.176	0.401	0.193	0.36
2/13/2007 9:40	Membrane-Trial	0.0041	<0.002	0.013	<0.02
2/13/2007 11:50	Pyrolusite-1st Draw	0.018	0.083	0.005	0.07
2/13/2007 12:00	Dual Media-4.5gpm-24hr	0.0011	0.004	0.012	<0.02
2/13/2007 11:30	Pyrolusite-9.4gpm-24hr	0.0019	0.010	0.013	<0.02
2/13/2007 12:15	Greensand-3.1gpm-24hr	0.0017		0.013	
2/13/2007 12:20	GSR-5.5gpm-24hr	0.0019	0.014	0.011	<0.02
2/14/2007 11:15	GSR-5.5gpm 48hr	0.0039	0.027	0.001	<0.02
2/14/2007 11:35	Pyrolusite-9.4gpm-24hr	0.0017	0.011	0.012	<0.02
2/14/2007 13:20	Dual Media-4.5gpm-48hr	0.006	0.012	0.015	<0.02
2/14/2007 13:30	Greensand-3.1gpm-48hr	0.0011	<0.002	0.011	<0.02
2/15/2007 12:10	Pyrolusite-24hr	0.0049	0.033	0.01	<0.02
2/15/2007 12:40	GSR-3.9gpm-24hr	0.0011	0.007	0.013	<0.02
2/15/2007 14:20	Red-Dual Media	0.0041	0.016	0.019	<0.02
2/15/2007 14:30	Raw Well 29	0.179	0.4	0.193	0.34
2/15/2007 14:43	Blue-Greensand	0.0022	<0.002	0.026	<0.02
2/16/2007 11:00	Greensand-42hr 3.9gpm	0.0016	<0.002	0	<0.02
2/19/2007 10:15	Pyrolusite-9.5	0.0007	0.008	0	<0.02
2/18/2007 13:20	GSR + Yellow	0.0019	0.008	0.024	<0.02
2/18/2007 12:45	Pyrolusite (white)	0.0002	<0.002	0.018	<0.02
2/17/2007 13:05	Dual Media (Red)	0.158	0.005	0.021	<0.02
2/16/2007 14:25	Dual Media-6.5gpm 48hr	0.0084	0.049	0	<0.02
2/18/2007 15:15	Raw H2O	0.178	0.426	0.191	0.35
2/17/2007 13:00	Membrane		<0.002		<0.02
2/16/2007 12:55	GSR-48hr-5gpm/ft2	0.0008	0.006	0.001	<0.02
2/16/2007 12:25	Pyrolusite	0.0024	0.019	0	<0.02
2/19/2007 11:15	Dual Media	0.296	<0.002	0.279	<0.02
2/17/2007 13:05	Raw H2O	0.175	0.402	0.189	0.34
2/17/2007 12:45	Pyrolusite (white)	0.002	0.009	0.012	<0.02
2/17/2007 12:30	Dual Media (Red)	0.0074	0.017	0.021	<0.02
2/17/2007 12:05	GSR Plus (Yellow)	0.0029	0.013	0.017	<0.02
2/18/2007 12:35	Membrane	0.045	<0.002	0.052	<0.02
2/19/2007 11:05	GSR	0.0003	<0.002	0	<0.02
2/20/2007 13:00	Membrane 150	0.013	<0.002	0.024	<0.02
2/20/2007 13:15	Pyrolusite	0.0061	0.05	0.011	<0.02
2/20/2007 15:00	GSR-5-24	0.0013	0.008	0.006	<0.02
2/20/2007 15:15	Dual Media-24	0.0018	0.004	0.009	0.03
2/21/2007 10:15	Membrane 150	0.017	<0.002	0.014	<0.02

APPENDIX E
Lab and Field Test Results
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

		Lab		Field	
	Sample Description	**Mn**	**Fe**	**Mn**	**Fe**
2/21/2007 10:20	Raw Well 29	0.175	0.408	0.182	0.32
2/21/2007 10:45	Dual MEdia-6.5	0.058	0.35	0.053	<0.02
2/21/2007 11:00	GSR-3.9	0.0013	0.006	0.009	<0.02
2/21/2007 11:15	Pyrolusite	0.004	0.061	0.008	<0.02
2/21/2007 11:50	GSR-on/off	0.0009	0.004	0.01	<0.02
	Standard Deviation	0.0911199	0.202360704		
	Average	0.0781286	0.185363636		

APPENDIX E
Lab and Field Test Results - Raw Water
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

		Lab		Field	
	Sample Description	**Mn**	**Fe**	**Mn**	**Fe**
		mg/L	**mg/L**	**mg/L**	**mg/L**
1/29/2007 10:47	Raw Well 29-1st Draw 1/29	0.134	3.31	0.273	>3.3
1/30/2007 9:00	Raw Well 29-1/30	0.192	0.353	0.189	0.34
1/31/2007 11:10	Raw Well 29	0.188	0.363	0.206	0.31
2/1/2007 9:28	Raw Well 29	0.183	0.362	0.193	0.34
2/2/2007 13:13	Raw Well 29	0.176	0.368	0.19	0.33
2/3/2007 15:20	Raw Well 29	0.174	0.382	0.189	0.33
2/4/2007 15:45	Raw Well 29	0.173	0.378	0.186	0.33
2/6/2007 15:17	Raw Well 29	0.176	0.413	0.175	0.34
2/7/2007 14:00	Raw Well 29	0.179	0.397	0.173	0.36
2/8/2007 11:00	Raw Well 29	0.182	0.402	0.188	0.4
2/8/2007 13:23	Raw Well 29-50%	0.181	0.394	0.185	0.36
2/8/2007 15:42	Raw Well 29-60%	0.181	0.385	0.183	0.35
2/9/2007 10:00	Raw Well 29-70%	0.178	0.405	0.189	0.35
2/9/2007 11:27	Raw Well 29-80%	0.178	0.388	0.184	0.36
2/10/2007 16:10	Raw Water	0.176	0.393	0.183	0.68
2/11/2007 16:10	Raw Water	0.175	0.391	0.178	0.36
2/13/2007 9:30	Raw Water	0.176	0.401	0.193	0.36
2/15/2007 14:30	Raw Water	0.179	0.4	0.193	0.34
2/17/2007 13:05	Raw Water	0.175	0.402	0.189	0.34
2/18/2007 15:10	Raw Water	0.178	0.426	0.191	0.35
2/21/2007 10:20	Raw Water	0.175	0.408	0.182	0.32

Standard Deviation	0.011	0.637
Average	0.177	0.530

APPENDIX E
Lab and Field Test Results - GSR
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

		Lab		Field	
	Sample Description	**Mn**	**Fe**	**Mn**	**Fe**
		mg/L	**mg/L**	**mg/L**	**ppm**
1/30/2007 11:15	GSR Plus 24 hr	0.0008	0.006	0.012	<0.02
1/31/2007 10:40	GSR-48 hr 3.1 gpm	0.0007	0.004	0.014	<0.02
1/31/2007 14:53	GSR-1 hr 3.1 gpm	0.003	0.023	0.012	<0.02
2/1/2007 11:18	GSR-3.1 gpm 20 hr	0.001	0.009	0.008	<0.02
2/2/2007 13:35	GSR ~48hr	0.0009	0.003	0.008	<0.02
2/3/2007 15:55	GSR - 3.1 - 74 hour	0.001	0.004	0.007	<0.02
2/4/2007 15:35	GSR-3.1-97 hour	0.0092	0.062	0.015	0.02
2/6/2007 15:55	GSR - 3.9 - 24 hr	0.001	0.012	0.001	<0.02
2/7/2007 15:00	GSR-3.9 gpm-48hr	0.0012	0.005	0	<0.02
2/9/2007 17:23	GSR-4.7gpm-1hr	0.0059	0.067	0.014	0.07
2/10/2007 3:45	Yellow-GSR	0.0014	0.007	0.018	<0.02
2/11/2007 16:25	Yellow-GSR	0.0012	0.009	0.003	<0.02
2/12/2007 13:15	GSR	0.0059	0.048	0.013	0.01
2/13/2007 12:20	GSR-5.5gpm-24hr	0.0019	0.014	0.011	<0.02
2/14/2007 11:15	GSR-5.5gpm 48hr	0.0039	0.027	0.001	<0.02
2/15/2007 12:40	GSR-3.9gpm-24hr	0.0011	0.007	0.013	<0.02
2/18/2007 13:20	GSR + Yellow	0.0019	0.008	0.024	<0.02
2/16/2007 12:55	GSR-48hr-5gpm/ft2	0.0008	0.006	0.001	<0.02
2/17/2007 12:05	GSR Plus (Yellow)	0.0029	0.013	0.017	<0.02
2/19/2007 11:05	GSR	0.0003	<0.002	0	<0.02
2/20/2007 15:00	GSR-5-24	0.0013	0.008	0.006	<0.02
2/21/2007 11:00	GSR-3.9	0.0013	0.006	0.009	<0.02
2/21/2007 11:50	GSR-on/off	0.0009	0.004	0.01	<0.02

Standard Deviation	0.002	0.019	
Average	0.002	0.016	

APPENDIX E
Lab and Field Test Results - Pyrolusite
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

		Lab		Field	
	Sample Description	**Mn**	**Fe**	**Mn**	**Fe**
		mg/L	**mg/L**	**mg/L**	**ppm**
1/30/2007 13:40	Pyrolusite 24 hr 7.9 gpm	0.0007	0.004	0.005	<0.02
1/31/2007 10:55	Pyrolusite-48 hr 7.9 gpm	0.0003	<0.002	0.026	<0.02
1/31/2007 14:30	Pyrolusite-1 hr 9.4 gpm	0.0018	0.014	0.001	<0.02
2/1/2007 11:27	Pyrolusite 9.3 gpm 20 hr	0.0014	0.012	0.007	<0.02
2/2/2007 13:25	Pyrolusite ~ 48hr - 9.3gpm	0.0054	0.037	0.009	<0.02
2/3/2007 15:30	Pyrolusite	0.0045	0.029	0.009	<0.02
2/3/2007 21:30	Pyrolusite 11.1 gom - 5 hour	0.0014	0.009	0.008	<0.02
2/4/2007 15:15	Pyrolusite - 11.7 gpm 23 hour	0.024	0.164	0.022	<0.02
2/6/2007 15:06	Pyrolusite	0.0021	0.014	0.001	<0.02
2/7/2007 14:10	Pyrolusite 9.9 gpm-48hr	0.0034	0.021	0.001	<0.02
2/9/2007 17:12	Pyrolusite-9.4-1hr	0.0021	0.016	0.005	<0.02
2/10/2007 15:45	White-Pyrolusite	0.0012	0.009	0.009	<0.02
2/11/2007 15:15	White-Pyrolusite	0.0002	<0.002	0.004	<0.02
2/13/2007 11:50	Pyrolusite-1st Draw	0.018	0.083	0.005	0.07
2/13/2007 11:30	Pyrolusite-9.4gpm-24hr	0.0019	0.010	0.013	<0.02
2/14/2007 11:35	Pyrolusite-9.4gpm-24hr	0.0017	0.011	0.012	<0.02
2/15/2007 12:10	Pyrolusite-24hr	0.0049	0.033	0.01	<0.02
2/19/2007 10:15	Pyrolusite-9.5	0.0007	0.008	0	<0.02
2/18/2007 12:45	Pyrolusite (white)	0.0002	<0.002	0.018	<0.02
2/16/2007 12:25	Pyrolusite	0.0024	0.019	0	<0.02
2/17/2007 12:45	Pyrolusite (white)	0.002	0.009	0.012	<0.02
2/20/2007 13:15	Pyrolusite	0.0061	0.05	0.011	<0.02
2/21/2007 11:15	Pyrolusite	0.004	0.061	0.008	<0.02

	Standard Deviation	0.034	0.082
	Average	0.010	0.046

APPENDIX E
Lab and Field Test Results - Dual Media
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

		Lab		Field	
	Sample Description	**Mn**	**Fe**	**Mn**	**Fe**
		mg/L	**mg/L**	**mg/L**	**ppm**
1/30/2007 9:20	Dual Media-24 hr 3.9gpm	0.0023	<0.002	0.01	<0.02
1/31/2007 10:28	Dual Media-48 hr 3.9 gpm	0.0048	0.006	0.019	<0.02
1/31/2007 15:08	Dual Media-1 hr 3.9 gpm	0.0076	0.019	0.021	<0.02
2/1/2007 11:07	Dual Media 3.9 gpm 20 hr	0.016	0.006	0.027	<0.02
2/6/2007 16:05	Dual Media - 2gpm - 4 hour	0.0009	0.004	0.001	<0.02
2/7/2007 14:30	Dual Media 2.5 gpm-24 hr	0.0008	0.003	0.001	<0.02
2/9/2007 17:35	Dual Media	0.0021	0.012	0.012	<0.02
2/10/2007 15:45	Red-Dual Media	0.0084	0.054	0.009	<0.02
2/11/2007 15:15	Red-Dual Media	0.003	0.003	0.009	<0.02
2/12/2007 12:55	Dual Media 3.9	0.0007	0.004	0.012	<0.02
2/13/2007 12:00	Dual Media-4.5gpm-24hr	0.0011	0.004	0.012	<0.02
2/14/2007 13:20	Dual Media-4.5gpm-48hr	0.006	0.012	0.015	<0.02
2/15/2007 14:20	Red-Dual Media	0.0041	0.016	0.019	<0.02
2/17/2007 13:05	Dual Media (Red)	0.158	0.005	0.021	<0.02
2/16/2007 14:25	Dual Media-6.5gpm 48hr	0.0084	0.049	0	<0.02
2/19/2007 11:15	Dual Media	0.296	<0.002	0.279	<0.02
2/17/2007 12:30	Dual Media (Red)	0.0074	0.017	0.021	<0.02
2/20/2007 15:15	Dual Media-24	0.0018	0.004	0.009	0.03
2/21/2007 10:45	Dual MEdia-6.5	0.058	0.35	0.053	<0.02

	Standard Deviation	0.074	0.083
	Average	0.031	0.033

APPENDIX E
Lab and Field Test Results - Greensand
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

		Lab		Field	
	Sample Description	**Mn**	**Fe**	**Mn**	**Fe**
		mg/L	**mg/L**	**mg/L**	**ppm**
2/6/2007 15:45	Greensand - 2.5 - 1 hr	0.0041	0.011	0.007	<0.02
2/7/2007 14:58	Greensand 2.5 gpm-24 hr	0.0028	<0.002	0	<0.02
2/8/2007 21:10	Greensand	0.0026	<0.002	0.013	<0.02
2/9/2007 17:13	Greensand-2.4-1hr	0.0025	0.006	0.013	<0.02
2/10/2007 15:45	Blue-Greensand	0.002	<0.002	0.019	<0.02
2/11/2007 16:00	Blue-Greensand	0.003	0.002	0.007	<0.02
2/12/2007 13:05	Greensand	0.0017	<0.002	0.011	<0.02
2/13/2007 12:15	Greensand-3.1gpm-24hr	0.0017		0.013	
2/14/2007 13:30	Greensand-3.1gpm-48hr	0.0011	<0.002	0.011	<0.02
2/15/2007 14:43	Blue-Greensand	0.0022	<0.002	0.026	<0.02
2/16/2007 11:00	Greensand-42hr 3.9gpm	0.0016	<0.002	0	<0.02

	Standard Deviation	0.001	0.005
	Average	0.002	0.006

APPENDIX F

CHLORINE DEMAND TEST RESULTS

Appendix F
Chlorine Demand Test Results
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

Bottle Number	Delay Time (min)	Actual Delay (min)	Chlorine Addition mg/L	Chlorine Residual mg/L	Chlorine Demand mg/L	NOTES
1.0 mg/L						
1	0	0	0.90	0.44	0.46	
2	5	5	0.90	0.37	0.53	
3	10	10	0.90	0.25	0.65	
4	15	15	0.90	0.21	0.69	
1.3mg/L						
5	0	0.5	1.3	0.98	0.32	
6	5	5	1.3	0.58	0.72	
7	10	10	1.3	0.73	0.57	
8	15	15	1.3	0.58	0.72	
1.5mg/L						
9	0	0	1.515	1.47	0.05	
10	5	4.25	1.515	1.03	0.49	
11	10	8	1.515	1.12	0.40	
12	15	12.25	1.515	1.12	0.40	

Method for all is DPD - AccuVacs and HACH analyzer.
Chlorine addition determined by averaging chlorine residual in two distilled water samples.

APPENDIX G

DUAL MEDIA – FILTER RUN TEST

Appendix G
Process Optimization Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

Dual Media

#				pre-filter					Post-Filter					
	Date	Time	Flow	Aeration	Cl	KMnO4	Detention	Headloss (ft	Fe	Mn	Cl	ORP	Temp.	pH
1	23-Jan	9:50	3.1	N	2.15	N	N	2.307						
2	23-Jan	11:22	3	N	2.22	N	N	2.5377	0	0.168	0.12T/0.0F	143	12.7	7.6
3	23-Jan	13:40	3.05	N	2.50	N	N	4.1526	0	0.068	0.39T/0.21F	156	13.1	7.22
4	23-Jan	16:25	3	N	2.22	N	N	3.6912	0	0.027	0.70T/0.47F	227	12.9	7.23
5	23-Jan	21:27	3.1	N	2.15	N	N	3.6912	0	0.013	1.23T/1.06F	543	13.3	7.14
6	24-Jan	2:55	3.1	N	1.54	N	N	3.9219	--	--	--	--	--	--
7	24-Jan	7:08	3.1	N	1.54	N	N	4.1526	0	0.001	0.56F	420	12.8	7.41
8	24-Jan	9:15	3	N	1.27	N	N	4.614	0	0.001	0.34F	243	13	7.23
9	24-Jan	10:30		N	1.27	N	N	4.614	0	0	0.34F	344	12.9	7.25
10	24-Jan	12:30	3.1	N	1.27	N	N	4.8447	0	0.004	0.33F	400	13.9	7.26
11	24-Jan	15:50	3.1	5%	1.27	N	N	3.9219	0	0.01	0.70T/0.53F	486	15.2	7.25
12	25-Jan	9:20	3.1	5%	0.92	N	N	4.8447	0	0.007	0.16F	229	14.3	7.27
13	25-Jan	10:00	2.5	5%	30%	N	N	4.8447	0	0.003	0.22F	396	12.9	7.24
14	25-Jan	12:30	3.05	N	N	1.04	N	6.6903	0	0	N	58	13	7.26
15	25-Jan	15:55	3.05	N	N	1.04	N	7.1517	0	0	N	146	13.7	7.27
16	25-Jan	20:35	3.1	5%	N	0.58	N	8.5359	0	0	N	278	14	7.21
17	26-Jan	3:45	3.1	N	N	0.58	N	8.5359	--	--	--	--	--	--
18	26-Jan	8:15	3.1	N	N	0.58	N	9.228	0	0.001	N	230	13	7.25
	Notes:	Start Test #3 at 13:25 - Backwashed 10 min to clear 15 min total												

L:\work\Projects\98102\eng\Field Test\[Process Optimization.xls]Dual Media

Appendix G
Dual Media - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	1/26/07 11:30	0	3.9	0	1.37							
2	1/26/07 13:25	1.92	4	454.3	1.37	6.6903	0.01	0.007	0.07	285	13.4	7.22
3	1/29/07 11:17	1.92	3.9	454.3	1.3	3.2298						
4	1/29/07 12:47	3.42	3.8	800.8	1.93	5.9982	0	0.021	0.63	201	13.3	7.25
5	1/29/07 14:02	4.67	3.8	1085.8	1.98	3.4605	0	0.009	0.68	331	13.1	7.24
6	1/29/07 16:30	7.13	3.8	1648.2	2.02	3.6912	0	0.008	0.72	158	13.5	7.25
7	1/29/07 20:37	11.25	3.8	2586.8	2.05	4.614	0	0.003	0.75	579	12.8	7.24
8	1/30/07 3:10	17.80	3.9	4099.8	1.8	2.9991		0.001	0.5			
9	1/30/07 9:20	23.97	3.9	5542.8	1.72	5.7675	0	0.01	0.42	550	12.8	7.25
10	1/30/07 11:00	25.63	3.9	5932.8	1.78	6.6903		0.009	0.48			
11	1/30/07 13:25	28.05	3.9	6498.3	1.47	6.921		0.015	0.17	436	13.2	7.23
12	1/30/07 15:21	29.98	3.9	6950.7	1.69	6.921	0	0.016	0.39	311	13.1	7.23
13	1/30/07 22:17	36.92	3.9	8573.1	1.12	7.6131		0.008	0.45	518	13.4	7.22
14	1/31/07 4:10	42.80	3.9	9949.8	1.12	8.3052	0	0.007	0.36	322	13	7.24
15	1/31/07 10:28	49.10	3.9	11424.0	1.12	10.1508	0	0.019	0.4	397	13.5	7.27
16	1/31/07 12:28	51.10	3.8	11886.0	1.76	10.1508		0.018	0.46	489	14.2	7.26
			4.9	gpm/ft2								

Backwashed at 1/31 14:00 at 6 gpm clear after 6 min. Stopped after 10 min. Took Imhoff sample after 2 min of backwash. Sample had 20 mL solids after 1 hour. Water yellow after 1.5 hour settling.

Appendix G
Dual Media - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	1/31/07 14:15	0	3.9	0	1.59	4.1526						
2	1/31/07 15:08	0.88	3.9	206.7	1.59	4.1526	0	0.021	0.29	439	12.8	7.24
3	2/1/07 9:04	18.82	3.9	4403.1	1.55	5.9982		0.026	0.25	453	14	7.26
4	2/1/07 11:07	19.98	3.9	4882.8	1.65	5.7675	0	0.027	0.35	350	14.1	7.24
			5.2	gpm/ft2								

Backwashed at 13:24 2/1/07 5.5 min to clear. Total 15 min at 6 gpm

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/1/07 13:45	0	3.1	0	1.50	2.7684						
2	2/1/07 15:30	1.75	3.1	325.5	1.5	4.1526		0.024	0.2			
3	2/1/07 17:00	1.50			1.49			0.016	0.19			
4	Backwash				KMnO4							
5	2/1/07 17:30	0.00	2.8	0.0	0.269036	2.0763						
6	2/1/07 21:30	4.00	2.8	672.0	0.269036	2.0763		0.024	0.3	439		
7	2/2/07 3:45	10.25	2.8	1722.0	0.269036	2.307						
8	2/2/07 10:10	16.67	2.8	2800.0	0.269036	2.307		0.123				
9	2/2/07 13:50	20.33	3.1	3449.0	0.243	4.1526		0.223		165		
10	2/2/07 16:10	22.67	3.1	3883.0	0.32	4.614		0.168				
11	2/2/07 21:50	28.33	3	4920.0	0.42	4.614		0.138				
12	2/3/07 3:28	33.97	3.1	5950.9	0.49	5.5368						
13	2/3/07 10:00	40.50	3	7146.5	0.50	5.7675		0.093				

Appendix G
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Madison, Wisconsin

14	2/3/07 15:45	46.25	3	8181.5	0.59	6.921		0.072				
15	2/3/07 21:56	52.43	2	9109.0	0.88	4.614		0.054				
16	2/4/07 3:12	57.70	2	9741.0	1.00	5.3061						
17	2/4/2007 9:40	64.17	2	10517.0	0.00	6.2289						
18	2/4/2007 16:03	70.55	2	11283.0	3.12	6.2289		0.022	0.67			
19	2/4/2007 21:03	75.55	2	11883.0	3.12	5.9982		0.01	0.67	445		
20	2/5/2007 2:55	81.42	2	12587.0	3.12	6.921						
21	2/5/2007 10:13	88.72	2	13463.0	3.12	7.8438		0.01	1.04	506	13.1	7.2
22	2/5/2007 16:45	95.25	2	14247.0	3.12	10.8429	0	0.005	1.07	241	12.8	7.21
23	2/5/2007 22:50	101.3333333	2	14977.0	3.12	11.0736		0.005	1.35	538	13.5	7.19
24	2/6/2007 4:40	107.1666667	2	15677.0	3.12	11.3043						
25	2/6/2007 10:35	113.0833333	2	16387.0	3.12	9.228		0.001	1.29	554	13.4	7.19
			3.1	gpm/ft2								

Backwash 8.5 gpm 15 min 6 min clearing flow meter stuck and fixed

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/6/07 11:40	0	2.5	0	2.50	2.9991						
2	2/6/07 14:15	2.58	2.1	356.5	2.97	2.7684	0	0.001	>2.2	616	13.2	7.22
3	2/6/07 16:05	4.42	2	582.0	1.324615	1.6149	0	0.001	0.59	504	13.2	7.24
	2/6/07 16:06	4.43	2.6	584.3	0.918952	2.7684						
4	2/6/07 20:30	8.83	2.5	1257.5	0.980215	2.5377		0.001	0.18	280	13.3	7.23
5	2/7/07 2:58	15.30	2	2130.5	1.2915	2.0763		0.005	0.48			

Appendix G
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Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

6	2/7/07 3:00	15.33	2.5	2135.0	1.0332	2.5377						
7	2/7/07 9:55	22.25	2.1	3089.5	1.23	2.5377		0.001	0.36	559	13.4	7.23
8	2/7/07 10:15	22.58	2.5	3135.5	1.94	4.3833						
	2/7/07 11:50	24.17	2.5			2.9991						
	2/7/07 14:30	26.83	2.5			5.0754	0	0.001	1.17	555	13.1	7.18
9	2/8/07 10:15	46.58	2.5	6735.5	1.94	4.614	0	0.007	0.64	589	13.5	7.27
10	2/8/07 12:56	49.27	1.25	7037.4	3.1	2.5377						
11	2/8/07 13:58	50.30	1.25	7114.9	3.1	3.2298	0	0.005	1.8	600	14.3	7.23
12	2/8/07 14:10	50.50	1.8	7133.2	1.85	4.1526						
13	2/8/07 17:10	53.50	1.8	7457.2	1.85	4.3833	0	0.007	0.55	447		
14	2/8/07 17:45	54.08	2.1	7525.4	1.89	5.7675						
15	2/8/07 21:15	57.58	2.1	7966.4	1.89	5.7675		0.008	0.59	531	13.7	7.38
16	2/9/07 9:15	69.58	2.1	9478.4	1.65	5.3061		0.008	0.35	373	13.9	7.35
17	2/9/2007 9:40	70	1.8	9527.2	1.42	4.614						
18	2/9/2007 10:40	71	1.8	9635.2	1.42	4.614	0	0.008	0.12	435	13.2	7.4
19	2/9/2007 10:55	71.25	1.9	9662.9	1.56	5.3061						
20	2/9/2007 12:10	72.5	1.9	9805.4	1.56	5.3061	0	0.007	0.26	381	13.2	7.38
			2.9	gpm/ft2								

Backwash Start 3:23pm at 8.3 gpm clearing at 7 min stoped at 3:45pm

Appendix G
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Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/9/07 15:50	0	3.9	0	1.85							
2	2/9/07 16:10	0.333333333	3.9	78.0	1.85	4.1526						
3	2/9/07 17:35	1.75	3.9	409.5	1.85	3.9219	0	0.012	0.55	564	13	7.41
4	2/10/07 9:15	17.41666667	3.8	4028.5	1.93	4.1526	0	0.023	0.63	190	13.9	7.12
5	2/10/07 9:20	17.5	3.9	4047.8	1.712821							
6	2/10/07 15:15	23.41666667	2	5095.0	3.34	0		0.009	2.04	663	14.1	7.24
7	2/10/07 15:20	23.5	3.9	5109.8	1.72	4.3833						
8	2/10/07 21:15	29.41666667	3.9	6494.3	1.72	6.921		0.063	0.42	499	14.6	7.26
9	2/11/07 9:15	41.41666667	3.9	9302.3	1.3	8.0745		0.018	0	524	15.7	7.23
10	2/11/07 15:15	47.41666667	3.9	10706.3	1.81	8.7666	0	0.009	0.51	603	14.8	7.22
11	2/11/07 21:15	53.41666667	3.9	12110.3	1.78	9.4587		0.021	0.48	462	13.9	7.23
12	2/12/07 9:55	66.08333333	3.9	15074.3	1.6	11.535		0.026	0.3	555	14.1	7.22
13	2/12/07 12:55	69.08333333	3.8	15767.3	1.5	12.6885	0	0.012	0.2	519	13.9	7.24
14			4.8	gpm/ft2								

Backwash 8.0 gpm Clearing at 6 min total time 11 min

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/12/07 15:30	0	4.3	0	0.96	4.8447						
2	2/12/07 18:15	2.75	4.3	709.5	1.09	5.0754						
3	2/12/07 22:10	6.666666667	4.3	1720.0	1.09	3.9219		0.017	0.57	618	13.2	7.24

Appendix G
Dual Media - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

4	2/13/07 9:00	17.5	4.3	4515.0	1.09	7.1517		0.018	0.62	650	12.8	7.23
5	2/13/07 12:00	20.5	4.6	5316.0	1.29	9.228	0	0.012	0.51	631	12.8	7.96
6	2/14/07 9:00	41.5	4.5	11049.0	1.240385	11.535						
7	2/14/07 13:20	45.83333333	4.5	12219.0	1.240385	11.7657	0	0.015	0.07	217	13.4	7.97
8			5.7	gpm/ft2								

Backwash 10 mins composite sampel every 30 secons rate 9.0 gpm setting in 15 min 3" clear at top after 15 min. Next morning 7" total only trace solids at bottom and clear yellowish top liquid.

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/14/07 15:20	0	6.5	0	1.32	9.4587						
2	2/14/07 15:25	0.083333333	7	33.7	1.21	9.228						
3	2/15/07 9:00	17.66666667	6.4	7102.2	1.32	13.1499						
4	2/15/07 9:05	17.75	6.5	7134.5	1.32	13.3806						
5	2/15/07 10:50	19.5	6.5	7817.0	1.32	13.1499	0	0.025	0.02	302	13.9	7.93
6	2/15/07 12:50	21.5	6.5	8597.0	1.508571	14.0727						
7	2/15/07 14:20	23	6.5	9182.0	1.3	15.6876	0	0.019	0	347	14.1	7.28
8	2/15/07 17:50	26.5	6.5	10547.0	1.4	15.6876	0	0.014	0.1	446	13.2	7.23
9	2/16/07 8:20	41	6.5	16202.0	1.94	18.456	0	0.002	0.64	572	13	7.26
10	2/16/07 11:00	43.66666667	6.2	17218.0	2.047778	20.763						
11	2/16/07 14:25	47.08333333	6.3	18499.2	2.015273	20.0709	0	0	0.65	495	13.1	7.31
12			8.3	gpm/ft2								

Appendix G
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Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

Backwash 10 min at 8.3 gpm sample every 30 seconds

#			pre-filter				Post filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/16/07 14:55	0	8	0	1.74	12.6885						
2	2/16/07 15:35	0.666666667	8	320.0	1.74	12.4578		0.015	0.27	469	13	7.33
	2/16/07 15:45	0.833333333	8.5	402.5	1.637647	13.3806						
3	2/17/07 9:45	18.83333333	8	9312.5	1.74	19.6095		0.027	0.44	485	13.4	7.35
4	2/17/07 12:30	21.58333333	7.75	10611.9	1.39	20.763	0	0.021	0.09	299	13.9	7.3
5	2/17/07 16:10	25.25	7.5	12289.4	1.87	19.6095		0.033	0.57	282	13.5	7.32
6	2/17/07 17:40	26.75	7.25	12953.1	1.69	24.6849		0.063	0.39	490	13.2	7.32
7	2/18/07 13:05	46.16666667	7	21253.7	1.32	25.377	0	0.232	0.02	249	14.1	7.32
8	2/18/07 15:35	48.66666667	6.75	22285.0	1.78	27.684		0.026	0.48	252	13.6	7.34
9	2/19/07 11:15	68.33333333	6.5	30102.5	0	25.377	0	0.279	0	245	13.4	7.28
10	2/19/07 14:30	71.58333333	2.5	30980.0	3.28	12.6885		0	1.98	630	14	7.25
12			9.2	gpm/ft2								

Backwash 15:30 8.5 gpm 10 min clear at 7 to 8 min

#			pre-filter				Post filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/19/07 15:45	0	6.5	0	1.72	7.3824						
2	2/19/07 22:10	6.416666667	6.5	2502.5	1.72	10.8429		0	0.42	556	13.9	7.23
3	2/20/07 4:00	12.25	6.5	4777.5	1.42	11.7657		0	0.12	522	13.8	7.27
4	2/20/07 10:35	18.83333333	6.2	7285.7	1.59	13.3806		0.008	0.29	551	13.2	7.31

Appendix G
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Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

5	2/20/07 15:15	23.5	6.2	9021.7	1.75	14.7648	0.03	0.009	0.45	551	13.9	7.29
6	2/20/07 22:15	30.5	6.5	11688.8	1.31	16.149		0.014	0.01	311	13.7	7.29
7	2/21/07 4:58	37.21666667	6.1	14227.6	1.63	18.2253		0.013	0.33	542	13.5	7.25
8	2/21/07 10:45	43	6.2	16361.7	2.04	19.1481	0	0.053	0.74	558	14.1	7.29
	2/21/07 10:50	43.08333333	6.5	16393.5	2.04	20.763						
9	2/21/07 13:25	45.66666667	6.5	17401.0	2.3	20.3016		0.012	1	561	14.2	7.29
10			8.1	gpm/ft2								

Backwash 8.8 gpm clearing at 4 min 10 min total

#			pre-filter				Post filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/21/07 14:00	0	6.9	0	2.166667	9.4587						
2	2/21/07 14:10	0.166666667	3.9	54.0	2.1	4.8447						
3	2/22/07 10:30	20.5	3.8	4751.0	2.1	6.4596		0.006	0.8	551	14	7.25
5	2/22/07 13:10	23.16666667	3.9	5367.0	1.08	6.921	0	0.009	0.52	440	15.1	7.28
6	2/22/07 20:12	30.2	3.9	7012.8	1.08	8.0745	0	0.008	0.44	417	13.6	7.26
7	2/23/07 1:35	35.58333333	3.9	8272.5	1.02	8.5359		0.012	0.33	369	13.8	7.21
			4.9	gpm/ft2								

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APPENDIX H

GREENSAND – FILTER RUN TEST

Appendix H
Process Optimization Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

Greensand

#			pre-filter					Post-Filter					
	Date/time	Flow	Aeration	Cl	KMnO4	Detention	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	1/23/2007 9:50	3.1	N		N	N	3.4605						
2	1/23/2007 11:41	2.7	N		N	N	2.7684	0	AD	0.01	149	13.2	7.2
3	1/23/2007 13:50	3.1	N		N	N	2.9991	0	AD	0	233	13.2	7.29
4	1/23/2007 16:35	3	N		N	N	4.614	0	AD	0.23	70	13	7.29
5	1/23/2007 21:37	3.05	N		N	N	4.3833	0	0.725	0.3	406	13.1	7.38
6	1/24/2007 2:55	2.95	N		N	N	5.0754						
7	1/24/2007 7:15	3.2	N		N	N	6.921	0	0.056	0.52	448	12.9	7.35
8	1/24/2007 9:32	3.15	N	N	N	N	7.1517	0	0.119	0.53	404	13	7.31
	1/24/2007 12:45	3.02	N	N		N	8.9973	0	0.1		280	12.9	7.34
9	1/24/2007 2:15	3.1	N	N		N	8.0745	0.02	0.091		178	13.1	7.36
10	1/25/2007 9:25	3.1	N	N		N	10.1508	0	0.035		218	13.5	7.36
11	1/25/2007 12:40	3	N	N		N	13.6113	0	0.038		72	13.2	7.34
12	1/25/2007 16:00	3.2	N	N	1.047	N	13.6113	0	0.035		142	13.2	7.34
Backwashed													
13	1/25/2007 20:45	3.05	N	N	0.585862	N	2.9991	0	0.032		263	15.2	7.33
14	1/26/2007 8:33	2.95	N	N	0.908583	N	4.1526	0	0.026		220	13.6	7.35
15	1/26/2007 13:05	3.2	N	N	1.047	N	4.614	0	0.018		151	13.3	7.34
16	1/29/2007 10:00		N	N	1.2564	N							
17	1/29/2007 12:50	2.9	N	N	1.386372	N	5.0754	0	0.114		200	14.7	7.36
18	1/29/2007 14:10	2.8	N	N	1.435886	N	5.5368	0	0.106		311	13.6	7.33
19	1/29/2007 16:40	2.5	N	N	1.608192	N	5.7675	0	0.095		168	13.5	7.33
20	1/29/2007 20:45	2.4	N	N	1.1168	N	6.921	0	0.08		407	12	7.33

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Appendix H
Greensand - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	1/31/07 11:45	0	3.1	0	70%							
2	1/31/07 12:40	0.92	2.95	166.4	70%							
3	1/31/07 16:20	4.58	2.9	809.9	60							
4	2/1/07 9:15	21.50	2.85	3728.0		4.8447		0.097		441		
5	2/1/07 11:13	23.47	2.83	4063.1		6.2289		0.046				
6	2/1/07 13:51	26.10	2.81	4508.7		6.4596		0.038				
7	2/1/07 17:33	29.80	2.91	5143.6		7.1517		0.02				
8	2/1/07 20:00	32.25	2.91	5571.4	0.450619	8.5359		0.021				
9	2/2/07 3:45	40.00	2.91	6924.5	0.300412	9.4587						
10	2/2/07 10:10	46.42	2.85	8033.3	0.306737	11.0736		0.021				
11	2/2/07 13:45	50.00	3.1	8672.9	0.282	11.7657		0.017		156		
12	2/2/07 14:15	50.50	3.1	8765.9	0.282	12.2271		0.016		192		
13	2/2/07 21:53	58.13	3	10162.8	0.32054	12.6885		0.017				
14	2/3/07 3:29	63.73	3.05	11179.2	0.334393	13.842						
15	2/3/07 10:04	70.32	3	12374.1	0.339967	14.9955		0.022				
Backwash												

Appendix H
Greensand - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/3/07 15:46	0.00	2.5	0.0	0.40796	2.307		0.02				
2	2/3/07 15:50	0.07	3.1	11.2	0.329							
3	2/3/2007 21:58	6.20	2.7	1078.4	0.377741	3.9219		0.025				
4	2/4/2007 3:15	11.48	2.7	1934.3	0.431704	4.614						
5	2/4/2007 10:40	18.90	2.7	3135.8	0.431704	4.3833						
6	2/4/2007 16:08	24.37	2.65	4013.2	1.766038	4.1526		0.015	0.01			
7	2/4/07 21:10	29.40	2.7	4821.0	2.31	4.614		0.016	0.32	449		
8	2/5/07 2:55	35.15	2.65	5743.9	2.35	4.8447						
9	2/5/07 10:25	42.65	2.6	6925.2	2.4	4.8447		0.017	0.75	540	12.9	7.32
10	2/5/07 16:58	49.20	2.6	7947.0	2.4	5.9982		0.01	1.24	473	13	7.31
11	2/5/07 23:00	55.23	2.5	8870.1	2.496	6.921		0.024	1.27	580	13.1	7.27
12	2/6/07 4:40	60.90	2.5	9720.1	2.496	6.921						
13	2/6/07 10:50	67.07	2.5	10645.1	2.496	9.228		0.008	0.99	518	13	7.27
14	2/6/07 11:58	68.20	2.5	10815.1	1.9968	8.9973		0.001	1.32	599	12.9	7.3
15	2/6/07 14:20	70.57	2.5	11170.1	1.4976	9.228		0.005	0.7	550	13.1	7.26
			3.4 gpm/ft2				Average	0.012				

Backwash

Appendix H
Greensand - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/6/07 14:55	0	2.5	0.0	1.42	2.307						
2	2/6/07 15:45	0.83	2.5	125.0	1.42	1.3842	0	0.007	0.12	314	13.1	7.29
3	2/6/07 20:40	5.75	2.3	833.0	1.46	1.8456		0.003	0.16	377	13.1	7.32
4	2/6/07 20:45	5.83	2.5	845.0	1.47	2.307						
5	2/7/07 3:05	12.17	2.5	1795.0	1.47	2.5377		0.016	0.17			
6	2/7/07 10:00	19.08	2.5	2832.5	1.48	3.2298		0.003	0.18	528	13.1	7.25
	2/7/07 14:50	23.92	2.4	3543.0	1.65	3.9219	0	0	1.17	457	13.5	7.29
7	2/8/07 11:15	44.33	2.4	6483.0	1.81	4.1526	0	0.011	0.51	351	14.1	7.35
8	2/8/07 12:55	46.00	1.4	6673.0	2.30	2.5377						
9	2/8/07 13:50	46.92	1.5	6752.7	2.15	2.9991	0	0.007	0.85	495	13.3	7.3
10	2/8/07 14:10	47.25	1.8	6785.7	1.37	4.3833						
11	2/8/07 16:58	50.05	1.8	7088.1	1.37	4.614	0	0.008	0.32	356		
12	2/8/07 17:45	50.83	2.5	7189.2	1.632	5.3061						
13	2/8/07 21:20	54.42	2.4	7715.9	1.7	7.6131	0	0.013	0.4	528	13.1	7.44
	2/8/07 21:25	54.50	2.5	7728.2	1.66	5.9982						
14	2/9/07 9:20	66.42	2.5	9515.7	1.66	6.4596		0.009	0.36	530	13.3	7.45
15	2/9/07 9:40	66.75	1.7	9557.7	1.524706	1.6149						
16	2/9/07 10:30	67.58	1.8	9645.2	1.44	2.0763	0	0.01	0.14	405	12.3	7.47
17	2/9/2007 10:55	68	2	9692.7	1.944	5.9982						
18	2/9/2007 12:00	69.08333333	2	9822.7		6.2289	0	0.01	0	224	14.1	7.48
19	2/9/2007 12:25	69.5	2.2	9875.2		7.6131						

Appendix H
Greensand - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

3.0 gpm/ft2

Backwash

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/9/07 15:20	0	2.4	0.0	1.55	2.307						
2	2/9/07 17:13	1.883333333	2.4	271.2	1.55	2.0763	0	0.013	0.52	479	13	7.47
3	2/10/07 9:35	18.25	2.4	2628.0	1.55	1.6149	0	0.027	0.62	185	13.6	7.37
4	2/10/07 16:00	24.66666667	2.4	3552.0	1.55	2.9991		0.019	0.32	465	14.4	.7.43
5	2/10/07 21:35	30.25	2.4	4356.0	1.55	3.6912		0.053	0.42	460	13.5	7.41
6	2/11/07 9:35	42.25	2.4	6084.0	0.00	3.9219		0.015	0.01	433	13.9	7.40
7	2/11/07 16:00	48.66666667	2.4	7008.0	1.73	3.9219	0	0.007	0.27	486	14.1	7.27
8	2/11/07 21:30	54.16666667	2.4	7800.0	1.73	3.6912		0.001	0.43	498	13.2	7.28
9	2/12/07 10:00	66.66666667	2.4	9600.0	1.78	7.6131		0.015	0.48	608	13.7	7.22
10	2/12/07 13:05	69.75	2.4	10044.0	1.78	6.2289	0	0.011	0.46	470	14	7.35
11			3.1 gpm/ft2									

Backwash 6 gpm 11 min total 6 min clearing

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/12/07 16:00	0	3.1	0.0	0.83	2.307						
2	2/12/07 18:15	2.25	3.1	418.5	0.83	2.307						
3	2/12/07 21:15	5.25	2	877.5	1.29	2.307						

Appendix H
Greensand - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

4	2/12/07 21:20	5.33	3.1	890.3	0.83	2.7684			0.88	652	13.6	7.3
5	2/13/07 9:10	17.17	2.9	3020.3	0.89	5.0754		0.038	0.36	621	12.9	7.3
6	2/13/07 9:15	17.25	3.1	3035.2	0.83	6.2289						
7	2/13/07 12:15	20.25	3.1	3593.2	0.93	5.7675		0.013	0.57	491	13	8.01
8	2/14/07 9:00	41.00	3	7390.5	0.86	7.1517						
9	2/14/07 9:05	41.08	3.1	7405.7	0.83	8.7666						
10	2/14/07 13:30	45.50	3.1	8227.3	0.85	8.3052	0	0.011	0.51	545	13.1	8.01
11			3.8 gpm/ft2									

Backwash at 6.0 gpm for 10 min clarted at 6.5 min. Took composite sample every 30 seconds. Settled by 15:15 with trace on the bottom. 2/15/07 9:00 5.5" clear and trace on bottom

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/14/07 14:40	0	3.9	0.0	1.43	2.9991						
2	2/15/07 9:00	18.33	4	4345.0	1.43	7.1517						
3	2/15/07 11:00	20.33	3.9	4819.0	1.29	6.2289	0	0.014	0.69	490	13.6	8.05
4	2/15/07 12:50	22.17	3.9	5248.0	1.29	6.4596						
5	2/15/07 14:43	24.05	3.9	5688.7	1.29	6.2289	0	0.026	0.6	524	14.6	7.38
6	2/15/07 18:40	28	3.9	6613.0	1.29	7.1517	0	0.012	0.37	551	13.1	7.39
7	2/16/07 8:30	41.83333333	3.3	9601.0	1.29	8.0745	0	0.001	0.34	535	12.9	7.39
8	2/16/07 8:34	41.9	3.9	9615.4	1.29	9.6894						
9	2/16/07 11:00	44.33333333	3.9	10184.8	1.29	9.9201	0	0	0.19	400	13.7	7.41
			4.9 gpm/ft2									

APPENDIX I

GSR – FILTER RUN TEST

Appendix I
Process Optimization Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

GSR Plus

#							Post-Filter					
	Date	Time	Flow	Cl	KMnO4	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	23-Jan	9:50	3.1	N	0.62	0	--	--	--	--	--	--
2	23-Jan	11:56	2.72	N	0.71	0.4614	0	0.07	N	121	12.8	7.23
3	23-Jan	16:45	2.85	N	0.68	0.2307	0	0.053	N	28	12.8	7.25
4	23-Jan	21:45	3	N	0.64	1.1535	0	0.047	N	364	13.1	7.3
5	24-Jan	3:00	2.98	N	0.65	3.9219	--	--	--	--	--	--
6	24-Jan	7:25	2.98	N	0.65	4.1526	0.01	0.04	N	341	12.7	7.25
7	24-Jan	9:35	2.95	N	0.75	6.6903	0	0.032	N	264	13.2	7.22
8	24-Jan	12:50	3.09	N	0.63	6.921	0	0.038	N	238	13.2	7.27
9	24-Jan	14:30	3.15	N	0.66	8.5359	0	0.051	N	183	13.9	7.39
10	25-Jan	9:45	2.95	N	0.70	12.6885	0	0.024	N	212	13.3	7.22
11	25-Jan	12:50	3.1	N	0.67	5.3061	0	0.022	N	84	13.3	7.24
	Notes:	Pre-filter Mn = 0.409 / 0.396 - Took sample = 22ppb Mn and 0.002ppm Fe										
12	25-Jan	16:10	3.08	1.33	0.67	8.9973	0	0.014	0.20T/0.05	146	14.9	7.26
	Notes:											
13	25-Jan	17:45	3.05	2.40	0.36	9.6894	0	0.012	0.34T/0.06	368	13.4	7.25
	Notes:	Pre-filter Cl = 1.99 F and > 2.2 total										
14	25-Jan	20:55	3.08	N	0.36	11.535	0	0.012	N	264	13.2	7.23
15	26-Jan	8:45	3.08	1.36	N	18.2253	0	0.002	0.00T	172	13.4	7.24
16	26-Jan	10:45	3	2.09	N	18.456	0	0.001	0.27T/0.00	179	13.7	7.25
17	26-Jan	11:55	3.1	2.69	N	18.6867	0	0	0.34T/0.01	157	14.6	7.24
	Notes:	Backwashed 6 min to clean flowrate = 30 sec for 5 gal. Stopped backwash at 20 min										

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Appendix I
GSR Plus - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	1/29/07 11:15	0	3.1	0	1.6							
2	1/29/07 13:00	1.75	2.72	305.5	1.78	3.9219	0	0.009	0.48	207	12.9	7.23
3	1/29/07 14:20	3.08	2.6	518.3	2.1	3.6912	0	0.006	0.8	141	14.2	7.24
4	1/29/07 16:40	5.42	2.95	906.9	2.42	3.9219	0	0.007	1.12	608	13	7.23
5	1/29/07 20:55	9.67	2.98	1662.9	2.21	4.1526	0	0.002	0.91	603	13	7.23
6	1/30/07 3:15	16.00	2.95	2789.6	1.93	5.7675		0.004	0.63			
7	1/30/07 9:15	22.00	3	3860.6	1.9	6.921	0	0.009	0.6	430	13.1	7.25
8	1/30/07 11:15	24.00	2.95	4217.6	1.63	7.1517	0	0.012	0.33	286	12.9	7.22
9	1/30/07 13:35	26.33	2.95	4630.6	1.57	8.0745		0.008	0.27	517	12.9	7.24
10	1/30/07 16:00	28.75	2.95	5058.4	1.95	8.3052	0	0.006	0.65	203	13.3	7.23
11	1/30/07 22:30	35.25	2.93	6205.0	1.92	8.7666		0.006	0.62	585	12.7	7.25
12	1/31/07 4:20	41.08	3.05	7251.5	1.78	11.3043	0	0.001	0.48	509	12.9	7.26
13	1/31/07 10:40	47.42	3.02	8404.8	1.68	11.9964	0	0.014	0.38	285	13.7	7.23
14	1/31/07 12:40	49.42	3.01	8766.6	1.25	12.4578		0.019	0.38	460	13.1	7.2

3.8 gpm/ft2

Backwashed 13:35 clear at about 6 min stopped at 15 min.

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	1/31/07 13:53	0	3.1	0	1.31	3.6912						
2	1/31/07 14:53	1.00	3	183.0	1.31	3.6912	0	0.012	0.3	511	13	7.26
3	2/1/07 9:21	19.47	2.88	3440.5	1.43	5.9982		0.003	0.42	507	13.7	7.24

Appendix I
GSR Plus - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

4	2/1/07 11:18	21.42	3.1	3790.3	1.39	8.0745	0	0.008	0.38	464	13.9	7.23
5	2/1/07 14:00	24.12	3.09	4291.7	1.36	7.1517		0.005	0.35	510	13.7	7.21
6	2/1/07 17:47	27.90	3.18	5003.4	1.38	8.3052		0.007	0.37	529	13.2	7.2
6	2/1/07 21:40	31.78	3.12	5737.3	1.21	9.228		0.007	0.2	431	13.4	7.25
7	2/2/07 3:50	37.95	3.15	6897.3	1.17	8.9973		0.01	0.16			
8	2/2/07 10:15	44.37	3.15	8110.0	1.37	10.1508		0.003	0.35	498	13	7.2
9	2/2/07 13:35	47.70	3.05	8730.0	1.38	9.4587	0	0.008	0.37	174	13	7.23
10	2/2/07 14:20	48.45	3.15	8869.5	1.3	10.1508		0.004	0.29	461	13.2	7.19
11	2/2/07 21:58	56.08	3.1	10300.8	1.35	12.9192		0.013	0.34	475	12.9	7.2
12	2/3/07 3:30	61.62	3.09	11328.3	1.35	12.4578		0.006	0.34	494	13.1	7.19
13	2/3/07 10:08	68.25	3.09	12558.1	1.36	12.9192		0.011	0.35	365	13.3	7.18
14	2/3/07 15:55	74.03	3.07	13626.9	1.37	13.3806	0	0.007	0.36	220	13.2	7.23
15	2/3/07 22:00	80.12	3.1	14752.9	0.87	13.6113		0.017	0.38	419	12.9	7.21
16	2/4/07 3:15	85.37	3.11	15731.0	0.87	14.9955		0.011	0.31			
17	2/4/07 10:43	92.83	3.11	17124.3	0.87	15.6876		0.008	0.33			
18	2/4/07 15:35	97.70	3.1	18030.9	0.87	15.4569	0.02	0.015	0.31	335	12.9	7.24
19	2/4/07 21:15	103.37	3.08	19081.5	0.88	16.149	0	0.015	0.37	445	12.7	7.21
20	2/5/07 3:00	109.12	3.08	20144.1	0.88	17.9946	0	0.011	0.38	267	12.5	7.18
21	2/5/07 10:40	116.78	3.08	21560.9	0.88	19.8402	0	0.008	0.35	488	12.7	7.26

3.9 gpm/ft2
Backwash 6 min clearing and 8 min clear Backwashed 12 min
3 5 gallon samples at 0, 30, and 120 seconds - 0 = yellow water13.5" total 1/2" solids at 1 hour
30 seconds cleartop 12.5" total and 8" clear water, 120 second sample not settled in 1 hour

Appendix I
GSR Plus - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/5/07 16:40	0	3.9	0	0.92	4.1526						
2	2/5/07 17:18	0.63	3.8	146.3	0.94	4.1526	0	0.007	0.65	309	12.6	7.24
3	2/5/07 17:20	0.67	4	154.1	0.80							
4	2/5/07 23:10	6.50	3.9	1536.6	0.82	5.5368		0.012	0.49	519	13.2	7.23
5	2/6/07 4:40	12.00	3.88	2820.3	0.76	5.9982		0.004	0.07	320	12.9	7.2
6	2/6/07 10:55	18.25	3.9	4279.0	0.76	6.6903		0.002	0	416	12.9	7.25
7	2/6/07 12:08	19.47	3.85	4561.9	2.21	7.3824		0.001	0.91	600	12.8	7.27
8	2/6/07 14:30	21.83	3.85	5108.6	1.84	8.3052		0.001	0.54	505	13	7.26
9	2/6/07 15:55	23.25	3.9	5438.0	0.46	6.4596		0.001	0	255	13	7.25
10	2/6/07 20:50	28.17	3.6	6544.2	0.667333	6.921		0.001	0.1	376	12.9	7.25
11	2/7/07 3:10	34.50	3.6	7912.3	0.75075	8.7666		0.001	0.13			
12	2/7/07 3:15	34.58	3.9	7931.0	0.77	10.3815						
13	2/7/07 10:10	41.50	3.85	9539.1	0.77	10.8429		0.001	0.14	525	12.9	7.22
14	2/7/07 15:00	46.33	3.88	10660.0	0.764046	11.7657	0	0	0.89	547	13.3	7.23
15	2/8/07 11:25	66.75	3.9	15425.2	0.684115	14.0727	0	0.007	0	257	14.3	7.24
16			4.9	gpm/ft2								

Backwash 12:04 30 and 29 seconds for 5 gallons at 3 min clearing at 14 min stopped settling at 15:30 0 sec sample = yellow, 12 3/4" clear 13.5" total
30 sec sample clear 11" clear 12.5" total.
180 sec sample yellow 11.75" clear 12" total

Appendix I
GSR Plus - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/8/07 12:20	0	3.9	0		4.8447						
2	2/8/07 12:57	0.62	2.2	112.8		2.9991						
3	2/8/07 13:40	1.33	2.3	209.6		2.9991	0	0.007	1.39	575	13.1	7.28
4	2/8/07 14:10	1.83	2.7	284.6		2.9991						
5	2/8/07 16:50	4.50	2.7	716.6					0.43			
6	2/8/07 17:24	5.07	2.7	808.4		4.3833	0	0.012	0.3	480		
7	2/8/07 17:45	5.42	3.75	876.1		4.1526						
8	2/8/07 17:50	5.50	3.9	895.2		4.614						
9	2/8/07 21:30	9.17	3.7	1731.3		5.0754		0.009	0.63	552	13	7.38
10	2/8/07 21:35	9.25	3.9	1750.2		8.3052						
11	2/9/07 9:25	21.08	3.78	4476.6		6.921		0.009	0.48	560	13	7.32
12	2/9/07 9:30	21.17	3.9	4495.9		7.8438						
13	2/9/07 9:40	21.33	3.1	4530.9		6.2289						
14	2/9/07 10:20	22.00	3.15	4655.8		6.4596	0	0.009	0.14	427	12.5	7.4
15	2/9/07 10:55	22.58	3.6	4774.0		8.0745						
16	2/9/07 11:45	23.42	3.5	4951.5		8.0745	0	0.005	0.36	283	12.8	7.39
			4.5 gpm/ft2									

Backwash start 3:57pm stop 4:12pm (15min) Noted open valve effluent valve so rebackwashed start 4:21 stop at 4:38.

Appendix I
GSR Plus - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/9/07 16:39	0	4.7	0	1.89	3.4605						
2	2/9/07 17:23	0.73	4.6	204.6	1.89	2.9991	0.07	0.014	0.59	499	12.8	7.41
3	2/10/07 10:05	17.43	4.5	4763.7	1.88	5.9982	0	0.014	0.58	228	13.2	7.23
	2/10/07 10:10	17.52	4.7	4786.7	1.8							
4	2/10/07 16:25	23.77	4.5	6511.7	1.88	8.7666		0.018	0.58	556	13.4	7.36
5	2/10/07 22:00	29.35	4.5	8019.2	1.91	8.7666		0.013	0.61	522	12.9	7.26
6	2/11/07 10:10	41.52	4.5	11304.2	1.35	8.5359		0.009	0.05	496	13.3	7.26
7	2/11/07 16:20	47.68	4.5	12969.2	0	10.3815	0	0.003	0	466	14.5	7.23
8	2/11/07 22:00	53.35	4.5	14499.2	1.99	8.0745		0	0.69	483	13.2	7.25
9	2/12/07 10:07	65.47	4.15	17643.5	2.01	13.3806		0.013	0.71	633	13.3	7.23
10	2/12/07 13:15	68.60	4.7	18475.4	1.86	14.9955	0.01	0.013	0.56	608	13.2	7.28
11			5.7 gpm/ft2									

Backwash at 13:30 0, 5, 8 min samples 32, 32, and 30 seconds for 5 gallons. 10 min total at 15:10 1st draw clear top and 5 min and 8 min not settled
Mixed 5 min and 1st draw at 15:10. Settled to 15.25" clear and 16" total. 8 min trace sediment and clear liquid.

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/12/07 13:50	0	5.5	0	0.72	3.4605						
2	2/12/07 20:15	6.42	5.4	2098.2	0.715	4.1526						
3	2/12/07 20:20	6.50	5.4	2125.2	0.715	8.3052		0.012	0.51	639	13.2	7.27
4	2/12/07 21:20	7.50	5.4	2449.2	1.200694	7.6131						
5	2/13/07 9:20	19.50	5.25	6283.2	1.235	8.3052		0.011	0.52	647	13.2	7.26

Appendix I
GSR Plus - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

6	2/13/07 9:25	19.58	5.5	6310.1	1.134591	9.6894						
7	2/13/07 12:20	22.50	5.45	7268.3	1.145	9.4587	0	0.011	0.43	580	12.6	7.98
8	2/14/07 9:00	43.17	5.3	13933.2	0.988302	14.7648						
9	2/14/07 9:05	43.25	5.5	13960.2	0.952364	14.5341						
10	2/14/07 11:15	45.42	5.4	14668.7	0.97	14.0727	0	0.01	0.255	344	14.3	7.96
11			6.9 gpm/ft2									

Backwash 12:15 29, 28, 27 seconds per 5 gallon fill. Composite sample taken every 30 seconds. 10 min total about 5 min clearing.Composite sample trace solids at bottom and clear top at 9:00 2/15

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/14/07 12:40	0	6	0	0.91	5.9982						
2	2/14/07 14:40	2.00	6	720.0	0.905	6.921			0.19			
3	2/14/07 15:20	2.67	3.9	918.0	1.225	3.6912						
4	2/14/07 15:25	2.75	4.1	938.0	2.17622	3.9219						
5	2/15/07 9:00	20.33	3.9	5158.0	1.225	6.4596						
6	2/15/07 10:45	22.08	3.9	5567.5	1.225	6.4596			0.51			
7	2/15/07 12:40	24.00	3.85	6013.1	1.085	6.4596	0	0.013	0.37	513	13	7.31
8	2/15/07 14:20	25.67	3.8	6395.6	1.361711	6.2289						
9	2/15/07 18:30	29.83	3.75	7339.4	1.379867	6.6903	0	0.011	0.26	529	13.3	7.26
10	2/16/07 8:15	43.58	3.8	10453.7	1.361711	7.3824	0	0.002	0.24	477	12.9	7.23
11	2/16/07 11:00	46.33	3.95	11093.1	1.31	10.6122						
12	2/16/07 12:50	48.16666667	3.95	11527.6	1.31	9.4587	0	0.001	0.28	458	12.9	7.26

Appendix I
GSR Plus - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

5.1 gpm/ft2

Backwash 10 min at 9.8 gpm sampled every 30 seconds at 15:10 clearing - end 7.75" total and 7.5" clear

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/16/07 13:35	0	4	0	0.82	2.5377						
2	2/16/07 15:20	1.75	3.9	414.8	0.845	3.6912		0	0.13	472	12.8	7.33
	2/16/07 15:30	1.916666667	4.15	455.0	0.795181	5.9982						
3	2/17/07 9:05	19.5	4	4754.1	0.825	7.1517		0.035	0.11	448	14.8	7.3
4	2/17/07 12:05	22.5	3.7	5447.1	0.745	8.3052	0	0.017	0.03	322	14.4	7.3
5	2/17/07 15:57	26.36666667	3.9	6328.7	0.995	9.4587		0.02	0.28	243	13.8	7.25
6	2/18/07 9:30	43.91666667	3.9	10435.4	0.975	12.9192		0.019	0.26	381	13.9	7.26
7	2/18/07 13:20	47.75	3.9	11332.4	0.905	10.6122	0	0.024	0.19	264	14.6	7.32
8	2/18/07 15:45	50.16666667	3.9	11897.9	0.935	12.9192		0.005	0.22	271	13.8	7.3
9	2/19/07 11:05	69.5	4	16479.9	0.725	11.0736	0	0	0.01	247	13.8	7.31
10	2/19/07 14:45	73.16666667	3.7	17326.9	0.895	12.2271		0	0.18	528	13.8	7.3
11			5.0 gpm/ft2									

Backwash at 10.1 gpm for 10 min. Sample every 30 seconds photos of sample. Left 2.5" in bucket before collecting sample from last backwash.

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/19/07 15:15	0	3.9	0	1.39	2.5377						
2	2/19/07 22:00	6.75	3.7	1539.0	1.46	2.5377		0	0.26	527	13.6	7.27
	2/19/07 22:05	6.833333333	3.9	1558.0	1.39	2.5377						
3	2/20/07 3:55	12.66666667	3.8	2905.5	1.42	4.1526		0	0.34	547	14.3	7.23

Appendix I
GSR Plus - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

	2/20/07 4:00	12.75	3.9	2924.7	1.39	3.4605						
4	2/20/07 10:25	19.16666667	3.8	4407.0	1.42	4.614		0.007	0.3	559	13.7	7.26
5	2/20/07 11:08	19.88333333	3.95	4573.6	1.37	4.614	0.07	0.01	0.03	232	14.7	7.29
6	2/20/07 15:00	23.75	3.9	5484.2	1.39	5.3061	0	0.006	0.42	532	14.3	7.27
7	2/20/07 22:00	30.75	3.8	7101.2	1.42	6.4596		0.011	0.06	301	13.7	7.26
	2/20/07 22:05	30.83333333	4	7120.7	1.35	6.6903						
8	2/20/07 4:50	13.58333333	3.95	3006.6	1.37	7.3824		0.011	0.26	469	13.5	7.28
9	2/21/07 11:00	43.75	3.9	10110.9	1.39	8.3052	0	0.009	0.81	557	13.3	7.3
10	2/21/07 11:50	44.58333333	3.9	10305.9	1.39	7.6131	0	0.01	0.24	430	14.3	7.27
11	2/21/07 14:50	47.58333333	3.9	11007.9	1.39	8.7666		0.009	0.77	575	13.7	7.31
	2/21/07 14:55	47.66666667	4	11027.6	1.35	8.9973						
12	2/22/2007 10:20	67.08333333	3.85	15600.2	1.41	11.7657		0.007	0.69	540	13.3	7.28
14	2/22/2007 14:15	71	3.95	16516.7	1.18	12.6885	0	0.013	0.49	419	14.1	7.32
15	2/22/2007 20:20	77.08333333	3.9	17949.3	1.20	13.6113		0.011	0.4	480	13.2	7.26
16	2/23/2007 1:50	82.58333333	3.9	19236.4	1.04	14.0727		0.009	0.32	380	13.6	7.27

4.9 gpm/ft2

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APPENDIX J

PYROLUSITE – FILTER RUN TEST

Appendix J
Process Optimization Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

Pyrolusite

#						Post-Filter					
	Date	Time	Flow	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	1/26/2007	10:25		1.78	Start						
	Notes:	Chlorine 15 gallons 2.5 L Cl									
2	1/26/2007	11:40	7.3	1.78	179.8	0	0.001	0/.51	255	14.2	7.22
	Notes:	Turned Cl up to 90%									
3	1/26/2007	13:50	7.4	2.26	0	0	0	0.49	508	13.6	7.21
	Notes:	Cl feed 1.96 mg/L Free sample taken									
4	29-Jan	11:00	7.9	1.41	10.29023	--	--	--	--	--	--
5	29-Jan	12:35	7.4	1.32	9.598133	0	0.003	.39F	243	13.1	7.19
6	29-Jan	13:45	7.2	1.55	10.29023	0	0.002	0.40F	426	13.2	7.2
	Notes:	Backwashed at 14:44 for 5 min at 19 gpm. 3.5 min till clear									

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Appendix J
Pyrolusite - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#							Post-Filter						
	Date	Lapsed Time	Flow	Gallons Treated	Feed Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	1/29/07 14:55	0	7.9	0.00	1.5	7.6131						
2	1/29/07 16:15	1.33	7.8	628.00	1.5	9.6894	0	0.001	0.38	422	13.2	7.19
3	1/29/2007 20:30	5.58	7.9	2629.75	1.5	12.4578	0	0.002	0.34	436	12.8	7.18
4	1/30/2007 3:20	12.42	7.9	5868.75	1.5	14.3034		0.002	0.34			
5	1/30/2007 9:40	18.75	7.9	8870.75	1.5	17.3025	0	0.008	0.31	375	13.1	7.2
6	1/30/2007 11:20	20.42	7.9	9660.75	1.5	19.3788		0.005	0.26	512	13.2	7.21
7	1/30/2007 13:40	22.75	7.9	10766.75	1.55		0	0.005	0.33	467	13.1	7.19
8	1/30/2007 14:45	23.83	7.9	11280.25	1.55	21.9165						
9	1/30/2007 16:07	25.20	7.9	11928.05	1.55	22.3779		0.002	0.32	475	13.4	7.19
10	1/30/2007 22:40	31.75	7.9	15032.75	1.55	26.0691	0.01	0.001	0.3	463	13	7.21
11	1/31/2007 4:26	37.52	7.9	17766.15	0	28.1454	0	0.002	0	410	13.1	7.2
12	1/31/2007 10:55	44.00	7.9	20839.25	0	28.1454	0	0.026	0	257	13.5	7.21
13	1/31/2007 13:00	46.08	7.8	21820.50	1.56	33.4515	0	0.013	0.2	434	13.1	7.2
			10.0 gpm/ft2									

Backwashed at 13:10 flowrate 18.2 gpm 2 min to clear backwashed 5 min total. Took 1st draw sample on backwash waste. After 45 min = 460 mL solids after 2 hr = 340 mL solids. Clear top water

Appendix J
Pyrolusite - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	1/31/07 13:18	0	9.4	0.00	1.56	8.7666			0.21			
2	1/31/07 14:30	1.20	9.3	673.20	1.43	8.5359	0	0.001	0.212	370	13.1	7.19
3	2/1/07 9:27	20.15	9.3	11247.30	1.43	20.9937		0.005	0.21	505	13.3	7.2
4	2/1/07 11:27	22.15	9	12345.30	1.43	23.5314	0	0.007	0.22	443	13.5	7.2
5	2/1/07 14:07	24.82	9	13785.30	1.43	25.8384		0.005	0.14	481	13.1	7.18
6	2/1/07 15:00	25.70	9.5	14275.55	1.66	28.3761			0.37			
7	2/1/07 21:45	32.45	9	18021.80	1.870333	32.298		0.008	0.29	468	13.1	7.2
8	2/2/07 3:55	38.62	9.3	21407.30	1.81	36.912		0.012	0.26			
9	2/2/07 10:25	45.12	8.8	24936.80	1.912841	40.8339		0.008	0.33	410	13.5	7.19
10	2/2/07 13:25	48.12	9.3	26565.80	1.81	44.9865	0	0.009	0.25	200	13.1	7.19
11	2/2/07 14:27	49.15	8.8	27126.90	1.912841	47.9856		0.015	0.25	495	13.2	7.21
12	2/2/07 22:03	56.75	9.1	31208.10	1.84978	53.9838		0.01	0.26	501	13.2	7.19
13	2/3/07 3:40	62.37	9	34257.95	1.870333	57.9057		0.008	0.28	450	13.2	7.2
14	2/3/07 10:11	68.88	8.5	37679.20	1.980353	68.5179		0.012	0.27	390	13.5	7.21
15	2/3/07 15:20	74.03	7.1	40089.40	2.370845	71.9784	0	0.009	0.17	275	13.3	7.16
			11.5 gpm/ft2									

Appendix J
Pyrolusite - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/3/07 16:20	0	11.8	0.00	1.46	9.228						
2	2/3/07 21:30	5.17	11.1	3549.50	1.46	14.9955	0	0.008	0.06	217	13.4	7.21
3	2/4/07 3:25	11.08	11.3	7525.50	1.63	20.0709		0.008	0.23			
4	2/4/07 9:30	17.17	11.3	11650.00	2.08	25.8384	0.14	0.009	0.68			
5	2/4/07 15:15	22.92	11.7	15617.50	1.67	34.3743	0	0.022	0.27	345	13.2	7.2
6	2/4/07 16:15	23.92	11.5	16313.50	1.70	34.3743	0	0.008	0.18			
7	2/4/07 21:15	28.92	11	19688.50	1.78	39.219	0	0.009	0.31	224	13	7.16
8	2/5/07 3:08	34.80	10.5	23483.25	1.86	43.6023	0	0.01	0.38	254	12.9	7.2
9	2/5/07 3:10	34.83	11	23504.75	1.78	48.9084						
10	2/5/07 10:55	42.58	10	28387.25	1.87	53.5224	0	0.008	0.29	408	13	7.21

14.1 gpm/ft2

Backwash at 18 gpm. 5.5 min to clear 7.5 min total

1st draw sample 10 gallons with 19" total and 4.5 inches solids and clear liquid at top.

Appendix J
Pyrolusite - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/5/07 16:00	0	9.8	0.00	1.91	9.228						
2	2/5/07 17:04	1.07	9.3	611.20	2.01	11.7657	0	0.003	0.29	411	12.9	7.19
3	2/5/07 17:10	1.17	9.9	668.80	1.89	9.228						
4	2/5/07 23:18	7.30	9	4146.40	1.49	14.0727		0.006	0.19	438	13	7.19
5	2/5/07 23:20	7.33	9.8	4165.20	1.68	14.9955						
6	2/6/07 4:55	12.92	9.1	7330.95	1.68	20.9937		0.004	0.38	430	13	7.2
7	2/6/07 5:00	13.00	9.9	7378.45	1.6	21.2244						
8	2/6/07 11:00	19.00	9	10780.45	1.6	25.8384		0	0.3	419	13	7.18
9	2/6/07 11:01	19.02	9.8	10789.85	1.54	25.8384						
10	2/6/07 14:04	22.07	9.3	12537.50	1.54	31.1445						
11	2/6/07 14:15	22.25	9.9	12643.10	1.54	29.991						
12	2/6/07 15:06	23.10	9.9	13148.00	1.54	30.4524	0	0.001	0.24	432	13.4	7.22
13	2/6/07 15:15	23.25	9.8	13236.65	1.3	29.991						
14	2/6/07 16:18	24.30	9.9	13857.20	1.3	32.0673						
15	2/6/07 20:55	28.92	9.9	16599.50	1.3	32.5287		0.001	0	300	13	7.18
16	2/6/07 21:30	28.92	9.9	16599.50	2.54	22.8393						

Appendix J
Pyrolusite - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

17	2/7/2007 2:43	34.13	9.9	19698.20	2.54	34.605		0.001	1.24			
18	2/7/2007 2:45	34.17	9.9	19718.00	2.08	39.219						
19	2/7/2007 9:45	41.17	9.9	23876.00	2.08	48.447		0.001	0.78	534	13.6	7.21
20	2/7/2007 14:10	45.58	10	26512.75	1.35	53.061	0	0.001	0.32	392	13.2	7.22
21	2/8/2007 9:55	65.33	9	37770.25	1.5	72.6705	0	0.007	0.6	546	13.5	7.2
22			12.3 gpm/ft2									

Backwash 11:15 am 18.5 gpm Sampled at 1st draw, 4 min, 6min, 10 min, 15 min, and 20 min. Photos available

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/8/07 11:40	0	9.8	0.00	1.50	9.228						
2	2/8/07 12:55	1.25	6	592.50	2.45	5.7675						
3	2/8/07 13:33	1.88	6	820.50	2.45	6.6903	0	0.005	0.55	380	13.4	7.19
4	2/8/07 14:10	2.50	7.8	1075.80	1.60	7.3824						
5	2/8/07 16:40	5.00	7.8	2245.80	1.60	10.3815	0	0.009	0.16	303		
6	2/8/07 17:45	6.08	9.8	2817.80	1.98	13.3806						
7	2/8/07 21:00	9.33	9.9	4738.55	1.98	16.149		0.008	0.68	515	13.4	7.27
8	2/9/07 8:00	20.33	9.8	11239.55	1.43	26.5305		0.005	0.13	388	13.3	7.35
9			11.7 gpm/ft2									

Backwash at 18.5 gpm 1st draw, 2 min, 5 min, 10 min sampels . Stoped at 10 min.

Appendix J
Pyrolusite - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/9/07 9:05	0	10	0.00	1.14	9.228						
2	2/9/07 9:40	0.58	8	315.00	1.42	8.0745						
3	2/9/07 10:10	1.08	7.9	553.50	1.42	7.6131	0	0.009	0.12	370	12.6	7.37
4	2/9/07 10:50	1.75	9	891.50	1.51	7.3824						
5	2/9/07 12:15	3.17	9	1656.50	1.51	9.4587	0	0.006	0.21	402	12.9	7.37
6	2/9/07 12:25	3.33	9.9	1751.00	1.37	11.535						
7			11.1 gpm/ft2									

Backwash 4:25 pm 17.8 gpm sample 1st draw, 2 min, 5 min. Stop at 4:30 pm
2/12/07 1st draw 16.25" total 16" clear 2 min sample trace at bottom and clar. 5 min sample trace at bottom and clear

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/9/07 16:33	0.00	9.4	0.00	1.71	8.0745						
2	2/9/07 17:42	1.15	9.4	648.60	1.44	8.5359	0	0.005	0.14	506	13.3	7.4
3	2/10/07 10:30	17.95	9.4	10123.80	1.55	15.9183	0	0.025	0.25	226	13.4	7.27
4	2/10/07 16:40	24.12	9.4	13601.80	1.49	22.8393		0.009	0.19	425	13.7	7.24
5	2/10/07 22:20	29.78	9.4	16797.80	1.63	18.2253		0.03	0.33	427	13.6	7.23
6	2/11/07 10:30	41.95	9.4	23659.80	0.00	28.6068		0.016	0	428	12.9	7.24
7	2/11/07 16:40	48.12	9.4	27137.80	1.69	37.3734	0	0.004	0.39	563	13.2	7.2

Appendix J
Pyrolusite - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

8	2/11/07 22:25	53.87	9.4	30380.80	1.82	41.9874		0.001	0.52	569	13.4	7.25
9	2/12/07 9:35	65.03	8.2	36276.80	1.99	54.9066		0.008	0.69	570	13.6	7.24
10			11.8 gpm/ft2									

Backwash 11:23 start 17.2 gpm 3 min and 5 min still discolored stopped at 10 min. 10 min only slight color was clearing.

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/12/07 11:35	0.00	9.4	0.00	2.72	8.3052						
2	2/12/07 18:12	6.62	9	3652.40	2.84	11.535						
3	2/12/07 18:15	6.67	9.4	3680.00	2.72	13.842						
4	2/12/07 20:55	9.33	7.3	5016.00	3.50	13.842		0.009	2.2	663	13.3	7.18
5	2/12/07 21:00	9.42	9.4	5057.75	2.53	16.149						
6	2/13/07 9:40	22.08	9	12049.75	2.53	21.6858		0.012	1.23	669	13.5	7.24
7	2/13/07 9:50	22.25	9.4	12141.75	1.81	27.684						
8	2/13/07 11:30	23.92	9.3	13076.75	1.81	28.8375	0	0.013	0.51	287	13.6	7.85
7			11.6 gpm/ft2									

Backwash 11:36 start 5 min total. Composite sample 10 seconds at 0, 1, 2, 3, and 4 minutes.
At 13:20 top 5" clear and rest cloudy. 2/14/07 9:15 clar yellowish top 18" total and 17" clear.
Poured off 8.5"

Appendix J
Pyrolusite - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/13/07 11:45	0.00	9.4	0.00	1.80	8.7666	0.07	0.05	0.5	458	13.2	7.88
2	2/14/07 9:00	21.25	8.8	11602.50		25.8384						
3	2/14/07 9:05	21.33	9.4	11648.00		26.5305						
4	2/14/07 10:18	22.55	9	12319.60		26.5305						
5	2/14/07 11:35	23.83	9.4	13028.00		28.6068	0	0.012	0.12	243	13.7	7.86
6			11.6	gpm/ft2								

Backwash 12:00 at 17.5 gpm. 5" from previous backwash added 5 sec sample every min. At 13:45 top claring at 14:40 top 8" clear
2/15/07 9:00 17.5" clear and 19" total

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/14/07 12:10	0.00	9.4	0.00		9.4587						
2	2/14/07 14:40	2.50	9.1	1387.50		9.6894						
3	2/14/07 14:45	2.58	10	1435.25		10.3815						
4	2/15/07 9:00	20.83	9.4	12056.75		23.07						
5	2/15/07 12:10	24.00	9.4	13842.75		29.5296	0	0.01	0.13	352	13.3	7.41
6			12.2	gpm/ft2								

Backwash for 5 min at 17 gpm. Sample for 3 seconds every minute.

Appendix J
Pyrolusite - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/15/07 12:35	0.00	9.4	0.00	1.91	4.614						
2	2/15/07 14:10	1.58	9.4	893.00	1.91	4.3833						
3	2/15/07 18:15	5.67	9.2	3171.50	1.95	13.3806	0	0.013	0.65	556	13.3	7.29
	2/15/07 18:20	5.75	9.4	3218.00	1.80	14.3034						
4	2/16/07 7:45	19.17	9	10624.00	1.88	23.7621	0	0.009	0.58	530	13.5	7.28
	2/16/07 7:50	19.25	9.4	10670.00	1.34	26.9919						
5	2/16/07 12:25	23.83	9.4	13255.00	1.34	29.991	0	0	0.04	347	13.3	7.3
6			11.8 gpm/ft2									

Backwash 12:35 for 5 min sampled every 30 seconds. Tank with 3.75" from previous. At 3:10 16" clear and 18.75 total. At 24 hours 17.75 clear 18.75 total.

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/16/07 12:45	0.00	9.4	0.00		10.3815						
2	2/16/07 15:15	2.50	9.4	1410.00		11.9964	0	0	0.53	510	13.2	7.29
3	2/17/07 10:00	21.25	9.7	12153.75		29.991		0.027	0.14	405	13.2	7.28
4	2/17/07 12:45	24.00	9.5	13737.75		32.298	0	0.012	0	305	14.2	7.3
5	2/17/07 16:23	27.63	9.5	15808.75		35.7585		0.021	0.01	255	13.7	7.29
6	2/18/07 9:10	44.42	9.5	25375.25		46.14		0.012	0.12	270	14.3	7.27
7	2/18/07 12:45	48.00	9.5	27417.75		44.9865	0	0.018	0.02	274	14.5	7.25
8	2/18/2007 15:25	50.67	9.5	28937.75		46.14		0.005	0	210	14.2	7.26
9	2/19/2007 10:15	69.50	8.2	38938.25		53.5224	0	0	0	255	13.4	7.29

11.9 gpm/ft2

Appendix J
Pyrolusite - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

Backwash 5.5 min 17.8 gpm no sample

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/19/07 14:25	0.00	14.2	0.00		14.9955						
2	2/19/07 16:00	1.58	13.2	1301.50		14.9955	0	0	0.42	474	13.4	7.28
3	2/19/07 21:50	7.42	13.8	6026.50		15.6876		0	0.35	485	13.5	7.26
4	2/20/07 3:45	13.33	13.7	10907.75		26.5305		0	0.15	440	13.5	7.25
5	2/20/07 10:10	19.75	12.5	15951.25		31.8366		0.032	0.64	586	13.9	7.24
6	2/20/07 13:15	22.83	12.2	14796.00		33.4515	0	0.011	0.02	373	13.6	7.27
			13.8 gpm/ft2									

Backwash 5 min 17 gpm compsoite 5 sec once per minute 22:30 mostly settled, however still brownish color at top

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/20/07 16:30	0.00	15	0.00		15.2262						
3	2/20/07 22:20	5.83	14.8	5215.00		21.6858		0.011	0	299	13.7	7.32
4	2/21/07 4:35	12.08	13.9	10596.25		23.9928		0.016	0	292	13.5	7.26
7	2/21/07 11:15	18.75	11.6	15696.25		28.1454	0	0.008	.43/.46	511	14.2	7.26
8	2/21/2007 14:25	21.92	11.2	17862.25		31.6059		0.012	.52/.57	553	13.9	7.27

17.3 gpm/ft2

Backwash 5 minutes sample 5 sec every min. Settability composite. Photos 10 20, 30. Composite = 200 ppm 3 min sample = 20 ppm.

Appendix J
Pyrolusite - Filter Run Test
Well 29 Fe and Mn Pilot Study
Madison, Wisconsin

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/21/07 14:45	0.00	12.2	0.00		13.6113						
2	2/22/07 10:00	19.25	12.1	14033.25		13.1499	0	0.006	0	272	15	7.26
3	2/22/07 14:45	24.00	11.8	17439.00		21.9165	0	0.012	0.2	386	13.4	7.35
			15.4 gpm/ft2									

Backwashed 5 min at 17.8 gpm 2 min clearing 3 min clear

#			pre-filter				Post-Filter					
	Date	Lapsed Time	Flow	Gallons Treated	Cl	Headloss	Fe	Mn	Cl	ORP	Temp.	pH
1	2/22/07 15:05	0.00	9.4	0.00		8.5359						
3	2/22/07 19:40	4.58	9.3	2571.25		13.3806	0	0.006	0.2	400	16.1	7.32
4	2/23/07 1:20	10.25	9	5682.25		16.149		0.011	0.23	303	13.6	7.33
5	2/23/07 1:25	10.33	9.4	5728.25		17.3025						
			11.8 gpm/ft2									

Backwash 5 min 17 gpm compsoite 5 sec once per minute 22:30 mostly settled, however still brownish color at top

L:\work\Projects\98102\eng\Field Test\[Pilot Study Data.xls]Pyrolusite

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