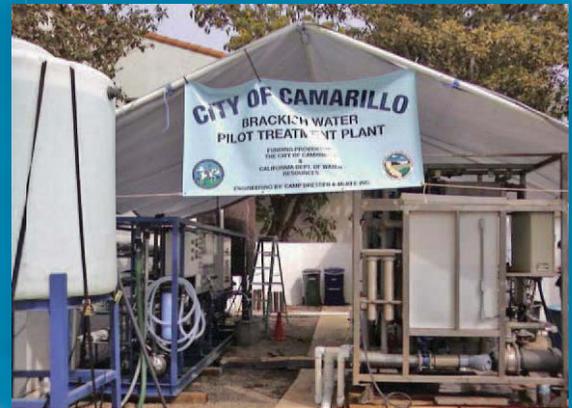




CITY OF CAMARILLO

Brackish Water Desalination Pilot Study



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List of Acronyms and Abbreviations

Avg	Average
CaCO ₃	Calcium Carbonate
CCL	Contaminant Candidate List
CDPH	California Department of Public Health
CF	Cartridge Filter
CIP	Clean-In-Place
Cl ₂	Chlorine
ClO ₂	Chlorine Dioxide
CMWD	Calleguas Municipal Water District
CT	Contact Time
CU	Color Unit
CWD	Camarillo Water Division
CWRP	Camarillo Water Reclamation Plant
DBP	Disinfection Byproduct
DHS	Department of Health Services
DLR	Detection Limit for the Purpose of Reporting
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DPH	Department of Public Health
DWR	Department of Water Resources
EBCT	Empty Bed Contact Time
EPA	Environmental Protection Agency
EQ	Equalization
Fe	Iron
gfd	gallons per day per square foot
GMF	Granular Media Filter, Granular Media Filtration
gpd	gallons per day
gpm	gallons per minute
LR	Loading Rate
LSI	Langelier Saturation Index
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
max	maximum
MCL	Maximum Contaminant Levels
MEK	Methyl ethyl ketone
MF	Microfiltration
mg/L	milligrams per liter
mgd	million gallons per day
min	minutes, minimum
Mn	Manganese
MTC	Mass Transfer Coefficient

N/A	Not applicable
Na ₂ S ₂ O ₃	Sodium Thiosulfate
NaHSO ₃	Sodium Bisulfite
NaOH	Caustic Soda, Sodium Hydroxide
ND	Non-detect
NDMA	N-nitroso-dimethylamine
NF	Nanofiltration
NH ₃ -N	Ammonia Nitrogen
NL	Notification Level
NTU	Nephelometric Turbidity Units
O ₂	Oxygen
OEHHA	Office of Environmental Health Hazard Assessment
P&ID	Process and Instrumentation Diagram
PCA	Possible Contaminating Activity
PFD	Process Flow Diagram
PHG	Public Health Goal
psi	pounds per square inch
PT	Pretreatment
PTF	Pretreatment Feed
PTP	Pretreatment Product
PTW	Pretreatment Waste
PV	Pressure Vessel
PWS	Public Water System
PWT	Professional Water Technologies
QA/QC	Quality Assurance/Quality Control
RL	Reporting Limit
RO	Reverse Osmosis
ROF	Reverse Osmosis Feed
ROP	Reverse Osmosis Permeate, Reverse Osmosis Product
ROW	Reverse Osmosis Waste, Concentrate, Brine
RW	Raw Water
RWQCB	Regional Water Quality Control Board
SLR	Surface Loading Rate
SDI	Silt Density Index
SDS	Simulated Distribution System
SDWA	Safe Drinking Water Act
sf	square foot
Siemens	Siemens Water Technologies
TBD	To Be Determined
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TMP	Transmembrane Pressure
TOC	Total Organic Carbon
TSS	Total Suspended Solids

THM	Trihalomethane
TTHM	Total Trihalomethane
UCMR 1	Unregulated Contaminant Monitoring Rule 1
UCMR 2	Unregulated Contaminant Monitoring Rule 2
UV	ultraviolet
WTP	Water Treatment Plant

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Section 1

Project Information

1.1 Overview

This section provides project information, including project type, project title, start/end dates, grantee information, contact person information, grant awarded, and total cost of the project. This section also provides the outline of the report.

1.2 Project Information

The City of Camarillo (City) and Camp Dresser and McKee Inc. (CDM) have conducted a desalination pilot study to test high-pressure membrane technologies in conjunction with various pretreatment options for treating brackish groundwater. The objective was to select a practical and cost-effective treatment technology that allows the City to treat brackish groundwater to produce a reliable high quality drinking water supply. This work was funded by the City through a grant from the California Department of Water Resources (DWR) under the Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002, Proposition 50 – Chapter 6, 2006 Water Desalination (Prop 50 grant). The City contracted CDM to design, install, and operate the pilot plant.

Agreement Number:	4600007441
DWR ID Number:	P 2006-14
Project Title:	City of Camarillo Brackish Water Desalination Pilot Study
Grant Awarded:	Proposition 50 – Chapter 6, 2006 Water Desalination
Total Cost of the Project:	\$767,744
Start Date of Contract:	April 1, 2007
End Date of Contract:	March 31, 2009
Recipient Organization:	City of Camarillo
Partners:	Camp Dresser and McKee, Inc. Trussell Technologies, Inc.

Contact Person: Lucia McGovern
Deputy Director of Public Works
City of Camarillo/Camarillo Sanitary District
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1.2 Report Outline

Section 1 of this report presents project information, including project type, title, start/end dates, grantee information, contact person information, grant awarded and the total cost of the project.

Section 2 provides an executive summary of the project, its purpose, and a short description of the main findings/accomplishments.

Section 3 summarizes the goals and objectives of the project.

Section 4 describes project tasks/activities, implementation methods, and procedures.

Section 5 presents the results of the pilot study.

Section 6 describes the outreach activities performed, including presentations of the project to the public, conferences, workshops, coordination with various stakeholders, tours, and ways used to disseminate project results and information.

Section 7 presents the list of project deliverables and materials produced during the project.

Section 8 summarizes the results of the project, challenges and the lessons learned during the project.

Section 9 presents the project budget information including level of project execution and expenditures to date

Section 2

Executive Summary

2.1 Background

In an effort to reduce dependence on imported water, the City of Camarillo (City) has embarked on a groundwater treatment program to develop a reliable, high quality, local water supply. With the State of California experiencing a severe drought and significant water restrictions imposed on imported water supplies, the City's efforts to desalinate groundwater will be a critical aspect of the City's future drinking water supply. The City has contracted with Camp Dresser & McKee, Inc. (CDM) to conduct pilot testing of various groundwater treatment alternatives. This work is a matching funds project, funded by the City and California Department of Water Resources (DWR) under the Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002, Proposition 50 – Chapter 6, 2006 Water Desalination (Prop 50 grant).

The City's water supply currently consists of approximately 60 percent imported water, purchased through the Calleguas Municipal Water District (CMWD), and 40 percent local well water produced from two active and one stand-by well. Water quality of two of the City's wells, Well A and Well B, have been steadily deteriorating over the past 18 years. In addition to naturally-occurring high levels of manganese and iron, dramatic increases in total dissolved solids (TDS) have occurred, which are partially attributed to increases in sulfate, chloride and hardness. The increase in TDS for Wells A and B represent a general deterioration in the City's source water that needs to be addressed to comply with state regulations, specifically from the California Department of Public Health (CDPH) and the Los Angeles Regional Water Quality Control Board (RWQCB). A 2005 Groundwater Treatment Facility Feasibility Study identified reverse osmosis (RO) membrane treatment as the only viable treatment process for this application.

2.2 Project Goals

The final treated water quality goals for this project are presented in Table 2-1, listing the most significant constituents, which exceed CDPH secondary regulations, RWQCB limits, or are significantly different from the imported water the City purchases through CMWD. If the groundwater RO facility meets these water quality objectives, the City will produce a potable water that is safely within all primary and secondary maximum contaminant levels established by CDPH.

Table 2-1 Final Product Water Quality Goals			
Constituent	Units	Goal	Imported Water ⁽²⁾
Chloride	Mg/L	65	61
Gross Alpha	pCi/L	12	< 3
Iron	Mg/L	0.2	<0.02
Manganese	Mg/L	0.025 ⁽¹⁾	<0.005
pH		> 8.0 ⁽³⁾	8.3
Sulfate	Mg/L	70	52
Total Dissolved Solids	Mg/L	250	267
Total Hardness as CaCO ₃	Mg/L	75 – 120	112
Notes:			
(1) Established as 50% of CDPH MCL			
(2) Based on CMWD 2007 Water Quality Report			
(3) Final pH depends on finished water hardness and alkalinity, and compatibility with existing distribution system water.			

The goal of the pilot study was to test RO and/or nanofiltration (NF) membranes for brackish water desalination in conjunction with various pretreatment options that are designed to protect these membranes from iron and manganese fouling. During the first nine months of pilot testing, the following five pretreatment options were evaluated:

- Phase I Oxygen quenching: dose sodium thiosulfate to quench dissolved oxygen (DO) and keep iron and manganese in reduced state.
- Phase II Aeration plus granular media filtration (GMF): determine if aeration plus GMF will effectively remove iron oxide through the GMF and keep manganese in the reduced state so that it is removed by the RO membranes.
- Phase III Chlorine dioxide plus GMF: determine if chlorine dioxide will oxidize both iron and manganese to allow iron and manganese oxides to be effectively removed by the GMF.
- Phase IV Chlorine plus greensand: evaluate chlorine oxidation of both iron and manganese using a catalytic media such as pure manganese dioxide (pyrolucite).
- Phase V Aeration plus microfiltration (MF): determine if aeration plus MF will effectively remove iron through MF and keep manganese in the reduced state so that it is removed by the RO.

The last three months of the pilot testing were dedicated to the desalination evaluation, in which RO and/or NF membranes were optimized using the selected most effective pretreatment process tested during the five phases of this study and design criteria was established for a full-scale treatment plant.

2.3 Pretreatment Testing

The following conclusions were drawn based on the pretreatment testing:

- Oxygen quenching successfully prevented iron oxidation and thereby prevented metal oxide fouling of the reverse osmosis (RO) membranes.
- Aeration plus media filtration effectively oxidized and removed iron when a minimum of six minutes of contact time was provided. Providing additional contact time, beyond six minutes, did not have significant impact on iron oxidation. However, aeration plus media filtration was problematic because partial manganese oxidation occurred after a certain length of time.
- Complete oxidation of iron with aeration was accomplished with nearly zero minutes of contact time, when the pH was adjusted to 8.0 through the addition of caustic soda. However, raising the pH of the Well A raw water was problematic, as it caused severe scaling in the piping, valves, the granular media filters, and the cartridge filters. This scaling could not be controlled with the addition of antiscalant upstream of the caustic soda injection point.
- Chlorine dioxide feed and media filtration effectively oxidized and removed 100 percent of iron and 70 percent of manganese and appears to have prevented metal oxide fouling of the RO membranes, however, this pretreatment method was problematic due primarily to RO membrane damage. Chlorine dioxide appears to have damaged the RO membranes, as was evident in the steadily increasing permeate conductivities and the gradually increasing membrane permeability (MTC) during the first three weeks of the Phase III testing.
- Chlorine feed with Pyrolox (greensand) media filtration pretreatment was similar in performance to the chlorine dioxide feed plus media filtration pretreatment (Phase III). Both pretreatment processes oxidized and removed 100 percent of total iron and approximately 70 percent of total manganese. The difference was that manganese oxidation occurred in the filtration stage during Phase IV, whereas manganese oxidation occurred prior to the filtration stage during Phase III.
- Chlorine feed plus Pyrolox media filtration pretreatment was partially effective, particularly during the early portion of the testing. However, the two issues of concern for this process are the risk of damaging the RO membranes with chlorine, and the difficulty in maintaining properly functioning media filters. Although the dechlorination process was successful during the pilot study and, therefore, did not cause damage to the RO membranes, the possible failure of a dechlorination

process is risky for a full-scale plant, given the capital investment required to replace damaged RO membranes. The operation of the Pyrolox media filters causes some concern, due to the high backwashing rates and possible air scour systems required to remove iron oxides from the dense media.

- With the aeration and MF pretreatment process, the iron was only partially oxidized by the DO in the contact tank within the 3 to 36 minutes of contact time tested, and additional oxidation of iron was observed within the MF basin, the break tank after the MF, and within the cartridge filters.
- The rate of iron and manganese oxidation was sensitive to the contact time and the concentration of DO in the water. For the aeration followed by MF pretreatment process to completely oxidize and remove the iron, it was determined that the pretreatment feed water must be saturated at approximately 8.7 mg/L of DO, and approximately 35 minutes of contact time must be provided. To provide 35 minutes of contact time in a full-scale plant, a 210,000 gallon capacity tank must be provided.
- Aeration followed by MF was found to be less effective than the aeration followed by media filtration pretreatment process, evaluated in Phase II. Although the MF could be considered a better filtration process than the media filtration, the media filters provide improved oxidation of iron, resulting in greater removal.
- Ultimately, the Phase I approach of oxygen quenching was selected for operation of the RO optimization testing and the future full scale facility.

2.4 RO Optimization Testing

The following conclusions were drawn based on the RO optimization testing:

- Complications were seen in the oxygen quenching pretreatment approach, first with the build-up of biological growth and iron on the cartridge filters, and second with the fouling of second stage membranes. The addition of muriatic acid (HCl) ahead of the cartridge filters, and the reduction of thiosulfate dose to less than 2 mg/L appeared to control the fouling both of the cartridge filters and the RO.
- The oxygen quenching with acid addition pretreatment maintained manganese and iron in the dissolved form and produced stable membrane permeability data for all membrane systems tested, when the feed water pH was adjusted to 6.5 by acid addition. However, when the target feed water pH was adjusted to 6.8, the RO membranes began to foul and the MTC decreased rapidly.
- The Dow RO membrane (model XLE 4040) stabilized at a membrane permeability of 0.15 gfd/psi, while the Saehan RO membrane (model RE 4040 BLR) stabilized around 0.25 gfd/psi. The quality of the Dow RO membrane permeate was superior to the Saehan RO membrane permeate.

- The permeate of the Saehan RO membranes had the highest TDS at 95 mg/L, possibly caused by damage to the RO elements during Phase III testing, when the membranes were exposed to chlorine dioxide. Nonetheless, based on the permeate mineral water quality alone, the Saehan RO membranes performed the worst of the four membranes tested, which is contrary to results of the membrane manufacturers' modeling software.
- Membranes I (Dow XLE 4040) and III (Toray TM710) showed the greatest rejection of boron (50 percent), and because no vanadium was detected in any of the membrane permeates, vanadium performance could not be compared. Regardless, all raw water and membrane permeate samples had boron and vanadium concentrations less than the CDPH notification levels. No additional treatment considerations are recommended based on this emerging contaminant analysis.
- Manganese and sulfate are the limiting constituent for blending, and only 5 to 7 percent of the total flow can be allowed to bypass the RO. Such a bypass flow will result in a blended water TDS between 150 and 200 mg/L, and a blended water hardness between 70 and 80 mg/L, without exceeding any of the finished water quality goals.

2.5 Recommendations and Conclusions

Based on the results of the pilot testing, a treatment train was recommended consisting of oxygen quenching at the wells, acid and antiscalant addition at the treatment facility, and reverse osmosis using standard rejection brackish RO elements (similar to Saehan RE 4040 BLR or Dow XLE 4040). Figure 2-1 presents a process schematic of the recommended treatment approach that was tested during the RO optimization testing. Sodium bisulfite, sodium thiosulfate, or sodium metabisulfite may be utilized for oxygen quenching, however, the most efficient and cost effective chemical should be determined based on bench-top testing with the final source water. Muriatic acid is recommended to depress the pH of the feed water to 6.5. While sulfuric acid is more commonly used at desalination facilities, the high sulfate concentrations in the City wells and concern about the saturation limits of calcium sulfate, make muriatic acid a better approach for the City. Approximately 5 to 7 percent of the well flow should be bypassed around the RO membranes and blended with the permeate to produce a blended product water that is stable, non-corrosive, and in compliance with all of the treatment goals for the facility.

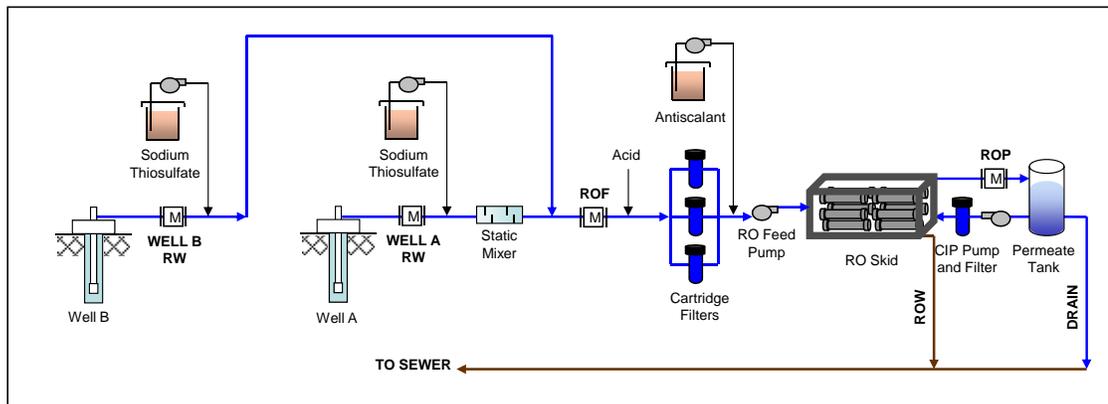


Figure 2-1.
Selected Treatment Approach Process Schematic

Table 2-2 presents the full-scale design flows for the well supplies, treatment plant flows, bypass flow, and final product water flow.

Table 2-2 Design Flows	
Stream	Flow Rate
Well Production	8.6 mgd
RO Influent (i.e., pre-treated groundwater)	8.3 mgd
RO Permeate (i.e., desalinated groundwater)	6.2 mgd (See Note 1)
Groundwater Blending (i.e., RO bypass, blending at the facility)	0.3 mgd (See Note 2)
Total Plant Product (i.e., RO permeate + groundwater blending)	6.5 mgd
Note: 1) Assuming 75% RO permeate water recovery rate. 2) Assuming 5% bypass and blend.	

Section 3

Goals and Objectives of the Project

3.1 Overview

This section provides background information including the source water quality, regulatory compliance, and water quality treatment goals. This section also identifies the goals and objectives of the project.

3.2 Background

In an effort to reduce dependence on imported water, the City has embarked on this groundwater treatment program to develop a reliable, high quality, local water supply. With the State of California experiencing a severe drought and significant water restrictions imposed on both major imported water supplies (State Water Project and Colorado River Water), the City's efforts to desalinate groundwater will be a critical aspect of the City's future drinking water supply. The City has contracted with Camp Dresser & McKee, Inc. (CDM) to conduct pilot testing of various groundwater treatment alternatives. This work is funded by the City through a grant from the California Department of Water Resources (DWR) under the Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002, Proposition 50 - Chapter 6, 2006 Water Desalination (Prop 50 grant).

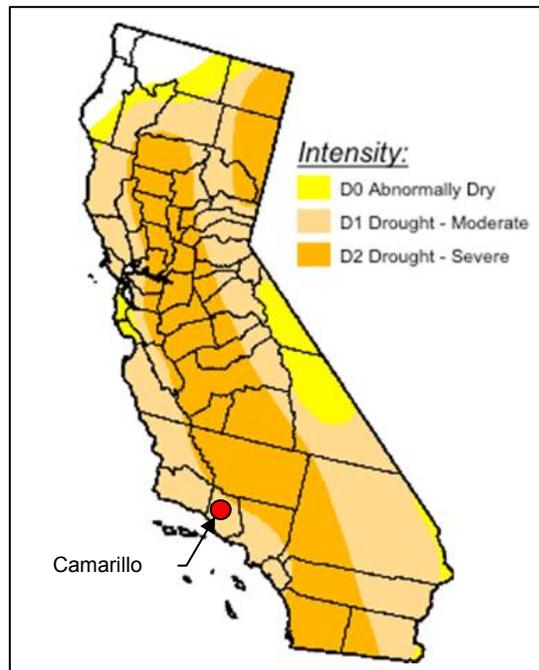


Figure 3-1.
California's Drought Conditions in November 2008
(National Oceanic and Atmospheric Administration, 2008)

3.2.1 Source Water Quality

The City's water supply currently consists of approximately 60 percent imported water, purchased through the Calleguas Municipal Water District (CMWD), and 40 percent local well water produced from two active and one stand-by well. Table 3-1 presents 2007 water quality data from the three City wells (two active and one stand-by) and the imported water supply. Two of the City's wells, Well A and Well B, have been steadily deteriorating in water quality over the past 18 years. In addition to naturally-occurring high levels of manganese and iron, dramatic increases in total dissolved solids (TDS) have occurred, which are partially attributed to increases in sulfate, chloride and hardness. From 1990 to 2008, the TDS concentration in Well A has increased 77 percent from 1000 mg/L to 1768 mg/L. Well B TDS concentrations have increased an even more dramatic 136 percent since 1990 and current TDS is 1414 mg/L. The increase in TDS for Wells A and B represent a general deterioration in the City's source water that needs to be addressed to comply with state regulations, with the only viable treatment process for this application being reverse osmosis (RO) membrane treatment.

Table 3-1. Summary of Water Quality Data					
Constituent	Unit	City of Camarillo Wells			Imported Water
		Well A ⁽¹⁾	Well B ⁽²⁾	Well D ⁽³⁾	Calleguas MWD ⁽⁴⁾
pH		7.2	7.3	NA	NA
Calcium	mg/L	260	210	87	24
Potassium	mg/L	6.2	5.3	4.5	3
Magnesium	mg/L	80	49	24	12
Sodium	mg/L	190	140	97	50
Strontium	mg/L	1.9	1.4	NA	NA
Fluoride	mg/L	0.24	0.21	0.38	0.1
Alkalinity as CaCO ₃	mg/L	300	240	230	82
Ammonia as N	mg/L	0.25	0.33	NA	NA
Gross Alpha	pCi/L	15	10	NA	ND
Total Hardness as CaCO ₃	mg/L	980	730	320	110
Nitrate as NO ₃ ⁻	mg/L	0.9	ND	ND	0.6
Total Dissolved Solids	mg/L	1800	1400	700	270
Total Organic Carbon	mg/L	1.6	1.6	NA	2.2
Chloride	mg/L	170	150	60	61
Sulfate	mg/L	840	560	210	52
Total Silica	mg/L	37	36	NA	NA
Barium	mg/L	0.04	0.05	NA	NA
Boron	mg/L	0.70	0.57	NA	0.18
Total Vanadium	mg/L	ND	ND	NA	NA
Total Iron	mg/L	0.22	0.22	0.17	ND
Total Manganese	mg/L	0.22	0.16	0.05	ND

Table 3-1.					
Summary of Water Quality Data					
Constituent	Unit	City of Camarillo Wells			Imported Water
		Well A ⁽¹⁾	Well B ⁽²⁾	Well D ⁽³⁾	Calleguas MWD ⁽⁴⁾
Notes:					
(1) Average of water quality data from August 1998 through October 2008					
(2) Average of water quality data from April 2001 through October 2008					
(3) 2007 Average					
(4) Based on CMWD 2007 Water Quality Report					
ND: Not detectable or below detection limits					
NA: Not available					

3.2.2 Regulatory Compliance

Wells A and B have existing permits that allow the City to operate these wells to feed directly into the distribution system following the addition of sodium hypochlorite. However, as discussed above, the source water quality has deteriorated to the point that the water quality does not meet the concentrations established in the secondary drinking water standards. Specifically, Well A and B exceed the manganese, sulfate, and total dissolved solids concentrations that are detailed in the California Department of Public Health’s (CDPH) literature on drinking water regulations. The City had decommissioned Well A prior to this study due to poor water quality, maintaining it only as an emergency water supply. Observing Table 3-1, Well A has a high enough Gross Alpha level that it is at the primary drinking water standard of 15 pCi/L. Table 3-2 presents the primary and secondary maximum contaminant levels (MCL) set by CDPH for relevant feed water contaminants.

Table 3-2.					
Select CDPH Maximum Contaminant Levels					
Constituent	Units	Primary MCL	Secondary MCL		
			Recommended	Upper	Short Term
Chloride	mg/L		250	500	600
Gross Alpha	pCi/L	15			
Iron	mg/L			0.3	
Manganese	mg/L			0.05	
Sulfate	mg/L		250	500	600
Total Dissolved Solids	mg/L		500	1000	1500

In addition to the CDPH regulations, the wastewater effluent from the Camarillo Water Reclamation Plant (CWRP) must comply with total maximum daily load (TMDL) limits on a number of parameters, as established by the California Regional Water Quality Control Board (RWQCB). The TMDL limits for chloride, sulfate, and TDS are particularly relevant to the City’s drinking water quality, as the primary

method for controlling the CWRP effluent water quality for these parameters will be to limit the water quality in the drinking water supply. Domestic and industrial water uses in the City will add significant quantities of chloride, sulfate and TDS to the water going to the CWRP facility, with the processes in the facility itself adding further to the final concentrations. Water quality monitoring data from 2007, taken from the CWRP effluent and the City drinking water distribution system at 2159 Gorman, indicate that the domestic and industrial water uses in the City and the treatment processes at the CWRP facility add approximately 125 mg/L of chloride, 180 mg/L of sulfate, and 380 mg/L of TDS into the water before being discharged by the CWRP. These effluent TMDL limits require additional constituents to be considered when establishing the drinking water quality treatment objectives. Table 3-3 presents the TMDL limits for these parameters, the estimated incremental increase between the drinking water supply and the wastewater effluent, along with the resulting drinking water objectives.

Table 3-3. Select CWRP Discharge Limitations				
Constituent	Units	Total Maximum Daily Load Limits ⁽¹⁾	Typical Increase ⁽²⁾	Implied Drinking Water Objective ⁽³⁾
Chloride	mg/L	190	125	65
Sulfate	mg/L	250	180	70
Total Dissolved Solids	mg/L	850	380	470
Notes:				
(1) Established by California Regional Water Quality Control Board, January 2004				
(2) Represents the average increase in 2007 between the Camarillo drinking water distribution system measured at 2159 Gorman and the CWRP Effluent				
(3) Calculated as the total maximum daily load limit minus the typical increase				

3.2.3 Water Quality Treatment Goals

The final treated water quality goals in Table 3-4 were established for the most significant constituents, which exceed secondary maximum contaminant levels, CDPH regulations, TMDL limits, or are significantly different from the imported water the City purchases through CMWD. If the groundwater RO facility meets these water quality goals, the City will produce a potable water quality that is well below all primary and secondary maximum contaminant levels (MCLs) established by CDPH.

Table 3-4. Final Product Water Quality Goals			
Constituent	Units	Goal	Imported Water ⁽²⁾
Chloride	mg/L	65	61
Gross Alpha	pCi/L	12	< 3
Iron	mg/L	0.2	< 0.02
Manganese	mg/L	0.025 ⁽¹⁾	< 0.005
pH		> 8.0 ⁽³⁾	8.3
Sulfate	mg/L	70	52
Total Dissolved Solids	mg/L	≤ 250	267
Total Hardness as CaCO ₃	mg/L	70 – 120	112
Notes:			
(1) Established as 50% of CDPH MCL			
(2) Based on CMWD 2007 Water Quality Report			
(3) Final pH depends on design water quality, distribution system age, pipe/valve components, and composition.			

The iron and manganese goals identified above were established below the required secondary MCLs to address colored water issues. It is anticipated that the water quality goal for either manganese or sulfate will control how much water can be bypassed to blend with the RO product water. Manganese, even at low concentrations (below 0.05 mg/L), can be oxidized in the distribution system and result in a fine colloidal form that adsorbs to pipes and settles out in quiescent zones in the distribution system. These “pockets” of manganese turn into pockets of colored water that can cause significant customer complaints. Ideally, the water served in the City would contain non-detect manganese concentrations (< 0.005 mg/L), however, the goal established in Table 3-3 has been set at half the secondary MCL, or 0.025 mg/L.

Goals for hardness and pH were established to produce a water quality that is considered reasonable for distribution and similar to the imported water supply. It should be noted that the final pH target should be determined after the final water quality from the ultimate groundwater RO facility design is determined. This final pH target should then be determined with significant consideration given to the distribution system components and the age of these materials. There are significant concerns that arise from corrosion of lead and copper fittings, iron from any valving or lined ductile iron pipes in the distribution system, or deterioration in the strength of cement asbestos pipes. It is important that the City incorporate a post-treatment process to ensure proper mineral content and select a final product water pH that minimizes any impacts that may occur in the transition to this new water supply while minimizing treatment costs.

3.3 Goals and Objectives of the Pilot Study

The goal of the pilot study was to test reverse osmosis (RO) and/or nanofiltration (NF) membranes for brackish water desalination in conjunction with various pretreatment options that are designed to protect these membranes from fouling. While the majority of the treatment goals for the facility are addressed through the desalination process, pretreatment is required to assure efficient, reliable operation for the downstream RO process. Specifically, many utilities have faced membrane fouling and operational problems from iron or manganese in their water supplies. Other problems have been experienced from biofouling or damage from oxidants used in their pretreatment processes. The selected pretreatment process will need to provide water of a quality acceptable to feed an RO system, and must be reliable, simple to operate, safe, and cost effective. During the first nine months of pilot testing, the following five pretreatment options were evaluated:

- Alternative 1 Oxygen quenching: dose sodium thiosulfate to quench dissolved oxygen (DO) and keep iron and manganese in reduced state (i.e., in solution, not particulate).
- Alternative 2 Aeration plus granular media filtration (GMF): determine if aeration plus GMF will effectively remove iron oxide through the GMF and keep manganese in the reduced state so that it is removed by the RO membranes.
- Alternative 3 Chlorine dioxide plus GMF: determine if chlorine dioxide will oxidize both iron and manganese to allow iron and manganese oxides to be effectively removed by the GMF.
- Alternative 4 Chlorine plus greensand: evaluate chlorine oxidation of both iron and manganese using a catalytic media such as pure manganese dioxide (pyrolucite).
- Alternative 5 Aeration plus microfiltration (MF): determine if aeration plus MF will effectively remove iron through MF and keep manganese in the reduced state so that it is removed by the RO.

The last three months of the pilot testing was dedicated to desalination evaluation, in which the RO and/or NF membranes were optimized and design criteria were established for a full-scale treatment plant. The following presents the specific evaluation criteria that were used to select the most appropriate pretreatment process.

3.3.1 Pretreatment Water Quality Goals

The water quality goals for the pretreatment system relate to the performance and efficiency of the RO system. The following water quality goals were established for the pretreatment systems:

- Particulate Iron < 0.01 mg/L
- Particulate Manganese < 0.005 mg/L
- Silt Density Index (SDI) < 2
- RO Fouling Rate < 0.5 percent per day

Particulate Iron

The particulate iron goal of 0.01 mg/L is based on the accuracy of the testing method, which typically lists the reported detection limit as 0.02 mg/L for both total and dissolved iron. Particulate iron is calculated as the difference between total and dissolved iron. Iron results in the range of 0.01 mg/L or lower cannot be accurately measured, so this treatment goal assures that detectible levels of particulate iron are not present.

Particulate Manganese

The detection limit for manganese is 0.005 mg/L. The treatment goal for particulate manganese was set at the detection limit to ensure that particulate manganese is not present in the RO feed.

Silt Density Index

The SDI test is a direct measure of the short term fouling potential of the water on a membrane disk. SDI values of 3 or lower are typically considered acceptable for RO feed. A goal of 2 has been established for this pilot to ensure that the selected treatment method produces water exceeding the quality typically recommended for RO feed.

RO Fouling Rate

The RO fouling rate is defined here as the percent change in the mass transfer coefficient (MTC) of water across the membranes. A reduced MTC represents a loss of performance (or membrane permeability), requiring more pressure to produce the same amount of water. The fouling rate should be low enough to avoid chemical cleaning of the membranes more frequently than once every 6 months, but ideally the membranes would be capable of running for a year between cleanings. The RO fouling rate goal has been set at 0.5 percent per day.

3.3.2 Reliability

Reliability of the pretreatment system represents the consistency of the water produced by the process, in terms of both quality and quantity. A reliable pretreatment system is not significantly impacted by changes in the raw quality, but produces a steady supply of water for the RO system with a consistent water. A reliable pretreatment system is essential for efficient operation of the downstream RO system. The measure of reliability is more subjective than the specific treatment goals identified above, however, it considers the ability to consistently meet treatment goals over varying operating conditions.

3.3.3 Simplicity and Ease of Operation

Simplicity and ease of operation are important for the pretreatment system, as they will impact both the cost of operating a full scale facility and the risk of unintended operational problems that impact the downstream processes. Simplicity and ease of operation are impacted by the number of unit processes, number and quantities of chemicals used, and by the number and quantity of waste flow streams created by the processes.

3.3.4 Safety

Safety will be the highest priority in operation of any plant, however, treatment processes should be selected which will minimize the risk of safety hazards for the future facility operators. Safety considerations made in evaluating the treatment processes include use of hazardous chemicals, operating pressures, and risk of health impacts to the general public.

3.3.5 Cost

While detailed cost estimates were not developed for each of the pretreatment alternatives, general cost considerations were evaluated from both a capital construction and operating cost perspective.

3.4 Definitions and Equations

The following terms are used in the discussion of the pilot study results:

- Antiscalant – a chemical used to inhibit scaling (i.e., precipitation or crystallization of salt compounds)
- Clean-in-Place (CIP) – the in-situ chemical cleaning of membranes that consists of soaking membranes in one or more chemical solutions (typically acid and caustic solutions) to remove accumulated foulants and restore permeability
- Concentrate – a continuous waste stream, typically containing concentrated dissolved solids, from the membrane process
- Element – an encased spiral-wound membrane module
- Flux – the unit rate at which water passes through the membrane expressed as flow per unit of membrane area (e.g., gallons per square foot per day (gfd))

$$\text{Flux} = \text{Flow} / \text{Membrane Area}$$

- Fouling – the accumulation of contaminants on the membrane surface, within membrane pores, or media surface that inhibits the passage of water

- Microfiltration (MF) – a pressure-driven membrane filtration process that employs hollow-fiber membranes with a pore size range of approximately 0.1 to 0.2 μm (nominally 0.1 μm)

- Mass Transfer Coefficient (MTC) or Permeability – the ability of the membrane to allow the passage or diffusion of a substance (i.e., a gas, a liquid, or solute)

$$\text{MTC} = \text{Flux} * \text{Temperature Correction Factor (25 }^\circ\text{C)} / \text{TMP}$$

- Nanofiltration (NF) – a pressure-driven membrane separation process that employs the principles of reverse osmosis to remove dissolved contaminants from water

- Net Driving Pressure (NDP) – the pressure available to force water through a semi-permeable NF or RO membrane

$$\text{NDP} = \text{TMP} - \text{Osmotic Pressure}$$

- Normalization – the process of evaluating membrane system performance at a given set of reference conditions (e.g., at standard temperature, per unit pressure, etc.) to directly compare and trend day-to-day performance independent of changes to the actual system operating conditions

- Osmotic Pressure – the amount of pressure that must be applied to stop the natural process of osmosis

- Particulate Iron = Total Iron – Dissolved Iron

- Particulate Manganese = Total Manganese – Dissolved Manganese

- Percent Oxidation = Particulate Iron/Total Iron

- Permeate – a continuous stream of water that passes through a NF or RO membrane

- Recovery – the volumetric percent of feed water that is converted to permeate

$$\text{Recovery} = \text{Permeate Flow Rate}/\text{Feed Flow Rate}$$

- Reverse Osmosis (RO) – the pressure-driven membrane separation process that employs the principles of reverse osmosis (i.e., the passage of water through a semi-permeable membrane against the concentration gradient, achieved by applying pressure greater than the osmotic pressure) to remove dissolved contaminants from water

- Scaling – the precipitation or crystallization of salts on a surface (e.g., on the feed side of a membrane)

- Stage – a group of membrane units operating in parallel
- Transmembrane Pressure (TMP) – the difference in pressure from the feed (or feed-concentrate average) to the permeate across the membrane

TMP for MF = Feed Pressure – Filtrate Pressure

TMP for NF or RO = [(Feed Pressure + Concentrate Pressure)/2] – Permeate Pressure

Section 4

Project Implementation

4.1 Overview

This section describes project tasks/activities, implementation methods and procedures. In addition, the descriptions of the pilot plant configuration, equipment, testing phases and schedule are also provided in this section.

4.2 Project Tasks, Implementation Methods and Procedures

The project tasks consist of project management, pilot test preparation, pilot testing, data evaluation, and report development.

4.2.1 Task 1 Project Management

4.2.1.1 General Project Management and Administration

The City and CDM performed daily project administration and management responsibilities including resource management, contract management, monitoring and management of costs, development and submittal of invoices and monthly progress reports, and schedule management.

CDM created the overall project schedule, action item list, and contact information list and updated these as the project progressed.

4.2.1.2 Project Team Coordination and Communication

The City and CDM held monthly progress meetings to discuss recent activities and piloting results, using these discussions to adapt and refine the implementation of the project on an ongoing basis. The topics of discussion at each monthly meeting are summarized below:

- Progress Meeting #1 (April 24, 2007): The topics discussed include the pretreatment processes to be tested, use of Well A and Well B, pilot plant logistics, electrical/power needs, and lab selection for outside analytical tests.
- Progress Meeting #2 (May 15, 2007): The topics discussed include the schedule, deliverables, Well B rehabilitation, pilot plant equipment, CA Department of Water Resources (DWR) involvement, and emerging contaminants evaluation.
- Progress Meeting #3 (June 12, 2007): The topics discussed include the emerging contaminants evaluation, testing protocol, and contact list and communication.
- Progress Meeting #4 (July 10, 2007): The topics discussed include the testing protocol, emerging contaminants evaluation, health and safety (H&S) plan, and pilot plant construction schedule and logistics.

- Progress Meeting #5 (August 14, 2007): The topics discussed include the testing protocol, sulfate concerns, pilot plant installation and startup schedule and logistics, and chlorine dioxide alternatives.
- Progress Meeting #6 (September 11, 2007): The topics discussed include Phase I test operation, well operation and shutdown coordination, pilot plant weekend monitoring and remote monitoring, and sulfate concerns.
- Progress Meeting #7 (October 9, 2007): The topics discussed include the pilot plant operation, well operation and shutdown coordination, pilot plant shut-down and start-up procedures, emergency contact protocol, and aeration pretreatment option.
- Operator Training Workshop (October 9, 2007): The City and CDM also held the Operator Training Workshop on October 9, 2007. The topics covered in the workshop include: project background; pilot study objectives; technology overview of reverse osmosis (RO), aeration, and filtration; and the testing protocol. The training also included a pilot plant site visit, and on-site discussions of the pilot plant equipment and sampling protocol. Approximately 15 City staff and operators attended the workshop.
- Progress Meeting #8 (November 13, 2007): The topics discussed include the Phase I test results, dissolved iron test concerns, Phase II test progress update, and future testing plans.
- Progress Meeting #9 (December 10, 2007): The topics discussed include the emerging contaminants tests results, Phase II test results, City Council site visit, and future testing plans.
- Progress Meeting #10 (January 8, 2008): The topics discussed include the emerging contaminants sampling results, review of Phase II testing results, Phase III testing progress update, and future testing plans.
- Progress Meeting #11 (February 12, 2008): The topics discussed include the updated pilot testing schedule, minimum contact tank volume calculation, and review of Phase III testing results.
- Progress Meeting #12 (March 11, 2008): The topics discussed include the Phase IV testing results and updated pilot testing schedule.
- Progress Meeting #13 (April 8, 2008): The topics discussed include the Phase IV testing results, and future testing plans.
- Progress Meeting #14 (May 13, 2008): The topics discussed include the updated pilot testing schedule, and reviewed of Phase V testing results.

- Progress Meeting #15 (June 17, 2008): The topics discussed include the Phase V testing results, plans for Phase VI RO optimization testing, full scale water treatment plant design implications, full scale plant water quality goals, emerging contaminants sampling schedule, and final report outline.
- Progress Meeting #16 (July 8, 2008): The topics discussed include the review of Phase VI testing results.
- Progress Meeting #17 (August 12, 2008): The topics discussed include the review of Phase VI testing results.
- Progress Meeting #18 (September 11, 2008): The topics discussed include the review of Phase VI testing results.
- Progress Meeting #19 (October 14, 2008): The topics discussed include the review of Phase VI testing results.

4.2.2 Task 2 Pilot Test Preparation

4.2.2.1 Pilot Test Protocol

CDM submitted the draft Testing Protocol to the City in June 2007. The testing Protocol, which is intended to provide a detailed testing program to direct the pilot study, contained the following sections: introduction; testing phases; equipment; operations; data control and management; sampling and monitoring; quality assurance/quality control (QA/QC); schedule, staffing, and communications; and attachments. The draft Testing Protocol was submitted to DWR on June 29, 2007. The draft Testing Protocol was revised in accordance with recommendations made at the July and August progress meetings, and finalized for operation in September 2007. The Testing Protocol, final for operation, was submitted to DWR on October 30, 2007, and is included in Appendix A.

CDM prepared the Health and Safety Plan for the pilot plant site at Well A in June 2007. The Health and Safety Plan was submitted to the City and finalized in July 2007.

Table 4-1 summarizes the pilot plant operation monitoring and water quality test methods that were used during the pilot study.

Table 4-1 Pilot Plant Operation Monitoring and Water Quality Test Methods		
Parameter	Sampling Location ⁽¹⁾	Test Method ⁽²⁾
Pressure (psi)	RW, PTF, PTP, Pre-CF, Post-CF, ROF, RO Interstage, ROW, ROP, RO 1 st Stage Permeate, RO 2 nd Stage Permeate	Online
Flow (gpm)	PTF, PTP, ROF, RO 2 nd Stage Permeate, ROP, ROW	Online

Table 4-1 Pilot Plant Operation Monitoring and Water Quality Test Methods		
Parameter	Sampling Location ⁽¹⁾	Test Method ⁽²⁾
Tank level (gal or percent full)	Contact tank, equalization tank, chemical feed tanks	Visual
Temp (deg C)	RW	HACH WQ Kit
pH	RW, PTF, PTP, ROF, ROP, ROW	HACH WQ Kit
Conductivity (uS/cm ²)	RW, ROF, ROW, ROP, PV-1, PV-2, PV-3, PV-4, PV-5, PV-6	HACH WQ Kit
Dissolved Oxygen (mg/L)	RW, PTF	HACH DO probe
Free Chlorine (mg/L)	PTF, PTP, ROF	DR4000 Method 8021, DPD Method
Chlorine Dioxide (mg/L)	PTF, PTP, ROP	DR4000 Method 10126, DPD Method
Redox Potential/ORP	ROF	HACH WQ Kit
Total Iron (mg/L)	RW, PTF, PTP, ROP, ROW	DR4000 Method 8147, FerroZine Method
Dissolved (Ferrous) Iron (mg/L) ⁽³⁾	RW, PTF, PTP, ROP, ROW	DR4000 Method 8146, 1,10 Phenanthroline Method
Particulate Iron (mg/L)	Calculated value. Particulate Iron = Total Iron – Dissolved Iron	
Total Manganese (mg/L)	RW, PTF, PTP, ROP, ROW	DR4000 Method 8149, PAN Method
Dissolved Manganese (mg/L)	Same samples as above. Measured after filtering the samples.	DR4000 Method 8149, PAN Method
Particulate Manganese (mg/L)	Calculated value. Particulate Manganese = Total Manganese – Dissolved Manganese	
UV254	RW, PTP	DR4000 Method 10054, Direct Reading Method
Apparent Color (CU)	RW, ROF, ROP	DR4000 Method 8025, Platinum-Cobalt Standard Method
Turbidity (NTU)	RW, PTP, ROW	DR4000 Method 10047, Attenuated Radiation Method (Direct Reading)
SDI	ROF	SDI Kit
Alkalinity (mg/L CaCO ₃)	RW, ROF, ROP, ROW	Outside Lab, SM2320B
Calcium (mg/L)	ROF, ROP, ROW	Outside Lab, EPA 200.7
Magnesium (mg/L)	ROF, ROP, ROW	Outside Lab, EPA 200.7
Total Hardness (mg/L CaCO ₃)	ROF, ROP, ROW	Outside Lab, EPA 200.7
Sulfate (mg/L)	RW, ROF, ROP, ROW	DR4000 Method 8051, SulfaVer 4 Method; or Outside Lab, EPA 300.0
Silica (mg/L)	ROF, ROP, ROW	DR4000 Method 8185, Silicomolybdate Method; or Outside Lab, EPA 200.7

Table 4-1 Pilot Plant Operation Monitoring and Water Quality Test Methods		
Parameter	Sampling Location ⁽¹⁾	Test Method ⁽²⁾
Chloride (mg/L)	RW, ROF, ROP	DR4000 Method 8113, Mercuric Thiocyanate Method; or Outside Lab, EPA 300.0
Sodium (mg/L)	RW, ROP, ROP	Outside Lab, EPA 200.7
Boron (mg/L)	RW, ROP	Outside Lab, EPA 200.8
Vanadium (mg/L)	RW, ROP	Outside Lab, EPA 200.8
Gross Alpha	RW, ROP	Outside Lab, EPA 900.0
NH3-N (mg/L) (Low)	RW, ROP, ROW	DR4000 Method 8038, Nessler Method; or Outside Lab, EPA 350.1
TSS (mg/L)	RW, PTW, ROF	Outside Lab, SM2540D
TOC (mg/L)	RW, PTP	Outside Lab, SM5310C
TDS (mg/L)	RW, ROP	Outside Lab, SM2540C
Strontium (mg/L)	ROF, ROP, ROW	Outside Lab, EPA 200.7
Barium (mg/L)	ROF, ROP, ROW	Outside Lab, EPA 200.7
<p>Notes:</p> <p>(1) RW = Raw water, PTF = Pretreatment Feed, PTP = Pretreatment Product, PTW = Pretreatment Waste (backwash waste), ROF = Reverse Osmosis Feed, ROP = Reverse Osmosis Product (permeate), ROW = Reverse Osmosis Waste (Concentrate), CF = cartridge filter (RO skid), PV = RO Pressure Vessel.</p> <p>(2) DR4000 indicates the HACH DR4000 Spectrophotometer.</p> <p>(3) The dissolved iron measured in an unfiltered sample using the ferrous iron test method (1,10 Phenanthroline Method) produced similar results as the total iron measured in a filtered sample using the Ferrozine Method, which proved that the 1,10 Phenanthroline Method was a reliable test method for measuring dissolved iron.</p>		

4.2.2.2 Emerging Contaminants Evaluation

CDM and its subconsultants submitted the draft Emerging Contaminants Evaluation memorandum to the City in May 2007. The purpose of the emerging contaminants evaluation was to identify pertinent emerging contaminants recommended for monitoring during the pilot study. The draft Emerging Contaminants Evaluation memorandum was submitted to DWR on June 29, 2007, and the final Emerging Contaminants Evaluation memorandum was submitted to DWR on October 30, 2007.

4.2.2.3 System Design and Equipment Procurement

CDM started the pilot system design in May 2007, in conjunction with the development of the Testing Protocol, to facilitate successful implementation of the project. CDM contacted reputable equipment vendors for major pieces of pilot test equipment starting in April 2007, and started procurement in June 2007. Equipment such as the multi-media filters, microfiltration (MF) systems, and RO systems were selected based on cost, availability, and compliance with the project specifications.

CDM selected Weck Laboratories Inc. as the outside laboratory to be used for the pilot sampling analysis.

CDM continued the pilot system design, equipment procurement, and off-site and on-site construction as the project progressed through each pilot testing phase. CDM also continued to procure chemicals, analytical equipment and reagents for field analysis, and sample bottles for outside laboratory analysis throughout the project.

4.2.2.4 Equipment Installation and System Construction

CDM performed equipment installation and off-site and on-site construction of the pilot plant system throughout the project through CDM's specialized pilot plant fabrication group. The pilot plant configuration is described in detail in Section 4.4. Notable events of equipment installation and system construction are listed below in chronological order.

- The City installed power and phone lines at Well A pilot plant site in May 2007, and constructed a transmission pipeline from Well B to Well A pilot plant site in June 2007. The City completed rehabilitation of Well B pump in July 2007.
- CDM completed off-site construction of RO system equipment and on-site installation of pilot plant equipment for Phase I pilot testing on August 30, 2007. CDM started the pilot plant operation on August 31, 2007.
- CDM completed off-site construction and on-site installation of granular media filters for Phase II pilot testing on October 25, 2007.
- CDM replaced the existing Hydranautics RO membranes with the new Saehan RO membranes on January 2, 2008.
- CDM installed a secondary containment pallet for bulk chemical storage and a chemical metering pump for chlorine dioxide (ClO₂) feed during Phase III testing. Two 330-gallon bulk chemical totes containing 0.3 percent chlorine dioxide were delivered separately to the pilot plant site on December 27, 2007 and on January 17, 2008 to be used for Phase III testing. CDM also installed a chemical metering pump and a chemical injection nozzle in the Well A raw water pipe upstream of the chlorine dioxide feed point to feed caustic soda in the Well A raw water for pH adjustment. CDM also changed the overflow piping arrangement on the contact tank and installed an overflow tank and sump pump assembly to use lower overflow levels and thereby test lower contact times.
- CDM removed the existing granular media from the filter vessels and loaded the filter vessels with Pyrolox media on February 18, 2008. CDM also replaced the RO boost pump and two pressure gauges on the RO skid, and installed a new chemical injection port on the pretreatment product water pipe on February 18, 2008.

- Microfiltration (MF) pilot system supplied by Siemens Water Technologies (Siemens) was delivered to the pilot plant site on April 1, 2008. CDM and Siemens completed the installation of the MF system, ancillary equipment and piping on April 4, 2008.
- CDM removed the existing Pyrolox media from the filter vessels and loaded the filter vessels with new dual media (sand and anthracite) on May 29, 2008.
- CDM replaced the existing Saehan RO membranes (model CRM) with new Dow/Filmtec RO membranes (model XLE 4040) in Train A on June 2, 2008.
- CDM installed two pressure gauges on the RO permeate side (stage-2 of both trains) on June 26, 2008.
- CDM replaced the existing Dow/Filmtec RO membranes (model XLE 4040) in Train A with Toray RO membranes (model TM710), and the existing Saehan RO membranes (model RE4040 BLR) in Train B with Dow/Filmtec NF membranes (model NF90) on August 26, 2008.
- CDM fixed the RO boost pump bypass valve and piping, and the low pressure shut-down switch on the RO feed piping on September 26, 2008.

4.2.3 Task 3 Conduct Pilot Testing

4.2.3.1 Pretreatment Evaluation

CDM conducted the five pretreatment evaluation testing from August 31, 2007 through May 23, 2008.

4.2.3.2 New Membrane Element Testing

CDM conducted Phase VI desalination process evaluation testing from June 2, 2008 through October 10, 2008.

4.2.3.3 Decommissioning

CDM removed granular media filters from the pilot plant site on September 26, 2008. CDM removed MF membrane system from the pilot plant site on May 30, 2008.

Decommissioning of the RO equipment is scheduled in December 2008.

4.2.4 Task 4 Data Evaluation

4.2.4.1 Operating Data Evaluation

CDM performed preliminary evaluation of pilot test operating data throughout all testing phases.

4.2.4.2 Water Quality Data Evaluation

CDM performed preliminary evaluation of pilot test water quality data throughout all testing phases.

4.2.5 Task 5 Report Development

4.2.5.1 Draft Report Preparation/Workshop

CDM submitted the draft report to the City on December 4, 2008. The City submitted the draft report to DWR on December 12, 2008.

4.2.5.2 Final Report Preparation

CDM will submit the final report to the City on January 15, 2009. The City will submit the final report to DWR on January 30, 2009.

4.3 Testing Phases

The pilot unit consisted of two overall processes: the pretreatment process and the desalination process. The five pretreatment processes were tested in five testing phases as summarized in Table 4-2.

Testing Phases	Pretreatment Process	Schedule
Phase I.	Oxygen Quenching (Alternative 1)	08/31/07 – 10/23/07
Phase II.	Aeration plus Media Filtration (Alternative 2)	10/30/07 – 01/01/08 02/01/08 – 02/17/08
Phase III.	Chlorine Dioxide Feed plus Media Filtration (Alternative 3)	01/02/08 – 01/31/08
Phase IV.	Chlorine Feed plus Pyrolox Media Filtration (Alternative 4)	02/20/08 – 04/04/08
Phase V.	Aeration plus Microfiltration (Alternative 5)	04/07/08 – 05/23/08

During the last testing phase, Phase VI desalination process evaluation, new RO and NF membranes were tested using the recommended pretreatment process, as shown in Table 4-3.

Testing Phase	Pretreatment Process	Membranes Tested	Schedule
Phase VI. Desalination Process Evaluation	Aeration plus Media Filtration	Train A: Saehan RO Model RE4040 BLR; Train B: Dow/Filmtec RO Model XLE	06/02/08 – 07/30/08 07/31/08 – 08/26/08
	Oxygen Quenching	Train A: Toray RO Model TM710; Train B: Dow/Filmtec NF Model NF90	08/26/08 – 10/10/08

The recommended pretreatment process initially selected was aeration plus media filtration. However, based on deteriorating testing results from partial manganese oxidation, the recommended pretreatment process was changed to oxygen quenching.

During the first part of Phase VI testing, Saehan low-pressure brackish water RO membranes (model RE4040 BLR) and Dow/Filmtec RO membranes (model XLE) were tested. During the latter part of Phase VI testing, Toray RO membranes (model TM710) and Dow/Filmtec NF membranes (model NF90) were tested.

Each of the testing phases are described in detail below.

4.3.1 Phase I – Oxygen Quenching (Alternative 1)

The Phase I pretreatment evaluation, which consisted of oxygen quenching followed by reverse osmosis (RO) desalination, was conducted from August 31, 2007 through October 23, 2007.

4.3.1.1 Objectives

Iron and manganese in the well water are generally present in a reduced, soluble state when oxygen is not present, allowing RO membranes to remove the metals along with other dissolved compounds. However, if any oxygen is present in the well or enters the water through the wellhead or transmission line, iron and sometimes manganese may oxidize, creating the risk of excessive, and possibly irreversible fouling on the RO membranes. Because of this, steps are often taken at desalination facilities to prevent oxidation of iron or to increase solubility through pH suppression.

The purpose of the Phase I pretreatment evaluation was to determine if oxygen quenching could prevent oxidation of iron and manganese or if the iron or manganese have already been oxidized in the well or wellhead. The goal of oxygen quenching is to keep iron and manganese dissolved (in the reduced state) so they can be removed by the RO membranes without causing particulate fouling.

4.3.1.2 Description

During this phase of the pilot testing, sodium thiosulfate was introduced into the raw water at each of the wells to quench dissolved oxygen and prevent the oxidation of iron and manganese. Sodium thiosulfate may react with the oxygen by the following reaction, removing it, and preventing it from oxidizing the iron and manganese.



Other oxygen quenching agents, such as sodium bisulfite or sodium metabisulfite, could also be used to prevent oxygen oxidation within transmission lines.

Should this process prove effective, it would eliminate the need to oxidize and filter these metals prior to the desalination step and would significantly decrease the solids and residuals handling needed at the treatment facility. If, however, oxidation of one or both of these metals has already occurred prior to the addition of the sodium thiosulfate, the process cannot be effectively reversed and the treatment approach would be ineffective at preventing fouling.

4.3.1.3 Configuration

Both Well A and Well B raw water (RW) were blended at the pilot plant site and tested during the first half of the Phase I testing, and only Well A water was tested in the second half. For pretreatment, sodium thiosulfate was injected to the raw water close to the wellhead for oxygen quenching. Sodium thiosulfate dose was varied to test the impact of sodium thiosulfate dose on oxygen quenching and prevention of iron oxidation. After oxygen quenching, the RO feed (ROF) water was fed to the cartridge filters, after which antiscalant was injected, and then pumped to the RO membranes. Figure 4-1 presents a simplified schematic of the Phase I treatment process.

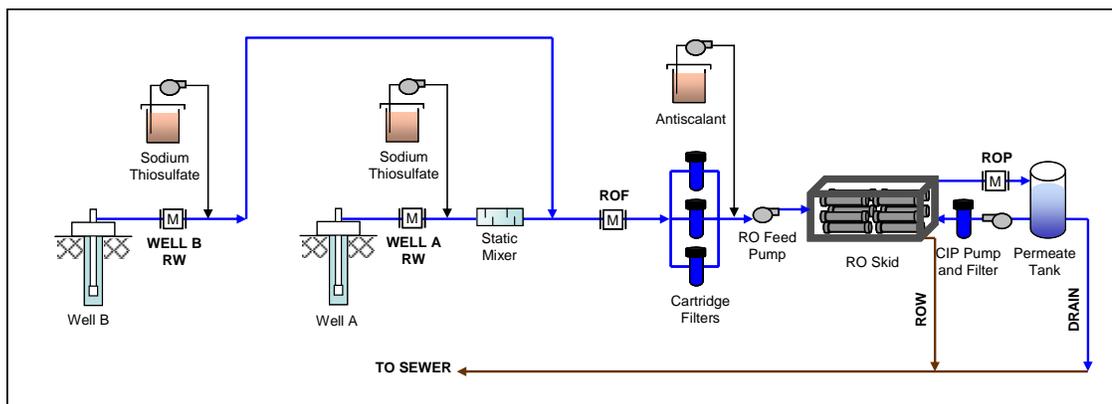


Figure 4-1.
Phase I Oxygen Quenching Process Schematic

4.3.1.4 Operating Conditions

During the Phase I pretreatment evaluation, eight operating conditions were tested, as summarized below in Table 4-4:

Table 4-4.
Phase I – Oxygen Quenching + RO: Operating Conditions

	Time Period	Operating Hours	Sodium Thiosulfate Dose (mg/L)	Well A Flow (gpm)	Well B Flow (gpm)	ROF Flow (gpm)	ROP Flow (gpm)	ROW Flow (gpm)	Recovery (%)
1A	8/31/07 – 9/9/07	~235	33	14	16	27	21	8	73
1B	9/10/07 – 9/14/07	~96	87	12	18	28	21	8	72
1C	9/15/07 – 9/21/07	151	17	14	15	27	21	8	72
1D	9/22/07 – 9/24/07	69	8	30	0	27	20	8	72
1E	9/25/07 – 10/02/07	192	0	18	12	27	20	8	71
1F	10/03/07- 10/04/07	52	18	13	15	25	17	8	67
1G	10/5/07- 10/19/07	285	19 to 30	20	0	15 to 25	7 to 16	8	46 to 67
1H	10/20/07- 10/23/07	86	17	30	0	29	20	8	72

As indicated in Table 4-4 above, during Operating Conditions 1A through 1E, sodium thiosulfate dose was varied between the operating conditions while keeping other conditions, such as feed flow and percent recovery, relatively constant. The sodium thiosulfate feed was stopped during Operating Condition 1E, and restarted during Operating Condition 1F. Well B was taken offline and only Well A water was tested during Operating Conditions 1G and 1H.

During Operating Conditions 1F and 1G, the RO system was operated at decreasing recovery rates and flows due to membrane fouling. During Operating Condition 1G, the recovery rate was decreased to as low as 46 percent and the feed flow to 15 gpm. After the RO membranes were chemically cleaned on October 19, the RO system was restarted under Operating Condition 1H with 72 percent recovery and 30 gpm feed flow.

4.3.1.5 Testing Protocol

Flows, pressures, temperature, chemical storage tank levels, and metering pump settings were recorded daily. pH, conductivity, dissolved oxygen, and oxidation reduction potential (ORP) were measured five times a week. Total iron, dissolved iron, total manganese, UV254, and apparent color were measured for selected sample

streams three times a week. Silt density index (SDI), chloride, silica, sulfate, and ammonia nitrogen were measured once a week.

In addition, weekly samples were sent to an outside lab to test for alkalinity, total hardness, boron, calcium, magnesium, sodium, vanadium, total dissolved solids (TDS), total organic carbon (TOC), and gross alpha. Samples were also tested for iron and manganese at the outside lab to compare against data measured at the pilot plant for QA/QC.

4.3.2 Phase II - Aeration plus Media Filtration (Alternative 2)

The Phase II pretreatment evaluation consisted of aeration plus media filtration pretreatment, followed by reverse osmosis (RO) desalination. The first part of the Phase II pretreatment evaluation was conducted from October 30, 2007 through January 1, 2008, and additional Phase II pretreatment evaluation was conducted from February 1, 2008 through February 17, 2008.

4.3.2.1 Objectives

The purpose of the Phase II pretreatment evaluation was to test if i) iron could be oxidized through aeration and removed through the granular media filtration; and ii) manganese could be kept in the reduced state during the pretreatment stages so that it could be removed by the RO membranes without causing fouling of the RO elements.

The purpose of the additional Phase II pretreatment evaluation was to evaluate i) the impact of the contact time on the oxidation of iron; and ii) the impact of the pH on the oxidation of iron.

4.3.2.2 Description

During this phase of the pilot testing, aeration was used to introduce oxygen to the raw water to oxidize the iron while maintaining manganese in its dissolved state.

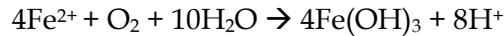
Once aeration oxidized the iron, the iron oxide was removed through media filtration before entering the RO process. The soluble manganese passed through the GMF to the RO process. Dual GMF, using a mix of sand and anthracite, was used with a filtration rate of approximately 5 gpm/sf.

The main benefit to aeration is that it is the least costly method of oxidizing iron and no chemicals are needed for oxidation.

The aeration plus media filtration pretreatment process takes advantage of the vast difference of oxidation rates between iron and manganese when air is used for oxidation. Oxidation of iron using oxygen can occur in a matter of seconds, but could take up to 20 minutes, depending on the pH of the aerated water. Oxidation of iron is faster at higher pH. Oxidation of manganese with oxygen will take in excess of 24 hours, and therefore should not be occurring within the pilot system or contributing to membrane fouling in the desalination process.

Dissolved Oxygen Demand

The oxidation of iron with oxygen (O₂) can be described by the following reaction (MWH, 2005):



The amount of oxygen required for the oxidation of iron is 0.14 mg O₂/mg Fe²⁺. Therefore, approximately 0.03 mg/L of oxygen is required to oxidize 0.19 mg/L of iron.

The oxidation of manganese with oxygen can be described by the following reaction (MWH, 2005):



Although aeration can also be used for the oxidation of manganese, it has been found that the oxidation of manganese with oxygen is slow, even at elevated pH.

4.3.2.3 Configuration

Only Well A water was tested during the additional Phase II testing. Well A raw water (RW) was aerated using an eductor, upstream of the static mixer and the contact tank. Three overflows on the contact tank at different levels (full tank, 1/2 tank, and 1/3 tank) were used to vary the contact time (i.e., hydraulic residence time) for iron oxidation to occur. From the contact tank, the pretreatment feed (PTF) water was pumped and filtered through the granular media filters (GMFs) in parallel. To test close to zero minutes of contact time, the contact tank was bypassed and the pretreatment feed water was fed through the GMFs using the pressure in Well A raw water pipe. The hydraulic loading rate through the GMFs was varied by using two or three GMFs. After granular media filtration, the pretreatment product (PTP) water was fed through the cartridge filters, after which the antiscalant was injected, and the RO feed (ROF) water was then pumped to the RO membranes. Figure 4-2 presents a simplified schematic of the Phase II treatment process.

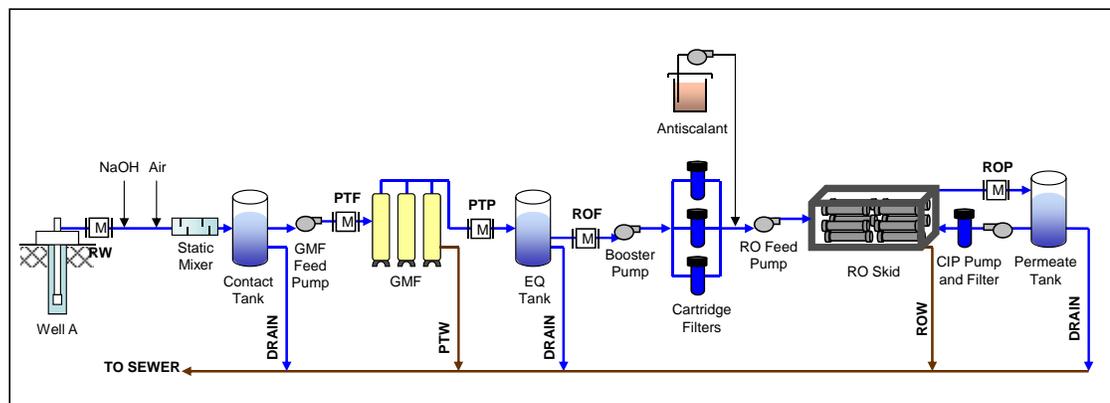


Figure 4-2.
Phase II Aeration plus Media Filtration Process Schematic

In addition, to test the impact of pH on the oxidation of iron, caustic soda (NaOH) was fed to Well A raw water, upstream of aeration.

4.3.2.4 Operating Conditions

The variables tested during the Phase II pretreatment evaluation were: Well A raw water pH, contact time, GMF loading rate, and the RO operating parameters. These variables are listed in Table 4-5, which summarizes the pilot plant operating conditions for all of Phase II pretreatment evaluation.

Table 4-5.

Phase II – Aeration + Media Filtration + RO: Operating Conditions

	Time Period	Operating Hours	NaOH Feed	PTF pH	Contact Time (min)	No. of GMF Used	GMF Loading Rate (gpm/sf)	EQ Tank Used	Antiscalant Feed Location	RW Flow (gpm)	PTF Flow (gpm)	ROF Flow (gpm)	ROP Flow (gpm)	ROW Flow (gpm)	Recovery (%)
2A	10/30/07 – 11/09/07	233	No	7.7	30	3	3.5	Yes	ROF	37	33	28	20	8	71
2B	11/10/07 – 11/20/07	261	No	7.7	29	2	5.1	No	ROF	38	32	26	18	8	69
2C	11/21/07	25	No	7.8	0	3	3.2	No	ROF	30	31	24	16	8	66
2D	11/22/07 – 11/29/07	190	No	7.7	22	3	3.4	No	ROF	51	32	24	16	8	66
2E	11/30/07 – 12/18/07	447	No	7.2	21	3	3.3	No	ROF	54	31	30	21	9	71
2F	12/19/08 – 1/1/08	291	No	7.4	21	2	4.1	No	ROF	52	26	28	20	8	71
2G	2/1/08	23	No	7.3	6	2	5.6	Yes	ROF	55	35	29	21	8	74
2H	2/2/08 – 2/5/08	92	No	7.4	10	2	5.4	Yes	ROF	36	35	28	21	8	74
2J	2/6/08 – 2/8/08	79	Yes	8.0	9	2	4.6	No	RW	38	34	28	21	8	74
2K	2/9/08 – 2/10/08	65	No	n/a	10	3	3.1	No	RW	35	29	28	21	8	74
2L	2/11/08	4	Yes	8.0	0	3	3.1	No	RW	28	29	29	21	8	74
2M	2/12/08 – 2/17/08	141	No	7.5	9	3	3.0	No	ROF	51	28	28	21	8	74

- Adjusting the pH of Well A Raw Water and Feeding Antiscalant Upstream of Aeration** – The pH of the Well A raw water and the location of antiscalant feed were varied as summarized in Table 4-6. For most operating conditions, the pH of Well A raw water was not adjusted, and the antiscalant was fed in the RO feed water, upstream of the RO. During operating conditions 2J and 2L, caustic soda was added upstream of the aeration point to raise the pH of Well A raw water to pH 8, and the antiscalant feed location was moved to the Well A raw water. This test was designed to evaluate i) whether improved iron oxidation could be achieved at a more optimal oxidation pH, and ii) whether antiscalant has any impact on iron oxidation.

Table 4-6.			
Phase II – Aeration + Media Filtration: pH Adjustment			
PTF pH	NaOH Feed	Antiscalant Feed Location	Operating Conditions
7.3 to 7.5	No	ROF (Upstream of RO)	2E, 2F, 2G 2H, 2M
7.7 to 7.8	No	ROF (Upstream of RO)	2A, 2B, 2C, 2D
8.0	Yes	RW (Upstream of Aeration)	2J, 2L

- Contact Time** – The contact time (hydraulic residence time in the contact tank located downstream of aeration and upstream of the GMFs) was varied to evaluate the impact of reaction time on iron oxidation, as summarized in Table 4-7.

Table 4-7.	
Phase II – Aeration + Media Filtration: Contact Time	
Contact Time (min)	Operating Conditions
29 to 30	2A, 2B
21 to 22	2D, 2E, 2F
9 to 10	2H, 2J, 2K, 2L
6	2G
0	2C, 2L

- GMF Loading Rate** – The hydraulic loading rates for the GMFs were varied as summarized in Table 4-8.

Table 4-8.	
Phase II – Aeration + Media Filtration: GMF Loading Rate	
GMF Loading Rate (gpm/sf)	Operating Conditions
3.0 to 3.5	2A, 2C, 2D, 2E, 2K, 2L, 2M
4.1 to 4.6	2F, 2J
5.1 to 5.6	2B, 2G, 2H

4.3.2.5 Testing Protocol

Flows, pressures, temperature, chemical storage tank levels, and metering pump settings were recorded daily. pH, conductivity, dissolved oxygen, and turbidity were measured five times a week. Total iron, dissolved iron, total manganese, dissolved manganese, UV254, and apparent color were measured for selected sample streams three times a week.

Silt density index (SDI) was measured once a week. Chloride, silica, sulfate, and ammonia nitrogen were measured once a week until the third week of December 2007. In addition to the tests performed at the pilot plant lab, samples were sent to an outside lab to test for alkalinity, total hardness, boron, calcium, magnesium, sodium, vanadium, total dissolved solids (TDS), total organic carbon (TOC), and gross alpha. These outside lab tests were performed once a week until third week of December 2007. Starting the fourth week of December 2007, the frequency of all weekly tests, except the SDI test, was reduced to monthly.

Samples were also tested for iron and manganese at the outside lab to compare against data measured at the pilot plant for QA/QC once during Phase II testing.

4.3.3 Phase III – Chlorine Dioxide Feed plus Media Filtration (Alternative 3)

The Phase III pretreatment evaluation, which consisted of chlorine dioxide (ClO₂) injection plus media filtration pretreatment followed by reverse osmosis (RO) desalination, was conducted from January 2, 2008 through January 31, 2008.

4.3.3.1 Objectives

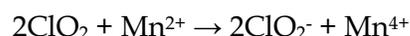
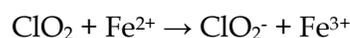
The purpose of this pretreatment evaluation was to test if both iron and manganese could be oxidized by adding chlorine dioxide and removed through the granular media filtration while preventing fouling or damage to the desalination process.

4.3.3.2 Description

Chlorine dioxide is a strong oxidant that quickly oxidizes both iron and manganese. Oxidized iron and manganese are removed by the granular media filters (GMFs), preventing fouling on the RO elements. While RO elements are generally reported to be resistant to damage from chlorine dioxide, ultra-pure solutions are required to prevent damage caused by residual levels of free chlorine or other oxidants. Chlorine dioxide was delivered in bulk at 0.3 percent concentration and 99.7 percent pure chlorine-free chlorine dioxide.

Chlorine Dioxide Dose and Demand

The oxidation of iron and manganese with chlorine dioxide can be described by the following reactions:



The typical chlorine dioxide doses that have been reported for the oxidation of iron and manganese are 1.2 mg ClO₂/mg Fe²⁺ and 2.5 mg ClO₂/mg Mn²⁺, respectively (MWH, 2005).

4.3.3.3 Configuration

Only Well A water was tested during Phase III testing. Chlorine dioxide was injected into Well A raw water (RW), upstream of the static mixer and the contact tank. Three overflows on the contact tank at different levels (full tank, 1/2 tank, and 1/3 tank) were used to vary the contact time (i.e., hydraulic residence time) for iron and manganese oxidations to occur. From the contact tank, the pretreatment feed (PTF) water was pumped and filtered through the GMFs operated in parallel. To test close to zero minutes of contact time, the contact tank was bypassed and the pretreatment feed water was fed through the GMFs using the pressure in Well A raw water pipe. The hydraulic loading rate through the GMFs was varied by using two or three GMFs. After granular media filtration, the pretreatment product (PTP) water was fed through the cartridge filters, after which the antiscalant was injected, and the RO feed (ROF) water was then pumped to the RO membranes. Figure 4-3 presents a simplified schematic of the Phase III treatment process.

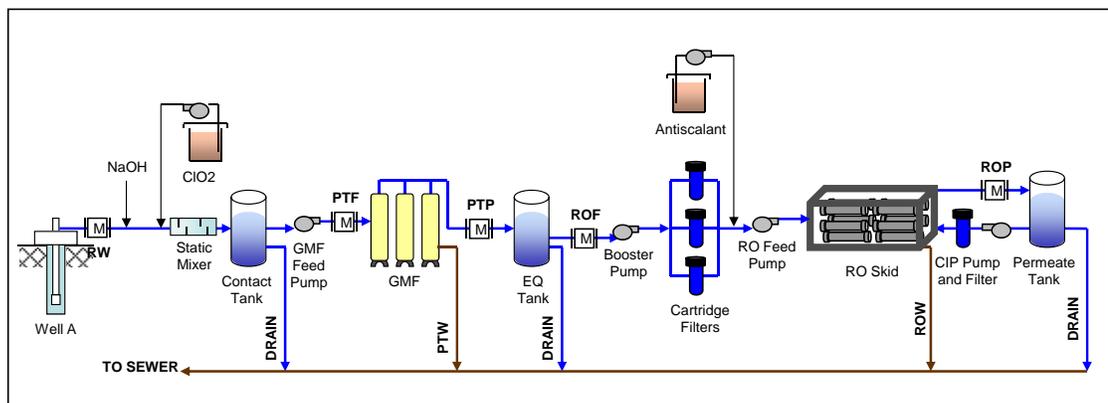


Figure 4-3.
Phase III Chlorine Dioxide Feed plus Media Filtration Process Schematic

In addition to the regular Phase III pretreatment process of chlorine dioxide injection plus media filtration, sodium thiosulfate feed upstream of the cartridge filters and caustic soda (NaOH) feed upstream of the chlorine dioxide feed point were also tested to evaluate the effects of quenching chlorine dioxide residual in the RO feed sample, and of raising the pH of Well A raw water to pH 8, respectively.

The test variables of the Phase III pretreatment evaluation were: Well A raw water pH, chlorine dioxide dose, chlorine dioxide contact time, GMF loading rate, sodium thiosulfate feed, and the RO operating parameters.

4.3.3.4 Operating Conditions

The operating conditions tested during the Phase III pretreatment evaluation are summarized in Table 4-9:

- **Chlorine Dioxide Dose** – The chlorine dioxide feed rate was adjusted on a daily basis to maintain a 1.5 mg/L concentration in the pretreatment feed water sampled downstream of the contact tank. On average, the chlorine dioxide dose was 1.7 mg/L, the chlorine dioxide level measured in the pretreatment feed sample was 1.4 mg/L, and the chlorine dioxide residual measured in the RO feed sample was 0.3 mg/L.
- **Contact Time** – During operating conditions 3A through 3G, the chlorine dioxide contact time was maintained at approximately 37 minutes. During operating conditions 3H, 3J, 3K and 3L, the contact time was reduced to 17 minutes, 15 minutes, 10 minutes and 6 minutes, respectively. During operating condition 3M, the contact time was reduced to near zero minutes by bypassing the contact tank. The contact time was varied to evaluate the impact of reaction time on manganese oxidation.
- **GMF Loading Rate** – During operating conditions 3A through 3C and 3H through 3L, two GMFs were operated at hydraulic loading rates ranging from 4.5 to 5.5 gpm/sf. During operating conditions 3D through 3G, three GMFs were operated at hydraulic loading rates ranging from 3.0 to 3.2 gpm/sf.
- **Quenching Chlorine Dioxide Residual** – During operating condition 3A, sodium thiosulfate was added upstream of the cartridge filters to quench the chlorine dioxide residual in the RO feed water. The purpose of this was to protect the membranes from potential oxidation damage during the initial stage of operation until it could be confirmed that stable operation was achieved.
- **Adjusting the Well A Raw Water pH** – During operating conditions 3D through 3F, caustic soda was added upstream of the chlorine dioxide feed point to raise the pH of Well A raw water to pH 8. This test was designed to evaluate whether improved manganese oxidation could be achieved at a more optimal oxidation pH.

Table 4-9.

Phase III – ClO₂ + Media Filtration + RO: Operating Conditions

	Time Period	Operating Hours	ClO ₂ Dose (mg/L)	Contact Time (min)	No. of GMF Used	GMF Loading Rate (gpm/sf)	NaOH Feed	PTF pH	Sodium Thiosulfate Feed	EQ Tank Used	RW Flow (gpm)	PTF Flow (gpm)	ROF Flow (gpm)	ROP Flow (gpm)	ROW Flow (gpm)	Recovery (%)
3A	01/02/08-01/07/08	115	1.8	36	2	4.7	No	7.3	6.8 mg/L	No	30	30	28	23	8.0	74
3B	01/08/08-01/11/08	87	1.7	38	2	4.6	No	7.3	No	No	29	29	28	22	7.8	74
3C	01/11/08-01/13/08	66	1.7	36	2	5.1	Yes	8.1	No	No	31	32	27	23	7.3	76
3D	01/14/08-01/15/08	23	1.8	38	3	3.0	Yes	8.1	No	No	29	28	27	21	7.2	75
3E	01/16/08	18	0	38	3	3.0	No	7.1	No	No	29	29	27	22	7.5	74
3F	01/17/08-01/22/08	116	2.1	38	3	3.0	No	7.3	No	No	29	29	28	21	7.6	74
3G	01/23/08	23	1.9	17	3	3.2	No	7.3	No	No	32	30	29	23	8.0	74
3H	01/24/08	20	1.8	15	2	4.5	No	7.3	No	No	36	29	29	21	7.5	74
3J	01/25/08	25	1.6	10	2	4.6	No	7.3	No	No	39	29	28	21	7.5	74
3K	01/28/08	29	1.3	6	2	5.6	No	7.4	No	Yes	62	35	28	21	7.5	74
3L	01/29/07-01/31/08	64	0.9 to 1.4	0	2	4.5	No	7.3	No	No	50 to 56	28	28	21	7.3	74

4.3.3.5 Testing Protocol

Flows, pressures, temperature, chemical storage tank levels, and metering pump settings were recorded daily. Chlorine dioxide concentrations, pH, and conductivity were measured five times a week. Also, during this phase, total iron, dissolved iron, total manganese, dissolved manganese, UV254, and apparent color were measured for selected sample streams four to five times a week.

Silt density index (SDI) was measured once a week. Chloride, silica, sulfate, and ammonia nitrogen were measured once a month. In addition to the tests performed at the pilot plant lab, samples were sent to an outside lab once a month to test for alkalinity, total hardness, boron, calcium, magnesium, sodium, vanadium, total dissolved solids (TDS), total organic carbon (TOC), and gross alpha. Also, filtered and unfiltered samples of raw water, pretreatment feed, RO feed, RO permeate and RO waste were sent to the outside lab for QA/QC of the iron and manganese tests.

4.3.4 Phase IV – Chlorine Feed plus Pyrolox Media Filtration (Alternative 4)

The Phase IV pretreatment evaluation, which consisted of chlorine (Cl₂) injection plus Pyrolox media filtration pretreatment followed by reverse osmosis (RO) desalination, was conducted from February 20, 2008 to April 4, 2008.

4.3.4.1 Objectives

The purpose of Phase IV pretreatment evaluation was to test if iron and manganese could be oxidized by adding chlorine and removed using Pyrolox media filtration while preventing fouling or damage to the desalination process.

Oxidation of both iron and manganese using chlorine and catalytic media, such as pure or partially pure manganese dioxide (pyrolucite) or greensand, is the process used most commonly for removing iron and manganese from groundwater.

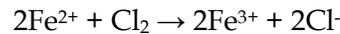
Similar to Phase III, this process would remove iron and manganese prior to desalination, however, the process requires a dechlorination step, using sodium bisulfite ahead of the RO membranes, to prevent damage to the membranes. Chlorine damage is a common concern for RO membrane manufacturers, some of whom will require a warranty clause exempting them from damage caused due to the dechlorination system failure.

4.3.4.2 Description

Sodium hypochlorite is used to oxidize iron and manganese in the raw water prior to filtration. While oxidation of manganese using chlorine can take in excess of 30 minutes to occur, pyrolucite-based media have proven effective at accelerating this process to occur within seconds. This phase employed the same GMF used during the Phases II and III, with the media replaced with a pyrolucite-based media (Pyrolox).

Chlorine Dose and Demand

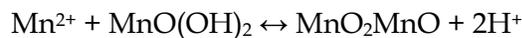
Iron Oxidation: The oxidation of iron with chlorine can be described by the reaction:



The amount of chlorine required for the oxidation of iron is 0.63 mg Cl₂/mg Fe²⁺ (MWH, 2005).

Manganese Oxidation: The oxidation of manganese with chlorine enhanced by filtration through media coated with MnO₂ can be described by the following two-step reactions:

Step 1: Adsorption of Mn²⁺ on the MnO₂ surface:



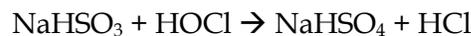
Step 2: Oxidation of the adsorbed species by chlorine:



The amount of chlorine required for the oxidation of manganese is about 1.29 mg Cl₂/mg Mn²⁺ (MWH, 2005).

Sodium Bisulfite Demand

Sodium bisulfite is added to the filtered water upstream of the equalization tank to quench the residual chlorine and prevent damage to the RO membranes. This reaction is summarized below.



4.3.4.3 Configuration

Only Well A water was tested during Phase IV testing. Chlorine was injected into Well A raw water (RW), upstream of the static mixer and the contact tank. Three overflows on the contact tank at different levels (full tank, 1/2 tank, and 1/3 tank) were used to vary the contact time (i.e., hydraulic residence time) for iron and manganese oxidations to occur. From the contact tank, the pretreatment feed (PTF) water was pumped and filtered through the granular media filters (GMFs) with Pyrolox media operated in parallel. The hydraulic loading rate through the GMFs was kept constant by using three GMFs during the whole phase. After granular media filtration, sodium thiosulfate or sodium bisulfite was fed to the pretreatment product (PTP) water to quench the residual chlorine. After dechlorination, the pretreatment product water was fed through the cartridge filters, after which the antiscalant was injected, and the RO feed (ROF) water was then pumped to the RO membranes. Figure 4-4 presents a simplified schematic of the treatment process.

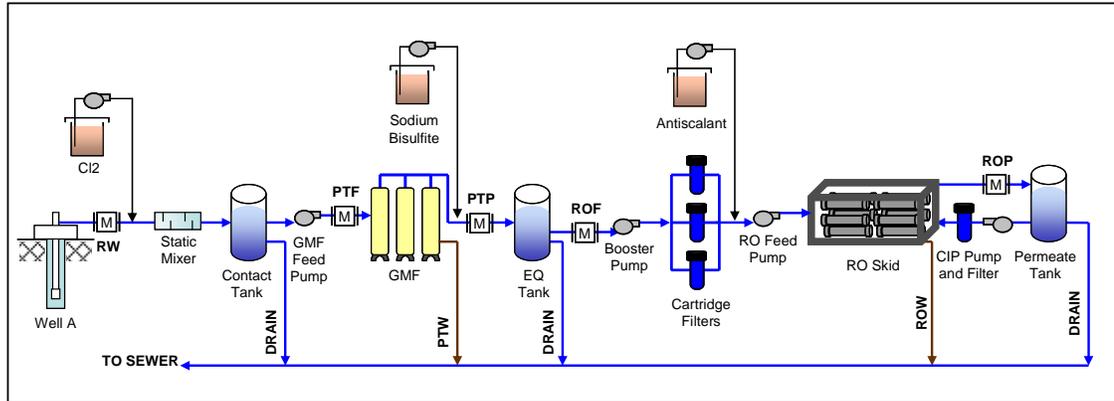


Figure 4-4.
Phase IV Chlorine Feed plus Pyrolox Media Filtration Process Schematic

The test variables of the Phase IV pretreatment evaluation are: chlorine dose, and contact time.

4.3.4.4 Operating Conditions

The operating conditions tested during Phase IV pretreatment evaluation are summarized in Table 4-10:

Table 4-10.
Phase IV – Cl2 + Pyrolox Media Filtration + RO: Operating Conditions

	Time Period	Operating Hours	Chlorine Dose (mg/L)	Contact Time (min)	No. of GMF Used	Pyrolox Media Filtration Loading Rate (gpm/sf)	Thiosulfate /Bisulfite Feed	Antiscalant Dose (mg/L)	RW Flow (gpm)	PTF Flow (gpm)	ROF Flow (gpm)	ROP Flow (gpm)	ROW Flow (gpm)	Recovery (%)
4A	2/20/08 – 3/12/08	321	1.0	15	3	3.1	Thiosulfate, 15 mg/L	1.1	37	30	27	21	8	74
4B	3/13/08-3/17/08	97	1.1	10	3	3.2	Thiosulfate, 14 mg/L	1.5	37	30	21	13	6	65
4C	3/18/08-3/19/08	38	1.2	15	3	3.2	Thiosulfate, 12 mg/L	0.9	37	30	31	20	7	74
4D	3/19/08-3/20/08	25	1.9	15	3	3.2	Thiosulfate, 24 mg/L	1.0	37	30	29	21	8	73
4E	3/21/08	19	4.4	16	3	3.2	Bisulfite, 3.3 mg/L	0.9	34	30	31	21	8	74
4F	3/24/08-3/25/08	17	2.4	15	3	3.2	Bisulfite, 6.6 mg/L	0.9	37	30	34	23	8	74
4G	3/26/08-3/28/08	73	1.8	15	3	3.3	Bisulfite, 1.7 mg/L	0.9	36	31	32	22	8	74
4H	3/29/08-3/30/08	45	1.5	15	3	3.3	Bisulfite, 1.7 mg/L	0.9	38	31	32	21	7	74
4J	3/31/08-4/2/08	72	1.5	10	3	3.4	Bisulfite, 1.7 mg/L	0.9	36	32	33	23	8	74
4K	4/3/08-4/4/08	49	1.8	7	3	3.5	Bisulfite, 1.7 mg/L	1.3	60	33	31	22	8	75

- **Chlorine Dose** – Chlorine was dosed at 1.0 to 4.4 mg/L as shown below:

Table 4-11. Phase IV – Cl2 + Pyrolox Media Filtration: Average Chlorine Dose	
Chlorine Dose (mg/L)	Operating Conditions
1.0 to 1.2	4A, 4B, 4C
1.5	4H, 4J
1.8 to 1.9	4D, 4G, 4K
2.4	4F
4.4	4E

- **Contact Time** – The contact time (hydraulic residence time in the contact tank located downstream of chlorine injection and upstream of the Pyrolox media filters) was varied to evaluate the impact of reaction time on manganese oxidation, as summarized in Table 4-12.

Table 4-12. Phase IV – Cl2 + Pyrolox Media Filtration: Contact Time	
Contact Time (min)	Operating Conditions
7	4K
10	4B, 4J
15 to 16	4A, 4C, 4D, 4E, 4F, 4G, 4H

- **Pyrolox Media Filter Loading Rate** – During this phase, all three Pyrolox media filters were operated at hydraulic loading rates ranging from 3.0 to 3.5 gpm/sf. The filters were backwashed weekly at a rate of 15 gpm/sf.
- **Dechlorination** – During operating conditions 4A through 4D, sodium thiosulfate was fed upstream of the cartridge filters to quench the residual chlorine in the pretreatment product water. During operating conditions 4E through 4K, sodium bisulfite was used to quench the residual chlorine in the pretreatment product water.

4.3.4.5 Testing Protocol

Flows, pressures, temperature, chemical storage tank levels, and metering pump settings were recorded daily. Free chlorine concentrations, pH, and conductivity were measured five times a week. Total iron, dissolved iron, total manganese, dissolved manganese, UV254, and apparent color were measured for selected sample streams three times a week.

Silt density index (SDI) was measured once a week. Chloride, silica, sulfate, and ammonia nitrogen were measured once a month. In addition to the tests performed at the pilot plant lab, samples were sent to an outside lab once a month to test for

alkalinity, total hardness, boron, calcium, magnesium, sodium, vanadium, total dissolved solids (TDS), total organic carbon (TOC), and gross alpha. Also, filtered and unfiltered samples of raw water, pretreatment feed, RO feed, RO permeate and RO waste were sent to the outside lab for QA/QC of the iron and manganese tests. The monthly tests for March were performed on March 12, 2008.

4.3.5 Phase V - Aeration plus Microfiltration (Alternative 5)

The Phase V pretreatment evaluation, which consisted of aeration plus microfiltration (MF) pretreatment followed by reverse osmosis (RO) desalination, was conducted from April 7 through May 23, 2008.

4.3.5.1 Objectives

The purpose of the Phase III pretreatment evaluation was to test if 1) iron could be oxidized through aeration and removed through the MF membranes; and 2) manganese could be kept in the reduced state during the pretreatment stages to be removed by the RO membranes without causing fouling of the RO membranes.

4.3.5.2 Description

The process for Phase V is the same as for Phase II, except that microfiltration is used instead of media filtration to filter the iron as a pretreatment to RO. Microfiltration should be capable of removing a higher percentage of the iron oxide, due to the small pore size in the membranes, however, process optimization would be needed for both microfiltration and media filtration to determine which will be more cost effective in a full-scale facility.

4.3.5.3 Configuration

Only Well A water was tested during Phase V testing. Well A raw water (RW) was aerated using an eductor (Mazzei air injector model 1584) or an air compressor upstream of the static mixer and the contact tank. Three overflows on the contact tank at different levels (full tank, 1/2 tank, and 1/3 tank) were used to vary the contact time (i.e., hydraulic residence time) for iron oxidation to occur. From the contact tank, the pretreatment feed (PTF) water was pumped and filtered through the MF membranes. After filtration, the pretreatment product water was fed through the cartridge filters, after which the antiscalant was injected, and the RO feed (ROF) water was then pumped to the RO membranes. Figure 4-5 presents a simplified schematic of the treatment process.

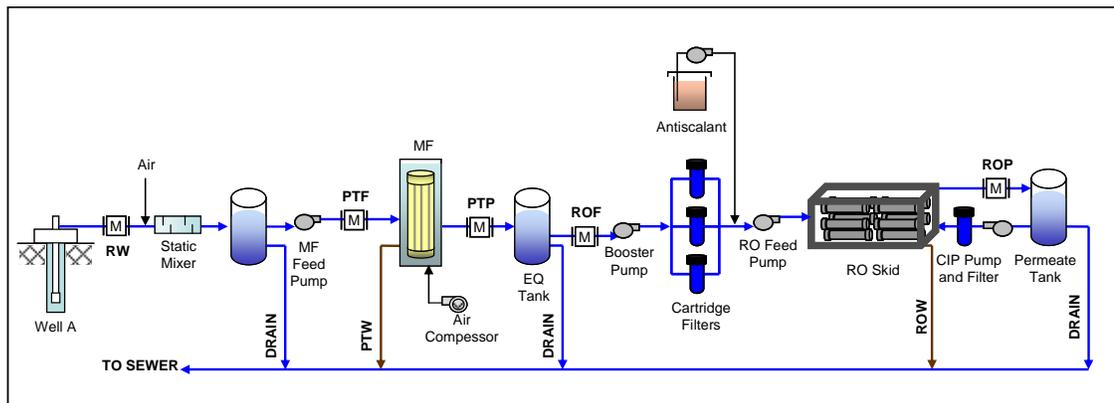


Figure 4-5.
Phase V Aeration plus Microfiltration Process Schematic

The test variables of the Phase V pretreatment evaluation were: dissolved oxygen (DO) concentration, and contact time.

4.3.5.4 Operating Conditions

The operating conditions tested during Phase V pretreatment evaluation are summarized in Table 4-13:

Table 4-13.

Phase V – Aeration + Microfiltration + RO: Operating Conditions

	Time Period	Operating Hours	Aeration Method	PTF DO (mg/L)	Contact Time (min)	MF Flux (gfd)	Antiscalant Feed	RW Flow (gpm)	PTF Flow (gpm)	ROF Flow (gpm)	ROP Flow (gpm)	ROW Flow (gpm)	Recovery (%)
5A	4/7/08	2	Eductor	5.5	3	31	Yes	41	33	29	21	8	74
5B	4/8/08	40	Eductor	7.7	19	31	Yes	37	32	13	8	5	62
5C	4/10/08	14	Eductor	5.6	45	16	Yes	28	17	14	9	5	64
5D	4/11/08 – 4/22/08	264	Eductor	4.1 to 5.9 (Avg 5.3)	31 to 34 (Avg 33)	34 to 36 (Avg 35)	Yes	36 to 40 (Avg 38)	36 to 38 (Avg 37)	14 to 29 (Avg 27)	11 to 21 (Avg 20)	4 to 8 (Avg 7)	71 to 74 (Avg 73)
5E	4/23/08 – 4/25/08	58	Air Compressor	8.1 to 8.8 (Avg 8.4)	33 to 36 (Avg 34)	33 to 36 (Avg 34)	Yes	35 to 38 (Avg 37)	34 to 37 (Avg 36)	14 to 18 (Avg 17)	11	4 to 7 (Avg 6)	62 to 74 (Avg 66)
5F	4/28/08	~ 0	Air Compressor	8.7	32	17	Yes	39	18	--	--	--	--
5G	4/29/08 – 4/30/08	16	Air Compressor	8.3	4	29	Yes	40	30	16	11	5	69
5H	4/30/08 – 5/23/08	522	Air Compressor	8.0 to 9.1 (Avg 8.5)	4	30 to 36 (Avg 33)	Yes	33 to 39 (Avg 36)	32 to 38 (Avg 35)	26 to 29 (Avg 27)	18 to 22 (Avg 20)	7 to 8 (Avg 7)	71 to 76 (Avg 73)

- **Aeration** – Two methods of aeration were used during Phase V. Initially, an eductor was used for aeration, similar to Phase II. Starting April 24, an air compressor was used to enhance aeration and thereby increase the dissolved oxygen concentration in pretreatment feed sample to close to saturation point. Aeration methods and average dissolved oxygen concentration are summarized in Table 4-14.

Table 4-14. Phase V – Aeration + Microfiltration: Average Dissolved Oxygen		
Aeration Method	Average DO (mg/L)	Operating Conditions
Eductor	5.6	5A – 5D
Air Compressor	8.7	5E – 5H

- **Contact Time** – The contact time (hydraulic residence time in the contact tank located downstream of aeration and upstream of the MF membranes) was varied to evaluate the impact of reaction time on iron oxidation, as summarized in Table 4-15.

Table 4-15. Phase V – Aeration + Microfiltration: Contact Time	
Contact Time (min)	Operating Conditions
3 to 4 (Avg 3.5)	5A, 5G, 5H
19	5B
31 to 36 (Avg 33)	5D, 5E, 5F
45	5C

- **Microfiltration Flux** – The MF flux (measured in gfd, or million gallons per day per square foot) was varied as summarized in Table 4-16.

Table 4-16. Phase V – Aeration + Microfiltration: Microfiltration Flux	
Flux (gfd)	Operating Conditions
16 to 17	5C, 5F
30 to 36	5A, 5B, 5D, 5E, 5G, 5H

4.3.5.5 Testing Protocol

Flows, pressures, temperature, chemical storage tank levels, and metering pump settings were recorded daily. Dissolved oxygen concentrations, pH, conductivity, and turbidity were measured five times a week. Total iron, dissolved iron, total manganese, dissolved manganese, UV254, and apparent color were measured for selected sample streams three times a week.

Silt density index (SDI) was measured once a week. Chloride, silica, sulfate, and ammonia nitrogen were measured once a month. In addition to the tests performed at the pilot plant lab, samples were sent to an outside lab once a month to test for alkalinity, total hardness, boron, calcium, magnesium, sodium, vanadium, total dissolved solids (TDS), total organic carbon (TOC), and gross alpha. Also, filtered and unfiltered samples of raw water, pretreatment feed, RO feed, RO permeate and RO waste were sent to the outside lab for QA/QC of the iron and manganese tests. The monthly tests for March were performed on March 12, 2008.

4.4 Pilot Plant Configuration

4.4.1 Site Layout

Both Well A and Well B water were tested during the pilot study, and the pilot plant was located at City Well A. Figure 4-7 shows the locations of Well A and Well B.

Figure 4-8 shows the zoomed-in view of the pilot plant site at Well A, and Figure 4-9 shows a photograph of the pilot plant site.



Figure 4-7.
Aerial Photo of Well A and Well B (Source: Google Map)



Figure 4-8.
Aerial Photo of Well A (Source: Google Map)



Figure 4-9.
Photo of Pilot Plant at Well A

The pilot plant tested water either from Well A or a blend of both Well A and Well B. Figure 4-10 shows the general layout of the pilot plant site. Figure 4-11 shows the process and instrumentation diagram (P&ID) for the overall pilot plant process.

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: _____
 DRAWN BY: _____
 SHEET CHK'D BY: _____
 GROSS CHK'D BY: _____
 APPROVED BY: _____
 DATE: JUNE 2007

**BRACKISH WATER DESALINATION PROJECT
 PILOT STUDY**

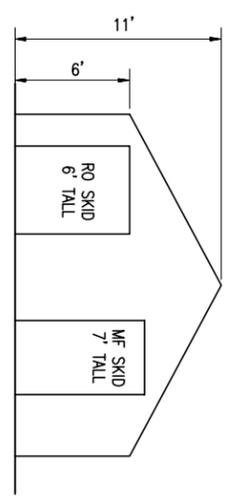
CITY OF CAMARILLO
 601 CARMEN DRIVE
 CAMARILLO, CA 93010

GENERAL SITE LAYOUT

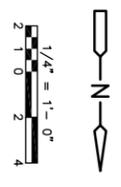
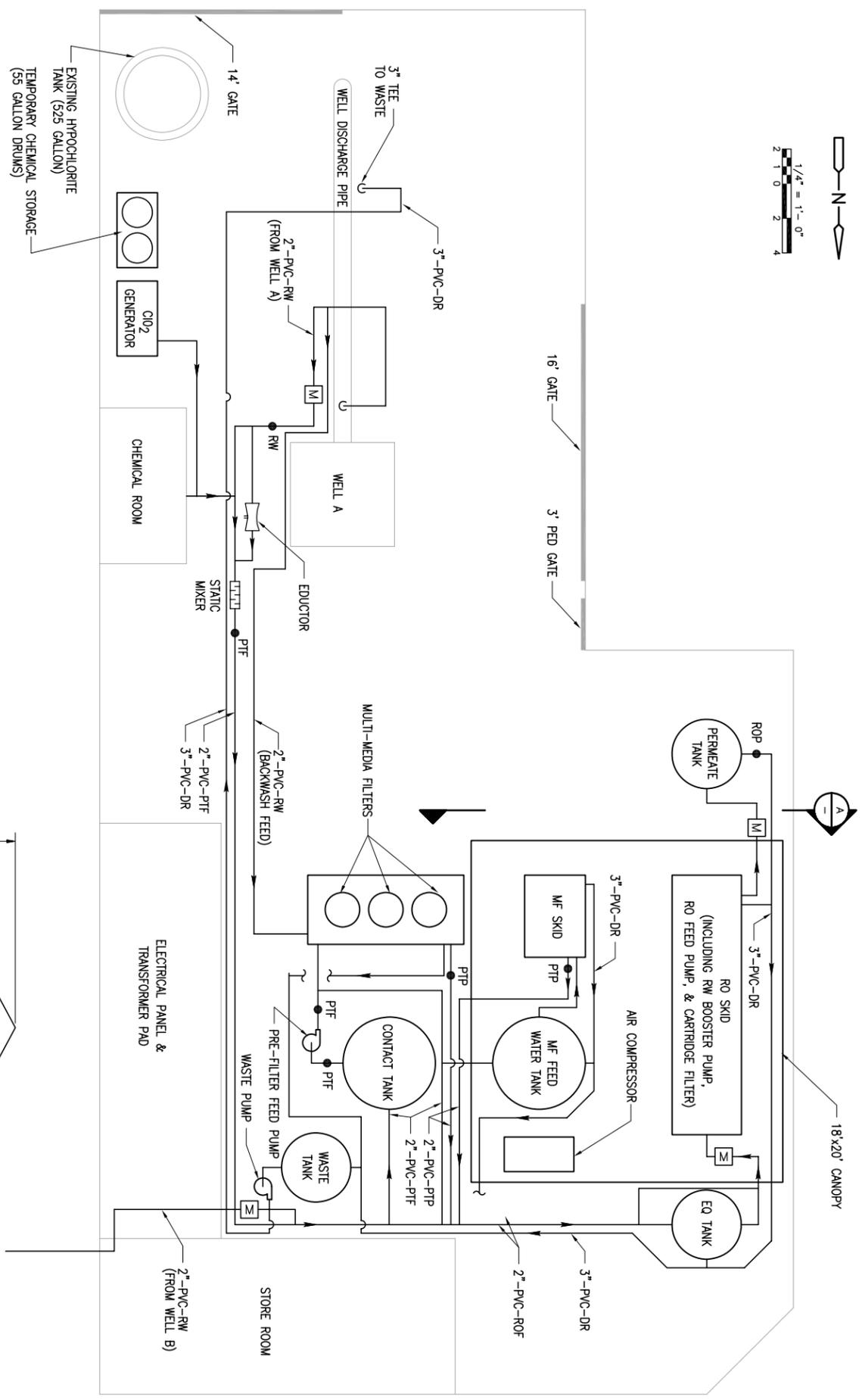
PROJECT NO. C-1.dwg
SHEET NO. FIGURE 4-10

DRAFT

SECTION A
 SCALE: NTS



- LEGEND**
- RW RAW WATER
 - PTF PRE-TREATMENT FEED
 - PTP PRE-TREATMENT PRODUCT
 - PTW PRE-TREATMENT WASTE
 - ROF REVERSE OSMOSIS FEED
 - ROP REVERSE OSMOSIS PRODUCT
 - ROW REVERSE OSMOSIS WASTE
 - DR DRAIN
 - SAMPLE PORT

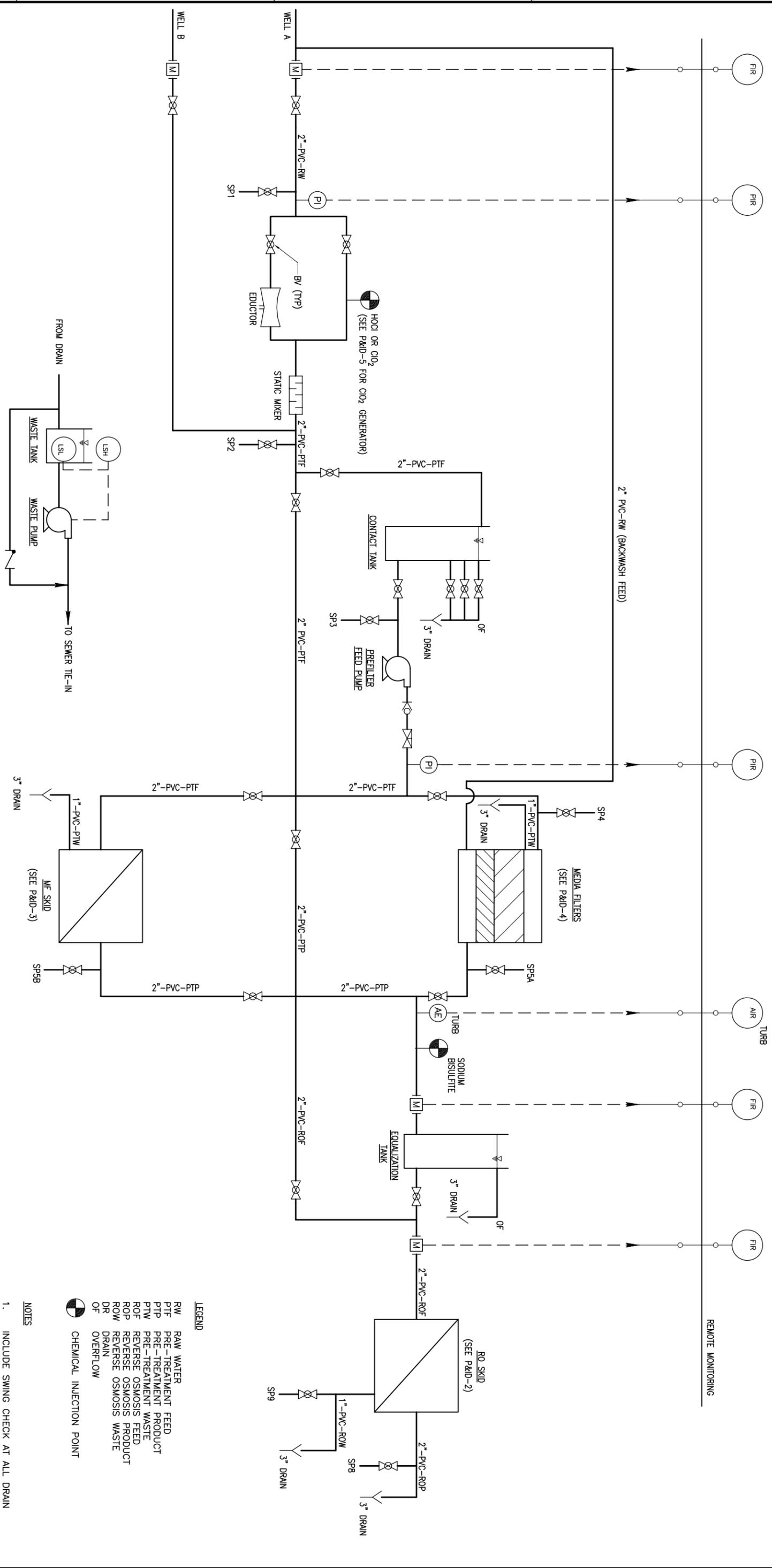


REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: _____	EGY
DRAWN BY: _____	MP
SHEET CHK'D BY: _____	MSB
GROSS CHK'D BY: _____	CW
APPROVED BY: _____	
DATE: _____	JUNE 2007

CDM Camp Dresser & McKee Inc.
 CITY OF CAMARILLO
 601 CARMEN DRIVE
 CAMARILLO, CA 93010
BRACKISH WATER DESALINATION PROJECT
PILOT STUDY

RO PILOT SYSTEM
 PROJECT NO. _____
 FILE NAME: P&ID-1.dwg
 SHEET NO. _____
FIGURE 4-11



- LEGEND**
- RW RAW WATER
 - PTF PRE-TREATMENT FEED
 - PTP PRE-TREATMENT PRODUCT
 - PTW PRE-TREATMENT WASTE
 - ROF REVERSE OSMOSIS FEED
 - ROP REVERSE OSMOSIS PRODUCT
 - ROW REVERSE OSMOSIS WASTE
 - DR DRAIN
 - OF OVERFLOW
 - CHEMICAL INJECTION POINT

- NOTES**
1. INCLUDE SWING CHECK AT ALL DRAIN LOCATIONS.

DRAFT

4.4.2 Equipment

The following is a list of equipment used for the pilot plant.

4.4.2.1 Process Equipment

Major process equipment used during the pilot study are described in Table 4-17.

Equipment	Description	Capacity
Eductor	Mazzei Model 1584-A supplied by Mazzei Injector Corporation	
Static Mixer	2-inch, clear PVC, in-line static mixer with standard 6-element or 12-element configurations, by Koflo	
Granular Media Filters	Three 24-inch diameter FRP pressure vessels. Dual media consisted of 11 inches of sand and 25 inches of anthracite. Pyrolox media consisted of 18 inches of 20x40 Pyrolox media with sand underbed.	Up to 15 gpm each.
Membrane Filters	Pressure microfiltration (MF) system (Memcor Model 6M10C Pilot Skid with CMF 6L10V membrane modules) by Siemens Water Technologies. Nominal pore size is 0.1 microns.	Up to 30 gpm
RO	NF/RO Pilot Skid custom-designed by CDM. Designed to test NF or RO membranes.	Up to 30 gpm at 225 psi

4.4.2.2 Chemical Addition

The chemicals used during each testing phase are summarized in Table 4-18.

Chemical	Phase I	Phase II	Phase III	Phase IV	Phase V	Phase VI
Sodium Thiosulfate (Na ₂ S ₂ O ₃), 31%	Used for oxygen quenching					Used for oxygen quenching
Aeration (O ₂)		Used to enhance iron oxidation			Used to enhance iron oxidation	
Caustic Soda (NaOH), 10%		Used intermittently for pH adjustment				
Chlorine Dioxide (ClO ₂), 0.3%			Used to oxidize iron and manganese			

Table 4-18.						
Chemicals Used for Treatment Process						
Chemical	Phase I	Phase II	Phase III	Phase IV	Phase V	Phase VI
Sodium Hypochlorite (NaOCl), 12.5%				Used to oxidize iron		
Sodium Bisulfite (NaHSO ₃), 36%			Used intermittently to quench residual ClO ₂	Used for dechlorination		
Muriatic Acid (HCl), 31%						Used to slow iron oxidation and prevent scaling
Antiscalant, 100%	SpectraGuard by Professional Water Technologies (PWT). Used to prevent scaling					

Additional chemicals used for membrane clean-in-place (CIP) are summarized in Table 4-19.

Table 4-19.			
Chemicals Used for Membrane Cleaning			
Chemical	MF Maintenance Clean	MF CIP	RO CIP
Caustic Soda (NaOH), 10% or 25%			Used for caustic clean
Citric Acid (C ₆ H ₈ O ₇), 50%		Used for heated acid clean	Used for acid clean
Sodium Hypochlorite (NaOCl), 12.5%		Used for chlorine clean	
Phosphoric acid (H ₃ PO ₄)	Used for weak acid clean. Weekly for 45 minutes.		

4.4.2.3 Pumps

The pumps used during the pilot study are described in Table 4-20.

Table 4-20.			
Pumps			
Pumps	Application	Description	Capacity
Chemical Metering Pumps	Chemical Feed	Diaphragm metering pumps (Pulsatron MP Series by Pulsafeeder).	12 gph to 24 gph
GMF Feed Pump	Pump pretreatment feed water to the media filter vessels	Horizontal end suction pump (G&L Series Model MCS by Goulds Pumps)	
MF Feed Pump	Pump pretreatment feed water to the MF membranes	Provided by Siemens Water Technologies as part of MF Skid	
RO Feed Pump	Pump RO feed water to the RO membranes	Vertical pump Provided as part of RO Skid. Variable frequency drive (VFD) controlled.	
RO Boost Pump	Boost flow through the RO membranes	Horizontal end suction pump (Model ACDU70/315TG by EBARA Pump)	

4.4.2.4 Tanks

The tanks used during the pilot study are described in Table 4-21.

Table 4-21.			
Tanks			
Tank	Application	Description	Capacity
Contact Tank	Provide contact time for oxidation of iron and/or manganese upstream of pretreatment filtration	HDPE tank with multiple overflow ports to facilitate testing of various contact times.	1100 gallons
Equalization Tank	Provide flow equalization between pretreatment and RO	HDPE with one overflow port and one drain port.	550 gallons
Permeate Tank	Provide storage of RO permeate and function as CIP tank during RO CIP	HDPE with one overflow port and one drain port.	550 gallons

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Section 5

Project Results

5.1 Overview

This section presents the results of the pretreatment evaluation (Section 5.2), selection of recommended pretreatment process (Section 5.3), reverse osmosis (RO) optimization test results (Section 5.4), and the emerging contaminants sampling results (Section 5.5).

5.2 Pretreatment Evaluation Results

The following presents the results of the pretreatment evaluation. The five pretreatment processes and testing phases are summarized in Table 5.2-1.

Table 5.2-1.			
Pretreatment Evaluation Testing Phases			
Phase	Pretreatment Process	Start Date	Finish Date
I	Alt 1: Oxygen Quenching	August 31, 2007	October 23, 2007
II	Alt 2: Aeration plus Media Filtration	October 30, 2007 February 1, 2008	January 1, 2008 February 17, 2008
III	Alt 3: Chlorine Dioxide Feed plus Media Filtration	January 2, 2008	January 31, 2008
IV	Alt 4: Chlorine Feed plus Pyrolox Media Filtration	February 20, 2008	April 4, 2008
V	Alt 5: Aeration plus Microfiltration	April 7, 2008	May 23, 2008

5.2.1 Phase I – Oxygen Quenching (Alternative 1)

The pretreatment process tested during Phase I was oxygen quenching. The objectives of this pretreatment evaluation, process description, pilot configuration, operating conditions, and testing protocol were described previously in Section 4.3.1. The primary objective was to prevent dissolved oxygen from oxidizing dissolved iron into particulate iron, which is known to foul RO membranes. A successful test would remove all dissolved oxygen, prevent particulate iron, and prevent a loss in mass transfer coefficient (MTC), or membrane permeability, across the RO membranes.

5.2.1.1 Oxygen Quenching Performance

During the Phase I pretreatment evaluation, the sodium thiosulfate dose was varied to test the impact of sodium thiosulfate dose on the dissolved oxygen (DO) and iron oxidation. Total iron, dissolved iron, and total manganese measurements are averaged for each operating condition and summarized below in Table 5.2-2. Dissolved manganese was not measured during this phase of testing. Particulate iron, not shown on this table, can be calculated from the total iron minus the dissolved iron.

Table 5.2-2.
Phase I – Oxygen Quenching + RO: Test Data per Operating Conditions

	Time Period	Sodium Thiosulfate Dose (mg/L)	WQ Parameters, Average Values	Well A Raw Water	Well B Raw Water	RO Feed	RO Permeate	RO Concentrate
1A	8/31/07 – 9/9/07	33	Total Iron, (mg/L)	0.23	0.14	0.21	0.06	0.65
			Dissolved Iron, (mg/L)	0.19	0.12	0.17	--	0.63
			Total Manganese, (mg/L)	0.24	0.18	0.22	0.05	--
1B	9/10/07 – 9/14/07	87	Total Iron, (mg/L)	0.23	0.20	0.19	0.01	0.66
			Dissolved Iron, (mg/L)	0.21	0.15	0.18	--	0.56
			Total Manganese, (mg/L)	0.30	0.20	0.24	≤ 0.005	--
1C	9/15/07 – 9/21/07	17	Total Iron, (mg/L)	0.24	0.19	0.19	≤ 0.008	0.66
			Dissolved Iron, (mg/L)	0.23	0.17	0.17	--	0.35
			Total Manganese, (mg/L)	0.32	0.23	0.25	0.01	--
1D	9/24/07	8	Total Iron, (mg/L)	0.22	--	0.21	0.03	0.74
			Dissolved Iron, (mg/L)	0.25	--	0.20	--	0.61
			Total Manganese, (mg/L)	0.25	--	0.24	≤ 0.005	--
1E	9/25/07 – 10/02/07	0	Total Iron, (mg/L)	0.25	0.18	0.22	0.03	0.56
			Dissolved Iron, (mg/L)	0.24	0.14	0.09	--	0.22
			Total Manganese, (mg/L)	0.30	0.17	0.21	≤ 0.005	--
1F	10/03/07- 10/04/07	18	Total Iron, (mg/L)	0.23	0.15	0.19	0.02	0.43
			Dissolved Iron, (mg/L)	0.20	0.19	0.15	--	0.30
			Total Manganese, (mg/L)	0.18	0.21	0.22	≤ 0.005	--
1G	10/5/07- 10/18/07	19 to 30	Total Iron, (mg/L)	0.22	--	0.20	0.01	0.36
			Dissolved Iron, (mg/L)	0.23	--	0.20	--	0.38
			Total Manganese, (mg/L)	0.33	--	0.29	≤ 0.005	0.61
1H	10/20/07- 10/23/07	16	Total Iron, (mg/L)	0.21	--	0.22	0.01	0.70
			Dissolved Iron, (mg/L)	0.19	--	0.21	--	0.37
			Total Manganese, (mg/L)	0.27	--	0.26	0.01	0.77
-- Not tested								

Dissolved Oxygen Level

Early measurements showed Well A and Well B raw water (RW) to have approximately 1 to 2 mg/L of DO. Average DO measurements in Well A raw water were 1.9 mg/L with a median value of 1.5 mg/L. Average DO measurements in Well B raw water were 1.7 mg/L with a median value of 1.3 mg/L.

Iron Oxidation

During Phase I testing, the median total iron level was approximately 0.23 mg/L in Well A raw water and 0.16 mg/L in Well B raw water, and particulate iron, calculated

from the total and dissolved iron, was below the reporting level of 0.02 mg/L (the median concentration was calculated as 0.01 mg/L). The RO feed (ROF) was a blend of 50 percent Well A raw water and 50 percent Well B raw water, sampled downstream of the cartridge filters and upstream of RO. The average total iron in the RO feed was 0.19 mg/L, and particulate iron in the RO feed was also below reporting level.

The effectiveness of oxygen quenching on preventing iron oxidation can be seen by comparing the particulate iron levels in the RO feed when sodium thiosulfate was fed at each well pump discharge (see Figure 5.2-1) against the particulate iron levels in the RO feed when sodium thiosulfate was not fed (see Figure 5.2-2).

When sodium thiosulfate was fed at each well pump discharge to quench DO, the total iron level in the RO feed was approximately the average of the iron levels in Well A raw water and Well B raw water, and the particulate iron level in the RO feed was below the detection level, as shown in Figure 5.2-1. This indicates that there was no measurable amount of iron oxidation when sodium thiosulfate was used for oxygen quenching.

However, when sodium thiosulfate feed was stopped, particulate iron levels in Well A raw water, Well B raw water and the RO feed increased, which indicates that unquenched DO oxidized iron within minutes of contact. The calculated particulate iron level in the RO feed represented more than 50 percent of the total iron, while substantial particulate fouling in the RO began to be observed, as discussed in Section 5.2.1.2.

It should be noted that wells A and B operations were stopped and restarted periodically throughout the testing period to simulate conditions in full scale operation, which may have contributed to air introduction into the raw water supplies.

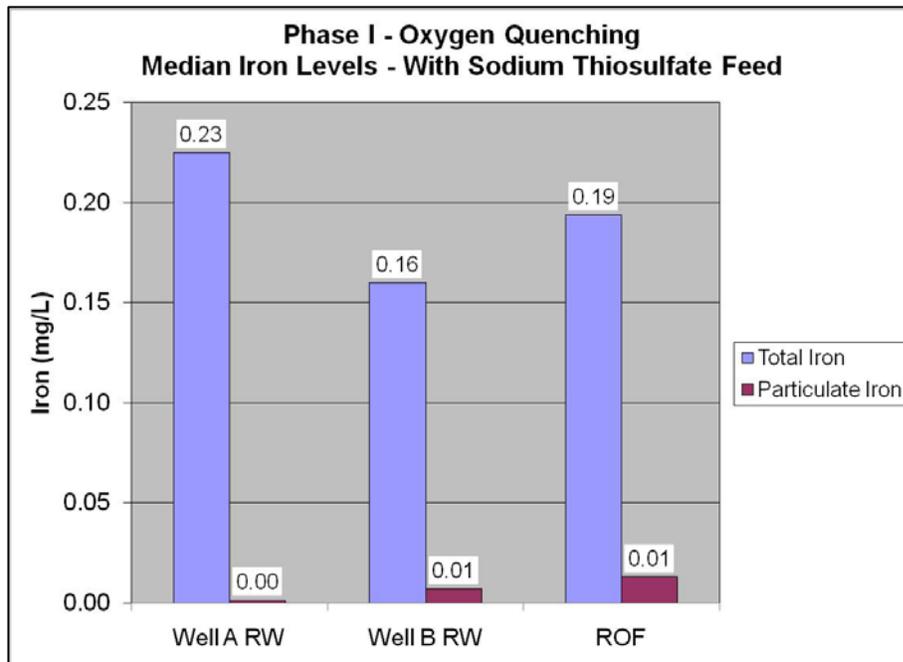


Figure 5.2-1.
Phase I – Median Iron Levels with Sodium Thiosulfate Feed

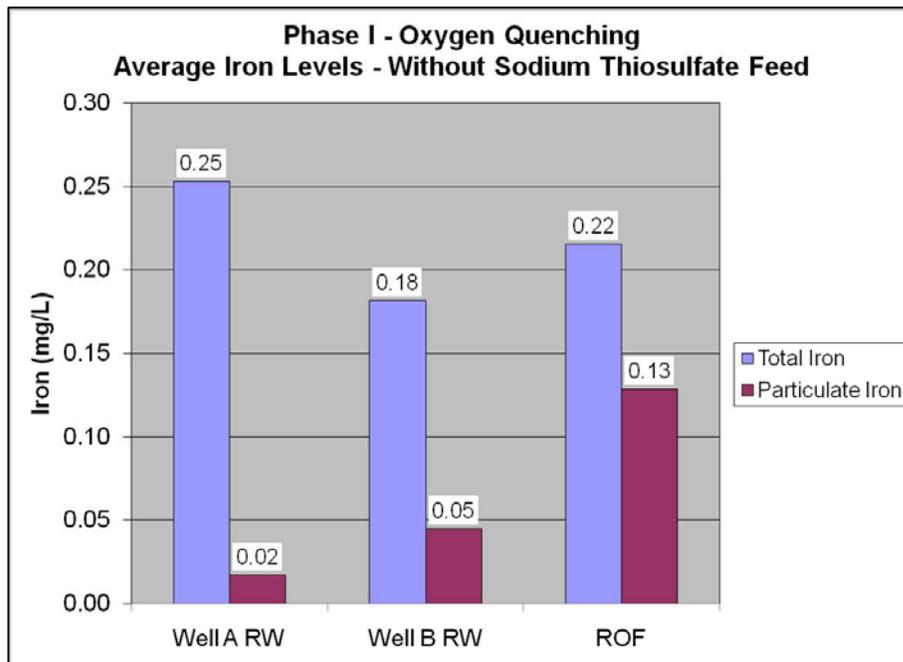


Figure 5.2-2.
Phase I – Average Iron Levels without Sodium Thiosulfate Feed

Manganese Oxidation

It appears that manganese was unaffected by the amount of DO in the raw water. The average total manganese level in the RO feed was approximately 0.25 mg/L, as

shown in Figure 5.2-3, representing the average of the Well A and Well B raw water. Dissolved manganese was not measured during this phase of the testing, preventing the calculation of particulate manganese, however, the lack of a decrease in total manganese between the raw water and the RO feed indicates that no manganese was oxidized or removed by the cartridge filters.

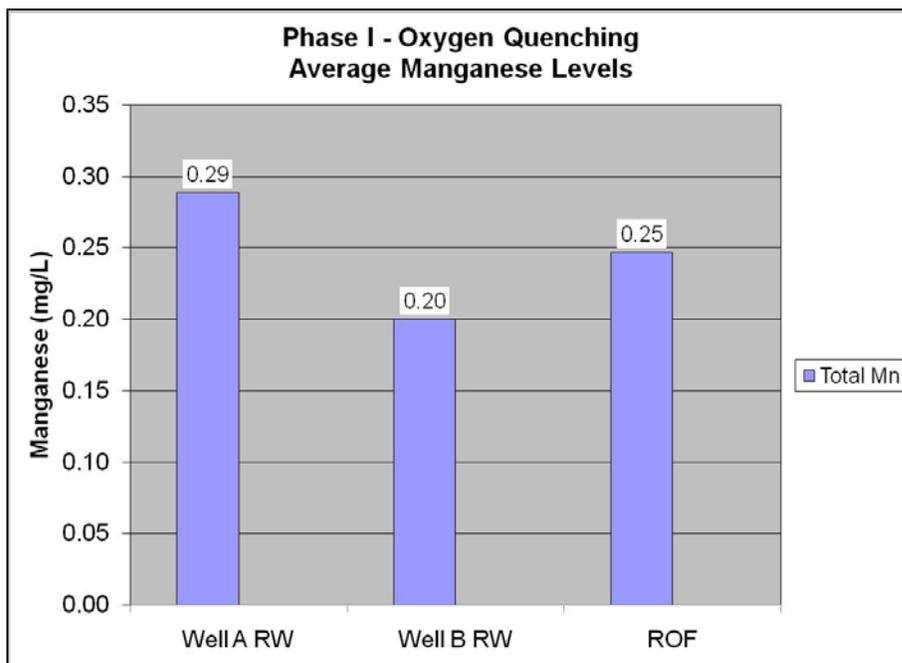


Figure 5.2-3.
Phase I – Average Manganese Levels

5.2.1.2 RO Membrane Performance

The first stage and second stage MTC (also referred to as membrane permeability), shown in Figure 5.2-4, remained approximately constant in Operating Conditions 1A through 1C, indicating that the membranes were not fouled when sodium thiosulfate was fed to quench oxygen in the raw water.

When sodium thiosulfate feed was stopped temporarily during part of Operating Condition 1D and all of Operating Condition 1E, the first stage MTC decreased rapidly due to membrane fouling, while the second stage MTC decreased more slowly. This data suggests that the membrane fouling was mainly caused by particulates, such as the oxidized iron particles, that would foul the first stage membranes more than the second stage membranes.

Restarting the sodium thiosulfate feed in Operating Condition 1F slightly slowed the membrane fouling but did not stop it, as shown in Figure 5.2-4. After the CIP on October 19, the MTCs were increased to approximately the same values as before the membrane fouling in Operating Condition 1E. This indicates that the CIP was successful, and the membranes were not irreversibly fouled.

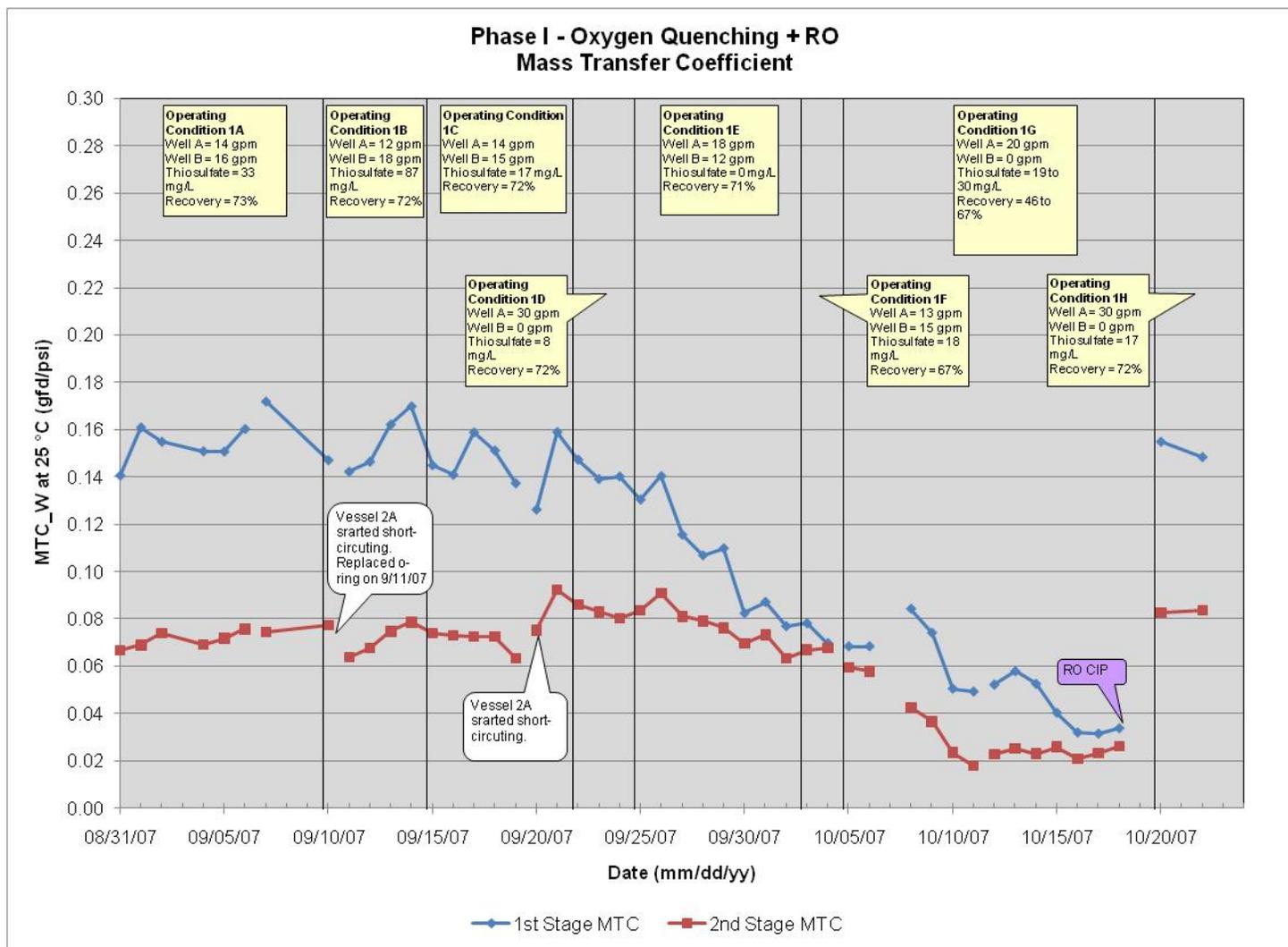


Figure 5.2-4.
Phase I – MTC_W at 25 °C

5.2.1.3 Water Quality

The water quality parameters tested during Phase I are summarized in Table 5.2-3.

Parameter	Detection Limit	Water Quality Goals		Water Quality Values, Median				
		Regulatory Requirement or Reporting Limit	City's Goals	Well A Raw Water	Well B Raw Water	RO Feed	RO Permeate	RO Waste
Temperature (°C)				--	--	22	--	--
pH		6.5 – 8.5	6.5 – 8.5	7.7	7.9	7.0	6.6	8.0
Conductivity (uS/cm ²)		900	900	2960	2260	2840	135	7175
UV254 (cm ⁻¹)				--	--	0.05	--	--
Color (C.U)	2	15	2	--	--	10	< 2	--
Total Iron (mg/L)	0.02	0.3	0.2	0.23	0.16	0.20	< 0.02	0.64
Total Manganese (mg/L)	0.005	0.05	0.02	0.28	0.20	0.25	< 0.005	0.63
Alkalinity as CaCO ₃ (mg/L)	2.0			300	240	265	10	940
Total Hardness as CaCO ₃ (mg/L)	0.66		120	--	--	890	3	3200
TDS (mg/L)	10	500	300	2000	1350	--	44	--
TSS (mg/L)	5			< 5	< 5	< 5	--	--
TOC (mg/L)	0.60			1.7	1.6	--	--	--
Ammonia (NH ₃ -N, mg/L)	0.017			0.81	0.32	--	0.03	1.15
Total Barium (mg/L)	0.0020			--	--	0.062	< 0.002	0.220
Total Boron (mg/L)	0.010	1	1	0.74	0.60	0.64	0.61	--
Calcium (mg/L)	0.10			--	--	250	0.83	910
Chloride (mg/L)	0.24	250	80	104	183	85	9.4	--
Magnesium (mg/L)	0.10			--	--	64	0.20	220
Silica (mg/L)	0.3			--	--	30.8	1.3	100.2
Sodium (mg/L)	0.50			210	140	170	10	--
Sulfate (mg/L)		250		1430	985	1195	5	2868
Total Strontium (mg/L)	0.0050			--	--	1.8	0.0089	6.6
Total Vanadium (mg/L)	0.0050			< 0.005	< 0.005	< 0.005	< 0.005	--
Gross Alpha (pCi/L)		15	15	15.1	7.65	--	0.48	--

Note:
-- Not measured.

Table 5.2-3 shows acceptable water quality for the RO permeate (ROP) for all parameters, including iron, manganese, TDS, chloride and sulfate.

5.2.1.4 Phase I Summary (Alternative 1)

Overall, oxygen quenching using sodium thiosulfate feed at the well pump discharges proved to be a successful pretreatment process to prevent metal oxide fouling of the RO membranes. However, when the sodium thiosulfate feed was stopped, iron oxidation immediately occurred and particulate fouling of the RO membranes started immediately. Particulate fouling of the membranes continued even when the sodium thiosulfate feed was resumed, and was stopped only when the membranes were cleaned with high concentrations of acid and caustic soda. Therefore, oxygen quenching pretreatment process must be carefully designed to safeguard against failure of the oxygen quenching agent.

5.2.2 Phase II – Aeration plus Media Filtration (Alternative 2)

The pretreatment process tested during Phase II was aeration plus media filtration. The objectives of this pretreatment evaluation, process description, pilot configuration, operating conditions, and testing protocol were detailed in Section 4.3.2. The primary objective was to oxidize dissolved iron into particulate iron and remove it with the media filters, while preventing the oxidation of manganese. A successful test would remove all iron in the media filters, prevent formation of particulate manganese, and prevent a loss in MTC across the RO membranes.

5.2.2.1 Oxidation Performance

Total iron, dissolved iron, total manganese, and dissolved manganese measurements are averaged for each operating condition of Phase II testing and summarized in Table 5.2-4.

	Time Period	WQ Parameters, Average Values	Well A Raw Water	Pre-treatment Feed ⁽¹⁾	Pre-treatment Product	RO Feed	RO Permeate	RO Waste
2A	10/30/07 - 11/09/07	Total Iron, (mg/L)	0.207	0.210	--	0.013	0.011	0.016
		Dissolved Iron, (mg/L)	0.182	0.158	--	0.008	≤ 0.008	0.010
		Total Manganese, (mg/L)	0.279	0.277	--	0.270	≤ 0.005	0.905
		Dissolved Manganese (mg/L)	--	0.278	--	0.268	--	--
2B	11/10/07 - 11/20/07	Total Iron, (mg/L)	0.196	0.193	--	≤ 0.008	≤ 0.008	0.013
		Dissolved Iron, (mg/L)	0.156	0.158	--	0.008	≤ 0.008	0.010
		Total Manganese, (mg/L)	0.259	0.255	--	0.256	≤ 0.005	0.788
		Dissolved Manganese (mg/L)	--	0.254	--	0.253	--	--
2C	11/21/07 - 11/21/07	Total Iron, (mg/L)	0.209	0.224	--	0.082	0.039	0.130
		Dissolved Iron, (mg/L)	0.087	0.109	--	0.017	≤ 0.008	0.010
		Total Manganese, (mg/L)	0.257	0.259	--	0.247	≤ 0.005	0.860
		Dissolved Manganese (mg/L)	--	0.288	--	0.276	--	--
2D	11/22/07 - 11/29/07	Total Iron, (mg/L)	0.208	0.211	--	≤ 0.008	≤ 0.008	0.013
		Dissolved Iron, (mg/L)	0.150	0.137	--	0.014	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.275	0.254	--	0.272	0.009	0.730
		Dissolved Manganese (mg/L)	--	0.253	--	0.273	--	--
2E	11/30/07 - 12/18/07	Total Iron, (mg/L)	0.189	0.168	--	0.009	≤ 0.008	0.008
		Dissolved Iron, (mg/L)	0.184	0.158	--	0.010	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.258	0.255	--	0.252	≤ 0.005	0.687
		Dissolved Manganese (mg/L)	--	0.253	--	0.252	--	--
2F	12/19/07 - 01/01/08	Total Iron, (mg/L)	0.188	0.175	--	0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.184	0.147	--	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.257	0.245	--	0.247	≤ 0.005	0.670

Table 5.2-4. Phase II – Aeration + Media Filtration + RO: Test Data per Operating Conditions								
	Time Period	WQ Parameters, Average Values	Well A Raw Water	Pre-treatment Feed ⁽¹⁾	Pre-treatment Product	RO Feed	RO Permeate	RO Waste
		Dissolved Manganese (mg/L)	--	0.243	--	0.242	--	--
2G	2/1/08	Total Iron, (mg/L)	0.166	0.166	--	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.170	0.149	--	≤ 0.008	≤ 0.008	≤ 0.008
2H	2/2/08 - 2/5/08	Total Iron, (mg/L)	0.179	0.151	--	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.175	0.166	--	≤ 0.008	≤ 0.008	≤ 0.008
2J	2/6/08 - 2/8/08	pH	7.5	8.0 ⁽²⁾	--	7.9	7.0	8.0
		Total Iron, (mg/L)	0.179	0.162	--	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.174	0.115	--	≤ 0.008	≤ 0.008	0.008
2L	2/11/08	pH	7.5	8.0 ⁽²⁾	--	7.9	6.8	8.0
		Total Iron, (mg/L)	0.176	0.167	--	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.171	0.148	--	≤ 0.008	≤ 0.008	≤ 0.008
2M	2/12/08 – 2/17/08	Total Iron, (mg/L)	0.169	0.163	≤ 0.008	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.166	0.150	≤ 0.008	≤ 0.008	≤ 0.008	≤ 0.008

(1) The pretreatment feed samples were grabbed from upstream of the contact tank from 10/30/07 through 12/11/07, and from downstream of the contact tank starting 12/12/07.

(2) pH of the pretreatment feed was raised to 8.0 by adding NaOH to Well A raw water. pH of the pretreatment feed was measured from samples grabbed from upstream of the contact tank.

-- Not measured.

NOTE: Iron and manganese levels were not measured during operating condition 2K, and manganese levels were not measured during operating conditions 2G through 2L.

Aeration

Phase I testing demonstrated that normal operation of Wells A and B entrained sufficient amounts of DO to oxidize some portion of dissolved iron if the DO was not quenched. The DO in the blended raw water requires either i) oxygen quenching to completely remove the DO to prevent iron oxidation, or ii) sufficient aeration to saturate the water with DO promoting complete iron oxidation.

Iron Oxidation

The average total iron concentration in Well A raw water was 0.20 mg/L, and the particulate iron was below the detection level (< 0.01 mg/L), as shown in Figure 5.2-5.

Aeration using an eductor increased the DO concentrations in the pretreatment feed (PTF) water to oxidize and remove iron. Approximately 95 percent of the total iron was oxidized and removed by the granular media filters (GMFs) when 6 minutes or more of contact time was provided (all operating conditions except Operating Condition 2C), as shown in Figure 5.2-5.

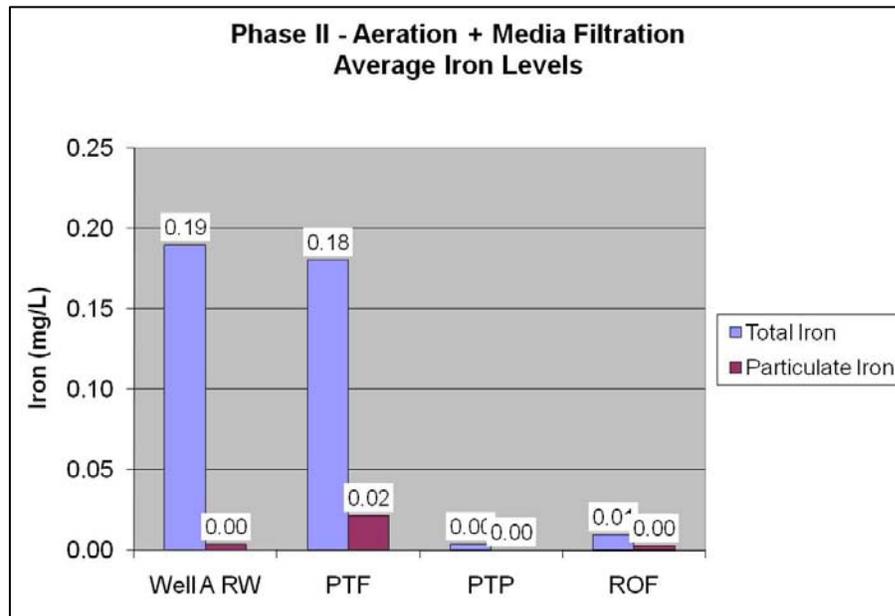


Figure 5.2-5.
Phase II – Average Iron Levels for Contact Time Greater than 6 Minutes

When the Contact Tank was bypassed during Operating Condition 2C, the effectiveness of the pretreatment process decreased. During Operating Condition 2C, about 60 percent of the total iron was oxidized and removed by the GMFs and about 40 percent passed through the GMFs as dissolved iron, providing a significant solids load onto the cartridge filters and RO membranes.

Iron Oxidation vs. Contact Time

The aeration plus media filtration pretreatment was effective at oxidizing and removing iron when a minimum of six minutes of contact time was provided. Figure 5.2-6 shows that the concentrations of total iron in the RO feed and the RO waste (ROW) were close to or below the detection level when the contact time was 6 minutes or more. Figure 5.2-6 also shows that aeration plus media filtration pretreatment was ineffective when the contact time was close to zero minutes. Note that concentrations below the detection level of 0.02 mg/L can be recorded by the testing method, however, the accuracy of these low values is uncertain. This can be noted in the fact that the RO waste often recorded identical iron concentrations to the RO feed when less than 0.02 mg/L was measured in the feed, but recorded significantly higher concentrations when greater than 0.02 mg/L were present in the feed.

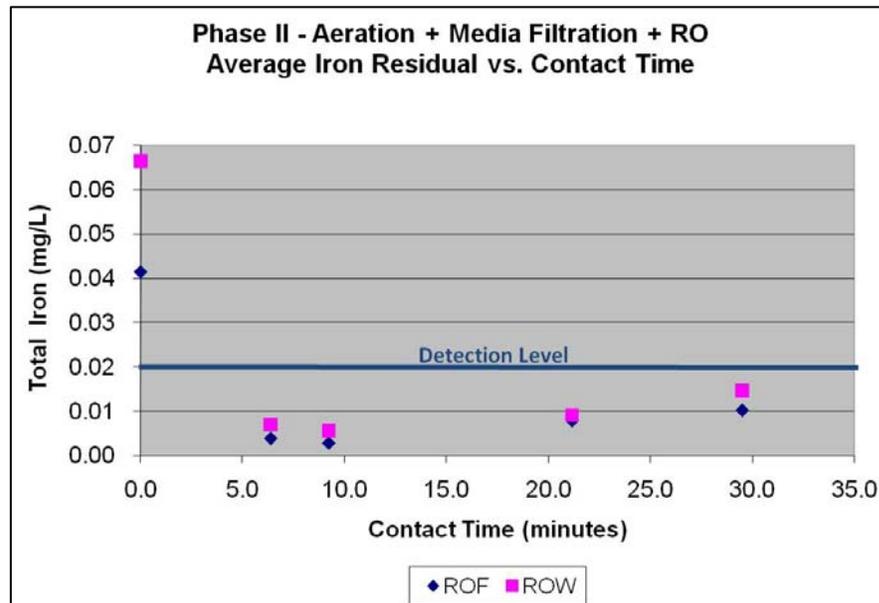


Figure 5.2-6.
Phase II – Average Total Iron Residual in ROF and ROW vs. Contact Time

Iron Oxidation vs. pH

pH adjustments of the raw water was conducted to determine whether increased pH could reduce the contact time required to oxidize the dissolved iron. While testing without pH adjustment had indicated that a minimum of 6 minutes of contact time were required for complete oxidation of iron, adjusting the pH to 8.0 allowed complete oxidation with nearly zero minutes of contact time. These results are presented in Figure 5.2-7. While this would indicate that pH adjustment was successful at accelerating iron oxidation, raising the pH with caustic soda also caused severe scaling in the piping, valves, media filters, and cartridge filters. The scaled media filters were cleaned with acid solution on February 13, 2008, and the cartridge filters were replaced as often as twice a day when the pH was raised. The antiscalant injection point was moved ahead of the aeration eductor in an attempt to reduce this scaling, however, this was not successful and the media filters, piping, valves, and cartridge filters continued to scale. Increasing the pH did not appear to be a feasible alternative for the Well A supply.

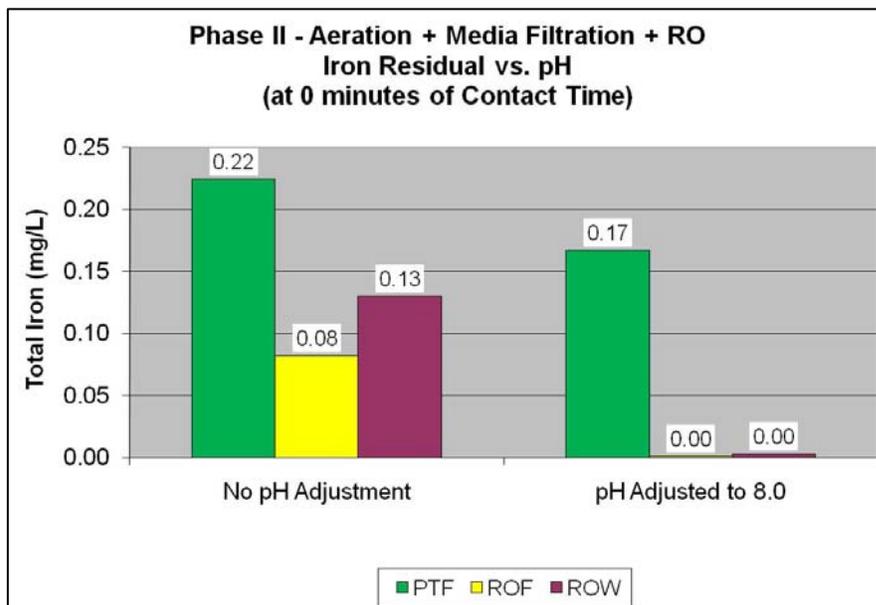


Figure 5.2-7.
Phase II –Total Iron Residual in PTF, ROF, and ROW vs. pH at Zero Minute Contact Time

Manganese Oxidation

Manganese appears to have been kept in the reduced state through the pretreatment processes, unaffected by aeration. Almost all of the total manganese in Well A raw water was fed to the RO membranes, all of it dissolved (in the reduced state) as shown in Figure 5.2-8. Also, the RO membranes effectively removed almost all of the dissolved manganese, as shown in Table 5.2-4.

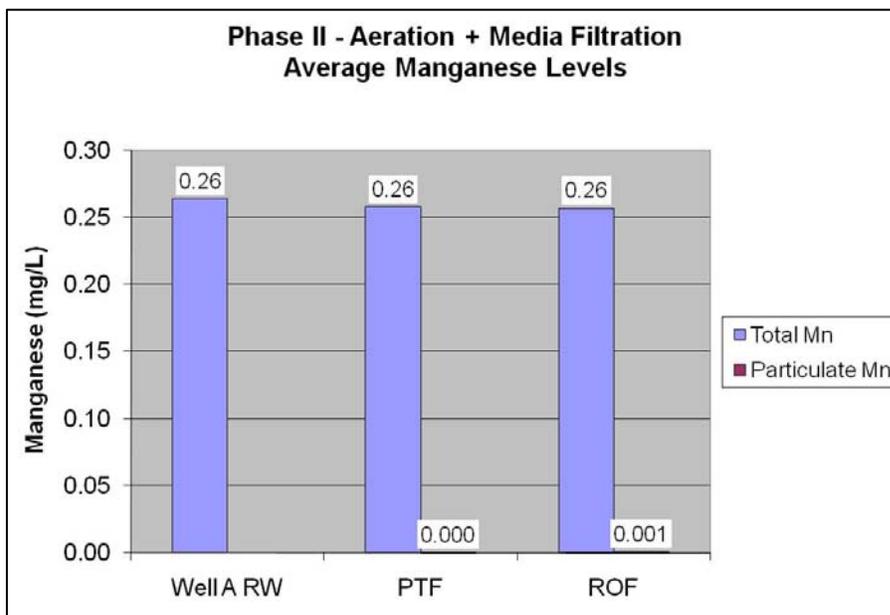


Figure 5.2-8.
Phase II – Average Manganese Levels (All Operating Conditions)

5.2.2.2 RO Performance

Phase II pretreatment method appears to be providing acceptable quality water for the RO, based on the low silt density index (SDI) numbers, typically less than 2, and the low iron in the RO feed, typically less than 0.01 mg/L.

A steady decline in MTC in the first stage, however, indicates that particulate fouling was occurring during Operating Conditions 2A through 2D, as shown on Figure 5.2-9. This fouling could be from particulate iron, or could be a result of algal growth observed in the equalization tank and cartridge filters prior to bypassing the equalization tank. It is because of this fouling, and the uncertainty of its cause, that a CIP was conducted on November 30, 2007. Phase II testing was therefore continued through the month of December 2007 to confirm whether the treatment process could be effective at preventing fouling on the RO.

The first stage MTC was more stable in December, but there was a slight decline in the first stage MTC toward the end of Operating Condition 2F that indicates particulate fouling. It appears that the GMF was more prone to iron breakthrough when the GMF loading rates was higher than 3.5 gpm/sf (e.g., Operating Conditions 2B and 2F). However, it is possible that a different media (lower effective size), deeper bed, or more aggressive backwashing approach could have allowed for a higher loading rate without breakthrough.

The first stage MTC and the second stage MTC for the additional Phase II pretreatment evaluation during January and February 2008 (e.g., Operating Conditions 2G through 2E) are also shown in Figure 5.2-9. Both the first stage and second stage MTC are relatively flat indicating that particulate fouling did not occur during this time.

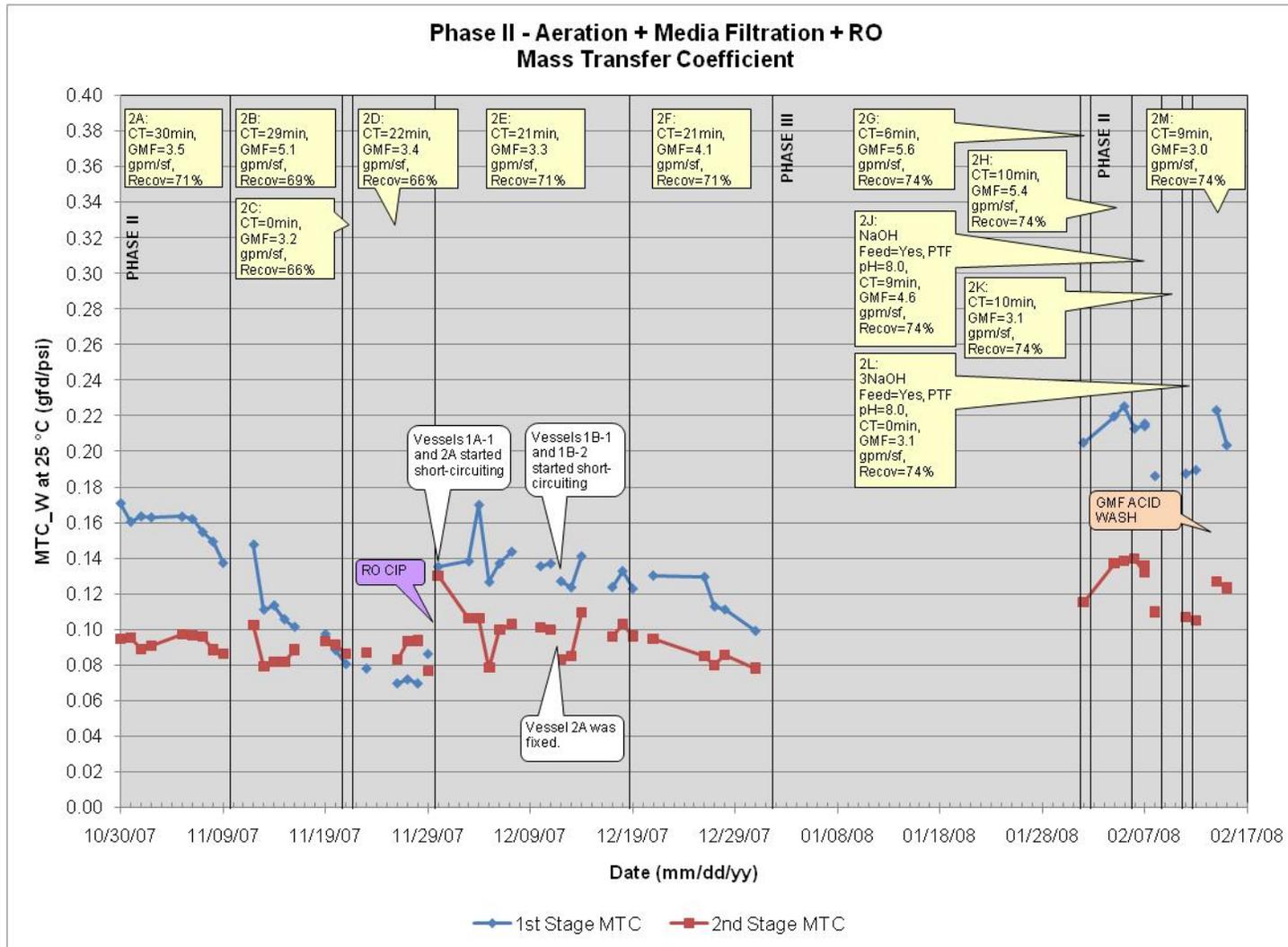


Figure 5.2-9.
Phase II – MTC_W at 25 °C

5.2.2.3 Water Quality

The water quality parameters tested during Phase II are summarized in Table 5.2-5.

Parameter	Detection Limit	Water Quality Goals		Water Quality			
		Regulatory Requirement or Reporting Limit	City's Goal	Well A Raw Water	RO Feed	RO Permeate	RO Waste
Temperature (°C)				--	21	--	--
pH		6.5 – 8.5	6.5 – 8.5	7.5	7.6	6.6	7.9
Conductivity (uS/cm ²)		900	900	2885	2930	148	7445
UV254 (cm ⁻¹)				0.04	0.03	--	--
Color (C.U)	2	15	2	5	3	< 2	--
Total Iron (mg/L)	0.02	0.3	0.2	0.19	0.01	< 0.001	0.01
Total Manganese (mg/L)	0.005	0.05	0.02	0.26	0.26	< 0.005	0.76
Alkalinity as CaCO ₃ (mg/L)	2.0			300	300	14	920
Total Hardness as CaCO ₃ (mg/L)	0.66		120	1000	980	4	3400
TDS (mg/L)	10	500	300	1850	1800	63	--
TSS (mg/L)	5			< 5	5	--	7
TOC (mg/L)	0.60			1.7	2.0	--	--
Ammonia (NH ₃ -N, mg/L)	0.017			0.25	--	< 0.017	0.19
Total Barium (mg/L)	0.0020			--	0.056	< 0.002	0.170
Total Boron (mg/L)	0.010	1	1	0.75	--	0.65	--
Calcium (mg/L)	0.10			--	270	1.0	955
Chloride (mg/L)	0.24	250	80	92	--	10	--
Magnesium (mg/L)	0.10			--	74	0.24	235
Silica (mg/L)	0.3			31	--	2.6	78
Sodium (mg/L)	0.50			--	205	13	--
Sulfate (mg/L)		250		1320	--	1.1	3040
Total Strontium (mg/L)	0.0050			--	2.1	0.0051	6.3
Total Vanadium (mg/L)	0.0050			< 0.005	--	< 0.005	--
Gross Alpha (pCi/L)		15	15	8.9	--	1.7	--
Note: -- Not measured.							

Table 5.2-5 shows acceptable water quality for the RO permeate for all parameters, including iron, manganese, TDS, chloride and sulfate. In particular, the TDS level in the RO permeate was 63 mg/L, much lower than the City's goal of 300 mg/L.

However, boron concentrations in Well A raw water have been measured at 0.75 mg/L, approximately twice their historic levels, as shown in Table 5.2-5. While this level is still lower than the California Department of Public Health (CDPH) notification level of 1 mg/L, the measured concentrations could create toxicity concerns for certain plants, such as roses and citrus, among others. Boron is difficult to remove with brackish RO elements, and is present in the RO permeate at concentrations only 10 to 20 percent lower than in the feed water, as shown in Table 5.2-5.

5.2.2.4 Phase II Summary (Alternative 2)

The aeration plus media filtration pretreatment was effective at oxidizing and removing iron when a minimum of six minutes of contact time was provided. Providing additional contact time, beyond six minutes, did not have significant impact on iron oxidation. Complete iron oxidation was achieved with zero minute contact time when the pH was elevated to 8.0 standard units using caustic soda, however, pH adjustment was found to cause severe scaling in the piping, valves, the granular media filters, and the cartridge filters.

Although the particulate iron levels did not indicate iron breakthrough at any point in the testing, an observed decrease in first stage MTC suggests that the GMFs are more prone to solids breakthrough when the GMF loading rates are higher than 3.5 gpm/sf. Higher loading rates may be sustainable, however, if utilizing media with greater depth, smaller effective size, or a more aggressive backwashing approach than utilized in the pilot.

5.2.3 Phase III – Chlorine Dioxide Feed plus Media Filtration (Alternative 3)

The pretreatment process tested during Phase III was chlorine dioxide (ClO₂) feed plus media filtration. The objectives of this pretreatment evaluation, process description, pilot configuration, operating conditions, and testing protocol were described previously in Section 4.3.3. The primary objective was to oxidize both dissolved iron and dissolved manganese into particulate iron and manganese, removing both with the media filters. A successful test would remove all iron and manganese in the media filters and prevent a loss in MTC across the RO membranes.

5.2.3.1 Oxidation Performance

Chlorine dioxide, total iron, dissolved iron, total manganese, and dissolved manganese measurements are averaged for each operating condition of Phase III testing and summarized in Table 5.2-6.

Table 5.2-6.							
Phase III – Chlorine Dioxide Feed + Media Filtration + RO: Test Data per Operating Conditions							
	Time Period	WQ Parameters, Average Values	Well A Raw Water	Pre-treatment Feed ⁽²⁾	RO Feed	RO Permeate	RO Waste
3A	01/02/08-01/07/08	pH	7.3	7.3	7.3	6.3	7.8
		Chlorine Dioxide, (mg/L)	1.6 ⁽¹⁾	1.65	0.30	0.23	--
		Total Iron, (mg/L)	0.177	0.166	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.181	0.012	≤ 0.008	≤ 0.008	0.009
		Total Manganese, (mg/L)	0.238	0.214	0.059	≤ 0.005	0.230
		Dissolved Manganese (mg/L)	0.215	0.059	0.057	0.006	0.015
3B	01/08/08-01/11/08	pH	7.3	7.3	7.3	6.4	7.7
		Chlorine Dioxide, (mg/L)	1.7 ⁽¹⁾	1.61	0.56	0.56	--
		Total Iron, (mg/L)	0.174	0.168	0.009	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.171	≤ 0.008	≤ 0.008	≤ 0.008	0.009
		Total Manganese, (mg/L)	0.245	0.208	0.063	≤ 0.005	--
		Dissolved Manganese (mg/L)	0.222	0.066	0.065	0.007	--
3D	01/14/08-01/15/08	pH	7.3	8.1 ⁽⁴⁾	7.7	6.8	7.8
		Chlorine Dioxide, (mg/L)	1.8 ⁽¹⁾	1.02	0.13	0.10	--
		Total Iron, (mg/L)	0.182	0.167	0.054	≤ 0.008	0.165
		Dissolved Iron, (mg/L)	0.181	≤ 0.008	≤ 0.008	≤ 0.008	0.008
		Total Manganese, (mg/L)	0.243	0.219	0.083	≤ 0.005	--
		Dissolved Manganese (mg/L)	0.230	0.062	0.061	≤ 0.005	--
3E	01/16/08	pH	7.3	7.1	7.3	6.5	7.8
		Chlorine Dioxide, (mg/L)	0.0 ⁽¹⁾	≤ 0.04	--	--	--
		Total Iron, (mg/L)	--	--	--	--	--
		Dissolved Iron, (mg/L)	0.176	0.120	0.010	≤ 0.008	0.015
		Total Manganese, (mg/L)	0.255	0.280	0.096	≤ 0.005	--

Table 5.2-6.							
Phase III – Chlorine Dioxide Feed + Media Filtration + RO: Test Data per Operating Conditions							
	Time Period	WQ Parameters, Average Values	Well A Raw Water	Pre-treatment Feed ⁽²⁾	RO Feed	RO Permeate	RO Waste
		Dissolved Manganese (mg/L)	0.254	0.251	0.114	0.006	--
3F	01/17/08-01/22/08	pH	7.3	7.3	7.2	6.4	7.7
		Chlorine Dioxide, (mg/L)	2.1 ⁽¹⁾	1.54 ⁽³⁾	0.17	--	--
		Total Iron, (mg/L)	0.170	0.172	≤ 0.008	≤ 0.008	0.008
		Dissolved Iron, (mg/L)	0.171	0.011	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.240	0.228	0.061	≤ 0.005	0.315
		Dissolved Manganese (mg/L)	0.238	0.075	0.069	0.011	0.344
3G	01/23/08	pH	7.4	7.3	7.3	6.7	7.7
		Chlorine Dioxide, (mg/L)	1.9 ⁽¹⁾	1.40 ⁽³⁾	0.26	0.28	--
		Total Iron, (mg/L)	0.175	0.169	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.176	≤ 0.008	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.257	0.230	0.075	≤ 0.005	0.230
		Dissolved Manganese (mg/L)	0.253	0.085	0.088	≤ 0.005	0.300
3H	01/24/08	pH	7.4	7.3	7.4	6.6	7.8
		Chlorine Dioxide, (mg/L)	1.8 ⁽¹⁾	1.47 ⁽³⁾	0.29	0.22	--
		Total Iron, (mg/L)	0.176	0.165	≤ 0.008	0.009	≤ 0.008
		Dissolved Iron, (mg/L)	0.167	≤ 0.008	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.247	0.214	0.065	≤ 0.005	0.250
		Dissolved Manganese (mg/L)	0.220	0.084	0.080	0.014	0.300
3J	01/25/08	pH	7.4	7.3	7.5	6.6	7.8
		Chlorine Dioxide, (mg/L)	1.6 ⁽¹⁾	1.47 ⁽³⁾	0.47	0.50	--
		Total Iron, (mg/L)	0.174	0.165	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.170	≤ 0.008	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.259	0.230	0.081	≤ 0.005	0.250
		Dissolved Manganese (mg/L)	0.247	0.091	0.069	0.005	0.230
3K	01/28/08	pH	7.5	7.4	7.4	6.6	7.8
		Chlorine Dioxide, (mg/L)	1.3 ⁽¹⁾	0.82 ⁽³⁾	0.15	0.06	--
		Total Iron, (mg/L)	0.169	0.171	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.173	≤ 0.008	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.240	0.212	0.137	≤ 0.005	0.400
		Dissolved Manganese (mg/L)	0.227	0.119	0.067	≤ 0.005	0.350
3L	01/29/07-01/31/08	pH	7.4	7.3 ⁽³⁾	7.4	6.6	7.8
		Chlorine Dioxide, (mg/L)	1.1 ⁽¹⁾	0.90 ⁽³⁾	0.06	0.06	--
		Total Iron, (mg/L)	0.167	0.177	0.012	≤ 0.008	0.015
		Dissolved Iron, (mg/L)	0.163	≤ 0.008	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.241	0.231	0.087	≤ 0.005	0.297
		Dissolved Manganese (mg/L)	0.234	0.077	0.083	0.009	0.275

(1) Chlorine dioxide dose injected to Well A raw water.

Table 5.2-6.							
Phase III – Chlorine Dioxide Feed + Media Filtration + RO: Test Data per Operating Conditions							
	Time Period	WQ Parameters, Average Values	Well A Raw Water	Pre-treatment Feed ⁽²⁾	RO Feed	RO Permeate	RO Waste
(2) All pretreatment feed samples were grabbed from downstream of the contact tank, unless otherwise noted. (3) Measured in the pretreatment feed sample grabbed upstream of the contact tank. (4) pH raised to 8.1 by adding NaOH to Well A raw water. -- Not measured. NOTE: Iron and manganese levels were not measured during operating condition 3C.							

Chlorine Dioxide Dose and Demand

The chlorine dioxide dose fed to Well A raw water, and the chlorine dioxide levels in the pretreatment feed and the RO feed are shown in Figure 5.2-10. On average, chlorine dioxide was dosed at approximately 1.7 mg/L, and the chlorine dioxide residual measured in the RO feed sample was 0.29 mg/L. The chlorine dioxide demand fluctuated from 0.8 to 2.1 mg/L, with an average of 1.4 mg/L.

The chlorine dioxide test, USEPA accepted DPD Method, was tested for interferences from oxidized manganese in the water samples, starting January 24, 2008. On average, the chlorine dioxide test interference due to oxidized manganese was 0.4 mg/L in the pretreatment feed, and 0.05 mg/L in the RO feed. The chlorine dioxide test interference was greater in the pretreatment feed sample because the pretreatment feed sample had higher concentrations of oxidized manganese than the RO feed sample. Correcting the chlorine dioxide measurements for oxidized manganese interferences, the average chlorine dioxide residual measured in the RO feed sample was 0.24 mg/L, and the average chlorine dioxide demand was 1.5 mg/L.

Based on the typical chlorine dioxide dosages needed to oxidize iron and manganese, it appears 0.6 mg/L of the 1.5 mg/L chlorine dioxide demand was used for oxidizing these minerals. Other oxidant demanding substances, such as organics, appear to have contributed to the remaining 0.9 mg/L demand. In addition, these other demands competed for the chlorine dioxide available to complete the oxidization of dissolved manganese, leaving a fraction of the manganese in a reduced (non-oxidized) state.

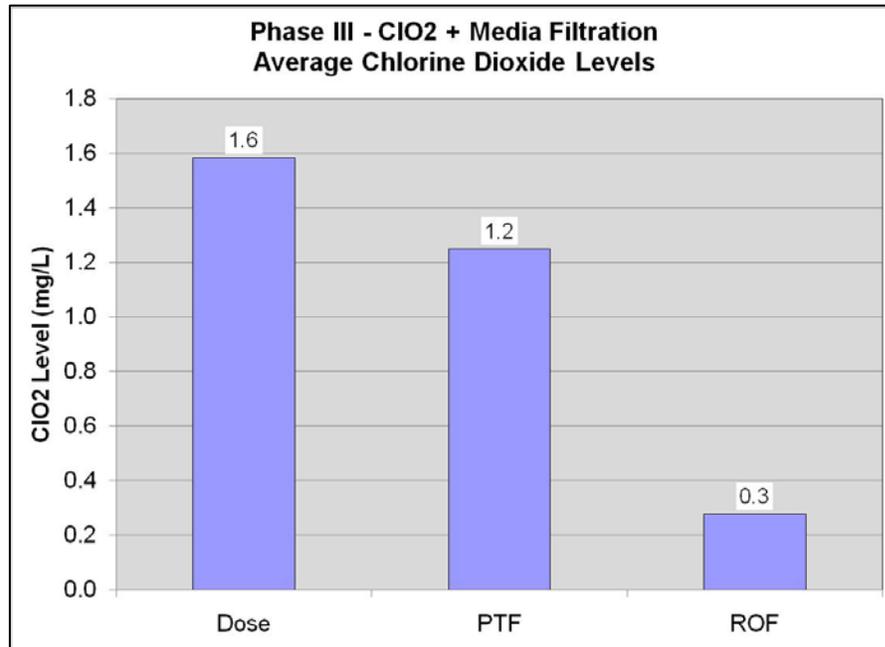


Figure 5.2-10.
Phase III – Average Chlorine Dioxide Levels

Iron Oxidation

The total and dissolved iron data shows that the chlorine dioxide feed plus media filtration is an effective pretreatment process for removing iron by oxidation and filtration. Figure 5.2-11 summarizes the average total iron and particulate iron levels in the Well A raw water, the pretreatment feed and the RO feed.

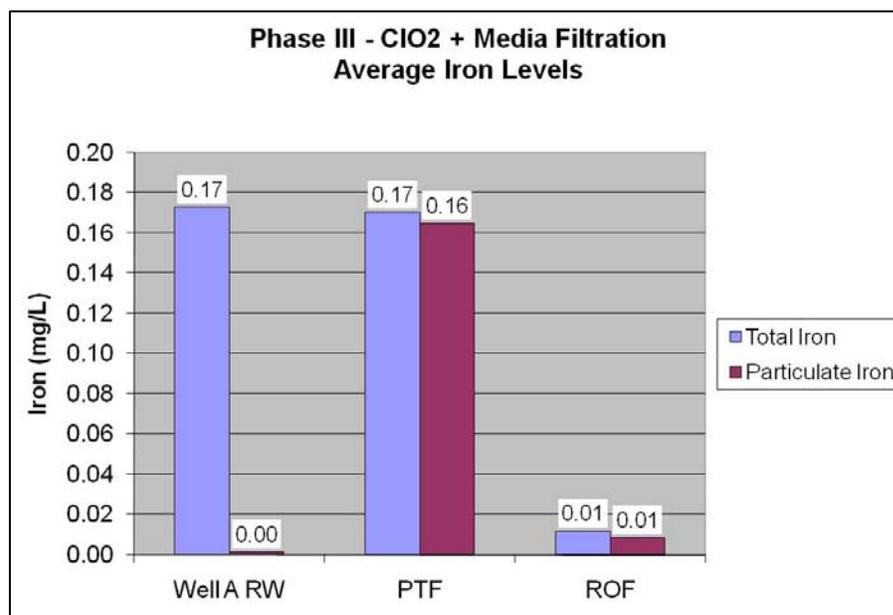


Figure 5.2-11.
Phase III – Average Iron Levels

The total and particulate iron data for Well A raw water and the pretreatment feed shows that chlorine dioxide oxidized nearly 100 percent of iron when chlorine dioxide was dosed. The only time iron was not fully oxidized was on January 16, 2008, when chlorine dioxide feed was stopped.

The contact time had no effect on iron oxidation because chlorine dioxide reacts with iron nearly instantaneously. Although the contact time was reduced to nearly zero minutes by bypassing the contact tank during Operating Condition 3K, nearly 100 percent of iron was oxidized. The pH adjustment also had no effect on iron oxidation.

On all days except January 14, 2008, the total iron concentrations were nearly non-detect in the RO feed, which indicates that the iron was nearly 100 percent oxidized and removed by the granular media filters and/or the cartridge filters.

On January 14, 2008, on the sixth day after the last change-out of the cartridge filters, the cartridge filters were heavily fouled (see Figure 5.2-12) and particulate iron was evidently breaking through to the RO membranes. After the cartridge filters were replaced on January 15, 2008, the total and dissolved iron in the RO feed was nearly non-detect on all days including January 16, 2008, when the chlorine dioxide dose was zero.



Figure 5.2-12.
Phase III - Heavily Fouled Cartridge Filters

The presence of oxidized iron on the cartridge filters, in spite of the high rate of oxidation ahead of the media filters is indication that the media filters were only partially effective at removing oxidized iron, even at the low filtration rates utilized during this testing (averaging between 3 to 5 gpm/sf). It is likely that the accumulation of oxidized iron in the media was not being fully removed through the backwashing approach, and more aggressive backwashing, perhaps with the addition of air scour, may have been required. Such capabilities were not available for the pilot unit, with backwashing limited to 15 gpm/sf.

Manganese Oxidation

The total and particulate manganese data shows that chlorine dioxide feed plus media filtration pretreatment removed 55 percent to 80 percent of total manganese. On average, 70 percent of total manganese was oxidized and removed by pretreatment. Figure 5.2-13 summarizes the average total and particulate manganese levels in the Well A raw water, the pretreatment feed and the RO feed.

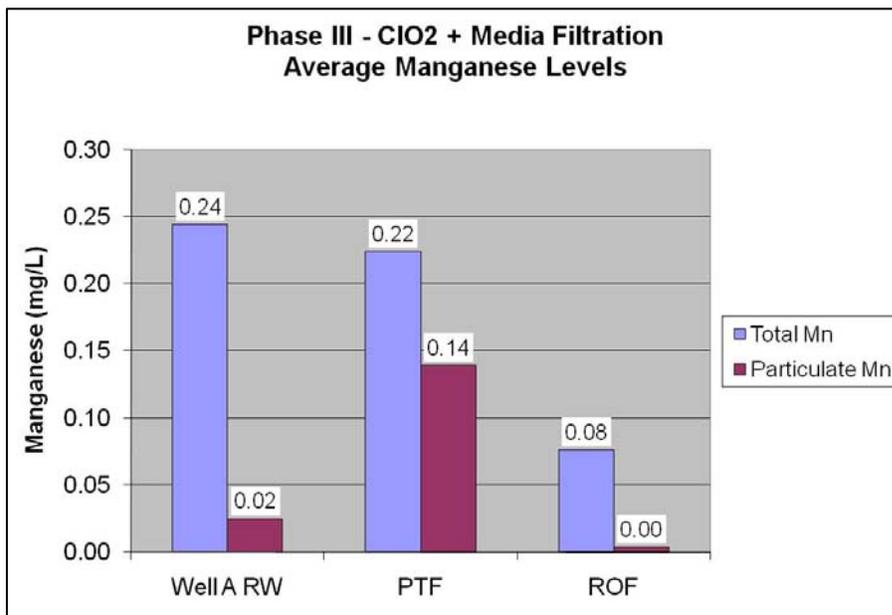


Figure 5.2-13.
Phase III – Average Manganese Levels

The total and dissolved manganese data for the RO feed shows that 0.08 mg/L of total manganese in the RO feed was nearly all in the dissolved stage. Further, it should be noted that these manganese levels were nearly equivalent to the dissolved manganese levels upstream of the media filters (e.g., total manganese in the pretreatment feed - particulate manganese in the pretreatment feed). The data indicates that approximately 0.08 mg/L of dissolved manganese that was not oxidized during the pretreatment stage did not get oxidized in the RO, even in the presence of residual chlorine dioxide in the RO feed. Although the chlorine dioxide oxidized only 70 percent of total manganese, the remaining 30 percent of total manganese that was dissolved in the RO feed water remained dissolved and was removed by desalination process without causing particulate fouling of the RO.

Manganese Oxidation vs. Dose

Manganese oxidation was slightly improved with increased chlorine dioxide dose as shown in Figure 5.2-14. Up to 80 percent of manganese oxidation was achieved with chlorine dioxide dose between 1.5 mg/L and 2.2 mg/L. Higher doses were not tested, and it is unclear whether complete oxidation of manganese could have been achieved with substantially higher doses than those employed.

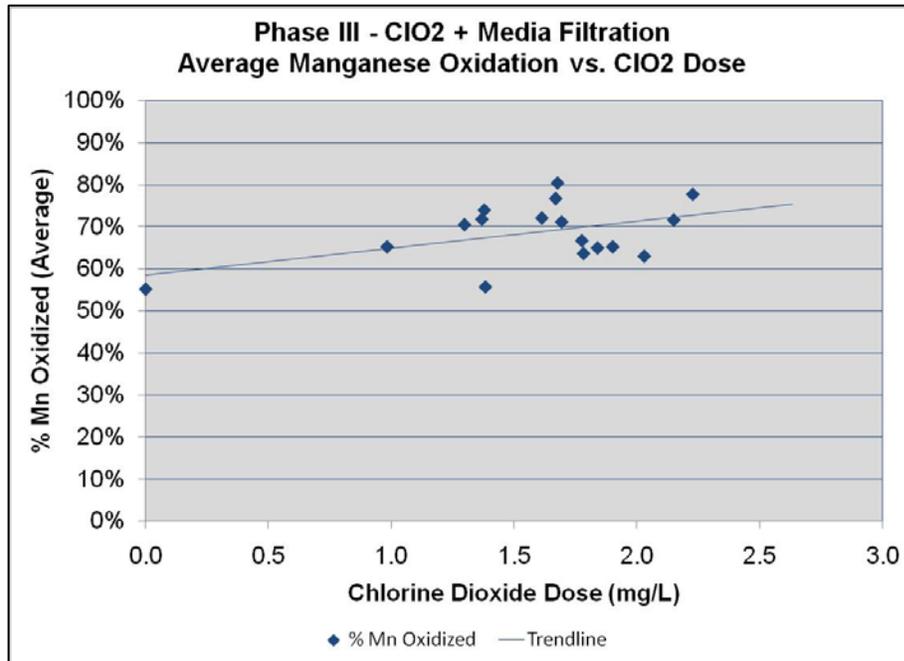


Figure 5.2-14.
Phase III – Average Manganese Oxidation vs. Chlorine Dioxide Dose

Manganese Oxidation vs. Contact Time

The contact time had no apparent impact on manganese oxidation. On average, the same amount of manganese was oxidized with nearly zero minutes of contact time as with 37 minutes of contact time. Figure 5.2-15 shows the average manganese oxidation rates per contact time.

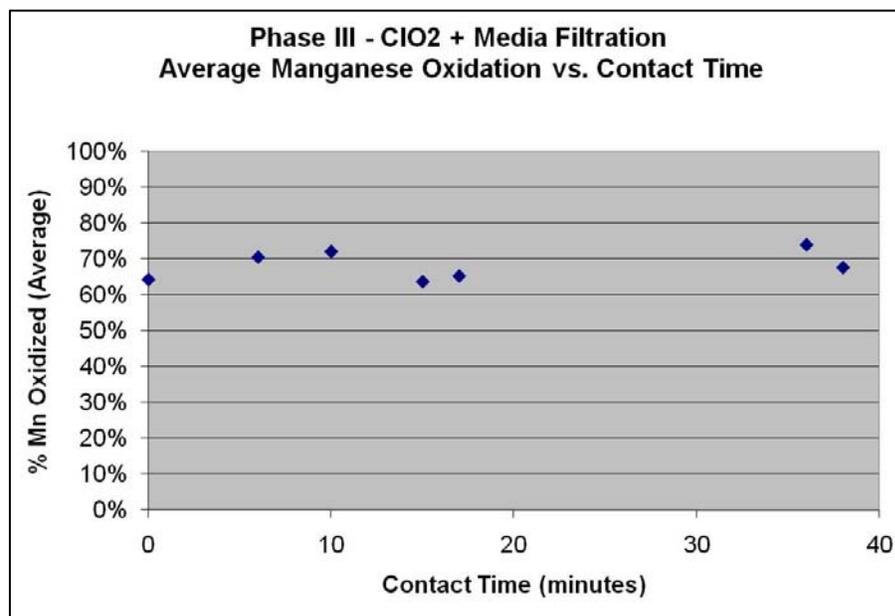


Figure 5.2-15.
Phase III – Average Manganese Oxidation vs. Contact Time

Manganese Oxidation vs. pH

It appears that raising the Well A raw water pH from 7.3 to 8.1 also did not improve manganese oxidation rate significantly (see Figure 5.2-16), however, elevating the pH was found during Phase II testing to cause considerable scaling from calcium carbonate in the piping, valves, and media filters.

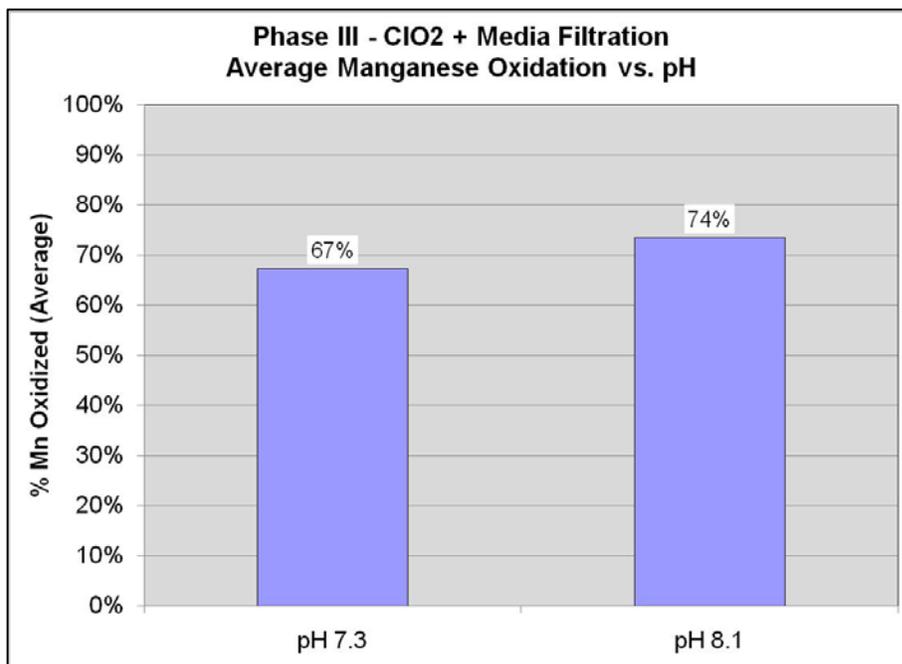


Figure 5.2-16.
Phase III - Average Manganese Oxidation vs. pH

5.2.3.2 Filtration Performance

Granular Media Filters Performance

The GMFs were fouled at a much faster rate during this phase than during Phase II, with the GMFs removing both oxidized iron and oxidized manganese. Table 5.2-7 summarizes the estimated fouling rates of the GMFs. The differential pressure across the GMFs increased by 1.5 psi/day at the hydraulic loading rate of 3.0 gpm/sf, and 3.6 psi/day at the hydraulic rate of 4.5 to 4.7 gpm/sf. The higher fouling rates require more frequent backwashes.

When caustic soda was used to raise the pH of Well A raw water from 7.3 to 8.1, the GMFs were fouled at a much faster rate due to added fouling from scale build-up. The differential pressure across the GMFs increased by as much as 13 psi/day at the hydraulic loading rate of 5.1 gpm/sf. Consequently, an acid soak and backwash was required to fully remove the scale which had built up on the GMFs.

Table 5.2-7.
Phase III – Chlorine Dioxide Feed + Media Filtration: GMF Fouling Rate

GMF Loading Rate (gpm/sf)	Without pH Adjustment (pH 7.3) Average GMF Fouling Rate (psi/day)	With pH Adjustment (pH 8.1) Average GMF Fouling Rate (psi/day)
3.0	1.5	4.8
4.5 to 4.7	3.6	--
5.1	--	13

Cartridge Filters Performance

It was evident that the GMFs did not remove all oxidized iron or manganese based on the heavy fouling rate of the cartridge filters, which were replaced weekly. High total iron level in the RO feed on January 14, 2008, was evidence of particulate iron break-through. Also, the high SDI numbers measured on January 10 and January 29, 2008, two or more days after the cartridge filters replacement, as opposed to a low SDI number measured on January 23, less than a day after the cartridge filters change-out, may be evidence of particulate break-through.

Table 5.2-8 summarizes the estimated fouling rates of the cartridge filters. On average, the differential pressure across the cartridge filters increased by more than 1.2 psi/day when caustic soda was not used for pH adjustment. However, the fouling rate of the cartridge filters approximately doubled due to scale build-up when caustic soda was used to raise the pH of the Well A water.

Table 5.2-8.
Phase III – Chlorine Dioxide Feed + Media Filtration: Cartridge Filter Fouling Rate

Sets	Date	No. of Hours Used	NaOH Used for pH Adjustment	Initial Differential Pressure (psi)	Final Differential Pressure (psi)	Fouling rate (psi/day)
1	1/2/08 -1/8/08	137	No	--	--	--
2	1/8/08 - 1/15/08	151	Yes	~ 5	≥ 20	≥ 2.4
3	1/15/08 - 1/22/08	137	No	4	≥ 10.5	≥ 1.2
4	1/22/08 - 1/31/08	204	No	5	≥ 18	≥ 1.5

While iron was clearly evident in the fouled cartridge filters, black manganese colored foulant was also observed on the cartridge filters during Phase III. The fouled cartridge filters were dark brown in color while they were wet, but patches of black manganese were clearly visible when they were dry. This indicates that the media filters were only partially effective at removing the oxidized manganese, even at the low filtration rates, averaging between 3 to 5 gpm/sf, tested during Phase III. As stated previously, a more aggressive backwashing approach, utilizing an air scour,

may be required to prevent breakthrough of this type, however, it may also be necessary to utilize filters with smaller effective size media or a deeper bed depth.

The spent cartridge filters from Phase III (ClO₂ + GMF), were dark brown overall with patches of black manganese (see Figure 5.2-17). This compares against the fouled cartridge filters from Phase II (aeration + GMF), which were uniformly rust colored without black manganese fouling (see Figure 5.2-18).



Figure 5.2-17.
Fouled Cartridge Filters from Phase III (ClO₂ + Media Filtration)



Figure 5.2-18.
Fouled Cartridge Filters from Phase II (Aeration + Media Filtration)

5.2.3.3 RO Performance

The first stage MTC and the second stage MTC are shown in Figure 5.2-19, respectively. MTC is a measure of membrane performance, with fouled membranes demonstrating a drop or reduction in MTC. The first stage MTC shows a slight upward trend during most operating conditions, with a slight downward trend during the latter stages of testing. Overall, the first stage MTC looks relatively flat, indicating that particulate fouling was not a significant concern during this stage of testing. The slight rise in MTC during the first 3 weeks of Phase III testing, however, is a concern, as it indicates that membrane damage was occurring from chlorine dioxide or hypochlorite residuals in the chlorine dioxide. It should be noted that ultra-pure chlorine dioxide from CDG Research Corporation was used for this pilot

testing to avoid the risk of membrane damage from residual hypochlorite, chlorite, or chlorate byproducts. The CDG product is reported to be greater than 99.8 percent pure in chlorine dioxide, without significant residual concentrations of byproducts known to damage RO membranes. Our data suggests, however, that either the purity of chlorine dioxide was less than anticipated, or the chlorine dioxide itself caused significant damage to the membranes.

RO membrane damage is also evident in permeate conductivities shown in Figures 5.2-20 and 5.2-21. Standard brackish water membranes (Saehan BLR), used in Vessels 1B-1, 1B-2 and 2B, show evidence of damage with a steadily increasing permeate conductivity in all three vessels (see Figure 5.2-21). The chlorine resistant membranes (Saehan CRM), used in Vessels 1A-1, 1A-2 and 2A, did not show consistent evidence of membrane damage during the testing period (see Figure 5.2-20).

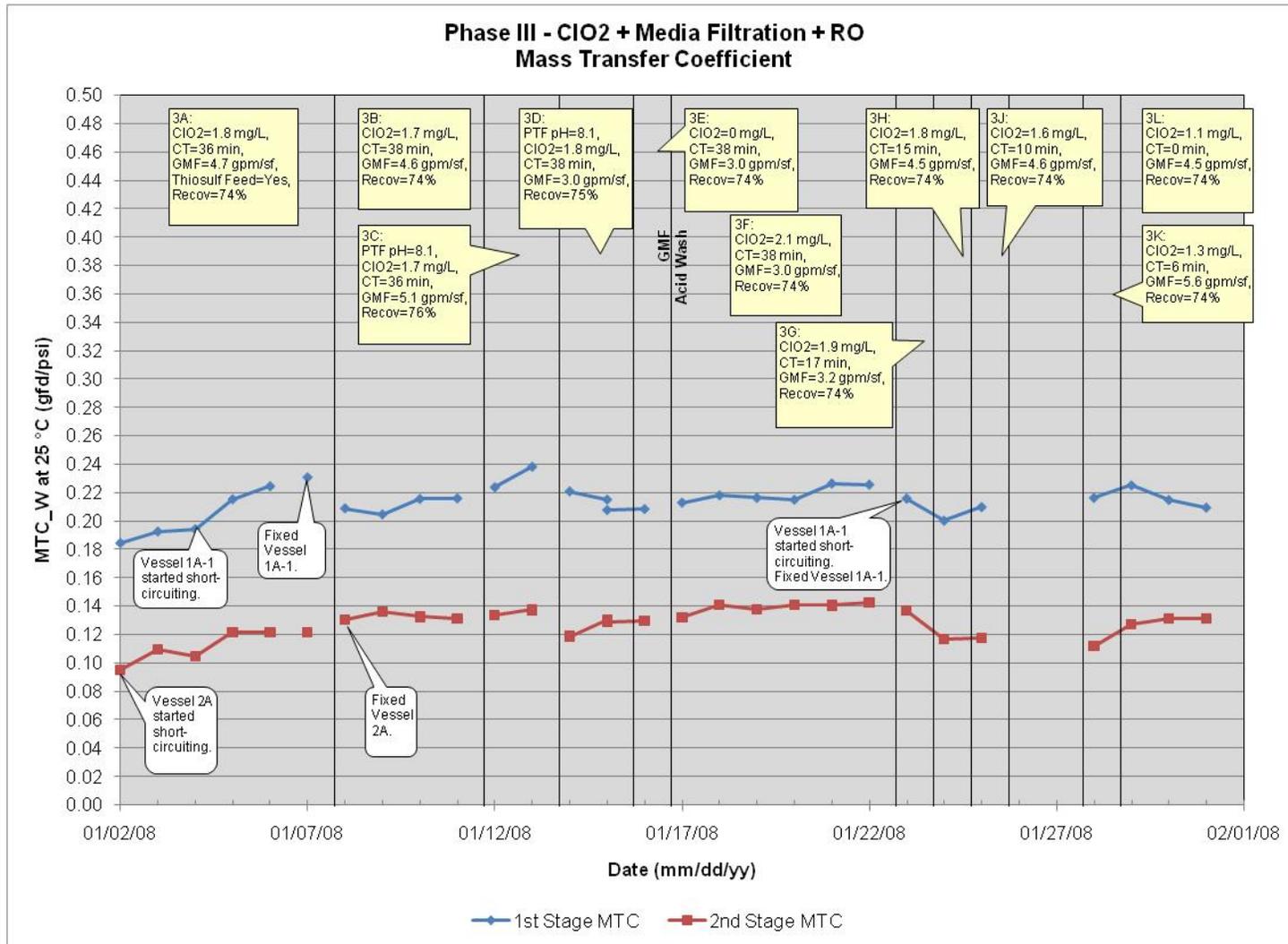


Figure 5.2-19.
Phase III – MTC_W at 25 °C

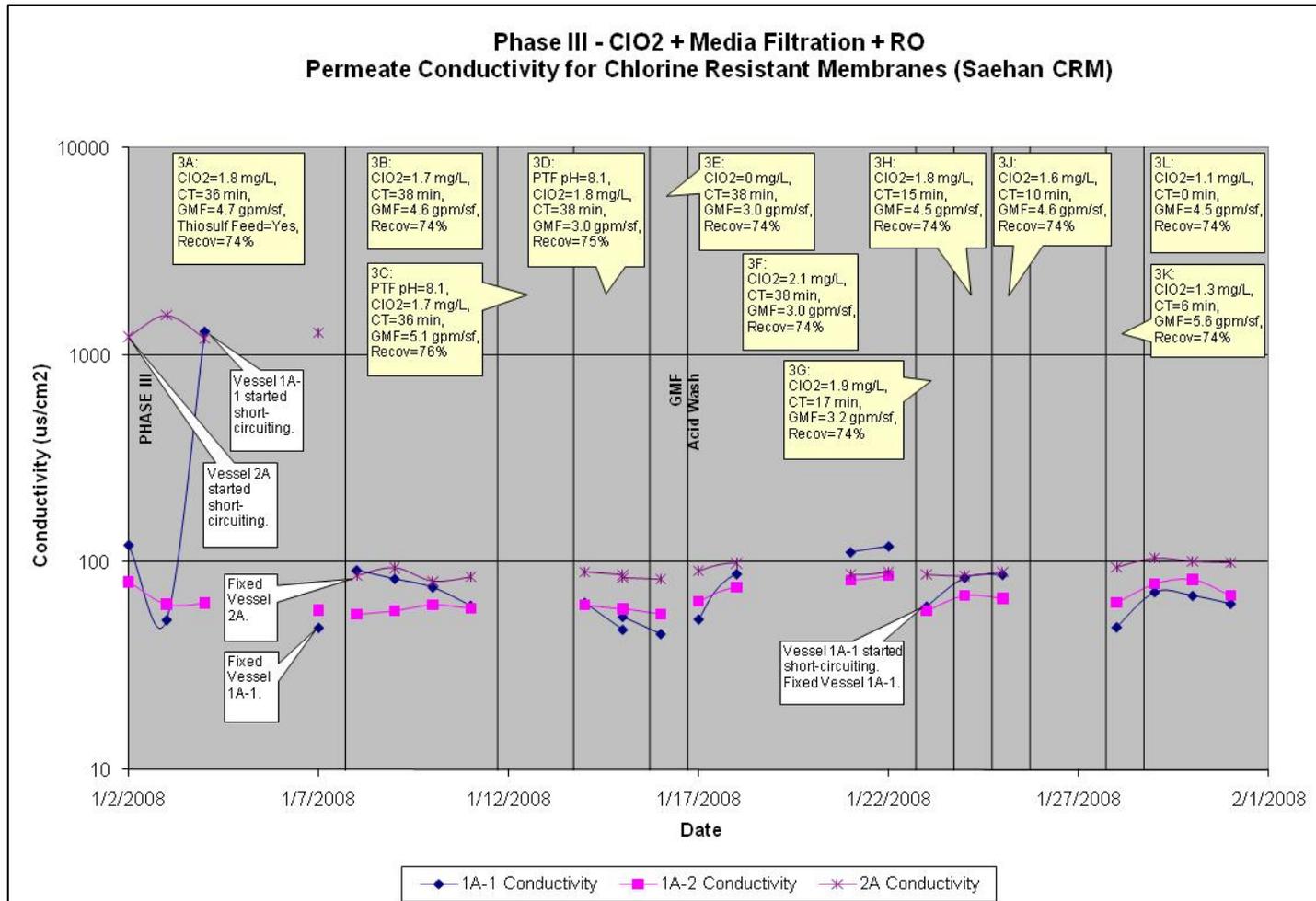


Figure 5.2-20.
Phase III – Permeate Conductivity for Chlorine Resistant Membranes (Saehan CRM)

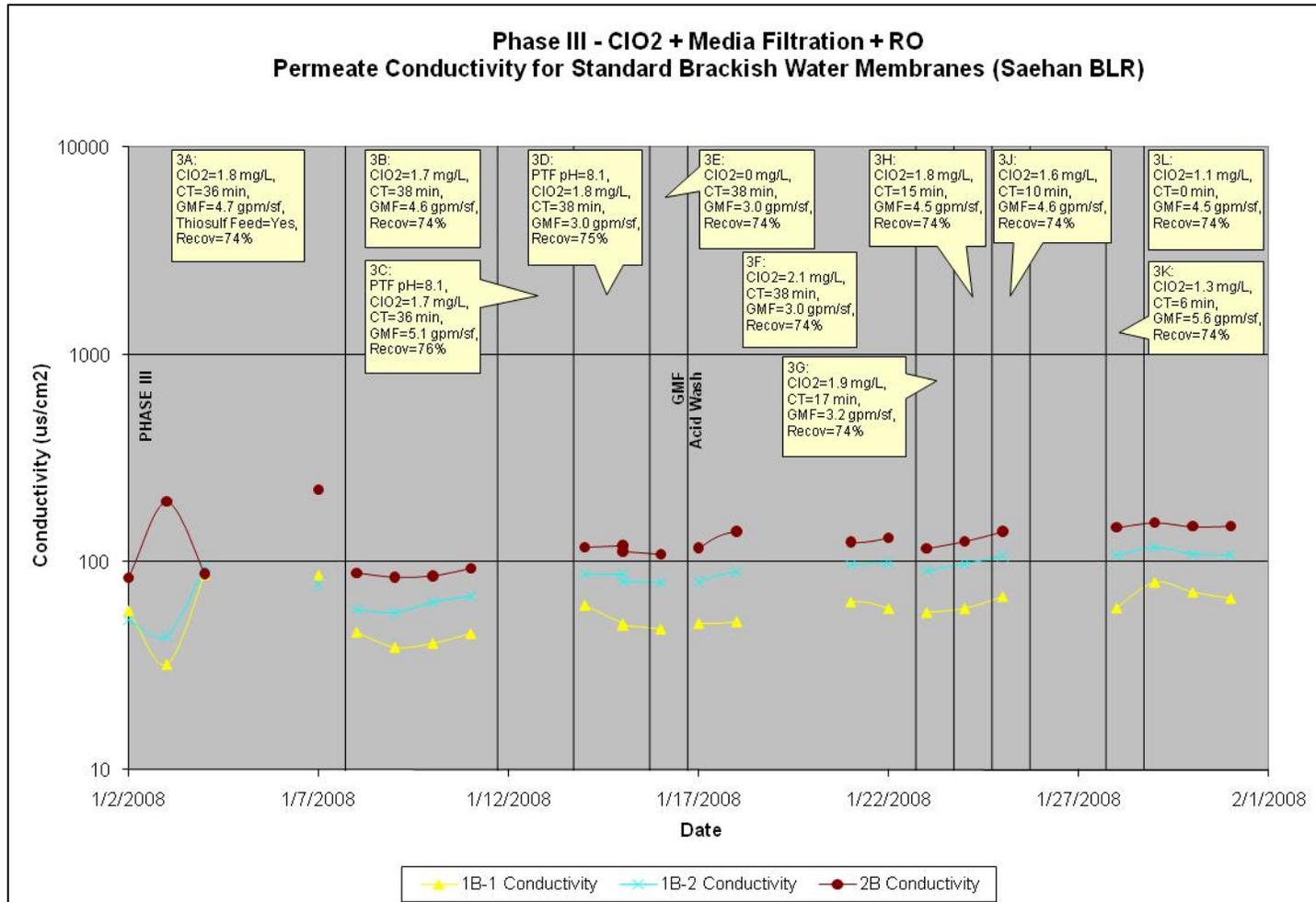


Figure 5.2-21.
Phase III – Permeate Conductivity for Standard Brackish Water Membranes (Saehan BLR)

5.2.3.4 Water Quality

The water quality parameters tested during Phase III are summarized in Table 5.2-9.

Parameter	Detection Limit	Water Quality Goals		Water Quality			
		Regulatory Requirements or Reporting Limit	City's Goal	Well A Raw Water	RO Feed	RO Permeate	RO Waste
Temperature (°C)				--	21	--	--
pH		6.5 – 8.5	6.5 – 8.5	7.3	7.3	6.4	7.8
Conductivity (uS/cm ²)		900	900	2630	2790	272	8970
UV254 (cm ⁻¹)				0.04	0.03	--	--
Color (C.U)	2	15	2	6	3	< 2	--
Total Iron (mg/L)	0.02	0.3	0.2	0.174	0.003	0.002	0.006
Total Manganese (mg/L)	0.005	0.05	0.02	0.245	0.073	0.001	0.250
Alkalinity as CaCO ₃ (mg/L)	2.0			300	300	25	1100
Total Hardness as CaCO ₃ (mg/L)	0.66		120	970	970	4	3500
TDS (mg/L)	10	500	300	1500	1600	78	--
TSS (mg/L)	5			< 5	< 5	--	< 5
TOC (mg/L)	0.60			1.6	1.8	--	--
Ammonia (NH ₃ -N, mg/L)	0.017			0.30	--	0.03	1.04
Total Barium (mg/L)	0.0020			--	0.054	< 0.002	0.180
Total Boron (mg/L)	0.010	1	1	0.70	--	0.68	--
Calcium (mg/L)	0.10			--	260	1.0	970
Chloride (mg/L)	0.24	250	80	101	--	18	--
Magnesium (mg/L)	0.10			--	76	0.29	270
Silica (mg/L)	0.3			29		5.1	87
Sodium (mg/L)	0.50			--	200	21	--
Sulfate (mg/L)		250		1125	--	0.10	3520
Total Strontium (mg/L)	0.0050			--	2.1	0.0071	7.1
Total Vanadium (mg/L)	0.0050			< 0.005	--	< 0.005	--
Gross Alpha (pCi/L)		15	15	18.8	--	2.9	--
Notes: -- Not measured.							

Table 5.2-9 shows acceptable water quality for the RO permeate for all parameters, including iron, manganese, TDS, chloride and sulfate. In particular, the TDS level in the RO permeate was 78 mg/L, much lower than the City's goal of 300 mg/L.

5.2.3.5 Phase III Summary (Alternative 3)

The estimated chlorine dioxide demand in Well A raw water ranged from 0.8 to 2.1 mg/L, with an average of 1.5 mg/L. Chlorine dioxide oxidized approximately 100 percent of iron and 70 percent of manganese. The ability of chlorine dioxide to oxidize iron and manganese was not affected by contact time or raw water pH. The same quantities of iron and manganese were oxidized when the contact tank was bypassed as when 37 minutes of contact time was provided. Also, the same quantities of iron and manganese were oxidized at pH of 7.3 as at pH of 8.1.

Although only 70 percent of manganese was oxidized during the pretreatment stages, the remaining 30 percent did not appear to cause fouling of the RO membranes. It appears that when manganese was not oxidized at the first exposure to chlorine dioxide during the pretreatment, it did not further oxidize downstream of the pretreatment, regardless of the level of chlorine dioxide residual present in the RO feed water. All of the non-oxidized manganese remained dissolved and was successfully removed by the RO without causing particulate fouling.

Chlorine dioxide plus media filtration pretreatment appears to be problematic for several reasons. First and foremost, chlorine dioxide appears to have damaged the RO membranes, as was evident in the steadily increasing permeate conductivities and the gradually increasing MTC during the first three weeks of the Phase III testing. Although the chlorine resistant membranes (Saehan CRM) appeared to be more resistant to chlorine dioxide than the standard brackish water membranes (Saehan BLR), these membranes are a new product currently only produced by one manufacturer, and not in use in any full scale applications. For chlorine dioxide to be used in a full-scale plant with any membranes other than the CRMs, it is likely that dechlorination with sodium bisulfite or sodium thiosulfate would be required.

In addition to the RO damage, particulate iron and manganese appeared to be passing through the media filtration process and fouling the cartridge filters. The cartridge filters should not be relied on for filtration, but were heavily loaded with particulate iron and manganese during this phase. Further, the fouling rate on the media filters was high, averaging 3 to 6 psi/day at a filtration rate less than 5 gpm/sf.

5.2.4 Phase IV – Chlorine Feed plus Pyrolox Media Filtration (Alternative 4)

The pretreatment process tested during Phase IV was chlorine (Cl₂) feed plus Pyrolox media filtration, sometimes referred to as greensand. The objectives of this pretreatment evaluation, process description, pilot configuration, operating conditions, and testing protocol were described previously in Section 4.3.4. Similar to Phase III, the primary objective was to oxidize both dissolved iron and dissolved manganese into particulate iron and manganese, removing both with the Pyrolox or “greensand” filters. A successful test would remove all iron and manganese in the Pyrolox filters and prevent a loss in MTC across the RO membranes.

5.2.4.1 Oxidation Performance

Free chlorine concentration, total iron, dissolved iron, total manganese, and dissolved manganese measurements are averaged for each operating condition of Phase IV testing and summarized in Table 5.2-10.

	Time Period	WQ Parameters, Average Values	Well A Raw Water	Pre-treatment Feed ⁽²⁾	Pre-treatment Product	RO Feed	RO Permeate	RO Waste
4A	2/20/08-3/12/08	Chlorine, (mg/L)	1.0 ⁽¹⁾	0.4 ⁽³⁾	0.2	≤ 0.01	≤ 0.01	--
		Total Iron, (mg/L)	0.165	0.168	0.026	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.167	≤ 0.008	--	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.248	0.243	0.079	0.062	≤ 0.005	0.274
		Dissolved Manganese (mg/L)	0.236	0.186	--	0.073	≤ 0.005	0.241
4B	3/13/08-3/17/08	Chlorine, (mg/L)	1.1 ⁽¹⁾	0.2 ⁽³⁾	0.1	≤ 0.01	≤ 0.01	--
		Total Iron, (mg/L)	0.168	0.169	0.047	0.011	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.168	≤ 0.008	--	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.235	0.229	0.095	0.061	≤ 0.005	0.225
		Dissolved Manganese (mg/L)	0.205	0.198	--	0.061	≤ 0.005	0.160
4C	3/18/08-3/19/08	Chlorine, (mg/L)	1.2 ⁽¹⁾	0.2 ⁽³⁾	0.1	≤ 0.01	≤ 0.01	--
		Total Iron, (mg/L)	0.152	0.169	0.079	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.168	≤ 0.008	--	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.245	0.236	0.110	0.051	≤ 0.005	0.230
		Dissolved Manganese (mg/L)	--	--	--	--	--	--
4D	3/19/08-3/20/08	Chlorine, (mg/L)	1.9 ⁽¹⁾	0.4 ⁽³⁾	0.2	≤ 0.01	≤ 0.01	--
		Total Iron, (mg/L)	0.165	0.170	0.055	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.169	≤ 0.008	--	≤ 0.008	≤ 0.008	0.010
		Total Manganese, (mg/L)	0.248	0.266	0.133	0.080	≤ 0.005	0.290
		Dissolved Manganese (mg/L)	--	--	--	--	--	--
4E	3/21/08-3/21/08	Chlorine, (mg/L)	4.4 ⁽¹⁾	1.5 ⁽³⁾	0.1	≤ 0.01	≤ 0.01	--
		Total Iron, (mg/L)	0.131	0.156	0.039	0.016	≤ 0.008	0.018
		Dissolved Iron, (mg/L)	0.140	0.013	--	≤ 0.008	≤ 0.008	≤ 0.008

Table 5.2-10.
Phase IV – Chlorine Feed + Pyrolox Media Filtration + RO: Test Data per Operating Conditions

	Time Period	WQ Parameters, Average Values	Well A Raw Water	Pre-treatment Feed ⁽²⁾	Pre-treatment Product	RO Feed	RO Permeate	RO Waste
		Total Manganese, (mg/L)	0.230	0.238	0.095	0.061	≤ 0.005	0.330
		Dissolved Manganese (mg/L)	0.239	0.123	--	0.064	≤ 0.005	0.420
4F	3/24/08-3/25/08	Chlorine, (mg/L)	2.4 ⁽¹⁾	0.9 ⁽³⁾	0.3	≤ 0.01	≤ 0.01	--
		Total Iron, (mg/L)	0.157	0.171	0.088	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.172	≤ 0.008	--	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.227	0.226	0.142	0.061	≤ 0.005	0.180
		Dissolved Manganese (mg/L)	0.213	0.188	--	0.073	≤ 0.005	0.240
4G	3/26/08-3/28/08	Chlorine, (mg/L)	1.8 ⁽¹⁾	0.5 ⁽³⁾	0.2	≤ 0.01	≤ 0.01	--
		Total Iron, (mg/L)	0.165	0.167	0.067	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.166	≤ 0.008	--	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.252	0.249	0.123	0.084	0.011	0.420
		Dissolved Manganese (mg/L)	--	--	--	--	--	--
4J	3/31/08-4/02/08	Chlorine, (mg/L)	1.5 ⁽¹⁾	0.3 ⁽³⁾	0.2	≤ 0.01	≤ 0.01	--
		Total Iron, (mg/L)	0.156	0.168	0.113	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.171	≤ 0.008	--	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.241	0.235	0.180	0.072	≤ 0.005	0.315
		Dissolved Manganese (mg/L)	0.225	0.209	--	0.081	≤ 0.005	0.310
4K	4/03/08-4/04/08	Chlorine, (mg/L)	1.8 ⁽¹⁾	0.3 ⁽³⁾	0.2	≤ 0.01	≤ 0.01	--
		Total Iron, (mg/L)	0.157	0.164	0.078	≤ 0.008	≤ 0.008	≤ 0.008
		Dissolved Iron, (mg/L)	0.145	≤ 0.008	--	≤ 0.008	≤ 0.008	≤ 0.008
		Total Manganese, (mg/L)	0.244	0.239	0.109	0.071	≤ 0.005	0.295
		Dissolved Manganese (mg/L)	0.226	0.203	--	0.083	≤ 0.005	0.230

(1) Chlorine dose injected to Well A raw water.
(2) All pretreatment feed samples were grabbed from downstream of the contact tank, unless otherwise noted.
(3) Measured in the pretreatment feed sample grabbed upstream of the contact tank.
-- Not measured.
NOTE: Iron and manganese levels were not measured during Operating Condition 4H.

Chlorine Dose and Demand

The chlorine dose fed to Well A raw water, and the chlorine levels in the pretreatment feed and the pretreatment product (PTP) are shown in Figure 5.2-22. On average, chlorine was dosed at approximately 1.4 mg/L, and the chlorine residual measured in the PFP sample was 0.2 mg/L. Therefore, the average chlorine demand was 1.2 mg/L.

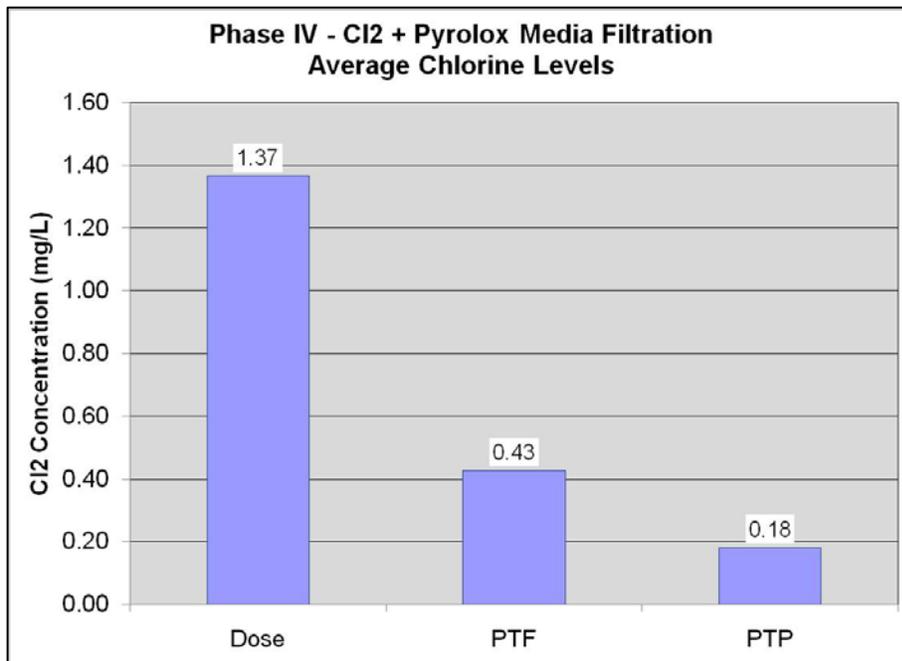


Figure 5.2-22.
Phase IV – Average Chlorine Levels

The typical chlorine dose that has been reported for the oxidation of iron and manganese are 0.63 mg Cl₂/mg Fe²⁺ and 1.29 mg Cl₂/mg Mn²⁺, respectively (MWH, 2005). The average dissolved iron concentration in Well A raw water was 0.17 mg/L, all of which was oxidized by chlorine. The average dissolved manganese concentration in Well A raw water was 0.22 mg/L, of which 0.17 mg/L was oxidized by chlorine feed plus Pyrolox media filtration. Therefore, it can be calculated, based on the above ratios, that approximately 0.4 mg/L of chlorine was used to oxidize iron and manganese in the Well A raw water, with the remaining chlorine demand coming from other materials, such as dissolved organics.

Of the 0.24 mg/L of total manganese in the raw water, approximately 0.07 mg/L of manganese was not oxidized with chlorine during the testing, even with chlorine doses in excess of 4 mg/L.

It is important to note that the chlorine dose did not affect the amount of iron and manganese oxidized. As summarized in Table 5.2-11, 100 percent of iron oxidation and 70 percent of manganese oxidation was achieved at for all doses ranging from 1.0 mg/L to 4.4 mg/L. It is not clear whether chlorine doses significantly higher than those utilized here could have resulted in complete oxidation of the dissolved manganese.

Table 5.2-11.
Phase IV – Chlorine Feed + Pyrolox Media Filtration: Chlorine Demand and Oxidation Rates

Average Cl ₂ Dose (mg/L)	Average Cl ₂ Demand (mg/L)	Contact Time (min)	% Iron Oxidized	Well A Raw Water Total Manganese (mg/L)	RO Feed Dissolved Manganese (mg/L)	% Manganese Oxidized
1.0	0.8	15	100%	0.25	0.07	70%
1.1	0.9	10	100%	0.24	0.06	75%
1.5	1.3	10	100%	0.24	0.08	66%
1.8	1.6	7	100%	0.25	0.08	68%
2.4	2.1	15	100%	0.23	0.07	69%
4.4	4.3	15	100%	0.23	0.06	73%

It appears that 1.0 mg/L of chlorine dose was sufficient to achieve 100 percent of iron oxidation and approximately 70 percent of manganese oxidation, while higher doses of chlorine achieved only marginal changes in manganese oxidation.

Iron Oxidation

The total iron levels for Well A raw water, the pretreatment product, and the RO permeate samples during Phase III testing are shown in Figure 5.2-23. A sudden increase in iron levels in the pretreatment product was seen beginning March 7, 2008.

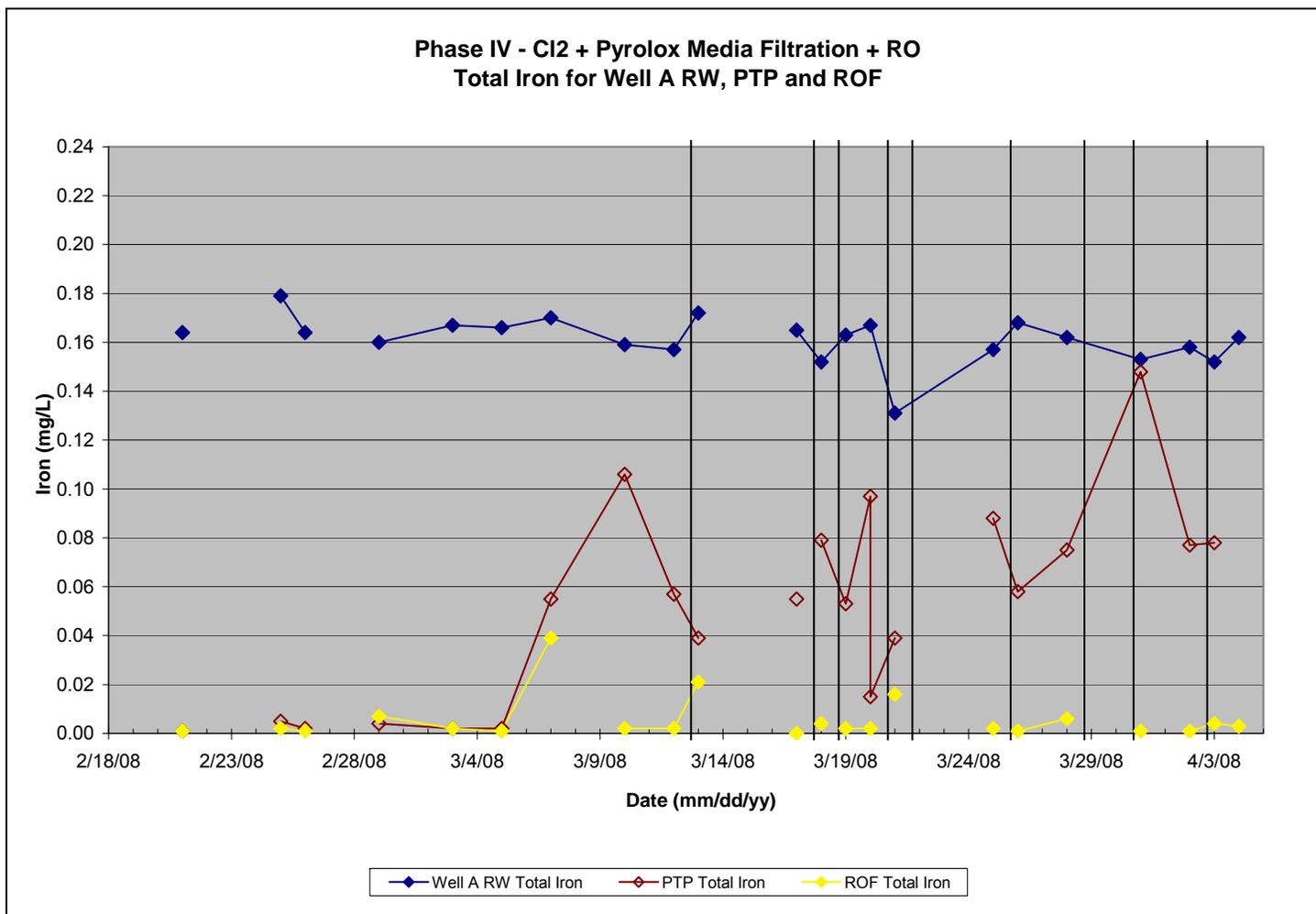


Figure 5.2-23.
Phase IV – Total Iron for Well A RW, PTP, and ROF

The average total and dissolved iron data are shown in Figures 5.2-24 and 5.2-25. Both figures show that 100 percent of total iron was oxidized in the pretreatment feed water (after the contact tank), indicating that chlorine is an effective oxidant for iron at these concentrations and contact times.

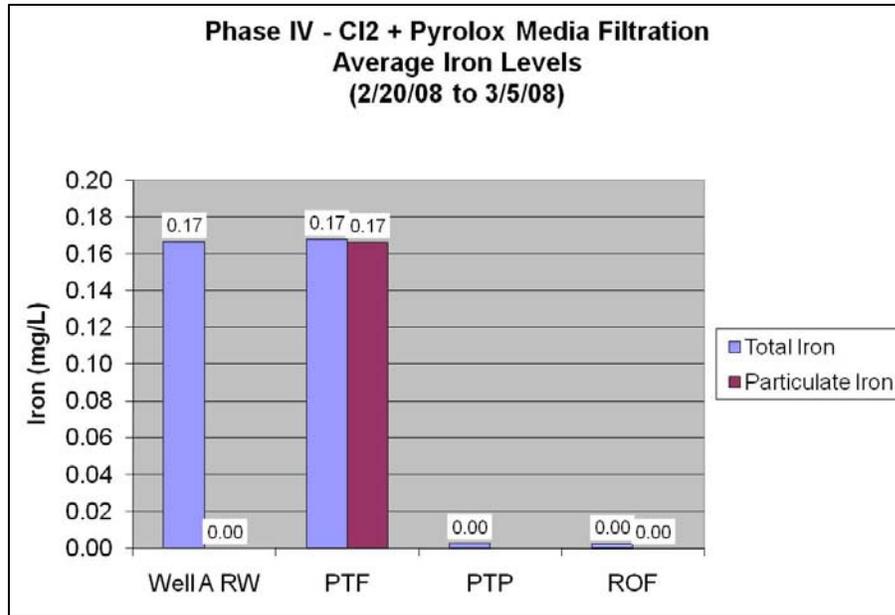


Figure 5.2-24.
Phase IV – Average Iron Levels (2/20/08 to 3/5/08)

The total and dissolved iron data from February 20, 2008 to March 5, 2008, shown in Figure 5.2-24, shows that the chlorine feed plus Pyrolox media filtration is an effective pretreatment method for removing iron by oxidation and filtration, as the iron level in the pretreatment product is below detection level.

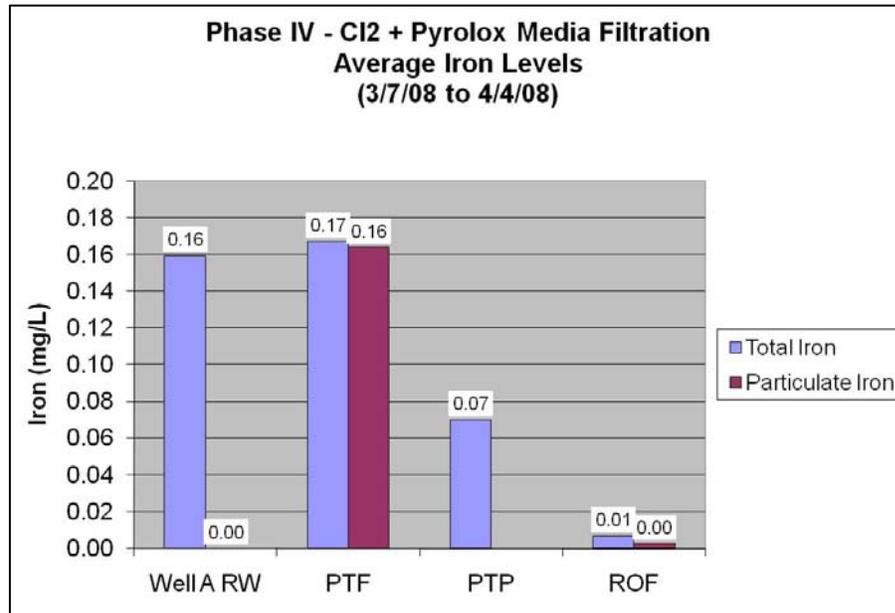


Figure 5.2-25.
Phase IV – Average Iron Levels (3/7/08 to 4/4/08)

However, the total and dissolved iron data from March 7, 2008 to April 4, 2008, shown in Figure 5.2-25 shows significant quantities of iron passing through the media filters, which appears to be the result of insufficient backwashing of the media filters. Although all of the iron in the pretreatment feed was oxidized and should have been removed by the Pyrolox media filters, approximately 40 percent of total iron passed through the Pyrolox media filters and was removed by the cartridge filters instead.

It should be noted here that operation of Pyrolox media filters often requires backwashing rates in excess of 25 to 30 gpm/sf, to achieve 40 percent filter bed expansion when significant quantities of iron are present in the water source. Such backwash rates were not feasible with the pilot unit, due to the large degree of media carryover seen when operating with high bed expansion rates. Pyrolox and greensand facilities often employ air scour in the backwash process to reduce the backwashing rates, however, such capabilities were not included in the pilot unit tested here. Backwashing rates during the pilot study did not exceed 15 gpm/sf, which is a generally a sufficient rate for typical media filters, but was not effective for the heavily fouled Pyrolox media.

Manganese Oxidation

The average total and dissolved manganese data are shown in Figures 5.2-26 and 5.2-27. Both figures show that the total and dissolved manganese levels in the Well A raw water were approximately 0.24 mg/L, and the total and dissolved manganese levels in the RO feed water was approximately 0.07 mg/L. The chlorine feed plus Pyrolox media filtration achieved approximately 70 percent of manganese oxidation, which is similar to the level of oxidation achieved with chlorine dioxide during the Phase III testing.

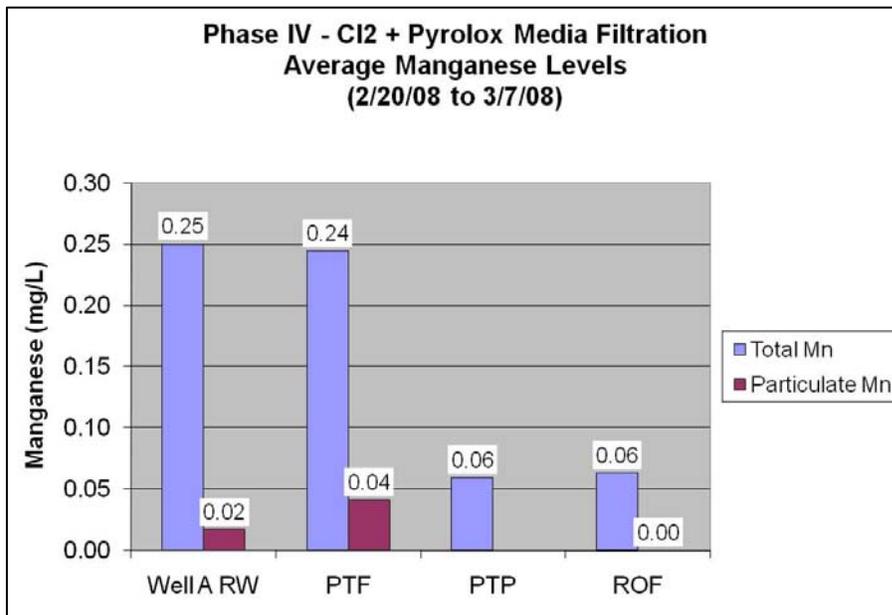


Figure 5.2-26.
Phase IV – Average Manganese Levels (2/20/08 to 3/7/08)

The total and dissolved manganese data from February 20, 2008 to March 7, 2008, shown in Figure 5.2-26, indicates that chlorine feed plus Pyrolox media filtration pretreatment oxidized and removed approximately 70 percent of total manganese. Approximately 17 percent of total manganese was oxidized by chlorine in the pretreatment feed, grabbed downstream of the contact tank and upstream of the Pyrolox media filters. An additional 53 percent of manganese was oxidized on the surface of the Pyrolox media.

It should be noted that during this period, from February 20, 2008 to March 7, 2008, the Pyrolox media removed all oxidized manganese, and all of the total manganese in the pretreatment product was dissolved.

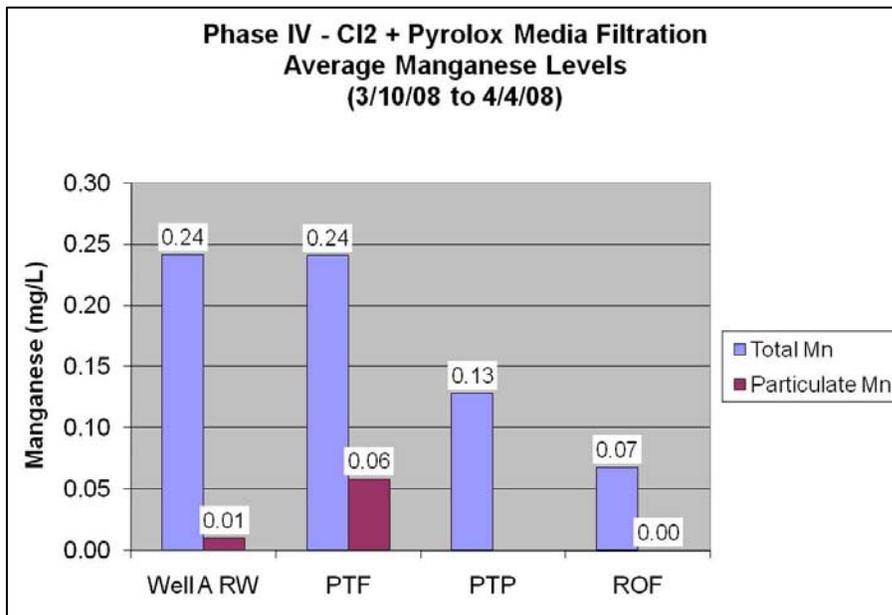


Figure 5.2-27.
Phase IV – Average Manganese Levels (3/10/08 to 4/4/08)

The total and dissolved manganese data from March 10, 2008 to April 4, 2008, shown in Figure 5.2-27, indicates manganese breakthrough similar to what was seen with the iron. Build-up of the organics and iron oxides likely occurred within the media due to the insufficient backwashing rates mentioned previously. Breakthrough for iron began on March 7. With the adsorption sites on the media reduced by the build-up of these materials, manganese oxidation began to reduce, to the point where manganese breakthrough was seen three days after the initial iron breakthrough. Figure 5.2-28 shows a sudden increase in manganese levels in the pretreatment product starting March 10, 2008.

Figure 5.2-27 shows that the total manganese level was 0.13 mg/L in the pretreatment product and 0.07 mg/L in the RO feed. This indicates that 0.06 mg/L of the total manganese in the pretreatment product had been oxidized, but was removed by the cartridge filters rather than the media filters.

The total and dissolved manganese data for the RO feed shows that the manganese in the RO feed was all in the dissolved state. The data indicates that during phase IV approximately 0.07 mg/L of dissolved manganese that was not oxidized during the pretreatment stage did not get oxidized in the RO and was removed by desalination.

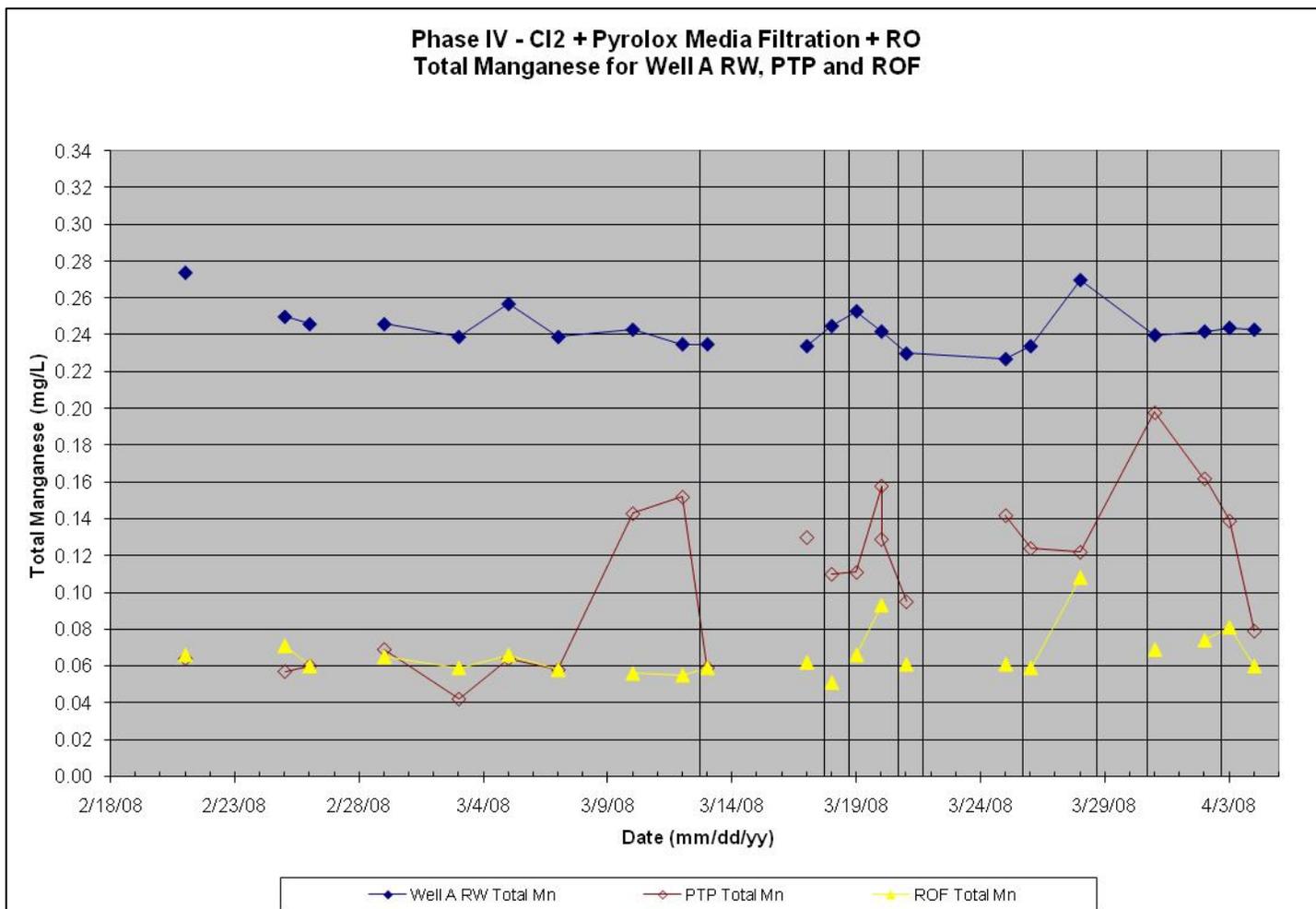


Figure 5.2-28.
Phase IV – Total Manganese for Well A RW, PTP, and ROF

Manganese Oxidation vs. Chlorine Dose

Manganese oxidation did not improve with increased chlorine dose, as shown in Figure 5.2-29. While chlorine dose of 1 mg/L to 2 mg/L achieved up to 80 percent manganese oxidation, increasing the chlorine dose to greater than 4 mg/L did not increase the manganese oxidation.

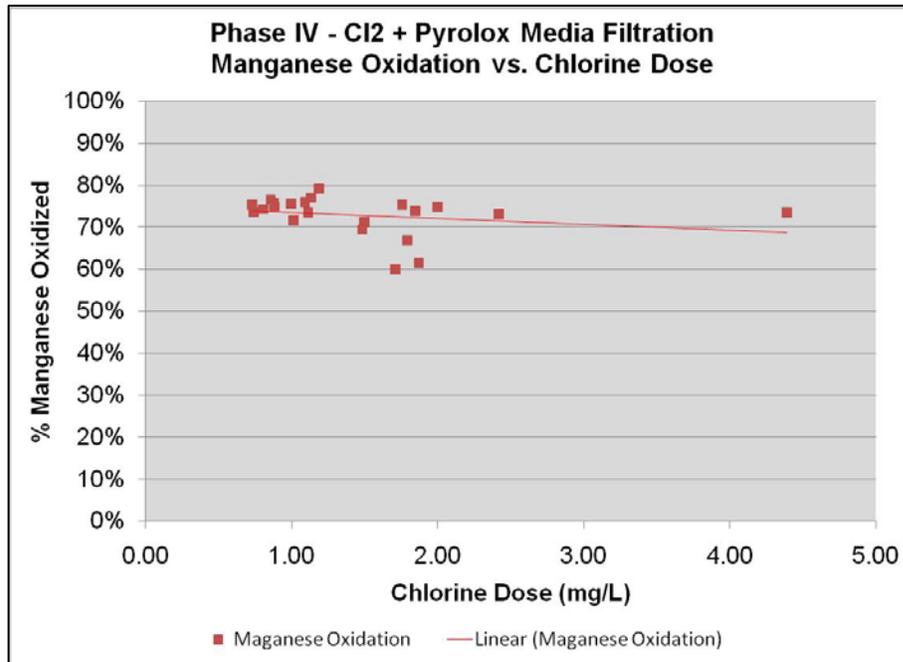


Figure 5.2-29.
Phase IV –Manganese Oxidation vs. Chlorine Dose

5.2.4.2 Filtration Performance

Pyrolox Media Filters Performance

The Pyrolox media filters were used to i) remove the oxidized iron; and ii) oxidize and remove manganese. In general, the Pyrolox media filters have been shown to work well if they are operated properly, however, high loading of iron is often problematic for these types of filters. The iron and manganese data from February 20, 2008 through March 5, 2008 show the Pyrolox media filters performing properly, and the data after March 5, 2008 show the Pyrolox media performing poorly.

The break-through of particulate iron and manganese was likely caused by the build-up of particulate iron and organic silts on the surface of the Pyrolox media, which were not completely removed by the weekly backwashes. While the build-up of oxidized manganese enhances the manganese oxidation, the build-up of oxidized iron on the surface of the media reduces the filtration capacity and interferes with manganese adsorption to the media surface. Backwashing of Pyrolox filters is also somewhat difficult, due to the high specific gravity of the media, requiring filtration rates in excess of 25-30 gpm/sf. Such filtration rates could not be achieved in the pilot without loss of media due to excessive bed expansion. Without proper backwashing,

the filters continued to accumulate iron oxides and silts, resulting in the breakthrough of both iron and manganese.

During Phase IV, the Pyrolox media filters were operated at an average loading rate of 3.2 gpm/sf, and the differential pressure across the filters increased at an average rate of 1 psi/day.

Cartridge Filters Performance

The fouling rate of the cartridge filters were in congruence with the performance of the Pyrolox media filters. Between February 20, 2008 and March 6, 2008, before the iron and manganese began breaking through the media filters, the differential pressure across the cartridge filters barely increased. However, from March 7, 2008 to April 20, 2008, the cartridge filters began getting loaded with particulate iron and manganese, and had to be replaced frequently.

The first set of cartridge filters, removed on March 10, 2008, were greenish brown with gray slime, indicating fouling from algae, iron and manganese. All other sets of cartridge filters removed afterwards were dark brown when wet, and predominantly gray when dried, indicating fouling from iron and manganese.

Figure 5.2-30 compares the clean cartridge filters against wet fouled cartridge filters immediately after removal. Figure 5.2-31 shows the fouled cartridge filters after they have dried.



Figure 5.2-30.
Phase IV – Clean and Wet Fouled Cartridge Filters



Figure 5.2-31.
Phase IV – Dry Fouled Cartridge Filters

Table 5.2-12 summarizes the estimated fouling rates of the cartridge filters. Before the Pyrolox media break-through of particulate iron and manganese, the differential pressure across the cartridge filters increased at approximately 0.27 psi/day. After the break-through, the differential pressure across the cartridge filters increased at an average of 4.3 psi/day.

Table 5.2-12.					
Phase IV – Chlorine Feed + Pyrolox Media Filtration + RO: Cartridge Filter Fouling Rate					
Sets	Date	No. of Hours Used	Fouling rate (psi/day)		Fouling rate (psi/day)
1a	2/20/08 – 3/6/08	181	0.27	Before Pyrolox Media Break-Through	0.27
1b	3/6/08 – 3/10/08	95	5.1	After Pyrolox Media Break-Through	4.3
2	3/10/08 – 3/13/08	70	5.1		
3	3/13/08 – 3/17/08	66	4.4		
4	3/17/08 – 3/19/08	38	12.3		
5	3/19/08 – 3/20/08	19	8.2		
6	3/20/08 – 3/28/08	90	1.9		
7	3/28/08 – 4/1/08	73	2.8		
8	4/1/08 – 4/4/08	71	2.0		

5.2.4.3 RO Performance

The first stage MTC and the second stage MTC are shown in Figure 5.2-32. MTC is a measure of membrane performance, with fouled membranes demonstrating a drop or reduction in MTC. The first stage MTC shows a slight downward trend toward the latter part of operating condition 4A, starting March 6, 2007, indicating particulate fouling due to iron and manganese break-through. Starting operating condition 4C, the first stage MTC is relatively flat. The second stage MTC is also relatively flat during this phase.

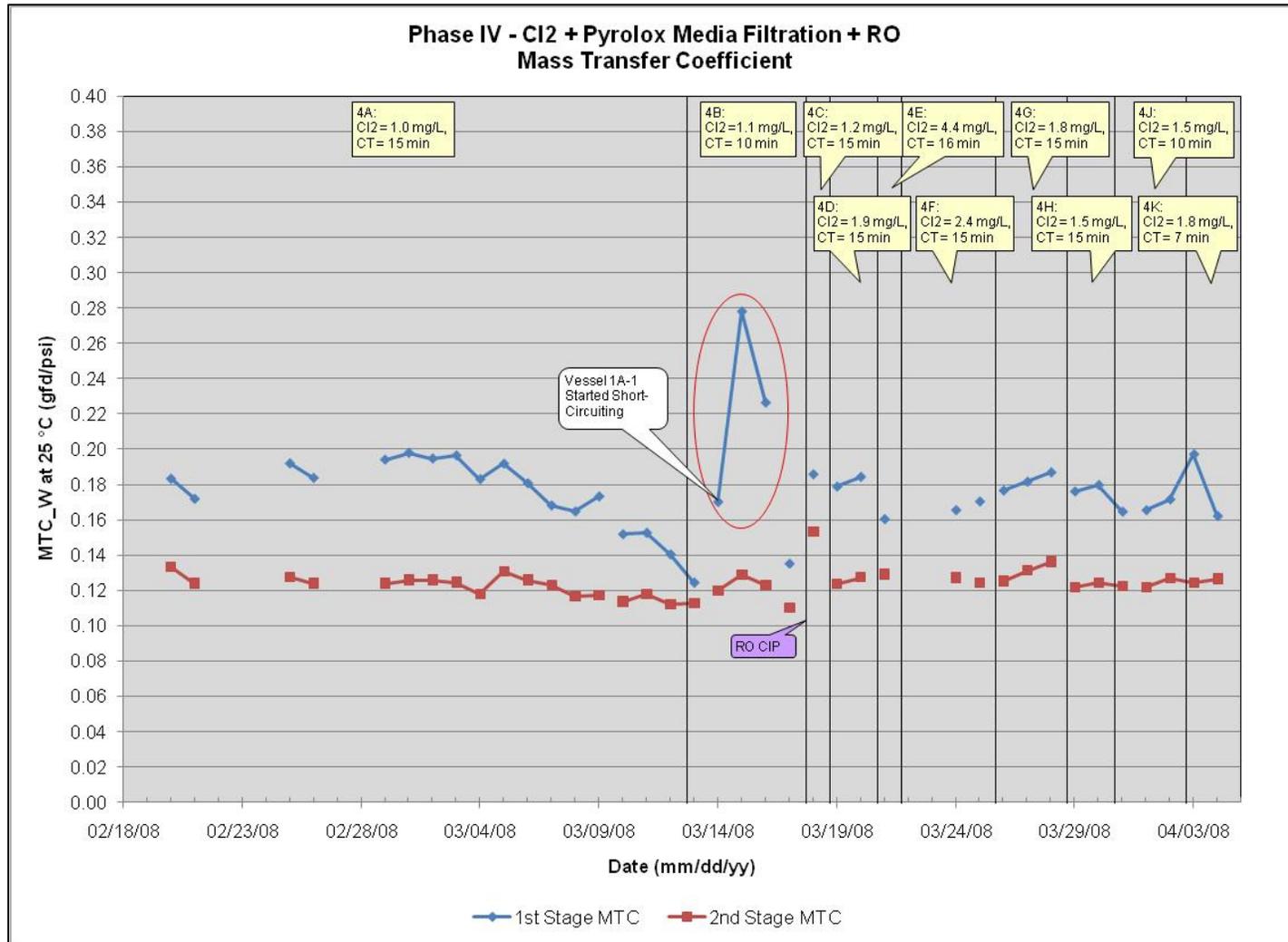


Figure 5.2-32.
Phase IV – MTC_W at 25 °C

5.2.4.4 Water Quality

The water quality parameters tested during Phase IV are summarized in Table 5.2-13.

Parameter	Detection Limit	Water Quality Goals		Water Quality			
		Regulatory Requirement or Reporting Limit	City's Goal	Well A Raw Water	RO Feed	RO Permeate	RO Waste
Temperature (°C)				--	22	--	--
pH		6.5 – 8.5	6.5 – 8.5	7.4	7.4	6.4	7.7
Conductivity (uS/cm ²)		900	900	2333	2388	85	6815
UV254 (cm ⁻¹)				0.03	0.04	--	--
Color (C.U)	2	15	2	3	3	< 2	--
Total Iron (mg/L)	0.02	0.3	0.2	0.163	0.002	< 0.002	< 0.002
Total Manganese (mg/L)	0.005	0.05	0.02	0.243	0.062	< 0.005	0.250
Alkalinity as CaCO ₃ (mg/L)	2.0			290	300	21	950
Total Hardness as CaCO ₃ (mg/L)	0.66		120	920	940	5	3200
TDS (mg/L)	10	500	300	1300	1300	51	--
TSS (mg/L)	5			< 5	< 5	--	< 5
TOC (mg/L)	0.60			1.6	1.8	--	--
Ammonia (NH ₃ -N, mg/L)	0.017			0.52	--	0.01	0.88
Total Barium (mg/L)	0.0020			--	0.046	< 0.002	0.180
Total Boron (mg/L)	0.010	1	1	0.69	--	0.54	--
Calcium (mg/L)	0.10			--	260	1.3	830
Chloride (mg/L)	0.24	250	80	93	--	13	--
Magnesium (mg/L)	0.10			--	71	0.36	270
Silica (mg/L)	0.3			30	--	3.8	82
Sodium (mg/L)	0.50			--	200	14	--
Sulfate (mg/L)		250		1320	--	1.6	3530
Total Strontium (mg/L)	0.0050			--	2.1	0.0099	8.3
Total Vanadium (mg/L)	0.0050			< 0.005	--	0.26	--
Gross Alpha (pCi/L)		15	15	14.5	--	0.5	--
Notes: -- Not measured.							

Table 5.2-13 shows acceptable water quality for the RO permeate for all parameters, including iron, manganese, TDS, chloride and sulfate. In particular, the TDS level in the RO permeate was 51 mg/L, much lower than the City's goal of 300 mg/L.

5.2.4.5 Phase IV Summary (Alternative 4)

The estimated chlorine demand in Well A raw water was approximately 0.8 mg/L. Chlorine demand of 1.0 mg/L was sufficient to oxidize 100 percent of iron and approximately 70 percent of manganese with the aid of the Pyrolox media filters. Although higher doses of chlorine may enhance manganese oxidation by a few percentages, the impact of higher doses was minimal.

Chlorine feed plus Pyrolox media filtration pretreatment (Phase IV) was similar in performance to the chlorine dioxide feed plus media filtration pretreatment (Phase III). Both pretreatment processes oxidized and removed 100 percent of total iron and approximately 70 percent of total manganese. The difference was that manganese oxidation occurred in the filtration stage during Phase IV, whereas manganese oxidation occurred prior to the filtration stage during Phase III.

Although only 70 percent of manganese was oxidized during the pretreatment stages, the remaining 30 percent non-oxidized manganese did not appear to impact RO performance, as it remained dissolved throughout the RO process and into the RO waste stream.

Chlorine feed plus Pyrolox media filtration pretreatment was partially effective, particularly during the early portion of the testing. However, the two issues of concern for this process are the risk of damaging the RO membranes with chlorine, and the difficulty in maintaining properly functioning media filters. Although the dechlorination process was successful during the pilot study and, therefore, did not cause damage to the RO membranes, the possible failure of a dechlorination process is risky for a full-scale plant, given the capital investment required to replace damaged RO membranes.

In addition to the dechlorination process requirement, the operation of the Pyrolox media filters causes some concern, due to the high backwashing rates and possible air scour systems required to remove iron oxides from the dense media. Pyrolox systems tend to work best in systems with high manganese levels, but low iron, and are commonly used at smaller facilities where waste washwater volumes from the high backwashing rates do not create site constraints. Based on the two primary concerns mentioned here, and the difficult performance during the pilot testing, it is unlikely that this process will prove to be the most appropriate approach for pretreatment at the Camarillo desalination facility.

5.2.5 Phase V – Aeration plus Microfiltration (Alternative 5)

The pretreatment process tested during Phase V was aeration plus microfiltration (MF). The objectives of this pretreatment evaluation, process description, pilot configuration, operating conditions, and testing protocol were described previously in Section 4.3.5. Similar to Phase II, the primary objective was to oxidize dissolved iron into particulate iron and remove it with the membrane filters, while preventing the oxidation of manganese. A successful test would remove all iron in the membrane filters, prevent formation of particulate manganese, and prevent a loss in MTC across the RO membranes.

5.2.5.1 Oxidation Performance

DO concentration, pH, total iron, dissolved iron, total manganese, and dissolved manganese measurements are averaged for each operating condition of Phase V testing and summarized in Table 5.2-14.

	Sampling Date	WQ Parameters, Average Values	Well A Raw Water	Pre-treatment Feed ⁽²⁾	Pre-treatment Product	RO Feed	RO Permeate	RO Waste
5A	4/7/08	DO, (mg/L)	2.6 ⁽¹⁾	5.5 ⁽³⁾	--	--	--	--
		pH	7.0	7.1	7.2	7.0	6.0	7.4
		Total Iron, (mg/L)	0.165	0.157	0.145	0.111	≤ 0.008	0.327
		Dissolved Iron, (mg/L)	0.165	0.158	--	0.089	≤ 0.008	0.010
		Total Manganese, (mg/L)	0.240	0.246	0.239	0.236	≤ 0.005	1.000
		Dissolved Manganese (mg/L)	--	0.234	--	0.235	--	--
5B	4/8/08	DO, (mg/L)	--	7.7 ⁽³⁾	--	--	--	--
		pH	7.1	7.2	7.4	7.2	--	7.5
		Total Iron, (mg/L)	--	0.162	0.102	--	--	--
		Dissolved Iron, (mg/L)	--	0.111	0.085	--	--	--
5D	4/11/08,	DO, (mg/L)	1.8 ⁽¹⁾	5.3 ⁽³⁾	--	--	--	--
	4/14/08,	pH	7.1	7.2	7.4	7.3	6.4	7.7
	4/15/08,	Total Iron, (mg/L)	0.162	0.150	0.076	0.047	≤ 0.008	0.161
	4/16/08,	Dissolved Iron, (mg/L)	0.160	0.117	--	0.044	≤ 0.008	0.010
	4/18/08,	Total Manganese, (mg/L)	0.220	0.222	0.226	0.223	≤ 0.005	0.825
	4/21/08	Dissolved Manganese (mg/L)	--	0.229	--	0.211	--	--
5E	4/24/08,	DO, (mg/L)	2.1 ⁽¹⁾	8.4 ⁽³⁾	--	--	--	--
	4/25/08	pH	7.3	7.3	7.4	7.3	6.4	7.7
		Total Iron, (mg/L)	0.157	0.161	0.018	≤ 0.008	≤ 0.008	0.012
		Dissolved Iron, (mg/L)	0.157	0.059	--	≤ 0.008	≤ 0.008	0.005
		Total Manganese, (mg/L)	0.224	0.234	0.231	0.231	0.043	0.645
		Dissolved Manganese (mg/L)	--	0.218	--	0.223	--	--
5F	4/28/08	DO, (mg/L)	1.6 ⁽¹⁾	8.7 ⁽³⁾	--	--	--	--
		pH	7.1	7.2	7.4	--	--	--

Table 5.2-14. Phase V – Aeration + Microfiltration + RO: Test Data per Operating Conditions								
	Sampling Date	WQ Parameters, Average Values	Well A Raw Water	Pre-treatment Feed ⁽²⁾	Pre-treatment Product	RO Feed	RO Permeate	RO Waste
		Total Iron, (mg/L)	0.152	0.143	0.009	--	--	--
		Dissolved Iron, (mg/L)	0.155	0.093	--	--	--	--
5G	4/29/08	DO, (mg/L)	1.0 ⁽¹⁾	8.3 ⁽³⁾	--	--	--	--
		pH	7.0	7.2	7.3	7.2	6.1	7.5
		Total Iron, (mg/L)	0.154	0.159	0.065	0.020	≤ 0.008	0.079
		Dissolved Iron, (mg/L)	0.169	0.151	--	0.022	≤ 0.008	0.013
		Total Manganese, (mg/L)	0.230	0.219	0.223	0.229	0.013	0.910
		Dissolved Manganese (mg/L)	--	0.223	--	0.221	--	--
5H	5/1/08,	DO, (mg/L)	2.1 ⁽¹⁾	8.5 ⁽³⁾	--	--	--	--
	5/2/08,	pH	7.1	7.2	7.4	7.3	6.3	7.7
	5/5/08,	Total Iron, (mg/L)	0.163	0.156	0.080	0.039	≤ 0.008	0.125
	5/7/08,	Dissolved Iron, (mg/L)	0.153	0.140	--	0.031	≤ 0.008	0.007
	5/9/08,	Total Manganese, (mg/L)	0.230	0.230	0.230	0.233	≤ 0.005	0.881
	5/12/08,	Dissolved Manganese (mg/L)	--	0.225	--	0.219	--	--
	5/16/08,							
	5/20/08,							
	5/21/08,							
	5/23/08							

(1) Air injected to Well A raw water.
(2) All pretreatment feed samples were grabbed from downstream of the contact tank, unless otherwise noted.
(3) Measured in the pretreatment feed sample grabbed upstream of the contact tank.
-- Not measured.
NOTE: Iron and Manganese levels were not measured during operating condition 5C.

Aeration

During this phase, the aeration was accomplished using two different methods:

- **Eductor** – From April 7 through April 22, the aeration was accomplished using an eductor and one 12 element static mixer. During this testing period, the DO in the pretreatment feed ranged from 4.1 to 7.7 mg/L, with an average of 5.6 mg/L.
- **Air Compressor** – From April 23 through May 23, aeration was accomplished using an air compressor, one 12 element static mixer and two 6 element static mixers. During this testing period, the DO in the pretreatment feed ranged from 8.0 to 9.1 mg/L, with an average of 8.5 mg/L.

Iron Oxidation with Dissolved Oxygen

The amount of oxygen required for the oxidation of iron is 0.14 mg O₂/mg Fe²⁺ (MWH, 2005). As shown on Figures 5.2-33 through 5.2-35, the average dissolved iron

concentration in Well A raw water was 0.16 mg/L. Therefore, approximately 0.02 mg/L of oxygen was required to oxidize 0.16 mg/L of iron.

In general, the DO only partially oxidized the iron within the 3 to 36 minutes of contact time tested. The rate of oxidation was sensitive to the contact time and the concentration of DO in the water. Furthermore, the iron was oxidized not only in the contact tank, but also in the MF. The rate of oxidation of iron is summarized in Table 5.2-15.

Table 5.2-15.
Phase V – Aeration + Microfiltration: Dissolved Oxygen and Oxidation Rates

	Time Period	Aeration Method	Pretreatment Feed DO (mg/L)	Pretreatment Feed pH	Contact Time (min)	% Iron Oxidized in Contact Tank *	% Iron Oxidized in Contact Tank and Removed by MF **
5A	4/7	<i>Eductor</i>	5.5	7.1	3	4	12
5B	4/8	<i>Eductor</i>	7.7	7.2	19	--	37
5D	4/11 – 4/22	<i>Eductor</i>	4.1 to 5.9	7.0 to 7.3	31 to 34	25 to 32 (Avg 28)	36 to 65 (Avg 53)
5E	4/23 – 4/25	<i>Air Compressor</i>	8.1 to 8.8	7.3 to 7.5	33 to 36	49 to 76 (Avg 62)	84 to 93 (Avg 88)
5F	4/28	<i>Air Compressor</i>	8.7	7.2	32	39	94
5G	4/29 – 4/30	<i>Air Compressor</i>	8.3	7.2	4	2	58
5H	4/30 – 5/23	<i>Air Compressor</i>	8.6	7.2	4	0 to 26 (Avg 14)	23 to 68 (Avg 50)

* % Iron Oxidized = $[1 - (\text{Dissolved iron in the pretreatment feed} / \text{Total iron in raw water})] * 100$
 ** % Iron Oxidized = $[1 - (\text{Total iron in pretreatment product} / \text{Total iron in raw water})] * 100$

The average total and dissolved iron data are shown in Figures 5.2-33, 5.2-34, and 5.2-35. All three figures show that iron was only partially oxidized and removed during the pretreatment stages.

Figure 5.2-33 shows the average iron levels in Well A raw water, the pretreatment feed, the pretreatment product and the RO feed, between April 7 and April 22, when aeration was accomplished using the eductor. During this time, the average DO in the pretreatment feed was 5.6 mg/L, and the average pH of the pretreatment feed was 7.2. On average, 44 percent of total iron was oxidized and removed during the pretreatment processes. About 25 percent was oxidized in the contact tank, and an additional 19 percent was oxidized in the MF.

Aeration with an eductor followed by MF was ineffective, evidenced also by the cartridge filters, which were heavily loaded with oxidized iron, removing an average

of 0.03 mg/L iron that was oxidized inside the equalization tank. Also, the RO feed had an average of 0.06 mg/L of total iron, which continued to be oxidized in the RO, fouling the membranes.

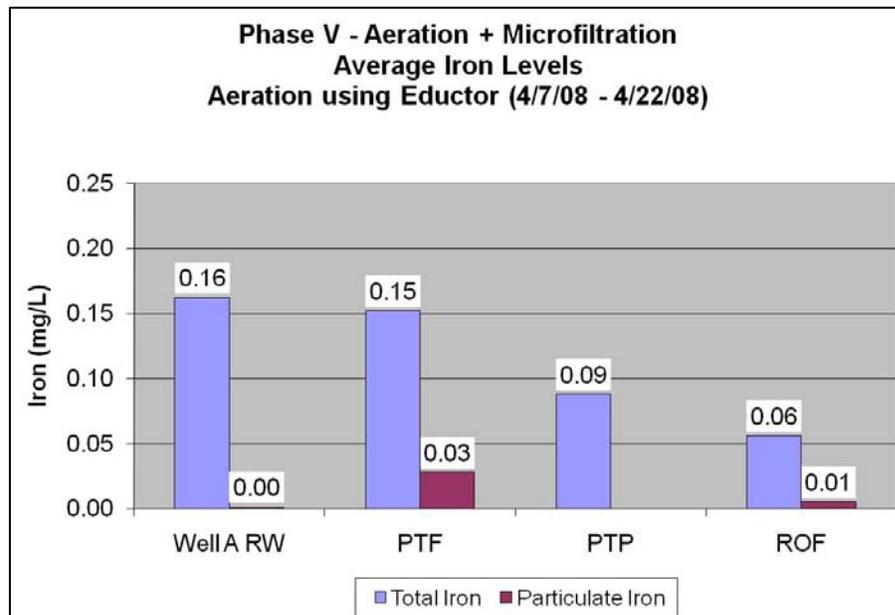


Figure 5.2-33.
Phase V – Average Iron Levels: Aeration using Eductor (4/7/08-4/22/08)

Figure 5.2-34 shows the average iron levels in Well A raw water, the pretreatment feed, the pretreatment product and the RO feed, between April 23 and April 28, when aeration was accomplished using the air compressor and 33 minutes of contact time. During this period, the average DO in the pretreatment feed was 8.5 mg/L, and the average pH of the pretreatment feed was 7.3. On average, 88 percent of total iron was oxidized and removed during the pretreatment processes. About 56 percent was oxidized in the contact tank, and additional 32 percent was oxidized in the MF. This was an improvement over conditions when an eductor was used for aeration, due to the higher DO concentrations, however, clogging of the cartridge filters from iron oxidized in the equalization tank continued.

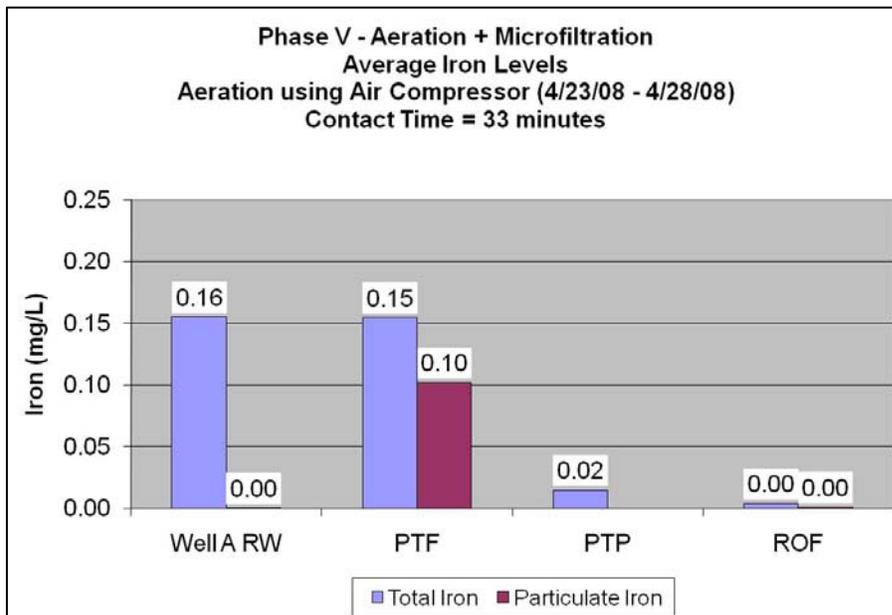


Figure 5.2-34.
Phase V – Average Iron Levels: Aeration using Air Compressor with 33 Minutes of Contact Time (4/23/08-4/28/08)

Figure 5.2-35 shows the average iron levels in Well A raw water, the pretreatment feed, the pretreatment product and the RO feed, between April 29 and May 23, when aeration was accomplished using the air compressor and 4 minutes of contact time. During this period, the average DO in the pretreatment feed was 8.5 mg/L, and the average pH of the pretreatment feed was 7.2. On average, 50 percent of total iron was oxidized and removed during the pretreatment processes. About 13 percent was oxidized in the contact tank, and an additional 37 percent was oxidized in the MF.

These results were similar to conditions when an eductor was used for aeration with lower DO concentrations. As with the other two operating conditions, problems continued to be experienced with iron oxidation in the equalization tank and clogging of the cartridge filters.

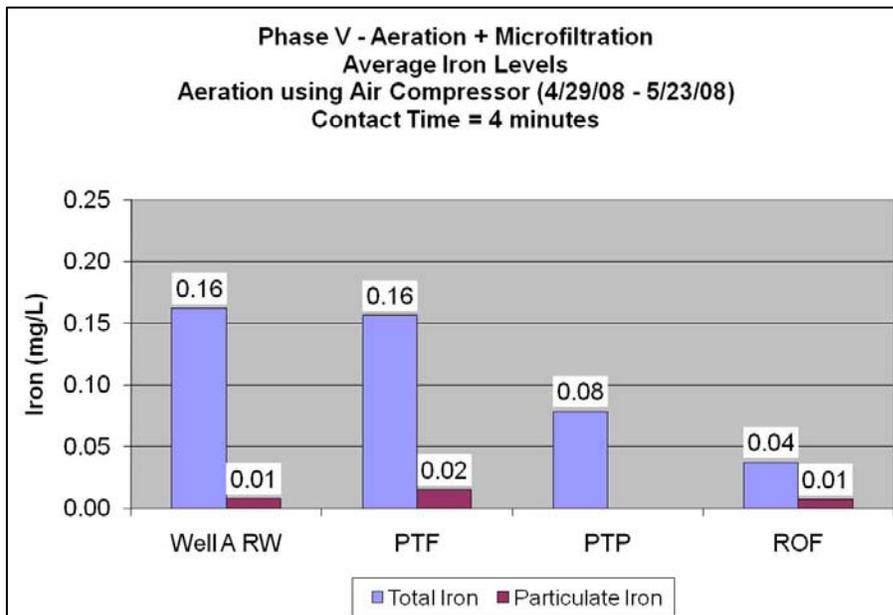


Figure 5.2-35.
Phase V – Average Iron Levels: Aeration using Air Compressor with 4 Minutes of Contact Time (4/29/08-5/23/08)

Effect of Contact Time on Iron Oxidation

Figures 5.2-36 and 5.2-37 show the dissolved iron residual in the pretreatment feed and total iron residual in the pretreatment product versus the contact time. Both figures show that more than 30 minutes of contact time is required to completely oxidize and remove iron by aeration and MF.

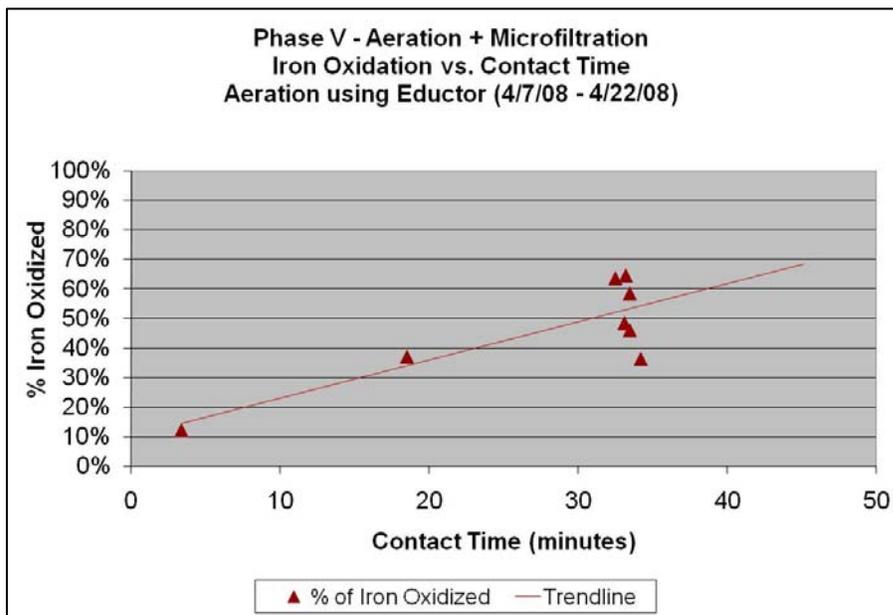


Figure 5.2-36.
Phase V – Iron Oxidation vs. Contact Time: Aeration using Educator (4/7/08-4/22/08)

As previously presented in Figure 5.2-33 already, Figure 5.2-36 shows that aeration with an eductor followed by MF was not an effective pretreatment method, with more than 0.06 mg/L of iron remaining in the pretreatment product at approximately 33 minutes of contact time.

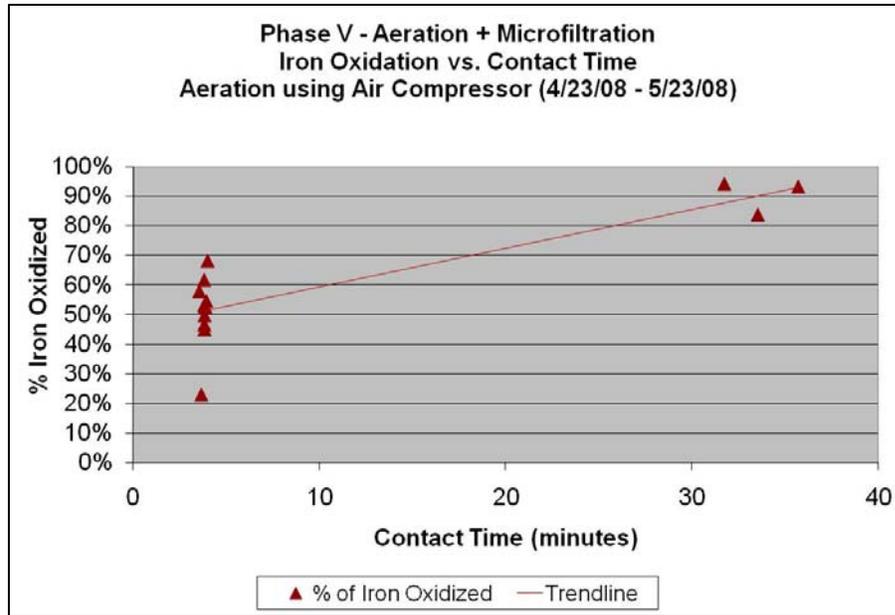


Figure 5.2-37.
Phase V – Iron Oxidation vs. Contact Time: Aeration using Air Compressor (4/23/08-5/23/08)

Figure 5.2-37 demonstrates that aeration with an air compressor followed by MF was more effective with greater than 90 percent iron oxidation when 35 minutes or more of contact time is provided. However, even with this improved oxidation, problems continued to persist with iron oxide clogging in the cartridge filters.

Effect of Dissolved Oxygen Concentration on Iron Oxidation

Figures 5.2-38 and 5.2-39 show the dissolved iron residual in the pretreatment feed and total iron residual in the pretreatment product versus the DO. Clear decreasing trends of the iron residual in the pretreatment feed and the pretreatment product with increasing DO concentration in the pretreatment feed indicate that better oxidation was achieved at higher DO concentrations.

Figure 5.2-38 shows that, at an average of 33 minutes of contact time, the DO in the pretreatment feed must be saturated at approximately 8.7 mg/L in order to achieve greater than 90 percent iron oxidation and removal.

Figure 5.2-39 confirms that 4 minutes of contact time was not sufficient to fully oxidize and remove iron, even when the water was fully saturated with DO.

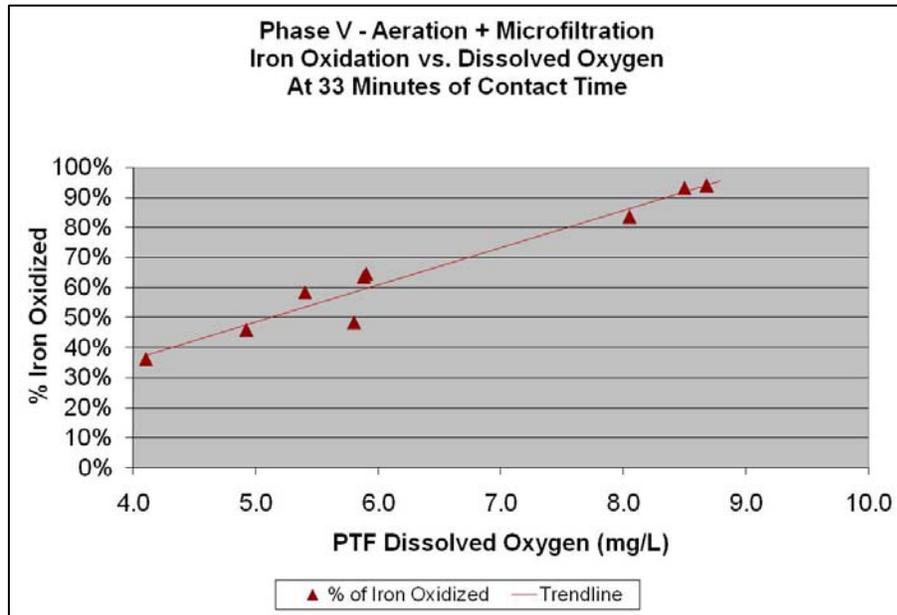


Figure 5.2-38.
Phase V –Iron Oxidation vs. Dissolved Oxygen at 33 Minutes of Contact Time

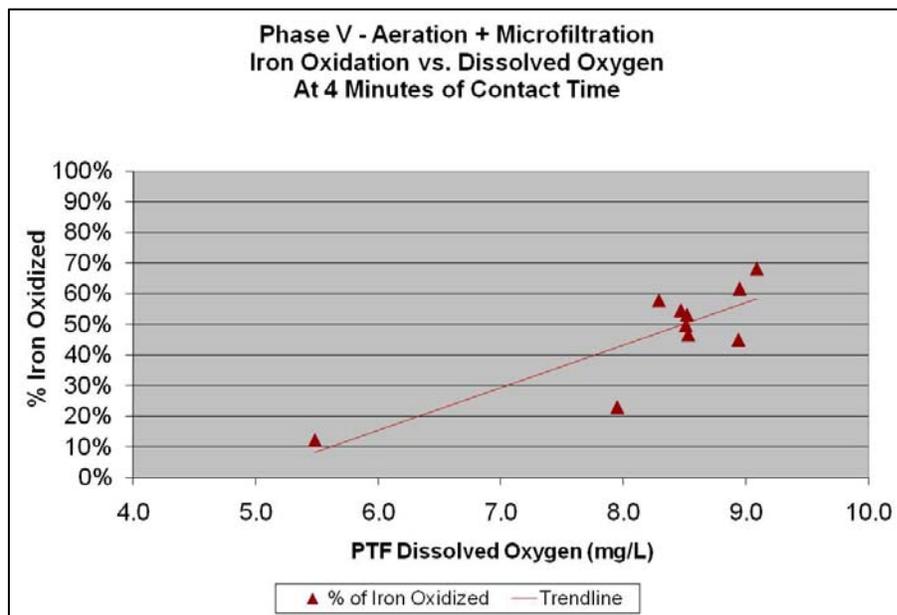


Figure 5.2-39.
Phase V – Iron Oxidation vs. Dissolved Oxygen at 4 Minutes of Contact Time

Different Rates of Oxidation with MF and Media Filters

It has long been known that the presence of oxides of manganese serve as a catalyst to accelerate the oxidation of manganese. This is often discussed in textbooks to explain the mechanism of manganese removal on acclimated filter media preceded by an oxidant residual (JMM, 1985, HDR 2001). Less well-recognized is the fact that a similar catalysis occurs in the oxidation of ferrous iron. This effect was first published

by Takai (1973) and further elucidated by Sung and Morgan (1980). Thus the presence of oxides of iron on the surface of granular media, or microfiltration membranes, can greatly accelerate the oxidation of ferrous iron to ferric iron, facilitating its removal from solution.

In a meeting with the project team, Dr. Morgan explained that this effect could easily explain why ferrous iron, which had still not been oxidized after 30 minutes was effectively removed by media filtration. The vast surface area of the ferric oxides, which accumulate in the granular media filters, serve to greatly accelerate the oxidation and removal of ferrous iron in the presence of modest levels of oxygen. Similar catalytic effect on iron oxidation could be observed by the build-up of iron oxides in microfiltration, but to a lesser extent than in media filtration, because the iron oxides can build up on the surface of microfiltration membranes only in thin layers, greatly limited by the transmembrane pressure (TMP).

5.2.5.2 Filtration Performance

During this phase, the MF was operated at an average instantaneous flux of 33 gfd, and the TMP of the MF increased at approximately 1.34 psi/day.

Table 5.2-16 summarizes the estimated fouling rates of the MF membranes between each chemical cleaning.

Runs	Date	Average MF Flux (gfd)	No. of Operating Hours	Fouling rate (psi/day)		Fouling Rate (psi/day)
1	4/7/08 – 4/28/08	33	378	1.27	Without Maintenance Wash	1.27
2	4/29/08 – 5/7/08	35	160	0.46	With Maintenance Wash	1.40
3	5/7/08 – 5/14/08	31	157	0.85		
4	5/14/08 – 5/19/08	33	115	2.89		
5	5/19/08 – 5/21/08	33	47	2.39		
6	5/21/08 – 5/22/08	33	23	3.91		
7	5/22/08 – 5/23/08	33	22	N/A		

The MF was operated without chemical cleaning from April 7 through April 28. The MF was cleaned in place with citric acid on April 28, and with chlorine on April 29. In May, the MF was chemically cleaned with weak phosphoric acid for 45 minutes each on May 7, 14, 19, 21 and 22, 2008. The chemical maintenance washes were ineffective at cleaning the MF membranes.

Cartridge Filters Performance

The fouling of the cartridge filters was the result of incomplete iron oxidation in the pretreatment processes. Because the aeration followed by MF only partially oxidized and removed the iron, the iron residual in the pretreatment product was further oxidized in the equalization tank and cartridge filter surface, fouling the cartridge filters.

Figure 5.2-40 shows the fouled cartridge filters, which were removed on April 17. The uniform rust-color indicates fouling from iron oxides.



Figure 5.2-40.
Phase V – Fouled Cartridge Filters

Table 5.2-17 summarizes the estimated fouling rates of the cartridge filters. During this phase, the differential pressure across the cartridge filters increased at an average of 0.7 psi/day.

Table 5.2-17. Phase V – Aeration + Microfiltration: Cartridge Filter Fouling Rate				
Sets	Date	No. of Hours Used	Fouling rate (psi/day)	Average Fouling Rate (psi/day)
1	4/7/08 – 4/17/08	199	0.55	0.68
2	4/17/08 – 5/2/08	239	0.62	
3	5/2/08 – 5/9/08	158	0.52	
4	5/9/08 – 5/16/08	159	0.77	
5	5/16/08 – 5/23/08	161	1.04	

5.2.5.3 RO Performance

The first stage mass transfer coefficient (MTC) and the second stage MTC are shown in Figure 5.2-41. Due to problems with the O-rings in the RO vessels that occurred many times in April, the MTCs did not show any clear trend of RO fouling in April. However, the first stage and second stage MTC show clear downward trend in May indicating heavy particulate fouling due to iron. The second stage MTC also showed a significant decline, indicating scaling in the second stage.

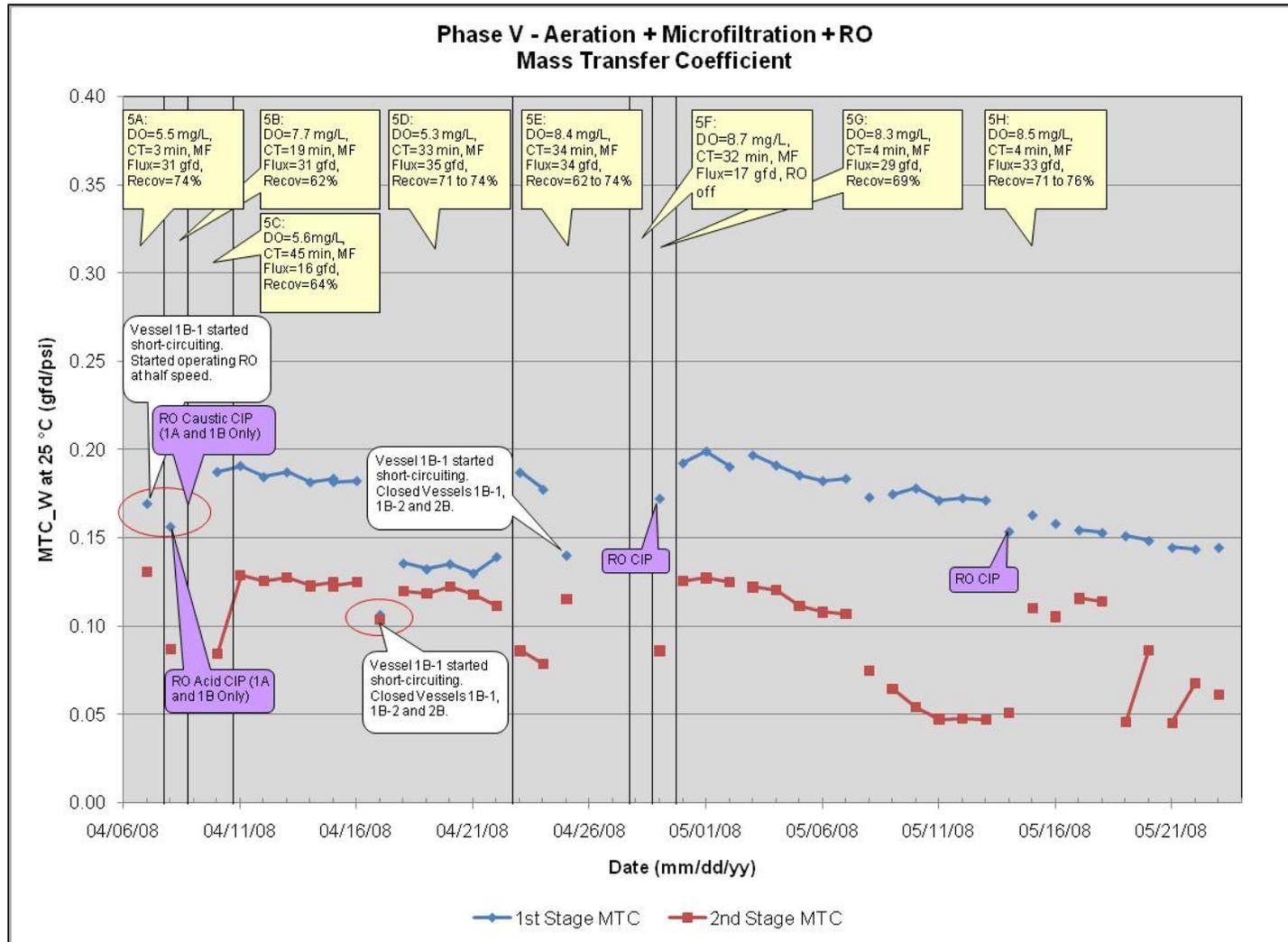


Figure 5.2-41.
Phase V – MTC_W at 25 °C

5.2.5.4 Water Quality

The water quality parameters tested during Phase V are summarized in Table 5.2-18.

Parameter	Detection Limit	Water Quality Goals		Water Quality			
		Regulatory Requirement or Reporting Limit	City's Goal	Well A Raw Water	RO Feed	RO Permeate	RO Waste
Temperature (°C)				--	22	--	--
pH		6.5 – 8.5	6.5 – 8.5	7.1	7.3	6.3	7.7
Conductivity (uS/cm ²)		900	900	1964	2130	130	6645
UV254 (cm ⁻¹)				0.03	0.03	--	--
Color (C.U)	2	15	2	4	3	< 2	--
Total Iron (mg/L)	0.02	0.3	0.2	0.16	0.04	< 0.002	0.12
Total Manganese (mg/L)	0.005	0.05	0.02	0.23	0.23	< 0.005	0.88
Alkalinity as CaCO ₃ (mg/L)	2.0			310	300	22	1400
Total Hardness as CaCO ₃ (mg/L)	0.66		120	920	920	15	4100
TDS (mg/L)	10	500	300	1600	1700	11	--
TSS (mg/L)	5			< 5	< 5	--	< 5
TOC (mg/L)	0.60			1.9	1.9	--	--
Ammonia (NH ₃ -N, mg/L)	0.017			0.29	--	0.02	0.98
Total Barium (mg/L)	0.0020			--	0.052	< 0.002	0.220
Total Boron (mg/L)	0.010	1	1	0.66	--	0.55	--
Calcium (mg/L)	0.10			250	250	4.1	1100
Chloride (mg/L)	0.24	250	80	94	--	16	--
Magnesium (mg/L)	0.10			69	69	1.1	300
Silica (mg/L)	0.3			30	--	3.8	--
Sodium (mg/L)	0.50			--	190	20	--
Sulfate (mg/L)		250		1245	--	13.1	3920
Total Strontium (mg/L)	0.0050			--	1.9	30	8.1
Total Vanadium (mg/L)	0.0050			0.005	--	0.075	--
Gross Alpha (pCi/L)		15	15	16.5	--	3.8	--
Notes: -- Not measured.							

Table 5.2-18 shows acceptable water quality for the RO permeate for all parameters, including iron, manganese, TDS, chloride and sulfate. In particular, the TDS level in the RO permeate was 11 mg/L, much lower than the City's goal of 300 mg/L.

5.2.5.5 Phase V Summary (Alternative 5)

The Phase V pretreatment evaluation, which consisted of aeration followed by microfiltration (MF), was tested during this period.

The pretreatment feed water had an average of 5.6 mg/L of dissolved oxygen (DO) when the eductor was used for aeration, and 8.5 mg/L of DO when an air compressor was used. Under both conditions, the iron was only partially oxidized by the DO in the contact tank within the 3 to 36 minutes of contact time tested. Additional oxidation of iron was observed in the MF.

The rate of oxidation was sensitive to the contact time and the concentration of DO in the water. For the aeration followed by MF pretreatment process to completely oxidize and remove the iron, it was determined that the pretreatment feed water must be saturated at approximately 8.7 mg/L of DO, and approximately 35 minutes of contact time must be provided. To provide 35 minutes of contact time in a full-scale plant, a 210,000 gallon capacity tank would need to be provided.

Aeration followed by MF was found to be less effective than the aeration followed by media filtration pretreatment process, evaluated in Phase II. Although the MF could be considered a better filtration process than the media filtration, the media filters provide improved oxidation of iron, resulting in greater removal.

5.3 Pretreatment Process Selection

The purpose of the pretreatment evaluation was to identify the most appropriate treatment approach to prepare the water from City wells for desalination. The following discussion explains the criteria used to evaluate the various pretreatment approaches, discusses how each process met these criteria, and makes a final recommendation for a pretreatment process used both in the final optimization stage of the pilot and in the proposed full-scale facility.

5.3.1 Evaluation Criteria

While the majority of the treatment goals for the facility are addressed through the desalination process, pretreatment is required to assure efficient, reliable operation for the downstream RO process. Specifically, many utilities have faced membrane fouling and operational problems from iron or manganese in their water supplies. Other problems have been experienced from biofouling or damage from oxidants used in their pretreatment processes. The selected pretreatment process will need to provide water of a quality acceptable to feed an RO system, and must be reliable, simple to operate, safe, and cost effective. These goals were discussed previously in Section 3.

5.3.2 Evaluation

The following includes a discussion of the rankings for each of the five pretreatment approaches based on the criteria presented above.

5.3.2.1 Water Quality Goals

Table 5.3-1 lists the water quality goals and performance results for each of the five pretreatment alternatives. Treatment Alternatives 1 and 2 (oxygen quenching and aeration plus media filtration, respectively) were the most effective at meeting all of the treatment objects. For Alternative 1 considerable fouling was experienced on the RO unit after the oxygen quenching chemical (sodium thiosulfate) was turned off for several days, with the fouling continuing after chemical feeding was restarted. However, water quality goals were consistently met when the chemical feed remained uninterrupted, and the fouling was easily reversed through chemical cleaning of the membranes. Similarly, Alternative 2 saw fouling when adequate contact time was not maintained after aeration, however, under optimized conditions, the treatment goals were met for both Alternatives 1 and 2.

While Alternative 3 (chlorine dioxide feed plus media filtration) met the treatment goals for particulate iron and manganese, considerable irreversible damage to the RO membranes was experienced from contact with chlorine dioxide. It is not clear whether the RO fouling rate would have been acceptable had the membranes not been damaged, however, the SDI for the pretreatment product water did not meet the treatment goals. It should also be noted that only 70 percent of the manganese was oxidized with this process, regardless of the contact time, pH, or chlorine dioxide dose.

Alternative 4 (chlorine feed plus greensand) met the treatment goals for RO Fouling rate, particulate iron and particulate manganese, however, the SDI goal of 2.0 was not met for this process, and considerable problems were experienced with the cartridge filters becoming clogged within days of being replaced. High breakthrough of both iron and manganese occurred with this process, due in part to the difficulty of effectively backwashing the dense media. Similar to Alternative 3, only 70 percent of the manganese was oxidized with this process.

Alternative 5 (aeration plus microfiltration) did not meet the treatment goals for RO fouling or particulate manganese. While this process resulted in the lowest SDI (0.7) of any pretreatment alternative, a significant portion of the iron remained unoxidized after the MF membranes, but was subsequently oxidized within the break tank ahead of the RO membranes. Cartridge filter replacement was high during this phase, with RO fouling rate higher than any of the other pretreatment alternatives.

Table 5.3-1.						
Water Quality Goals for Pretreatment Alternatives						
Criteria	Goal	Alt 1 Oxygen Quenching	Alt 2 Aeration + Media Filtration	Alt 3 ClO₂ + Media Filtration	Alt 4 Cl₂ + Greensand	Alt 5 Aeration + MF
RO Fouling Rate Representative Conditions	0.5%	0.07%	0.5%	Membrane Damage	0.2%	2.9%
SDI Representative conditions	< 2	0.8	0.9	3.3	2.5	0.7
Particulate Iron in RO Feed	< 0.01	0.01	< 0.01	0.01	< 0.01	0.01
Particulate Manganese in RO Feed	< 0.005		< 0.005	< 0.005	< 0.005	0.01
Treatment Goals Rating		1	1	2	2	4
Rating Scale: 1-Best, 2-Good, 3-Average, 4-Poor, 5-Worst						

5.3.2.2 Reliability

Table 5.3-2 presents the reliability rankings for each of the five pretreatment alternatives. Alternative 2 provided the most reliable product water quality of the pretreatment methods tested. While Alternative 1 also provided high quality product water, it was ranked lower than Alternative 2, due to the continued RO fouling experienced after the brief period in which the oxygen quenching agent was shut off. It should be noted, however, that Alternative 1 demonstrated reliable performance when the oxygen quenching agent was consistently fed at both wells and the fouling which was experienced was readily removed through chemical cleaning. Alternatives 3 and 4 both employed oxidants which were found to be damaging to the membranes

and therefore require effective and complete quenching of these oxidants prior to feeding water to the RO membranes. Alternatives 4 and 5 also saw considerably high replacement rates for the cartridge filters due to plugging from particulate iron and other particulates. Alternative 5 was ranked last from a reliability standpoint, due to its inability to meet to treatment goals under the various operating conditions tested.

Table 5.3-2.
Reliability Ratings for Pretreatment Alternatives

	Alt 1 Oxygen Quenching	Alt 2 Aeration + Media Filtration	Alt 3 ClO2 + Media Filtration	Alt 4 Cl2 + Greensand	Alt 5 Aeration + MF
Reliability Rating	3	1	3	3	4
Rating Scale: 1-Best, 2-Good, 3-Average, 4-Not Poor, 5-Worst					

5.3.2.3 Simplicity

Table 5.3-3 presents the simplicity rankings for each of the five pretreatment alternatives. Alternative 1 was ranked best, due to the overall simplicity of this pretreatment process, which involves nothing more than a chemical feed system at each of the operational wells. Alternatives 2 and 5 also offer relatively simple operation, with no chemical feed systems required for operation, however, aeration systems would be required, along with significant contact tanks, and filtration systems, making these alternatives considerably more complex than Alternative 1. Alternatives 3 and 4 were ranked last in simplicity. Chlorine dioxide generation is a complex process, requiring multiple chemicals and complex generation equipment. Both Alternatives 3 and 4 will require reliable quenching of the oxidizing agent, whether chlorine dioxide or free chlorine, to prevent damage to the RO membranes.

Table 5.3-3.
Simplicity Ratings for Pretreatment Alternatives

	Alt 1 Oxygen Quenching	Alt 2 Aeration + Media Filtration	Alt 3 ClO2 + Media Filtration	Alt 4 Cl2 + Greensand	Alt 5 Aeration + MF
Simplicity Rating	1	3	4	4	3
Rating Scale: 1-Best, 2-Good, 3-Average, 4-Poor, 5-Worst					

5.3.2.4 Safety

Table 5.3-4 presents the safety rankings for each of the five pretreatment alternatives. Alternatives 2 and 5 do not involve the use of any chemicals in every day operation, however, both make use of high pressure air, both for injection into the process stream and for control of frequently operated automated valves. The safety risks for these alternatives are low, as are the risks for Alternative 1, which involves the

injection of a non-hazardous chemical at each of the wells and no additional pumping. Safety issues for Alternative 4 are also relatively low. While this alternative involves the injection of a hazardous chemical, sodium hypochlorite, the chemical will already be in use at the treatment facility for post RO disinfection. The highest safety risks are associated with Alternative 3, which makes use of multiple hazardous chemicals and an explosive chemical product.

Table 5.3-4.
Safety Ratings for Pretreatment Alternatives

	Alt 1 Oxygen Quenching	Alt 2 Aeration + Media Filtration	Alt 3 ClO₂ + Media Filtration	Alt 4 Cl₂ + Greensand	Alt 5 Aeration + MF
Hazardous Chemicals	Non-hazardous	No chemicals	Multiple hazardous chemicals	Hypochlorite only	No chemicals
Operating pressures	Low	High pressure air	Low	Low	High pressure air
Risk to Public	Low	Low	Explosive chemical	Low	Low
Overall Ranking	2	1	4	2	1
Rating Scale: 1-Best, 2-Good, 3-Average, 4-Poor, 5-Worst					

5.3.2.5 Cost

Detailed cost estimates were not developed for each of the pretreatment alternatives, however, the alternatives were evaluated from a relative cost perspective, based on an assumption that the cost of the RO equipment would not be impacted by which of the pretreatment alternatives is selected. Table 5.3-5 presents the relative cost ratings for each alternative from a capital, operations and maintenance, and lifecycle cost perspective. Similar to the other rating categories, costs were rated from 1 to 5, with 1 being the lowest cost and 5 being the highest. The lowest capital cost alternative is Alternative 1, which includes only equipment for chemical injection at the wells. This alternative, however, has a higher O&M cost than either Alternatives 2 or 5, due to the use of chemicals, which are not required for the latter alternatives. The highest cost alternatives, from both capital and O&M perspective, are Alternatives 3 and 4, which require the capital cost of both chemical feed and filtration equipment, and also the operating costs for both.

Table 5.3-5.
Cost Ratings for Pretreatment Alternatives

Criteria	Alt 1 Oxygen Quenching	Alt 2 Aeration + Media Filtration	Alt 3 ClO ₂ + Media Filtration	Alt 4 Cl ₂ + Greensand	Alt 5 Aeration + MF
Capital Cost	1	4	5	5	4
O&M Cost	3	2	5	4	2
Lifecycle Cost	2	3	5	5	3

Rating Scale: 1-Lowest, 2-Low, 3-Average, 4-High, 5-Highest

5.3.3 Recommended Pretreatment Process

Table 5.3-6 presents a summary of the process alternative rankings for each of the categories discussed above. Based on this evaluation, Alternatives 1 and 2 were identified as the most appropriate for RO pretreatment in the Phase VI pilot testing.

It was initially recommended to proceed using aeration plus media filtration, which had been shown to operate with greater reliability, when compared with the fouling observed in the oxygen quenching tests after the oxygen quenching chemical was turned off temporarily. However, after several weeks of operation, it was found that manganese oxidation was occurring within the media filters, causing significant fouling of the cartridge filters and RO membranes. The pretreatment process for Phase VI testing was therefore changed to oxygen quenching, which was ranked equally to Alternative 2 in the pretreatment evaluation. These issues will be discussed further with the Phase VI results.

Table 5.3-6.
Pretreatment Alternatives Ranking

	Alt 1 Oxygen Quenching	Alt 2 Aeration + Media Filtration	Alt 3 ClO ₂ + Media Filtration	Alt 4 Cl ₂ + Greensand	Alt 5 Aeration + MF
Water Quality Goals	1	1	2	2	4
Reliability	3	1	3	3	4
Simplicity	1	3	4	4	3
Safety	2	1	4	2	1
Cost	2	3	5	5	3
Overall Ranking	9	9	18	16	15

Note: Lower overall ranking number indicates more desirable pretreatment alternative.

5.4 Reverse Osmosis (RO) Optimization Test Results

The following presents the results of the RO optimization evaluation.

5.4.1 Overview

The purpose of the Phase VI testing was to optimize the RO process for finished water quality and energy usage, and to achieve the lowest operating costs that would meet the City's water quality goals.

Four different membranes, ranging from nanofiltration (NF) to recently developed low-pressure RO membranes, were considered in this evaluation. There were two parallel RO trains treating the same feed water. Both RO trains were operated at approximately 15 gfd flux and 75 percent feed water recovery.

An overview of the Phase VI testing is provided in Table 5.4-1, including the names of the RO membranes studied and the pilot study dates.

RO Optimization Test	Membranes Tested	Pretreatment Strategies Studied	Start Date	End Date
I	I. Dow Filmtec XLE 4040	Aeration plus Media Filtration	June 2, 2008	July 28, 2008
		Oxygen Quenching Alone	July 29, 2008	Aug. 13, 2008
	II. Saehan RE 4040 BLR	Oxygen Quenching plus Acid Addition (pH ~6.4)	Aug. 14, 2008	Aug. 26, 2008
II	III. Toray TM710	Oxygen Quenching plus Acid Addition (pH~6.4)	Aug. 26, 2008	Sep. 11, 2008
	IV. Dow Filmtec NF90	Oxygen Quenching plus Acid Addition (pH~6.4)	Sep. 19, 2008	Oct. 10, 2008
		Oxygen Quenching plus Acid Addition (pH~6.8)	Sep. 11, 2008	Sep. 18, 2008

5.4.2 Selected Pretreatment Test Results

5.4.2.1 RO Optimization Test I - Aeration plus Media Filtration

Description

Only Well A water was tested during RO Optimization Test I in the Phase VI testing in which aeration plus media filtration was studied. Well A raw water (RW) was aerated using an eductor (Mazzei air injector model 1584) upstream of the static mixer. The contact tank (following the static mixer) provided 15 min retention time for the iron oxidation. From the contact tank, the pretreatment feed (PTF) water was pumped and filtered through three granular media filters (GMFs) at 10 gpm feed flow rate per filter. After filtration, the pretreatment product (PTP) water was fed through the cartridge filters, after which the antiscalant was injected, and the RO feed (ROF) water was then pumped into the two parallel RO trains. Both RO trains were operated at approximately 15 gfd flux and 75 percent feed water recovery.

DO Concentration

Figure 5.4-1 shows the DO concentration in Well A (RW) and GMF feed (PTF). The average DO concentration in Well A raw water was 2.2 mg/L while in the GMF feed water it was 5.6 mg/L. This shows that the eductor increased the DO level in the GMF feed water by 250 percent, however, the feed water was not fully saturated with DO.

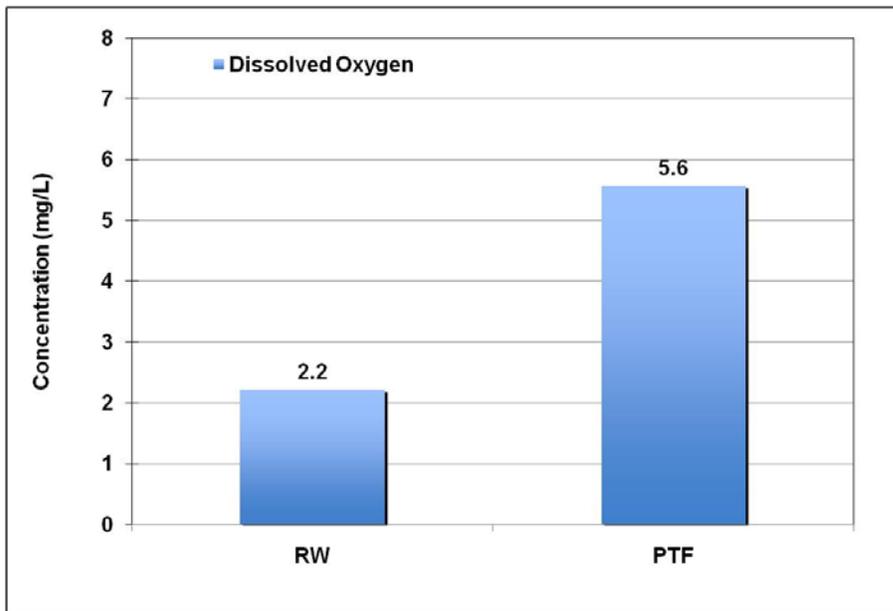


Figure 5.4-1.
Phase VI - Aeration + Media Filtration: DO Profiles in Well A RW and PTF

Iron Oxidation and Filtration

The total and particulate iron data for Well A (RW), GMF feed (PTF), GMF product (PTP), and RO feed (ROF) for the entire period of the aeration plus media filtration testing in Phase VI (July and July 2008) are depicted in Figure 5.4-2. On average, both total and particulate iron present in Well A raw water were removed by the aeration plus media filtration pretreatment process. About 95 percent of the total iron was removed by the aeration plus media filtration pretreatment. The particulate iron was increased by 120 percent in the contact tank (0.03 to 0.06 mg/L).

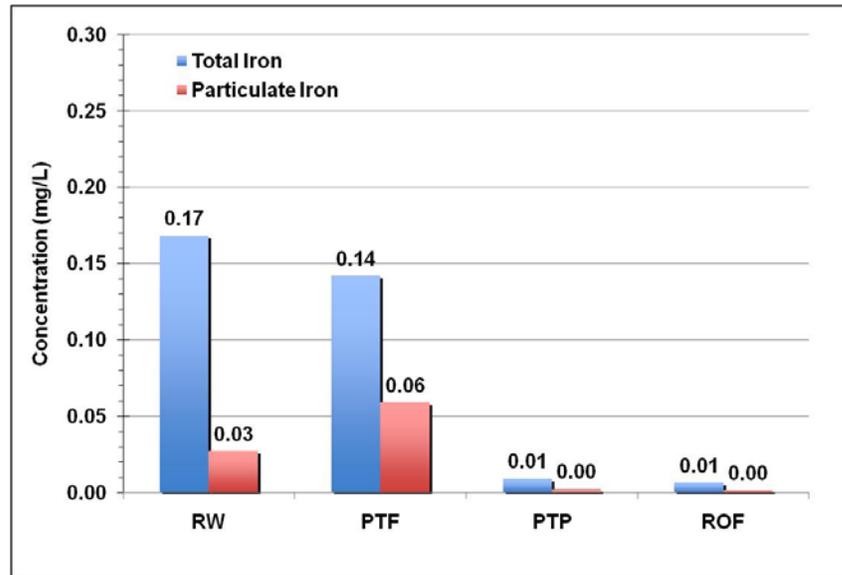


Figure 5.4-2.
Phase VI - Aeration + Media Filtration: Total Iron and Particulate Iron Profiles

Manganese Oxidation and Filtration

The total manganese data for Well A (RW), GMF feed (PTF), GMF product (PTP), and RO feed (ROF) water are depicted in Figure 5.4-3 for the entire period of aeration plus media filtration pretreatment testing in Phase VI (RO Optimization Test 1 in June and July 2008). Unlike iron, 15 minutes contact time did not change the total manganese concentration between Well A raw water and GMF feed water. However, there is a slight drop in the average manganese concentration following GMF, from 0.23 to 0.22 mg/L (about 5 percent difference). This suggests some of the manganese may unexpectedly have been oxidized and removed by the GMF.

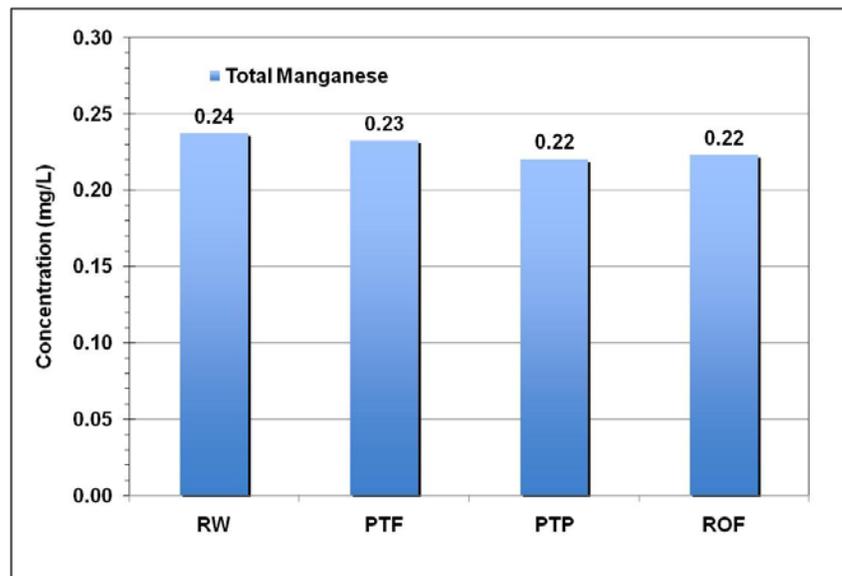


Figure 5.4-3.
Phase VI - Aeration + Media Filtration: Total Manganese Profiles

The total and dissolved manganese data for Well A (RW), GMF feed (PTF), GMF product (PTP), and RO feed (ROF) for July 2008 are depicted in Figure 5.4-4. To a much less extent than particulate iron, 15 minutes contact time changed the particulate manganese concentration between Well A raw water and GFM feed from 0.011 to 0.015 mg/L (about 36 percent difference). There is also a slight increase in the particulate manganese concentration following GMF, from 0.016 to 0.020 mg/L (about 25 percent difference). These results suggest that a small fraction of the dissolved manganese was oxidized to particulate manganese by the aeration and GMF process. This unexpected result was further verified by performing an autopsy on the cartridge filters, which is discussed next.

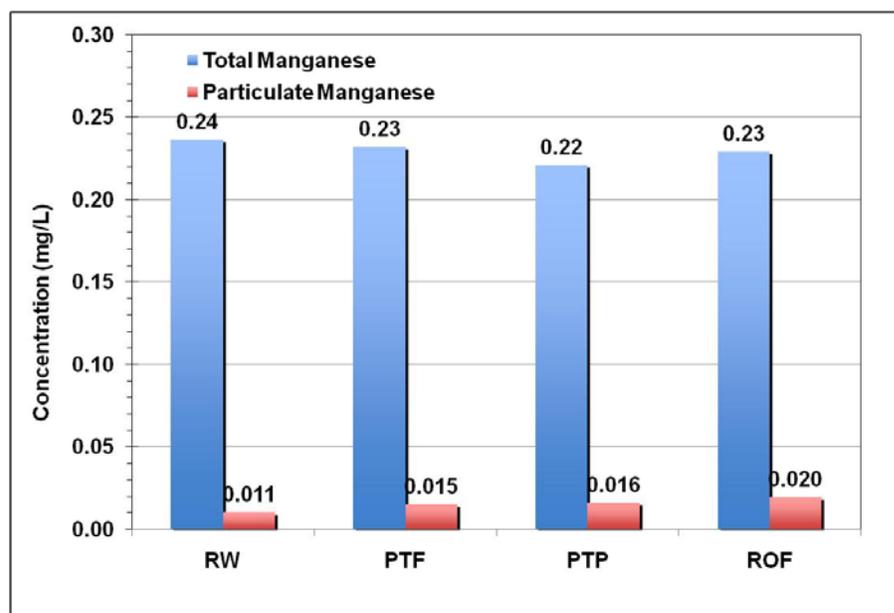


Figure 5.4-4.
Phase VI - Aeration + Media Filtration: Total Manganese and Particulate Manganese Profiles

Figure 5.4-5 shows a picture of the fouled cartridge filters. The dark brown color on the cartridge filters is indicative of the particulate manganese deposit. A detailed chemical analysis of this foulant material was performed by the Weck Lab and results are summarized in Table 5.4-2.

As shown in Table 5.4-2, the foulant deposit on the cartridge filter is primarily composed of manganese. The autopsy results confirmed that (1) dissolved manganese is being oxidized in the pretreatment process to particulate manganese, and (2) particulate manganese is not fully removed by the GMF. Such oxidation of manganese by air was both unexpected and unseen during the two months of previous pilot testing using aeration and media filtration (Phase II). Under normal conditions, the oxidation of manganese with air would take numerous hours of contact time to achieve, however, the presence of residual concentrations of

manganese dioxide on the media, perhaps a remnant of the Phase IV Pyrolox testing, may have accelerated the manganese oxidation through catalytic means. If this is the cause of the manganese oxidation, then it should be anticipated that similar results would be seen at a full scale facility, given enough time for the media to acclimate, building up its own layer of manganese dioxide. For this reason it was recommended that the pretreatment process be revised, with oxygen quenching selected to prevent oxidation of both iron and manganese for the remainder of the Phase IV testing period.



Figure 5.4-5.
Phase VI - Aeration + Media Filtration: Photo of Cartridge Filters

Table 5.4-2. Phase VI – Aeration + Media Filtration: Cartridge Filters Autopsy Results	
Analyte	mg of Analyte per kg of Cartridge Filter Fabric ⁽¹⁾
Iron, total	260
Manganese, total	1100
TOC	12
Note: 1) Chemical analysis was performed after acid digestion of the solid sample	

5.4.2.2 RO Optimization Test I - Oxygen Quenching

Description

Only Well A water was tested during the initial period of Phase VI testing, RO Optimization Test I. Beginning July 29, use of oxygen quenching was begun, such that Well A raw water was injected with sodium thiosulfate upstream of the static mixer, with no aeration, contact tank, or filtration ahead of the cartridge filters and RO unit. After the cartridge filters, antiscalant was injected, and the RO feed water was then pumped into the two parallel RO trains. Both RO trains were operated at 15 gfd flux and 75 percent feed water recovery. On August 14, the addition of muriatic acid began upstream of the cartridge filters to reduce the pH of the RO feed in addition to oxygen quenching at the well.

During the portion of the testing with oxygen quenching alone (July 29 – August 13), the concentration of sodium thiosulfate was varied from 1 mg/L to 20 mg/L to try to improve performance, but declines in MTC were observed for the RO membranes and fouling of the cartridge filters was seen. It was also attempted to vary the antiscalant feed to improve performance. Once oxygen quenching with acid addition was in place, the antiscalant feed was leveled at the manufacturer recommended concentration of 1.5 mg/L and the sodium thiosulfate feed concentration was reduced to 4 mg/L.

DO concentration

At the end of July 2008, a new device was proposed for measuring the dissolved oxygen in the water samples to minimize the influence of atmospheric oxygen. This device, pictured in Figure 5.4-6, was used throughout the entire measuring period in August. It yielded results much lower than those seen in June and July 2008.

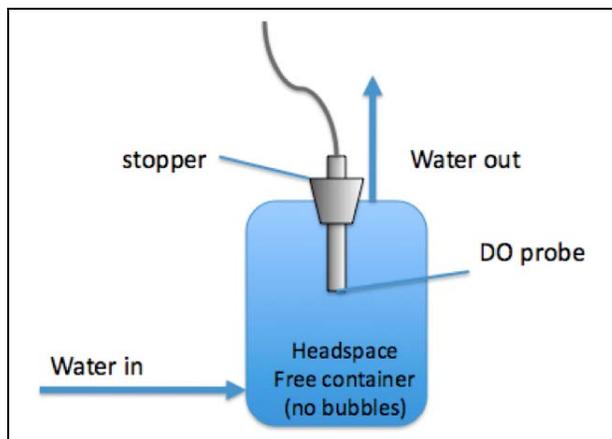


Figure 5.4-6.
Schematic of New Measuring DO Device

Figure 5.4-7 shows the DO measurements at the Well (RW) and in the RO feed (ROF) during RO Optimization Test I testing in Phase VI with oxygen quenching / oxygen quenching with acid addition pretreatment in August 2008. The DO concentrations for the raw water shown in Figure 5.4-7 are much lower than those shown in Figure 5.4-1 for June and July, demonstrating the effectiveness of the change in DO measurement protocol.

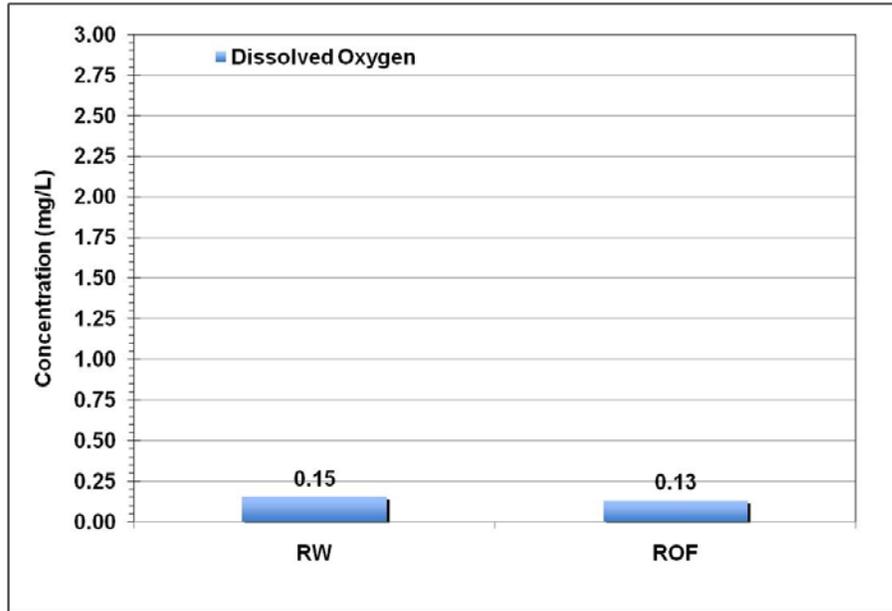


Figure 5.4-7.
Phase VI – Test I Oxygen Quenching: DO Levels

Iron oxidation and filtration

The total and particulate iron data for Well A (RW), water upstream of the RO cartridge filter (PTF), and RO feed (ROF) for August are depicted in Figure 5.4-8. At the end of July, the contact tank and the media filtration process were bypassed. The iron levels up to the RO cartridge filters were fairly consistent, but the cartridge filters seemed to be removing a significant amount of the iron as there was about a 10 percent difference in total iron between the raw water and the RO feed.

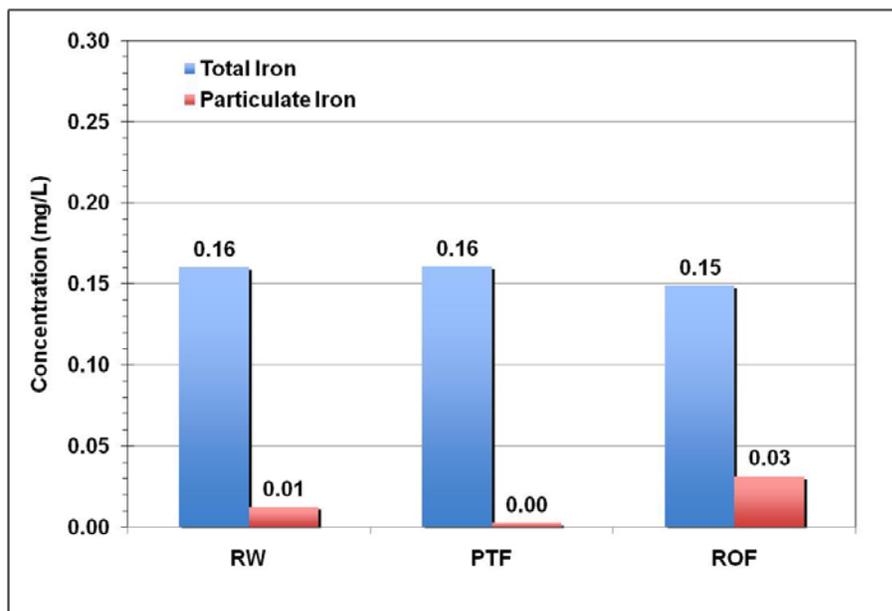


Figure 5.4-8.
Phase VI – Test I Oxygen Quenching: Total Iron and Particulate Iron Profiles

In mid-August 2008, the pretreatment strategy was refined to incorporate oxygen quenching with acid addition. On August 14, 2008, muriatic acid was fed into the system in order to slow the oxidation of iron, which was occurring to a small degree on the surface of the cartridge filters. With acid addition, an average pH of 6.4 was achieved in the RO feed for the duration of RO Optimization Test I.

The impact of acid addition on iron concentrations in the RO feed can be seen in Figure 5.4-9. Before acid addition began, the iron concentration in the RO feed was below the average concentration for Well A. After the addition of muriatic acid was initiated on August 14, 2008, the iron concentration in the RO feed was near the average concentration for Well A, which is depicted by the blue line in the figure.

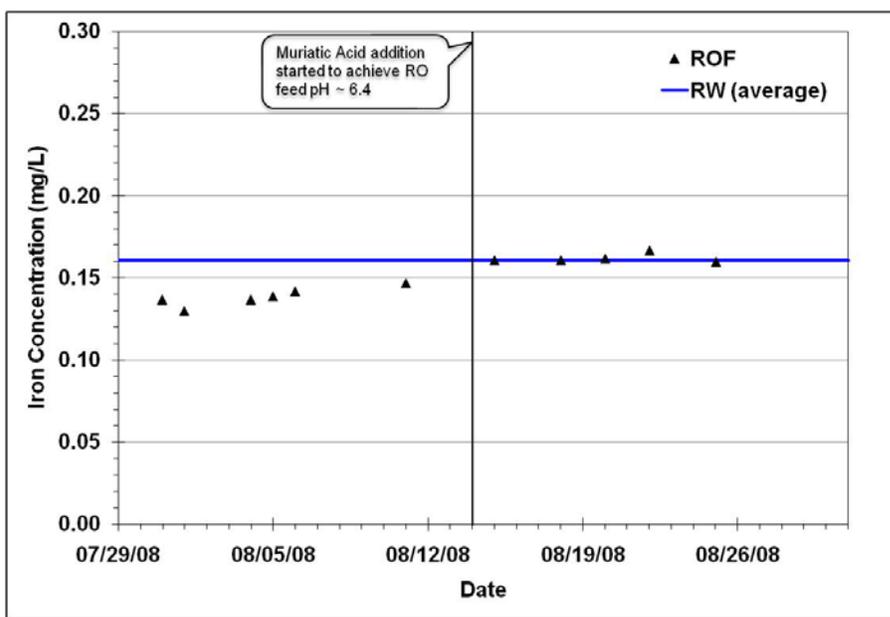


Figure 5.4-9.
Phase VI – Test I Oxygen Quenching: Summary of Iron Concentration in the ROF

Manganese Oxidation and filtration

The total and particulate manganese data for Well A (RW) and RO feed (ROF) for August is depicted in Figure 5.4-10. The cartridge filters did not do much to alter the manganese, so the total manganese concentrations from the well to the RO feed water were similar.

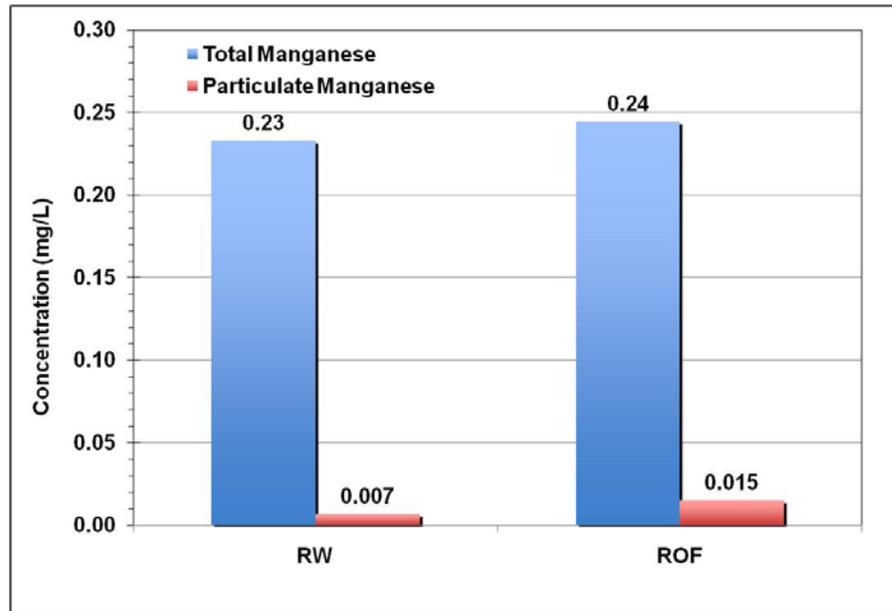


Figure 5.4-10.

Phase VI – Test I Oxygen Quenching: Total Manganese and Particulate Manganese Profiles

5.4.2.3 RO Optimization Test II - Oxygen Quenching with Well A

Description

Both Well A water and Well B water were tested during the latter period of Phase VI testing, RO Optimization Test II, which ran from August 26, 2008 to October 10, 2008. Well A feed was used from August 26 to September 19 with Well B feed thereafter. The use of oxygen quenching was continued, such that Well A raw water was injected with sodium thiosulfate upstream of the static mixer, with no aeration, contact tank, or filtration ahead of the cartridge filters and RO unit. After the cartridge filters, antiscalant was injected, and the RO feed water was then pumped into the two parallel RO trains. Both RO trains were operated at 15 gfd flux and 75 percent feed water recovery. The addition of muriatic acid was continued upstream of the cartridge filters to reduce the pH of the RO feed in addition to oxygen quenching at the well.

Well A feed was used during the initial part of RO Optimization Test II as discussed above. For most of this test period, the acid addition achieved an RO feed pH of 6.4 similar to the acid addition in RO Optimization Test I. In an attempt to test whether a lower acid dose might be possible, an RO feed pH of 6.8 was achieved during a one week portion of this part of the testing with Well A feed in RO Optimization Test II from September 11 to September 18, 2008. Late September 18, acid addition was restored to achieve the original target of RO feed pH 6.4.

DO concentration

At the end of July 2008, a new device was proposed for measuring the dissolved oxygen in the water samples to minimize the influence of atmospheric oxygen and use of this device continued in RO Optimization Test II from August through

October. On September 11, further refinements in the DO sampling protocol to further reduce the impact of ambient air on DO levels were made. This change resulted in measured DO levels even lower than those seen earlier with the new device and much lower than the DO levels measured in June and July before the new device was introduced. Figure 5.4-11 shows the DO levels measured during the portion of RO Optimization Test II with Well A feed. The results suggest a lack of DO at the Well A feed.

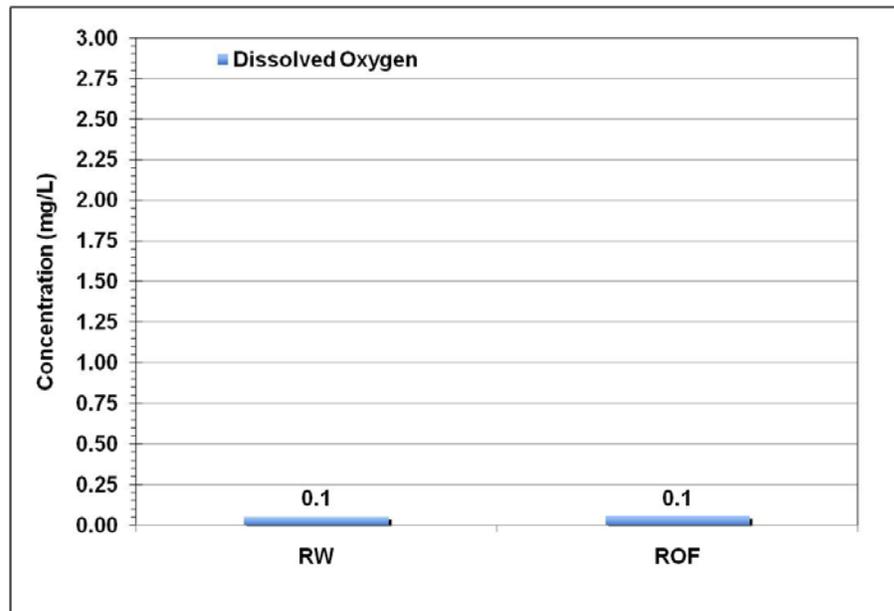


Figure 5.4-11.
Phase VI – Test II Oxygen Quenching with Well A: DO Levels

Iron Oxidation and Filtration

The total and dissolved iron data for Well A (RW), water upstream of the RO cartridge filter (PTF), and RO feed (ROF) for the portion of RO Optimization Test II with Well A feed are depicted in Figure 5.4-12. The results demonstrate that the iron concentration did not change much between the Well A raw water and the RO feed provided sufficient acid addition was achieved.

It should be noted that during the testing with lower acid dose to achieve RO feed pH 6.8, a difference in total iron between the raw water and the RO feed as high as 6 percent was observed (compared to difference in average levels of < 0.1 percent) and rapidly accelerated decline in MTC was observed during this portion of the testing, most notably for the Dow Filmtec NF90 membranes. This suggests that sufficient acid dose to achieve pH 6.4 in the RO feed is necessary to reduce problems with iron oxidation and that the lower acid dose to achieve pH 6.8 in the RO feed is not sufficient.

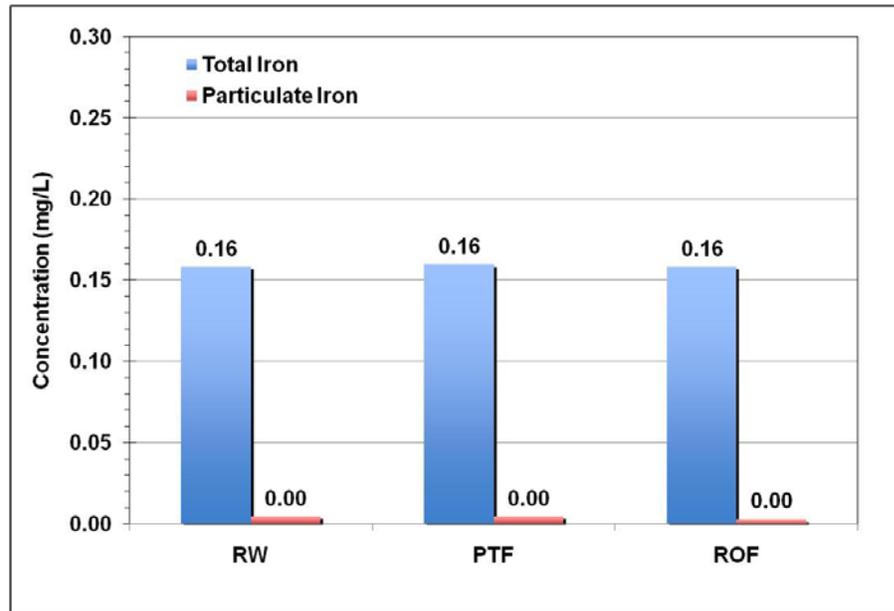


Figure 5.4-12.

Phase VI – Test II Oxygen Quenching with Well A: Total Iron and Particulate Iron Profiles

Manganese Oxidation and filtration

The total and particulate manganese data for Well A (RW) and RO feed (ROF) for the portion of RO Optimization Test II with Well A feed is depicted in Figure 5.4-13. The cartridge filters did not do much to alter the manganese, so the total manganese concentration from the well to the RO feed water were similar.

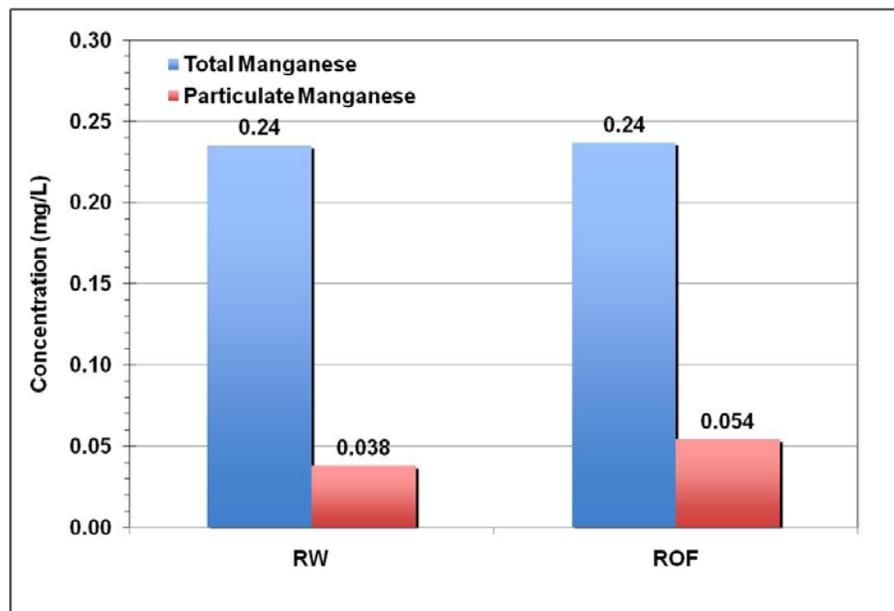


Figure 5.4-13.

Phase VI – Test II Oxygen Quenching with Well A: Total Manganese and Particulate Manganese Profiles

5.4.2.4 RO Optimization Test II - Oxygen Quenching with Well B

Description

Well B feed was used during the latter part of RO Optimization Test II as discussed above. For this portion of the testing, the acid addition achieved an RO feed pH of 6.4 similar to the acid addition in RO Optimization Test I and most of the earlier portion of RO Optimization Test II.

DO Concentration

At the end of July 2008, a new device was proposed for measuring the dissolved oxygen in the water samples to minimize the influence of atmospheric oxygen and use of this device continued in RO Optimization Test II from August through October. On September 11, further refinements in the DO sampling protocol to further reduce the impact of ambient air on DO levels were made. This change resulted in measured DO levels even lower than those seen earlier with the new device and much lower than the DO levels measured in June and July before the new device was introduced. Figure 5.4-14 shows the DO levels measured during the portion of RO Optimization Test II with Well B feed from September 19 to October 10. The results suggest a lack of DO at the Well B feed and represent the lowest DO levels observed at Well A or Well B during the Phase VI testing.

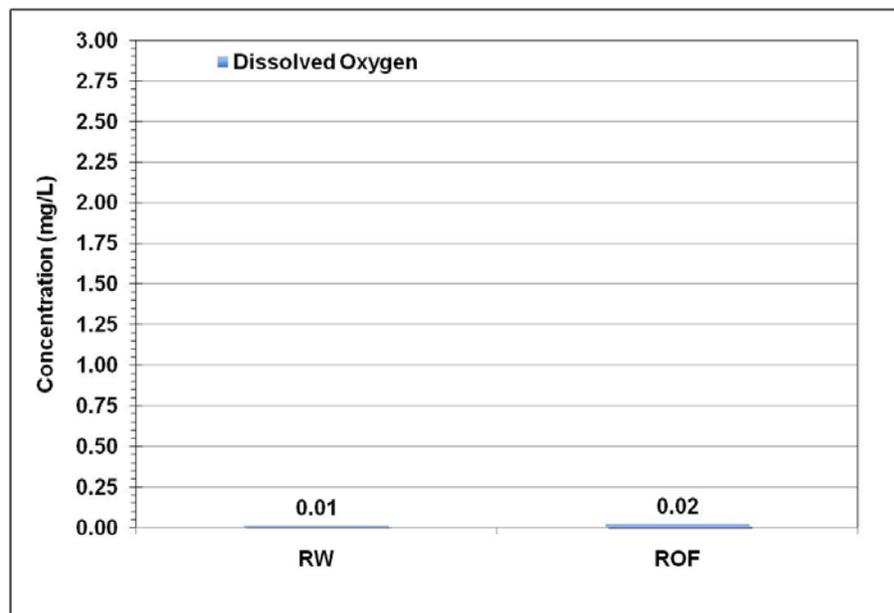


Figure 5.4-14.
Phase VI – Test II Oxygen Quenching with Well B: DO Levels

Iron Oxidation and Filtration

The total and particulate iron data for Well A (RW), water upstream of the RO cartridge filter (PTF), and RO feed (ROF) for the portion of RO Optimization Test II with Well B feed are depicted in Figure 5.4-15. The results demonstrate that the total iron concentration did not change much between the raw Well A raw water and the RO feed with acid addition to achieve RO feed pH 6.4.

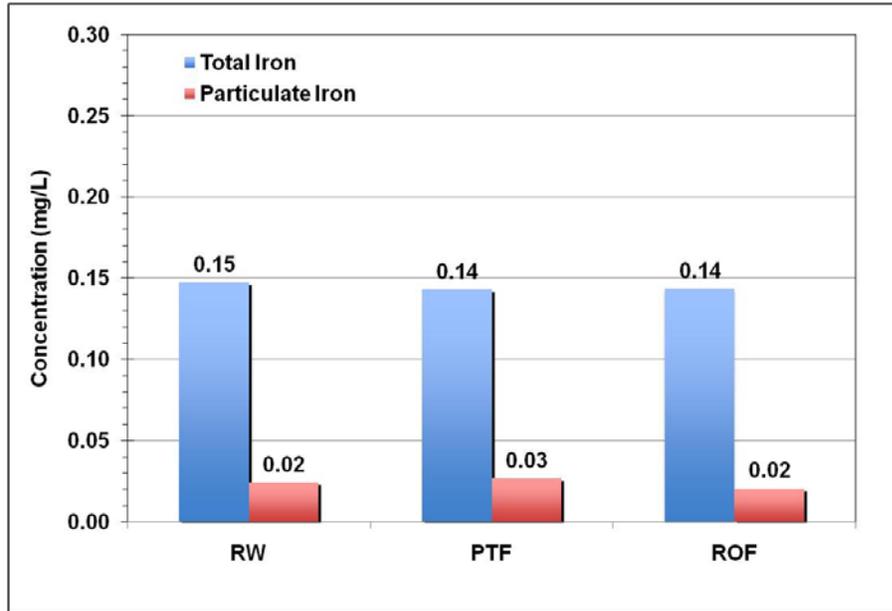


Figure 5.4-15.
Phase VI – Test II Oxygen Quenching with Well B: Total Iron and Particulate Iron Profiles

Manganese Oxidation and filtration

The total and particulate manganese data for Well A (RW) and RO feed (ROF) for the portion of RO Optimization Test II with Well B feed is depicted in Figure 5.4-16. The cartridge filters did not do much to alter the manganese, so the manganese concentration from the well to the RO feed water were similar.

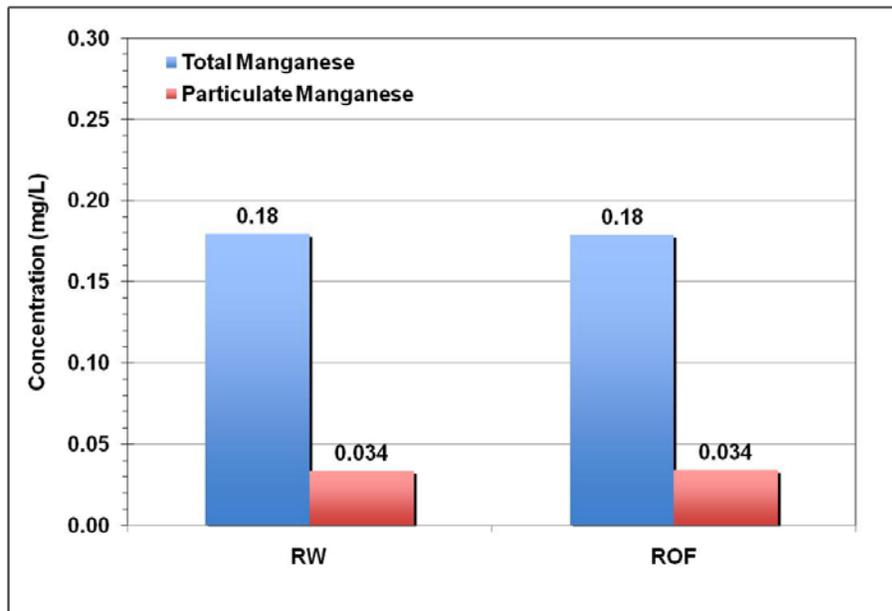


Figure 5.4-16.
Phase VI – Test II Oxygen Quenching with Well B: Total Manganese and Particulate Manganese Profiles

5.4.2.5 RO Feed Water Quality

During the course of Phase VI testing, various feed water constituents were measured. Table 5.4-3 provides a summary of various parameters measured in the lab for Well A and Well B during RO Optimization Test I and RO Optimization Test II including average concentrations for Well A over multiple days of laboratory testing. The levels of iron and manganese in the well and RO feed water were discussed in detail above.

Table 5.4-3.								
Phase VI – Summary of Feed Water Quality Parameters Measured in the Lab								
Parameter	Units	RO Optimization Test I			RO Optimization Test II		Summary	
		Well A	Well A	Well A	Well A	Well B	Well A	Well B
		6/27/08	7/10/08	7/14/08	9/19/08	10/6/08	Average	10/6/08
Total Barium	mg/L	0.049	0.052	0.052	0.047	0.064	0.050	0.064
Calcium	mg/L	240	250	260	230	200	245	200
Potassium	mg/L	5.3	6	5.9	5.7	5.4	5.7	5.4
Magnesium	mg/L	66	72	71	67	49	69	49
Sodium	mg/L	180	200	200	190	140	193	140
Strontium, Total	mg/L	1.8	1.9	1.9	1.9	1.4	1.9	1.4
Total Fluoride	mg/L	0.26	0.24	0.24	0.23	0.22	0.24	0.22
Alkalinity as CaCO ₃	mg/L	290	290	280	290	230	288	230
Carbonate Alkalinity as CaCO ₃	mg/L		ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)
Bicarbonate Alkalinity as HCO ₃	mg/L		360	350	350	280	353	280
Hydroxide Alkalinity as CaCO ₃	mg/L		ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)
Ammonia as N	mg/L	0.24	0.24	0.26	0.26	0.33	0.25	0.33
Gross Alpha	pCi/L	13.2	10.1	9.29	5.2	8	9.4	8.0
Gross Alpha counting error (+/-)	pCi/L	1.28	1.14	1.1	1.05	1.19	1.1	1.2
Gross Alpha MDA95	pCi/L	0.35	0.362	0.362	0.343	0.343	0.35	0.34
Total Hardness as CaCO ₃	mg/L	870	930	930	850	710	895	710
Nitrate as NO ₃	mg/L	0.99	0.81	1.5	0.69	ND (< 0.50)	1.0	ND (< 0.50)
Total Dissolved Solids	mg/L	1800	1700	1600	1800	1400	1725	1400

Table 5.4-3.
Phase VI – Summary of Feed Water Quality Parameters Measured in the Lab

Parameter	Units	RO Optimization Test I			RO Optimization Test II		Summary	
		Well A	Well A	Well A	Well A	Well B	Well A	Well B
		6/27/08	7/10/08	7/14/08	9/19/08	10/6/08	Average	10/6/08
Total Organic Carbon (TOC)	mg/L	1.5	1.4	1.4	1.5	1.4	1.5	1.4
Chloride	mg/L	170			170	170	170	170
Sulfate	mg/L	840			790	590	815	590
Silica as SiO ₂ , Total	mg/L	16			34	36	25	36

Table 5.4-4 provides a summary of feed water quality parameters in the raw water and the RO feed measured onsite during RO Optimization Test I and RO Optimization Test II including total and dissolved manganese as well as total and dissolved iron.

Table 5.4-4.
Phase VI – Summary of Feed Water Quality Parameters Measured Onsite

Parameter ⁽¹⁾	Units	RO Optimization Test I		RO Optimization Test II			
		6/2/08 - 8/26/08		8/26/08 - 9/19/08		9/19/08 - 10/10/08	
		Well A	RO Feed	Well A	RO Feed	Well B	RO Feed
Total Manganese	mg/L	0.236	0.230	0.235	0.237	0.180	0.180
Dissolved Manganese	mg/L	0.226	0.217	0.340	0.216	0.178	0.181
Total Iron	mg/L	0.165	0.070	0.158	0.158	0.148	0.144
Dissolved Iron	mg/L	0.1	0.053	0.155	0.155	0.13	0.13
Note: (1) Average values							

Table 5.4-5 shows an overview of total iron and total manganese during portions of RO Optimization Test I and RO Optimization Test II corresponding to the various pretreatment strategies discussed above, as well as the RO feed pH achieved during the portions of the testing when acid addition was employed as a part of the pretreatment strategy.

Table 5.4-5.											
Overview of Feed Water Quality Parameters Measured Onsite during Various Parts of the Phase VI Testing											
Parameter ⁽¹⁾	Units	RO Optimization Test I				RO Optimization Test II					
		6/2/08 – 8/26/08				8/26/08 – 9/19/08			9/19/08 – 10/10/08		
		Well A	RO Feed		RO Feed	Well A	RO Feed		Well B	RO Feed	
			6/2 – 7/28		7/29 – 8/13		8/26 – 9/10, 9/19			9/11 – 9/18	
Aeration + Media Filtration			Oxygen Quenching	Oxygen Quenching + Acid Feed (pH target ~6.5)			Oxygen Quenching + Acid Feed (pH target ~6.5)			Oxygen Quenching + Acid Feed (pH target ~6.8)	
Total Manganese	mg/L	0.236	0.223	0.249	0.234	0.235	0.216	0.260	0.180	0.180	
Total Iron	mg/L	0.165	0.007	0.139	0.162	0.158	0.160	0.155	0.148	0.144	
Summary of RO Feed pH during Portions of Pilot Study involving Muriatic Acid Addition											
pH	pH units	-	-	-	6.4	-	6.4	6.8	-	6.4	
Note: (1) Average values											

5.4.2.6 Phase VI Pretreatment Summary

The level of DO in the wells is an important consideration within to selection of a pretreatment strategy. The measurement of DO levels for the Camarillo wells was refined and improved over the course of the Phase VI testing. These improvements are summarized on Figure 5.4-17. By introduction of a flow through device to minimize the impact of ambient air on DO levels measured for the wells, DO levels down near zero (< 0.02 mg/L) were measured once the measurement technique was refined. It would be a prudent strategy to take steps to monitor DO at the wells during plant operation and take appropriate steps to mitigate the impact of rising DO levels promptly should they be observed.

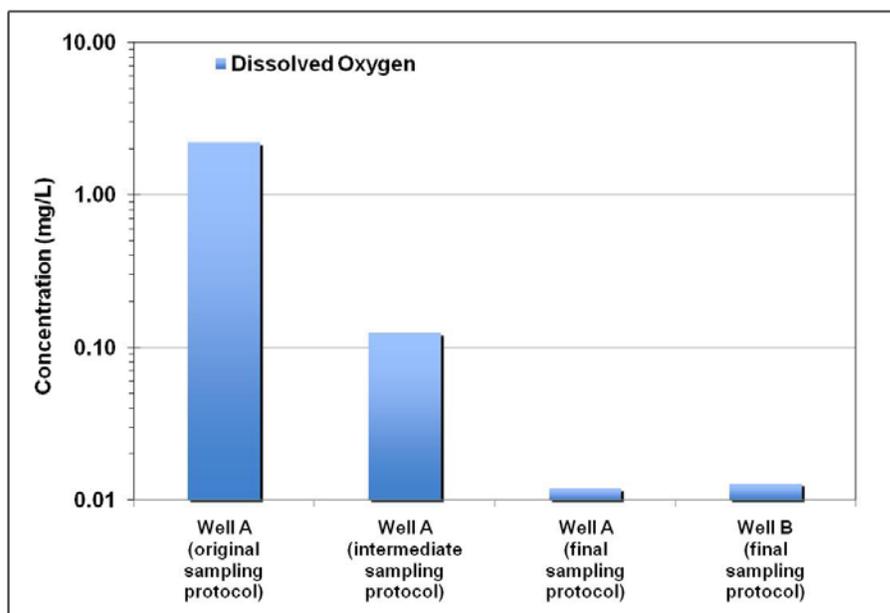


Figure 5.4-17.
Phase VI – Comparison of DO Levels

Various observations on pretreatment from the Phase VI testing are summarized in Table 5.4-6. The most promising pretreatment strategy based on the Phase VI testing appears to be oxygen quenching with acid addition. It should be noted that the oxygen levels during Phase VI testing appear to have been near zero at the wells. Because of this and because declines in MTC were observed for certain membranes even with the oxygen quenching with acid addition strategy, care must be exercised in the selection of the RO membrane for the plant and to avoid changes in DO levels in the wells to assure that the pretreatment strategy will be effective.

Table 5.4-6. Phase VI – Observations on Pretreatment Strategies		
Pretreatment Strategy		Observations based on Phase VI Results
Aeration plus Media Filtration		Appeared to result in fouling of the cartridge filters by manganese and in accelerated declines in MTC for membranes
Oxygen Quenching	No Acid Addition	Reduction in iron levels observed in cartridge filters; Accelerated decline in MTC for membranes
Oxygen Quenching with Acid Addition	Acid to pH ~ 6.4	No reduction in iron levels observed in cartridge filters; Most stable MTCs, still some declines in MTC observed for certain membranes
	Acid to pH ~ 6.8	Reduction in iron levels observed in cartridge filters; Accelerated decline in MTC for membranes

5.4.3 RO Optimization Test I Results

The following discussion will present pilot testing results for two low-pressure brackish RO membranes downstream of the selected pretreatment system (e.g., Phase II - Aeration plus Media Filtration). After completing 2 months of pilot testing, the pretreatment system was simplified to a chemical addition approach (similar to Phase I testing) to remediate undesired RO fouling that occurred during the sustained operation with the aeration plus media filtration approach.

5.4.3.1 Objectives

The objectives of RO Optimization Test I is to develop water quality and pressure information to select the optimal RO membrane, which will minimize the capital and O&M costs. The RO membranes will be evaluated based upon their ability to produce the defined water quality objectives set forth in Section 3.1.3 with the lowest total energy requirements (e.g., kWh/kgal). A secondary objective was to confirm that RO membrane fouling rates for the selected manufacturer were acceptable for the selected pretreatment process.

5.4.3.2 Description

The RO system was re-plumbed for Phase VI to allow parallel testing of two RO membranes on the same feed water. For the RO Optimization Test I, the low-pressure RO membranes offered by Saehan and Dow were evaluated for their fouling propensity, operating pressures, and product water quality. Each individual RO system was operated independently with a target feed water recovery of 75 percent and membrane flux of 15 gfd.

5.4.3.3 Membrane I Performance

Figure 5.4-18 presents the MTC for the Phase VI testing of Dow's FilmTec XLE 4040 membranes. The RO pilot was successfully operated for the three month time period without significant shutdowns, except for three CIPs (two acid and one caustic). Continuous data operation provides an excellent means to evaluate the influence of the entire treatment train on RO water quality and performance. From June 2, 2008 to

July 28, 2008, the aeration plus media filtration pretreatment produced the RO feed water. Unfortunately, unlike the testing performed in Phase II that demonstrated a moderate decline in the MTC, the RO membranes exhibited a significant decline in the MTC over the two-month testing period. In an effort to stop the decline in the MTC, an acid CIP followed by a caustic CIP was performed at the end of June, but provided little recovery of the MTC. The system continued to operate with aeration plus media filtration pretreatment until the RO membranes were acid cleaned again on July 30, 2008 to restore the MTC and begin a new operational run. Following this CIP, the pretreatment was changed significantly by eliminating the aeration plus media filtration completely. Instead of pretreatment equipment (aeration plus media filtration), chemical addition (muriatic acid and thiosulfate) was used to maintain the RO feed water iron and manganese in the dissolved form. Additional discussion on the rationale for this change in pretreatment process is provided in the upcoming section on water quality. Following these changes to the pretreatment process, the RO membranes exhibited minimal membrane fouling with the MTC declining very gradually in the second stage, but no loss in MTC was observed in the first stage (unlike the testing with the aeration plus media filtration pretreatment). The stable MTC in the first stage provides a good indication that the RO membrane was no longer fouling due to the presence of colloidal fouling components in the feed water. Once the feed water pH was reduced to 6.4 on August 14, 2008, the MTC values stabilized in the second stage.

Although the FilmTec XLE 4040 membranes initially exhibited high MTC values, they could not be restored to those initial values following the CIPs that were performed. The MTC stabilized around 0.17 gfd/psi for the first stage and 0.13 gfd/psi for the second stage.

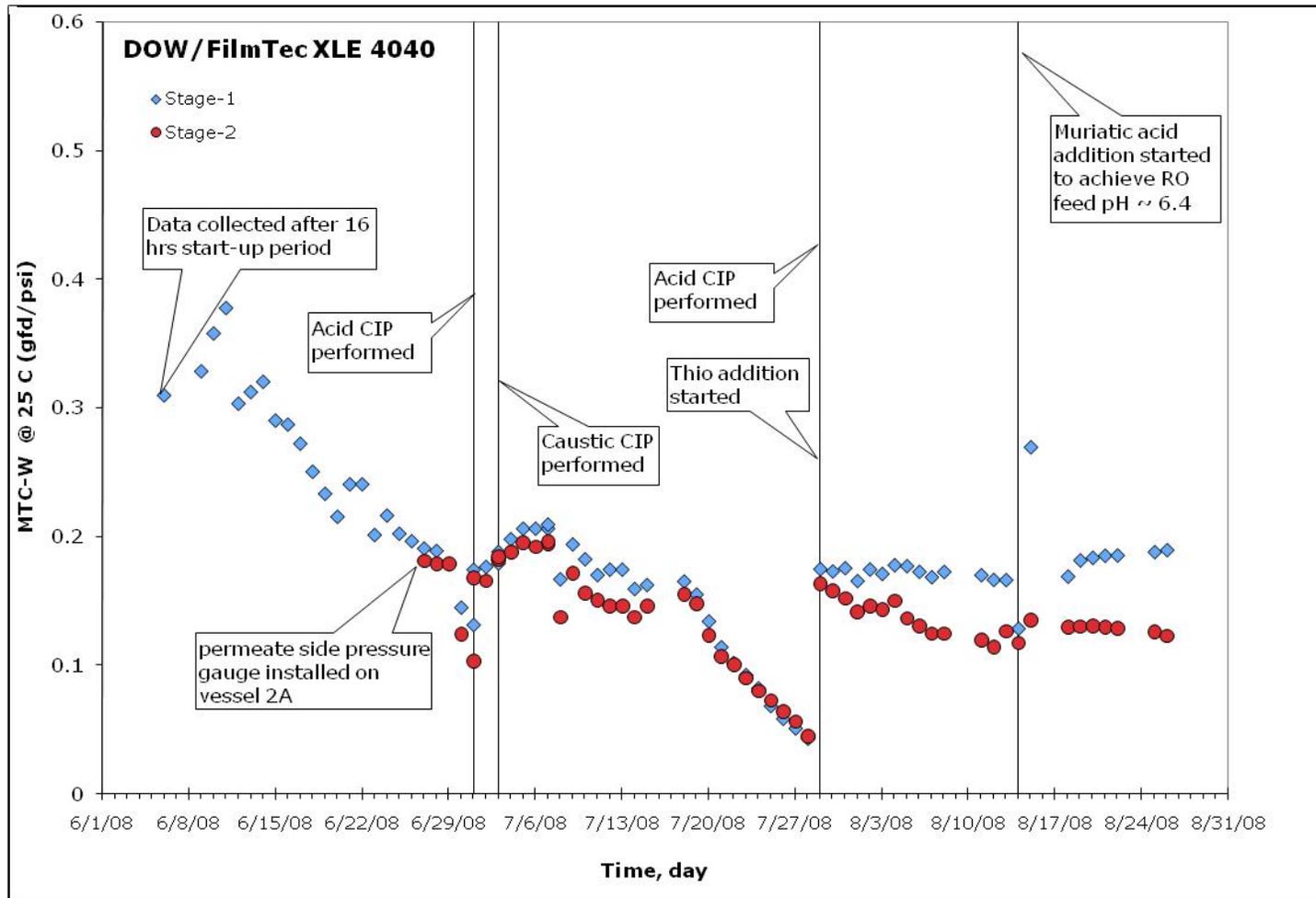


Figure 5.4-18.
Phase VI – Dow/FilmTec XLE 4040 Membrane Performance

5.4.3.4 Membrane II Performance

Figure 5.4-19 presents the MTC for the Phase VI testing of Saehan's RE4040 BLR membranes. Similar to the results presented for Dow's XLE 4040, the RO system operated continuously for three months. However, the membrane fouling observed with the RE4040 BLR membranes was more severe and five CIPs (four acid and one caustic) were performed in an attempt to restore the MTC. From June 2 to July 28, 2008, the aeration plus media filtration pretreatment produced the RO feed water and the RO membranes exhibited a significant decline in the MTC over the two-month testing period. An acid CIP was performed to begin the Phase VI operation and the MTC was relatively stable for the first couple weeks of operation. However, near the end of June, the MTC for both stages began a rapid decline and decreased from approximately 0.25 gfd/psi to less than 0.1 gfd/psi over a 2 week period. The RO membranes were acid cleaned on July 15, 2008 and the MTC was restored to approximately 0.2 gfd/psi. However, the rapid loss of MTC in both RO systems lead to the project team to conclude that a change in the pretreatment was required. Instead of pretreatment equipment (aeration plus media filtration), chemical addition (muriatic acid and thiosulfate) was used to maintain the RO feed water iron and manganese in the dissolved form. Again, additional discussion on the rationale for this change in pretreatment process is provided in the upcoming section on water quality. While these changes were being made to the pretreatment process, an acid CIP was performed. Similar to the fouling observed with the Dow XLE 4040, the first stage MTC was relatively stable, but the second stage MTC continued to decline until acid addition was implemented on August 14, 2008. The stable MTC in the first stage provides a good indication that the RO membrane was no longer fouling due to the presence of colloidal fouling components in the feed water. The muriatic acid addition appears critical to maintaining iron in a dissolved form, as it is concentrated in the second stage.

The Saehan RE4040 BLR membranes did not exhibit the same irrecoverable decline in the MTC that was observed with the XLE 4040s. The MTC initially stabilized around 0.25 to 0.3 gfd/psi for the first stage and the MTC remained stable towards the end of the testing period around 0.25 gfd/psi.

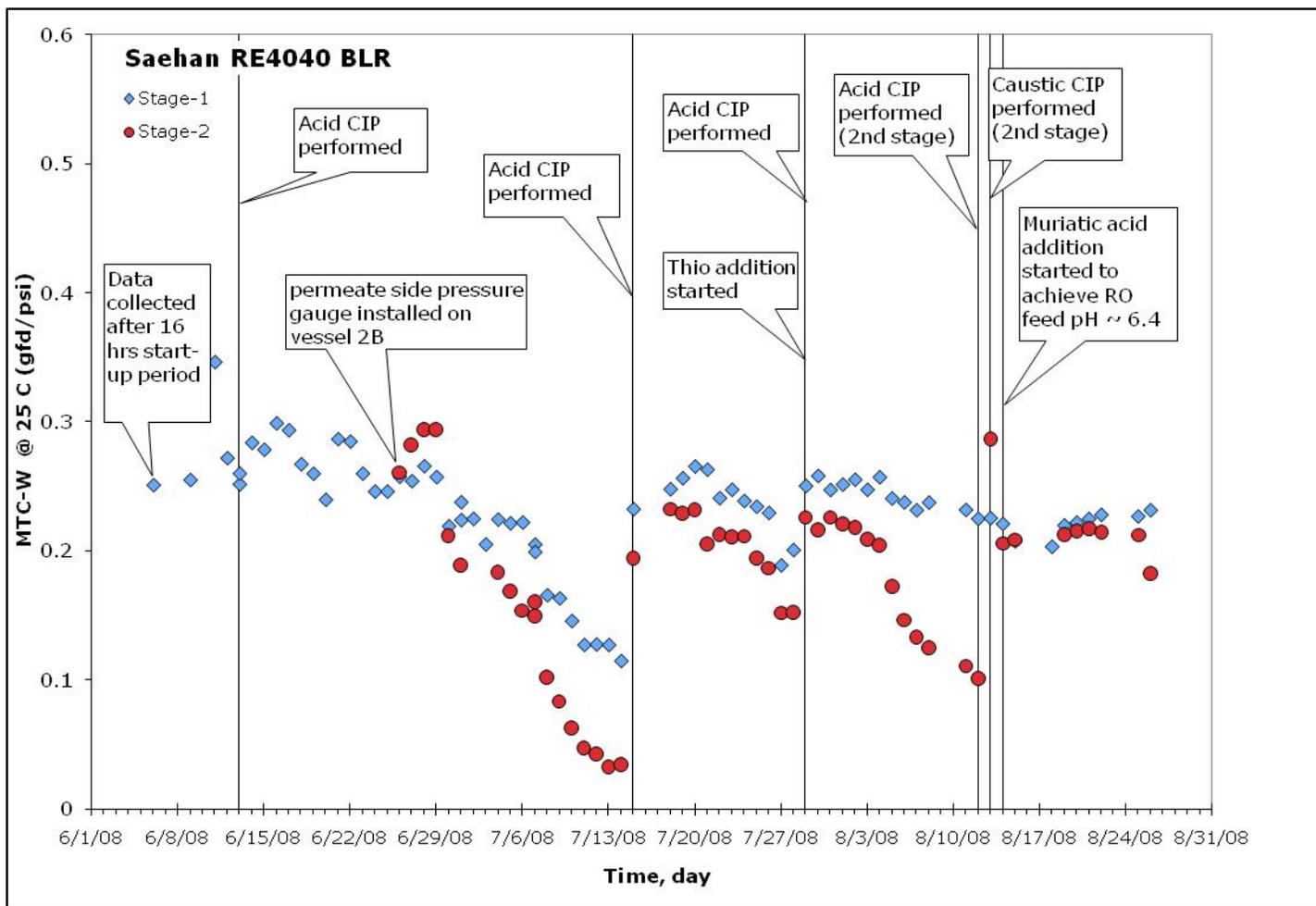


Figure 5.4-19.
Phase VI – Saeahan RE4040 BLR Membrane Performance

5.4.3.5 RO Permeate Water Quality

The feed water, RO permeate, and concentrate water quality for the Dow FilmTec XLE 4040 membranes is summarized in Table 5.4-7 for the total iron and manganese concentrations. The observed concentrations in Table 5.4-7 shows that:

- *Pretreatment (Well A and RO Feed data)*
 - Total iron was effectively removed by the aeration plus media filtration pretreatment between 6/2 and 7/28
 - Total iron was unchanged when feed water was dosed with acid and thiosulfate
 - Total manganese was slightly reduced by aeration plus media filtration pretreatment
 - Total manganese was unchanged with thiosulfate and acid addition
- *Influence of Iron on Dow RO Membrane Fouling at 75 percent recovery (RO Feed and Concentrate data)*
 - 3.7 grams per day of iron adsorbed to the membrane with the aeration plus media filtration pretreatment (e.g., concentrate iron is 0.006 mg/L, but should be 0.028 mg/L based on 0.007 mg/L in RO feed)
 - 13.9 grams per day of iron continued to adsorb to the membrane with thiosulfate alone as pretreatment (e.g., concentrate iron is 0.473 mg/L, but should be 0.556 mg/L based on 0.139 mg/L in RO feed)
 - No iron adsorbed to the membrane when thiosulfate and acid (pH ~ 6.5) were dosed to the feed water
- *Influence of Manganese on Dow RO Membrane Fouling at 75 percent recovery (RO Feed and Concentrate data)*
 - 27 grams per day of manganese adsorbed to the membrane with the aeration plus media filtration pretreatment (e.g., concentrate manganese is 0.731 mg/L, but should be 0.892 mg/L based on 0.223 mg/L in RO feed)
 - No manganese adsorbed to the membrane when chemical addition alone was used (July 29 to August 26, 2008)

Table 5.4-7.				
Phase VI – Total Iron and Total Manganese Concentrations with Dow Filmtec XLE 4040				
Dates	Location	Pretreatment	Membrane I (Dow Filmtec XLE 4040)	
			Total Manganese (mg/L)	Total Iron (mg/L)
6/2/08 – 8/26/08	Well A	All	0.236	0.165
	RO Feed		0.230	0.070
	Permeate		0.002	0.007
	Concentrate		0.818	0.264
6/2/08 – 7/28/08	Well A	Aeration + Media Filtration	0.238	0.169
	RO Feed		0.223	0.007
	Permeate		0.002	0.005
	Concentrate		0.731	0.006
7/29/08 – 8/13/08	Well A	Oxygen Quenching	0.233	0.157
	RO Feed		0.249	0.139
	Permeate		0.001	0.007
	Concentrate		1.007	0.473
8/14/08 – 8/26/08	Well A	Oxygen Quenching + Acid Feed (target pH~6.5)	0.234	0.165
	RO Feed		0.234	0.162
	Permeate		0.001	0.014
	Concentrate		0.999	0.632

The feed water, RO permeate and concentrate water quality for the Saehan RE 4040 BLR is summarized in Table 5.4-8 for total iron and manganese concentrations observed throughout the various stages of Phase VI. The iron and manganese concentrations through the treatment train show that:

- ***Pretreatment (Well A and RO Feed data)***
 - Same conclusions as from Table 5.4-7
- ***Influence of Iron on Saehan RO Membrane Fouling at 75 percent recovery (RO Feed and Concentrate data)***
 - 3.5 grams per day of iron adsorbed to the membrane with the aeration plus media filtration pretreatment (e.g., concentrate iron is 0.007 mg/L, but should be 0.028 mg/L)
 - 21 grams per day of iron adsorbed to the membrane with thiosulfate alone as pretreatment (e.g., concentrate iron is 0.431 mg/L, but should be 0.556 mg/L)
 - Unlike the Dow XLE 4040, 6 grams per day of iron continued to adsorb to the membrane when thiosulfate and acid (pH ~ 6.5) were dosed to the feed water.

- **Influence of Manganese on Saehan RO Membrane Fouling at 75 percent recovery (RO Feed and Concentrate data)**
 - 20.5 grams per day of manganese adsorbed to the membrane with the aeration plus media filtration pretreatment (e.g., concentrate manganese is 0.770 mg/L, but should be 0.892 mg/L)
 - Unlike the Dow XLE 4040, 13.5 grams per day of manganese continued to adsorb to the membrane when dosing thiosulfate
 - When the feed water was dosed with both acid and thiosulfate, the rate of manganese deposition was reduced to 4 grams per day

Table 5.4-8.				
Phase VI – Total Iron and Total Manganese Concentrations with Saehan RE 4040 BLR				
Dates	Location	Pretreatment	Membrane II (Saehan RE4040 BLR)	
			Total Manganese (mg/L)	Total Iron (mg/L)
6/2/08 – 8/26/08	Well A	All	0.236	0.165
	RO Feed		0.230	0.070
	Permeate		0.005	0.008
	Concentrate		0.823	0.260
6/2/08 – 7/28/08	Well A	Aeration + Media Filtration	0.238	0.169
	RO Feed		0.223	0.007
	Permeate		0.007	0.005
	Concentrate		0.770	0.007
7/29/08 – 8/13/08	Well A	Oxygen Quenching	0.233	0.157
	RO Feed		0.249	0.139
	Permeate		0.003	0.007
	Concentrate		0.916	0.431
8/14/08 – 8/26/08	Well A	Oxygen Quenching + Acid Feed (target pH~6.5)	0.234	0.165
	RO Feed		0.234	0.162
	Permeate		0.003	0.018
	Concentrate		0.909	0.612

Tables 5.4-9 and 5.4-10 present the general mineral water quality analyses for the Dow/FilmTec XLE 4040 and Saehan RE4040 BLR membranes, respectively. The XLE 4040 membranes produced a high quality permeate with TDS ranging from non-detect (< 10 mg/L) to 11 mg/L. The Saehan membranes, which were believed to be partially oxidized from previous testing, produced TDS concentrations between 74 and 110 mg/L. Additional discussion on the importance of water quality on the membrane selection is provided in Section 5.4.5.

Table 5.4-9. Phase VI – Mineral Water Quality Results for Dow Filmtec XLE 4040								
Parameter	Units	Membrane 1 (Dow Filmtec XLE 4040)						
		Well A	RO Permeate	RO Waste	Well A	RO Permeate	Well A	RO Permeate
		6/27/08	6/27/08	6/27/08	7/10/08	7/10/08	7/14/08	7/14/08
Total Barium	mg/L	0.049	ND (< 0.0020)	0.21	0.052	ND (< 0.0020)	0.052	ND (< 0.0020)
Calcium	mg/L	240	0.4	1100	250	0.59	260	0.36
Potassium	mg/L	5.3	ND (< 0.10)	25	6	1.3	5.9	0.62
Magnesium	mg/L	66	ND (< 0.10)	290	72	0.13	71	0.11
Sodium	mg/L	180	3.8	860	200	8.9	200	3.1
Strontium, Total	mg/L	1.8	ND (< 0.0050)	8	1.9	ND (< 0.0050)	1.9	ND (< 0.0050)
Total Fluoride	mg/L	0.26	ND (< 0.10)	0.94	0.24	ND (< 0.10)	0.24	ND (< 0.10)
Alkalinity as CaCO ₃	mg/L	290		1200	290	4.8	280	4.8
Carbonate Alkalinity as CaCO ₃	mg/L				ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)
Bicarbonate Alkalinity as HCO ₃	mg/L				360	5.9	350	5.9
Hydroxide Alkalinity as CaCO ₃	mg/L				ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)
Ammonia as N	mg/L	0.24	ND (< 0.10)	ND (< 0.10)	0.24	ND (< 0.10)	0.26	ND (< 0.10)
Gross Alpha	pCi/L	13.2			10.1	0.72	9.29	1.2
Gross Alpha counting error (+/-)	pCi/L	1.28			1.14	0.2	1.1	0.25
Gross Alpha MDA95	pCi/L	0.35			0.362	0.038	0.362	0.037
Total Hardness as CaCO ₃	mg/L	870	0.99	4100	930	2	930	1.3
Nitrate as NO ₃	mg/L	0.99	ND (< 0.50)	7.6	0.81	ND (< 0.50)	1.5	ND (< 0.50)
Total Dissolved Solids	mg/L	1800	11	8000	1700	ND (< 10)	1600	ND (< 10)
Total Organic Carbon (TOC)	mg/L	1.5	ND (< 0.30)	7.3	1.4	ND (< 0.30)	1.4	ND (< 0.30)
Chloride	mg/L	170	3.6	740				
Sulfate	mg/L	840	1.1	3700				
Silica as SiO ₂ , Total	mg/L	16	0.14	71				

Table 5.4-10. Phase VI – Mineral Water Quality Results for Saehan RE 4040 BLR							
Parameter	Units	Membrane II (Saehan RE 4040 BLR)					
		Well A		RO Permeate		RO Permeate	
		6/27/08	6/27/08	7/10/08	7/10/08	7/14/08	7/14/08
Total Barium	mg/L	0.049	ND (< 0.0020)	0.052	ND (< 0.0020)	0.052	ND (< 0.0020)
Calcium	mg/L	240	2.2	250	4.1	260	4.1
Potassium	mg/L	5.3	0.6	6	1.7	5.9	1.1
Magnesium	mg/L	66	0.59	72	1.2	71	1.2
Sodium	mg/L	180	24	200	47	200	33
Strontium, Total	mg/L	1.8	0.015	1.9	0.029	1.9	0.03
Total Fluoride	mg/L	0.26	ND (< 0.10)	0.24	ND (< 0.10)	0.24	ND (< 0.10)
Alkalinity as CaCO ₃	mg/L	290	29	290	48	280	43
Carbonate Alkalinity as CaCO ₃	mg/L			ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)
Bicarbonate Alkalinity as HCO ₃	mg/L			360	59	350	53
Hydroxide Alkalinity as CaCO ₃	mg/L			ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)
Ammonia as N	mg/L	0.24	ND (< 0.10)	0.24	ND (< 0.10)	0.26	ND (< 0.10)
Gross Alpha	pCi/L	13.2		10.1	2.1	9.29	1
Gross Alpha counting error (+/-)	pCi/L	1.28		1.14	0.42	1.1	0.27
Gross Alpha MDA95	pCi/L	0.35		0.362	0.06	0.362	0.052
Total Hardness as CaCO ₃	mg/L	870	7.9	930	15	930	15
Nitrate as NO ₃	mg/L	0.99	1	0.81	1.2	1.5	0.76
Total Dissolved Solids	mg/L	1800	74	1700	110	1600	100
Total Organic Carbon (TOC)	mg/L	1.5	ND (< 0.30)	1.4	ND (< 0.30)	1.4	ND (< 0.30)
Chloride	mg/L	170	26				
Sulfate	mg/L	840	3.5				
Silica as SiO ₂ , Total	mg/L	16	3.2				

5.4.3.6 RO Optimization Test I Summary

The selected pretreatment process from Phase II (Aeration plus Media Filtration) resulted in partial oxidation removal of manganese and significant RO fouling. Acid and thiosulfate addition successfully maintained the iron and manganese in the dissolved form which dramatically reduced RO fouling rates. The Dow XLE 4040 stabilized at a 0.17 and 0.13 gfd/psi for the first and second stages while the Saehan membrane stabilized around 0.25 gfd/psi. The mineral water quality produced by the Dow membrane was superior to the Saehan membrane.

5.4.4 RO Optimization Test II Results

The following discussion will present pilot testing results for a new low-pressure brackish RO membrane and a NF membrane downstream of the modified pretreatment system (e.g., oxygen quenching plus acid addition). The testing lasted for approximately 45 days.

5.4.4.1 Objectives

The objectives of RO Optimization Test II is to develop water quality and pressure information for two different desalination membrane types to select the optimal RO membrane, which will minimize the capital and O&M costs. The membranes will be evaluated based upon their ability to produce the defined water quality objectives set forth in Section 3.1.3 with the lowest total energy requirements (e.g., kWh/kgal). A secondary objective was to confirm that RO membrane fouling rates for the selected manufacturer were acceptable for the selected pretreatment process.

5.4.4.2 Description

For the RO Optimization Test II, the low-pressure RO membrane offered by Toray was compared with Dow's NF90 membrane for their fouling propensity, operating pressures, and product water quality. Each individual desalination system was operated independently with a target feed water recovery of 75 percent and membrane flux of 15 gfd.

5.4.4.3 Membrane III Performance

Figure 5.4-20 presents the MTC for the Phase VI testing of Toray's TM710 membrane. With the new chemical pretreatment, the RO membranes maintained a stable MTC throughout the entire testing period. An attempt was made on September 11, 2008 to increase the pH target from 6.5 to 6.8 to reduce acid consumption. However, this change resulted in membrane fouling, particularly of the second stage. The membranes were cleaned with caustic and acid solutions and put back into service with a target pH of 6.5 on September 19, 2008. Additionally, all work prior to this was performed on Well A, but Well B was put in service on September 19, 2008. The Toray membrane's MTC remained stable once acid dosing was restored to achieve a target pH of 6.5.

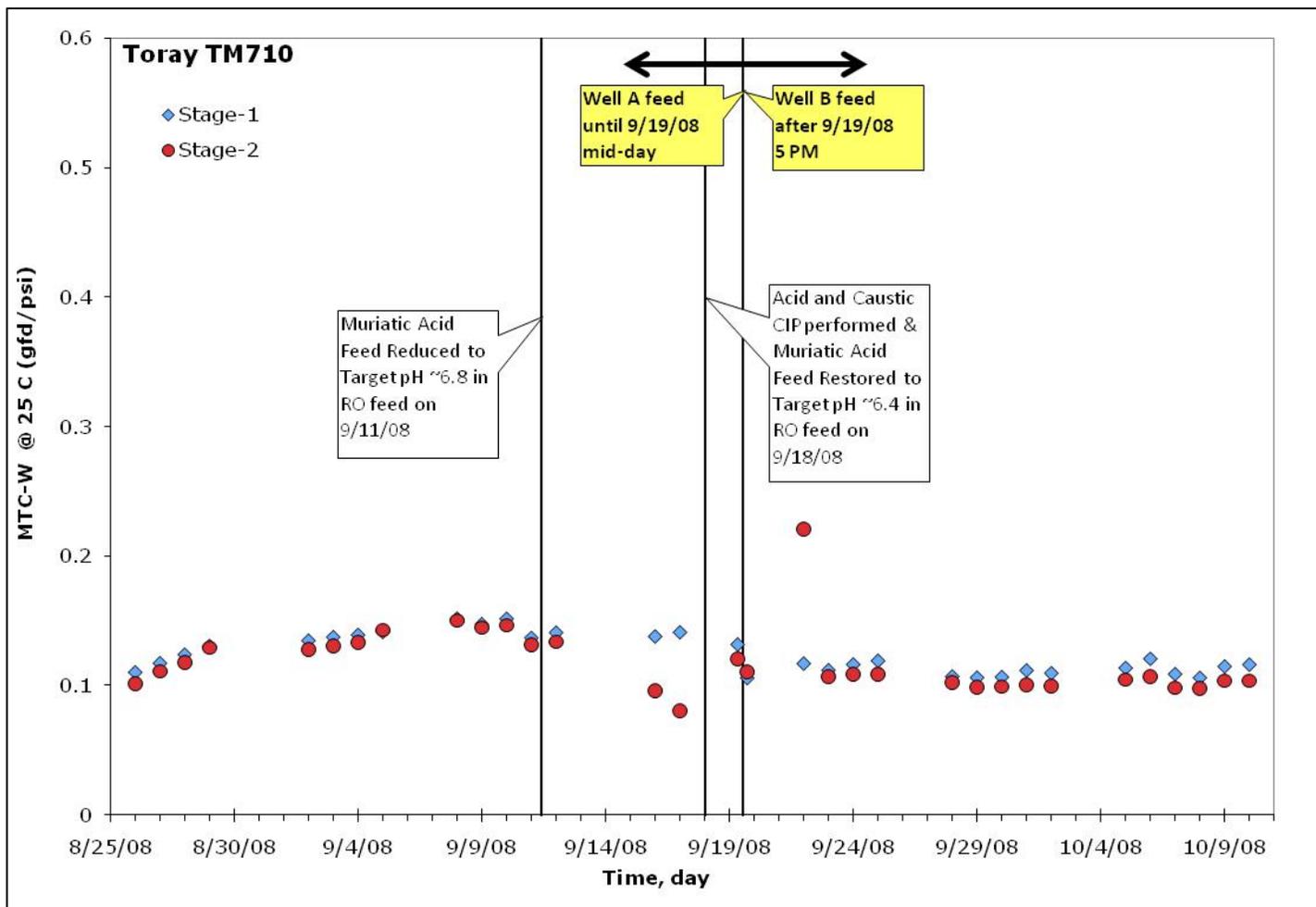


Figure 5.4-20.
Phase VI – Toray TM710 Membrane Performance

5.4.4.4 Membrane IV Performance

Figure 5.4-21 presents the MTC for the Phase VI testing of Dow's NF90 membrane. Unlike the Toray RO membranes, the NF membranes experienced a rapid decline in the MTC over the first two weeks of testing. Similar to the Toray RO membranes, the second stage of the Dow NF90 membranes was fouled significantly when an attempt was made to reduce the acid consumption on September 11, 2008. However, once the NF membranes were chemically cleaned and the pH target of 6.5 was restored, the MTC was more stable, but continued a gradual decline that indicates membrane fouling continued.

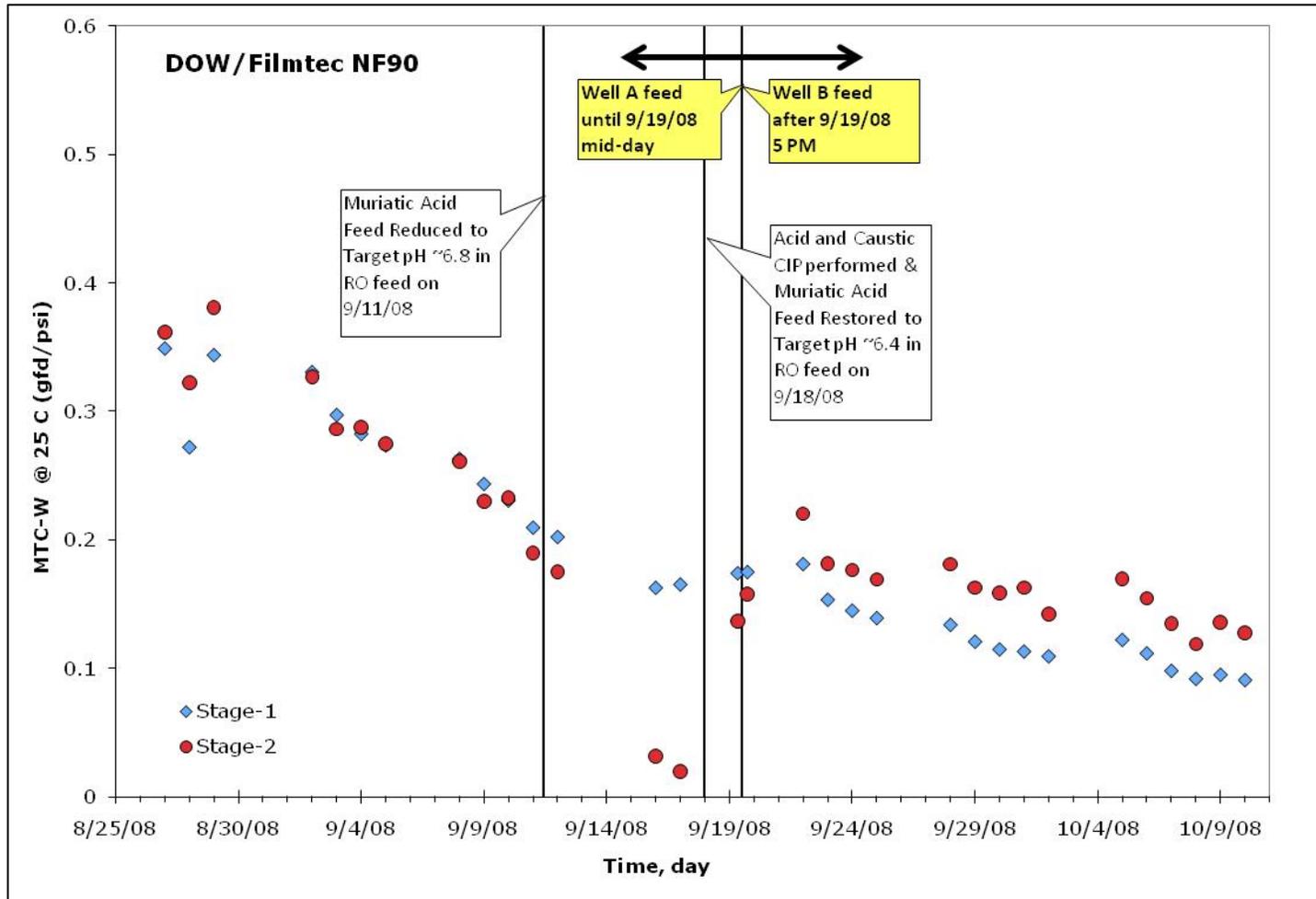


Figure 5.4-21.
Phase VI – Dow/FilmTec NF90 Membrane Performance

5.4.4.5 RO Permeate Water Quality

The feed water, RO permeate, and concentrate water quality for the Toray TM710 membranes are summarized in Table 5.4-11 for the total iron and manganese concentrations. The observed concentrations in Table 5.4-11 shows that:

- **Pretreatment (Well A and RO Feed data)**
 - Total iron and manganese were unchanged when feed water was dosed with acid and thiosulfate
- **Influence of Iron on Toray RO Membrane Fouling at 75 percent recovery (RO Feed and Concentrate data)**
 - Little iron was adsorbed to the membrane with a feed water pH of 6.5 and thiosulfate addition (August 26 to September 10, 2008)
 - 42.7 grams per day of iron adsorbed to the membrane when the target feed water pH was increased to 6.8
 - No iron adsorbed to the membrane when target feed water pH was returned to 6.5
- **Influence of Manganese on Toray RO Membrane Fouling at 75 percent recovery (RO Feed and Concentrate data)**
 - No manganese adsorbed to the membrane when target feed water pH was 6.5
 - 35.7 grams per day of manganese adsorbed to the membrane when the target feed water pH was increased to 6.8

Dates	Location	Pretreatment	Membrane III (Toray TM710)	
			Total Manganese (mg/L)	Total Iron (mg/L)
8/26/08 – 9/19/08	Well A	All (Well A feed)	0.235	0.158
	RO Feed		0.237	0.158
	Permeate		0.001	0.018
	Concentrate		0.910	0.554
8/26/08 – 9/10/08, 9/19/08	Well A	Oxygen Quenching + Acid Feed (target pH~6.5)	0.228	0.158
	RO Feed		0.216	0.160
	Permeate		0.001	0.020
	Concentrate		0.933	0.629

Table 5.4-11. Phase VI – Total Iron and Total Manganese Concentrations with Toray TM710				
Dates	Location	Pretreatment	Membrane III (Toray TM710)	
			Total Manganese (mg/L)	Total Iron (mg/L)
9/11/08 – 9/18/08	Well A	Oxygen Quenching + Acid Feed (target pH~6.8)	0.250	0.159
	RO Feed		0.260	0.155
	Permeate		0.001	0.014
	Concentrate		0.828	0.366
9/19/08 – 10/10/08	Well B	Oxygen Quenching + Acid Feed (target pH~6.5)	0.180	0.148
	RO Feed		0.180	0.144
	Permeate		0.001	0.006
	Concentrate		0.773	0.614

The feed water, RO permeate and concentrate water quality for the Dow FilmTec NF90 is summarized in Table 5.4-12 for total iron and manganese concentrations observed throughout the various stages of Phase VI. The iron and manganese concentrations through the treatment train show that:

- ***Pretreatment (Well A and RO Feed data)***
 - Total iron and manganese were unchanged when feed water was dosed with acid and thiosulfate
- ***Influence of Iron on Dow NF Membrane Fouling at 75 percent recovery (RO Feed and Concentrate data)***
 - 5.7 grams per day of iron adsorbed to the membrane with a feed water pH of 6.5 and thiosulfate addition (August 26 to September 10, 2008)
 - 50.8 grams per day of iron adsorbed to the membrane when the target feed water pH was increased to 6.8
 - Minimal iron adsorbed to the membrane when target feed water pH was returned to 6.5
- ***Influence of Manganese on Dow NF Membrane Fouling at 75 percent recovery (RO Feed and Concentrate data)***
 - No manganese adsorbed to the membrane when target feed water pH was 6.5
 - 49.5 grams per day of manganese adsorbed to the membrane when the target feed water pH was increased to 6.8

5.4-12. Phase VI – Total Iron and Total Manganese Concentrations with Dow FilmTec NF90				
Dates	Location	Pretreatment	Membrane IV (Dow Filmtec NF90)	
			Total Manganese (mg/L)	Total Iron (mg/L)
8/26-9/19	Well A	All (Well A feed)	0.235	0.158
	RO Feed		0.237	0.158
	Permeate		0.001	0.018
	Concentrate		0.878	0.524
8/26-9/10, 9/19	Well A	Oxygen Quenching + Acid Feed (target pH~6.5)	0.228	0.158
	RO Feed		0.216	0.16
	Permeate		0.001	0.022
	Concentrate		0.893	0.606
9/11-9/18	Well A	Oxygen Quenching + Acid Feed (target pH~6.8)	0.250	0.159
	RO Feed		0.260	0.155
	Permeate		0.004	0.01
	Concentrate		0.746	0.318
9/19-10/10	Well A	Oxygen Quenching + Acid Feed (target pH~6.5)	0.180	0.148
	RO Feed		0.180	0.144
	Permeate		0.001	0.005
	Concentrate		0.735	0.572

Tables 5.4-13 and 5.4-14 present the general mineral water quality analyses for the Toray TM710 and Dow/FilmTec NF90 membranes, respectively. The TM710 membranes produced a high quality permeate with TDS ranging from non-detect (< 10 mg/L) to 26 mg/L. The NF90 membranes produced TDS concentrations between 27 and 85 mg/L, which is excellent water quality for a NF membrane. Additional discussion on the importance of water quality on the membrane selection is provided in Section 5.4.5.

5.4-13. Phase VI – Mineral Water Quality Results for Toray TM710							
Parameter	Units	Membrane III (Toray TM710)					
		Well A	RO Permeate	RO Concentrate	Well B	RO Permeate	RO Concentrate
		9/19/08	9/19/08	9/19/08	10/6/08	10/6/08	10/6/08
Total Barium	mg/L	0.047	ND (< 0.0020)	0.18	0.064	ND (< 0.0020)	0.22
Calcium	mg/L	230	0.19	960	200	0.11	650
Potassium	mg/L	5.7	0.13	23	5.4	ND (< 0.10)	20
Magnesium	mg/L	67	ND (< 0.10)	260	49	ND (< 0.10)	160
Sodium	mg/L	190	4.7	770	140	2.9	560
Strontium, Total	mg/L	1.9	ND (< 0.0050)	7.3	1.4	ND (< 0.0050)	5
Total Fluoride	mg/L	0.23	ND (< 0.10)	0.63	0.22	ND (< 0.10)	0.58
Alkalinity as CaCO ₃	mg/L	290	7.2	820	230	7.2	650
Carbonate Alkalinity as CaCO ₃	mg/L	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)
Bicarbonate Alkalinity as HCO ₃	mg/L	350	8.8	1000	280	8.8	790
Hydroxide Alkalinity as CaCO ₃	mg/L	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)
Ammonia as N	mg/L	0.26	ND (< 0.10)	0.98	0.33	ND (< 0.10)	0.96
Gross Alpha	pCi/L	5.2	0.0		8	0.0	
Gross Alpha counting error (+/-)	pCi/L	1.05	1.0		1.19	0.71	
Gross Alpha MDA95	pCi/L	0.343	1.6		0.343	1.1	
Total Hardness as CaCO ₃	mg/L	850	ND (< 0.66)	3500	710	ND (< 0.66)	2300
Nitrate as NO ₃	mg/L	0.69	0.91	1.9	ND (< 0.50)	ND (< 0.50)	ND (< 0.50)
Total Dissolved Solids	mg/L	1800	26	9900	1400	ND (< 10)	4900
Total Organic Carbon (TOC)	mg/L	1.5	ND (< 0.30)	4.6	1.4	ND (< 0.30)	5.2
Chloride	mg/L	170	2.4	860	170	1.2	740
Sulfate	mg/L	790	0.52	3400	590	ND (< 0.50)	2100
Silica as SiO ₂ , Total	mg/L	34	0.21	130	36	0.12	120

5.4-14. Phase VI – Mineral Water Quality Results for Dow Filmtec NF90					
Parameter	Units	Membrane IV (Dow Filmtec NF90)			
		Well A	RO Permeate	Well B	RO Permeate
		9/19/08	9/19/08	10/6/08	10/6/08
Total Barium	mg/L	0.047	ND (< 0.0020)	0.064	ND (< 0.0020)
Calcium	mg/L	230	0.33	200	0.29
Potassium	mg/L	5.7	0.37	5.4	0.5
Magnesium	mg/L	67	ND (< 0.10)	49	ND (< 0.10)
Sodium	mg/L	190	13	140	8.5
Strontium, Total	mg/L	1.9	0.0024	1.4	ND (< 0.0050)
Total Fluoride	mg/L	0.23	ND (< 0.10)	0.22	ND (< 0.10)
Alkalinity as CaCO ₃	mg/L	290	8.4	230	4.8
Carbonate Alkalinity as CaCO ₃	mg/L	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)
Bicarbonate Alkalinity as HCO ₃	mg/L	350	10	280	5.9
Hydroxide Alkalinity as CaCO ₃	mg/L	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)
Ammonia as N	mg/L	0.26	ND (< 0.10)	0.33	ND (< 0.10)
Gross Alpha	pCi/L	5.2	0.0	8	0.0
Gross Alpha counting error (+/-)	pCi/L	1.05	0.85	1.19	0.98
Gross Alpha MDA95	pCi/L	0.343	1.5	0.343	1.6
Total Hardness as CaCO ₃	mg/L	850	0.83	710	0.72
Nitrate as NO ₃	mg/L	0.69	0.77	ND (< 0.50)	ND (< 0.50)
Total Dissolved Solids	mg/L	1800	85	1400	27
Total Organic Carbon (TOC)	mg/L	1.5	ND (< 0.30)	1.4	ND (< 0.30)
Chloride	mg/L	170	14	170	10
Sulfate	mg/L	790	ND (< 0.5)	590	ND (< 0.5)
Silica as SiO ₂ , Total	mg/L	34	1.3	36	0.95

5.4.4.6 RO Optimization Test II Summary

The change in pretreatment processes to chemical addition to maintain manganese and iron in a dissolved form (e.g., similar to Phase I pretreatment) provided stable MTC data for both membrane systems tested. During the testing of Toray's TM710 and Dow's NF90 membrane, the attempt to increase the target feed water pH from 6.5 to 6.8 resulted in a rapid loss of MTC. However, the MTC was recovered with CIPs and the MTC was stable again once the target feed water pH was returned to 6.5. During the period where the target feed water pH was increased to 6.8, both iron and manganese fouled the RO membranes. The Dow NF90 membranes experienced a rapid decline in MTC that was never recovered. However, the MTC did stabilize at around 0.1 to 0.15 psi/gfd while the Toray membrane remained relatively unchanged at 0.1 gfd/psi for the duration of testing. The mineral water quality produced by both membranes was excellent with TDS concentrations less than 100 mg/L.

5.4.5 Summary of RO Optimization Findings

The complete mineral quality attained from the four desalination membranes that were evaluated is presented in Table 5.4-15. The data in this table shows that the Saehan membrane produced the effluent with the highest TDS at 95 mg/L, which was higher than the NF membrane tested by Dow. This higher TDS concentration means that the Saehan permeate had higher concentrations of sodium, calcium, magnesium, alkalinity, chloride, sulfate and silica than any of the four membrane manufacturers tested. Some of the loss in rejection is believed to be caused by damage to the RO elements that happened during a previous phase where the Saehan membranes were exposed to chlorine dioxide. However, based on permeate mineral water quality, the Saehan membrane performed the worst. This was not anticipated based on the membrane manufacturers' modeling software. According to the membrane manufacturers' software, the Dow NF90 membrane should have produced the highest permeate TDS followed by the Dow XLE 4040.

Table 5.4-15.						
Phase VI - Summary of Mineral Water Quality Results for the Four Desalination Membranes						
Parameter (See Note 1)	Units	Feed	RO Permeate			
		Well A Average	Membrane I (Dow Filmtec XLE 4040)	Membrane II (Saehan RE4040 BLR)	Membrane III (Toray TM710)	Membrane IV (Dow Filmtec NF90)
Total Barium	mg/L	0.05	ND (< 0.0020)	ND (< 0.0020)	ND (< 0.0020)	ND (< 0.0020)
Calcium	mg/L	245	0.45	3.5	0.15	0.31
Potassium	mg/L	5.7	0.96	1.1	0.13	0.44
Magnesium	mg/L	69	0.12	1.0	ND (< 0.10)	ND (< 0.10)
Sodium	mg/L	193	5.3	35	3.8	11
Strontium, Total	mg/L	1.9	ND (< 0.0050)	0.025	ND (< 0.0050)	0.0024
Total Fluoride	mg/L	0.24	ND (< 0.10)	ND (< 0.10)	ND (< 0.10)	ND (< 0.10)
Alkalinity as CaCO ₃	mg/L	288	4.8	40	7.2	6.6
Carbonate Alkalinity as CaCO ₃	mg/L	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)
Bicarbonate Alkalinity as HCO ₃	mg/L	353	5.9	56	8.8	8.0
Hydroxide Alkalinity as CaCO ₃	mg/L	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)	ND (< 2.0)
Ammonia as N	mg/L	0.25	ND (< 0.10)	ND (< 0.10)	ND (< 0.10)	ND (< 0.10)
Gross Alpha	pCi/L	9.4	0.96	1.6	0.0	0.0
Gross Alpha counting error (+/-)	pCi/L	1.1	0.23	0.35	0.86	0.92
Gross Alpha MDA95	pCi/L	0.35	0.038	0.06	1.35	1.55
Total Hardness as CaCO ₃	mg/L	895	1.43	12.63	ND (< 0.66)	0.78
Nitrate as NO ₃	mg/L	1.00	ND (< 0.50)	0.99	0.91	0.77
Total Dissolved Solids	mg/L	1725	11	94.67	26	56
Total Organic Carbon (TOC)	mg/L	1.5	ND (< 0.30)	ND (< 0.30)	ND (< 0.30)	ND (< 0.30)
Chloride	mg/L	170	3.6	26	1.8	12
Sulfate	mg/L	815	1.1	3.5	0.52	ND (< 0.5)
Silica as SiO ₂ , Total	mg/L	25	0.14	3.2	0.17	1.1
Note:						
1) Average values used where multiple measurements were available						

Table 5.4-16 presents a comparison of actual water quality obtained during pilot testing to the projected concentrations from the RO manufacturers' model. All model runs were performed at a flux of 15 gfd with a 75 percent feed water recovery and a feed water temperature of 22°C. This table shows that Dow's modeling software is the most conservative of the three membrane manufacturers that were evaluated. All of the projected permeate concentrations were greater than those observed during actual pilot testing. Only the potassium of the XLE 4040 was greater than what the model projected. The Toray modeling software was almost as conservative, but like the Dow XLE 4040 the potassium observed during pilot testing was greater than what their model projected. In addition to potassium, Toray's software under projected the sodium and the TDS concentrations. Saehan's software was quite different from those offered by the other two manufacturers and it projected permeate concentrations that were too low for almost every component identified in Table 5.4-16. The only ionic species that were found in the RO permeate to be lower than the concentration projected by Saehan was sulfate. However, it is extremely important to note that it is believed that the Saehan membrane was damaged in a previous phase of pilot testing. As a result, it is likely that the Saehan membrane could achieve the projected by the manufacturer's software. Another important general note is that none of the membrane manufacturers include a prediction for manganese in their software and only 2 provided predictions for permeate iron concentrations.

Table 5.4-17 presents the allowable bypass flows to the blended water quality objectives established in Section 3 for each of the desalination products tested. As demonstrated in this table, sulfate and manganese are the limiting constituents and approximately 5 to 7 percent of the total flow can be a bypass stream (i.e., not treated by desalination process).

Table 5.4-16.
Phase VI – Comparison of Manufacturer Model Projections to Actual Water Quality

Parameter (See Note 1)	Units	Feed Well A Average	Membrane I (Dow Filmtec XLE 4040)			Membrane II (Saehan RE4040 BLR)			Membrane III (Toray TM710)			Membrane IV (Dow Filmtec NF90)		
			Actual	Projected	Percent Difference	Actual	Projected	Percent Difference	Actual	Projected	Percent Difference	Actual	Projected	Percent Difference
Iron	mg/L	0.16					0.0			0.0006				
Manganese	mg/L	0.23												
Calcium	mg/L	245	0.45	4.6	-1,000%	3.5	1.1	33%	0.15	0.90	-600%	0.31	4.1	-1,300%
Potassium	mg/L	5.7	0.96	0.46	48%	1.1	0.1	6%	0.13	0.085	66%	0.44	0.95	-220%
Magnesium	mg/L	69	0.12	1.3	-1,100%	1.0	0.3	32%	ND (<0.10)	0.25	-250%	ND (<0.10)	1.2	-1,200%
Sodium	mg/L	193	5.3	11.4	-220%	35	1.8	5%	3.8	2.6	67%	10.8	23.4	-220%
Alkalinity as CaCO ₃	mg/L	288	4.8	11.7	-240%	40		NA	7.2		NA	6.6	23.4	-350%
Total Hardness as CaCO ₃	mg/L	895	1.4	16.7	-1,200%	12.6	4.2	33%	ND (<0.66)	3.3	-500%	0.78	15.1	-1,900%
Total Dissolved Solids	mg/L	1,725	11	59.1	-540%	95	13.0	14%	26	11.8	45%	56	95.1	-170%
Chloride	mg/L	170	3.6	9.0	-250%	26	1.6	6%	1.8	3.5	-190%	12	19.3	-160%
Sulfate	mg/L	815	1.1	17.1	-1,600%	3.5	4.2	-120%	0.52	1.3	-260%	ND (< 0.5)	15.4	-3,100%

NOTES:
1) Average values used where multiple measurements were available
2) The actual value is X% more (+ sign) than the model or X% less than the model (- sign)
3) Model is reference point for calculating percent difference

Table 5.4-17.
Phase VI - Allowable Bypass Flows to Meet Blended Water Quality Goals for Each Membrane Tested

Parameter (See Note 1)	Units	Goal	Feed	Actual RO Permeate and Percent Bypass							
		Product	Well A Average	Membrane I (Dow Filmtec XLE 4040)		Membrane II (Saehan RE4040 BLR)		Membrane III (Toray TM710)		Membrane IV (Dow Filmtec NF90)	
				Actual Permeate	Percent of Plant Feed Flow Bypassing the RO	Actual Permeate	Percent of Plant Feed Flow Bypassing the RO	Actual Permeate	Percent of Plant Feed Flow Bypassing the RO	Actual Permeate	Percent of Plant Feed Flow Bypassing the RO
Iron	mg/L	0.2	0.16	0.0083	140%	0.0095	139%	0.015	140%	0.014	140%
Manganese	mg/L	0.025	0.23	0.0015	7.9%	0.0045	7.0%	0.001	8.1%	0.0018	7.8%
Total Hardness as CaCO ₃	mg/L	70 - 120	895	1.4	10%	12.6	9.4%	ND (< 0.66)	10%	0.78	10%
Total Dissolved Solids	mg/L	250	1,725	11	11%	95	7.3%	26	10.2%	56	9.0%
Sulfate	mg/L	70	815	1.1	6.5%	5.5	6.1%	0.52	6.5%	0.5	6.5%
Chloride	mg/L	65	170	3.6	31%	26	22%	1.8	31%	12	28%

Note:
1) Average values used where multiple measurements were available

Figures 5.4-22, 5.4-23, 5.4-24, and 5.4-25 provide visual comparisons of the product water TDS concentration, chloride concentration, sulfate concentration and iron concentration that were measured during this study compared to the manufacturers' software model predictions, respectively. It is clear from these figures that Saehan's software projected lower permeate concentrations than what was actually observed while the other three manufacturers provided more conservative projections with their software. It is important to note that none of the membrane manufacturers have software that is able to accurately predict permeate iron or manganese concentrations.

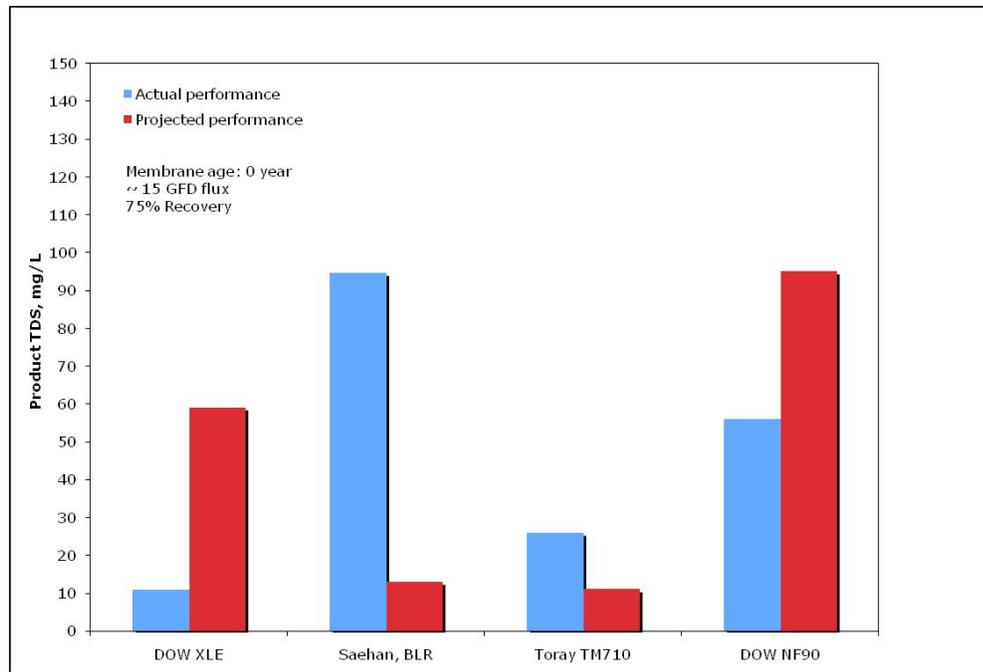


Figure 5.4-22.
Phase VI – Comparison of Observed and Projected Permeate TDS Concentrations

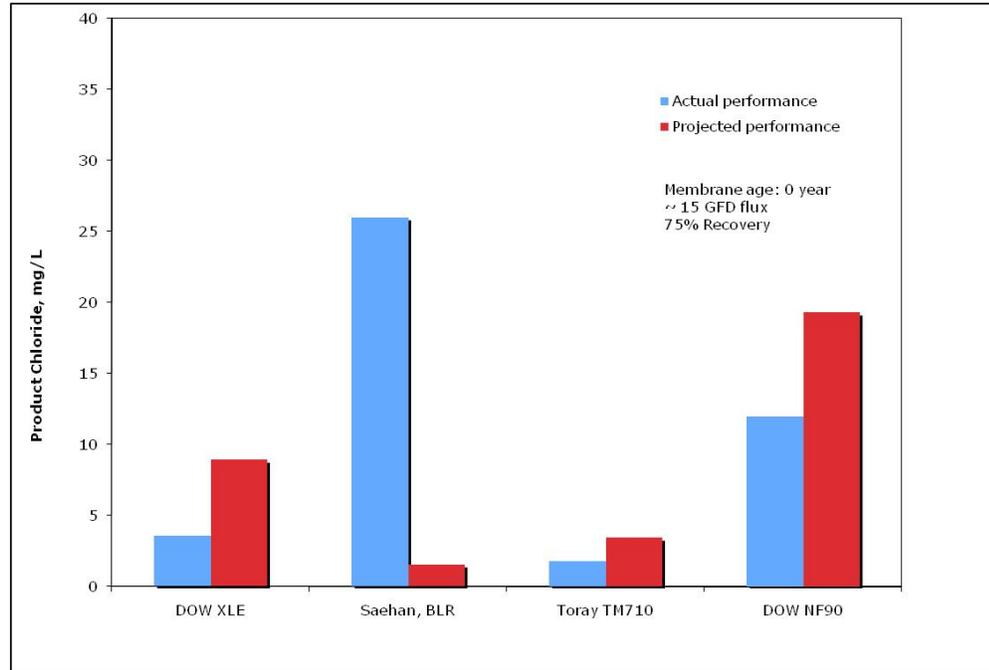


Figure 5.4-23.
Phase VI – Comparison of Observed and Projected Permeate Chloride Concentrations

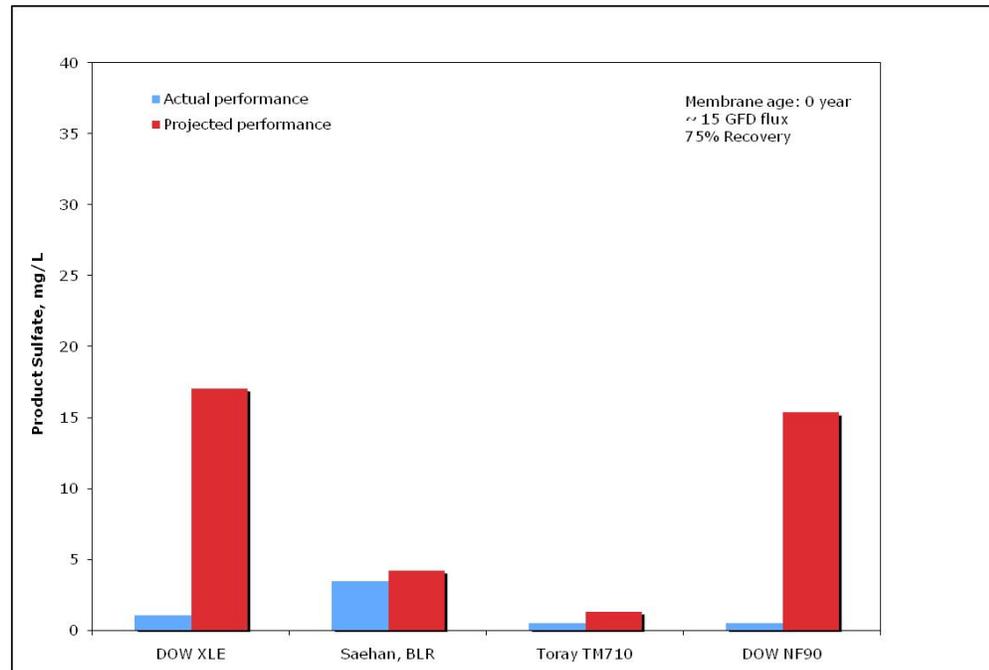


Figure 5.4-24.
Phase VI – Comparison of Observed and Projected Permeate Sulfate Concentrations

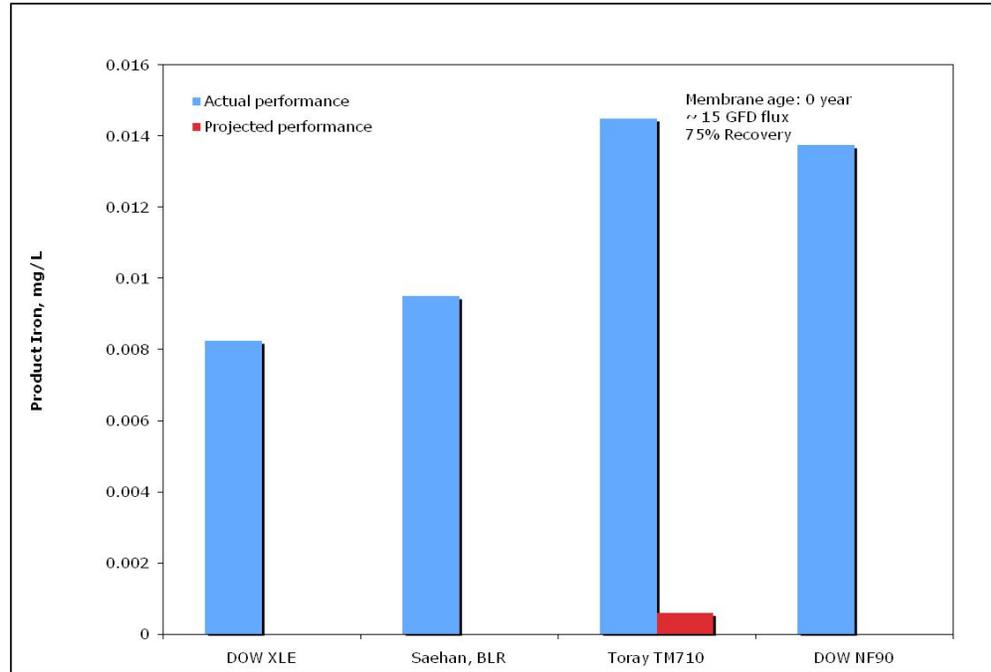


Figure 5.4-25.
Phase VI – Comparison of Observed and Projected Permeate Iron Concentrations

5.5 Emerging Contaminants Sampling Results

5.5.1 Overview

Technology advancements have made possible the detection of chemicals at increasingly lower concentrations, creating an awareness of drinking water contaminants that were previously unknown. In addition, current research suggests that some chemicals have human health effects, where previously no effects were known. These chemicals are referred to as emerging contaminants; they are chemicals not currently regulated for drinking water treatment, but that may someday have mandated removal. California is a leading state in identifying and dealing with these emerging contaminants. As part of the City of Camarillo Water Division's (CWD) pilot groundwater treatment study, Trussell Tech developed a list of emerging contaminants that were of particular interest and studied these contaminants as part of the pilot project.

Emerging contaminants identified by California Department of Public Health (CDPH) and the Environmental Protection Agency (EPA) contaminant lists were reviewed in the context of the CWD's groundwater wells. In addition, a vulnerability assessment for CWD source water was used to identify possible contaminating activities (PCAs) that may be releasing emerging contaminants that would be of interest. Seven contaminants were identified as being of particular interest to CWD and were monitored as part of this study.

5.5.2 Short List of Emerging Contaminants

Based on an analysis of existing monitoring data for emerging contaminants, with consideration of source water vulnerability to possible contaminating activities (PCAs) and new regulations recently enacted, seven emerging contaminants were selected for monitoring (Table 5.5-1).

Table 5.5.-1
Short List of Emerging Contaminants Monitored
<i>Three of CDPH's 33 Unregulated Chemicals</i>
Boron
Vanadium
Hexavalent Chromium
<i>One of EPA's UCMR 2 Chemicals</i>
N-nitroso-dimethylamine (NDMA)
<i>Three Pesticides</i>
Chloropicrin
Methyl Bromide (bromomethane)
1,3-Dichloropropene (cis and trans)

5.5.2.1 Pre-Screening Criteria

Potential contaminants of interest were chosen from the following categories: (1) unregulated chemicals for which CDPH has a monitoring requirement and/or a notification level, (2) chemicals that are listed as part of the EPA's Unregulated Contaminant Monitoring Rule 2 (UCMR 2) List 1 and List 2, as well as the Contaminant Candidate List (CCL) and (3) pesticides with significant usage in Ventura County (CWD source water area). Chemicals that CDPH and/or EPA already regulate were not considered emerging contaminants in the context of this part of the study.

The emerging contaminants monitored in this study were selected using following criteria: (1) occurrence in past monitoring efforts, (2) identification through the vulnerability assessment, and (3) likelihood of being regulated in the near future.

5.5.2.2 Pre-Screening Discussion

The following describes how the seven emerging contaminants of interest were identified.

Evaluation of CDPH's 33 Unregulated Chemicals:

Boron, Vanadium, and Hexavalent Chromium monitoring selections

There are 30 unregulated chemicals that lack Maximum Contaminant Levels (MCLs) for which CDPH has established health-based advisory levels in drinking water called *Notification Levels* (NLs). California's Title 22 regulations require monitoring of six of the unregulated chemicals with NLs, plus an additional three unregulated chemicals under certain conditions¹. These 33 unregulated chemicals identified by CDPH were of particular interest for this project as emerging contaminants.

Based on previous chemicals detected through past monitoring efforts of Well A and Well B, boron and vanadium were chosen from the CDPH list unregulated chemicals² to be monitored regularly throughout the project. Both chemicals have been previously detected at concentrations less than the NL, but at concentrations exceeding the detection limit for the purpose of reporting (DLR). The complete pre-existing data set on unregulated contaminants from the CDPH database for CWD wells A and B (Smith, 2007b) is provided in Appendix C (Section C.1; Summary Tables C.25 and C.26).

In addition, monitoring of any of these 33 emerging contaminants that may be released by possible contaminating activities was also considered. Based on

¹ The 9 unregulated chemicals requiring monitoring are listed in Title 22 California Code of Regulations (CCR) § 64450. Note that 6 of the 9 contaminants requiring monitoring have NLs.

² While manganese has a CDPH NL and has been detected in past monitoring at levels that exceed the DLR (but < NL), it is not classified as an *emerging* contaminant because it is regulated (secondary MCL in 22 CCR § 64449) and will be considered elsewhere in the project.

information from the CWD (Smith, 2007a; Appendix C, Section C.3) and CDPH (CDHS, 2005; Ali, 2007; Appendix C, Section C.2) regarding a vulnerability assessment identifying possible contaminating activities to which the source water (Wells A and B) was vulnerable, there were no additional unregulated chemicals subject to monitoring. Therefore, with the exception of hexavalent chromium discussed below, no additional monitoring of the 33 emerging contaminants was recommended.

There is an ongoing evaluation in California of hexavalent chromium, which is one of the three unregulated chemicals that do not have NLs, but require monitoring under certain conditions. CDPH guidance on unregulated chemical monitoring states that, “generally, all sources are considered vulnerable to hexavalent chromium unless a screening using total chromium analysis indicates by a non-detect that a source is not vulnerable” (CDHS, 2001). CWD had previously measured total chromium in Wells A and B and all results were below the detection limit for the purpose of reporting (DLR), which is 0.01 mg/L (Appendix C, Table C.33). The DLR for hexavalent chromium is 0.001 mg/L, 10 times lower than the total chromium DLR. CWD also measured hexavalent chromium in Well B in two measurements at non-detect levels in 2002, but the detection limit for hexavalent chromium was not clear from these data. CDPH states that if total chromium is used in screening for hexavalent chromium, then the analytical technique must be able to achieve a reporting limit of 0.001 mg/L (CDHS, 2001).

California’s Safe Drinking Water Act of 1996 requires the Office of Environmental Health Hazard Assessment (OEHHA) to perform risk assessments and adopt public health goals (PHGs) for contaminants in drinking water based exclusively on public health considerations (CA Health and Safety Code § 116365). OEHHA is in the process of setting a PHG for hexavalent chromium. Once the PHG is specified, CDPH is mandated to set a MCL for hexavalent chromium as close as “technically and economically feasible” to the PHG by January 1, 2004 (CA Health and Safety Code, § 116365.5 and § 116365). The establishment of the MCL has been delayed because OEHHA has not set the PHG yet. A pre-release draft of the PHG from OEHHA recommended a PHG of 0.002 mg/L for hexavalent chromium, but peer review of the draft PHG by an expert panel raised questions about the draft PHG and the evaluation process is ongoing (OEHHA, 2005). The National Toxicology Program (NTP) is currently carrying out a toxicological study to ascertain if ingestion of hexavalent chromium causes cancer (OEHHA, 2005).

Because the process of establishing a PHG and a MCL for hexavalent chromium is ongoing and there is uncertainty at what levels the PHG, MCL and possibly a revised DLR might be established, monitoring of emerging contaminant hexavalent chromium once in each well (A and B) was recommended for this study.

***Evaluation of EPA's Unregulated Contaminant Monitoring Rule 2 (UCMR 2)
Chemicals: NDMA monitoring selection***

The federal Safe Drinking Water Act (SDWA) requires monitoring of certain unregulated contaminants under the Unregulated Contaminants Monitoring Rule (UCMR), which includes three lists of contaminants (more background provided in Appendix C, Section C.4). List 1, termed Assessment Monitoring, includes chemicals for which analytical methods are available. The first round of UCMR monitoring (UCMR 1) was conducted from 2001 – 2006 and is complete. The second round of UCMR sampling (UCMR 2) was on the horizon at the outset of this project in 2007 (scheduled for Jan. 2008 – Dec. 2010). Public water systems (PWSs) that serve greater than 10,000 people (including CWD) are required to monitor for all List 1 chemicals. There are ten chemicals, including five flame retardants and three explosives on EPA's UCMR 2 List 1 (Assessment Monitoring), as shown in Appendix C, Section C.4 and Table C.32.

The vulnerability assessment showed that source water Well B is vulnerable to PCAs encompassing but not limited to irrigated crops (including orchards) and fertilizer (pesticide/herbicide application). The UCMR 2 List 1 chemical dimethoate is an insecticide used on orchard crops (EPA, 2006), but there is no reason to believe that source water Wells A or B are vulnerable to PCAs that may release dimethoate for the following reasons: (1) it is not on the list of the most widely used pesticides in Ventura County, and (2) dimethoate was also measured by CWD in Wells A and B at levels less than the reporting limit. Further, there is no reason to believe that source water Wells A and B are vulnerable to PCAs that may release any of the other contaminants on UCMR 2 List 1. Because it is believed that source water Wells A and B are not vulnerable to PCAs that may release any of the contaminants on UCMR 2 List 1 and because sampling for UCMR 2 List 1 chemicals in summer 2007 could not be applied to meet the requirements of EPA's UCMR 2 program (according to EPA Region 9's UCMR 2 coordinator; Ryan, 2007), no sampling of UCMR 2 List 1 chemicals was recommended for this project.

The second list of contaminants under UCMR includes chemicals for which analytical methods have recently been developed. Monitoring of UCMR 2 List 2 (Screening Survey) chemicals is required by 320 representative PWSs serving 10,001-100,000 people (CWD falls into this category). CWD is not among the PWSs being required by EPA to monitor for UCMR 2 List 2 chemicals.

There are fifteen chemicals including three parent acetanilides, six acetanilide degradates, and six nitrosamines on EPA's UCMR 2 List 2 (Screening Survey), as shown in Appendix C, Section C.4 and Table C.32. Based on the vulnerability assessment, it is not believed that source water wells A or B are vulnerable to PCAs that may release contaminants on EPA's UCMR 2 List 2. However, one contaminant on the list, NDMA, is a disinfection byproduct of particular interest in California (Najm and Trussell, 2001). Trussell Tech recommended monitoring NDMA, downstream of where Well B water is blended with imported water, in a simulated distribution system (SDS) test to mimic conditions in the distribution system. If

NDMA was detected in the SDS test at levels above the DLR, other sampling locations would have been recommended, but this was not the case. No other emerging contaminants on UCMR 2 List 2 (Screening Survey) were recommended for monitoring.

Pesticides with Relatively High Use in Ventura County: Chloropicrin, Methyl Bromide, and 1,3-Dichloropropene monitoring selection

As previously mentioned, well B in particular is vulnerable to PCAs encompassing but not limited to irrigated crops (including orchards) and fertilizer (pesticide/herbicide application). Three pesticides with relatively high use in Ventura County (PANNA, 2007) are chloropicrin, methyl bromide (bromomethane), and 1,3-dichloropropene (cis-1,3-dichloropropene and trans-1,3-dichloropropene). Therefore, it was recommended that these three pesticides be monitored once at each well A and B during the project, and that additional sampling be conducted for any of these chemicals measured at levels that exceed their detection limit.

Additional Chemicals Monitored

Several of the analytical methods used (EPA methods 521, 524.2, and 551.1) to measure the selected emerging contaminants are designed to quantify several chemicals at once. All additional chemicals (a total of 80) that could be measured using these methods were included at no additional cost (full list of chemicals provided in Appendix C, Table C.34). Many of these chemicals are not considered emerging contaminants, as they are currently regulated.

5.5.3 Emerging Contaminants Sampling Results

The initial monitoring effort was conducted on October 11, 2007; samples were collected from both wells (A and B) and analyzed for the selected emerging contaminants. Weck Laboratories (Industry, CA) performed the analysis using the EPA methods listed in Table 5.5-2 and following standard quality control and assurance procedures.

Table 5.5-2. List of Analytical Methods used for Emerging Contaminant Detection	
Emerging Contaminant	EPA Method
Boron	200.8
Vanadium	200.8
Hexavalent Chromium	218.6
N-nitroso-dimethylamine (NDMA)	521
Chloropicrin	551.1
Methyl Bromide (bromomethane)	524.2
1,3-Dichloropropene (cis and trans)	524.2

Of the seven emerging contaminants monitored during this initial test, only boron (both wells) and vanadium (well B only) were detected at concentrations above the

reporting limit (Table 5.5-3). Hexavalent chromium and the three pesticides (chloropicrin, methyl bromide, and 1,3-dichloropropene) were not detected in samples from either well. In addition, NDMA was not present in the SDS test at detectable levels. However, of the 80 additional chemicals measured incidentally by the EPA methods, one chemical, 2-butanone (a.k.a. methyl ethyl ketone), was detected in the well water (Well B only) using EPA method 524.2.

Table 5.5-3.				
Results from Initial Emerging Contaminant Monitoring of Wells A and B on October 11, 2007				
Chemical	Well A	Well B	Blend of Well B and imported water ^a	Laboratory Reporting Limit
Unregulated Chemicals				
Boron	0.78 mg/L	0.66 mg/L	--	0.003 mg/L
Vanadium	0.0012 mg/L	ND	--	0.0005 mg/L
Chromium VI	ND	ND	--	0.0003 mg/L
UCMR 2 Chemical (DBP of particular interest in California)				
NDMA	--	--	ND	0.002 mg/L
Pesticides				
Chloropicrin	ND	ND	--	0.0005 mg/L
Methyl bromide	ND	ND	--	0.0005 mg/L
1,3-dichloropropene	ND	ND	--	0.0005 mg/L
Other chemicals incidentally detected using EPA methods				
Methyl ethyl ketone (MEK)	ND	0.029 mg/L	--	0.005 mg/L
^a Simulated Distribution System (SDS) test				
-- indicates sample location is not applicable for contaminate monitoring				
"ND" indicates chemical not detected or concentration below reporting level				

Methyl ethyl ketone (MEK) is *not* among CDPH's list of 33 unregulated chemicals with NLs or monitoring requirements. MEK is a solvent used in production of resins and vinyl surface coatings (EPA 2000). One possible source of the MEK detected was identified as possible leaching off of PVC piping used in the pilot plant. On December 18, 2007, both wells were retested for MEK (again using EPA 524.2), but this time the sampling location was at the wellhead, upstream of any PVC pipe. The repeated samples showed no detectable levels of MEK in either well.

The laboratory analysis of the December 2007 MEK sampling also measured all constituents that are detected through EPA method 524.2. All constituents were non-detect (ND) in Well A. However, the following regulated contaminants were detected in well B: THMs bromodichloromethane at 3.4 µg/L, bromoform at 6.4 µg/L, chloroform at 1.9 µg/L, dibromochloromethane at 6.8 µg/L for a TTHM concentration of 18.5 µg/L. These disinfection byproducts (DBPs) are regulated under the EPA's Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), measured regularly in accordance with regulatory requirements, and are not considered

emerging contaminants. Two possible reasons for the detection of THMs at the levels measured include (1) sampling at a location downstream of chlorination of the water supply or (2) the influence of wastewater on the groundwater supply. It should be noted that in the initial emerging contaminant sampling in October 2007, no DBPs were detected in either Well A or in Well B.

As recommended, boron and vanadium were monitored in both the raw well water and RO membrane permeates at regular intervals throughout the pilot testing (Table 5.5-4). In addition, both chemicals were measured in the RO membrane concentrate as part of the July 11, 2008 sampling. Weck Labs performed the analysis and percent removals were calculated for each membrane (Table 5.5-4).

Boron was consistently detected in both the raw well water and the membrane permeates for all four membranes tested. The percent of boron removed varied between the membranes; RO membranes I (Dow Filmtec XLE 4040) and III (Toray TM710) had the greatest rejection (approximately 50 percent), while membrane IV (Dow Filmtec NF90) was less effective (approximately 34 percent) and membrane II (Saehan RE 4040 BLR) was ineffective. As discussed elsewhere, it is believed that membrane II (Saehan RE 4040 BLR) was compromised due to exposure to chlorine dioxide in earlier phases of testing, before the Phase VI pilot testing. Regardless, boron concentrations in the raw water and permeate samples were all lower than the CDPH notification level (1 mg/L for boron).

Vanadium, on the other hand, was detected in all raw water samples, but was reduced to a concentration below the reporting limit by all membranes. Thus a performance comparison between membranes was not possible for vanadium. All vanadium concentrations were also less than the CDPH notification level (0.05 mg/L for vanadium).

Table 5.5-4. Results of Boron and Vanadium Monitoring during Phase VI Testing					
Sampling Date	Location	Boron		Vanadium	
		Concentration (mg/L)	Percent Removal	Concentration (mg/L)*	Percent Removal
6/27/08	Raw Water (Well A)	0.56	--	0.0012	--
	RO Membrane I Permeate (Dow Filmtec XLE 4040)	0.27	52%	ND (<0.0005)	> 58%
	RO Membrane II Permeate (Saehan RE 4040 BLR)	0.48	14%	ND (<0.0005)	> 58%
7/11/08	Raw Water (Well A)	0.56	--	0.0013	--
	RO Membrane I Permeate (Dow Filmtec XLE 4040)	0.28	50%	ND (<0.0005)	> 62%
	RO Membrane I Concentrate	1.70	--	ND (<0.01)	--
	RO Membrane II Permeate (Saehan RE 4040 BLR)	0.57	0%	ND (<0.0010)	> 23%
	RO Membrane II Concentrate	0.90	--	ND (<0.01)	--
10/6/08	Raw Water (Well B)	0.57	--	0.00052	--
	RO Membrane III Permeate (Toray TM710)	0.26	54%	ND (<0.0005)	> 4%
	RO Membrane IV Permeate (Dow Filmtec NF90)	0.37	34%	ND (<0.0005)	> 4%

*Variation in reporting limit result of different sample dilution

5.5.4 Emerging Contaminants Conclusions

Potential emerging contaminants of specific interest to CWD were identified from state and federal emerging contaminant lists, as well as from a vulnerability assessment of the City of Camarillo's source water area. Seven emerging contaminants were chosen for monitoring as part of the CWD ground water treatment pilot project. Of these chemicals, only boron and vanadium were detected in the raw well water. Boron and vanadium were monitored at regular intervals during the pilot study. Membranes I (Dow Filmtec XLE 4040) and III (Toray TM710) showed the greatest rejection of boron (approximately 50 percent), and because no vanadium was detected in any of the membrane permeates, vanadium performance could not be compared. Regardless, all raw water and membrane permeate samples had boron and vanadium concentrations less than the CDPH notification levels. No additional treatment considerations are recommended based on this emerging contaminant analysis.

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Section 6

Dissemination/Outreach Activities

6.1 Overview

This section describes the types of outreach performed, including presentations of the project to the public, conferences, workshops, coordination with various stakeholders, tours, and ways used to disseminate project results and information.

6.2 Tours

6.2.1 City Council Tours

The City and CDM provided a tour of the pilot plant site for the City of Camarillo Council on May 28, 2008 from 6 pm to 8 pm. Approximately 20 City Council members and city residents attended the tour. The City and CDM gave a brief presentation of the project, followed by a question and answer session. The following topics were covered during the pilot plant tour:

- Current drinking water sources and water quality;
- Drinking water quality regulations and goals;
- Pilot study objectives; and
- Technology overview of Reverse Osmosis technology, oxidation, and filtration.

The posters used during the tour are included in Appendix B.

6.2.2 Proposition 50 Tours

The State Water Resources Control Board (SWRCB) Proposition 50 staff also visited the pilot plant site on two separate visits. The first visit was on February 13, 2008 and the second visit was on March 20, 2008.

6.3 Training/Workshops

The City and CDM held a three-hour, Operator Training Workshop on October 9, 2007. The following topics were covered during the PowerPoint presentation:

- Project background;
- Pilot study objectives;
- Technology overview of Reverse Osmosis technology, oxidation, and filtration; and
- Testing protocol.

The training also included a pilot plant site visit, and on-site discussions of the pilot plant equipment and sampling protocol.

6.4 Website

The City constructed a webpage on the City's website <<http://www.ci.camarillo.ca.us/main.aspx?q=6087&p=9201>> so that the project information is available to the public. The webpage summarizes the objectives of the pilot study and the City's goals for the drinking water system. The webpage also presents a poster containing the schematic of the recommended pretreatment alternative and descriptions of each treatment process.

Section 7

Project Deliverables

7.1 Overview

This section lists deliverables and materials produced during the project.

7.2 Project Deliverables

The project deliverables included monthly progress reports, quarterly progress reports, draft and final Pilot Test Protocol, draft and final Emerging Contaminants Evaluation Summary, and draft and final Summary Report. The submittal dates of each deliverable are summarized in Table 7-1.

Table 7-1 Project Deliverables			
Deliverable	Complete	Submittal Date to City	Submittal Date to DWR
Task 1.1 Quarterly Progress Reports			
Quarterly Progress Report #1	Complete	July 16, 2007	July 30, 2007
Quarterly Progress Report #2	Complete	October 26, 2007	October 30, 2007
Quarterly Progress Report #3	Complete	January 21, 2008	January 30, 2008
Quarterly Progress Report #4	Complete	April 25, 2008	April 29, 2008
Quarterly Progress Report #5	Complete	July 31, 2008	July 31, 2008
Quarterly Progress Report #6	Complete	October 21, 2008	October 30, 2008
Task 2.1			
Draft Pilot Test Protocol	Complete	June 20, 2007	June 29, 2007
Final Pilot Test Protocol	Complete	October 26, 2007	October 30, 2007
Task 2.2			
Draft Emerging Contaminants Evaluation Summary	Complete	June 22, 2007	June 29, 2007
Final Emerging Contaminants Evaluation Summary	Complete	October 26, 2007	October 30, 2007
Task 5.1 Draft Summary Report	Complete	December 4, 2008	December 12, 2008
Task 5.2 Final Summary Report		January 30, 2009	January 30, 2009

7.3 Publications

The publications on the findings from this project are listed below:

- You, E.; Wetterau, G.; Burbano, M.; and McGovern, L. 2008. "Control of Metal Oxide Fouling in Reverse Osmosis." *2008 IWA North American Membrane Research Conference*. Amherst, Massachusetts.
- Hokanson, D.; Trussell, S.; Trussell, R.; Wetterau, G.; and McGovern, L. 2009. "A Groundwater Pilot Study in Camarillo: Occurrence and Removal of PhPCPs." *Annual Conference & Exposition 2009*. San Diego, CA

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Section 8

Conclusions/Lessons Learned

8.1 Overview

This section summarizes the results of the project and recommendations for the full-scale brackish water desalination facility design. This section also describes problems encountered, lessons learned, and recommendations for future studies.

8.2 Findings

8.2.1 Pretreatment Evaluation Findings

Key findings from the pretreatment evaluation testing include the following:

8.2.1.1 Phase I Summary (Alternative 1)

- Oxygen quenching successfully prevented iron oxidation and thereby prevented metal oxide fouling of the reverse osmosis (RO) membranes.
- Periodic starting and stopping of Wells A and B, intended to simulate normal operation of a full-scale facility, may have contributed to the entrainment of air into the feed water that was not seen later during Phase VI testing where only one well at a time was utilized.
- Oxygen quenching pretreatment process must be carefully designed to safeguard against failure of the oxygen quenching agent. When oxygen quenching was stopped, iron oxidation occurred immediately and particulate fouling of the RO membranes started immediately. Particulate fouling of the membranes continued even when oxygen quenching was resumed, and was stopped only when the membranes were cleaned with high concentrations of acid and caustic soda.

8.2.1.2 Phase II Summary (Alternative 2)

- Aeration plus media filtration effectively oxidized and removed iron when a minimum of six minutes of contact time was provided. Providing additional contact time, beyond six minutes, did not have significant impact on iron oxidation.
- Complete oxidation of iron was accomplished with nearly zero minutes of contact time, when the pH was adjusted to 8.0 through the addition of caustic soda. However, raising the pH of the Well A raw water was problematic, as it caused severe scaling in the piping, valves, the granular media filters, and the cartridge filters. This scaling could not be controlled with the addition of antiscalant upstream of the caustic soda injection point.
- Although the particulate iron levels did not indicate iron breakthrough at any point in the testing, an observed decrease in first stage mass transfer coefficient (MTC), or membrane permeability, suggests that the media filters were more prone to solids breakthrough when the filter loading rates were higher than 3.5 gpm/sf. Higher

loading rates may be sustainable, however, if utilizing media with greater depth, smaller effective size, or a more aggressive backwashing approach than utilized in the pilot. Backwashing rates were limited to 15 gpm/sf in the pilot study due to the media carry-over seen with higher rates, however, more aggressive backwashing could be achieved with the use of an air scour system or with higher sidewall depths.

8.2.1.3 Phase III Summary (Alternative 3)

- The estimated chlorine dioxide demand in Well A raw water ranged from 0.8 to 2.1 mg/L, with an average of 1.5 mg/L.
- Chlorine dioxide feed and media filtration effectively oxidized and removed 100 percent of iron and 70 percent of manganese and appears to have prevented metal oxide fouling of the RO membranes.
- The ability of chlorine dioxide to oxidize iron and manganese was not affected by contact time or raw water pH. The same quantities of iron and manganese were oxidized when the contact tank was bypassed as when 37 minutes of contact time was provided. Also, the same quantities of iron and manganese were oxidized at pH of 7.3 as at pH of 8.1.
- Chlorine dioxide plus media filtration pretreatment was problematic due primarily to RO membrane damage. Chlorine dioxide appears to have damaged the RO membranes, as was evident in the steadily increasing permeate conductivities and the gradually increasing MTC during the first three weeks of the Phase III testing.
- Particulate iron and manganese appeared to be passing through the media filtration process and fouling the cartridge filters. The cartridge filters should not be relied on for filtration, but were heavily loaded with particulate iron and manganese during this phase. Further, the fouling rate on the media filters was high, averaging 3 to 6 psi/day at a filtration rate less than 5 gpm/sf.

8.2.1.4 Phase IV Summary (Alternative 4)

- The estimated chlorine demand in Well A raw water was approximately 0.8 mg/L. A chlorine dose of 1.0 mg/L was sufficient to oxidize 100 percent of iron and approximately 70 percent of manganese with the aid of the Pyrolox (greensand) media filters. Although higher doses of chlorine may be capable of enhancing manganese oxidation, the impact of higher doses seen in the piloting was minimal.
- Chlorine feed with Pyrolox media filtration pretreatment was similar in performance to the chlorine dioxide feed plus media filtration pretreatment (Phase III). Both pretreatment processes oxidized and removed 100 percent of total iron and approximately 70 percent of total manganese. The difference was that manganese oxidation occurred in the filtration stage during Phase IV, whereas manganese oxidation occurred prior to the filtration stage during Phase III.

- Although only 70 percent of manganese was oxidized during the pretreatment stages, the remaining 30 percent non-oxidized manganese did not appear to impact RO performance, as it remained dissolved throughout the RO process and into the RO waste stream.
- Chlorine feed plus Pyrolox media filtration pretreatment was partially effective, particularly during the early portion of the testing. However, the two issues of concern for this process are the risk of damaging the RO membranes with chlorine, and the difficulty in maintaining properly functioning media filters. Although the dechlorination process was successful during the pilot study and, therefore, did not cause damage to the RO membranes, the possible failure of a dechlorination process is risky for a full-scale plant, given the capital investment required to replace damaged RO membranes.
- The operation of the Pyrolox media filters causes some concern, due to the high backwashing rates and possible air scour systems required to remove iron oxides from the dense media. Pyrolox systems tend to work best in systems with high manganese levels, but low iron, and are commonly used at smaller facilities where waste washwater volumes from the high backwashing rates do not create site constraints.

8.2.1.5 Phase V Summary (Alternative 5)

- The average dissolved oxygen (DO) level in the pretreatment feed water was 5.6 mg/L of when the eductor was used for aeration, and 8.5 mg/L of DO when an air compressor was used.
- With the aeration and microfiltration (MF) pretreatment process, the iron was only partially oxidized by the DO in the contact tank within the 3 to 36 minutes of contact time tested, and additional oxidation of iron was observed within the MF, the break tank after the MF, and within the cartridge filters.
- The rate of oxidation was sensitive to the contact time and the concentration of DO in the water. For the aeration followed by MF pretreatment process to completely oxidize and remove the iron, it was determined that the pretreatment feed water must be saturated at approximately 8.7 mg/L of DO, and approximately 35 minutes of contact time must be provided. To provide 35 minutes of contact time in a full-scale plant, a 210,000 gallon capacity tank must be provided.
- Aeration followed by MF was found to be less effective than the aeration followed by media filtration pretreatment process, evaluated in Phase II. Although the MF could be considered a better filtration process than the media filtration, the media filters provide improved oxidation of iron, resulting in greater removal.

8.2.1.6 Pretreatment Process Selection

- The five pretreatment process alternatives were evaluated based on the ability to meet water quality goals, reliability, simplicity, safety, and cost. Based on this

evaluation, Alternative 1 Oxygen Quenching and Alternative 2 Aeration plus Media Filtration were identified as the most appropriate for RO pretreatment in the Phase VI pilot testing.

8.2.2 RO Optimization Findings

Key findings from the RO optimization testing include the following:

- The aeration plus media filtration pretreatment resulted in partial oxidation and removal of manganese and significant RO fouling. While this did not occur during two months of Phase II testing, using the same pretreatment approach, it is believed that the presence of previously oxidized manganese dioxide, possibly from the Pyrolox media used during Phase IV, may have catalyzed the manganese oxidation. While manganese oxidation with air normally takes several hours to occur, the presence of previously oxidized manganese dioxide may have accelerated the oxidation of a small portion of manganese, which subsequently caused operational complications with the downstream processes.
- When the pretreatment process was changed to oxygen quenching (Alternative 1), further complications were seen, first with the build-up of biological growth and iron on the cartridge filters, and second with the fouling of second stage membranes. The addition of muriatic acid (HCl) ahead of the cartridge filters, and the reduction of thiosulfate dose to less than 2 mg/L appeared to control the fouling both of the cartridge filters and the RO.
- The oxygen quenching with acid addition pretreatment maintained manganese and iron in the dissolved form and produced stable MTC data for all membrane systems tested, when the feedwater pH was adjusted to 6.5 by acid addition.
- When the target feedwater pH was adjusted to 6.8, the RO membranes began to foul and the MTC decreased rapidly.
- The Dow RO membrane (model XLE 4040) stabilized at a membrane permeability of 0.15 gfd/psi, while the Saehan RO membrane (model RE 4040 BLR) stabilized around 0.25 gfd/psi. The mineral water quality of the Dow RO membrane permeate was superior to the Saehan RO membrane permeate.
- The permeate of the Saehan RO membranes had the highest TDS at 95 mg/L, possibly caused by damage to the RO elements during Phase III testing, when the membranes were exposed to chlorine dioxide. Nonetheless, based on the permeate mineral water quality alone, the Saehan RO membranes performed the worst of the four membranes tested, which is contrary to results of the membrane manufacturers' modeling software. According to the membrane manufacturers' model projections, the Dow NF90 membrane should have produced the highest permeate TDS followed by the Dow XLE 4040.

- Dow's modeling software is the most conservative of the three membrane manufacturers' softwares that were evaluated. All of the projected permeate concentrations were greater than those observed during actual pilot testing. Only potassium was measured greater than what the model projected.
- Toray's modeling software was almost as conservative, but it underestimated the potassium, sodium and the TDS concentrations.
- Saehan's software was quite different from those offered by the other two manufacturers and it projected permeate concentrations that were too low for almost every parameter. The only ionic species that were found in the RO permeate to be lower than the projected concentration was sulfate. However, it is extremely important to note that the Saehan membrane was exposed to chlorine dioxide during Phase III testing. Therefore, it is likely that the Saehan membrane could perform as projected by the manufacturer's software.
- Manganese and sulfate are the limiting constituent for blending, and only 5 to 7 percent of the total flow can be allowed to bypass the RO. Such a bypass flow will result in a blended water TDS between 150 and 200 mg/L, and a blended water hardness between 70 and 80 mg/L, without exceeding any of the finished water quality goals.

8.2.3 Emerging Contaminants Findings

Key findings from the emerging contaminants evaluation include the following:

- Potential emerging contaminants of specific interest to CWD were identified from state and federal emerging contaminant lists, as well as from a vulnerability assessment of the City of Camarillo's source water area.
- Seven emerging contaminants were chosen for monitoring as part of the CWD ground water treatment pilot project. Of these chemicals, only boron and vanadium were detected in the raw well water. Boron and vanadium were monitored at regular intervals during the pilot study.
- Membranes I (Dow Filmtec XLE 4040) and III (Toray TM710) showed the greatest rejection of boron (50 percent), and because no vanadium was detected in any of the membrane permeates, vanadium performance could not be compared. Regardless, all raw water and membrane permeate samples had boron and vanadium concentrations less than the CDPH notification levels. No additional treatment considerations are recommended based on this emerging contaminant analysis.

8.3 Recommendations

Based on the findings from the pilot study, presented in Section 5 and summarized in Section 8.2, oxygen quenching with acid feed was selected as the optimum pretreatment process. The recommendations for pretreatment are summarized below:

- Dosing oxygen quenching chemical (sodium thiosulfate, sodium bisulfite or sodium metabisulfite) at the wellhead facilities to quench oxygen;
- Decreasing the pH to 6.5 with acid for stable RO performance;
- UV to prevent biofouling; and
- Antiscalant dose of 1.5 mg/L to prevent scaling.

Also, the following design parameters for the RO were established:

- Stable RO membrane performance can be sustained at 75 percent recovery;
- Blending is limited by manganese and sulfate goals; and
- The four membranes tested allow 5 to 7 percent blending to meet final water quality goals.

The following subsections describe the basic design parameters for the pretreatment processes, RO, and post-treatment. This section also presents projection of probably cost information, and preliminary schedule for the design and construction of the full-scale treatment plant.

8.3.1 Preliminary Design Criteria

8.3.1.1 Design Flows

Two existing wells (Well A and Well B) and one future well will be used to pump groundwater to the new brackish water desalination facility. Table 8-1 summarizes the pumping capacities of the three groundwater wells.

Table 8-1.	
Total Groundwater Pumping Capacity	
Well	Pumping Capacity
Well A	1,500 gpm = 2.16 mgd
Well B	1,500 gpm = 2.16 mgd
Future Well	3,000 gpm = 4.32 mgd
Total Groundwater Pumping Capacity	6,000 gpm = 8.64 mgd

The City's water system demand is 8.9 mgd or 10,000 ac-ft/yr. This demand will be met by treating pumped groundwater and then blending the treated water in the

distribution system with imported water. A small fraction of untreated groundwater will also be bypassed around the treatment process and blended to produce a product water that is stable, non-corrosive, and similar to the quality of imported water in the distribution system. Table 8-2 summarizes the expected design flows of the treated water and blend water.

Table 8-2. Design Flows	
Stream	Flow Rate
Water System Demand	8.9 mgd = 10,000 ac-ft/yr
Well Production	8.6 mgd
RO Influent (i.e., pre-treated groundwater)	8.3 mgd
RO Permeate (i.e., desalinated groundwater)	6.2 mgd (See Note 1)
Groundwater Blending (i.e., RO bypass, blending at the facility)	0.3 mgd (See Note 2)
Total Plant Product (i.e., RO permeate + groundwater blending)	6.5 mgd
Imported Water Required	2.4 mgd
Note:	
1) Assuming 75% RO permeate water recovery rate.	
2) Assuming 5% bypass and blend.	

8.3.1.2 Wellhead Facilities

The recommended pretreatment process consists of oxygen quenching, which is accomplished by feeding sodium thiosulfate or sodium bisulfite to the well water. Since this pretreatment process is most effective when the chemicals are fed close to the wellheads to prevent iron oxidation as early as possible, the chemical storage and feed facilities will be located at each of the three wells. Preliminary design criteria for the wellhead facilities are summarized in Table 8-3.

Table 8-3. Wellhead Facilities Design Criteria				
	Units	Well A	Well B	Future Well
Main Process Stream		Well A Raw Water (1,500 gpm)	Well B Raw Water (1,500 gpm)	Future Well Raw Water (3,000 gpm)
Chemical		Sodium Bisulfite	Sodium Bisulfite	Sodium Bisulfite
Concentration	%	36	36	36
Dose	mg/L	2	2	2
Feed Equipment				
Pump Type		Peristaltic	Peristaltic	Peristaltic
Pump Capacity, each	gph	0.4	0.4	0.8
Number of Pumps	each	2	2	2
Wetted Materials				

Table 8-3. Wellhead Facilities Design Criteria				
	Units	Well A	Well B	Future Well
Storage System				
Tank Type		XLPE	XLPE	XLPE
Tank Capacity, each	gal	300	300	800
Storage Time, each	days	34	34	45
Number of Tanks		1	1	1
Piping Material		PVC	PVC	PVC

8.3.1.3 Desalination Facility

The main treatment processes at the desalination facility include the following:

- Acid feed to reduce the pH of raw water to 6.5, to slow down iron oxidation and prevent scaling;
- Cartridge filters to remove debris and suspended solids;
- Ultraviolet (UV) to prevent biological fouling;
- Antiscalant feed to prevent scaling;
- In-line boost pumps to increase the RO feed water pressure to push water through the RO;
- Two-stage RO for desalination;
- Decarbonator to remove carbon dioxide from RO permeate water and increase the pH;
- Blending of RO permeate with raw water;
- Chlorine feed for disinfection;
- Caustic soda feed for pH adjustment; and
- Finished water pumps to pump treated water to the distribution system.

Other ancillary equipment includes:

- RO membrane clean-in-place (CIP) system.

The preliminary process flow diagram for the desalination facility is show in Figure 8-1, and the preliminary site layout is presented in Figure 8-2. The preliminary design criteria for each of the main treatment processes are described below.

REV. NO.	DATE	DRWN	CHKD	REMARKS

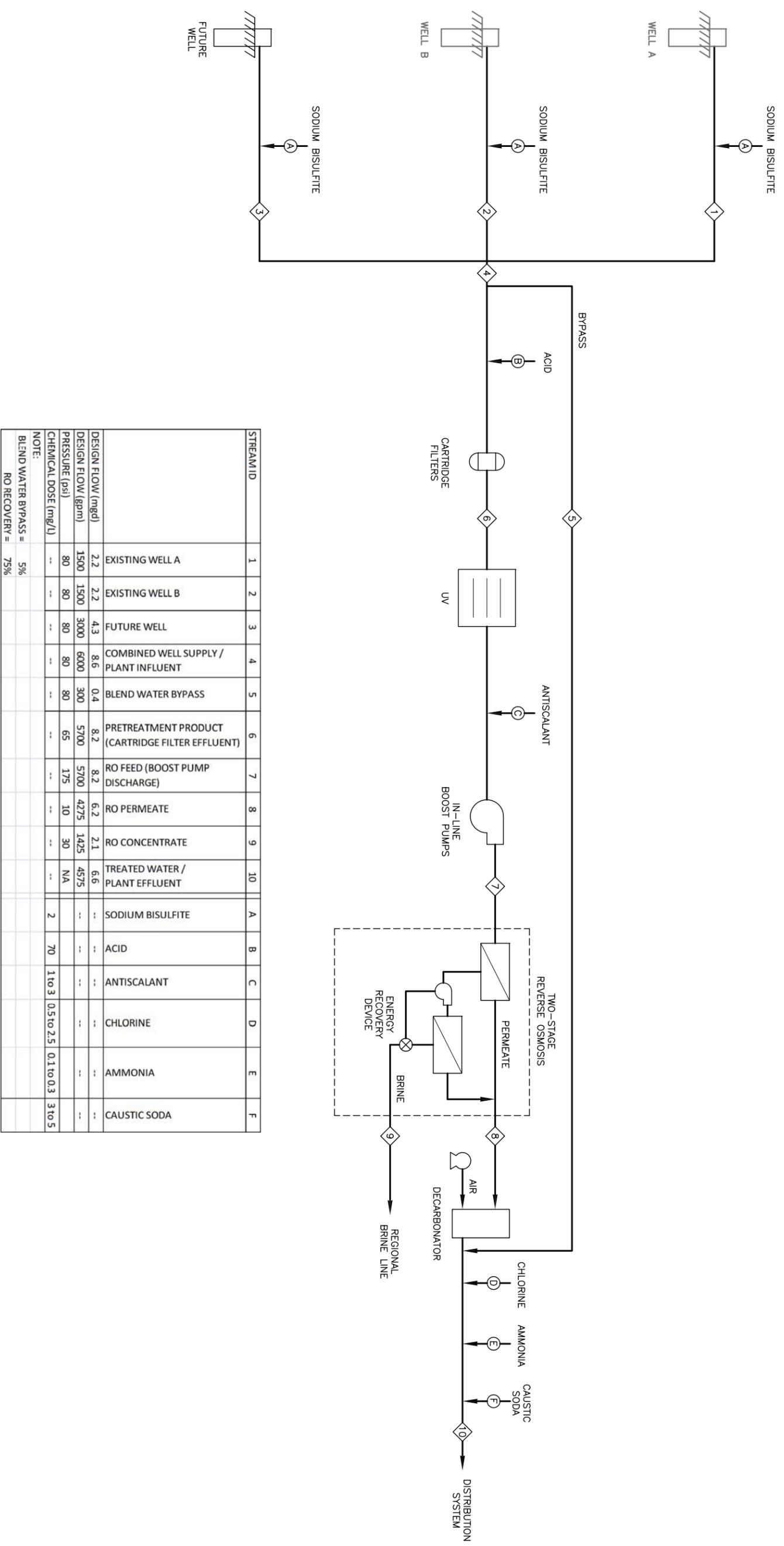
DESIGNED BY: _____
 DRAWN BY: _____
 SHEET CHK'D BY: _____
 CROSS CHK'D BY: _____
 APPROVED BY: _____
 DATE: AUGUST, 2008



CDM Camp Dresser & McKee Inc.
 1331 17th Street, Suite 1200
 Denver, Colorado 80202
 Contact: Mr. Tom Strives (303) 298-1311

CITY OF CAMARILLO
 BRACKISH WATER
 DESALINATION FACILITY

PROCESS FLOW DIAGRAM
 SHEET NO. 2689-58780
 FILE NAME: MROPLA03
 FIGURE 8-1



STREAM ID	1	2	3	4	5	6	7	8	9	10	A	B	C	D	E	F
DESIGN FLOW (mgd)	2.2	2.2	4.3	8.6	0.4	8.2	8.2	6.2	2.1	6.6	--	--	--	--	--	--
DESIGN FLOW (gpm)	1500	1500	3000	6000	300	5700	5700	4275	1425	4575	--	--	--	--	--	--
PRESSURE (psi)	80	80	80	80	80	65	175	10	30	NA	--	--	--	--	--	--
CHEMICAL DOSE (mg/L)	--	--	--	--	--	--	--	--	--	--	2	70	1 to 3	0.5 to 2.5	0.1 to 0.3	3 to 5
NOTE:	BLEND WATER BYPASS = 5%															
	RO RECOVERY = 75%															

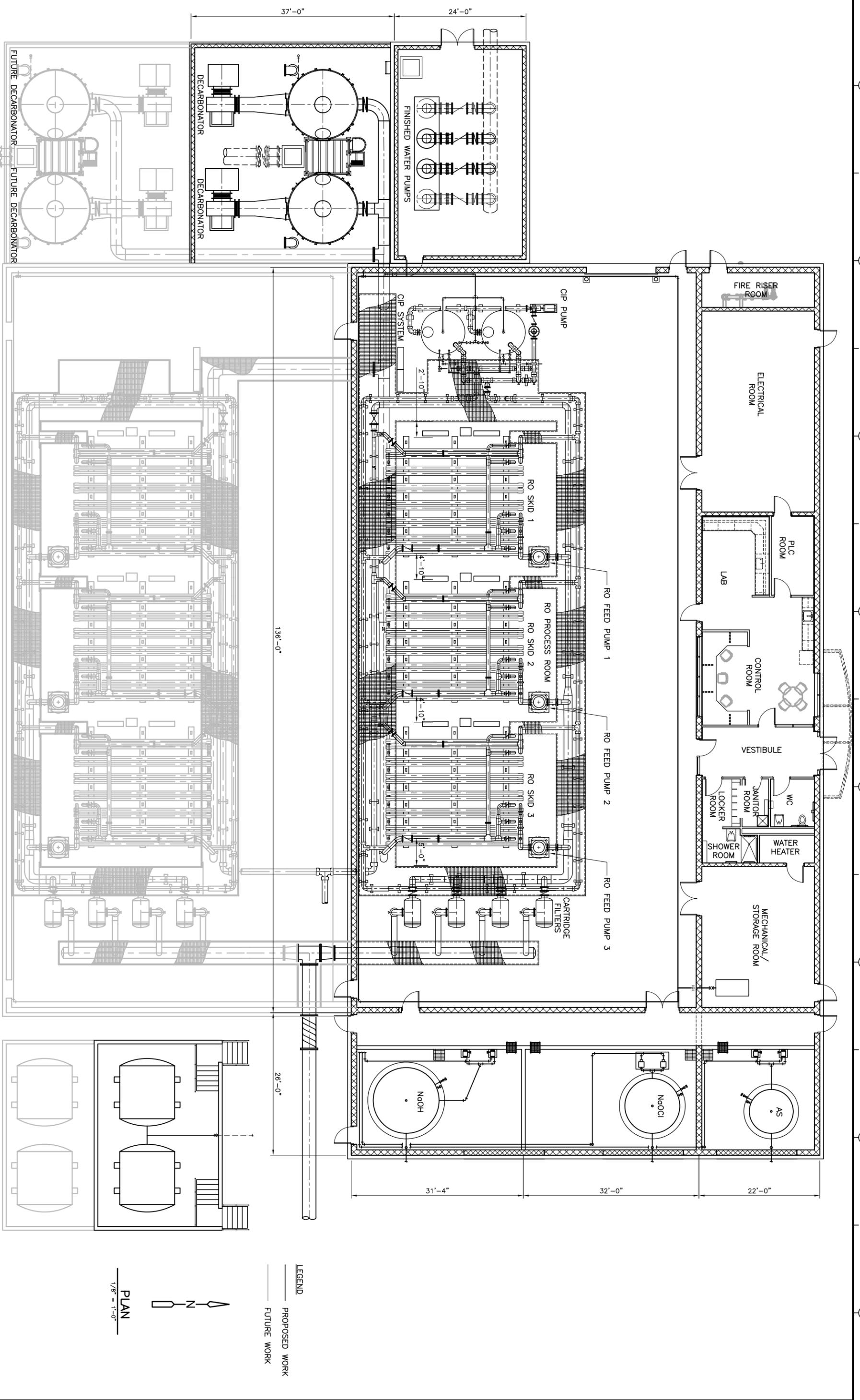
REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: _____
 DRAWN BY: _____
 SHEET CHK'D BY: _____
 CROSS CHK'D BY: _____
 APPROVED BY: _____
 DATE: AUGUST, 2008

CDM Camp Dresser & McKee Inc.
 1331 17th Street, Suite 1200
 Denver, Colorado 80202
 Contact: Mr. Tom Stripes (303) 298-1311

CITY OF CAMARILLO
 BRACKISH WATER
 DESALINATION FACILITY

PRELIMINARY SITE PLAN - ALTERNATIVE 1
 PROJECT NO. 2689-S8780
 FILE NAME: MROPLA01
 SHEET NO.
FIGURE 8-2



Acid Feed

The purpose of acid feed is to slow down iron oxidation and prevent scaling by reducing the pH of the raw water to pH 6.5. The acids that could be used for this purpose include muriatic acid and sulfuric acid, but other acids may be used. The disadvantage of using muriatic acid is that it is typically available in 31 percent concentration, and requires large storage tanks. The primary disadvantage of using sulfuric acid is that, while it is available in higher concentrations, it adds sulfate to the water, which can contribute to membrane scaling, as calcium sulfate.

Preliminary design criteria for muriatic acid and sulfuric acid feed system are summarized in Table 8-4. Other acids should be evaluated during preliminary design.

Table 8-4. Acid Feed System Design Criteria			
Parameter	Units	Design Value	Design Value
Main Process Stream		RO Feed Water (6,000 gpm)	RO Feed Water (6,000 gpm)
Chemical		Muriatic Acid (Hydrochloric Acid)	Sulfuric Acid
Concentration	%	31.45%	93.2%
Dose	mg/L	70	90
Feed Equipment			
Pump Type		Peristaltic	Peristaltic
Pump Capacity, each	gph	76	20
Number of Pumps	each	2	2
Wetted Materials			Teflon/Carpenter 20
Storage System			
Tank Type		Phenolic-coated Steel Tank	Phenolic-coated Steel Tank
Tank Capacity, each	gal	25,000	6,800
Storage Time, each	days	15	15
Number of Tanks	each	1	1
Piping Material		PVDF	PVDF

Cartridge Filters

The cartridge filters are used to protect the RO membranes by removing debris and suspended solids from the raw water. Preliminary design criteria for cartridge filters are summarized in Table 8-5.

Table 8-5. Cartridge Filters Design Criteria		
Parameter	Units	Design Value
Main Process Stream		RO Feed Water (6,000 gpm)
Number of Units		4
Design Feed Rate per Vessel	gpm	2,000
Maximum Loading Rate at Design Feed Rate	gpm	3.0
Initial Pressure Drop	psi	0.7
Cartridge Changeout Pressure Drop	psi	10
Filter Housings Orientation Housing Material		Horizontal 316L Stainless Steel
Filter Cartridges Cartridge Element Material Nominal Filter Rating	micron	Wound Polypropylene 5

UV

The purpose of UV is to prevent bio-fouling by disinfecting the feed stream ahead of the cartridge filters and RO membranes. Intermittent biological growth was observed on the cartridge filters during the pilot testing, introduced either from the chemical feed systems or directly from the wells. The UV system may not be required for a full scale facility, however, it provides a method to reduce the risk of biofouling and improved plant efficiency. Preliminary design criteria for a UV reactor system are summarized in Table 8-6.

Table 8-6. UV Reactor System Design Criteria		
Parameter	Units	Design Value
Main Process Stream		RO Feed Water (6,000 gpm)
Dose	mJ/cm ²	40
UV Transmittance at 253.7 nm	%	80
Number of Reactors		2
Capacity per Reactor	gpm	3,000
UV Reactor Configuration Number of Lamps per Reactor Number of Sensors per Reactor Materials of Construction Maximum Operating Pressure Auto-Wiper	Each each psi	30 3 316L Stainless Steel 150 Yes

Antiscalant Feed

The purpose of antiscalant feed is to prevent scaling of the RO membranes. Typical doses for antiscalant are 1 to 3 mg/L, and the antiscalant dose used during the pilot study was 1 to 2 mg/L. Preliminary design criteria for antiscalant feed system are summarized in Table 8-7.

Table 8-7. Antiscalant Feed System Design Criteria		
Parameter	Units	Design Value
Main Process Stream		RO Feed Water (6,000 gpm)
Chemical		Antiscalant
Concentration	%	100
Dose	mg/L	1 to 3
Manufacturers		King Lee Technologies; Professional Water Technologies; Avista Technologies
Feed Equipment		
Pump Type		Peristaltic
Pump Capacity, each	gph	0.6
Number of Pumps	each	2
Wetted Materials		CPVC/PVDF/ceramic
Storage System		
Tank Type		XLPE
Tank Capacity, each	gal	530
Storage Time, each	days	45
Number of Tanks		1
Piping Material		CPVC

In-line Boost Pumps

The in-line boost pumps will be used to increase the RO feed water pressure. Preliminary design criteria for in-line boost pumps are summarized in Table 8-8.

Table 8-8. In-Line Boost Pumps Design Criteria		
Parameter	Units	Design Value
Main Process Stream		RO Feed Water (6,000 gpm)
Number of Units		5
Type		Vertical Turbine, canned
Capacity, each	gpm	1,500
TDH	ft	TBD
Speed	rpm	1,800
Motor Size	hp	TBD
VFD		Yes
Pump Materials		316 Stainless Steel

Two-Stage RO

Two-stage RO system will be used for desalination. Preliminary design criteria for two-stage RO are summarized in Table 8-9.

Table 8-9. RO System Design Criteria		
Parameter	Units	Design Value
Number of Skids		3
Design Feed Rate per Skid	gpm	2,000
Permeate Flow per Skid	gpm	1,500
Permeate Water Recovery Rate	%	75
Number of Stages		2
Initial Feed Pressure	psi	200 psi
Energy Recovery Device (Inter-stage Boost)	gpm	1,000
Pressure Vessels (each skid)		
1 st Stage		34
2 nd Stage		16
Housing Material		FRP
Elements/Vessel		7
Total Elements		350
Membrane Elements		
Size		8-inch diameter x 40-inch length
Total Installed Number		1,050
Average Flux Rate		15
Material		Thin Film Composite/Polyamides (TFC / PA)

Decarbonator

The purpose of decarbonators is to remove carbon dioxide from RO permeate water and thereby increase the pH of the RO permeate to approximately pH 7.0 to 7.5. Preliminary design criteria for the decarbonators are summarized in Table 8-10.

Table 8-10. Decarbonators Design Criteria		
Parameter	Units	Design Value
Main Process Stream		RO Permeate (4,500 gpm)
Type		Packed Tower
Number of Units		2
Capacity, each	gpm	2,250
Air to Water Ratio		20:1
Target pH		7.0 to 7.5
Packed Tower		
Material		FRP

Table 8-10. Decarbonators Design Criteria		
Parameter	Units	Design Value
Blowers		
Number of Blowers per Tower	each	1
Capacity	scfm	6,000
Motor	hp	TBD

Chlorine and Ammonia Feed

Chloramination will be used for disinfection of the blended water to be consistent with the disinfection system of the imported water, which has chloramines. Since the ammonia in the City's well water will be removed by the RO, ammonia will be injected in addition to chlorine to form stable chloramines residual comparable with imported water. The chlorine to ammonia ratio will be maximum 7.5. The target total chlorine residual is 1.2 to 1.5 mg/L. Preliminary design criteria for chlorine and ammonia feed system are summarized in Tables 8-11 and 8-12.

Table 8-11. Chlorine Feed System Design Criteria		
Parameter	Units	Design Value
Main Process Stream		Blended Water (4,500 gpm)
Chemical		Sodium Hypochlorite
Concentration	%	12.5
Dose		
Average	mg/L	1.5
Minimum	mg/L	0.5
Maximum	mg/L	2.5
Feed Equipment		
Pump Type		Peristaltic
Pump Capacity, each	gph	7
Number of Pumps	each	2
Wetted Materials		PVDF/EPDM
Storage System		
Tank Type		FRP
Tank Capacity, each	gal	1,200
Storage Time, each	days	45
Number of Tanks		1
Piping Material		CPVC

Table 8-12. Ammonia Feed System Design Criteria		
Parameter	Units	Design Value
Main Process Stream		Blended Water (4,500 gpm)
Chemical		Aqua Ammonia (Ammonium Hydroxide)
Concentration	%	19
Chlorine to Ammonia Ratio		7.5:1
Dose		
Average	mg/L	0.2
Minimum	mg/L	0.07
Maximum	mg/L	0.3
Feed Equipment		
Pump Type		Peristaltic
Pump Capacity, each	gph	0.5
Number of Pumps	each	2
Wetted Materials		PVDF/EPDM
Storage System		
Tank Type		FRP
Tank Capacity, each	gal	500
Storage Time, each	days	45
Number of Tanks		1
Piping Material		CPVC

Caustic Soda Feed

Caustic soda will be used to adjust the pH of the disinfected water to pH 8.5 and Langelier Saturation Index (LSI) to greater than 0. Preliminary design criteria for caustic soda feed system are summarized in Table 8-13.

Table 8-13. Caustic Soda Feed System Design Criteria		
Parameter	Units	Design Value
Main Process Stream		Blended Water (4,500 gpm)
Chemical		Caustic Soda
Concentration	%	25
Dose	mg/L	3 to 5
Target Water Quality		pH 8.5 LSI > 0
Feed Equipment		
Pump Type		Peristaltic
Pump Capacity, each	gph	5
Number of Pumps	each	2
Wetted Materials		CPVC/viton

Table 8-13. Caustic Soda Feed System Design Criteria		
Parameter	Units	Design Value
Storage System		
Tank Type		FRP
Tank Capacity, each	gal	3,100
Storage Time, each	days	30
Number of Tanks		1
Piping Material		CPVC

RO Membrane CIP System

The purpose of RO membrane CIP system is to clean the membranes when membranes are fouled with inorganic fouling/scaling, particulate fouling, microbial fouling, and/or organic fouling. Inorganic fouling is typically cleaned with acidification (citric acid is typically used), and organic fouling is typically cleaned with caustic soda.

Preliminary design criteria for RO membrane CIP system equipment are summarized in Table 8-14.

Table 8-14. RO Membrane CIP System Design Criteria		
Parameter	Units	Design Value
CIP Tanks		
Tank Type		FRP
Tank Capacity, each	gal	TBD
Number of Tanks		2
CIP Pumps		
Pump Type		Horizontal Centrifugal
Pump Capacity, each	gph	TBD
Number of Pumps	each	1
Wetted Materials		Stainless Steel
Neutralization Pump		
Pump Type		Horizontal Centrifugal
Pump Capacity, each	gph	TBD
Number of Pumps	each	1
Wetted Materials		Stainless Steel
Piping Material		CPVC

8.3.2 Projection of Probable Cost Information

Based on the preliminary design criteria presented above in Section 8.3.1, the capital and operation and maintenance (O&M) costs have been projected. The projected

capital cost is presented in Table 8-15, the projected O&M cost is presented in Table 8-16, and the life-cycle cost is presented in Table 8-17.

Table 8-15.	
Probable Capital Cost	
Item	Capital Cost
New Well	\$3,500,000
Raw Water Pipelines	\$1,088,000
Wellhead Treatment Facilities (See Note 1)	\$587,000
RO Facilities (See Note 2)	\$19,851,000
Finished Water Facilities	\$2,147,000
Brine Line Connection	N/A (See Note 3)
Finished Water Pipelines	\$1,460,000
Subtotal	\$28,798,000
Contingency (30%)	\$8,639,000
Engineering (14%)	\$5,241,000
Total	\$42,678,000
Unit Cost (\$/acre-ft) (See Note 4)	\$472
<p>Note:</p> <p>1) The cost of the wellhead treatment facilities includes the equipment described in Section 8.3.1.2.</p> <p>2) The cost of the RO Facilities includes the systems described in Section 8.3.1.3, and emergency standby power generator system.</p> <p>3) The brine line connection will be installed in the future.</p> <p>4) The treated water capacity is 6.5 mgd or 7,300 acre-ft/yr. The capital cost has been amortized over 20 years at 5% discount rate.</p>	

Table 8-16.	
Probable O&M Cost	
Item	O&M Cost
Electricity	\$936,000
Chemicals	\$844,000
Membrane Replacement	\$150,000
Cartridge Filters	\$9,000
Miscellaneous Repair and Replacement	\$297,000
Well Pumping Charge	\$58,000
Brine Disposal Fee	(See Note 1)
Labor	\$105,000
Total	\$2,399,000
Unit Cost (\$/acre-ft) (See Note 3)	\$331
<p>Note:</p> <p>1) The cost of brine discharge to the regional brine line is not included in this estimate.</p> <p>2) The treated water capacity is 6.5 mgd or 7,300 acre-ft/yr.</p>	

Table 8-17.	
Probable Life-Cycle Cost	
Item	Unit Cost
Capital Cost (\$/acre-ft)	\$472
O&M Cost (\$/acre-ft)	\$331
Total Life-Cycle Cost (\$/acre-ft)	\$802
Note:	
1) The treated water capacity is 6.5 mgd or 7,300 acre-ft/yr.	

The basis for the life cycle economic analysis is as follows:

- Contingencies have been estimated at 30 percent of the capital cost, which is appropriate at this level of planning.
- Engineering costs have been estimated at 14 percent of the total capital cost including contingencies, and includes the design and construction services and inspection of the facilities.
- Capital cost amortization is based on a 20 year bond sale at an interest of 5 percent.
- Total costs per acre-ft is based on the total product water produced and the total annual costs of the facilities.

8.3.3 Schedule

The schedule for the design and construction of the new brackish water desalination facility is presented in Table 8-18.

Table 8-18.		
Schedule for Design and Construction		
Milestones	Start Date	Complete Date
Select Design-Build Firm		January 2009
Design	January 2009	July 2009
Permitting	July 2009	September 2009
Construction	September 2009	December 2010

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Section 9

Final Financial Statement

9.1 Overview

This section includes pertinent budget information including comparison of actual expenditures with the original spending plan. The expenditures from the grant funds as well as the City's share are included in the financial statement.

9.2 Progress Report

The estimated percent complete of the total project is: 92%

Table 9-1										
Project Progress (April 1, 2007 through September 30, 2008)										
Agreement Number: 4600007441		Starting Date: 4/1/2007		Completion Date: 3/31/2009		Quarter - Year 3 - 2008		Report Number		
Grantee Agency Name: City of Camarillo				% Time Elapsed 75%		Total Grant Funds Used To Date \$335,768.99		Grant Funds Remaining \$48,103.01		
Name of Project: City of Camarillo Brackish Water Desalination Pilot Study										
	YEAR	2007			2008				2009	Percent of Project Complete
TASKS	MONTH	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	
Task 1: Project Management										9
Task 2: Pilot Test Preparation										14
Task 3: Conduct Pilot Testing										62
Task 4: Data Evaluation										7
Task 5: Report Development										0
Show Progress by Use of Bar Chart	Scheduled =									92
	Completed =									

9.3 Expense Report

The total budget of the pilot study is \$767,744. The State's share and the City's share are each 50 percent of the total cost. The expenditures for the project to date are summarized in Table 9-2.

Expense Report from April 1, 2007 to September 30, 2008.

Table 9-2.				
Project Expenditure (April 1, 2007 through September 30, 2008)				
Expense Items (Budget Category or Task Description)	State's Cost Share		City's Cost Share	
	Expenses to Date	Remaining Balance	Expenses to Date	Remaining Balance
a. Administration – Task 1.1				
Salaries	\$120,715.99	\$7,000.01	\$15,000.00	\$0.00
Travel	\$26,582.13	\$3,917.87	\$750.00	\$0.00
b. Planning/Design/Engineering – Tasks 2.1, 2.2, 2.3	\$22,360.00	\$0.00	\$10,000.00	\$0.00
c. Equipment Purchases/Rentals/Rebates/Vouchers – Task 2.3	\$127,376.89	\$3,623.11	\$10,000.00	\$0.00
d. Materials/Installation/Implementation – Task 2.4	\$8,250.00	\$0.00	\$0.00	\$0.00
i. Environmental Compliance/Mitigation/Enhancement – Task 4.2	\$0.00	\$0.00	\$4,589.40	\$410.60
j. Construction – Task 2.4	\$0.00	\$0.00	\$60,088.00	\$0.00
l. Monitoring and Assessment – Tasks 3.1, 3.2, 4.1, 4.2	\$22,366.00	\$0.00	\$283,034.00	\$0.00
m. Report Preparation – Task 1.2, 5.1, 5.2	\$8,679.67	\$33,562.03	\$0.00	\$0.00
Totals	\$335,768.99	\$48,103.01	\$383,461.40	\$410.60

Note that the expenses shown in Table 9-2 do not cover October 2008 through January 2009, during which time the report will be finalized.

Appendix A - Pilot Plant Information

A.1 Pilot Test Protocol

A.2 Photos

A.3 MSDS of Chemicals Used

A.1 Pilot Test Protocol

A.2 Photos



Overall View of Pilot Plant Equipment at Well A



Overall View of Pilot Plant Equipment at Well A

Wellhead Facilities



Chemical Injection at Well B



Well A Raw Water Sample port at well A



Sodium Thiosulfate Drum and Metering Pump at Well B



Chemical Injection Port and Air Eductor at Well A



Well A



Static Mixer

Tanks



Contact Tank



Permeate Tank



Equalization Tank

RO System Equipment



RO Skid



RO Skid



Antiscalant Storage and Metering Pump



Antiscalant Feed Port, Acid Feed Port, and Pressure Gauges



Cartridge Filters



RO Feed Pump



RO Panel

Granular Media Filters



Granular Media Filters



Granular Media Filters



Media Filters Feed Pump

A.3 MSDS of Chemicals Used

- Antiscalant
- Chlorine Dioxide

2420 Grand Avenue, Suite A Vista, CA 92083
ph: (760)597-2434, (800)914-9072, fax: (760)597-2437
Internet: <http://www.PWTInc.com>, E-mail: Support@PWTInc.com

Section 01: Chemical Product Identification

Domestic Trade Name: *SpectraGuard SC[®]*

Export Trade Name: *SpectraGuard SC[®]*

Chemical Type: *Water Soluble Polymer*

MSDS

Material Safety Data Sheet
August 1, 2001

Section 02: Information on Hazardous Ingredients

Non Hazardous Ingredients

Section 03: Hazards Identification:

Acute Toxicity

Mutagenicity: AMES Salmonella Mutagenicity Testing Exhibits No Evidence of Mutagen Presence.

Oral Toxicity: Rat LD50>100,000 mg/kg

Dermal Toxicity: Not Absorbed Topically

Inhalation Toxicity: Exposure to Spray Will Cause Irritation to Mucous Membranes and Respiratory System.

Skin Irritation: Rabbit; No Irritation Observed.

Sensitizer: No Human Repeat Insult Patch Test; Not a Sensitizer.

DOT Corrosive: Not Applicable

Primary Route of Entry: Contact

Signs and Symptoms of Exposure

Symptoms of Ingestion: No Effect of Exposure Expected

Symptoms of Inhalation: If Misted, No Effects Expected

Symptoms of Skin Contact: No Effects Expected

Symptoms of Eye Contact: No Effects Expected With the Exception of Possible Irritation

Medical Conditions Aggravated by Exposure: None Known.

Other Toxicity:

Sub Chronic Oral Toxicity: None Known.

Sub Chronic Inhalation Toxicity: None Known.

Aquatic Toxicity: None Known.

Mutagenicity: AMES Salmonella Mutagenicity Testing Exhibits No Evidence of Mutagen Presence.

Section 04: First Aid Measures

First Aid For Ingestion: Do not induce vomiting, give 2 glasses of milk and several glasses of water.

Never Give Anything by Mouth to an Unconscious Person. Call a Physician Immediately.

First Aid Inhalation: None Required

First Aid Eye Contact: For all Foreign Materials; Immediately Flush Eyes with Plenty of Water.

First Aid Skin Contact: For all Foreign Materials; Wash After Exposure.

Section 05: Fire Fighting Measures

Autoignition Temp: N/A

Flammable Limits: LEL (Lower Explosive Limits) N/A

Fire Fighting Media: Use Media Appropriate to Primary Cause of Fire.

Special Fire Fighting Procedures: None Known.

Fire/Explosion Hazards: None Known.

NFPA Hazard Codes - Health/Flammability/Reactivity; 0,0,0.

HMIS Hazard Codes - Health/Flammability/Reactivity; 0,0,0.

Section 06: Accidental Release Measures

Spill/Leak Clean-Up Procedures: If Possible, Neutralize with Alkaline Soap.

Absorb with approved liquid spill absorbent. Dispose of with Solid Waste According to Federal, State, and Local Regulations. Flush Spill with Water.

***CAUTION:** Floor will be Slippery.

Section 07: Handling and Storage

Precautionary Measures: Avoid Breathing Spray.

Disposal Method: Dispose of with Solid Waste According to Federal, State and Local Regulations.

RCRA Class: Not Regulated.

Section 08: Exposure Control/Personal Protection

Ventilation: Use with Normal Adequate Ventilation.

Respiratory Protection: Dust Masks Where Spraying cannot be Avoided.

Eye Protection: Safety Glasses.

Skin Protection: Use OSHA Approved Neoprene Gloves, Boots, and Apron.

Personal Hygiene: Observe Ordinary Measures of Personal Hygiene.

Section 09: Physical and Chemical Properties

Boiling Point: That of Water.

Vapor Pressure: That of Water.

Vapor Density: That of Water.

Water Solubility: Complete.

Melting/Freezing Point: 32 °F

Appearance: Clear to light amber.

Specific Gravity: 1.0 – 1.2 g/ml

Percentage Volatile: 50 - 60%

Evaporation Rate: That of Water.

pH of Solution: 3 – 7.5 (5% Solution).

Odor: Mild.

Section 10: Stability and Reactivity

Stability: Stable.

Hazardous Polymerization: Will not Occur.

Conditions to Avoid: None Known.

Incompatible Materials: Strong Oxidizing or Reducing Agents.

Hazardous Decomposition Products: None Known.

Section 11: Transport Information

Domestic Data

Dot Shipping Name: Not Regulated.

Dot Hazard Class: Not Regulated.

Hazardous Ingredients: None.

Export Data

Export Shipping Name: Not Regulated.

Export Hazard Class: Not Regulated.

Hazardous Ingredients: None.

UN Number: None.

This material safety data sheet reflects information provided by raw material suppliers and other reliable sources.

Material Safety Data Sheet

Material: Chlorine Dioxide \leq 0.3% Aqueous Solution
Company: CDG Research Corporation
MSDS No. CD-003
Date of Preparation: April 4, 2007
Revision: 002

Section 1 – Chemical Product and Company Identification

Chemical Name: Chlorine Dioxide Aqueous Solution
General Class: Corrosive Liquid
General Purpose: Biocide
Synonyms: Chlorine Oxide Solution
Chlorine Peroxide Solution
Chlorine (IV) Oxide Solution
Chloroperoxyl Solution

UN ID: 1760

Company Name & Address: CDG Research Corporation
759 Roble Road
Allentown, PA 18109

Emergency Telephone Number: **800-424-9300** 24 hours, 7 days/week

Section 2 – Composition / Information on Ingredients

Hazardous component(s):

Chemical name	Chlorine Dioxide
Molecular formula	ClO ₂
Concentration	≤ 0.3% (≤ 3,000 ppm)

Non-hazardous component(s):

Chemical name	Water
Molecular formula	H ₂ O
Concentration	≥ 99.7% (≥ 997,000 ppm)

Section 3 – Hazard Identification

Potential Health Effects – General:

Chlorine dioxide gas is a mucous membrane and respiratory tract irritant.

Swallowing large amounts of this material may be harmful.

Respiration/protection should be worn if concentrations exceed applicable standards.

Primary Route(s) of Exposure:

The primary routes of exposure to this material are ingestion; inhalation; and eye and skin contact

Signs and Symptoms of Exposure

Ingestion

Signs and symptoms of exposure to this material through swallowing include stomach or intestinal upset (nausea, vomiting, diarrhea)

Inhalation

Signs and symptoms of exposure to this material through inhalation of its vapors include coughing, sore throat, breathing difficulty

Eye and Skin contact

Signs and symptoms of exposure to this material through skin contact include skin irritation and redness. Signs and symptoms of exposure to this material through eye contact include eye irritation, tearing and redness.

Section 4 – First Aid Measures

Eyes

If symptoms develop, move patient away from the source of exposure and into fresh air. Flush eyes gently with large amounts of water while holding eyelids apart. If symptoms persist or there is any visual difficulty, seek medical attention.

Skin

First aid is not normally required. However, concentrated solutions of the material (> 1000 ppm) may be highly irritating, especially on prolonged contact. Remove contaminated clothing immediately. Immediately flush exposed skin with large amounts of water. Wash thoroughly with mild soap. Consult a physician if irritation or burning persists. Contaminated clothing must be laundered before re-use. Lower concentrations (<1000) ppm may cause some irritation with very-prolonged exposure.

Swallowing

First aid is not normally required when small amounts of the material are ingested. If symptoms develop or if large amounts of material have been ingested, DO NOT induce vomiting. DO NOT give anything by mouth if the patient is unconscious. Drink large quantities of water. Consult a physician immediately. Neutralization and use of activated charcoal are not recommended.

Inhalation

If symptoms develop, immediately move individual away from exposure and into fresh air. Seek immediate medical attention; keep person warm and quiet. If person is not breathing, begin artificial respiration. If breathing is difficult, administer oxygen. Monitor the patient closely for delayed development of pulmonary edema, which may occur up to 72 hours after inhalation.

Notes to Physicians

No data

Section 5 – Fire-Fighting Measures

NFPA Rating

Health – 1
Flammability – 0
Reactivity – 1

Flash Point

Not applicable

Auto-ignition Temperature

Not applicable

Explosive Limit

Chlorine dioxide solution is not explosive. Chlorine dioxide gas, which may evolve from chlorine dioxide solution, may spontaneously decompose with a mild energy release at concentrations of 10% in air or greater at standard temperature and pressure (i.e., 76 mm Hg partial pressure).

Chlorine dioxide gas may explode with violent force at concentrations of 30% or greater in air at standard temperature and pressure (i.e., 228 mm Hg partial pressure)

Hazardous Products of Combustion

May form chlorine, hydrochloric acid gas, oxygen on combustion or decomposition

Fire and Explosion Hazards

There are no special fire hazards known to be associated with the material.

Extinguishing Media

Water

Fire Fighting Instructions

Wear a self-contained breathing apparatus (SCBA) with a full face piece operated in the “positive pressure demand” setting. Use SCBA in conjunction with appropriate chemically resistant personal protective gear. Refer also to the personal protective equipment section of this MSDS.

Section 6 – Accidental Release Measures

Large Spill

In the event of a large spill of the material, prevent runoff to sewers, streams, lakes or other bodies of water. If run-off occurs, notify proper authorities of any runoff, as required, Persons not wearing protective equipment should be excluded from area of spill until clean-up has been completed. Stop spill at source, dike area around spill to prevent spreading, and pump liquid to salvage tank. Remaining liquid may be taken up on sand, clay, earth, vermiculite, floor absorbent, or other absorbent material and shoveled into containers. Flush with water the area from which the bulk of the spill has been removed.

Small Spill

Absorb liquid on vermiculite, floor absorbent or other absorbent material. Flush area with water.

Section 7 – Handling and Storage

Handling

In order to prevent the evolution of chlorine dioxide gas into the breathing zones of workers, agitation of the material should be minimized, and the material should not be stirred, mixed turbulently, sprayed or splashed.

Storage

The material should be stored indoors, only in the containers in which it is shipped, or in containers authorized by the manufacturer for such storage. Storage temperatures should be maintained above 50°F and below 110°F. The material should not be stored outside or exposed to freezing temperatures (below 32°F). The material should not be heated to temperatures in excess of 140°F. At temperatures above 140°F, the gas concentration in the headspace of the container may reach high, energetically unstable concentrations.

Section 8 – Exposure Controls / Personal Protection

The OSHA permissible exposure limit (PEL) for ClO₂ gas in air is 0.1 ppm (0.3 mg/m³) as an 8-hour time weighted average. NIOSH recommended exposure limits (REL) and ACGIH threshold limit values (TLV) are also 0.1 ppm.

NIOSH and ACGIH short-term exposure limits (STEL) are 0.3 ppm (0.83 mg/m³) for periods not to exceed 15 minutes. The STEL concentration should not be repeated more than 4 times per day and should be separated by intervals of at least 60 minutes.

Exposure Guidelines (vapor)

OSHA PEL 0.100 ppm – TWA

ACGIH TLV 0.100 ppm – TWA

ACGIH TLV 0.300 ppm - STEL

Eye Protection

Wear splash-proof face and eye protection (PVC is preferred) where chlorine dioxide solution may splash or spray. Safety glasses should be in compliance with OSHA regulations.

Skin Protection

Wear waterproof protective clothing (PVC is preferred) where chlorine dioxide solution may splash or spray. Wear resistant gloves, such as Neoprene, to prevent skin contact, wear impervious clothing and boots. Other protective equipment: eyewash station, emergency shower.

Respiratory Protection

Exposures in the workplace should be monitored to determine if worker exposure exceeds the facility-specified exposure "action level" or the use of the material produces adverse health effects or symptoms of exposure. Provide adequate ventilation to maintain all work areas at concentrations below 0.1 ppm chlorine dioxide concentration. If the generation of vapors or mists is possible, use local ventilation. Where gas concentration may exceed 0.1 ppm, only a NIOSH/MSHA approved full-face acid gas respirator should be used. Monitoring results must be used to assess the proper level of respiratory protection necessary. Proper engineering and/or administrative controls should be used to reduce worker exposure. The facility's respiratory protection program must meet the requirements established in 29 CFR 1910.134, which includes a program for medical evaluation. A NIOSH/MSHA approved self-contained breathing apparatus, with full face piece, is required for leaks and emergencies where the concentration may exceed 5 ppm.

Engineering Controls

Provide sufficient mechanical ventilation-- general and/or local exhaust-- to maintain exposure below allowable limits.

Section 9 – Physical and Chemical Properties

Appearance and odor

Yellow-green liquid, with sharp, pungent odor

Liquid specific gravity

1.0 at 0° C

Boiling Point

100° C (212° F)

Odor threshold of gas

0.1 ppm

Section 10 – Stability and Reactivity

Hazardous Polymerization

Material does not undergo hazardous polymerization.

Hazardous Decomposition

Gas-phase vapors that evolve from the material may decompose on exposure to light, on contact with incompatible materials (see below), or spontaneously at concentrations above 10% in air at standard temperature and pressure (76mm Hg). On decomposition, material may form: Chlorine, hydrochloric acid gas and oxygen.

Chemical stability

The material, as solution, is stable in the dark. On exposure to light, the solution may decompose to an aqueous solution of chloride and chlorate ions. In regard to vapor (gas) that may evolve from the material, see “Hazardous Decomposition” above.

Incompatibility

Avoid exposure to light. Avoid contact with: metals, reducing agents, strong oxidizing agents, sulfur compounds or sulfur-containing components, carbon monoxide, excessive heat, mercury, organic materials, phosphorus.

Section 11 – Toxicological Information

Chlorine dioxide gas is a mucous membrane and respiratory tract irritant. Primary routes of exposure include ingestion, skin and eye contact and inhalation of vapors which may evolve from the material.

Target Organ Effects

This material may cause mild eye irritation; it is unlikely to cause serious eye irritation or injury

This material may cause mild skin irritation; it is unlikely to cause serious skin irritation or injury

Digestive Tract

This material may cause nausea, vomiting and diarrhea; it is unlikely to cause serious digestive tract injury. Chlorine dioxide given daily in drinking water at 1-100 ppm caused a decrease in blood glutathione, altered the morphology of erythrocytes, and caused osmotic fragility in laboratory animals.

Respiratory Tract

The fumes from this material may cause respiratory tract irritation, wheezing and difficulty breathing. In extreme cases, it may cause pulmonary damage and death.

Developmental/Reproductive Effects

Available information is insufficient to assess risk to the fetus from maternal exposure to this material during pregnancy. Chlorine dioxide did not cause birth defects in laboratory animals even at very high exposure levels.

Cancer Effects

Available information is insufficient to assess cancer risk (i.e., carcinogenicity) associated with exposure to this material. This material is not listed as a carcinogen by the International Agency for Research on Cancer (IARC), the National Toxicology Program (NTP), or the Occupational Safety and Health Administration (OSHA) United States Environmental Protection Agency (EPA) or American Conference of Industrial Hygienists (ACGIH).

Other Health Effects

No data available on other possible health effects

<h2>Section 12 – Ecological Information</h2>

No data available.

Section 13 – Disposal Considerations

Disposal of this material should be in accordance with all applicable Federal, State and local rules, regulations and requirements.

Section 14 – Transport Information

Transport of this material should be in accordance with all applicable Federal, State and local rules, regulations and requirements, including, without limitation, the rules and regulations of the US Department of Transportation, including all applicable packaging and labeling requirements.

DOT Information:

Proper shipping name:	chlorine dioxide solution (≤ 0.3)
Class:	N/A (Exempt under CFR 173.154(d))
Packing group:	None, but must not ship or store in metal Containers
Hazard label:	None Required

Section 15 – Regulatory Information

US Federal Regulations

TSCA (Toxic Substances Control Act) Status - United States

The intentional ingredients of this material are listed.

CERCLA RQ- 40 CFR 302.4(a)

None listed

SARA 302 Components - 40 CFR 355 Appendix A

None

Section 311/312 Hazard Class-40 CFR 370.2

Immediate ()

Delayed ()

Fire ()

Reactive ()

Sudden Release of Pressure ()

SAARA 313 Components - 40 CFR 372.65

Section 313 Components	CAS Number	Percent (%)
Chlorine dioxide	1004-04-4	0.03

OSHA Process Safety Management 29 CFR 1910

PSM Component(s)	Condition	TQ (lbs)
CHLORINE DIOXIDE		100

EPA Accidental Release Prevention 40 CFR 68

PSM Component(s)	Condition	TQ (lbs)
CHLORINE DIOXIDE Chlorine Oxide (ClO ₂)		100

International Regulations

Not determined

State and Local Regulations

California Proposition 65

None

Section 16 – Other Information

The information set forth herein is believed to be accurate. However, NO WARRANTY IS GIVEN AS TO THE ACCURACY OF ANY OF THE INFORMATION, WHETHER ORIGINATED BY THE COMPANY OR BY OTHERS. Recipients of this MSDS are advised to confirm, in advance of any need, that the information is current, applicable, and suitable to their circumstances.

- END -

Appendix B - Dissemination and Outreach Materials

B.1 Posters Used at Pilot Plant Site Tour

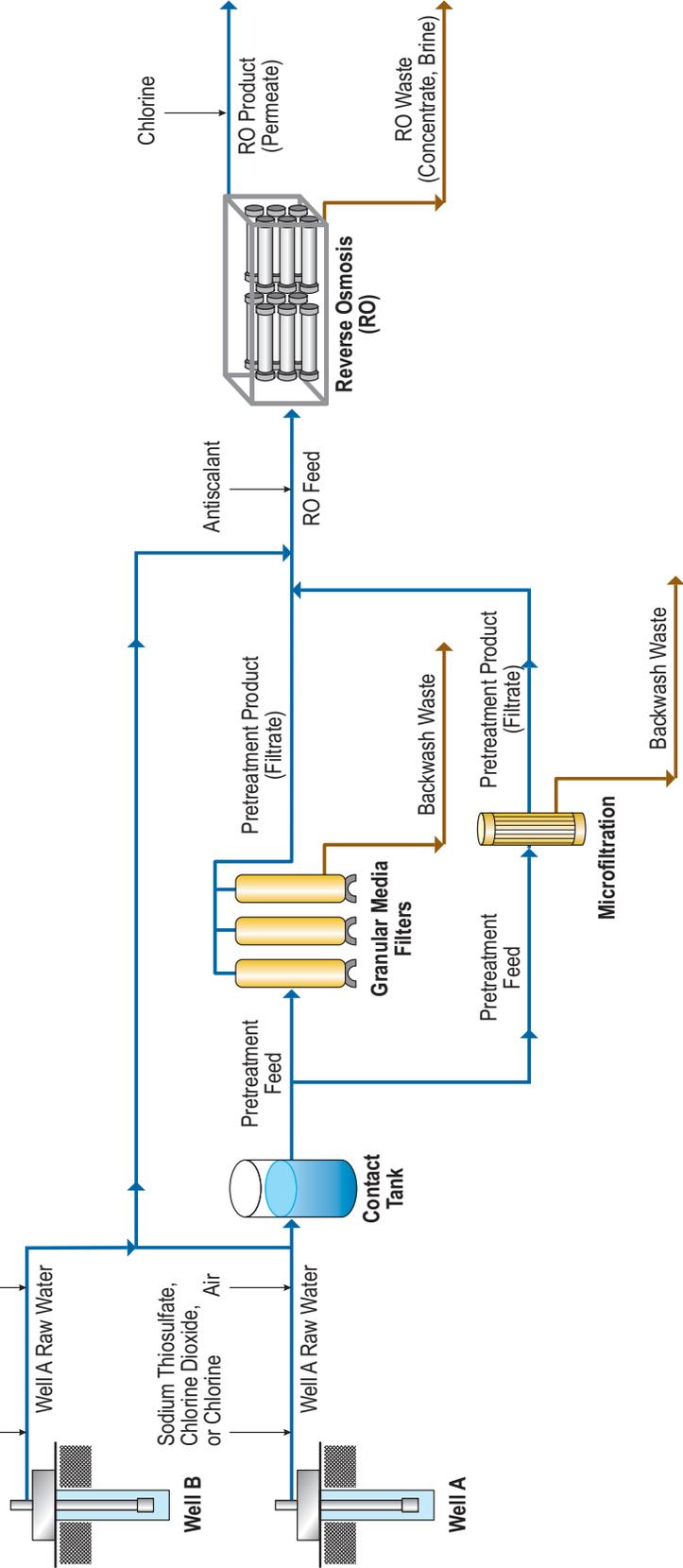
B.2 Operator Training Workshop Presentation

B.1 Posters Used at Pilot Plant Site Tour

City of Camarillo

Brackish Water Desalination Pilot Study

Alternatives are being evaluated to improve the performance of reverse osmosis, by reducing fouling caused by iron and manganese in the well water. This has been a common problem in southern California, and has cost millions of dollars in emergency installations at other utilities. The pilot has evaluated multiple methods of oxidation and filtration, as well as one method for preventing the oxidation of both metals.



Oxidation Alternatives

Aeration	Oxidizes iron only. Manganese will remain dissolved
Chlorine Dioxide (ClO ₂)	Oxidizes both iron and manganese
Chlorine (Cl ₂)	Oxidizes iron and manganese when used in conjunction with pyrolusite (greensand) media

Filtration Alternatives

Granular Media Filtration	Removes oxidized iron and manganese
Pyrolusite Media Filtration	Enhances oxidation of manganese, and removes oxidized iron and manganese
Microfiltration (MF)	Removes oxidized iron and manganese

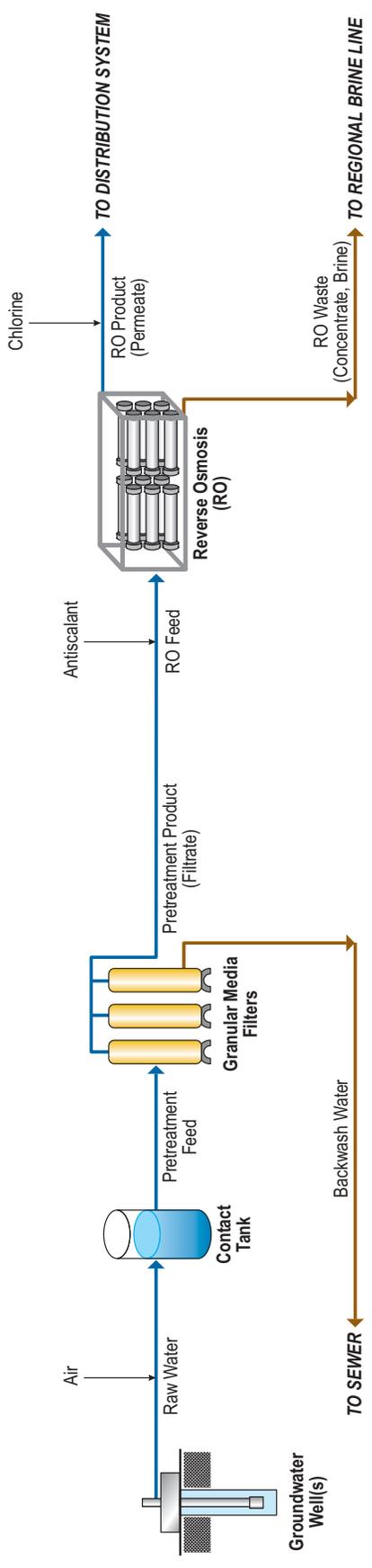
Sequestering

Sodium Thiosulfate or Sodium Bisulfite	Prevents oxidation
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Overall Pilot Plant Process Flow Diagram

City of Camarillo
Brackish Water Desalination Pilot Study



Aeration

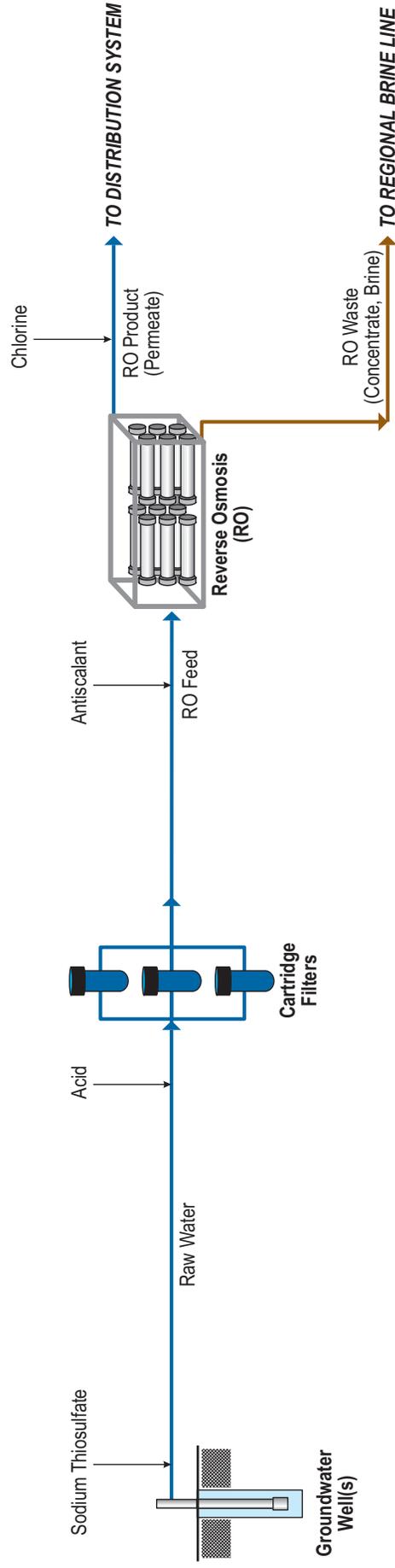
- Add air to increase dissolved oxygen (DO) level in water to saturation (8 to 9 mg/L)
- Oxidizes iron but not manganese

Granular Media Filtration

- Dual media filters using sand and anthracite media
- Depth filtration was found to accelerate iron oxidation, removing nearly 100% of the iron from the feed water
- Non-oxidized manganese remains dissolved, passing through the media filters
- Backwash waste from the granular media filters will be directed to the sewer system

Reverse Osmosis

- Reverse osmosis is used to remove salinity and sulfates from the water, allowing the city to meet drinking water standards
- Lower salinity and sulfate in the drinking water will also improve wastewater plant effluent, helping to meet current and anticipated TMDLs
- Non-oxidized manganese in the water will be removed, along with other salts, without causing fouling
- A concentrate stream from the reverse osmosis system will be disposed of in the future brine line.



Sequestering

- Sodium thiosulfate is added to quench dissolved oxygen (DO) in the raw water to slow down oxidation of iron and manganese.

pH Adjustment

- Acid is added to reduce the pH of RO Feed water to pH 6.5 to slow down oxidation of iron, and prevent scaling in the RO membranes.

Reverse Osmosis

- Reverse osmosis is used to remove salts, metals, and organic compounds from the water, allowing the city to meet drinking water standards.
- Lower salinity and sulfate in the drinking water will also improve wastewater plant effluent, helping to meet current and anticipated TMDLs.
- Non-oxidized iron and manganese in the water will be removed, along with other salts, without causing fouling
- A concentrate stream from the reverse osmosis system will be disposed of in the future brine line.

B.2 Operator Training Workshop Presentation

City of Camarillo Brackish Water Desalination Pilot Study

Operator Training Workshop

October 9, 2007



Introductions

- ◆ Greg Wetterau, Project Manager
WetterauGD@cdm.com
- ◆ Marie Burbano, Project Engineer
BurbanoMS@cdm.com
- ◆ Evelyn You, Task Leader
YouEC@cdm.com
- ◆ Chris Wessel, Field Engineer
WesselCJ@cdm.com
- ◆ Stephanie Roberts, Field Engineer
RobertsSC@cdm.com

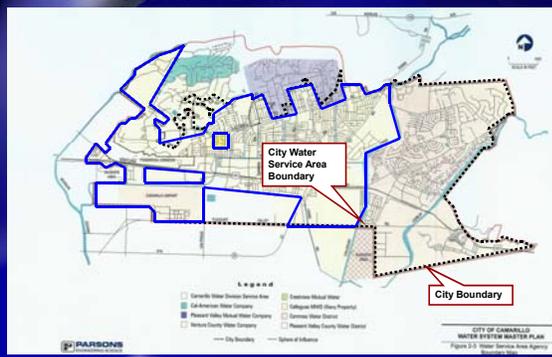
Outline

- ◆ Background
- ◆ Project Objectives
- ◆ Technology Overview
- ◆ Pilot Study Description and Testing Protocol
- ◆ Phase I Testing Preliminary Results
- ◆ Q&A

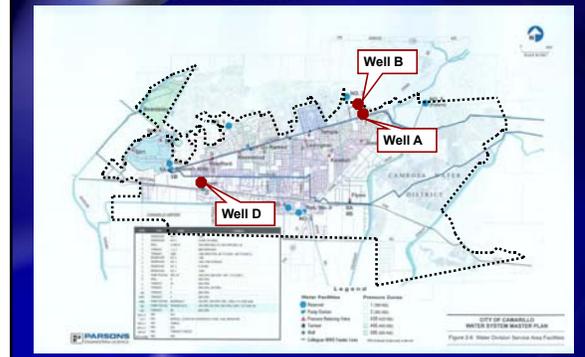
Background

- ◆ City provides water to 60% of City residents
- ◆ City obtains water from two sources:
 - ◆ Local groundwater wells
 - ◆ Imported water from Calleguas Municipal Water District

Water Service Areas



Groundwater Wells



Well A and Well B

- ◆ Groundwater quality from two wells (Wells A and B) have deteriorated:
 - ◆ High Total Dissolved Solids (TDS)
 - ◆ High Chloride (Cl)
 - ◆ High Sulfate (SO₄)
 - ◆ High Iron (Fe)
 - ◆ High Manganese (Mn)
- ◆ City normally operates by blending Well B water with the imported water to meet drinking water standards, and operates Well A on standby mode.

Capital Improvement Plan

- ◆ City's Goal:
 - ◆ Supply high quality water cost-effectively
 - ◆ Maximize the use of local water resources
- ◆ City's Plan:
 - ◆ Construct a groundwater treatment plant for Wells A and B, and a future well
 - ◆ Improve water supply reliability
 - ◆ Deliver high quality water from local groundwater resources

Current Water Quality & Goals

Parameter	Existing Water Quality* (mg/L)	Secondary or Recommended MCL (mg/L)	City's Water Quality Goal (mg/L)
TDS	~1700	500	300
Chloride	~160	250	80
Iron	~0.55	0.3	≤0.01**
Manganese	~0.18	0.05	≤0.01**

* Average of Well A and Well B data from Jan 2007.
 ** Water quality goals set based on removal method (i.e., RO)

Current Water Quality & Goals

Parameter	Existing Water Quality* (mg/L)	Secondary or Recommended MCL (mg/L)	City's Water Quality Goal (mg/L)
Calcium (mg/L)	~260	n/a	Varies – goal to prevent fouling
Sulfate (mg/L)	~755	250	
Silica (mg/L)	~39	n/a	
pH	7.2 – 7.8	n/a	

* Average of Well A and Well B data from Jan 2007. Silica was measured from Well A only in May 2004.

Project Objectives

- ◆ Develop design criteria for a treatment process that supplies high quality water cost effectively
 - ◆ Evaluate water treatment technologies to reduce high levels of iron, manganese, chloride, TDS, and sulfate
 - ◆ Demonstrate the feasibility and effectiveness of the selected treatment scheme
 - ◆ Comply with water quality goals
 - ◆ Optimize the operation of the treatment processes for full-scale design criteria
 - ◆ Minimize chemical usage, process waste streams, and life-cycle cost

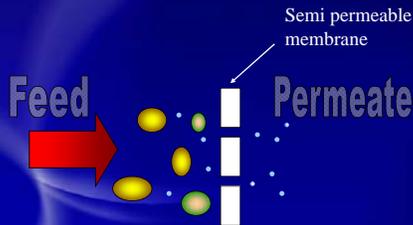
Technology Overview

- ◆ All contaminants of concern can be removed through desalination
- ◆ Oxidation and filtration may be required to increase reliability of desalination process
- ◆ Testing will focus on multiple oxidation/filtration approaches



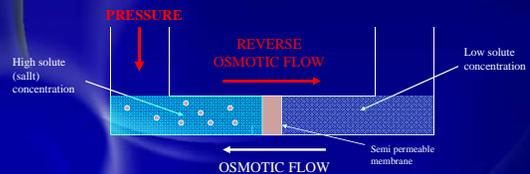
Desalination will be done by Reverse Osmosis (RO)

- ◆ Membrane is semi permeable: it only allows water to pass through it

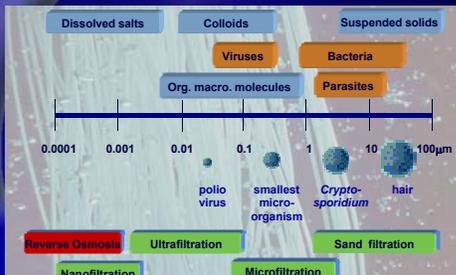


Why is it called reverse osmosis?

- ◆ Osmosis is the natural movement across membrane from low to higher solute concentration side
- ◆ Applied pressure reverses flow of osmosis by overcoming osmotic pressure



Reverse Osmosis (RO)



Membrane type defined by pore size

Reverse Osmosis (RO) Definitions

- ◆ Flux (Filtration Rate): Unit rate at which water passes through the membrane
 - ◆ $J = Q/A$
 - J = flux, gfd
 - Q = flow, gpd
 - A = membrane area, sf
- ◆ Transmembrane Pressure (TMP): Average pressure across the membrane
 - ◆ $TMP = (P_f + P_c)/2 - P_p$
 - P_f = feed pressure, psi
 - P_c = concentrate pressure, psi
 - P_p = permeate pressure, psi

Reverse Osmosis (RO) Definitions

- ◆ Osmotic pressure: Pressure induced by concentration difference across a membrane
 - ◆ $P_o = RT \ln(X_i)/V_w = (zRT/M)C$

(Gibbs) (Van't Hoff)

where: P_o = osmotic pressure;
 z = # of ions;
 C = mass concentration (g/L);
 M = molecular weight (g/mol);
 T = temperature (K);
 R = ideal gas law constant = $8.314 \text{ Pa}\cdot\text{m}^3/\text{mol}\cdot\text{K}$; and
 V_w = water molar volume = 0.018 L/mol
 - ◆ Net driving pressure (NDP)
 - $NDP = TMP - P_o$

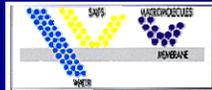
Reverse Osmosis (RO) Definitions

- ◆ Mass Transfer Coefficient (MTC) – Membrane resistance
 - ◆ Normalize rate at which water passes through the membrane
 - ◆ Commonly used to characterize membrane fouling, since it accounts for changes in concentration, filtration rate, and temperature
 - ◆ $MTC = J / NDP$

where J = volumetric flux of water
 NDP = Net Driving Pressure

Reverse Osmosis (RO)

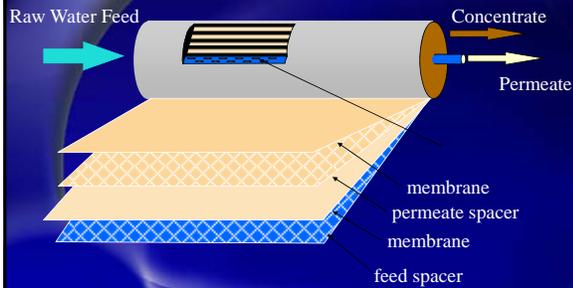
- ◆ Retains virtually all ions at > 98%
- ◆ Dissolved gases will pass (O₂, CO₂, H₂S)
- ◆ Typical Pressures
 - ◆ Brackish water RO: 150-600 psi
 - ◆ Seawater RO: 800-1,250 psi
- ◆ Typical Flux:
 - ◆ Brackish water RO: 10-20 gfd
 - ◆ Seawater RO: 10-15 gfd
- ◆ Recovery:
 - ◆ Brackish water RO: 60-90%
 - ◆ Seawater RO: 30-50%



Reverse Osmosis (RO) Membrane Materials

- ◆ Thin Film Composite (TFC)
 - ◆ Polysulfone support layer with polyamide membrane skin
- ◆ Benefits
 - High porosity, high uniformity
 - Good pH range
- ◆ Drawbacks
 - Low chlorine tolerance (no free chlorine)
 - Suffer from compaction

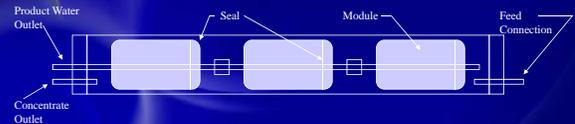
Reverse Osmosis (RO) Membrane Configuration



Spiral wound configuration

Reverse Osmosis (RO) Membrane Configuration

- ◆ Spiral wound:
 - ◆ Employ multiple elements in series
 - ◆ Last elements see highest concentrations
 - ◆ Cannot be backwashed
 - ◆ Do not reject at 100%



Reverse Osmosis (RO)



Membrane Fouling

- ◆ Fouling is the deposition of material onto the membrane surface, which impedes the production of water. The nature of the foulant can vary, as will methods of prevention and cleaning



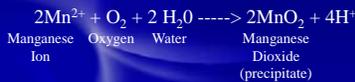
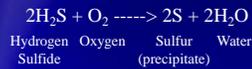
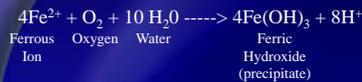
Types of Fouling

- ◆ **Scaling**
 - ◆ Inorganic scale from calcium, silica, or magnesium
 - ◆ Easily controlled, but very bad for membrane if some scales form
- ◆ **Biofouling**
 - ◆ organic
 - ◆ Not easily controlled, can be difficult to clean
- ◆ **Particulate**
 - ◆ Can be organic or inorganic
 - ◆ Not easily controlled, can be difficult to clean

Particulate Fouling

- ◆ **Main forms**
 - ◆ Organic carbon
 - ◆ Iron, manganese, aluminum
 - ◆ Hydrogen sulfide
 - ◆ Sand and silt
- ◆ Can be prevented by either removing foulants, or preventing them from entering feed
- ◆ Many cause by air entrainment

Particulate Fouling - Oxidation of Iron, Sulfide, and Manganese



Methods for Dealing With Fouling

- ◆ **Preventative**
 - ◆ Pretreatment (cartridge filters, acid, antiscalant, thiosulfate)
 - ◆ Reduce recovery
 - ◆ Careful monitoring of operations
- ◆ **Restorative**
 - ◆ Boost feed pressure
 - ◆ Chemical cleaning
 - ◆ Membrane replacement

Chemical Clean-in-Place

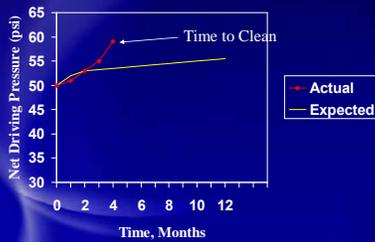
- ◆ Improves performance by eliminate scaling and fouling
- ◆ Prevent irreversible fouling and damage, which can be caused by excessive scaling or fouling
- ◆ Eliminate biological build-up, which can damage membranes and membrane performance

Cleaning Method

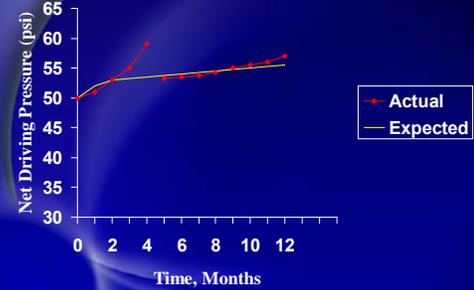
- ◆ Low pH solution for metallic scales/foulants
- ◆ High pH solution for biological, organic, and silica fouling
- ◆ High flow with low pressure
- ◆ Use warm water when possible
- ◆ Always follow guidelines of membrane manufacturer
- ◆ Improper cleaning can void warranty

When to Clean - Net Driving Pressure

- ◆ Whenever the net driving pressure increases 10-15% above expected, it is time to chemically clean the unit
- ◆ May also clean on increased TDS or pressure drop



Successful Cleaning



Chemical Pretreatment

- ◆ Antiscalant added to prevent silica and calcium scaling
- ◆ Sodium thiosulfate used at wells to remove oxygen and prevent oxidation of iron and manganese:

$$2\text{NaHSO}_3 + \text{O}_2 \rightarrow 2\text{NaHSO}_4$$
- ◆ Chemical usage may be costly
- ◆ Will only be effective when iron oxidation has not already occurred

Oxidation Alternatives

- ◆ Oxidation will be used in pilot to aid in removal of iron and manganese upstream of RO
- ◆ Oxidized metals insoluble and relatively easy to filter out of the water
- ◆ Oxidizing agents include:
 - ◆ Aeration
 - ◆ Chlorine Dioxide
 - ◆ Chlorine



Oxidation using Aeration

- ◆ Oxygen introduced to the feed water to oxidize iron and keep manganese in its dissolved state.
- ◆ Oxidation of iron using oxygen is fast (seconds)
- ◆ Oxidation of manganese with oxygen is slow (more than 24 hours) so it should not occur within the pilot system



Oxidation using Aeration

- ◆ Oxygen added to the water through a Mazzei Model 1584-A Injector provided by the Mazzei Injector Corporation (MIC) located in Bakersfield, California
- ◆ It operates in-line with a suction port to pull air into the line, dissolving oxygen into solution
- ◆ No chemical addition required
- ◆ Oxidized iron will foul RO membranes, if not removed



Oxidation using Chlorine Dioxide

- ◆ Strong oxidant that quickly oxidizes both iron and manganese
- ◆ Unlike chlorine and ozone, will not damage RO elements
- ◆ No disinfection byproducts
- ◆ Most effective method for oxidizing both iron and manganese



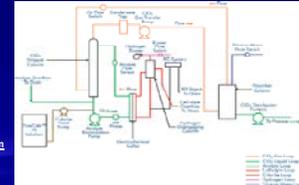
Oxidation using Chlorine Dioxide

- ◆ Requires ultra-pure system (>99% pure) to prevent damage to RO membranes
- ◆ Generated onsite by a Pureline 3 lb/day generator
- ◆ Can be costly, complex, and often requires handling of multiple hazardous chemicals



Process flow diagram

Source: Pureline



Oxidation using Chlorine (Hypochlorite)

- ◆ Oxidizes both iron and manganese
- ◆ Manganese oxidation can be slow, taking up to 30 minutes to complete
- ◆ Use pyrolusite as a catalyst to accelerate oxidation of manganese using chlorine



Oxidation using Chlorine

Disadvantages

- ◆ Can cause disinfection byproducts
- ◆ Will destroy RO membranes, requiring dechlorination ahead of RO

Advantages

- ◆ Inexpensive
- ◆ Already in use at all well sites
- ◆ Most common method



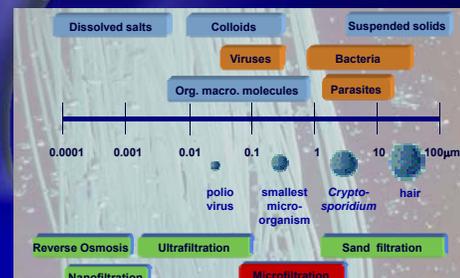
Filtration

- ◆ Filtration removes oxidized iron and manganese ahead of reverse osmosis
- ◆ Pilot will look at:
 - ◆ Membrane filtration (microfiltration)
 - ◆ Granular media filtration
 - ◆ Catalyzing media filtration



Microfiltration (MF)

- ◆ Pressure driven membrane separation process, similar to RO

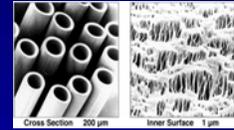


Microfiltration (MF)

- ◆ Filtration process
- ◆ Removes suspended solids, bacteria, and some viruses.
- ◆ Operating Pressure: Typically 10-30 psi
- ◆ Typical Flux: 30-40 gfd
- ◆ 90-98% Recovery, backwashing once every 30-40 minutes
- ◆ MF skid used: Siemens Memcor CMF L20 skid employing a low pressure microfiltration with a nominal pore size of 0.04 microns

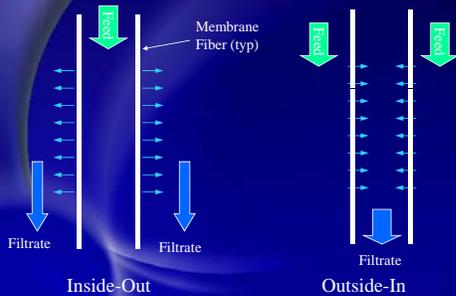
Microfiltration (MF)

- ◆ Polyvinyl Difluoride (PVDF)
 - MF/UF only
 - Benefits: - Chlorine tolerant
 - Low fouling from organics
- ◆ Hollow fiber membranes
 - Can be backwashed
 - Highest area/volume ratio
 - 100% rejection common
 - Generally limited to MF/UF



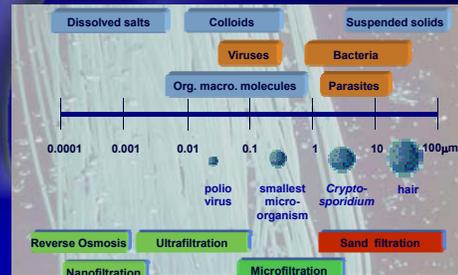
Microfiltration (MF)

- ◆ Hollow fiber membranes



Granular Media Filtration

- ◆ Removal highly dependent on filtration rate and other operating conditions



Granular Media Filtration

- ◆ Dual media filters using sand/anthracite
- ◆ Removal highly impacted by operating conditions
- ◆ Breakthrough can occur from high flowrates, dirty filters, or changes in feed water quality
- ◆ Operating Pressure: Typically 10-15 psi
- ◆ 97-99% Recovery, backwashing once every several days



Granular Media Filtration

- ◆ Multimedia Filters
 - Number: 3 vessels
 - Flowrate: 20 to 30 gpm
 - Filtration Rate: 5 gpm/sf
 - PVC pressure vessels
 - Media:
 - 18-inch anthracite
 - 18-inch silica sand



Catalyzing Media

- ◆ Manganese dioxide (pyrolucite) is a high-rate, granular filter media that operates both as a classical filter and as a catalyzing media
- ◆ Accelerates oxidation of manganese using chlorine within seconds in lieu of 30 minutes in general
- ◆ Regenerates as it is used
- ◆ Most common method for removing iron and manganese from well water



Pyrolucite

Catalyzing Media

- ◆ Most common form is greensand
 - ◆ Manganese dioxide coated silica
 - ◆ Requires conditioning with permanganate
- ◆ Pure pyrolucite available as
 - ◆ Laynox
 - ◆ Pyrolox
- ◆ Backwash to remove dirt, debris, and iron oxide
- ◆ Dense media can be difficult to backwash

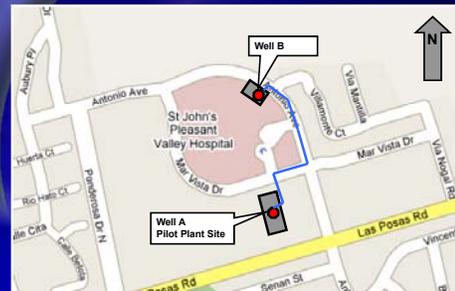


Pilot Study Description and Testing Protocol

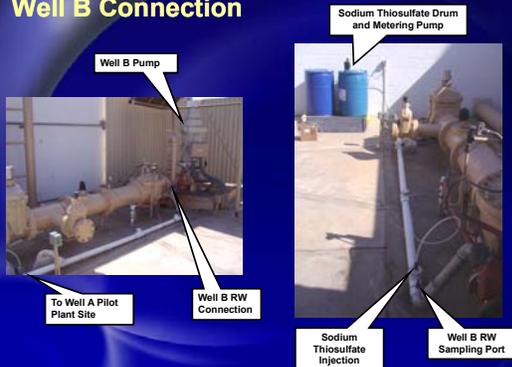
- ◆ Location
- ◆ Site Layout
- ◆ Pilot Study Schedule
- ◆ Testing Phases and Sampling Protocol



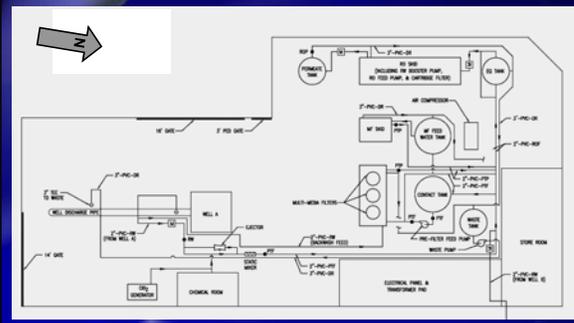
Pilot Plant Location



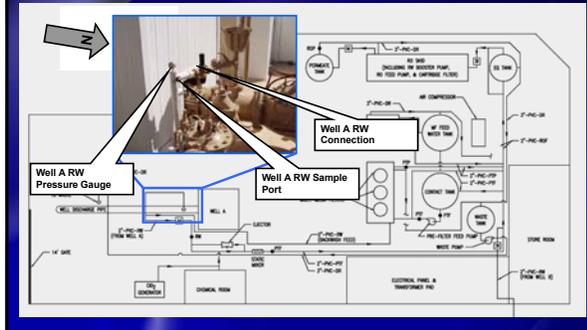
Well B Connection



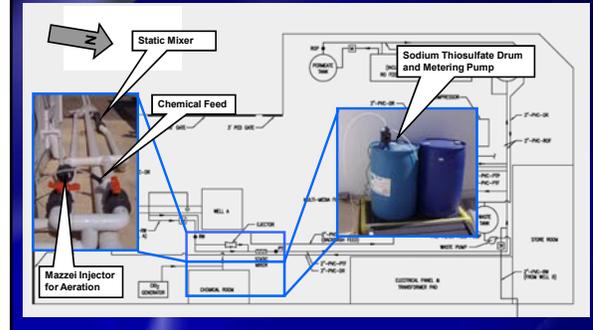
Well A Pilot Plant Site Layout



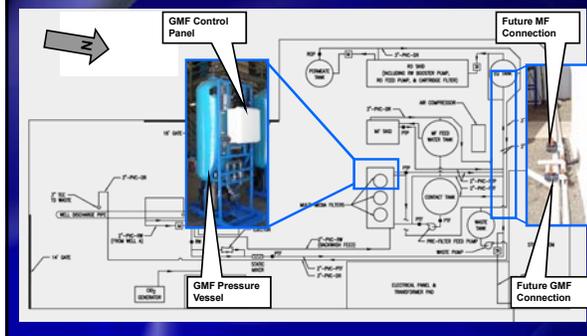
Well A Connection



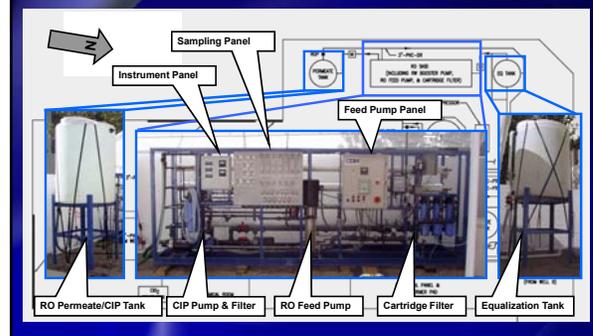
Oxidation



Pretreatment



Reverse Osmosis (RO)

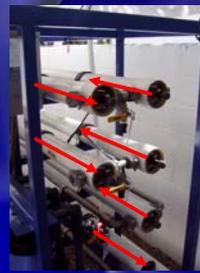


Reverse Osmosis (RO)

- ◆ RO skid used for the pilot plant study:
- ◆ CDM's NF/RO Pilot Skid No.1 designed to test nanofiltration or reverse osmosis membranes
- ◆ Skid-mounted and can treat feed water of up to a total dissolved solids (TDS) level of 5000 mg/L
- ◆ Can conduct tests on membrane softening at recovery rates up to 92 percent
- ◆ Can operate up to 30-gpm and 280-psi

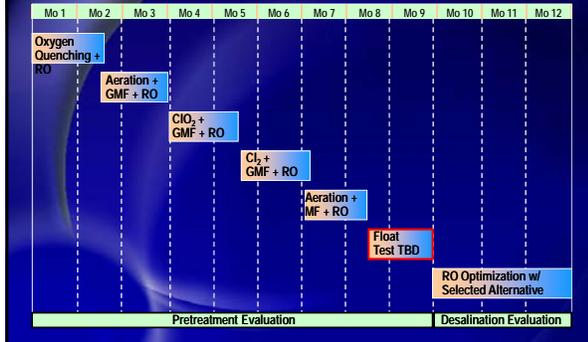


Reverse Osmosis (RO)



- ◆ Two stages of pressure vessels in a 2:1 array with four elements per vessel
- ◆ First stage = four 4-inch diameter vessels containing four membrane elements each connected => two parallel 8-element vessels
- ◆ Second stage = two 4-inch diameter vessels each connected => one 8-element vessel

Pilot Study Schedule



Sample Streams

- ◆ RW – Raw Water (i.e., untreated well water)
- ◆ PTF – Pretreatment Feed
- ◆ PTP – Pretreatment Product
- ◆ PTW – Pretreatment Waste (i.e., GMF or MF backwash water)
- ◆ ROF – RO Feed
- ◆ ROP – RO Product (i.e., RO Permeate)
- ◆ ROW – RO Waste (i.e., RO Concentrate)

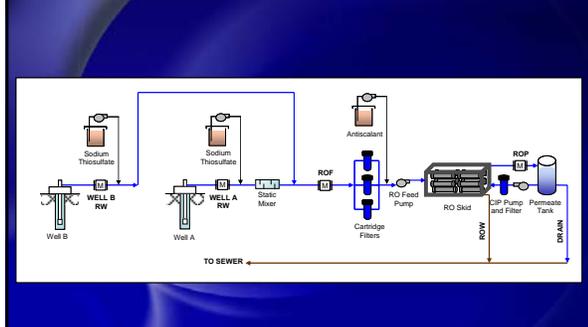
Phase I Oxygen Quenching + RO

- ◆ Purpose:
 - ◆ Determine if iron and/or manganese oxidation could be prevented if sodium thiosulfate is added at the wellhead to consume dissolved oxygen
- ◆ Note:
 - ◆ If oxygen is present, iron and/or manganese may oxidize and cause excessive RO membrane fouling

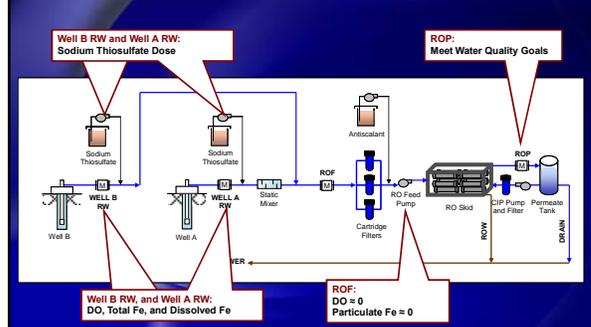
Phase I Oxygen Quenching + RO

- ◆ Dose sodium thiosulfate to quench DO and keep Fe and Mn in reduced state
- ◆ Monitor DO, Total Fe, Dissolved Fe, and Total Mn in ROF
 - ◆ Want to see:
 - DO ≈ 0
 - Particulate Fe = Total Fe – Dissolved Fe ≈ 0
- ◆ Monitor RO feed pressure to check RO fouling

Phase I Oxygen Quenching + RO



Phase I Oxygen Quenching + RO



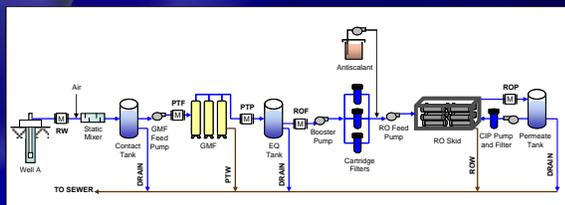
Phase II Aeration + GMF + RO

- ◆ Purpose:
 - ◆ Determine if aeration plus GMF will effectively remove iron oxide through the GMF and keep manganese in the reduced state so that it is removed by the RO
- ◆ Notes:
 - ◆ Aeration will provide O₂ to oxidize iron while keeping manganese in a reduced state (reaction is slower)
 - ◆ Aeration is the least costly method with no need of chemical oxidation

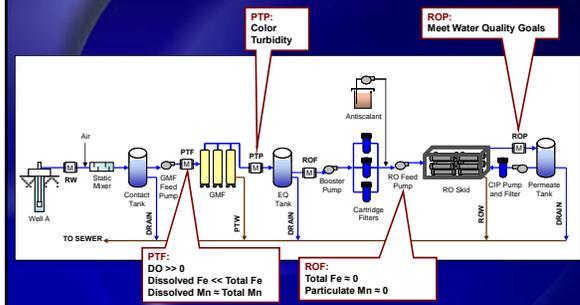
Phase II Aeration + GMF + RO

- ◆ Introduce air into RW using Mazzei injector to oxidize Fe while keeping Mn in reduced state
- ◆ Remove all iron oxides using GMF
- ◆ Check Color and Turbidity in PTF for breakthrough
- ◆ Monitor Fe and Mn in PTF and ROF
 - ◆ In PTF, want to see:
 - Dissolved Fe << Total Iron
 - Dissolved Mn ≈ Total Mn
 - ◆ In ROF, want to see:
 - Total Fe ≈ 0
 - Particulate Mn ≈ 0

Phase II Aeration + GMF + RO



Phase II Aeration + GMF + RO



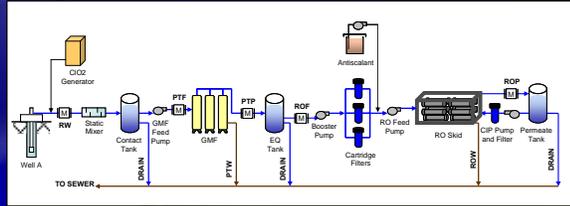
Phase III Chlorine Dioxide (ClO₂) + GMF + RO

- ◆ Purpose:
 - ◆ Determine if chlorine dioxide will oxidize both iron and manganese to allow iron and manganese oxides to be effectively removed through GMF
- ◆ Note:
 - ◆ ClO₂ strong oxidant that quickly oxidizes both iron and manganese so that they could be removed by the GMF
 - ◆ ClO₂ will be generated onsite and needs to be as pure as possible. This method may be the most costly

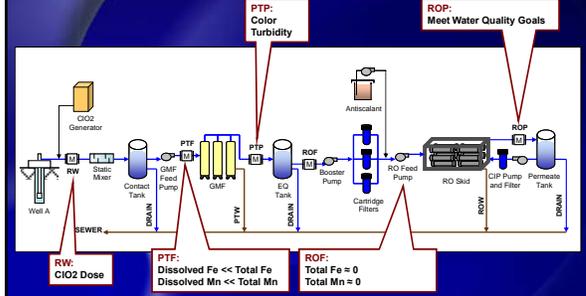
Phase III Chlorine Dioxide (ClO₂) + GMF + RO

- ◆ Feed ClO₂ in RW to oxidize Fe and Mn
- ◆ Remove iron and manganese oxides using GMF
- ◆ Check Color and Turbidity in PTF for breakthrough
- ◆ Monitor Fe and Mn in PTF and ROF
 - ◆ In PTF, want to see:
 - Dissolved Fe << Total Iron
 - Dissolved Mn << Total Mn
 - ◆ In ROF, want to see:
 - Total Fe ≈ 0
 - Total Mn ≈ 0

Phase III Chlorine dioxide (ClO₂) + GMF + RO



Phase III Chlorine Dioxide (ClO₂) + GMF + RO



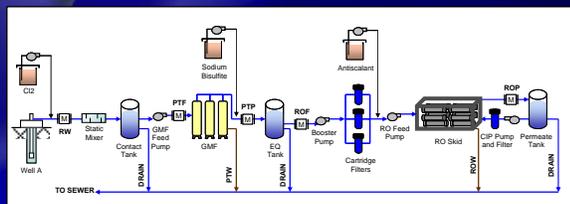
Phase IV Cl₂ + Catalyzing Media Filters + RO

- ◆ Purpose:
 - ◆ Evaluate chlorine oxidation of both iron and manganese using a catalytic media such as pure or partially pure manganese dioxide (pyrolucite)
- ◆ Note:
 - ◆ Sodium thiosulfate will be used ahead of RO to prevent damages to the elements by residual chlorine
 - ◆ Process most commonly used to remove iron and manganese from groundwater

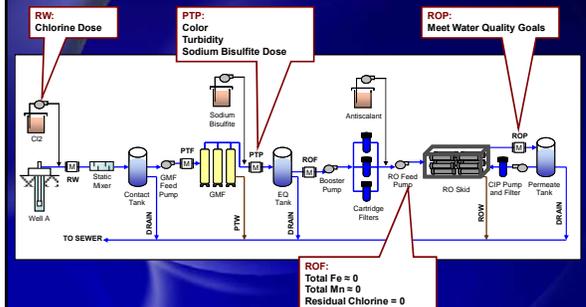
Phase IV Cl₂ + Catalyzing Media Filters + RO

- ◆ Feed chlorine in RW to oxidize Fe
- ◆ Pyrolucite to catalyze Mn oxidation and remove iron and manganese oxides
- ◆ Check Color and Turbidity in PTP for breakthrough
- ◆ Monitor Fe, Mn, and Residual Chlorine in ROF. Want to see:
 - Total Fe ≈ 0
 - Total Mn ≈ 0
 - Residual Chlorine = 0

Phase IV Cl₂ + Catalyzing Media Filters + RO



Phase IV Cl₂ + Catalyzing Media Filters + RO



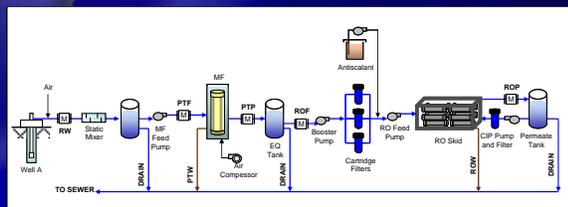
Phase V Aeration + MF + RO

- ◆ Purpose:
 - ◆ Determine if aeration plus MF will effectively remove iron through MF and keep manganese in the reduced state so that it is removed by the RO
- ◆ Note:
 - ◆ Similar to Phase II testing
 - ◆ MF should remove more iron oxide than GMF due to smaller pore size
 - ◆ Process optimization is required to determine which of MF and GMF will be more cost effective in a full-scale facility

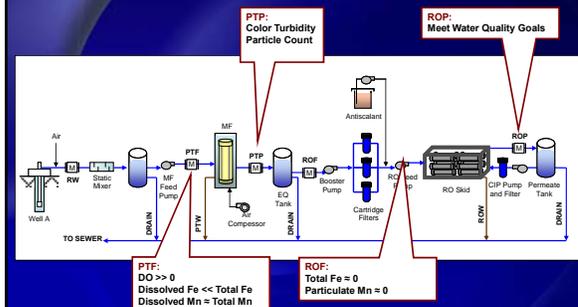
Phase V Aeration + MF + RO

- ◆ Introduce air into RW using eductor to oxidize Fe while keeping Mn in reduced state
- ◆ Remove all iron oxides using GMF
- ◆ Check Color, Turbidity, and Particle Count in PTF for breakthrough
- ◆ Monitor Fe and Mn in PTF and ROF
 - ◆ In PTF, want to see:
 - Dissolved Fe \ll Total Iron
 - Dissolved Mn \approx Total Mn
 - ◆ In ROF, want to see:
 - Total Fe \approx 0
 - Particulate Mn \approx 0

Phase V Aeration + MF + RO



Phase V Aeration + MF + RO



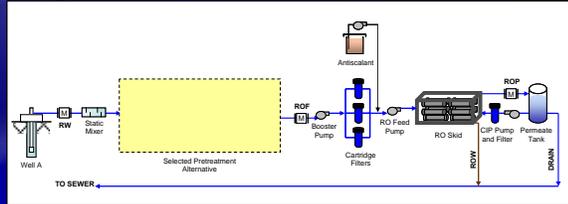
Phase VI RO Optimization w/ Selected Pretreatment

- ◆ Purpose:
 - ◆ Optimize the RO process for recovery, finished water quality and energy usage and achieve the lowest operating costs
- ◆ Notes:
 - ◆ Will use selected pretreatment process and RO membranes from a various list including brackish RO and nanofiltration membranes
 - ◆ Will run two parallel desalination trains

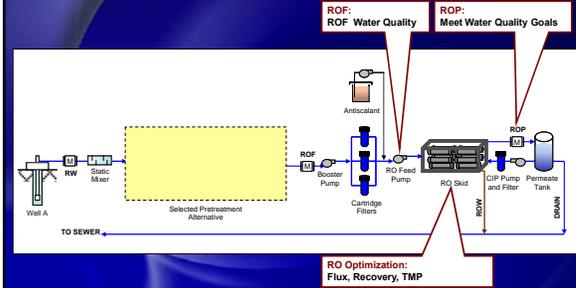
Phase VI RO Optimization w/ Selected Pretreatment

- ◆ Use selected pretreatment alternative
- ◆ Test different membrane types and configuration
- ◆ Monitor:
 - ◆ Flux, recovery, and transmembrane pressure (TMP)
 - ◆ Finished water quality
 - ◆ Energy usage
 - ◆ Operating costs

Phase VI RO Optimization w/ Selected Pretreatment



Phase VI RO Optimization w/ Selected Pretreatment



Equipment Performance Indicators

- ◆ Flow rate and pressure are good indicators of fouling
 - ◆ Differential Pressure
 - GMF
 - Cartridge Filters
 - ◆ Transmembrane Pressure of MF
 - ◆ Feed Pressure of RO
- ◆ Conductivity is a good indicator of RO membrane short-circuit

Water Quality Parameters of Interest

- ◆ Parameters measured 3 to 7 days/week:
 - ◆ Temperature & pH
 - ◆ Conductivity
 - ◆ Dissolved Oxygen (DO)
 - ◆ Redox Potential (ORP)
 - ◆ Total Iron & Dissolved Iron
 - ◆ Total Manganese
 - ◆ UV254
 - ◆ Apparent Color
 - ◆ Turbidity

Weekly Sampling

- ◆ Silt Density Index (SDI)
- ◆ Alkalinity, Total Hardness, TSS, TDS
- ◆ Metals
 - ◆ Fe, Mn, Ca, Mg, Na, B, V
- ◆ Sulfate
- ◆ Silica
- ◆ Chloride
- ◆ Ammonia Nitrogen
- ◆ TOC
- ◆ Gross Alpha

Monthly Sampling

- ◆ Barium
- ◆ Strontium

Emerging Contaminants

- ◆ Detection of new contaminants at very low levels now possible
- ◆ State of California is a leader in the domain of emerging contaminants regulations
- ◆ Evaluated data from wells A and B to identify which emerging contaminants will need to be monitored

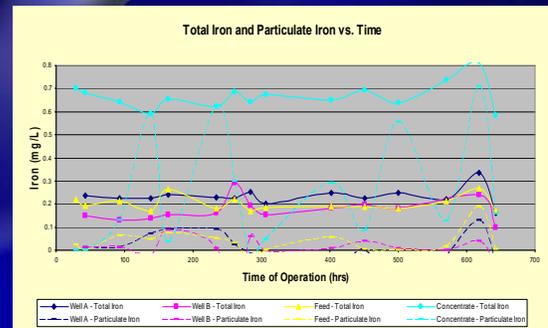
Emerging Contaminants

- ◆ 33 unregulated chemicals have notification levels (NLs) and/or monitoring requirements established by the California Department of Public Health (CDPH)
- ◆ 10 chemicals appear on List 1 (Assessment Monitoring) for EPA's Unregulated Contaminant Monitoring Rule 2 (UCMR 2) and 15 chemicals appear on List 2 (Screening survey) for EPA's UCMR 2
- ◆ Pesticides of relatively high use in Ventura County

Emerging Contaminants Sampling Plan

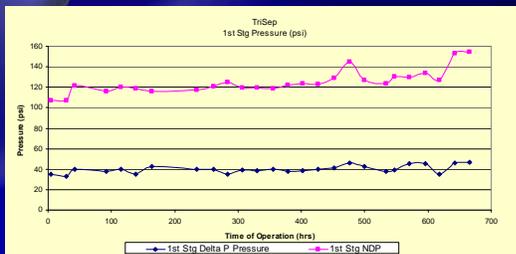
- ◆ Three of CDHS's 33 Unregulated Chemicals
 - ◆ Boron, Vanadium, Hexavalent Chromium
- ◆ Three Pesticides commonly used in Ventura County
 - ◆ Chloropicrin
 - ◆ Methyl Bromide (bromomethane)
 - ◆ 1,3-Dichloropropene (cis and trans)
- ◆ One of EPA's UCMR2 Chemicals
 - ◆ N-nitroso-dimethylamine (NDMA)

Phase I Testing Preliminary Results



Phase I Testing Preliminary Results

- ◆ Pressure
 - First stage



Phase I Testing Preliminary Results

- Second stage



Topics Covered

- ◆ Background
- ◆ Project Objectives
- ◆ Technology Overview
- ◆ Pilot Study Description and Testing Protocol
- ◆ Phase I Testing Preliminary Results

City of Camarillo Brackish Water Desalination Pilot Study

Q & A

Operator Training Workshop
October 9, 2007

CDM

Appendix C - Final Emerging Contaminant Evaluation

C.1 Pre-existing monitoring data on unregulated chemicals

The following tables present the pre-existing monitoring data for unregulated chemicals¹ in the City of Camarillo's Wells A1 and B2, summarized from data provided by the City of Camarillo (Smith, 2007b). The raw data were provided by CDPH (Mike Ali, CDHS-DWFOB-Santa Barbara) to the City of Camarillo.

The data are for Public Water System (PWS) Number 5610019, Camarillo Water Division. Data are provided for the following groundwater sources:

Source No. 005 with Name: WELL A 1 - STANDBY

Source No. 007 with Name: WELL B-2

C.1.1 Available Data for Chemicals with CDPH Notification Levels (NLs)

Table C.1 – Boron Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
Boron	5/29/2003	0.48	1	0.1	mg/l
Boron	5/13/2004	0.54	1	0.1	mg/l
Boron	1/31/2007	0.65	1	0.1	mg/l
Well B2					
Boron	1/20/1998	< DL	1	0.1	mg/l
Boron	4/11/2001	0.36	1	0.1	mg/l
Boron	7/11/2001	0.32	1	0.1	mg/l
Boron	10/3/2001	0.37	1	0.1	mg/l
Boron	1/24/2002	0.27	1	0.1	mg/l
Boron	7/24/2002	0.38	1	0.1	mg/l
Boron	1/21/2004	0.5	1	0.1	mg/l
Boron	4/7/2004	0.43	1	0.1	mg/l
Boron	5/13/2004	0.46	1	0.1	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

> DLR

¹ Unregulated chemicals with notification levels and/or unregulated chemicals requiring monitoring under Title 22 CCR and available data for chemicals listed in the EPA UCMR 2

Table C.2 - n-Butylbenzene Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
n-Butylbenzene	5/23/1994	< DL	0.26	0.0005	mg/l
n-Butylbenzene	5/16/1996	< DL	0.26	0.0005	mg/l
Well B2					
n-Butylbenzene	4/27/1994	< DL	0.26	0.0005	mg/l
n-Butylbenzene	5/15/1996	< DL	0.26	0.0005	mg/l
n-Butylbenzene	5/11/1999	< DL	0.26	0.0005	mg/l
n-Butylbenzene	5/22/2002	< DL	0.26	0.0005	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.3 - sec-Butylbenzene Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
sec-Butylbenzene	5/23/1994	< DL	0.26	0.0005	mg/l
sec-Butylbenzene	5/16/1996	< DL	0.26	0.0005	mg/l
Well B2					
sec-Butylbenzene	4/27/1994	< DL	0.26	0.0005	mg/l
sec-Butylbenzene	5/15/1996	< DL	0.26	0.0005	mg/l
sec-Butylbenzene	5/11/1999	< DL	0.26	0.0005	mg/l
sec-Butylbenzene	5/22/2002	< DL	0.26	0.0005	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.4 - tert-Butylbenzene Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
tert-Butylbenzene	5/23/1994	< DL	0.26	0.0005	mg/l
tert-Butylbenzene	5/16/1996	< DL	0.26	0.0005	mg/l
Well B2					
tert-Butylbenzene	4/27/1994	< DL	0.26	0.0005	mg/l
tert-Butylbenzene	5/15/1996	< DL	0.26	0.0005	mg/l
tert-Butylbenzene	5/11/1999	< DL	0.26	0.0005	mg/l
tert-Butylbenzene	5/22/2002	< DL	0.26	0.0005	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.5 - 2-Chlorotoluene Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
2-Chlorotoluene	5/23/1994	< DL	0.14	0.0005	mg/l
2-Chlorotoluene	5/16/1996	< DL	0.14	0.0005	mg/l
Well B2					
2-Chlorotoluene	4/27/1994	< DL	0.14	0.0005	mg/l
2-Chlorotoluene	5/15/1996	< DL	0.14	0.0005	mg/l
2-Chlorotoluene	5/11/1999	< DL	0.14	0.0005	mg/l
2-Chlorotoluene	5/22/2002	< DL	0.14	0.0005	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.6 - 4-Chlorotoluene Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
4-Chlorotoluene	5/23/1994	< DL	0.14	0.0005	mg/l
4-Chlorotoluene	5/16/1996	< DL	0.14	0.0005	mg/l
Well B2					
4-Chlorotoluene	4/27/1994	< DL	0.14	0.0005	mg/l
4-Chlorotoluene	5/15/1996	< DL	0.14	0.0005	mg/l
4-Chlorotoluene	5/11/1999	< DL	0.14	0.0005	mg/l
4-Chlorotoluene	5/22/2002	< DL	0.14	0.0005	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.7 - Dichlorodifluoromethane (Freon 12) Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
Dichlorodifluoromethane (Freon 12)	5/23/1994	< DL	1	0.001	mg/l
Dichlorodifluoromethane (Freon 12)	5/16/1996	< DL	1	0.001	mg/l
Well B2					
Dichlorodifluoromethane (Freon 12)	4/27/1994	< DL	1	0.001	mg/l
Dichlorodifluoromethane (Freon 12)	5/15/1996	< DL	1	0.001	mg/l
Dichlorodifluoromethane (Freon 12)	5/11/1999	< DL	1	0.001	mg/l
Dichlorodifluoromethane (Freon 12)	1/24/2002	< DL	1	0.0005	mg/l
Dichlorodifluoromethane (Freon 12)	5/22/2002	< DL	1	0.0005	mg/l
Dichlorodifluoromethane (Freon 12)	7/24/2002	< DL	1	0.0005	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.8 - Isopropylbenzene Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
Isopropylbenzene	5/23/1994	< DL	0.77	0.0005	mg/l
Isopropylbenzene	5/16/1996	< DL	0.77	0.0005	mg/l
Well B2					
Isopropylbenzene	4/27/1994	< DL	0.77	0.0005	mg/l
Isopropylbenzene	5/15/1996	< DL	0.77	0.0005	mg/l
Isopropylbenzene	5/11/1999	< DL	0.77	0.0005	mg/l
Isopropylbenzene	5/22/2002	< DL	0.77	0.0005	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.9 - Manganese Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
Manganese	1/14/1994	0.064	0.5	0.01	mg/l
Manganese	5/23/1994	0.09	0.5	0.01	mg/l
Manganese	5/23/1994	0.095	0.5	0.01	mg/l
Manganese	1/26/1995	0.121	0.5	0.01	mg/l
Manganese	4/3/1995	0.122	0.5	0.01	mg/l
Manganese	7/19/1995	0.178	0.5	0.01	mg/l
Manganese	10/3/1995	0.213	0.5	0.01	mg/l
Manganese	1/9/1996	0.245	0.5	0.01	mg/l
Manganese	7/15/1996	0.22	0.5	0.01	mg/l
Manganese	10/9/1996	0.205	0.5	0.01	mg/l
Manganese	1/29/1997	0.189	0.5	0.01	mg/l
Manganese	4/29/1997	0.163	0.5	0.01	mg/l
Manganese	7/16/1997	0.18	0.5	0.01	mg/l
Manganese	10/22/1997	0.186	0.5	0.01	mg/l
Manganese	1/14/1998	<0.03	0.5	0.01	mg/l
Manganese	4/22/1998	0.197	0.5	0.01	mg/l
Manganese	7/16/1998	0.162	0.5	0.01	mg/l
Manganese	8/11/1999	0.15	0.5	0.01	mg/l
Manganese	9/8/1999	0.179	0.5	0.01	mg/l
Manganese	5/29/2003	0.17	0.5	0.01	mg/l
Manganese	5/13/2004	0.24	0.5	0.01	mg/l
Manganese	1/31/2007	0.19	0.5	0.01	mg/l

Table C.9 – Manganese Data (continued)

Chemical	Date	Result	NL*	DLR**	Unit
Well B2					
Manganese	3/3/1994	0.059	0.5	0.01	mg/l
Manganese	4/20/1994	0.063	0.5	0.01	mg/l
Manganese	4/27/1994	0.06	0.5	0.01	mg/l
Manganese	1/1/1995	0.059	0.5	0.01	mg/l
Manganese	4/4/1995	<0.03	0.5	0.01	mg/l
Manganese	7/18/1995	0.06	0.5	0.01	mg/l
Manganese	10/4/1995	0.079	0.5	0.01	mg/l
Manganese	1/9/1996	0.082	0.5	0.01	mg/l
Manganese	7/15/1996	0.065	0.5	0.01	mg/l
Manganese	10/9/1996	0.106	0.5	0.01	mg/l
Manganese	1/17/1997	0.093	0.5	0.01	mg/l
Manganese	4/16/1997	0.065	0.5	0.01	mg/l
Manganese	7/15/1997	0.07	0.5	0.01	mg/l
Manganese	10/14/1997	0.08	0.5	0.01	mg/l
Manganese	1/13/1998	0.08	0.5	0.01	mg/l
Manganese	1/20/1998	0.08	0.5	0.01	mg/l
Manganese	4/15/1998	0.072	0.5	0.01	mg/l
Manganese	7/8/1998	0.0733	0.5	0.01	mg/l
Manganese	8/12/1998	0.0472	0.5	0.01	mg/l
Manganese	9/9/1998	0.08	0.5	0.01	mg/l
Manganese	10/7/1998	0.108	0.5	0.02	mg/l
Manganese	12/9/1998	0.086	0.5	0.02	mg/l
Manganese	1/13/1999	0.08	0.5	0.02	mg/l
Manganese	2/10/1999	0.038	0.5	0.02	mg/l
Manganese	3/2/1999	0.076	0.5	0.02	mg/l
Manganese	4/14/1999	0.086	0.5	0.02	mg/l
Manganese	5/12/1999	0.079	0.5	0.02	mg/l
Manganese	6/9/1999	0.073	0.5	0.02	mg/l
Manganese	7/7/1999	0.282	0.5	0.02	mg/l
Manganese	12/8/1999	0.1	0.5	0.02	mg/l
Manganese	1/12/2000	0.084	0.5	0.02	mg/l
Manganese	2/9/2000	0.096	0.5	0.02	mg/l
Manganese	3/8/2000	0.108	0.5	0.02	mg/l
Manganese	4/13/2000	0.074	0.5	0.02	mg/l
Manganese	6/14/2000	0.0883	0.5	0.02	mg/l
Manganese	7/5/2000	0.079	0.5	0.02	mg/l
Manganese	9/13/2000	0.082	0.5	0.02	mg/l
Manganese	10/11/2000	0.096	0.5	0.02	mg/l
Manganese	12/6/2000	0.101	0.5	0.02	mg/l
Manganese	4/11/2001	0.11	0.5	0.02	mg/l
Manganese	5/9/2001	0.08	0.5	0.02	mg/l
Manganese	6/7/2001	0.082	0.5	0.02	mg/l
Manganese	7/11/2001	0.15	0.5	0.02	mg/l

Table C.9 – Manganese Data (continued)

Chemical	Date	Result	NL*	DLR**	Unit
Well B2					
Manganese	8/8/2001	0.1	0.5	0.02	mg/l
Manganese	9/5/2001	0.098	0.5	0.02	mg/l
Manganese	10/3/2001	0.089	0.5	0.02	mg/l
Manganese	11/7/2001	0.13	0.5	0.02	mg/l
Manganese	12/5/2001	0.12	0.5	0.02	mg/l
Manganese	1/7/2002	0.14	0.5	0.02	mg/l
Manganese	3/20/2002	0.069	0.5	0.02	mg/l
Manganese	4/3/2002	0.1	0.5	0.02	mg/l
Manganese	4/24/2002	0.1	0.5	0.02	mg/l
Manganese	5/1/2002	0.12	0.5	0.02	mg/l
Manganese	6/5/2002	0.11	0.5	0.02	mg/l
Manganese	7/3/2002	0.12	0.5	0.02	mg/l
Manganese	8/7/2002	0.11	0.5	0.02	mg/l
Manganese	9/4/2002	0.13	0.5	0.02	mg/l
Manganese	10/2/2002	0.11	0.5	0.02	mg/l
Manganese	11/6/2002	0.14	0.5	0.02	mg/l
Manganese	12/4/2002	0.1	0.5	0.02	mg/l
Manganese	2/5/2003	0.12	0.5	0.02	mg/l
Manganese	3/4/2003	0.18	0.5	0.02	mg/l
Manganese	4/2/2003	0.17	0.5	0.02	mg/l
Manganese	5/7/2003	0.15	0.5	0.02	mg/l
Manganese	6/4/2003	0.13	0.5	0.02	mg/l
Manganese	7/2/2003	0.13	0.5	0.02	mg/l
Manganese	8/7/2003	0.13	0.5	0.02	mg/l
Manganese	9/3/2003	0.12	0.5	0.02	mg/l
Manganese	10/1/2003	0.1	0.5	0.02	mg/l
Manganese	11/5/2003	0.16	0.5	0.02	mg/l
Manganese	12/2/2003	0.16	0.5	0.02	mg/l
Manganese	1/6/2004	0.18	0.5	0.02	mg/l
Manganese	1/21/2004	0.17	0.5	0.02	mg/l
Manganese	2/3/2004	0.16	0.5	0.02	mg/l
Manganese	3/2/2004	0.14	0.5	0.02	mg/l
Manganese	4/7/2004	0.15	0.5	0.02	mg/l
Manganese	4/7/2004	0.13	0.5	0.02	mg/l
Manganese	5/5/2004	0.18	0.5	0.02	mg/l
Manganese	5/13/2004	0.2	0.5	0.02	mg/l
Manganese	6/2/2004	0.16	0.5	0.02	mg/l
Manganese	7/14/2004	0.17	0.5	0.02	mg/l
Manganese	7/15/2004	0.15	0.5	0.02	mg/l
Manganese	8/4/2004	0.16	0.5	0.02	mg/l
Manganese	9/15/2004	0.14	0.5	0.02	mg/l
Manganese	10/7/2004	0.15	0.5	0.02	mg/l
Manganese	11/3/2004	0.14	0.5	0.02	mg/l

Table C.9 – Manganese Data (continued)

Chemical	Date	Result	NL*	DLR**	Unit
Well B2					
Manganese	1/5/2005	0.14	0.5	0.02	mg/l
Manganese	2/1/2005	0.15	0.5	0.02	mg/l
Manganese	3/10/2005	0.15	0.5	0.02	mg/l
Manganese	8/17/2005	0.15	0.5	0.02	mg/l
Manganese	9/7/2005	0.15	0.5	0.02	mg/l
Manganese	10/10/2005	0.14	0.5	0.02	mg/l
Manganese	11/9/2005	0.16	0.5	0.02	mg/l
Manganese	12/6/2005	0.15	0.5	0.02	mg/l
Manganese	1/9/2006	0.15	0.5	0.02	mg/l
Manganese	2/6/2006	0.16	0.5	0.02	mg/l
Manganese	3/9/2006	0.15	0.5	0.02	mg/l
Manganese	4/3/2006	0.15	0.5	0.02	mg/l
Manganese	5/8/2006	0.16	0.5	0.02	mg/l
Manganese	6/6/2006	0.17	0.5	0.02	mg/l
Manganese	7/12/2006	0.15	0.5	0.02	mg/l
Manganese	10/10/2006	0.16	0.5	0.02	mg/l
Manganese	11/8/2006	0.15	0.5	0.02	mg/l
Manganese	12/4/2006	0.14	0.5	0.02	mg/l
Manganese	2/13/2007	0.16	0.5	0.02	mg/l
Manganese	3/12/2007	0.15	0.5	0.02	mg/l
Manganese	4/3/2007	0.16	0.5	0.02	mg/l

Table C.10 - Methyl isobutyl ketone (MIBK) (4-Methyl-2-pentanone) Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
Methyl isobutyl ketone (MIBK) (4-Methyl-2-pentanone)	5/23/1994	< DL	0.12	0.005	mg/l
Well B2					
Methyl isobutyl ketone (MIBK) (4-Methyl-2-pentanone)	4/27/1994	<DL	0.12	0.005	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.11 - Naphthalene Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
Naphthalene	5/23/1994	< DL	0.017	0.0005	mg/l
Naphthalene	5/16/1996	< DL	0.017	0.0005	mg/l
Well B2					
Naphthalene	4/27/1994	< DL	0.017	0.0005	mg/l
Naphthalene	5/15/1996	< DL	0.017	0.0005	mg/l
Naphthalene	5/11/1999	< DL	0.017	0.0005	mg/l
Naphthalene	5/22/2002	< DL	0.017	0.0005	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.12 - Perchlorate Data

Chemical	Date	Result	NL*	DLR**	Unit
Well B2					
Perchlorate	1/24/2002	< DL	0.006	0.004	mg/l
Perchlorate	7/24/2002	< DL	0.006	0.004	mg/l
Perchlorate	12/11/2002	< DL	0.006	0.004	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.13 - Propachlor Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
Propachlor	6/7/1994	< DL	0.09	0.0005	mg/l
Well B2					
Propachlor	4/27/1994	< DL	0.09	0.0005	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.14 - n-Propylbenzene Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
n-Propylbenzene	5/23/1994	< DL	0.26	0.0005	mg/l
n-Propylbenzene	5/16/1996	< DL	0.26	0.0005	mg/l
Well B2					
n-Propylbenzene	4/27/1994	< DL	0.26	0.0005	mg/l
n-Propylbenzene	5/15/1996	< DL	0.26	0.0005	mg/l
n-Propylbenzene	5/11/1999	< DL	0.26	0.0005	mg/l
n-Propylbenzene	5/22/2002	< DL	0.26	0.0005	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.15 - 1,2,3-Trichloropropane (1,2,3-TCP) Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
1,2,3-Trichloropropane (1,2,3-TCP)*	5/23/1994	<NL	5E-06	5.E-04	mg/l
1,2,3-Trichloropropane (1,2,3-TCP)*	5/16/1996	<NL	5E-06	5.E-04	mg/l
Well B2					
1,2,3-Trichloropropane (1,2,3-TCP)*	4/27/1994	<NL	5E-06	5.E-04	mg/l
1,2,3-Trichloropropane (1,2,3-TCP)*	5/15/1996	<NL	5E-06	5.E-04	mg/l
1,2,3-Trichloropropane (1,2,3-TCP)*	5/11/1999	<NL	5E-06	5.E-04	mg/l
1,2,3-Trichloropropane (1,2,3-TCP)*	1/24/2002	<NL	5E-06	5.E-04	mg/l
1,2,3-Trichloropropane (1,2,3-TCP)*	7/24/2002	<NL	5E-06	5E-06	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.16 - 1,2,4-Trimethylbenzene Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
1,2,4-Trimethylbenzene	5/23/1994	< DL	0.33	0.0005	mg/l
1,2,4-Trimethylbenzene	5/16/1996	< DL	0.33	0.0005	mg/l
Well B2					
1,2,4-Trimethylbenzene	4/27/1994	< DL	0.33	0.0005	mg/l
1,2,4-Trimethylbenzene	5/15/1996	< DL	0.33	0.0005	mg/l
1,2,4-Trimethylbenzene	5/11/1999	< DL	0.33	0.0005	mg/l
1,2,4-Trimethylbenzene	5/22/2002	< DL	0.33	0.0005	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.17 - 1,3,5-Trimethylbenzene Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
1,3,5-Trimethylbenzene	5/23/1994	< DL	0.33	0.0005	mg/l
1,3,5-Trimethylbenzene	5/16/1996	< DL	0.33	0.0005	mg/l
Well B2					
1,3,5-Trimethylbenzene	4/27/1994	< DL	0.33	0.0005	mg/l
1,3,5-Trimethylbenzene	5/15/1996	< DL	0.33	0.0005	mg/l
1,3,5-Trimethylbenzene	5/11/1999	< DL	0.33	0.0005	mg/l
1,3,5-Trimethylbenzene	5/22/2002	< DL	0.33	0.0005	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.18 - Vanadium Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
Vanadium	5/29/2003	<DL	0.05	0.003	mg/l
Vanadium	1/31/2007	< 0.002	0.05	0.003	mg/l
Well B2					
Vanadium	4/11/2001	<DL	0.05	0.003	mg/l
Vanadium	1/24/2002	<DL	0.05	0.003	mg/l
Vanadium	7/24/2002	<DL	0.05	0.003	mg/l
Vanadium	1/21/2004	0.02	0.05	0.003	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting



> DLR

C.1.2 Unregulated Chemicals Requiring Monitoring in Title 22 CCR § 64450

For the following unregulated chemicals requiring monitoring in Title 22 CCR, available data is presented above: boron; dichlorodifluoromethane (Freon 12); perchlorate; 1,2,3-trichloropropane (1,2,3-TCP); vanadium. Available data for other chemicals in this category is shown below.

Table C.19 – Chromium (VI) Data

Chemical	Date	Result	NL*	DLR**	Unit
Well B2					
Chromium (VI)*	1/24/2002	< DL	Not Applicable	----	mg/l
Chromium (VI)*	7/25/2002	< DL	Not Applicable	----	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.20 – Ethyl tertiary butyl ether Data

Chemical	Date	Result	NL*	DLR**	Unit
Well B2					
Ethyl tertiary butyl ether	5/11/1999	< DL	Not Applicable	0.003	mg/l
Ethyl tertiary butyl ether	5/22/2002	< DL	Not Applicable	0.003	mg/l
Ethyl tertiary butyl ether	7/24/2002	< DL	Not Applicable	0.003	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.21 – Tertiary amyl methyl ether Data

Chemical	Date	Result	NL*	DLR**	Unit
Well B2					
Tertiary amyl methyl ether*	5/11/1999	< DL	Not Applicable	0.003	mg/l
Tertiary amyl methyl ether*	5/22/2002	< DL	Not Applicable	0.003	mg/l
Tertiary amyl methyl ether*	7/24/2002	< DL	Not Applicable	0.003	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

C.1.3 Available Data for Unregulated Contaminant Monitoring Rule 2 (UCMR2) Chemicals

Table C.22 - Dimethoate Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
Dimethoate	6/7/1994	< DL	Not Applicable	0.01	mg/l
Well B2					
Dimethoate	4/27/1994	< DL	Not Applicable	0.01	mg/l
Dimethoate	5/25/2000	< DL	Not Applicable	0.01	mg/l
Dimethoate	4/24/2003	< DL	Not Applicable	0.01	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.23 - Alachlor Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
Alachlor	6/7/1994	< DL	No Applicable	0.001	mg/l
Well B2					
Alachlor	4/27/1994	< DL	No Applicable	0.001	mg/l
Alachlor	5/25/2000	< DL	No Applicable	0.001	mg/l
Alachlor	4/24/2003	< DL	No Applicable	0.001	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.24 - Metolachlor Data

Chemical	Date	Result	NL*	DLR**	Unit
Well A 1-Standby					
Metolachlor	6/7/1994	<DL	Not Applicable	----	mg/l
Well B2					
Metolachlor	4/27/1994	<DL	Not Applicable	----	mg/l
Metolachlor	5/25/2000	<DL	Not Applicable	----	mg/l
Metolachlor	4/24/2003	<DL	Not Applicable	----	mg/l

* NL = CDHS Notification Level

** DLR = Detection Limit for the Purpose of Reporting

Table C.25 Summary of Monitoring Results for Well A1

Chemical	Mean	Standard Deviation	Median	Minimum	Maximum	No. of Observations	Date of First Sample	Date of Most Recent Sample	Units	NL	MRL
Chemicals with Notification Levels (NLs)											
Boron	0.56	0.09	0.54	0.48	0.65	3	5/28/1999	1/30/2003	mg/L	1	0.1
n-Butylbenzene	All measurements < 0.0005 (< MRL)					2	5/22/1990	5/15/1992	mg/L	0.26	0.0005
sec-Butylbenzene	All measurements < 0.0005 (< MRL)					2	5/22/1990	5/15/1992	mg/L	0.26	0.0005
tert-Butylbenzene	All measurements < 0.0005 (< MRL)					2	5/22/1990	5/15/1992	mg/L	0.26	0.0005
2-Chlorotoluene	All measurements < 0.0005 (< MRL)					2	5/22/1990	5/15/1992	mg/L	0.14	0.0005
4-Chlorotoluene	All measurements < 0.0005 (< MRL)					2	5/22/1990	5/15/1992	mg/L	0.14	0.0005
Dichlorodifluoromethane (Freon 12)	All measurements < 0.001 (< MRL)					2	5/22/1990	5/15/1992	mg/L	1	0.001
Isopropylbenzene	All measurements < 0.0005 (< MRL)					2	5/22/1990	5/15/1992	mg/L	0.77	0.0005
Manganese	0.169	0.048	0.179	0.064	0.245	22	1/13/1990	1/30/2003	mg/L	0.5	0.01
Methyl isobutyl ketone (MIBK) (4-Methyl-2-pentanone)	All measurements < 0.005 (< MRL)					1	5/22/1990	NA	mg/L	0.12	0.005
Naphthalene	All measurements < 0.0005 (< MRL)					2	5/22/1990	5/15/1992	mg/L	0.017	0.0005
Propachlor	All measurements < 0.0005 (< MRL)					1	6/6/1990	NA	mg/L	0.09	0.0005
n-Propylbenzene	All measurements < 0.0005 (< MRL)					2	5/22/1990	5/15/1992	mg/L	0.26	0.0005
1,2,3-Trichloropropane (1,2,3-TCP)	All measurements < 0.0005 (< MRL)					2	5/22/1990	5/15/1992	mg/L	0.000005	0.0005
1,2,4-Trimethylbenzene	All measurements < 0.0005 (< MRL)					2	5/22/1990	5/15/1992	mg/L	0.33	0.0005
1,3,5-Trimethylbenzene	All measurements < 0.0005 (< MRL)					3	5/22/1990	5/15/1992	mg/L	0.33	0.0005
Vanadium	All measurements < 0.003 (< MRL)					2	5/29/2003	1/31/2007	mg/L	0.05	0.003
Unregulated Chemicals Requiring Monitoring in Title 22 CCR											
Boron	0.56	0.09	0.54	0.48	0.65	3	5/28/1999	1/30/2003	mg/L	1	0.1
Dichlorodifluoromethane	All measurements < 0.001 (< MRL)					2	5/22/1990	5/15/1992	mg/L	1	0.001
Ethyl-tert-butyl ether	All measurements < 0.003 (< MRL)					3	5/10/1995	7/23/1998	mg/L	NA	0.003
tert-Amyl-methyl ether	All measurements < 0.003 (< MRL)					3	5/10/1995	7/23/1998	mg/L	NA	0.003
1,2,3-Trichloropropane	All measurements < 0.0005 (< MRL)					2	5/22/1990	5/15/1992	mg/L	0.000005	0.0005
Vanadium	All measurements < 0.003 (< MRL)					2	5/29/2003	1/31/2007	mg/L	0.05	0.003
Unregulated Contaminant Monitoring Rule 2 (UCMR 2) Chemicals											
Dimethoate	All measurements < 0.01 (< MRL)					1		6/6/1990	mg/L	NA	0.01
Alachlor	All measurements < 0.001 (< MRL)					1		6/6/1990	mg/L	NA	0.001
Metolachlor	All measurements < MRL					1		6/6/1990	mg/L	NA	-

Table C.26 Summary of Monitoring Results for Well B2

Chemical	Mean	Standard Deviation	Median	Minimum	Maximum	No. of Observations	Date of First Sample	Date of Most Recent Sample	Units	NL	MRL
Chemicals with Notification Levels (NLs)											
Boron	0.39	0.075	0.38	0.27	0.5	9	1/20/1998	5/13/2004	mg/L	1	0.1
n-Butylbenzene	All measurements < 0.0005 (< MRL)					4	4/27/1994	5/22/2002	mg/L	0.26	0.0005
sec-Butylbenzene	All measurements < 0.0005 (< MRL)					4	4/27/1994	5/22/2002	mg/L	0.26	0.0005
tert-Butylbenzene	All measurements < 0.0005 (< MRL)					4	4/27/1994	5/22/2002	mg/L	0.26	0.0005
2-Chlorotoluene	All measurements < 0.0005 (< MRL)					4	4/27/1994	5/22/2002	mg/L	0.14	0.0005
4-Chlorotoluene	All measurements < 0.0005 (< MRL)					4	4/27/1994	5/22/2002	mg/L	0.14	0.0005
Dichlorodifluoromethane (Freon 12)	All measurements < 0.0005-0.001 (< MRL)					6	4/27/1994	7/24/2002	mg/L	1	0.0005 - 0.001
Isopropylbenzene	All measurements < 0.0005 (< MRL)					4	4/27/1994	5/22/2002	mg/L	0.77	0.0005
Manganese	0.12	0.04	0.12	0.038	0.282	107	3/3/1994	4/3/2007	mg/L	0.5	0.01 - 0.02
Methyl isobutyl ketone (MIBK) (4-Methyl-2-pentanone)	All measurements < 0.005 (< MRL)					1		4/27/1994	mg/L	0.12	0.005
Naphthalene	All measurements < 0.0005 (< MRL)					4	4/27/1994	5/22/2002	mg/L	0.017	0.0005
Perchlorate	All measurements < 0.004 (< MRL)					3	1/24/2002	12/11/2002	mg/L	0.006	0.004
Propachlor	All measurements < 0.0005 (< MRL)					1		4/27/1994	mg/L	0.09	0.0005
n-Propylbenzene	All measurements < 0.0005 (< MRL)					4	4/27/1994	5/22/2002	mg/L	0.26	0.0005
1,2,3-Trichloropropane (1,2,3-TCP)	All measurements < 0.000005-0.0005 (< MRL)					5	4/27/1994	7/24/2002	mg/L	0.000005	0.0005 - 0.000005
1,2,4-Trimethylbenzene	All measurements < 0.0005 (< MRL)					4	4/27/1994	5/22/2002	mg/L	0.33	0.0005
1,3,5-Trimethylbenzene	All measurements < 0.0005 (< MRL)					4	4/27/1994	5/22/2002	mg/L	0.33	0.0005
Vanadium	-	-	-	<0.003 (<MRL)	0.02	4	4/11/2001	1/21/2004	mg/L	0.05	0.003
Unregulated Chemicals Requiring Monitoring in Title 22 CCR											
Boron	0.38625	0.074821215	0.375	0.27	0.5	9	35815	38120	mg/L	1	0.1
Chromium VI	All measurements < MRL					2	1/24/2002	7/25/2002	mg/L	NA	-
Dichlorodifluoromethane	All measurements < 0.0005-0.001 (< MRL)					6	34451	37461	mg/L	1	0.0005 - 0.001
Ethyl-tert-butyl ether	All measurements < 0.003 (< MRL)					3	5/11/1999	7/24/2002	mg/L	NA	0.003
Perchlorate	All measurements < 0.004 (< MRL)					3	37280	37601	mg/L	0.006	0.004
tert-Amyl-methyl ether	All measurements < 0.003 (< MRL)					3	5/11/1999	5/11/1999	mg/L	NA	0.003
1,2,3-Trichloropropane	All measurements < 0.000005-0.0005 (< MRL)					5	34451	37461	mg/L	0.000005	0.0005 - 0.000005
Vanadium	-	-	-	<0.003 (<MRL)	0.02	4	36992	38007	mg/L	0.05	0.003
Unregulated Contaminant Monitoring Rule 2 (UCMR 2) Chemicals											
Dimethoate	All measurements < 0.01 (< MRL)					3	4/27/1994	4/24/2003	mg/L	NA	0.01
Alachlor	All measurements < 0.001 (< MRL)					3	4/27/1994	4/24/2003	mg/L	NA	0.001
Metolachlor	All measurements < MRL					3	4/27/1994	4/24/2003		NA	-

C.2 Background Information on CDPH's Drinking Water Source Assessment Program (DWSAP)

C.2.1 Source Water Assessment

The 1996 reauthorization of the federal Safe Drinking Water Act requires states to establish programs to assess source waters and encourages states to establish protection programs (CDHS, 1999). This sub-section discussing Source Water Assessment (SWA) requirements was prepared based on the Drinking Water Source Assessment Program (DWSAP) document (CDHS, 1999).

It should be noted that when a public water system completes an evaluation of a source water through another program that is the "functional equivalent of a portion or all of the drinking water source assessment," the results of the evaluation from the other program may be submitted to meet the source assessment requirements. One example is the Watershed Sanitary Survey (WSS) required for surface water sources (see discussion of the WSS in the next sub-section), which is likely to satisfy most SWA requirements except for the vulnerability assessment.

CDPH procedures for Source Water Assessments include the following:

Location of drinking water source

Delineation of source areas and protection zones for both surface waters and ground waters

Identification of possible contaminating activities (PCAs)

Determination of PCAs to which the source water is most vulnerable

Assessments of new drinking water sources by public water systems

These CDPH procedures will be discussed in more detail below.

C.2.2 Location of drinking water source

The location of ground water sources (wells) and surface water intakes (latitude and longitude) will be determined by CDPH using GPS. The CWD wells A1 and B2 represent groundwater that has NOT been classified as groundwater under the direct influence of surface water.

C.2.3 Delineation of source areas and protection zones for ground waters

For ground waters, CDPH will delineate as the source area the recharge area and protection zones.

The CDPH assumes ground water sources are from two aquifer types: porous media and fractured rock. The recharge area should be identified as much as possible based on the topography, hydrogeology, and other information for the area. For the SWA under the DWSAP, source areas to be assessed for ground water include a group of protection zones “at the land surface adjacent to and surrounding the well.” There are several methods that CDPH recommends for defining the zones, based on a primary criterion of time-of-travel (time for ground water to travel from a location in an aquifer to the well). The methods include arbitrary fixed radius (not allowed for community water systems), calculated fixed radius, modified calculated fixed radius, estimation of the direction of ground water flow, analytical methods, detailed hydrogeologic mapping, and numeric flow/transport models. CDPH will typically use the simpler approach, such as the calculated fixed radius method, to delineate the source area. At the same time, CDPH recognizes the value of more complex methods and is open to application of more complex methods by a water system if sufficient information is available to use them.

All ground water sources should have zones defined and CDPH recommends the following approach of four zones plus an optional fifth zone: Well Site Control Zone (wellhead), Zone A - Microbial/Direct Chemical Contamination Zone (defined by surface area overlying aquifer contributing water to well within a two-year travel time); Zone B5 - Chemical Contamination Zone (area between two- and five-year travel time); Zone B10 - Chemical Contamination Zone (area between five- and ten-year travel time); Optional Buffer Zone (for added protection of drinking water sources). The two-year time-of-travel for Zone A is based on EPA’s proposed Groundwater Rule (discussed in a later sub-section) in recognition of existing research showing bacteria and viruses survive less than two years in ground water and soil. Zones B5 and B10 are intended to prevent chemical contamination, focusing on contamination that could exist near the well but farther away than Zone A. CDPH recommends the following minimum radii for zones A, B5, and B10:

Table C.27 - CDPH Recommended Minimum Radius Based on Zone and Type of Aquifer

Zone	Porous Media	Fractured Rock
Zone A	600 ft	900 ft
Zone B5	1,000 ft	1,500 ft
Zone B10	1,500 ft	2,250 ft

C.2.4 Identification of possible contaminating activities (PCAs)

A possible contaminating activity (PCA) is a potential origin of contamination in source areas and protection zones. If any of the contaminants of concern are associated with an activity, then the activity needs to be included in the inventory of PCAs required in a SWA:

Microorganisms of drinking water importance (fecal coliform bacteria, E. coli, viruses, Giardia lamblia, Cryptosporidium)

Chemicals for which MCLs or California drinking water notification levels have been established and unregulated chemicals in drinking water that require monitoring – See section below on *MCLs and Notification Levels* for the list.

Turbidity

Total Organic Carbon (TOC)

The PCA inventory focuses on determining if a type of activity exists in a source area or protection zone. The exact location and number of sites are not needed, nor is the specific identification of a PCA in terms of name and address. The steps in a PCA inventory are listed below.

- a. Develop initial list of Types of PCAs of Concern that May Exist within or Near Source Area or Protection Zone. Assemble all resources that may help locate activities.
- b. Prepare a PCA inventory form – activities ranked from very high to low risk for use in vulnerability assessment. Some rankings vary by protection zone. CDPH has developed inventory forms for surface water and ground water sources.
- c. Conduct PCA Inventory
- d. Attach a list of PCAs to Assessment Map

C.2.5 Determination of PCAs to which the source water is most vulnerable

The vulnerability assessment prioritizes the list of PCAs in the PCA inventory by identifying the activities to which the drinking water source is most vulnerable. The steps in a vulnerability assessment are:

- a. Determine the physical barrier effectiveness (PBE), a measure of the ability of the geology, hydraulics, and construction features of well or intake, to prevent contaminant migration to the drinking water source. CDPH provides approaches to determining PBE for surface and ground water sources. The PBE is ranked as either low, moderate, or high.

b. Determination of vulnerability. The PCA inventory and PBE evaluation are used to prioritize the list of PCAs to determine the activities to which the source is most vulnerable based on analysis methods shown in the DWSAP document (CDHS, 1999; see pp. 103-105). The drinking water source is vulnerable to all PCA types above the cutoff. The drinking water source is most vulnerable to PCAs with the highest vulnerability points AND to those types of PCAs associated with a contaminant detected in the drinking water source, irrespective of the amount of vulnerability points. In addition to its role in the SWA, the CDPH will use the vulnerability assessment results to determine if a source is eligible for chemical monitoring relief.

C.3 Information provided by CWD Regarding Vulnerability Assessments of Wells A1 and B2

The following information associated with the source water assessment for wells A1 and B2 were provided by CWD (Smith, 2007a).

C.3.1 Location of drinking water source (Appendix H in DWSAP program document)

Well A1

Public Water System: City of Camarillo

ID No.: 5610019

Name of Source: Well A-1

ID No. of Source: 5610019005

Location Date: 5/30/01

Source Located by: Tom P. Smith

Method of Determining Location:

USGS Quad Map (7.5 minute series, 1:24,000 scale), hand calculated

Location of Well (decimal degrees):

Latitude: 341430.9

Longitude: 1190109.5

Well B2

Public Water System: City of Camarillo

ID No.: 5610019

Name of Source: Well B-2

ID No. of Source: 5610019007

Location Date: 5/30/01

Source Located by: Tom P. Smith

Method of Determining Location:

USGS Quad Map (7.5 minute series, 1:24,000 scale), hand calculated

Location of Well (decimal degrees):

Latitude: 341436.1

Longitude: 1190104..0

C.3.2 Delineation of source areas and protection zones for ground waters (Appendix I in DWSAP program document)

Method Used to Delineate the Zones:

Calculated Fixed Radius (Default)

Well A1

Porous Media Aquifer

Zone A: Radius = 801 ft

Zone B5: Radius = 1267 ft

Zone B10: Radius = 1792 ft

Well B2

Porous Media Aquifer

Zone A: Radius = 1003 ft

Zone B5: Radius = 1586 ft

Zone B10: Radius = 2243 ft

C.3.3 Determination of Physical Barrier Effectiveness (PBE) of Source Water (Appendix J in DWSAP program document)

Well A1

Physical Barrier Effectiveness (PBE) Score Interpretation = High

Well B2

Physical Barrier Effectiveness (PBE) Score Interpretation = High

C.3.4 Possible Contaminating Activity (PCA) Inventory Form (Appendix K in DWSAP program document)

The following PCAs were listed in the inventory form. This list does NOT represent the list of PCAs to which the source was determined vulnerable.

Table C.28 PCA inventory Form for Well A1

Zone	Type of PCA	Zone	Type of PCA
COMMERCIAL/INDUSTRIAL		AGRICULTURAL/RURAL	
A	Sewer collection systems	A	Septic systems - low density (<1/acre)
B5	Sewer collection systems	B5	Septic systems - low density (<1/acre)
B10	Sewer collection systems	B10	Septic systems - low density (<1/acre)
A	Parking lots/malls (>50 spaces)	A	Agricultural Drainage
B5	Parking lots/malls (>50 spaces)	B5	Agricultural Drainage
A	Office buildings/complexes	B10	Agricultural Drainage
B5	Office buildings/complexes	B5	Crops, irrigated (Berries, hops, mint, orchards, sod, greenhouses, vineyards, nurseries, vegetables)
RESIDENTIAL/MUNICIPAL		B10	Crops, irrigated (Berries, hops, mint, orchards, sod, greenhouses, vineyards, nurseries, vegetables)
A	Septic systems - high density (>1/acre)	B5	Fertilizer, Pesticide/Herbicide Application
B5	Septic systems - high density (>1/acre)	B10	Fertilizer, Pesticide/Herbicide Application
B10	Septic systems - high density (>1/acre)	B5	Crops, nonirrigated (e.g., Christmas trees, grains, grass seeds, hay, pasture) (includes drip-irrigated crops)
A	Sewer collection systems	B10	Crops, nonirrigated (e.g., Christmas trees, grains, grass seeds, hay, pasture) (includes drip-irrigated crops)
B5	Sewer collection systems	OTHER ACTIVITIES	
B10	Sewer collection systems	A	NPDES/WDR permitted discharges
A	Housing - high density (>1 house/0.5 acres)	A	Wells - Water supply
B5	Housing - high density (>1 house/0.5 acres)	B5	Wells - Water supply
B10	Housing - high density (>1 house/0.5 acres)	A	Road Right-of-ways (herbicide use areas)
A	Parks	B5	Road Right-of-ways (herbicide use areas)
B5	Parks	B10	Road Right-of-ways (herbicide use areas)
B10	Apartments and condominiums	A	Roads/Streets
B10	Schools	B5	Roads/Streets
		B10	Roads/Streets
		A	Hospitals
		A	Storm Water Detention Facilities
		A	Medical/dental offices/clinics
		B5	Medical/dental offices/clinics
		B5	Veterinary offices/clinics

Table C.29 PCA inventory Form for Well B2

Zone	Type of PCA	Zone	Type of PCA
COMMERCIAL/INDUSTRIAL		AGRICULTURAL/RURAL	
A	Sewer collection systems	A	Septic systems - low density (<1/acre)
B5	Sewer collection systems	B5	Septic systems - low density (<1/acre)
A	Parking Lots/Malls (>50 spaces)	B10	Septic systems - low density (<1/acre)
B5	Parking Lots/Malls (>50 spaces)	A	Agricultural Drainage
A	Office buildings/complexes	B5	Agricultural Drainage
B5	Office buildings/complexes	B10	Agricultural Drainage
RESIDENTIAL/MUNICIPAL		A	Crops, irrigated (Berries, hops, mint, orchards, sod, greenhouses, vineyards, nurseries, vegetables)
A	Septic systems - high density (>1/acre)	B5	Crops, irrigated (Berries, hops, mint, orchards, sod, greenhouses, vineyards, nurseries, vegetables)
B5	Septic systems - high density (>1/acre)	B10	Crops, irrigated (Berries, hops, mint, orchards, sod, greenhouses, vineyards, nurseries, vegetables)
B10	Septic systems - high density (>1/acre)	A	Fertilizer, Pesticide/Herbicide Application
A	Sewer Collection Systems	B5	Fertilizer, Pesticide/Herbicide Application
B5	Sewer Collection Systems	B10	Fertilizer, Pesticide/Herbicide Application
B10	Sewer Collection Systems	OTHER ACTIVITIES	
A	Housing - high density (>1 house/0.5 acres)	A	NPDES/WDR permitted discharges
B5	Housing - high density (>1 house/0.5 acres)	A	Wells - Water supply
B10	Housing - high density (>1 house/0.5 acres)	B5	Wells - Water supply
B5	Parks	A	Road Right-of-ways (herbicide use areas)
B10	Parks	B5	Road Right-of-ways (herbicide use areas)
B5	Apartments and condominium	B10	Road Right-of-ways (herbicide use areas)
B10	Schools	A	Roads/Streets
		B5	Roads/Streets
		B10	Roads/Streets
		A	Hospitals
		A	Storm Water Detention Facilities
		A	Medical/dental offices/clinics
		B5	Medical/dental offices/clinics
		B5	Veterinary offices/clinics

C.3.5 Determination of PCAs to which the source water is most vulnerable (Appendix M in DWSAP program document)

The Vulnerability Ranking was provided for Wells A1 and B2 (Smith, 2007a). A groundwater source is vulnerable to all types of PCAs with a Vulnerability Score greater than or equal to 8. The source is most vulnerable to the types of PCAs with the highest score (CDHS, 1999). The Vulnerability Rankings for Wells A1 and B2 are shown below. The tables show all types of PCAs to which Wells A1 and B2 are vulnerable.

Table C.30 List of the types of PCAs to which Well A1 -Standby is vulnerable

Zone	Type of PCA	PCA Points VH=7 H=5 M=3 L=1	Zone Points A=5 B5=3 B10=1 Unknown=0	PBE Points	Vulnerability Score PCA Points + Zone Points + PBE Points
COMMERCIAL/INDUSTRIAL					
A	Sewer collection systems (H if in Zone A, otherwise L)	5	5	1	11
A	Parking lots/malls (>50 spaces) (M)	3	5	1	9
RESIDENTIAL/MUNICIPAL					
A	Septic systems - high density (>1/acre) (VH if in Zone A, otherwise M)	7	0	1	8
A	Sewer collection systems (H if in Zone A, otherwise L)	5	5	1	11
A	Housing - high density (>1 house/0.5 acres) (M)	3	5	1	9
A	Parks (M)	3	5	1	9
AGRICULTURAL/RURAL					
A	Agricultural Drainage (H in Zone A, otherwise M)	5	5	1	11
OTHER ACTIVITIES					
A	NPDES/WDR permitted discharges (H)	5	5	1	11
A	Wells - Water supply (M)	3	5	1	9
A	Transportation corridors - Road Right-of-ways (herbicide use areas) (M)	3	5	1	9
A	Hospitals (M)	3	5	1	9
A	Storm Water Detention Facilities (M)	3	5	1	9

Table C.31 List of the types of PCAs to which Well B2 is vulnerable

Zone	Type of PCA	PCA Points VH=7 H=5 M=3 L=1	Zone Points A=5 B5=3 B10=1 Unknown=0	PBE Points	Vulnerability Score PCA Points + Zone Points + PBE Points
COMMERCIAL/INDUSTRIAL					
A	Sewer collection systems (H if in Zone A, otherwise L)	5	5	1	11
A	Parking Lots/Malls (>50 spaces) (M)	3	5	1	9
RESIDENTIAL/MUNICIPAL					
A	Septic systems - high density (>1/acre) (VH if in Zone A, otherwise M)	7	0	1	8
A	Sewer Collection Systems (H if in Zone A, otherwise L)	5	5	1	11
A	Housing - high density (>1 house/0.5 acres) (M)	3	5	1	9
AGRICULTURAL/RURAL					
A	Agricultural Drainage (H in Zone A, otherwise M)	5	5	1	11
A	Crops, irrigated (Berries, hops, mint, orchards, sod, greenhouses, vineyards, nurseries, vegetables) (M)	3	5	1	9
A	Fertilizer, Pesticide/Herbicide Application (M)	3	5	1	9
OTHER ACTIVITIES					
A	NPDES/WDR permitted discharges (H)	5	5	1	11
A	Wells - Water supply (M)	3	5	1	9
A	Transportation corridors - Road Right-of-ways (herbicide use areas) (M)	3	5	1	9
A	Hospitals (M)	3	5	1	9
A	Storm Water Detention Facilities (M)	3	5	1	9

C.4 EPA's Contaminant Candidate List (CCL) and Unregulated Contaminant Monitoring Rule (UCMR)

The Safe Drinking Water Act (SDWA) includes a mechanism by which EPA must identify and list unregulated contaminants that may require a National Primary Drinking Water Regulation (NPDWR) in the future. EPA must periodically publish the list, which is called the Contaminant Candidate List (CCL). The EPA must issue "regulatory determinations" that decide whether or not to regulate 5 or more candidates on the list at least every 5 years. The SDWA also requires monitoring of certain unregulated contaminants under the Unregulated Contaminants Monitoring Rule (UCMR), which includes three lists of contaminants:

List 1 – contaminants requiring monitoring for which analytical methods are available;

List 2 – screening survey of contaminants for which methods are just developed;

List 3 – pre-screen testing of contaminants that require research on methods) and must be issued every 5 years.

As shown on Figure C.1, the EPA published the first CCL (CCL1) in March 1998 with 60 contaminants and made regulatory determinations that 9 of the contaminants required no regulatory action in July 2003. In February 2005, EPA published the second CCL (CCL2), which carried over 51 contaminants from CCL1 and regulatory determinations of contaminants on CCL2 were not issued until July 2008. The third CCL (CCL3) was not published until February 2008. The selection of emerging contaminants for this study was completed prior to the most recent CCL updates. In the CCL2 regulatory determinations, the EPA decided not to set a national primary drinking water regulation (NPDWR) for boron, based on limited occurrence in surface and ground water sources (4.3% of ground water sources had >0.7 mg/L). The EPA did suggest that for states with localized occurrence, "State-level guidance (or some other type of action) may be appropriate" (EPA 2008).

UCMR1 includes 34 contaminants on CCL1 and 2 radionuclides that emerged during development of the regulation. UCMR2 includes some contaminants on CCL2 but also includes contaminants that have not been listed on the CCL including flame retardants and explosives on List 1 and nitrosamines on List 2. Emerging contaminants that appear on the UCMR but not on the CCL are likely a long way from being regulated (e.g., NDMA). On the other hand, emerging contaminants that appear on the CCL may be regulated in a shorter time frame.

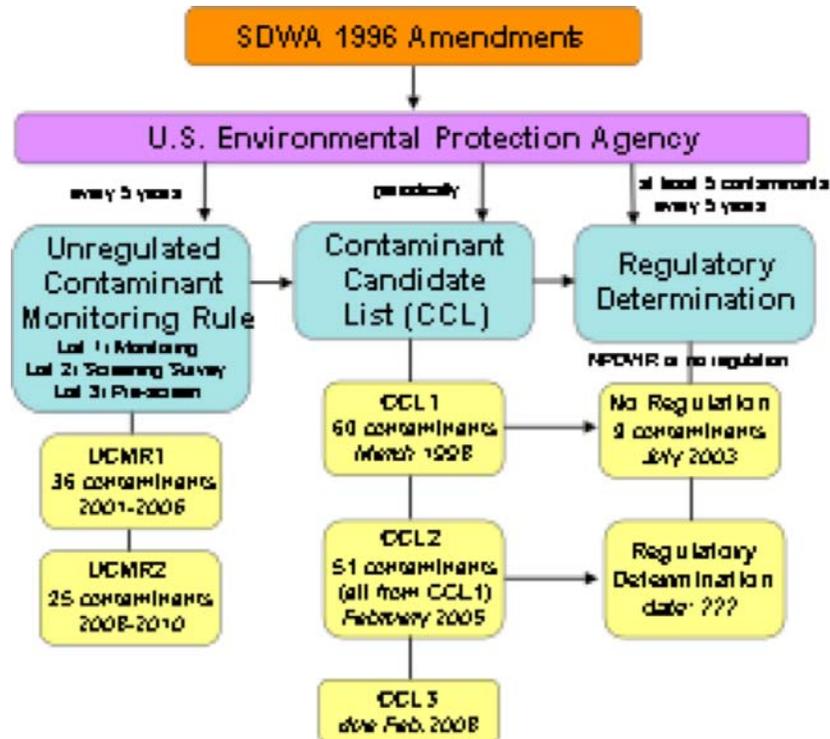


Figure C.1 - Status of Unregulated Contaminants

UCMR1 data was collected nationally over 2001-2006 and is complete. The UCMR2 List 1 and List 2 contaminants are listed in Table D.1.

Table C.32 – UCMR 2 Chemicals

UCMR 2 List 1 (Assessment Monitoring) Chemicals	
Dimethoate	Five Flame Retardants
Terbufos Sulfone	2,2',4,4'-tetrabromodiphenyl ether (BDE-47)
Three Explosives:	2,2',4,4',5-pentabromodiphenyl ether (BDE-99)
1,3-dinitrobenzene	2,2',4,4',5,5'-hexabromobiphenyl (HBB)
2,4,6-Trinitrotoluene (TNT)	2,2',4,4',5,5'-hexabromodiphenyl ether (BDE-153)
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	2,2',4,4',6-pentabromodiphenyl ether (BDE-100)
UCMR 2 List 2 (Screening Survey) Chemicals	
Six Nitrosamines	Three Parent Acetanilides
N-nitroso-diethylamine (NDEA)	Acetochlor
N-nitroso-dimethylamine (NDMA)	Alachlor
N-nitroso-di-n-butylamine (NDBA)	Metolachlor
N-nitroso-di-n-propylamine (NDPA)	Six Acetanilides Degradates
N-nitroso-methylethylamine (NMEA)	Acetochlor ethane sulfonic acid (ESA)
N-nitroso-pyrrolidine (NPYR)	Acetochlor oxanilic acid (OA)
	Alachlor ethane sulfonic acid (ESA)
	Alachlor oxanilic acid (OA)
	Metolachlor ethane sulfonic acid (ESA)
	Metolachlor oxanilic acid (OA)

Table C.33 Regulated Chemical Monitoring Data for Total Chromium

Chemical	Date	Result	MCL*	DLR**	Unit
Well A-1 Standby					
Chromium (total)	1/26/95	< DLR	0.05	0.010	mg/l
Chromium (total)	4/3/95	< DLR	0.05	0.010	mg/l
Chromium (total)	7/19/95	< DLR	0.05	0.010	mg/l
Chromium (total)	10/3/95	< DLR	0.05	0.010	mg/l
Chromium (total)	1/14/98	< DLR	0.05	0.010	mg/l
Chromium (total)	5/29/03	< DLR	0.05	0.010	mg/l
Chromium (total)	5/13/04	< DLR	0.05	0.010	mg/l
Chromium (total)	1/31/07	< DLR	0.05	0.010	mg/l
Well B-2					
Chromium (total)	4/27/94	< DLR	0.05	0.010	mg/l
Chromium (total)	1/1/95	< DLR	0.05	0.010	mg/l
Chromium (total)	4/4/95	< DLR	0.05	0.010	mg/l
Chromium (total)	7/18/95	< DLR	0.05	0.010	mg/l
Chromium (total)	10/4/95	< DLR	0.05	0.010	mg/l
Chromium (total)	1/13/98	< DLR	0.05	0.010	mg/l
Chromium (total)	1/20/98	< DLR	0.05	0.010	mg/l
Chromium (total)	4/11/01	< DLR	0.05	0.010	mg/l
Chromium (total)	1/21/04	< DLR	0.05	0.010	mg/l
Chromium (total)	5/13/04	< DLR	0.05	0.010	mg/l

* MCL = maximum contaminant level (Title 22 CCR § 64431)

** DLR = detection limit for the purpose of reporting (Title 22 CCR § 64432)

Table C.34 Complete results of emerging contaminant monitoring. Compounds marked in red were recommended for monitoring; all other compounds were measured incidentally using the same method at no additional cost.

(Table continues for a total of 5 parts)

Chemical	October 11, 2007 Sampling			December 18, 2007 Sampling		Laboratory Reporting Limit (mg/L)
	Well A Concentration (mg/L)	Well B Concentration (mg/L)	Well B/ Import Water Blend (mg/L)	Well A Concentration (mg/L)	Well B Concentration (mg/L)	
EPA Method 200.8						
Total Boron	0.78	0.66	--	--	--	0.003
Total Vanadium	0.0012	ND	--	--	--	0.0005
EPA Method 218.6						
Hexavalent Chromium (Chromium VI)	ND	ND	--	--	--	0.0003
EPA Method 521						
N-Nitrosodimethylamine (NDMA)	--	--	ND	--	--	0.002
N-Nitrosodiethylamine (NDEA)	--	--	ND	--	--	0.002
N-Nitrosodi-n-butylamine (NDBA)	--	--	ND	--	--	0.002
N-Nitrosodi-n-propylamine (NDPA)	--	--	ND	--	--	0.002
N-Nitrosomethylethylamine (NMEA)	--	--	ND	--	--	0.002
N-Nitrosopyrrolidine (NPYR)	--	--	ND	--	--	0.002
N-Nitrosomorpholine	--	--	ND	--	--	0.002
N-Nitrosopiperidine	--	--	ND	--	--	0.002

Table C.34 Continued (Part 2)

Chemical	October 11, 2007 Sampling			December 18, 2007 Sampling		Laboratory Reporting Limit (mg/L)
	Well A Concentration (mg/L)	Well B Concentration (mg/L)	Well B/ Import Water Blend (mg/L)	Well A Concentration (mg/L)	Well B Concentration (mg/L)	
Chloropicrin	ND	ND	--	--	--	0.0005
1,1,1-trichloro-2-propanone	ND	ND	--	--	--	0.0005
1,1-Dichloro-2-propanone	ND	ND	--	--	--	0.0005
Bromochloroacetonitrile	ND	ND	--	--	--	0.0005
Chloral hydrate	ND	ND	--	--	--	0.0005
Dibromoacetonitrile	ND	ND	--	--	--	0.0005
Dichloroacetonitrile	ND	ND	--	--	--	0.0005
Trichloroacetonitrile	ND	ND	--	--	--	0.0005
EPA 524.2						
Methyl Bromide (Bromomethane)	ND	ND	--	ND	ND	0.0005
1,3 Dichloropropene (total)	ND	ND	--	ND	ND	0.0005
cis-1,3-Dichloropropene	ND	ND	--	ND	ND	0.0005
trans-1,3-Dichloropropene	ND	ND	--	ND	ND	0.0005
1,1,1,2-Tetrachloroethane	ND	ND	--	ND	ND	0.0005
1,1,1-Trichloroethane	ND	ND	--	ND	ND	0.0005
1,1,2,2-Tetrachloroethane	ND	ND	--	ND	ND	0.0005
1,1,2-Trichloroethane	ND	ND	--	ND	ND	0.0005
1,1-Dichloroethane	ND	ND	--	ND	ND	0.0005
1,1-Dichloroethene	ND	ND	--	ND	ND	0.0005
1,1-Dichloropropene	ND	ND	--	ND	ND	0.0005
1,2,3-Trichlorobenzene	ND	ND	--	ND	ND	0.0005
1,2,3-Trichloropropane	ND	ND	--	ND	ND	0.0005

Table C.34 Continued (Part 3)

Chemical	October 11, 2007 Sampling			December 18, 2007 Sampling		Reporting Limit (mg/L)
	Well A Concentration (mg/L)	Well B Concentration (mg/L)	Well B/ Import Blend (mg/L)	Well A Concentration (mg/L)	Well B Concentration (mg/L)	
EPA 524.2						
1,2,4-Trichlorobenzene	ND	ND	--	ND	ND	0.0005
1,2,4-Trimethylbenzene	ND	ND	--	ND	ND	0.0005
1,2-Dichloroethane	ND	ND	--	ND	ND	0.0005
1,2-Dichloropropane	ND	ND	--	ND	ND	0.0005
1,3,5-Trimethylbenzene	ND	ND	--	ND	ND	0.0005
1,3-Dichloropropane	ND	ND	--	ND	ND	0.0005
2,2-Dichloropropane	ND	ND	--	ND	ND	0.0005
2-Butanone (Methyl Ethyl Ketone)	ND	0.029	--	ND	ND	0.005
2-Chloroethyl vinyl ether	ND	ND	--	ND	ND	0.001
2-Chlorotoluene	ND	ND	--	ND	ND	0.0005
2-Hexanone	ND	ND	--	ND	ND	0.005
4-Chlorotoluene	ND	ND	--	ND	ND	0.0005
4-Methyl-2-pentanone	ND	ND	--	ND	ND	0.005
Benzene	ND	ND	--	ND	ND	0.0005
Bromobenzene	ND	ND	--	ND	ND	0.0005
Bromochloromethane	ND	ND	--	ND	ND	0.0005
Bromodichloromethane	ND	ND	--	ND	0.0034	0.0005
Bromoform	ND	ND	--	ND	0.0064	0.0005
Carbon tetrachloride	ND	ND	--	ND	ND	0.0005

Table C.34 Continued (Part 4)

Chemical	October 11, 2007 Sampling			December 18, 2007 Sampling		Laboratory Reporting Limit (mg/L)
	Well A Concentration (mg/L)	Well B Concentration (mg/L)	Well B/ Import Blend (mg/L)	Well A Concentration (mg/L)	Well B Concentration (mg/L)	
EPA 524.2 (continued)						
Chlorobenzene	ND	ND	--	ND	ND	0.0005
Chloroethane	ND	ND	--	ND	ND	0.0005
Chloroform	ND	ND	--	ND	0.0019	0.0005
Chloromethane	ND	ND	--	ND	ND	0.0005
cis-1,2-Dichloroethene	ND	ND	--	ND	ND	0.0005
Dibromochloromethane	ND	ND	--	ND	0.0068	0.0005
Dibromomethane	ND	ND	--	ND	ND	0.0005
Dichlorodifluoromethane (Freon 12)	ND	ND	--	ND	ND	0.0005
Di-isopropyl ether	ND	ND	--	ND	ND	0.003
Ethyl tert-butyl ether	ND	ND	--	ND	ND	0.003
Ethylbenzene	ND	ND	--	ND	ND	0.0005
Freon 113	ND	ND	--	ND	ND	0.005
Hexachlorobutadiene	ND	ND	--	ND	ND	0.0005
Isopropylbenzene	ND	ND	--	ND	ND	0.0005
m,p-Xylene	ND	ND	--	ND	ND	0.001
m-Dichlorobenzene	ND	ND	--	ND	ND	0.0005
Methyl tert-butyl ether (MTBE)	ND	ND	--	ND	ND	0.003
Methylene chloride	ND	ND	--	ND	ND	0.0005
Naphthalene	ND	ND	--	ND	ND	0.0005
n-Butylbenzene	ND	ND	--	ND	ND	0.0005

Table C.34 Continued (Part 5)

Chemical	October 11, 2007 Sampling			December 18, 2007 Sampling		Laboratory Reporting Limit (mg/L)
	Well A Concentration (mg/L)	Well B Concentration (mg/L)	Well B/ Import Blend (mg/L)	Well A Concentration (mg/L)	Well B Concentration (mg/L)	
EPA 524.2 (continued)						
m-Dichlorobenzene	ND	ND	--	ND	ND	0.0005
Methyl tert-butyl ether (MTBE)	ND	ND	--	ND	ND	0.003
Methylene chloride	ND	ND	--	ND	ND	0.0005
Naphthalene	ND	ND	--	ND	ND	0.0005
n-Butylbenzene	ND	ND	--	ND	ND	0.0005
n-Propylbenzene	ND	ND	--	ND	ND	0.0005
o-Dichlorobenzene	ND	ND	--	ND	ND	0.0005
o-Xylene	ND	ND	--	ND	ND	0.0005
p-Dichlorobenzene	ND	ND	--	ND	ND	0.0005
p-Isopropyltoluene	ND	ND	--	ND	ND	0.0005
sec-Butylbenzene	ND	ND	--	ND	ND	0.0005
Styrene	ND	ND	--	ND	ND	0.0005
Tert-amyl methyl ether	ND	ND	--	ND	ND	0.003
tert-Butylbenzene	ND	ND	--	ND	ND	0.0005
Tetrachloroethene	ND	ND	--	ND	ND	0.0005
Toluene	ND	ND	--	ND	ND	0.0005
trans-1,2-Dichloroethene	ND	ND	--	ND	ND	0.0005
Trichloroethene	ND	ND	--	ND	ND	0.0005
Trichlorofluoromethane	ND	ND	--	ND	ND	0.005
Vinyl chloride	ND	ND	--	ND	ND	0.0005
Xylenes (total)	ND	ND	--	ND	ND	0.0005

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