



FINAL

Groundwater Replenishment Program – Pilot Treatment System

Testing Phase Summary Report



TETRA TECH

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Testing Phase Summary Report - FINAL

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ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
µg/L	Micrograms per Liter
AOP	Advanced Oxidation Process
ASR	Aquifer Storage Recovery
CDPH	California Department of Public Health
CEB	Chemically Enhanced Backwash
CFU	Colony Forming Unit
CIP	Clean in Place
DO	Dissolved Oxygen
ENR CCI	Engineering News Record Construction Cost Index
FAC	Florida Administrative Code
FAT	Full Advanced Treatment Train
FDEP	Florida Department of Environmental Protection
GFD	Gallon per Foot-Day
GPM	Gallons per Minute
HMI	Human Machine Interface
PR	Potable Reuse
LBG	Leggette, Brashears, and Graham
LPHO	Low Pressure High Output
MC	Membrane Contactor
MCLs	Maximum Contaminant Levels
MF/UF	Membrane Filtration/Ultrafiltration
MGD	Million Gallons per Day
mg/L	Milligrams per Liter
MOS	Margin of Safety
MRDL	Maximum Residual Disinfectant Level
NDMA	Nitrosodimethylamine
NEWRF	Northeast Water Reclamation Facility
ng/L	Nanograms per Liter
NTU	Nephelometric Turbidity Units
O&M	Operations and Maintenance
ORP	Oxidation Reduction Potential
PDT	Pressure Decay Test
PPB	Parts Per Billion

Acronyms/Abbreviations	Definition
PSI	Pounds per Square Inch
PVDF	Polyvinylidene Fluoride
PW	Purified Water
RO	Reverse Osmosis
RW	Reclaimed Water
SDI	Silt Density Index
SF	Square feet
T.O.N.	Threshold Odor Number
TDS	Total Dissolved Solids
TMP	Transmembrane Pressure
TOC	Total Organic Carbon
TOX	Total Organic Halogen
TTHMs	Total Trihalomethanes
UCMR3	Unregulated Contaminants Monitoring Rule 3
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
VFD	Variable Frequency Drive

EXECUTIVE SUMMARY

BACKGROUND AND PURPOSE

With the continual rise in population and the direct relationship for supporting resources, fresh water supplies are increasingly burdened. Alternatives to conventional supplies are often few and far between in most areas of the state. For the past decade, many coastal communities have looked to seawater desalination as a technically viable solution to meet future water shortages. However, high capital construction costs and annual operating expenses coupled with an extremely difficult permitting process have kept this option out of the forefront and forced utilities to identify and develop other alternative supplies.

Throughout the United States, many municipalities are identifying innovative, non-traditional resources to provide long-term sustainable supplies for their current and future customers. In particular, the City of Clearwater is proactively investigating the feasibility of replenishing a brackish water interval of the Floridan aquifer system with purified water using highly treated reclaimed water.

The concept of potable reuse has been around for decades, and recent advances in high-level treatment processes have made the concept more affordable for potential consideration by utilities seeking water management alternatives. The City of Clearwater, working in agreement with the Southwest Florida Water Management District implemented a Groundwater Replenishment Project to provide the data necessary to ultimately design and construct a full scale three (3) million gallon per day (MGD) recharge project to optimize water management in the and provide the following benefits:

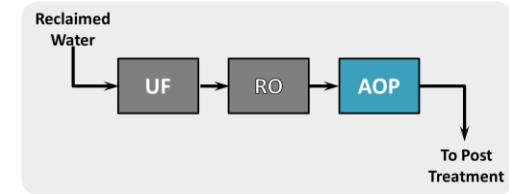
- Provide for safe increases in water withdrawals from local aquifers to meet future demands
- Protect local aquifers from saltwater intrusion through groundwater recharge
- Improve groundwater levels, benefiting public and private users in the recharge area of influence.
- Extend the useful life of existing infrastructure, such as wellfields and treatment systems, reducing the need for future expansion or investment.
- Reduce water withdrawn and imported from regional aquifers
- Reduce flows of excess reclaimed water to Tampa Bay
- Provide opportunities for public education, demonstrating the value of water and water conservation.
- Share experience to facilitate the development of other projects around the District, State, and Nation.

In 2011, the City authorized a feasibility study to investigate this concept as a solution to optimize water management for the City's future water needs. The purpose of this overall project was to determine both the technical and financial feasibility of using multi-barrier advanced treatment processes for purification of reclaimed water as a means of replenishing the local groundwater. The proposed purification treatment process adopted the multi-barrier processes used in other Potable Reuse (PR) projects in the United States and abroad. In addition, the proposed treatment process included an innovative dissolved oxygen removal step to minimize or eliminate any potential for metals mobilization in the receiving groundwater.



The 2011 Feasibility Study concluded that it was technically and financially feasible to implement a PR project to accomplish the Groundwater Replenishment (GWR) option. In 2013, the City initiated the next phase of this program, which included the pilot-scale operation and investigation of a purification process for the treatment of the reclaimed effluent for production of a highly purified water meeting regulatory water quality standards, suitable for direct injection into the lower Zone A of the Upper Floridan aquifer. The City's GWR Pilot Program was operated for a period of twelve (12) months, from June 2013 to June 2014, under the requirements of the Florida Department of Environmental Protection (FDEP) guidelines for satisfying requirements of Chapter 62-610.562 of the Florida Administrative Code (FAC).

The GWR Pilot system was assembled at the City's Northeast Water Reclamation Facility (NEWRF). The NEWRF is an advanced tertiary treatment water reclamation facility with a rated capacity of 13.5 million gallons per day (MGD), producing a high quality reclaimed water. The NEWRF supplied the pilot plant with reclaimed water throughout the duration of the pilot testing program. The GWR Pilot Purification System included three (3) main purification processes; membrane filtration (UF), reverse osmosis (RO), and advanced oxidation (AOP) consisting of ultraviolet (UV) disinfection with hydrogen peroxide.



These purification treatment steps were followed by post-treatment to condition the water for aquifer injection, including a four-stage membrane contactor (MC) system for dissolved oxygen (DO) removal, stabilization with calcium hydroxide, and addition of sodium bisulfide for dechlorination and neutralization of peroxide. The GWR pilot produced 8 gallons per minute (gpm) of purified water. The pilot plant product water and waste streams were recycled to the head of the NEWRF.

TESTING AND RESULTS

Results from the pilot testing programs show that the pilot testing facility produced purified water that reliably met drinking water quality standards. The water also consistently met all water quality requirements from the 2012 Full Treatment and Disinfection Requirements [Florida Administrative Code (FAC) Chapter 62-610.563(3)].

Over 25,000 tests were performed throughout the various unit processes of the water purification pilot for more than 204 constituents. These constituents included 103 regulated constituents and 101 unregulated constituents of potential significance for groundwater recharge. These tests demonstrated that the purification treatment system produced a water that met or surpassed regulated drinking water quality standards. Although a few

samples in the early stages of the pilot exceeded the standards for total trihalomethanes (TTHMs), source water modifications were investigated to identify a solution for alleviating the issue. The 101 additional unregulated constituents monitored included some from the Environmental Protection Agency's (EPA) Unregulated Contaminant Monitoring Rule 3 List (UCMR3), organic compounds, pharmaceutically active compounds, and other microconstituents. Only two (2) of the 101 additional constituents tested, chlorate and atenolol, were found at quantifiable levels of detection in the purified water during pilot testing. More importantly, the detection of these two

Frequency	Type	Parameter
Daily	Field	pH, Temp, Free Cl ₂ , DO, ORP, Conductivity, Turbidity
3/Week	Field	UV-254, Nitrate/Nitrite, Calcium, Total Hardness, Alkalinity
	Lab	TOC
Weekly	Field	Apparent Color, Ortho-Phosphate, Total Iron, SDI
	Lab	Ammonia, Anions (Cl ⁻ , SO ₄ ²⁻ , NO ₃ ⁻ , F ⁻), Metals (Ca, Mg, K, Si, Na, Fe), BOD ₅ , COD, TDS, TSS, TOX, Total Coliform, Total Phosphorous
Monthly	Lab	Primary + Secondary Standards, Nitrate/Nitrite, TKN, Total N, Chlorophyll A, Dissolved Mn, Dissolved Fe, Oil/Grease, Total Sulfide
Bimonthly	Lab	Enteric Viruses, Mammal Ova, Cryptosporidium, Giardia
Quarterly	Lab	Perchlorate, 1,1 Dichloroethane, Acetone, Unregulated Micro-constituents, Ethylene Glycol, NDMA, 1,4 Dioxane, Formaldehyde, Mutagenicity

constituents was concluded to be insignificant. Chlorate, a disinfection byproduct, was detected in the purified water on only three (3) occasions with a maximum concentration of 52 µg/L, average 42 µg/L (N=3). This is below the US EPA (2011) health reference level for chlorate, 210 µg/L. The maximum concentration in the reclaimed water was 490 µg/L with an average of 360 µg/L (N=3). Additionally, Atenolol, a blood pressure medication, was detected in the purified water in one sample at 16 ng/L. Four other samples for atenolol in the purified water were below the 5 ng/L detection limit. The sample that detected atenolol is well below the risk reference level for atenolol of 70,000 ng/L.

Of additional note, the groundwater injection conditioning steps including oxygen removal, remineralization, and quenching of chlorine and peroxide were capable of producing a nearly "oxidant-free" water suitable for injection into the Floridan aquifer. Rock core column testing was carried out in an effort to quantify the potential for metals mobilization in the aquifer after injection of purified water with varying levels of oxygen removal and post-

treatment. In conjunction with this work effort, Leggette, Brashears, and Graham (LBG) coordinated the rock core column testing to validate the aquifer recharge component of this project.

In summary, the results from the pilot testing sampling and laboratory analysis program clearly demonstrated that the pilot testing facility produced purified water that reliably met primary and secondary drinking water quality standards and the water quality and treatment requirements from (FAC) Chapter 62-610.563(3)].

NEXT STEPS

The City of Clearwater has followed responsible, straightforward steps to determine the viability of implementing PR for their community. In a time of limited freshwater resources, pilot studies such as these create a road map for developing and implementing cost-effective alternative water supply sources. The purpose of this Pilot Testing Phase was to test and confirm the technical and economic feasibility of developing a multi-barrier, advanced treatment processes for purification of the City's reclaimed water as a means of replenishing the local groundwater. The purification treatment process adopts the multi-barrier processes used for other Portable Reuse (PR) projects in the United States and abroad, but also adds dissolved oxygen removal to minimize any potential for metals mobilization in the receiving groundwater. The Pilot Testing Phase provided the opportunity for the City to demonstrate that the best available technologies (BAT) nationwide could be implemented in the City of Clearwater. With the successful completion of the 12-month pilot testing phase and the confirmation of the GWR Program from both a technical and financial feasibility perspective, the next steps for the City of Clearwater include the following:

Stakeholder Support and Public Education:

The pilot testing and demonstration phase introduced the concept and viability of the program to many public stakeholders. Presentations to community groups and public tours of the pilot building, provided opportunities for public participation and input. Additional public participation and education programs will be initiated following the completion of the Pilot Testing Phase to ensure project success and project schedule. Effective public participation is key to the planning and delivery process of a public project. Public participation allows for the public to provide meaningful input during project development.



Engineering Design and Permitting: The first step in this phase of the project is typically a preliminary design report (PDR). A PDR will be prepared to illustrate the design concepts and provide the technical criteria (basis of design) for the various unit processes, site work and buildings. The PDR is often developed to a 30-percent completion level in order to support decisions prior to final design and also to support regulatory permitting with FDEP and other agencies. Once permitted, the next step includes the remaining phases of design, which include the development of drawings and technical specifications for the various disciplines to a 60-percent completion level, followed by 90-percent and 100-percent deliverables.

Bidding and Construction: After the 100-percent documents have been approved, the City will advertise for competitive bids from contractors. Following review of the bids and selection of the lowest qualified bidder, the next step will be to construct the proposed improvements. Critical to this phase is the start-up, testing and training. Adequate measures will be specified to ensure a smooth turnover of the facilities from the general contractor to the City.

ACKNOWLEDGMENTS

The Groundwater Replenishment (GWR) Program was brought through the testing phase by the efforts of many individuals and organizations, which were indispensable to the successful completion of this phase of the project. This project was supported in part financially by the Southwest Florida Water Management District (SWFWMD). This page acknowledges individuals who made substantial contributions. Their efforts as well as those of many other individuals are gratefully acknowledged.

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1.0 INTRODUCTION

1.1 BACKGROUND

In an effort to provide beneficial use of reclaimed water in addition to irrigation, the City of Clearwater (City) has been investigating the replenishment of local aquifer systems with highly-purified water sourced from the Northeast Water Reclamation Facility (NEWRF). In 2011, the City authorized a feasibility study which determined that direct groundwater injection was a feasible solution to the City's forthcoming water supply needs. The City of Clearwater, working in agreement with the Southwest Florida Water Management District implemented a Groundwater Replenishment Project to provide the data necessary to ultimately design and construct a full scale 3 million gallons per day (MGD) recharge project to optimize water management in the and provide the following benefits:

- Provide for safe increases in water withdrawals from local aquifers to meet future demands
- Protect local aquifers from saltwater intrusion through groundwater recharge
- Improve groundwater levels, benefiting public and private users in the recharge area of influence.
- Extend the useful life of existing infrastructure, such as wellfields and treatment systems, reducing the need for future expansion or investment.
- Reduce water withdrawn and imported from regional aquifers
- Reduce flows of excess reclaimed water to Tampa Bay
- Provide opportunities for public education, demonstrating the value of water and water conservation.
- Share experience to facilitate the development of other projects around the District, State, and Nation.

A Groundwater Replenishment (GWR) Pilot Program was initiated in 2013, which included the operation and investigation of a purification process for the treatment of the reclaimed effluent for production of a highly purified water meeting regulated water quality standards, suitable for direct injection into the lower Zone A of the Upper Floridan aquifer. The GWR Pilot Program was operated for a period of twelve (12) months, from June 2013 to June 2014, per requirements of the Florida Department of Environmental Protection (FDEP) guidelines for satisfying requirements of Chapter 62-610.562 of the Florida Administrative Code (FAC).

Additionally, as part of the overall GWR Program, the City is conducting testing related to the hydraulics and characteristics of the aquifer that is proposed to be recharged by the purified water. The work includes injection testing of the aquifer with groundwater at a rate of 300 gallons per minute (gpm), as well as the specific testing of whole rock cores from the local aquifer with purified water from the pilot system to evaluate alternate levels of post treatment. The results from this aquifer testing program are to be reported in a separate document.

The GWR Pilot was assembled at the City's NEWRF, which is located at the northeast corner of State Road 580 and McMullen-Booth Road. The NEWRF currently has both a rated and permitted capacity of 13.5 MGD and supplied the pilot plant with reclaimed water throughout the 12-month pilot testing program. The GWR Pilot Purification System included three (3) main purification processes; membrane filtration (UF), reverse osmosis (RO), an advanced oxidation process (AOP) consisting of ultraviolet (UV) disinfection with hydrogen peroxide (H_2O_2). For purposes specific to the GWR Program, these purification treatment steps were followed by a fourth post-treatment step to condition the water for aquifer recharge. The post-treatment system consisted of a membrane contactor (MC) system for dissolved oxygen (DO) removal, stabilization with calcium hydroxide, and the addition of sodium bisulfide for dechlorination and neutralization of peroxide. A basic purification process block diagram is illustrated in Figure 1.

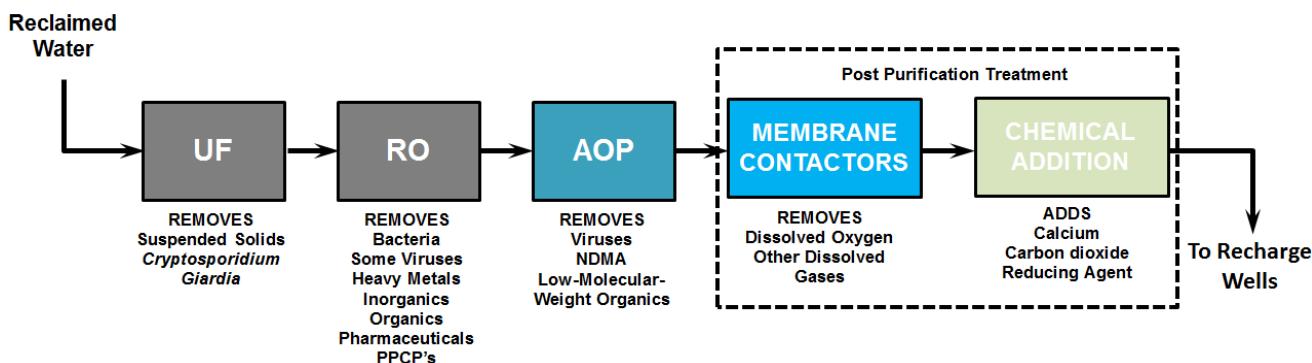


Figure 1. Purification Process Block Diagram

The GWR pilot produced eight (8) gpm of purified water based on a 94-percent recovery for the UF process and an 80-85-percent recovery for the RO process. The pilot plant product water and waste streams were discharged into a nearby sanitary sewer manhole that directed flow to the head of the NEWRF.

During the previous feasibility study phase, multiple alternative process trains were considered. As a part of its groundwater recharge regulations, the “full advanced treatment (FAT)” train, (UF, RO, UV/H₂O₂) was selected as the treatment process of choice since it has been demonstrated as the best available technology for groundwater replenishment and potable reuse, which is currently widely adopted in California groundwater recharge applications and Texas direct potable reuse projects. Treatment trains utilizing ozone have received increased attention as some have looked to find lower energy alternatives to the use of RO for membrane separation and UV peroxide as the advanced oxidation process. Additionally, the purification process proposed for this program was also selected due to its proven track record, presence of multiple physical barriers to pathogens, and superior treatment of NDMA and other emerging contaminants. Ozone-based treatment trains do not contain the same track record of multiple successful installations, do not effectively remove NDMA, and also have the potential to form bromate, a regulated disinfection byproduct. Further testing and development of ozone based treatment trains may make it a more attractive option in the future; however, for the purposes of providing a proven, permittable, and robust treatment train for groundwater replenishment, this purification treatment process is the most feasible option.

This report discusses the removal efficiency of the purification system, the expected quality of the recharge water and the impact of the findings in the field testing phase. This report also provides findings, conclusions and recommendations relative to the viability of the project and proceeding forward with the implementation of the full scale system based upon the information obtained during the field testing program.

1.2 OBJECTIVES

Based on the high quality of the reclaimed water at the NEWRF and in conjunction with the advanced, treatment process of the pilot system, the purpose of this pilot study was to successfully demonstrate that a highly purified water meeting Florida Department of Environmental Protection (FDEP) requirements for regulated contaminants could be produced continuously and consistently. The main water quality goals for the pilot system are outlined in Chapter 62-610, “Reuse of Reclaimed Water and Land Application” of the Florida Administrative Code (FAC) and also included:

- Demonstrating that the purified water was able to meet all drinking water standards by meeting full treatment requirements.
- Demonstrating that the full disinfection requirements were achieved with no detection of pathogens or coliforms.
- Demonstrating that the purified water does not exhibit mutagenic properties.

- Demonstrating that the purified water was suitable for blending with the native groundwater in the aquifer.

The project goals for the GWR Pilot (Pilot Testing Phase) Program are identified as:

- Designing, permitting and monitoring of the Pilot Purification Plant.
- Obtaining additional reclaimed water and groundwater quality sampling and analyses by the City.
- Expanding the Public Information Program.
- Obtaining information and pilot test data to support the final design and permitting of the full scale system.

Regulations for groundwater recharge include the requirement that the overall treatment process provide multiple barriers for organics and pathogens and that additional pollutant reduction for parameters reasonably expected to pose a risk to public health due to acute or chronic toxicity be provided. In order to recharge purified water into the lower Zone A of the Upper Floridan aquifer, a minimum of 12 months of data from the pilot was required per Chapter 62-610.564 (3) of the F.A.C. The design of the pilot plant was detailed in the construction documents, with relevant details provided here for clarity.

Other regulations abided by for groundwater recharge under the F.A.C included regulations found in Chapters 62-528, "Underground Injection Control", 62-520, "Groundwater Classes, Standards and Exemptions" and 62-600, "Domestic Wastewater Facilities".

1.3 TEST FACILITY

1.3.1 Location

The pilot plant was assembled at the NEWRF, in the southeast corner of the property near the existing reclaimed water storage tank as shown in Figure 2. The NEWRF is located in the northeast portion of the City off of the State Road (SR) 580 and McMullen-Booth Road intersection. The proposed recharge well locations are also shown in Figure 2. The proposed recharge zone for the purified water is the lower zone A of the Upper Floridan aquifer, which is slightly brackish and generally has a total dissolved solids (TDS) content between 800 and 3,000 mg/l TDS.

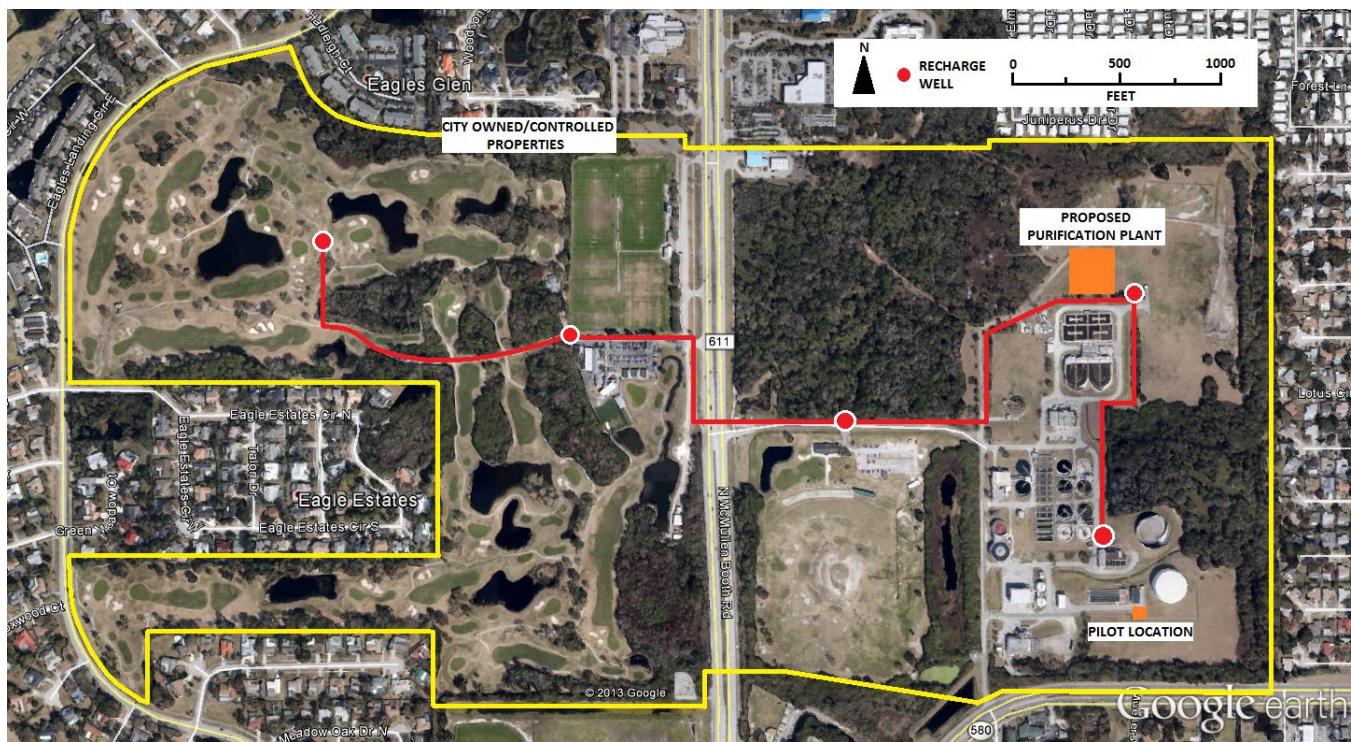


Figure 2. Map of Project Location

Due to inclement weather such as high temperatures and heavy rainfalls, the pilot plant equipment was protected by a self-supported shade structure as shown in Figure 3. It was also enclosed on both open ends by curtains of tarp material to minimize the entrance of strong winds or rain. Equipment or chemicals stored outside of the shade structure, such as sulfuric acid, were stored in protective containment enclosures.



Figure 3. Pilot Shelter

1.3.2 Overview

The GWR Pilot Treatment System was designed to produce eight (8) gpm of purified water based on a 94-percent recovery for the UF process and an 80-85-percent recovery for the RO process and is shown in the process flow diagram shown in Figure 4 below. The major process components shown in Figure 4 include three purification steps: membrane filtration in the form of ultrafiltration (UF), reverse osmosis (RO), and a UV light with hydrogen peroxide advanced oxidation process (AOP).

The purification treatment steps are followed by a series of post-treatment steps to condition the water for aquifer recharge, including: a membrane contactor (MC) system for DO removal, carbon dioxide injection for stabilization, calcium hydroxide (lime slurry) addition for stabilization, and sodium bisulfide addition for quenching of chloramine and peroxide residual.

1.3.3 Project Schedule

The pilot plant was mobilized into full-scale operation on June 4, 2013, and operated to collect 12 months of data per FAC 62-610.564(3), ceasing operations on June 4, 2014. Purification equipment was operated at steady-state targets and operating modes were not adjusted significantly except for the RO membranes. On April 14, 2014, the RO process of the pilot system was converted from 3-stage operation to 2-stage operation and operated in 2-stage for the remainder of pilot operations, as described in Section 1.3.5. Table 1-1 lists several other major events that were significant to pilot operations. These events include UF clean in place (CIP) operation, RO CIP operations, rock core testing, and membrane contactor skid maintenance. More information about CIPs and rock core testing are provided in Section 2.0.

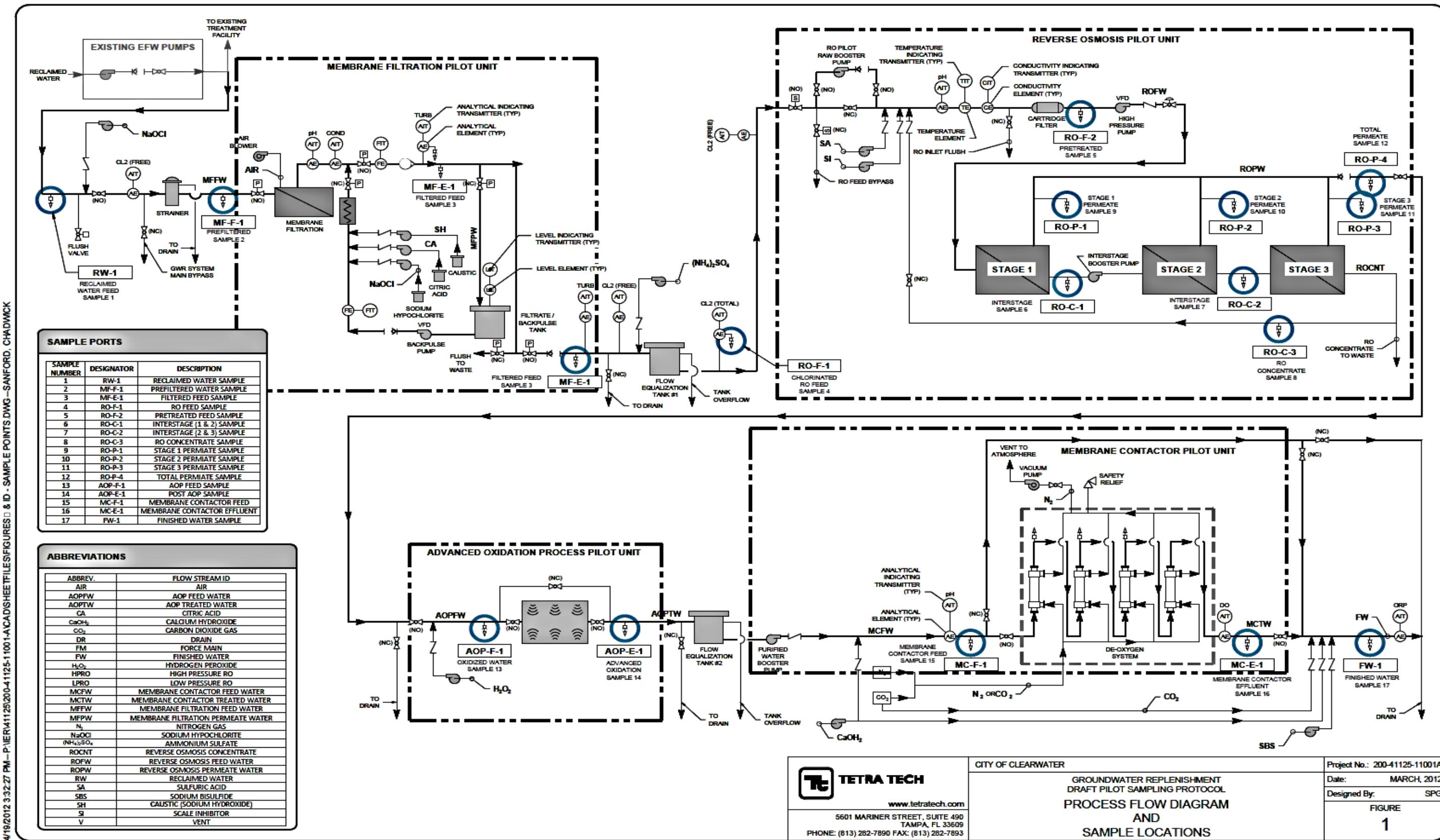


Figure 4. Process Flow Diagram

Table 1-1. Key Operating Events by Process

Date	UF	RO	UVAOP	MC
6/4/2013		Pilot Start Up		
8/16/2013				Replace DO sensor
9/8/2013				Replace DO sensor
9/17/2013		CIP #1 (High pH) on Stage 3 Only		
10/2/2013-10/3/2013		Rock Core Testing		
10/30/2013	CIP #1 (High pH)			
11/7/2013	CIP #2 (Low pH)			
11/13/2013			Spike Challenge Test #1 (1,4-dioxane, NDMA)	
11/14/2013-11/16/2013	CIP #3 (High/Low pH)			
1/4/2014				DO sensor tune up
1/7/2014-1/13/2014	CIP #4 (High/Low pH)			
1/18/2014	Repaired broken fibers in UF module			
1/28/2014			Spike Challenge Test #2 (1,4-dioxane, NDMA)	
2/2/2014		RO Black Box Element Installed		
2/11/2014-2/12/2014		CIP #2 (High/Low pH) on Stage 3 Only		
3/26/2014			Spike Challenge Test #3 (1,4-dioxane, NDMA, Atenolol)	
3/28/2014-3/31/2014		CIP #3 (High/Low pH) on Stage 3 Only		
4/1/2014-4/3/2014	CIP #5 (High/Low pH)			
4/14/2014		Switch from 3-Stage Operations to 2-Stage Operations		
4/25/2014-4/26/2014	CIP #6 (High/Low pH)			
5/7/2014			Spike Challenge Test #4 (1,4-dioxane, NDMA, Atenolol)	
5/13/2014-5/14/2014	CIP #7 (High/Low pH)			
6/4/2014		Pilot Shut Down		

1.3.4 Membrane Filtration (UF)

Membrane filtration (UF) can refer to either the use of microfiltration membranes or ultra-filtration membranes (UF). UF technology was the selected membrane filtration unit process for this pilot program. UF is typically applied to water purification processes for the removal of colloidal particles such as dissolved silica, viruses and small particles ranging larger than 0.01 µm. The UF membranes are composed of hollow fibers that separate these particles from water by a sieving mechanism through operation dead-end filtration mode. In dead-end flow filtration, the feed water is passed entirely through the membrane and impermeable substances are allowed to gradually accumulate on the membrane surface. Major process components of the UF pilot system as shown in Figure 4, include the following:

- Pretreatment strainer to protect the membrane elements from damage from abrasive materials such as sand or grit,
- Feed and filtrate water monitoring equipment,
- Vertical, pressurized hollow-fiber ultrafiltration membrane module,
- Feed and backwash pumps with variable frequency drives (VFDs),
- Filtrate/backwash tank,
- Backwash system for periodic backwashing of the membrane elements with or without chemicals,
- Air compressor for pneumatic valve operation and air scour during backwash and cleaning.

A human-machine interface (HMI) touch screen was provided for configuration of the pilot operating parameters and monitoring of the pilot status during operation. Figure 5 shows the UF process at the City's GWR pilot.



Figure 5. Membrane Filtration Pilot

The pretreatment strainer was constructed of stainless steel material with a nominal rating of 100 microns (micrometers) for prescreening of the source water. The strainer automatically backwashed after reaching a preset pressure differential.

The UF system was designed to produce 21 gpm of filtrate at an effective product recovery of 94-percent, accounting for water lost through backwash, and flushing. The feed pressure ranged from 10 to 20 pounds per square inch (psi), with an average pressure of 13 psi at an average membrane flux rate of 36.8 gallons per square foot day (gfd). The membrane utilized was a Dow SFD-2880 ultrafiltration membrane composed of polyvinylidene fluoride (PVDF) with a nominal pore diameter of 0.03 microns and an active membrane area of 829 square feet (sf). The UF membrane was operated in an outside-in configuration with dead-end flow.

The UF system was set to run 40 minutes before undergoing an air scour and regular backwash with filtered water. Chemical feed systems for low pH backwashes (citric acid) and high pH backwashes (sodium hydroxide (caustic soda) and sodium hypochlorite) were in place on the UF pilot, for automated chemically enhanced backwashes (CEBs) for chemical cleaning of the membrane elements. High pH backwashes with sodium hydroxide/caustic soda and sodium hypochlorite (chlorine) were performed after a set number of backwash cycles (approximately once per day), to a pH of 11.0 and a chlorine residual of 750 mg/L, per the membrane manufacturer's recommendations. Low pH backwashes were performed after a set number of backwash cycles (approximately once per week), to pH 3.0. The backwash water came from a 96-inch diameter high density polyethylene tank with 2,000 gallon capacity. The chemicals were injected into the backwash water stream during CEBs to provide a chemical benefit during a CEB event. An air compression system was provided for air scouring of the membrane element during routine backwashes, CEBs and clean-in-place (CIP) operations.

1.3.5 Reverse Osmosis

Reverse osmosis (RO) is a membrane-based desalting process used to separate dissolved solids, including ions, trace organics, and most other chemical compounds from solution. Thin film composite membranes are commonly used in water treatment as they provide high salt rejection rates at low operating pressures. Major process components of the RO pilot system are shown in Figure 4, and include:

- The addition of ammonium sulfate for the conversion of free chlorine in the reclaimed water to form chloramines,
- An equalization tank for balancing fluctuations in flow from the UF system to the RO system,
- A chemical pretreatment system including pH adjustment with sulfuric acid and antiscalant (scale inhibitor),
- Cartridge filtration,
- Membrane high pressure pump and interstage boost pump,
- Three-stage RO membrane system,
- And a membrane cleaning system.

A human-machine interface (HMI) touch screen was provided for configuration of the pilot operating parameters and monitoring of the pilot status during operation. Figure 6 shows the RO process at the GWR pilot.



Figure 6. Reverse Osmosis Pilot

The RO membrane process was designed to function in two different arrays as needed:

- As a two-stage process, in a 2:1 array with seven (7) elements in series per stage.
- As a three-stage process, in a 4:2:1 array with six (6) elements in series per stage.

The RO process was designed to produce a total permeate flow of 12.5 to 15.0 gpm at a design product recovery range of 80 to 85-percent. After pH adjustment, target parameters included a pH from 6.0 to 7.0, an RO feedwater silt density index (SDI) value of less than three (3.0) and turbidity less than one (1) nephelometric turbidity unit (NTU). The design feed pressure target for the membranes was 225 psi, at an average membrane flux rate of 9.5 to 10.5 gfd. The minimum second stage and third stage permeate flux rates were set to 9.0 gfd and 8.5 gfd, respectively.

The cartridge filter pretreatment unit upstream of the membrane process was designed to filter the raw water over the range of potential feed flow rates. The cartridge filters were constructed of polyethylene string wound filters with a 5-micron nominal rating. Instrumentation field devices included a total of eight (8) pressure transmitters, five (5) flow meters, one (1) pH analyzer, two (2) conductivity analyzers, one (1) temperature analyzer, one (1) oxidation-reduction potential (ORP) analyzer and pressure switches for the feed and interstage boost pumps.

The RO membranes were initially arranged as a 3-stage system in a 2:1:1, array of pressure vessels across the three stages. The first and second stages included 4-inch diameter membrane elements. The third stage included 2.5-inch diameter membrane elements. The RO membranes were also operated as a two stage system in a 2:1 array of pressure vessels consisting of all 4-inch diameter membrane elements.

During operation as a three-stage process (June 4, 2013 to April 14, 2014), all three stages contained six membrane elements each per pressure vessel. The first and second stages of the system each had 4-inch diameter Dow Filmtec XFRLE-4040 membrane elements with 78 square feet of membrane area and 34 mil-thick feed spacers. The third stage had 2.5-inch diameter Dow Filmtec XFRLE-2540 membrane elements with 26 square feet of membrane area and also 34-mil thick feed spacers. The process operated at 84 percent recovery and a total permeate flow of 12.6 gpm and at a permeate flux rate of 11.6 gfd.

During operation as a two-stage process (April 14, 2014 to June 3, 2014), the pressure vessels were expanded to include seven elements per stage. The process operated at 82.5-percent recovery (including concentrate recycle) and a higher total permeate flow of 13.2 gpm with the same permeate flux 11.6 gfd. Second stage concentrate

was recycled to the feed stream at a rate of 0.6 gpm to avoid low flow conditions in the tail end of the second stage.

1.3.6 UV Disinfection and Advanced Oxidation

The advanced oxidation process (AOP) used in the pilot program consisted of ultraviolet (UV) disinfection with hydrogen peroxide (H_2O_2) addition upstream of the UV lamps. The UV disinfection process helps provide disinfection through inactivation of microbes at germicidal wavelengths of UV light. The UV light also interacts with H_2O_2 to transform it into hydroxyl radicals ($OH\cdot$), which function as powerful oxidizing agents that destroy most trace organic compounds. The AOP process also provides significant removal of brominated trihalomethanes (THMs). The AOP system is the last step among the purification treatment processes and is shown in Figure 7.

The UV disinfection treatment process utilized low pressure high output (LPHO) amalgam UV lamps, operated at constant output. Each UV lamp is separated from the water inside a quartz sleeve. Dilute hydrogen peroxide was injected using a peristaltic pump at a target influent concentration of 2 mg/L peroxide. Ultraviolet transmittance (UVT) at 254 nm was measured regularly throughout the pilot, using a bench-top measurement apparatus, and an inline UVT analyzer. After the AOP process, the purified water enters an equalization tank before post treatment in the membrane contactors.

The performance of the AOP system in removing 1,4-dioxane and nitrosodimethylamine (NDMA) was tested through a series of four quarterly spike challenge tests. These compounds were selected for challenge testing to demonstrate system performance, to the level identified in the California Department of Public Health's (CDPH) Draft Groundwater Recharge Regulations. Atenolol was included in the third and fourth rounds of spike challenge testing since it was detected once in the purified water at 16 ng/L, to characterize the fate of atenolol through the AOP process.



Figure 7. UV Advanced Oxidation Process

1.3.7 Membrane Contactors

The membrane contactors (MC) as shown in Figure 8, are the first of three post treatment steps that prepare purified water for aquifer recharge. The membrane contactor process consists of four stages of polypropylene hollow-fiber membranes, for removal of dissolved oxygen (DO) from the purified water prior to groundwater injection. The same technology has been used previously in Florida for DO removal for Aquifer Storage and Recovery (ASR) projects. DO removal is recommended to avoid the possibility of undesirable metals mobilization in the aquifer. The hollow fiber membranes are permeable to gas but not permeable to water. Unlike UF membranes, water passes around the outside surface of the membrane contactor fibers, not entering the fiber. A vacuum pump is used to draw high-purity nitrogen through the inside of the hollow fibers, creating a low-pressure area inside the fiber, with very little oxygen present in the sweep gas. The lack of DO inside the hollow fiber creates a driving force for oxygen to diffuse out of the water, through the fiber wall, and into the hollow core to be carried away by the nitrogen sweep gas mixture. The pilot was originally designed to utilize either nitrogen and/or carbon dioxide as a sweep gas.

Nitrogen was fed at rates varying from 5 to 15 standard cubic feet per hour. A vacuum pump draws out the sweep gas mixture, with DO, and discharges it to the atmosphere. The process was capable of removing 4-log (99.99-percent) of the influent DO.

The membrane contactors also provide significant removal of carbon dioxide in the purified water, raising the pH to near 6.5. In addition, volatile chlorinated THMs are partially removed through diffusion across the membranes and into the sweep gas. Continuously monitoring DO and trace DO sensors (sensitive to 1 ppb) monitored and logged oxygen levels in the membrane contactor influent and effluent, respectively.



Figure 8. Membrane Contactor Pilot

1.3.8 Chemical Post-Treatment

After the treated water passes through the MC process, additional treatment was applied to adjust its water quality to be compatible with lower Zone A of the Upper Floridan aquifer. The target injection zone includes limestone and traces of arsenopyrite (FeAsS) mineral. One goal of post-treatment was to increase the calcium carbonate stability of the treated water to mitigate the potential for dissolution of limestone in the aquifer. Another important goal of post-treatment was to reduce the oxidation reduction potential (ORP) of the treated water to further reduce the potential for mobilization of undesirable metals, such as arsenic. Experience with aquifer storage recovery (ASR) in Florida has shown that oxygenated water can mobilize mineral-bound arsenic into groundwater. Therefore, post-treatment is used to remove or convert any residual oxidants in the water.

1.3.8.1 Carbon Dioxide

Carbon dioxide (CO_2) addition is necessary for pH control of the purified water to offset the high pH of lime slurry that is dosed downstream, and to reintroduce alkalinity removed by RO and the carbon dioxide lost through the MC. Pure carbon dioxide is injected through an in-line diffuser (Figure 9) into the membrane contactor effluent stream. Typically the pH of the MC effluent was about 6.5 after permeate CO_2 was removed. Without carbon dioxide addition, lime addition would increase the pH of the process water to nearly pH 11. The typical alkalinity of RO permeate and MC effluent was about the same, about 10 mg/L as CaCO_3 before CO_2 addition. The typical CO_2 dose was an estimated 70 mg/L to achieve pH 7.25. Direct injection of CO_2 was found to be a more effective treatment method than use of CO_2 as a sweep gas in the membrane contactors.



Figure 9. Carbon Dioxide Injection Point

1.3.8.2 Liquid Lime

A 15-percent slaked lime slurry ($\text{Ca}(\text{OH})_2$) was used to remineralize the purified water, in order to stabilize it with limestone in the target injection aquifer. Lime slurry was delivered in 275-gallon totes, dilutued, and mixed continuously to maintain a uniform suspension. The lime slurry feed pump rate was manually controlled.



Figure 10. Sodium Bisulfide System

1.3.8.1 Sodium Bisulfide

Sodium bisulfide (NaHS), as shown in Figure 10, was added using a peristaltic pump, in order to neutralize peroxide and chlorine species, adjust ORP, and to stabilize the purified water prior to aquifer recharge. Operational aspects of sodium bisulfide addition are discussed further in Section 2.5.2.

2.0 SUMMARY OF OPERATIONS

This section provides a summary of operational data that was monitored on a daily or intermittent basis for each process. By monitoring these parameters, operators and staff were able to determine whether there was a decline in performance in either of the purification processes and what the source causing declined performance was. Based on observations made during the 12-month study period, operators were able to make key decisions on how to optimize the multi-step purification process.

2.1 MEMBRANE FILTRATION

Operations results from the UF process are described for water recovery, turbidity removal, membrane cleanings, and pressure decay tests. Full-scale design considerations are presented in Section 4.0 of this report.

2.1.1 Recovery

The UF system operated at a recovery of 94-percent, with 6-percent of the total feed water being lost through backwashing.

2.1.2 Turbidity

Utilizing the UF process resulted in significant reductions in turbidity in the reclaimed water prior to delivery to the subsequent RO unit process. A time series of turbidity results from the reclaimed water and filtered water is shown in Figure 11. On average, the reclaimed water (pilot feed water) turbidity was 0.40 NTU and the average turbidity was 0.09 NTU post UF membrane filtration.

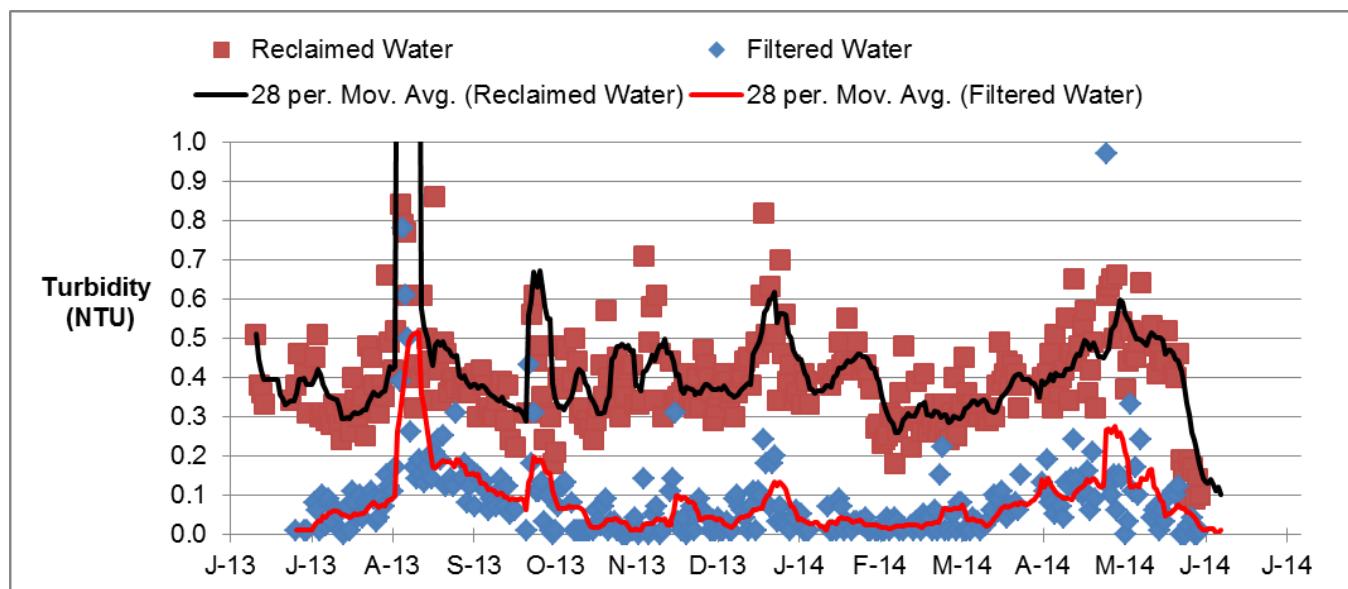


Figure 11. Turbidity Performance

2.1.3 Membrane Cleaning and Transmembrane Pressure

The transmembrane pressure (TMP) is the difference between the upper and lower feed pressure of the UF membrane module and the filtrate pressure. Membrane filtration cleans in place (CIPs) were typically carried out when the transmembrane pressure of the ultrafiltration membrane exceeded the 14.5 psi cleaning threshold recommended by Dow. Dow's technical service bulletin on membrane cleaning was used to guide the cleaning procedure, and is included in Appendix E. The membranes were cleaned using both high pH and low pH cleaning solutions. The high pH cleaning solution consisted of a 0.2-percent solution of sodium hypochlorite and 0.1-percent solution of caustic soda, with pH 12. The low pH cleaning solution consisted of a 0.2-percent solution of hydrochloric acid with pH 2. The CIPs were carried out with the high pH cleaning first, followed by the low pH cleaning.

A dedicated tank was used to mix up the UF skid cleaning chemicals. The cleaning solution was recirculated through the UF skid at a high flow for at least one hour to allow the UF foulants to be removed from the UF membrane fibers. Additional acid or caustic soda was added as needed to adjust for pH neutralization by foulants and to maintain the target cleaning pH. After the clean in place was complete, the spent solution was adjusted to a neutral pH and discharged to the front of the water reclamation facility.

A time series of the TMP for the UF system is shown in Figure 12. Initially, the TMP started below 5 psi, but increased over several months to as much as 24 psi. Seven (7) chemical cleans in place (CIPs) were performed on the UF system with good recovery of transmembrane pressure (TMP) throughout the testing period. The dates of the CIPs were given in Table 1-1. The pilot ran for approximately five months before requiring the first CIP. Towards the end of the pilot testing period the UF membrane fouled very rapidly after each clean in place, requiring three CIPs within a one month period.

In addition to regular backwashing, the ultrafiltration membrane was backwashed with a high pH chlorine solution approximately once per day to reduce fouling from organic matter. The membrane was backwashed approximately once per week with a low pH citric acid solution to remove iron.

A procedure of repeated chemically enhanced backwashes (CEBs), led to significant drops in TMP, near original levels, suggesting that the low pH CEB may have removed large masses of accumulated iron fouling. With more frequent low pH CEBs, it is anticipated that fewer cleans in place would be required. An autopsy of the UF module by Dow confirmed the need for increased low pH CEBs to remove iron.

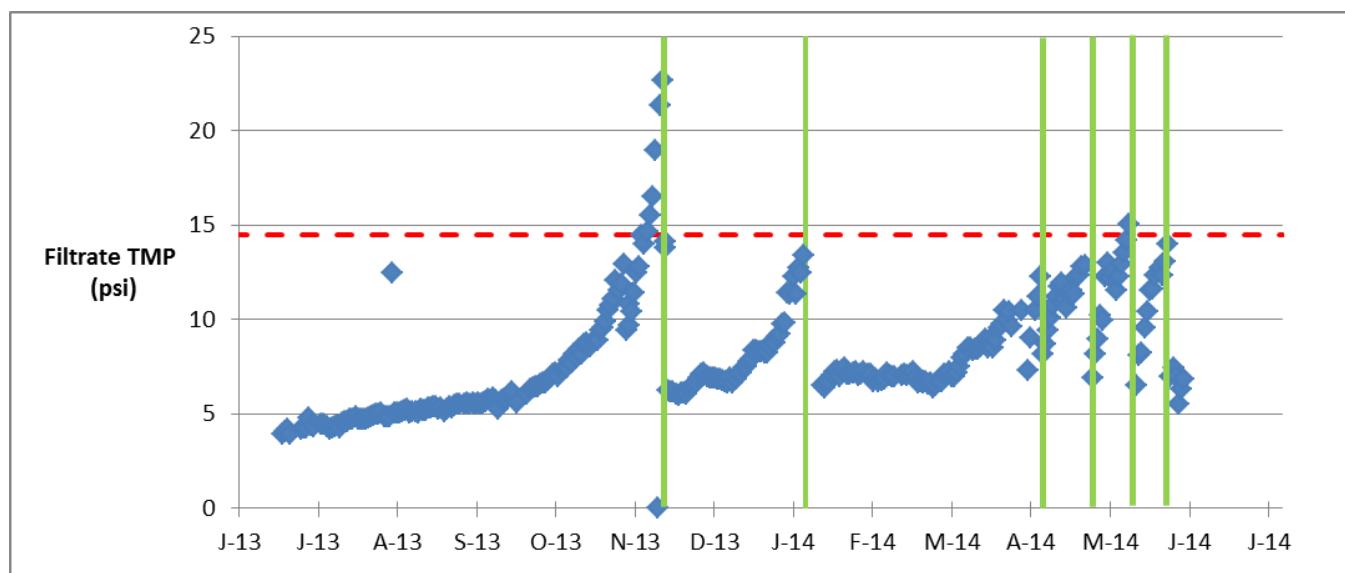


Figure 12. Transmembrane Pressure

2.1.4 Pressure Decay Test

The pressure decay test is used to determine the air-tightness of the membrane through pressurization of the feed side of the membrane, and a holding period of 5 minutes, where the pressure decays naturally over time as air escapes through small interstices in the UF filter vessel fittings, and through the UF membrane itself. Increases in the rate of pressure decay, often are indicators of a broken ultrafiltration fiber. A pressure decay limit of -0.29 psi/minute was used as the “alarm” limit during pilot testing. A broken UF fiber could allow unfiltered water to pass into the inner channel of the broken fiber, carrying along whatever solids or pathogens would also pass through to mix with the filtered water.

In the case of isolated fiber breaks, the integrity of the membrane can be restored, with a slight loss in capacity, by “pinning” the membrane hole at the top of the UF module, to block any water from flowing out of the broken fiber. The broken fiber can easily be detected during repair by looking for a bubble, indicating the fiber with the breach.

A time series of pressure decay test (PDT) results is shown in Figure 13. Beginning late October, the results of the pressure decay test began to decrease rapidly from about -0.10 psi/min to -0.20 psi/min. Through mid-January the PDT results held relatively steady. In January 2014, the UF vessel was opened, and broken fibers were identified and pinned. After that time, the PDT remained above -0.05 psi/min, higher than the initially recorded PDT results in June 2013, of about -0.10 psi/min. The PDT is a useful operational tool for monitoring the state of the UF membrane fibers. PDT levels and membrane fiber pinning repairs can be tracked at full-scale as an operational tool for timing pinning maintenance, as needed, for specific UF modules.

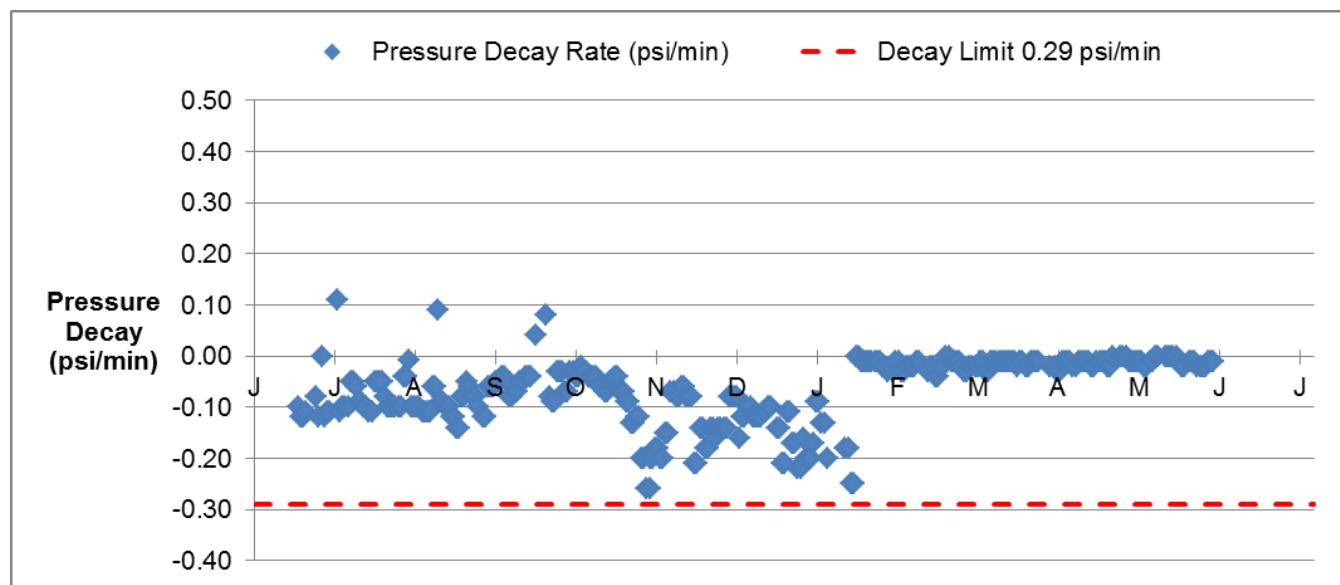


Figure 13. Pressure Decay Test Results

2.2 REVERSE OSMOSIS

Operations results from the RO process are described for normalized parameters, differential pressure, and membrane cleanings. Design considerations for full-scale implementation are later presented in Section 4.2.

2.2.1 Testing Periods

Two reverse osmosis configurations were tested for comparison of operating characteristics. A three stage configuration was tested from June 4, 2013 to April 14, 2014, with average 84-percent recovery. A two stage system was tested from April 14, 2014 to June 3, 2014, with an average 82.5-percent recovery. The average flux during both periods was 11.6 gfd. The three stage system showed signs of scaling in the third stage only. The two-stage system did not show any signs of scaling during operations. The membranes consistently produced water with low total dissolved solids and low total organic carbon, maintaining a high salt rejection.

On April 14, 2014, the 2.5-inch third stage elements were removed and the membranes were converted to two-stage operations. The tail element from the third stage was sent to Avista for a membrane autopsy. The other five elements were put into storage with a 1-percent sodium metabisulfite preservative solution for potential future use.

A membrane autopsy was carried out on a new element that was installed during the two-stage system operations period. No signs of fouling or scaling were observed on the membrane element. The autopsy report is included in Appendix H.

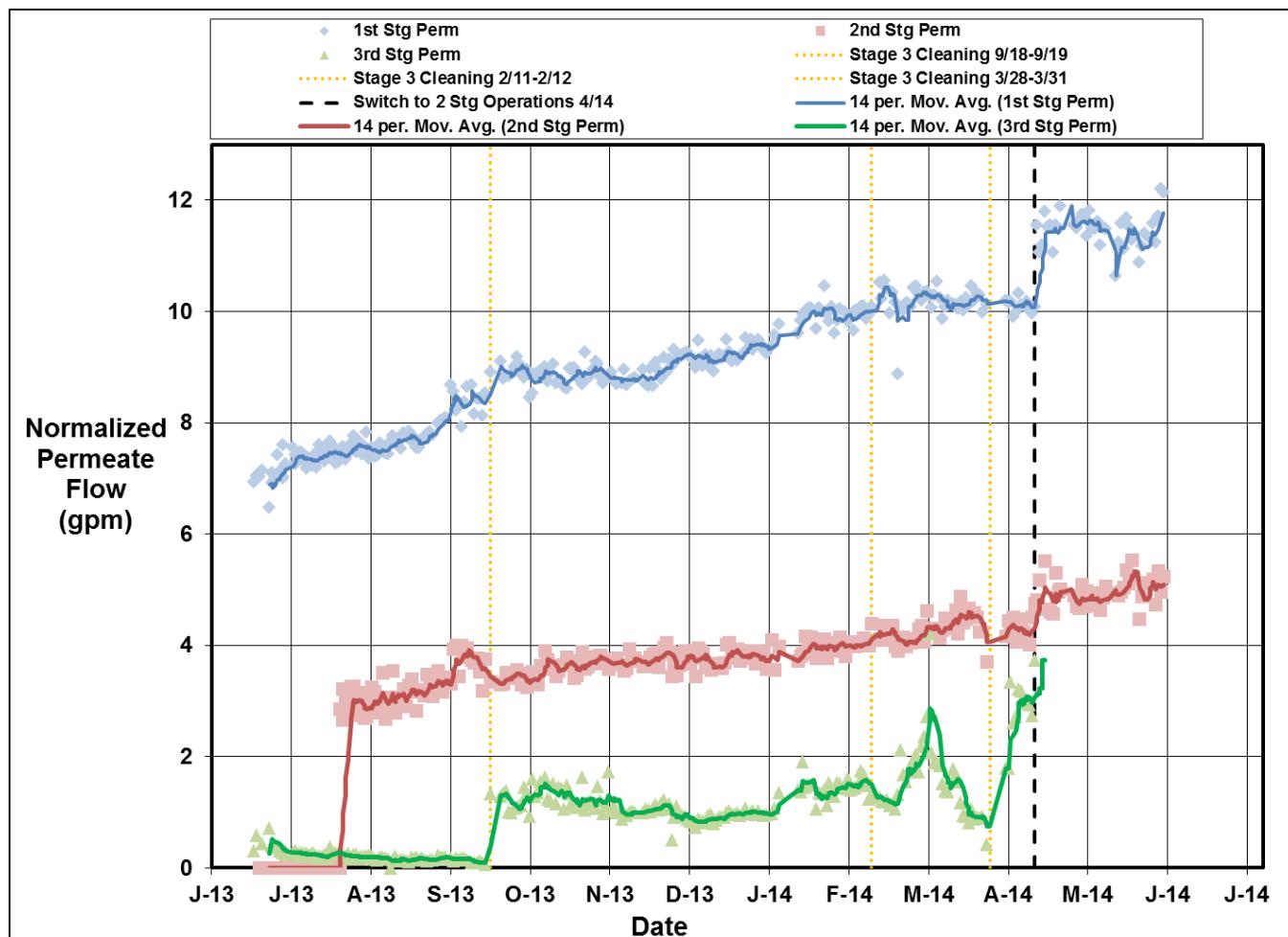
2.2.2 Normalized Parameters

Three normalized parameters for reverse osmosis operations were tracked for the duration of the pilot. These normalized parameters included normalized permeate flow, normalized salt passage, and differential pressure.

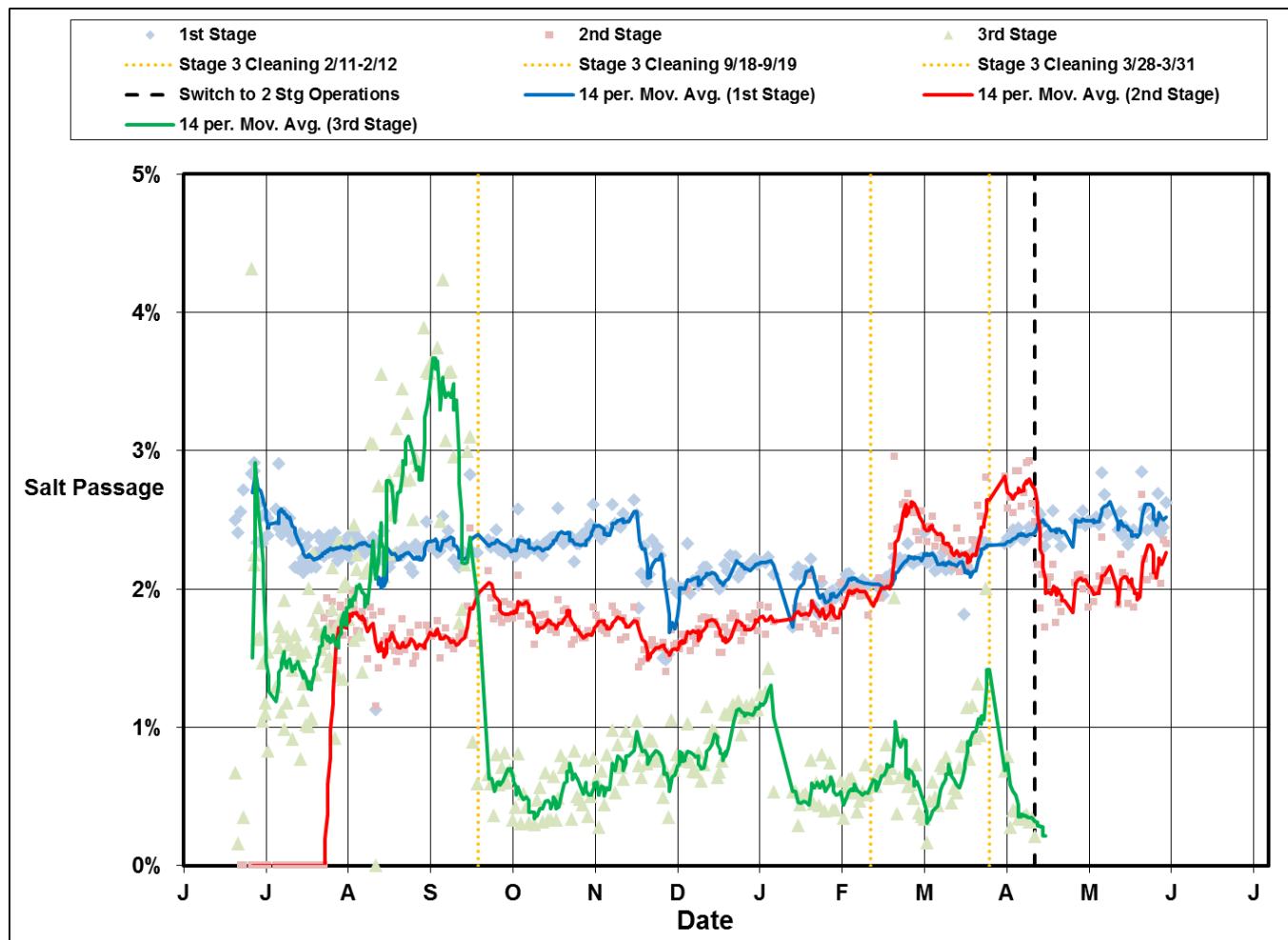
Normalized permeate flow (Figure 14) is a relative measurement of the productivity of the membranes in each stage. It is measured relative to an initial baseline flow for each membrane, and adjusted up or down based on the net pressure differential required to produce a unit increase in flux. It compensates for the effects of temperature and feed water salinity. Increases in normalized permeate flow can indicate chlorine oxidation of a membrane. Decreases in normalized permeate flow can indicate fouling or scaling on the membrane surface. The normalized permeate flow was calculated using a membrane manufacturer provided spreadsheet model.

Over time, normalized permeate flow increased in Stage 1, indicating the possibility of gradual chlorine oxidation, making the membrane more permeable to water. Normalized permeate flows were not available in Stage 2 until beginning in mid-July 2013, due to a high back-pressure in the 2nd stage permeate, which caused the 2nd-stage manual pressure gauge to “peg out” and be unrecordable. Stage 2 permeate flows also increased gradually over the testing period, following the pattern of Stage 1 closely.

From the beginning, a high pressure differential was required to obtain permeate out of Stage 3. The normalized permeate flow in Stage 3 increased only after it was cleaned in place between September 19th and September 22nd, 2014. It appears that Stage 3 was fouled at some point before the June 2013 start of the one year operating period. Harn performed a clean in place on Stage 3 prior to startup. Stage 3 experienced periods of decline in normalized permeate flow, from the beginning of records through the first clean, and from after the first clean through the second clean. High pH clean in places appeared to be most beneficial in removing fouling from the third stage. The first stage and second stage were not cleaned because they did not show any signs of fouling through net declines in permeate flow. While over the long-term, oxidation of RO membranes can lead to significant decreases in membrane performance, no major effects from the increases in normalized permeate flow were seen on water quality performance and contaminant removal in the pilot.

**Figure 14. Normalized Permeate Flow**

Normalized salt passage (Figure 15) is a measure of the percent removal of dissolved solids, measured by conductivity, that are removed by a RO stage. Whereas the normalized permeate flow measures the water productivity of a membrane versus pressure, the normalized salt passage measures the salt passing characteristics of a RO membrane. Similar to the normalized permeate flow, the normalized salt passage compensates for the effects of temperature and feed water salinity on salt passage. Increases in normalized salt passage can be the result of multiple factors such as chlorine oxidation of the membrane, scaling, a breach in a membrane element connector or gasket, or a perforation in one of the membranes. Decreases in normalized salt passage can be the result of fouling on the membrane surface by organics or biological films. The normalized permeate flow was calculated using a membrane manufacturer provided spreadsheet model.



Differential pressure (Figure 16) is a measure of fouling on the feed side of the membrane, corresponding to buildup of particles, foulant, or scale between the feed inlet and concentrate outlet end of the membrane. It is the difference between the feed pressure and the concentrate pressure. No significant net changes in differential pressure were observed in any of the stages.

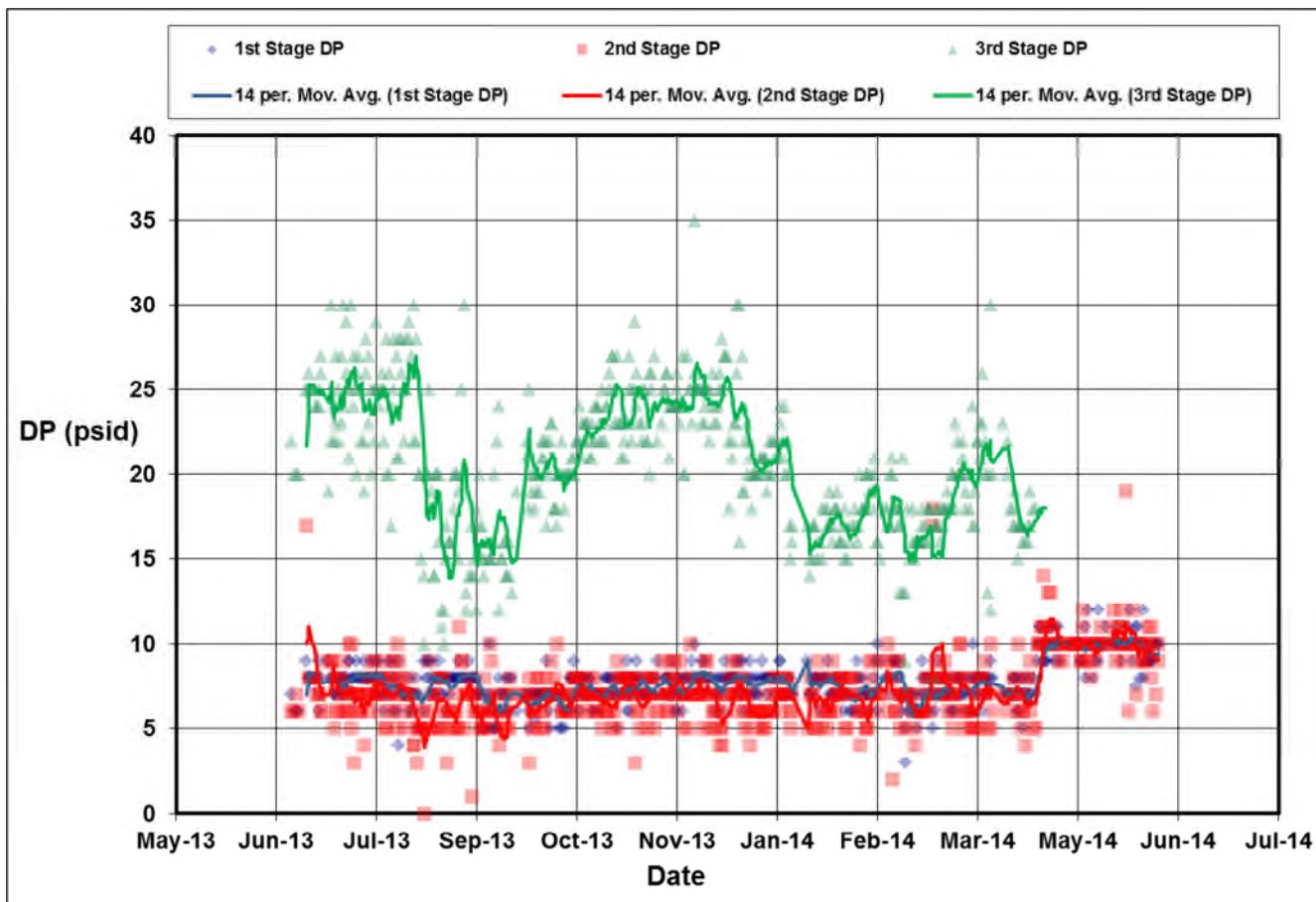


Figure 16. Differential Pressure

2.2.3 RO Clean in Place

The RO membranes in Stage 3 were cleaned on three (3) occasions (November 2013, February 2014, and March 2014) after the normalized permeate flow decreased by more than the 15-percent guideline provided by DOW. The dates of the RO CIPs are given in Table 1-1. CIPs were only performed on the third stage since most of the declines in permeate flux were seen in the third stage. Dow's technical service bulletin on membrane cleaning was used to guide the cleaning procedure, and is included in the Appendix E.

The RO membranes were cleaned using both high pH and low pH cleaning solutions. The high pH cleaning solution consisted of a 0.2-percent solution of sodium dodecylsulfate and 0.1-percent solution of caustic soda, with pH 12. The low pH cleaning solution consisted of a 0.2-percent solution of hydrochloric acid with pH 2. The CIPs were carried out with the high pH cleaning first, followed by the low pH cleaning.

A separate RO cleaning skid was used to mix, filter, and pump the cleaning solution to the RO skid. The cleaning solution was recirculated through the RO skid at a high flow for at least one hour to allow the RO foulants to be removed and washed away from the RO membranes. Additional acid or caustic soda was added as needed to adjust for pH neutralization by foulants and to maintain the target cleaning pH. After the clean in place was complete, the spent solution was adjusted to a neutral pH and discharged to the front of the water reclamation facility.

Avista technologies installed a RO "black box" in February 2014, after the third stage concentrate, to help identify the potential for scale formation in the membranes. The black box membrane included a 2.5-inch element that recovered a little bit more water from the concentrate. The 2.5-inch element was removed from the black box in

April 2014 when the system was converted from 3-stages to 2-stages. An autopsy of the element indicated that it had some calcium phosphate scale formation occurring

2.3 UV DISINFECTION AND ADVANCED OXIDATION

During the pilot testing period, the ultraviolet (UV) disinfection advanced oxidation system was operated for the destruction of organic contaminants. The contaminants were destroyed through the combined effects of direct photolysis by UV light and advanced oxidation by hydroxyl radicals that form when UV light reacts with peroxide. This section discusses operational results from the UV/AOP process, including performance on UV transmittance and challenge testing.

2.3.1 UV Transmittance

UV transmittance is a measure of the percentage of UV light at 254 nm that passes through a 1 cm cell of sample. It is important for the operations of the UV lamps. Water with lower UV transmittance requires more energy to treat than a similar water with higher UV transmittance. UV transmittance is controlled largely by the degree of UV absorbing organics in the water. The UV transmittance of the RO permeate was usually greater than 97 percent, and after UV AOP treatment, the UV transmittance increased to more than 99-percent. Removal of the lamp sleeves after the pilot testing period showed no signs of scaling on the sleeve.

2.3.2 Challenge Testing

Challenge testing was conducted using a mixed NDMA and 1,4-dioxane solution to demonstrate the log removal capabilities of the UV peroxide advanced oxidation process (AOP). NDMA and 1,4-dioxane were selected for challenge testing since these two chemicals have been used by the California Department of Public Health (CDPH) as criteria for utilities to demonstrate the treatment effectiveness of treatment of the AOP unit process. The target log removal value for 1,4-dioxane was at least 0.5 log (68-percent) removal. The target log removal value for NDMA was at least 1.2 log (94-percent) removal. The laboratory reporting limits for detection of 1,4-dioxane and NDMA were 1 µg/L and 2 ng/L respectively. The CDPH notification levels for 1,4-dioxane and NDMA are 1 µg/L and 10 ng/L respectively. Notification levels are health-based advisory levels set by CDPH for chemicals in drinking water that lack maximum contaminant levels (MCLs).

The UV-based AOP process is intended to reduce concentrations of microconstituents that are not removed by reverse osmosis. Concentrations of microconstituents are very low and often variable due to changes in community use of products and treatment plant performance. Consequently, it can be difficult to show that the UV-based AOP process is reducing microconstituents as intended. Spike testing, temporarily increases the concentration of a few target contaminants above background levels, raising the influent and effluent concentrations high enough to be measured, allowing UVAOP performance to be quantified. For each challenge test a spiking solution was prepared using the spiking compounds. In Events 1 and 2, a spiking solution was prepared with a mixture of NDMA and 1,4-dioxane. For Events 3 and 4, atenolol, was added to the spiking solution.

Sampling results have indicated that the UV-based AOP process meets the log removal goals for nitrosodimethylamine (NDMA) (1.2 log removal) and 1,4-dioxane (0.5 log removal) (Figure 17). These goals and target contaminants, were based on the California Department of Public Health's draft criteria for groundwater recharge with reclaimed water, and are widely used as a benchmark for measuring UVAOP performance in groundwater recharge applications. NDMA removal during spike testing exceeded the 1.2 log (94-percent) removal requirement formerly part of the California Department of Public Health (CDPH) Groundwater Replenishment Reuse Draft Regulation (2008). NDMA was removed below detection limits at all peroxide doses tested for all but one sample that still met the 1.2 log removal target. NDMA removal is based on UV irradiation only and does not require any peroxide addition.

1,4-dioxane removal during spike testing exceeded the 0.5 log (68-percent) removal requirement from the CDPH Groundwater Replenishment Reuse Draft Regulation (2011), when at least 2 mg/L of peroxide was added, with a peroxide residual of 1.2 mg/L leaving the reactor (Figure 18). On average, 1,4-dioxane was removed beyond the log removal target of 0.5 log removal, for tested peroxide doses greater than 2 mg/L. The removal of 1,4-dioxane was determined to be dependent on peroxide dose, with higher doses of peroxide providing greater degrees of removal of 1,4-dioxane. The 1,4-dioxane is destroyed by hydroxyl radicals that are formed when UV light activates hydrogen peroxide molecules.

Atenolol was included in the third and fourth rounds of challenge testing since it was detected once in the purified water at 16 ng/L, thus becoming the only microconstituent measured above reporting limits in the purified water during the pilot testing phase. The initial microconstituent results indicated that the pilot process removed 79-percent of atenolol (0.67 log removal) at a peroxide dose of 2 mg/L (Figure 19). Atenolol removal during spike testing exceeded the 0.5 log (68-percent) removal requirement from the CDPH Groundwater Replenishment Reuse Draft Regulation (2011), at the lowest peroxide dose tested, 0.8 mg/L. Removal to detection limits corresponds to at least 2.6 log removal, well above the 1.2 log removal value target. UV-based AOP challenge testing provided additional data to inform potential changes to the UV-based AOP operating conditions, if a higher level of treatment is desired. The laboratory reporting limit of atenolol was 5 ng/L. Performance was tested at constant UV irradiation over four hydrogen peroxide doses ranging from approximately 1 to 4 mg/L peroxide. Throughout pilot testing, the typical hydrogen peroxide dose was 2 mg/L.

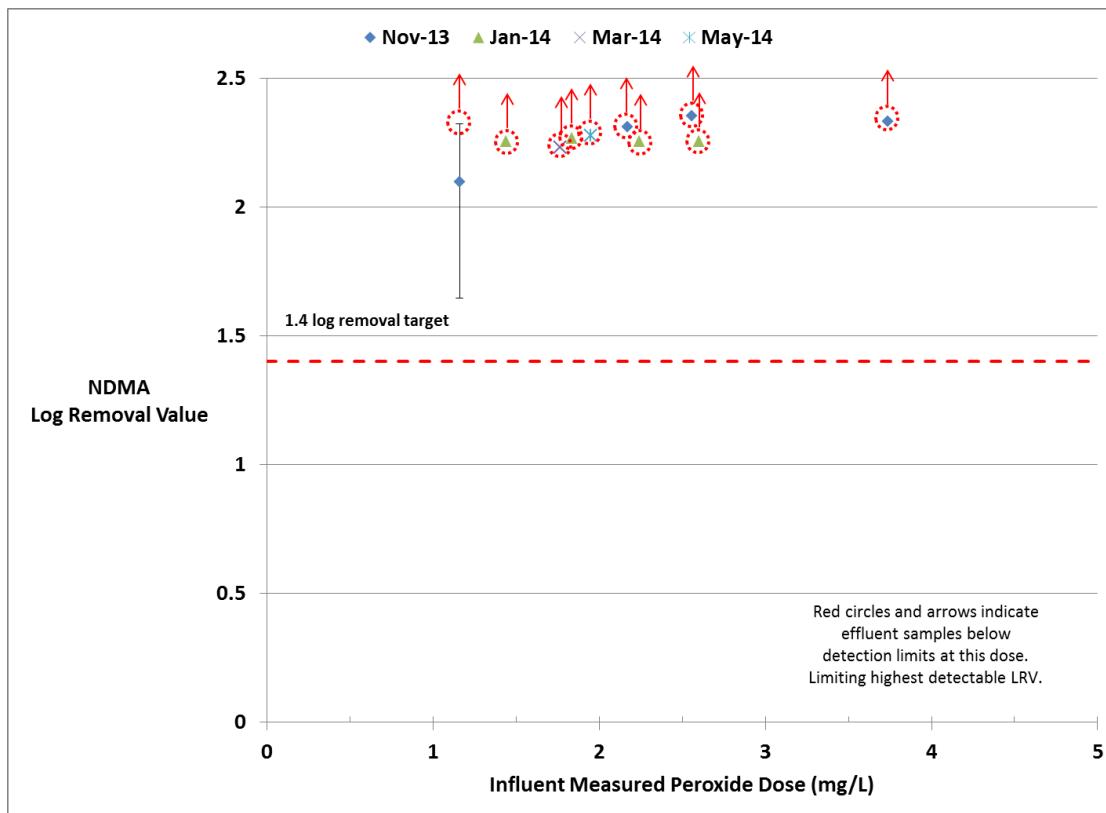
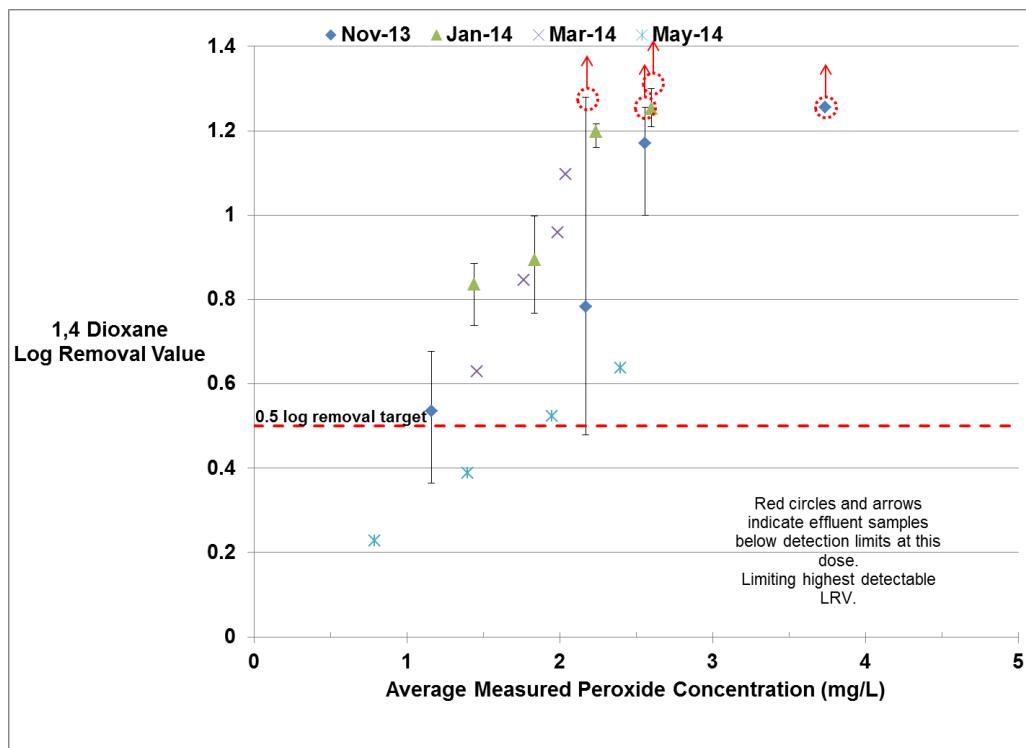
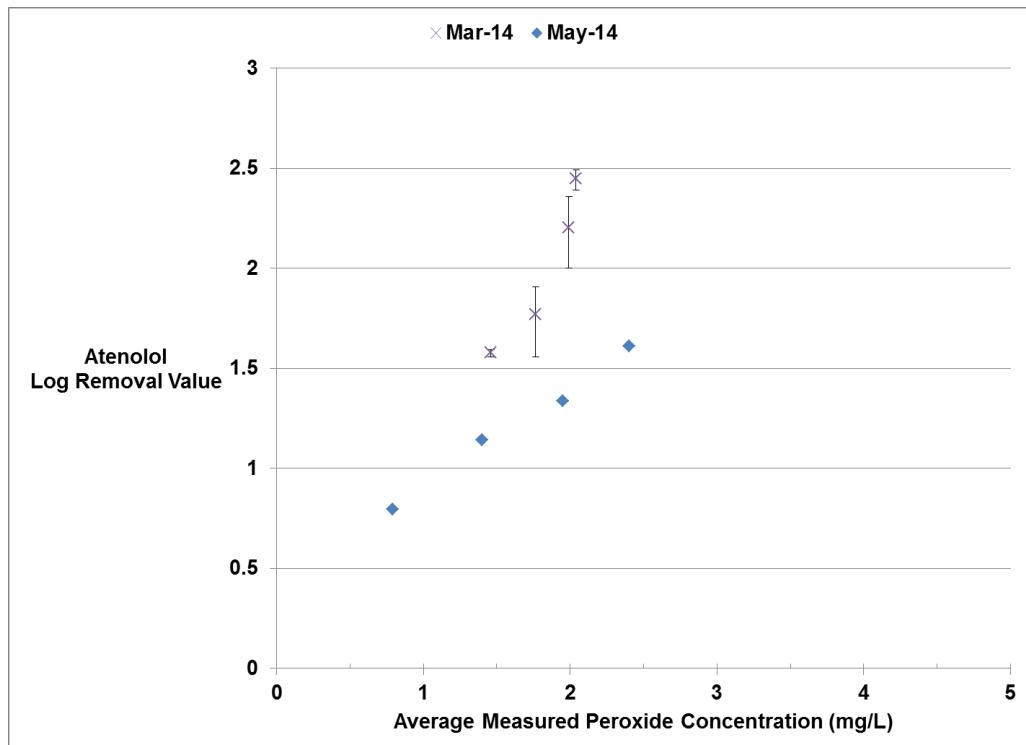


Figure 17. NDMA Log Removal Value vs. Peroxide Dose

**Figure 18. 1,4-Dioxane Log Removal vs. Peroxide Dose****Figure 19. Atenolol Log Removal Value vs. Peroxide Dose**

2.4 MEMBRANE CONTACTORS

The membrane contactor equipment used at the pilot facility utilized four membrane contactors in series intended to provide up to 4-log (99.99-percent) removal of dissolved oxygen from the purified water. This section discusses operational results from the membrane contactor process, including performance on oxygen removal, hydraulic performance and air stripping.

2.4.1 Oxygen Removal

The membrane contactors (MC) were used to remove most of the dissolved oxygen from the purified water, before post-treatment. The DO of the purified water ranged from 7 to 9 mg/L, depending on temperature, and was reduced to less than 10 µg/L consistently, often times reduced to levels nearing 1 ppb. Placement of the trace dissolved oxygen sensor immediately after the membrane contactor and before post-treatment chemical addition provided the most stable readings. There was no significant loss in performance measurable after one year of operations. Table 1-1 lists the dates for the trace DO sensor maintenance and MC system “tune up” that were carried out, to keep the system’s trace DO sensor functioning smoothly. Figure 20 illustrates a time series of the trace DO sensor readings after the membrane contactor. Before January 2014, this sensor was placed on the purified water line; however, the sensor began to degrade in performance through December, and the effluent trace DO readings increased through January 2014. At that time, the trace DO sensor was removed, and replaced with a new sensor, and isolated from the purified water. Inspection of the old DO sensor indicated that calcium particles and sodium bisulfide appeared to damage the membrane of the trace DO sensor, affecting its reading. Since January 2014, the new trace DO sensor remained stable and indicated consistent removal of DO to less than 10 µg/L.

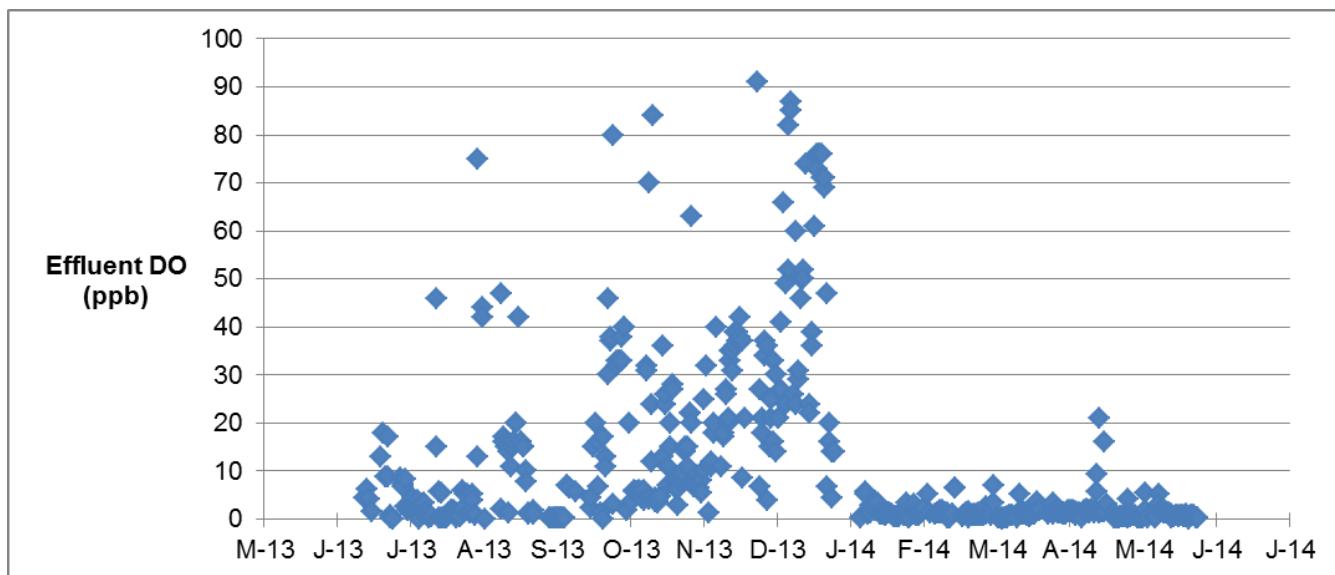


Figure 20. Membrane Contactor Oxygen Removal Results

2.4.2 Hydraulic Performance

The membrane contactor did not show any signs of fouling from particulates. Flow through the membrane contactor decreased when calcium carbonate scales built up in the purified water line, after post-treatment chemical addition, creating back pressure that reduced flow.

2.4.3 Air Stripping

One side effect of utilizing the membrane contactor process is that it not only removed DO, but also allowed for other gases such as carbon dioxide and volatile substances like chlorinated trihalomethanes to be stripped out of solution. Figure 21 shows how water increased in pH after passing through the membrane contactors, typically increasing by 0.5 to 1.0 pH units, as carbon dioxide was removed from solution. Chlorinated trihalomethane removal is discussed in Section 3.3.1.1.

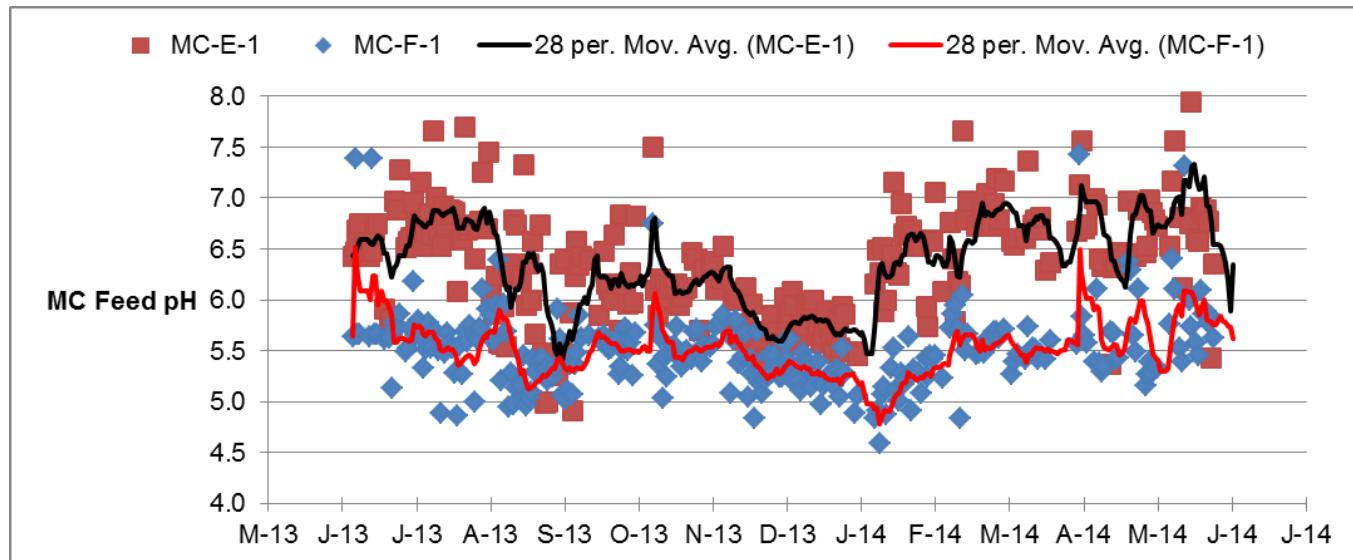


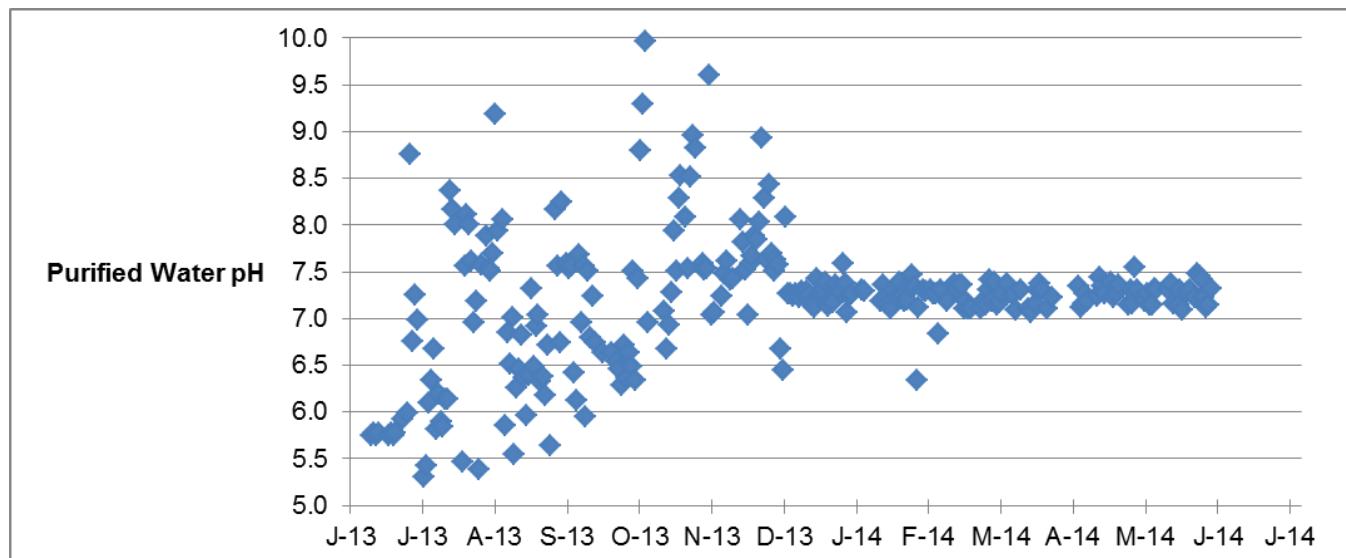
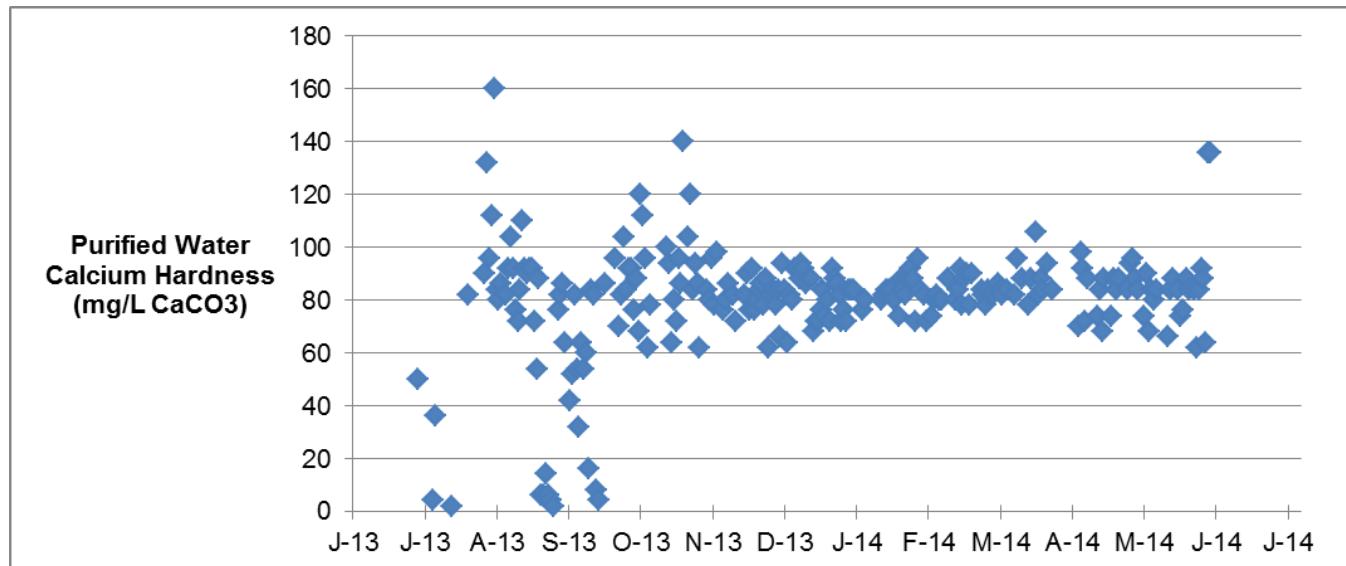
Figure 21. Change in pH through the Membrane Contactors

2.5 POST-TREATMENT

The post-treatment chemical addition system included the addition of carbon dioxide, liquid lime, and sodium bisulfide.

2.5.1 Lime Feed

Purified water pH was controlled by varying carbon dioxide addition, while maintaining a fixed calcium target concentration. It was difficult to control pH near the original pH target of 7.75 (Figure 22). Better pH stability was observed from when pH was decreased to pH 7.25, potentially due to increased buffer capacity, or more consistent feed of a larger volume of CO₂.

**Figure 22. Purified Water pH****Figure 23. Purified Water Calcium**

Lime slurry was also added in order to achieve a target purified water calcium concentration of approximately 80 mg/L as CaCO₃. Figure 23 shows the calcium feed was generally on target within about +/- 15 mg/L CaCO₃. Carbon dioxide injection and liquid lime injection were capable of stabilizing the purified water while maintaining extended steady operations. The purified water line at times experienced calcium carbonate scale formation on the inside pipe wall. This scaling was effectively monitored through tracking of backpressure and could be cleaned chemically by temporarily shutting off lime addition and depressing the pH using carbon dioxide.

Operational issues were encountered with lime feed included turbidity control, pH control, and line clogging. The issues appear to have been largely-related to the manual control feed systems associated with the pilot scale equipment. It is anticipated that a larger feed system with automatic control could show improved stability due to the ability to foresee and avoid overfeeding of lime and underfeeding of carbon dioxide. When calcium carbonate precipitation was high enough, it induced scale formation on the effluent pipe line, leading to an increase in backpressure, and decrease in purified water flow. This led to an increase in effective lime doses that

compounded the scale formation issue. As line pressure increased, pH tended to increase as the net carbon dioxide dose injected decreased. On several occasions, the pilot effluent pipeline accumulated a thin eggshell-type layer of calcium carbonate scale (Figure 24). This scaling was significant because the post-treatment chemical feed systems were manually-controlled with dosing at a constant rate. As such, as the inside of the pipe scaled up, back pressure increased, and flow through the membrane contactor decreased. Scaling in the pilot effluent pipeline could be monitored through back-pressure, and cleaned as needed with carbon dioxide to lower the pH and dissolve the scale.

Turbidity spiked above 10 NTU when the pH was targeted at 7.5. Under these conditions, the remineralization and carbon dioxide feed systems had difficulty maintaining the pH target and calcium target. Decreasing the pH target to 7.25 led to a significant improvement in pH and calcium stability, with turbidity being usually less than 10 NTU, and sometimes less than 1 NTU.

Clogging of lime feed equipment was a significant issue that led to changes in lime feed strength and lime feed equipment. Originally, a 30 percent solution of lime was added using a peristaltic pump; however the peristaltic line clogged regularly with particulate lime at this concentration. When the concentration was reduced to 15 percent and the feed pump was switched to a diaphragm type pump, the lime feed system operated more smoothly with less clogging. Even with these adjustments it was still necessary to clear the lime injector at least once per week of calcium buildup. Originally the lime feed pump injected upwards into the pipe solution; however this was modified to allow the lime to be injected downwards at a 45 degree angle. Changing the angle of lime injection did not make a noticeable difference in the frequency of lime injector clogging.



Figure 24. Calcium Carbonate Scale in the Purified Water Line

The effluent backpressure of the membrane contactors was a useful indicator (Figure 25) for tracking the extent of scaling in the pilot effluent lime. A low pH soak with carbon dioxide saturated water (pH 5) was adequate to dissolve the scale and decrease line pressures.

While a lime system would have the lowest direct chemical cost, alternative remineralization technologies are available that could operate without significant clogging, including limestone contactors, or calcium chloride injection with sodium hydroxide.

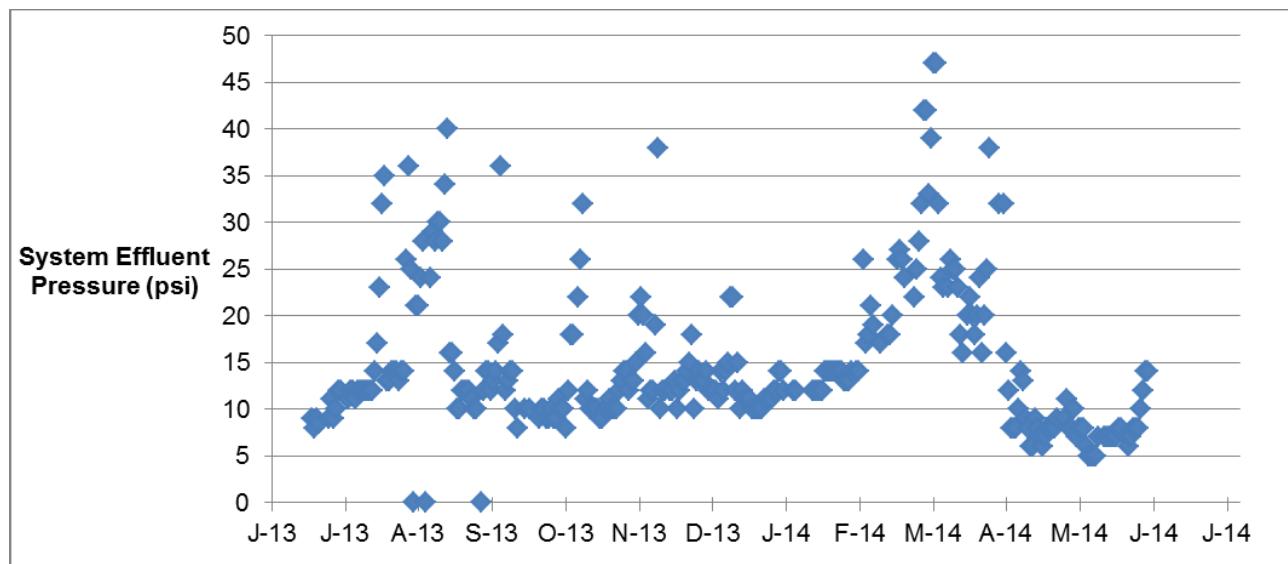


Figure 25. Membrane Contactor System Effluent Line Pressure

2.5.2 Bisulfide Feed

The bisulfide feed solution appeared to degrade over time, presumably through reaction with atmospheric oxygen. A change in color was observed in bisulfide chemicals from a bright yellow when fresh, to a reddish-brown when older (Figure 26). As bisulfide totes increased in age, a higher chemical feed rate was required to obtain the same neutralization of peroxide.

Sodium bisulfide provided effective quenching of chlorine and hydrogen peroxide. Approximately 2 mg/L of bisulfide was dosed, leaving a residual of 0.5 mg/L sulfide, after quenching the peroxide. Quenching of chlorine was rapid, going to completion within seconds. Quenching of peroxide took several minutes but could be accelerated by increasing sodium bisulfide dose.



Figure 26. Color of Fresh and Aged Sodium Bisulfide

2.6 ROCK CORE COLUMN TESTING

In Florida, mobilization of trace metals, such as arsenic, in aquifer minerals has been observed during aquifer recharge and aquifer storage and recovery (ASR). The two main water quality parameters that are thought to trigger arsenic release are high oxidation reduction potential (ORP)¹ and negative calcium carbonate precipitation potential.

Specialized rock core column testing was carried out onsite by Indewater, Inc, in order to identify potential effects of varying levels of post-treatment on aquifer minerals. Rock cores (Figure 27) were taken from the target injection zone during drilling of the aquifer recharge test well. These cores were held for use in testing and isolated from the atmosphere in pressurized cylinders filled with pure nitrogen gas. This testing technique is a recently-developed method that has not yet been widely applied around the state.

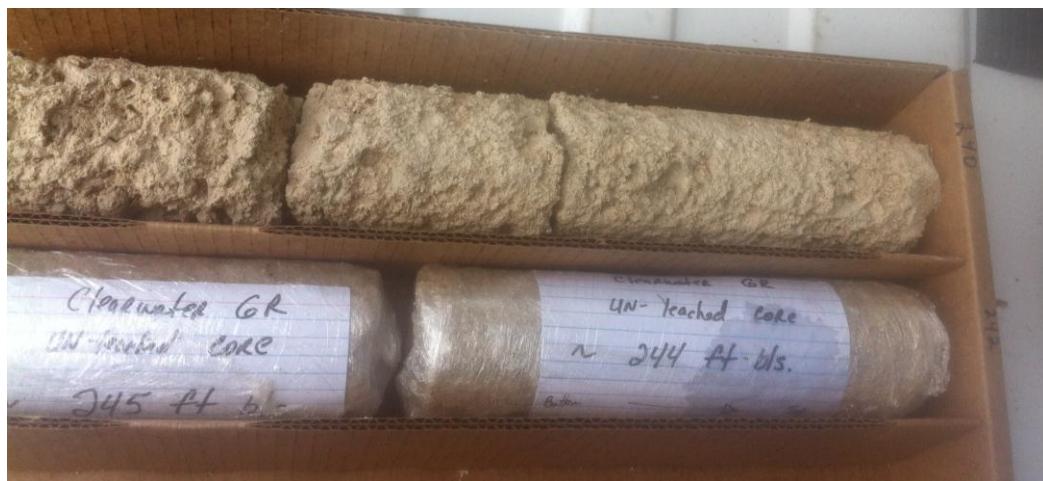


Figure 27. Rock Core Sample

Pilot post-treatment processes were selected in order to mitigate the potential for arsenic mobilization in the aquifer by reducing the ORP to match conditions in the target aquifer, and increasing the calcium carbonate precipitation potential to reduce the potential for the water to dissolve limestone. Seven different levels of post-treatment were tested using separate individual rock cores. These levels of post-treatment are shown in Table 2-1. Conditions tested included a “minimal pretreatment” option (Column 2) that only stabilized the water relative to calcium carbonate, and did not include any DO removal or bisulfide addition (for quenching peroxide and total chlorine). The most intensive pretreatment was provided by Column 6, which stabilized the water relative to calcium carbonate, removed DO to 3 parts per billion (3.5 log removal value, 99.96-percent removal), and added sodium bisulfide to fully quench peroxide and total chlorine). Another column, (Column 1), tested the native groundwater, as a “control” for the rock core testing method.

The rock cores were set up using a pressurized cylinder flow-through apparatus shown in Figure 28. Water quality samples downstream of the rock cores were taken at regular intervals during each test to identify the release profile of arsenic as water permeated through the rock sample. Details of the rock core testing procedure and results are provided in Appendix F.

¹ Southwest Florida Water Management District (2007). “Evaluation of Arsenic Mobilization Processes Occurring During Aquifer Storage Recovery Activities (H-046).”



Figure 28. Rock Core Column Testing Apparatus

Table 2-1. Rock Core Column Test Conditions

Parameter		Column						
		1	2	3	4	5	6	7
Date Tested		09/30/13	10/03/13	10/01/13	10/02/13	10/01/13	10/02/13	10/03/13
Preliminary	Native Groundwater	x	-	-	-	-	-	-
Treatment	RO/AOP	-	x	x	x	x	x	x
	Stabilization	-	x	x	x	x	x	x
	Membrane Degasification	-	-	x	x	x	x	x
	Bisulfide Addition (ppm)	-	-	-	-	2.0	2.0	2.0
Purified Water Concentration	Calcium (mg/L as CaCO ₃)	-	78	78	78	78	78	78
	pH	-	7.8	7.8	7.8	7.8	7.8	7.8
	Peroxide (mg/L)	-	1.2	1.2	1.2	0.0	0.0	0.0
	Total Chlorine (mg/L)	-	0.2	0.2	0.2	0.0	0.0	0.0
	DO (Log Removal)	-	Not Removed	2.2	3.0	2.3	3.5	1.2
	DO (ppb)	-	Not Removed	60	9.0	40	3.0	600

3.0 WATER QUALITY METHODS AND RESULTS

Over 25,000 water quality tests were performed during the testing period that demonstrated that the treatment system was capable of meeting all drinking water quality standards and anticipated groundwater recharge regulations. Beyond the 103 monitored constituents relating to existing or anticipated regulations, 101 additional unregulated constituents were also monitored including some that U.S. Environmental Protection Agency (EPA) is considering for future regulation under the Unregulated Contaminants Monitoring Rule 3 (UCMR3), organic compounds, pharmaceutically active compounds, and other microconstituents. Only two (2) of the 101 additional constituents, chlorate and atenolol, were found at quantifiable levels of detection in the purified water at any time.

Results from the water quality monitoring indicates that the purified product water from the pilot system consistently met all primary standard maximum contaminant levels (MCLs) established at the Federal and State levels, except for total trihalomethanes (TTHMs). The Federal drinking water MCLs are established by the US EPA and adopted by the Florida Department of Environmental Protection (FDEP). The purified water met all numerical secondary drinking water and MCLs, except for odor. The odor issue was concluded to be an effect of the addition of sodium bisulfide to the process water during the post-treatment step.

3.1 WATER QUALITY FIELD METHODS

Water quality testing was carried out through field testing and off-site laboratory testing. Field samples were taken as grab samples measured by operators and as continuous readings taken through online instrumentation.

3.1.1 Grab Samples

Field operators monitored the water quality performance of the pilot process seven (7) days a week though regular sampling of various water quality parameters on site. Field data notebooks were maintained for operational parameters as well as instrument parameters, and laboratory parameters. Table 3-1 illustrates field instrument parameters measured at various locations throughout the pilot.

Table 3-1. Field Instrument Parameters Monitored Daily

Parameter	Units	Method	Instrument
pH	-	SM-4500-H ⁺ B	Hach HQ11d
Temperature	°C	SM 2550 B	Hach HQ11d
DO	mg/L	EPA 360.1	YSI Pro DO
Oxidation Reduction Potential	mV	SM 2580 B	Hach HQ11d
Conductivity	µS/cm	SM 2510 B	TechPro (TP)-1
Turbidity	NTU	SM 2130 B	HF Micro TPI
UV-Transmittance	%	SM 5910 B	Realtech P200
Silt Density Index	-	ASTM D4189	Test Kit

“Laboratory” parameters were monitored daily in the field and included the parameters shown in Table 3-2, measured at various locations throughout the pilot. The difference between instrument parameters and laboratory parameters is that measurement of laboratory parameters mostly required addition of a reagent, whereas instrument parameters were reagentless.

Table 3-2. Laboratory Parameters Monitored Daily

Parameter	Units	Method	Instrument
Free Chlorine Residual	mg/L	SM 4500-Cl G	Hach DR 870
Total Chlorine Residual	mg/L	SM 4500-Cl G	Hach DR 870
Ammonia	mg/L as N	Hach Method 8155	Hach DR 870
Apparent Color	color units	SM 2120 B	Hach DR 870
Orthophosphate	mg/L as P	SM 4500-P E	Hach DR 870
Total Iron	mg/L	SM 3500-Fe D	Hach DR 870
Nitrate	mg/L as N	SM 4500 NO3-	Hach DR 870
Nitrite	mg/L as N	SM 4500 NO2-	Hach DR 870
Calcium Hardness	mg/L as CaCO ₃	SM 3500 – CaD	Titration
Total Hardness	mg/L as CaCO ₃	SM 2340C	Titration
Alkalinity	mg/L as CaCO ₃	SM 2320 B	Titration
Hydrogen Peroxide	mg/L	Ferric Thiocyanate	Chemetrics Visual Kit

3.1.2 In-Line Monitoring

Automatic monitoring devices were provided on the pilot for quick verification of crucial water quality parameters to support proper operation of the treatment equipment. The pilot plant included the following continuous monitoring devices:

- Free Chlorine Analyzer (After Chlorine Addition, Pre MF Treatment)
- Turbidity Analyzer (Post MF, Prior to Ammonia Injection)
- Total Chlorine Analyzer (Prior to RO Pretreatment)
- Free Chlorine Analyzer (Prior to RO Pretreatment)
- pH Analyzer (After RO Pretreatment Chemical Addition)
- Temperature Analyzer (After RO Pretreatment Chemical Addition)
- Conductivity Analyzer (After RO Pretreatment Chemical Addition)
- pH analyzer (Prior to MCs)
- DO (Two channels analyzing the MC feed and effluent streams)

- ORP Analyzer (Purified Water)

The analyzers were calibrated according to the manufacturer's directions and according to the SOP FT-1900 documents and monitored regularly for comparison to grab samples, and re-calibrated when appropriate. The free/total chlorine analyzers before RO pretreatment were removed from service on September 10th, 2013 after continued difficulty with measurement of low concentrations of chloramine below 1 mg/L, which led to automatic shutdowns of the RO skid.

3.1.3 Quality Management

Field instruments were calibrated on a regular basis, and checked against known standards for analytical accuracy. Field operators maintained a log of water meter checks and calibrations. All field data were entered into an Excel spreadsheet that was updated on a weekly basis, and monitored graphically through charts for parameters that were not under control. If a process appeared to be out of control, the project engineer contacted the City's operations staff to take corrective action to bring the process back into normal operating conditions.

3.2 WATER QUALITY LABORATORY METHODS

The water quality parameters tested by laboratories included general water quality parameters for physical, mineral and inorganic constituents for process monitoring and optimization, as well as post-treatment and stability considerations. In addition to these parameters, sampling of primary and secondary drinking water standards were performed on a routine basis to assess how the reclaimed water met the standards for full treatment and disinfection in Rule 62-610.563 (3)(b), FAC and to verify that the pilot treatment is able to achieve regulatory compliance. Sampling was also carried out to measure how the concentrations of total organic halogen (TOX) and total organic carbon (TOC) in the reclaimed and purified water complied with the requirements set forth in Rule 62-610.563 (3)(d) and (e), FAC Mutagenicity sampling was also carried out in accordance with Rule 62-610.563 (4)(c), FAC. Pathogen sampling was also carried out for demonstration of removal/inactivation in accordance with Rule 62-610.563 (4) (b), FAC. The actual dates of laboratory samples are listed in the Appendix.

3.2.1 Mutagenicity Sampling

Mutagenicity testing was performed as required by FAC 62-610.564. The Mutagenicity assays were performed using the "Ames Test" outlined in EPA 600/4-82-068. Although there are several documented methods for testing mutagenicity, the Ames Test was selected for three main reasons:

- The procedure has been recognized as a standard mutagenicity protocol since the early 1980s.
- The procedure requires minimal training, basic laboratory equipment, and is cost efficient
- Provides a quantification procedure that could be more easily documentable and could be explained to the general public better than other methods.

A standard commercial test kit (MUTA-CHROMOPATE™ manufactured by EBPI) was used for all mutagenicity testing. Each test kit incorporated standard 96-well microplates and can four (4) different strains (TA100, TA1535, TA97, TA98) of *salmonella typhimurium* bacteria and one strain (WP2) of *e. coli* bacteria. The reagents were prepared, then distributed into each microplate and incubated at 37-degrees C for 5 days. Mutagenicity was indicated by a positive color change from purple to yellow, which indicated that the reverse mutation of the bacteria by the sample allowed synthesis of the histidine reagent. The kit included a sterile blank, reagents, and a positive control to perform necessary quality controls.

The quantification of potential mutagenicity was performed by counting the number of wells that change color and comparing the results to the control blank using statistical significance tables. Mutagenicity testing was planned for quarterly testing (a minimum of 4 sampling events) for reclaimed (RW-1) and purified water (PW-1) samples.

The samples were performed in triplicate, and the plate counts for each sample were averaged. Additional samples were taken after incomplete peroxide quenching appeared to trigger mutagenic effects in the purified water sample bacteria.

Samples were collected in sterilized one-liter glass bottles and shipped overnight to a certified bacteriological laboratory. The following procedure was used for each strain of bacteria tested:

- Five (5) quality control microplates
- One (1) sterile sample (blank with reagents and bacteria)
- Three (3) background samples (with reagents but no bacteria)
- One (1) positive control sample (with positive control reagent and bacteria)
- Triplicate analysis of the reclaimed water (RW-1) sample
- Triplicate analysis of the purified water (PW-1) sample

Therefore a total of 11 microplates were used to investigate each bacteria strain, or 55 total microplates per sampling event. It was assumed that if the average microplate count for a sample exceeds the 95-percent confidence interval, it will be sufficient evidence of possible mutagenicity.

3.2.2 Pathogen Sampling

In accordance with 62-610.564, the pilot purified water (PW-1) was sampled for enteroviruses, cryptosporidium, giardia, and helminth ova. Sampling for pathogens was performed bimonthly. A minimum of 100 liters of sample was required to perform the pathogenic analyses. Reclaimed water (RW-1) and purified water (PW-1) samples were filtered on-site and the filters were sent to a commercial laboratory for microscopic counts and analyses. Analysis was performed in accordance with the EPA methods listed in the sampling schedule.

3.2.3 Microconstituents

The water purification process was designed to be effective at removing a wide variety of organics and small molecular weight compounds, known as microconstituents. Microconstituents include a broad range of compounds such as pharmaceutically-active agents (drugs and antibiotics), personal care products and hormones. As a part of this study, the ability of the pilot treatment processes to treat or remove microconstituents was evaluated. The expanded set of organics was measured along with the primary and secondary standards in the reclaimed water (RW-1) and the purified water (PW-1) on a monthly basis (minimum 12 sampling events). Attachment B lists the microconstituents that were analyzed. The microconstituents were measured in the reclaimed water (RW-1) and the purified water (PW-1) on a quarterly basis (in 4 sampling events). A sample of the native groundwater was taken in October 2013 before the aquifer performance test, to check for any microconstituents in the ground water.

3.3 WATER QUALITY RESULTS

The reclaimed water (pilot feed water) and purified water quality over the testing period are summarized in Table 3-3 and Table 3-4. From these tables, it is worth noting a few observations. First, the total dissolved solids levels for the reclaimed water were typically around 620 mg/L, which is about half of the original design TDS. Also, the total trihalomethanes averaged about 210 µg/L in the reclaimed water, which is above the 80 µg/L MCL. In addition, the odor in the reclaimed water is typically 1 T.O.N., which is less than the 3 T.O.N. secondary MCL.

Looking at the purified water in Table 3-4 it is evident that the total dissolved solids is typically reduced to about 90 mg/L and the TTHMs to about 70 µg/L. The odor increases to a typical value of 7 T.O.N. which is in excess of the secondary MCL for odor. As previously stated, the increase in odor was determined to derive from the addition of sodium bisulfide to the process water and should not be an issue for injection into a groundwater also containing high levels of sulfide.

Table 3-3. Reclaimed Water Quality Summary

Parameter	Units	Reporting Limit (PQL)	Min	5 th Percentile	Mean	Median	95 th Percentile	Max	No. of Samples
pH	SU	-	6.9	7.0	7.7	7.8	8.0	8.0	12
Ammonia as N	mg/L	0.04	0.011	0.015	0.029	0.026	0.043	0.063	51
Biochemical Oxygen Demand	mg/L	2	2.0	2.0	2.0	2.0	2.0	2.0	51
Bromate	mg/L	0.005	0.005	0.005	0.009	0.005	0.024	0.047	1
Calcium	mg/L	0.5	65.0	71.0	84.0	82.0	100.0	110.0	51
Chlorate	ug/L	40	0.000	0.0	76.3	0.000	441	625	2
Chloride	mg/L	2	190	196	225	220	265	270	12 ⁽¹⁾
		5	140.0	160.0	198.8	190.0	250.0	350.0	51 ⁽²⁾
COD	mg/L	25	11.0	11.0	22.6	25.0	32.0	45.0	51
Color	PCU	5	5.0	5.0	12.1	10.0	27.3	30.0	9
E. Coli	P/A	Present in 1 samples, absent in 50 samples.							51
Fluoride	mg/L	0.04	0.4	0.4	0.5	0.5	0.5	0.6	12 ⁽¹⁾
		0.1	0.120	0.280	0.445	0.440	0.603	0.870	50 ⁽²⁾
Dissolved Iron	mg/L	0.2	0.2	0.2	0.4	0.2	1.1	2.2	1
Iron	mg/L	0.1	0.020	0.021	0.039	0.025	0.100	0.100	51
Dissolved Manganese	mg/L	0.004	0.003	0.004	0.024	0.005	0.108	0.230	10
Manganese	mg/L	0.004	0.004	0.004	19.0	0.009	103	228	12
Magnesium	mg/L	0.5	7.60	8.10	10.22	10.00	13.00	13.00	51
Nitrate as N	mg/L	0.5	0.4	0.5	0.8	0.6	1.6	1.8	9 ⁽¹⁾
		0.04	0.12	0.48	0.88	0.90	1.50	1.60	51 ⁽²⁾
Nitrate Nitrite as N	mg/L	0.5	0.4	0.5	0.8	0.7	1.6	1.8	11
Nitrogen, Kjeldahl	mg/L	0.2	0.5	0.6	0.7	0.7	0.9	1.0	12
Nitrogen, Total	mg/L	0.25	0.9	0.9	1.5	1.4	2.3	2.5	11
Odor	T.O.N	1	1.0	1.0	1.1	1.0	1.6	2.0	2
Perchlorate	ug/L	1	0.000	0.0	0.0	0.000	0.023	0.052	1
Phosphorous - Total as P	mg/L	0.08	0.10	0.25	1.24	1.20	2.30	4.90	51
Potassium	mg/L	0.05	9.0	9.3	12.0	12.0	14.0	14.0	51
Selenium	mg/L	0.002	0.001	0.001	0.0	0.002	0.021	0.043	5
Silica (SiO ₂)	mg/L	0.11	11.0	12.0	14.9	14.0	21.0	21.0	50
Sodium	mg/L	0.5	100	114	136	140	150	150	12 ⁽¹⁾
		0.5	100	110	139	140	160	160	51 ⁽²⁾
Strontium	mg/L	0.005	0.2	0.2	0.3	0.3	0.4	0.4	12

Parameter	Units	Reporting Limit (PQL)	Min	5 th Percentile	Mean	Median	95 th Percentile	Max	No. of Samples
Sulfate	mg/L	0.6	47	49	70	61	98	100	12 ⁽¹⁾
		2.5	37	40	65	69	89	93	51 ⁽²⁾
Temperature	°C	0.1	19	19	25	22	37	40	12
Total Coliform	P/A	Present in 11 samples, absent in 40 samples.							51
Total Dissolved Solids	mg/L	10	530	536	621	615	736	750	12 ⁽¹⁾
		17	480	520	645	650	730	780	51 ⁽²⁾
Total Organic Carbon	mg/L	1	5.30	6.30	10.47	11.00	14.00	15.00	51
Total Organic Halides	mg/L	0.1	0.62	0.67	0.86	0.83	1.12	1.30	47
Total Suspended Solids	mg/L	1	1	1	1	1	3	7	51
Zinc	mg/L	0.02	0.015	0.017	0.022	0.020	0.035	0.051	6
Dibromoacetic acid	ug/L	1	1	2	1	2	4	5	12
Dichloroacetic acid	ug/L	1	1	3	11	10	27	28	11
Monobromoacetic acid	ug/L	1	1	1	1	1	1	1	3
Trichloroacetic acid	ug/L	1	21	24	36	39	46	0.0	12
Haloacetic Acids, Total	ug/L	1	1	18	49	49	80	100	11
Bromoform	ug/L	0.5	1.6	1.7	6.2	3.4	16.7	20.0	11
Chloroform	ug/L	0.5	31	37	81	78	130	130	12
Chlorodibromomethane	ug/L	0.5	3.2	10.2	39.7	33.5	84.2	88	12
Dichlorobromomethane	ug/L	0.054	26	29	65	68	93	100	12
Trihalomethanes, Total	ug/L	0.5	3	84	193	210	278	300	11

Notes:¹ Tested by Test America Laboratories² Tested by Southern Analytical Laboratories

Not Detected: Sulfide

Table 3-4. Purified Water Quality Summary

Parameter	Units	Reporting Limit (PQL)	Min	5 th Percentile	Mean	Median	95 th Percentile	Max	No. of Samples
pH	SU	-	6.6	6.9	8.5	8.2	11.2	11.5	12
Ammonia as N	mg/L	0.04	0.010	0.021	0.052	0.040	0.110	0.160	51
Biochemical Oxygen Demand	mg/L	2	2.0	2.0	2.4	2.0	3.5	11.0	51
Bromate	mg/L	0.005	0.005	0.005	0.009	0.005	0.024	0.047	1
Calcium	mg/L	0.5	0.2	0.4	39.8	40.0	63.0	100.0	51
Chlorate	ug/L	40	0.0	0.0	12.6	0.0	60.1	78.5	3
Chloride	mg/L	2	5.3	5.4	9.6	7.8	17.2	19.9	12 ⁽¹⁾
		5	3.9	4.5	8.0	7.4	13.5	15.0	51 ⁽²⁾
COD	mg/L	25	10.0	20.5	24.5	25.0	25.0	37.0	51
Color	PCU	5	5.0	5.0	25.9	5.0	110.0	200.0	9
Dissolved Manganese	mg/L	0.004	0.002	0.003	0.004	0.004	0.006	0.009	2
Total Coliform	P/A	Present in 0 samples, absent in 51 samples							51
Fluoride	mg/L	0.04	0.1	0.1	0.3	0.1	1.1	2.2	7 ⁽¹⁾
		0.1	0.040	0.043	0.113	0.088	0.248	0.440	51 ⁽²⁾
Dissolved Iron	mg/L	0.2	0.0	0.1	0.3	0.2	0.8	1.6	2
Iron	mg/L	0.1	0.028	0.032	0.079	0.045	0.100	1.033	51
Magnesium	mg/L	0.5	0.03	0.05	0.61	0.35	0.51	14.00	51
Nitrate as N	mg/L	0.5	0.2	0.2	0.4	0.5	0.5	0.6	5 ⁽¹⁾
		0.04	0.04	0.15	0.26	0.23	0.42	1.18	51 ⁽²⁾
Nitrate Nitrite as N	mg/L	0.5	0.2	0.2	0.4	0.5	0.5	0.6	5
Nitrogen, Kjeldahl	mg/L	0.2	0.2	0.2	0.2	0.2	0.3	0.4	2
Nitrogen, Total	mg/L	0.25	0.3	0.3	0.3	0.3	0.6	0.7	5
Odor	T.O.N	1	1.0	1.6	8.6	8.0	23.2	32.0	12
Perchlorate	ug/L	1	0.0	0.0	0.2	0.0	1.3	2.8	1
Phosphorus - Total as P	mg/L	0.08	0.01	0.01	0.07	0.02	0.05	1.01	51
Potassium	mg/L	0.05	0.7	0.8	1.1	1.0	1.4	3.8	51
Silica (SiO ₂)	mg/L	0.11	0.3	0.4	1.2	1.1	2.1	2.5	51
Sodium	mg/L	0.5	10.0	10.5	14.1	13.0	20.0	23.0	12 ⁽¹⁾
		0.5	9	10	16	13	23	83	51 ⁽²⁾
Strontium	mg/L	0.005	0.016	0.016	0.022	0.020	0.030	0.031	12
Sulfate	mg/L	0.6	0.8	1.0	5.2	4.1	13.4	17.0	12 ⁽¹⁾
		2.5	0	1	3	3	4	17	51 ⁽²⁾

Parameter	Units	Reporting Limit (PQL)	Min	5 th Percentile	Mean	Median	95 th Percentile	Max	No. of Samples
Sulfide	mg/L	1	2.4	3.2	5.8	5.0	10.5	15.0	12
Temperature	°C	0.1	19.1	19.4	27.1	21.9	47.3	47.5	12
Total Coliform	P/A	Present in 0 samples, absent in 51 samples.							51
Total Dissolved Solids	mg/L	10	50.0	62.1	103.2	100.0	149	160	12 ⁽¹⁾
		17	10	38	121	120	195	220	51 ⁽²⁾
Total Organic Carbon	mg/L	1	0.14	0.30	2.67	1.00	1.95	43.00	51
Total Organic Halides	mg/L	0.1	0.06	0.10	0.20	0.10	0.69	1.50	49
Total Suspended Solids	mg/L	1	1	1	16	5	62	124	51
Dichloroacetic acid	ug/L	1	1	1	2	1	4	5	6
Haloacetic Acids, Total	ug/L	1	1	1	2	1	4	6	5
Bromoform	ug/L	0.5	0.5	1.6	2.5	2.5	3.4	4.4	2
Chloroform	ug/L	0.5	19.0	19.6	38.6	36.0	66.5	67.0	12
Chlorodibromomethane	ug/L	0.5	1.8	1.9	6.3	3.1	21.0	40.0	12
Dichlorobromomethane	ug/L	0.054	14.5	19.2	25.2	24.5	31.8	34.0	12
Trihalomethanes, Total	ug/L	0.5	3	28	66	66	110	130	11

Notes:¹ Tested by Test America Laboratories² Tested by Southern Analytical Laboratories

Not Detected: Trichloroacetic Acid, Manganese, Selenium, Dibromoacetic Acid, Zinc, Monobromoacetic Acid

3.3.1 Regulated Constituents

3.3.1.1 Primary and Secondary Standard Samples

Results from the water quality monitoring indicated that the purified water produced from the treatment system consistently met all primary standard maximum contaminant levels (MCLs) established at the Federal and State levels, except for total trihalomethanes (TTHMs). The Federal drinking water MCLs are established by the US EPA and adopted by the Florida Department of Environmental Protection (FDEP).

Important information and observations related to these results follow:

Total Trihalomethanes

The treatment train provided effective reduction in disinfection byproduct levels. Disinfection byproducts, including total trihalomethanes (TTHMs) and haloacetic acids (HAA5), are regulated to the levels listed in the Primary Drinking Water Standards. The maximum contaminant level for TTHMs is 80 µg/L, and for HAA5 is 60 µg/L.

The treatment train consistently reduced TTHM concentration levels to between approximately 50 µg/L and 125 µg/L starting from reclaimed water concentrations ranging from approximately 150 µg/L to 300 µg/L. TTHM, is the sum of four regulated trihalomethanes: chloroform, bromodichloromethane, dibromochloromethane, and bromoform. TTHM levels were only infrequently above the 80 µg/L MCL.

On two occasions in 2013, the purified water total trihalomethanes (TTHM) were reported above the MCL of 80 µg/L with an average TTHM level of 66 µg/L (N=9) (Figure 29). The source water for the pilot water treatment

facility was taken from the reclaimed water storage tank, with an average TTHM level of 190 µg/L (N=9). Follow up testing was completed to compare the TTHMs in the reclaimed water storage tank (existing source), to two other potential source withdrawal locations, the tertiary filter effluent, and the chlorine contact chamber effluent. A TTHM sample before the reclaimed water storage tank had a TTHM level of 89 µg/L (N=1), the reclaimed water filter effluent before chlorination was 0.86 µg/L, and the reclaimed water storage tank effluent was 190 µg/L (N=1) with purified water TTHM of 56 µg/L (N=1). Relocating the source water withdrawal point upstream of the reclaimed water storage tank could help prevent TTHM formation.

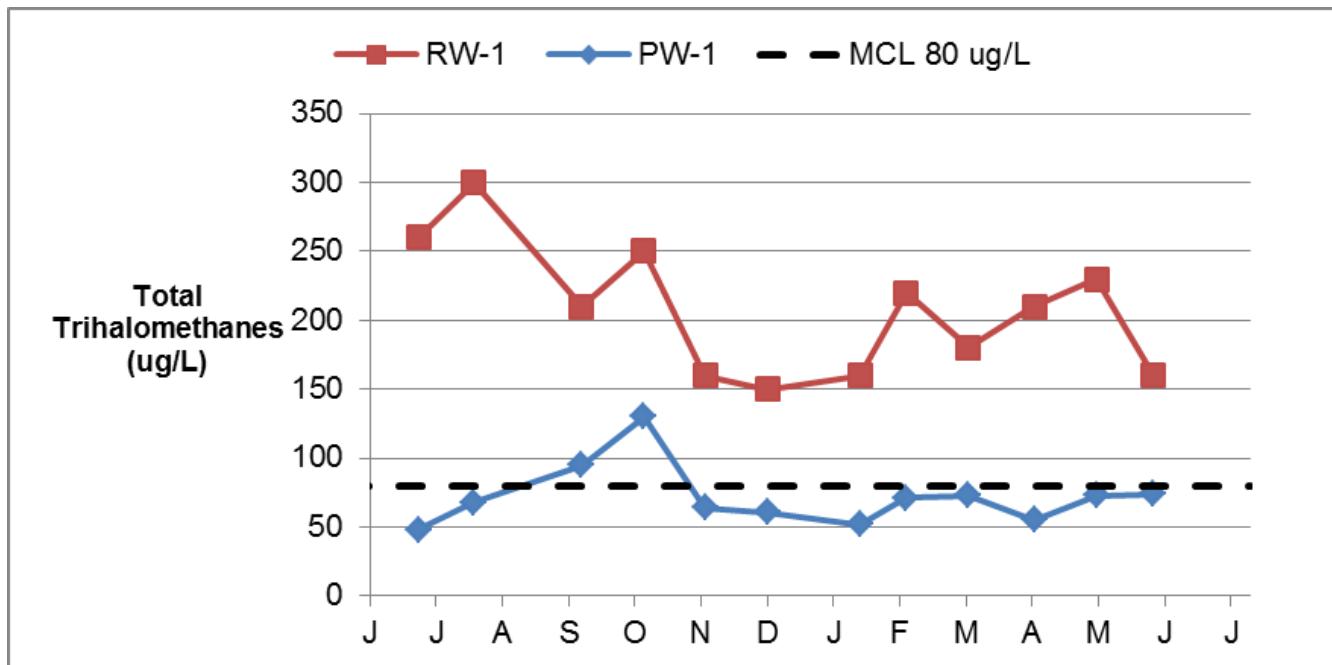


Figure 29. Total Trihalomethanes

In January 2014, after multiple high TTHMs sample results from the purified water were discovered, the pilot process was sampled for TTHMs in profile, to investigate the possibility of reducing purified water TTHM levels and to specifically identify the portions of the treatment process that were removing most of the TTHMs. Figure 30 shows the results of the system profile by location in the pilot plant. The profile includes two sample points before the pilot plant: post filters (after the reclaimed water filters) and post chlorine contact chamber. The sampling location MF-F-1 corresponds represents reclaimed water that has passed through the reclaimed water storage tank, and is before the membrane filtration step with ultrafiltration membranes.

The total trihalomethanes in MF-F-1, 190 µg/L, (corresponding to reclaimed water), were greater than the levels after the chlorine contact chamber, 89 µg/L, and after the reclaimed water filters, less than one (1) µg/L. This suggests that moving the pilot treatment source from the reclaimed water storage tank to the contact chamber effluent, could reduce TTHM concentrations by nearly 50-percent. Assuming a corresponding 50-percent reduction in purified water TTHMs, the pilot treatment system would be capable of bringing the TTHMs below the MCL. Typically, the whole pilot treatment process reduces the TTHMs by about 50-percent. This reduction is not attributable to one single process but rather several processes working in series. Reverse osmosis removes about 25-percent of TTHMs, with no significant difference by type of THM. The ultraviolet and hydrogen peroxide advanced oxidation process (UVAOP) removed about 30-percent of TTHMs, with chlorodibromomethane being much higher (85-percent removal) than the other species, and no significant removal of chloroform. Equalization tank 2 allows for UVAOP water to fall a short distance into the tank, providing natural aeration that removes approximately 20-percent of all TTHMs. The membrane contactor removed about 30-percent of TTHMs. The

difference in removal of trihalomethanes (THM) types provides insight into the specific role of each unit process in removing THMs.

Although the unit processes each provide some TTHM removal, the simplest solution to high TTHM levels would be relocating the source upstream of the reclaimed water storage tank to help minimize formation of TTHMs before treatment.

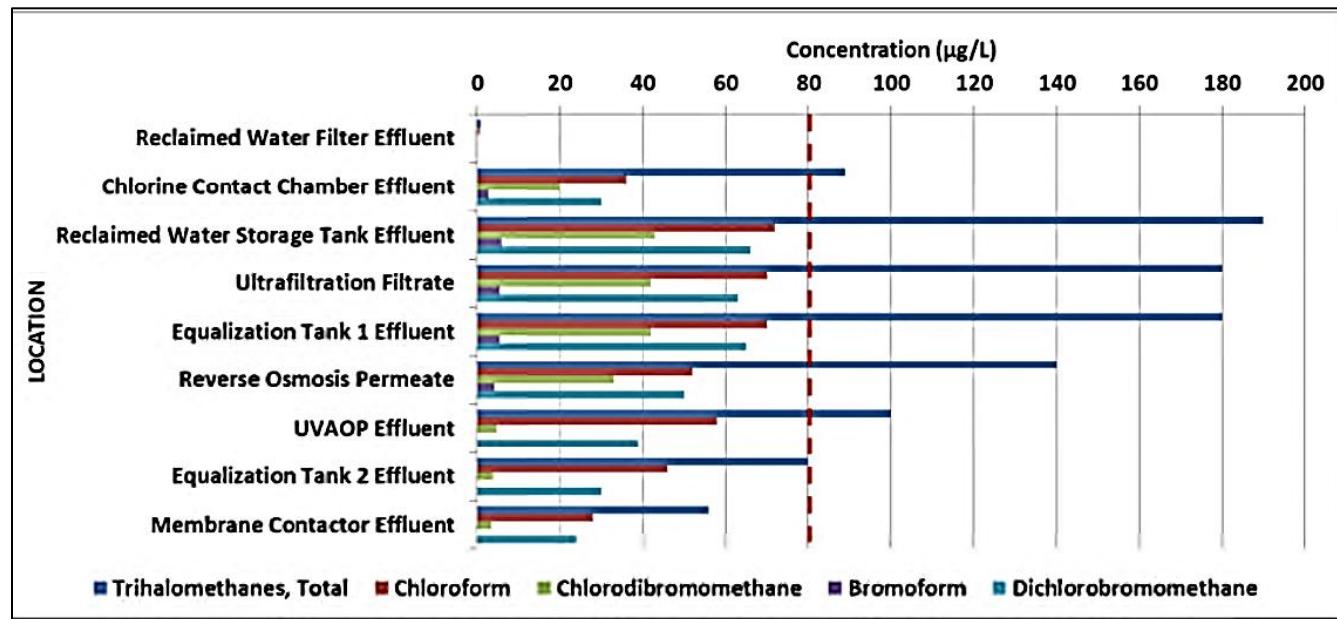


Figure 30. Trihalomethane Profile of System

The treatment train has consistently reduced HAA5 below the MCL of 60 µg/L to less than 10 µg/L starting from reclaimed water concentrations ranging from approximately 30 µg/L to 60 µg/L. HAA5 is the sum of five regulated haloacetic acids: monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid. A graph of HAA5 is shown in Figure 31.

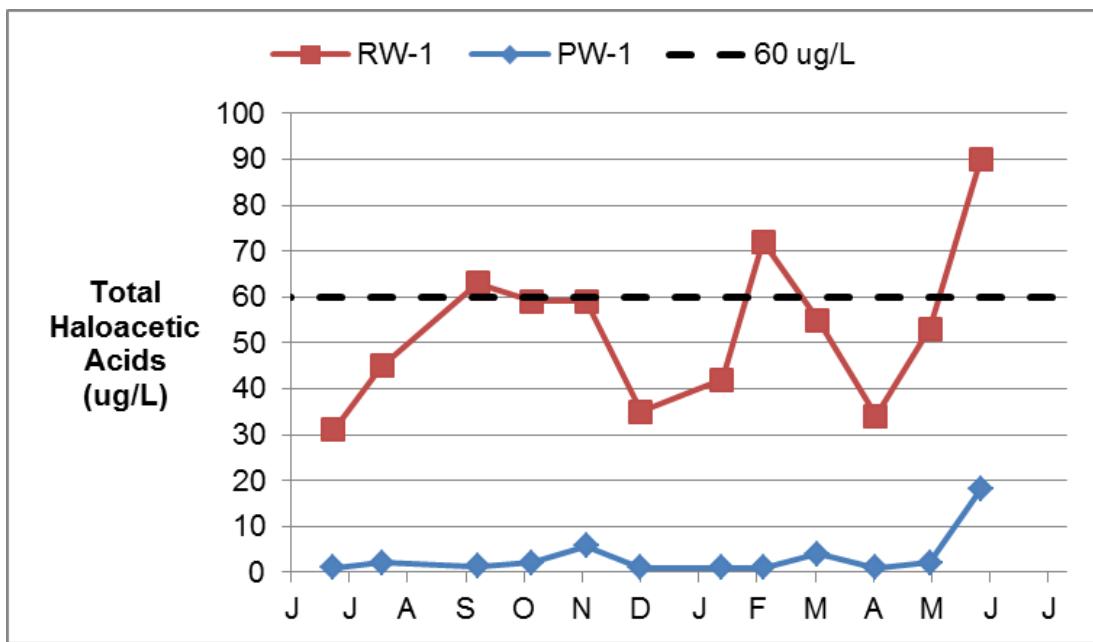


Figure 31. Haloacetic Acids

Disinfectants

Chlorine was added to the reclaimed water to provide some boost, while staying within the 4 mg/L maximum residual disinfectant level (MRDL). Chlorine levels in the reclaimed water, ultrafiltration feed, and purified water are shown in Figure 32, and reflect the boost in chlorine before ultrafiltration, and the quenching of chlorine by bisulfide in post treatment.

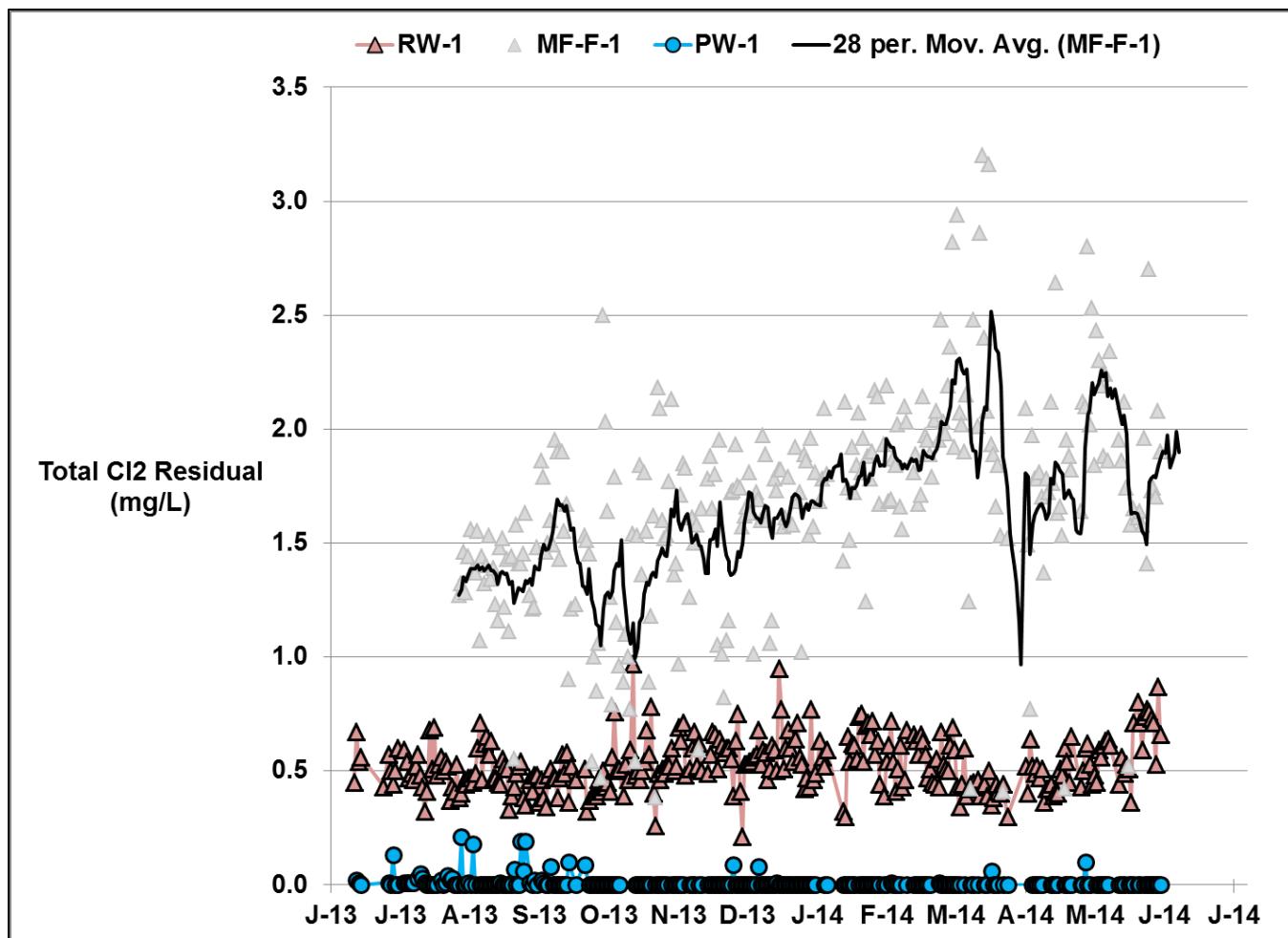


Figure 32. Total Chlorine

Another important graph to consider is one showing the chlorine to ammonia ratio (Figure 33). Ideally, the ratio should be maintained between 4:1 and 5:1 to maximize formation of monochloramines. However, the graph indicates that from about November 2013 through February 2014, the chlorine to ammonia ratio crossed the break point, several times, potentially challenging the RO membranes with free chlorine residual. As can be seen in Figure 34, the solution to this problem was to increase ammonium sulfate feed and to lower the chlorine to ammonia ratio.

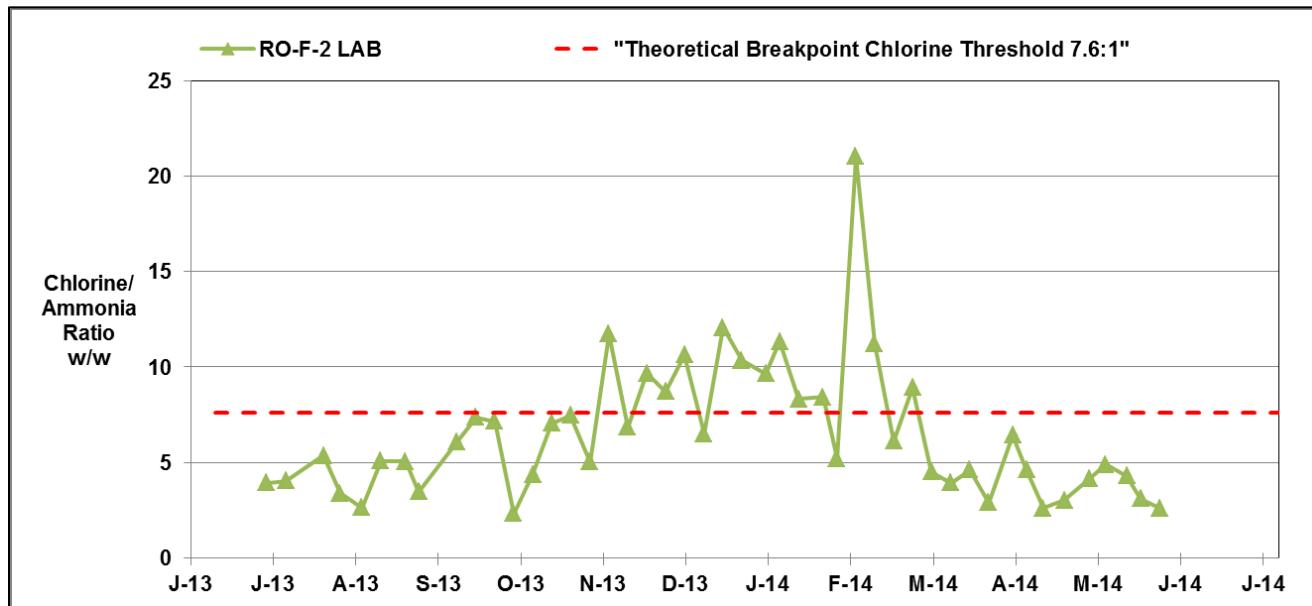


Figure 33. Chlorine to Ammonia Ratio

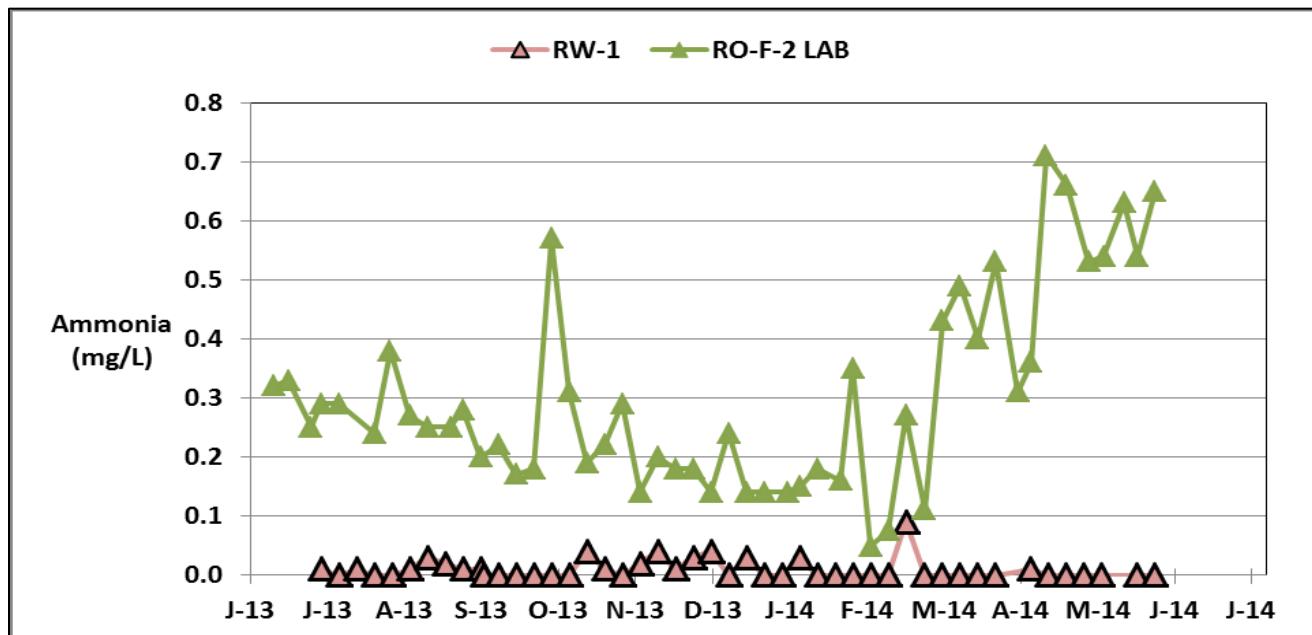


Figure 34. Ammonia

Microbial

Microbial tests for total and fecal coliform were all non-detect in the purified water (N=52). This is as expected, since the process filters should provide a tight barrier to passage of pathogens.

3.3.1.2 Secondary Standards

The purified water met all numerical secondary drinking water and MCLs, except for odor. Important observations and information related to these results follow:

Odor

The average odor of the purified water 7 T.O.N. was above the 3 T.O.N. MCL. The odor is an effect of sodium bisulfide addition during post-treatment.

3.3.1.1 FDEP Full Treatment and Disinfection Requirement

During the testing period total organic carbon (TOC) and total organic halogen (TOX) met all Florida Department of Environmental Protection (FDEP) requirements for full treatment and disinfection. The evaluation for pathogen removal demonstrated that the facilities were capable of producing water that is pathogen free. The evaluation for biological mutagenicity showed the purified water had no significant mutagenic effects.

Important observations and information related to these results follow:

Coliform Bacteria

The pilot treatment process provided full treatment for coliform disinfection. All purified water coliform samples (N=52) were non-detect.

Total Organic Halogen

During the testing period, total organic halogen (TOX) exceeded the 0.3 mg/L single sample limit five (5) times, all during the first three (3) months of operations (Figure 35). After a change in sample tap cleaning procedure, no more single limit exceedances occurred and 83-percent of the remaining samples were below the detection limit (0.1 mg/L).

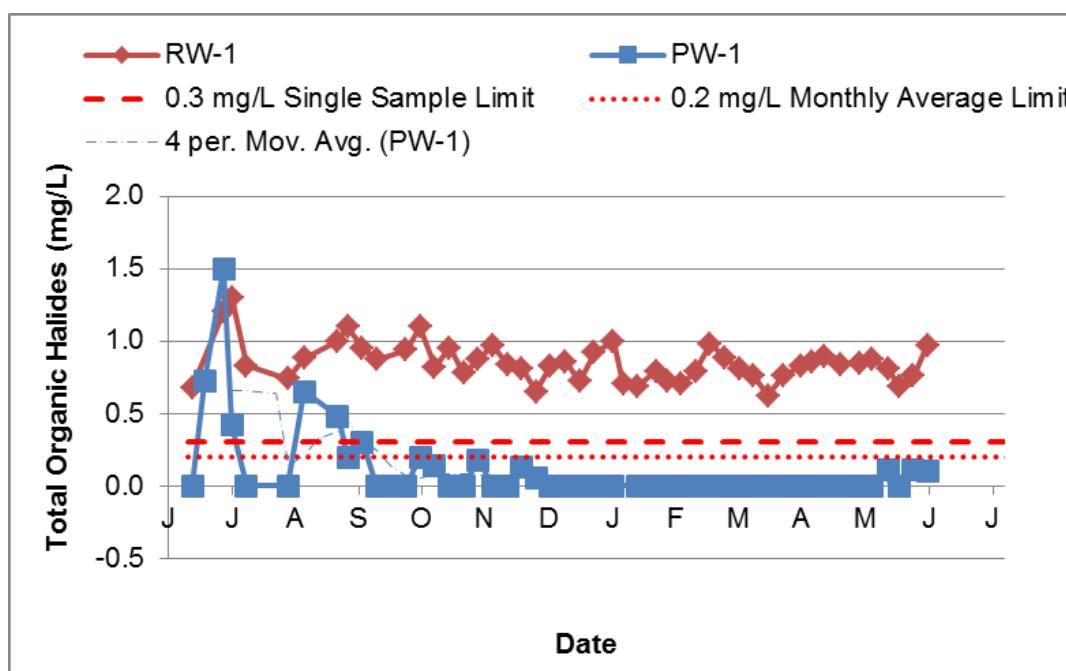


Figure 35. Total Organic Halides

Total Organic Carbon

During the testing period, total organic carbon (TOC) met the 5.0 mg/L single sample limit (Figure 36). The average purified water TOC was below the reporting limit of 1.0 mg/L (N = 51) in the purified water, with a maximum concentration of 1.9 mg/L. A single sample on January 23rd, 2014 was 43 mg/L and thrown out as an outlier, being greater than the average reclaimed water TOC of 10 mg/L (N = 49). Most of the TOC removal occurred through reverse osmosis.

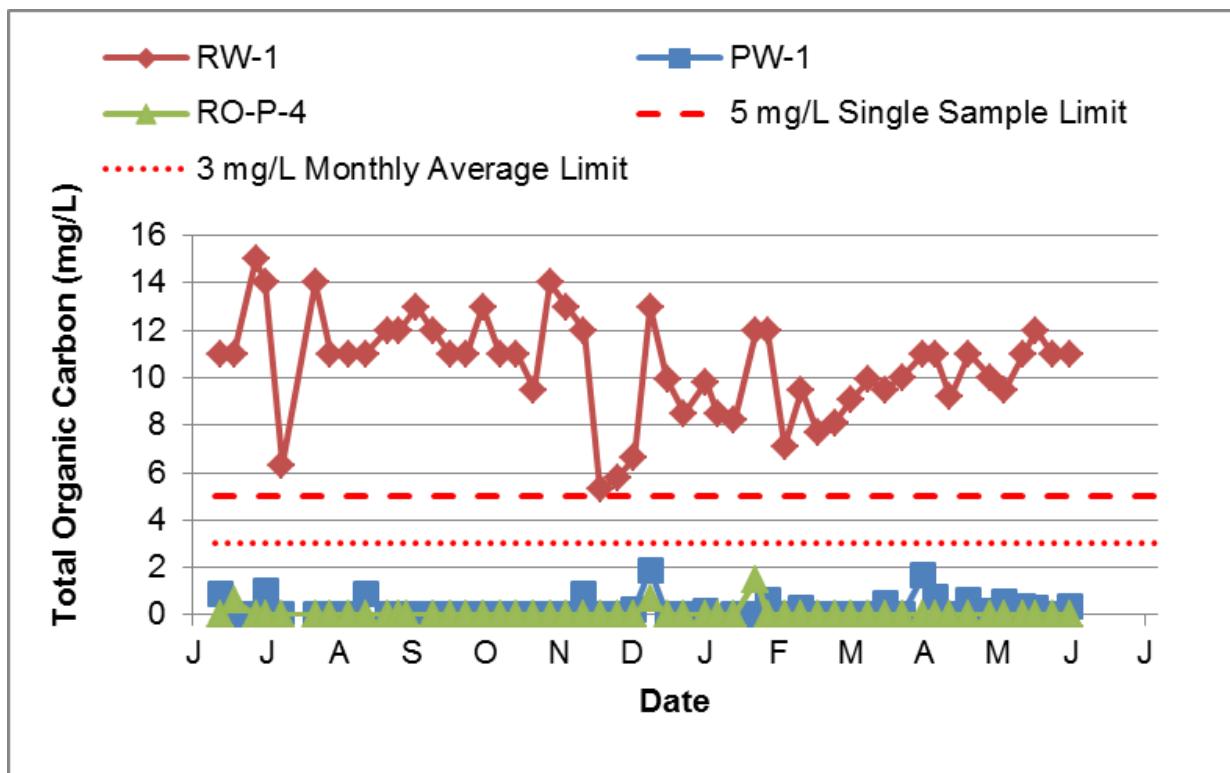


Figure 36. Total Organic Carbon

Mutagenicity

During the test period no significant mutagenic effects were observed in the purified water under normal operations. The purified water was assayed for biological mutagenicity on five sampling dates using five different bacterial test strains. In the first two sampling events (August and October) 4 of the 5 strains showed no significant mutagenic effect with some mutagenic effect being observed in one of the strains. A review of purified water quality indicated that the bisulfide was being underfed resulting in mutagenicity samples containing unquenched peroxide. Peroxide is a known mutagenic substance under the Ames' mutagenicity test. During the fifth sampling event, March 2014, the test was not able to assay WP2-strain mutagenicity due to interference in the laboratory negative control, indicating contamination of laboratory reagents.

Mutagenicity testing was performed in triplicate, and plate counts for each sample averaged. A summary of the mutagenicity test results by location, date, and strain of test bacteria is shown in Table 3-5, with the level of mutagenicity indicated by color. Early tests had shown some signs of mutagenic effects in the purified water; however, during these tests performed in August and October 2013, it was observed that sodium bisulfide was being under dosed, therefore allowing peroxide, an oxidant added to support the UVAOP process, to remain unquenched in the purified water. When peroxide was fully quenched with a slight sulfide residual of about 0.5 mg/L, no significant mutagenic effects were observed in November 2013 and January 2014.

Table 3-5. Mutagenicity Results

Sample Date	RW-1					PW-1				
	Bacterial Strain					Bacterial Strain				
	TA100	TA1535	TA97	TA98	WP2	TA100	TA1535	TA97	TA98	WP2
8/22/13										
10/8/13										
11/19/13										
1/24/14										
3/11/14										

Notes:

8/22 and 10/8 - Peroxide residuals not quenched.

3/11 - WP2 Laboratory Control showed signs of contamination within laboratory.

Green: Negligible mutagenic effects observed

Yellow: Moderate-weak mutagenic effects observed.

Red: Strong mutagenic effects observed

White: Not available

3.3.1.1 Pathogens

The purified water and reclaimed water have been sampled for multiple types of pathogens in accordance with 62-610.564(4)(b). Results from the testing period demonstrated that the facility was capable of producing a pathogen-free purified water. *Cryptosporidium*, *Giardia*, and *Enteroviruses* were all below detection limits in the purified water (N=6). On three occasions, particles suspected to be helminth ova were found in the purified water. Since helminth ova are too large to pass through the filters, it is suspected that the ova were carried in by an insect through the unscreened opening on the purified water storage tank, after UV disinfection advanced oxidation. Table 3-6 summarizes the pathogen counts from testing. A small amount of nonviable helminth ova were observed in the purified water on October 8th, 2013, December 3rd, 2013, February 4th, 2014, April 3rd, 2014, and May 27th, 2014; however, since these helminth ova were nonviable, they would not present any risk of infection.

Sampling results have indicated that the treatment train is providing effective treatment for removal of coliform bacteria. The purified water and reclaimed water have been sampled for total coliforms and *Escherichia coli* bacteria on a weekly basis using a presence/absence method. In the purified water, neither total coliform bacteria nor *E.coli* have been detected after 33 weekly samples. In the reclaimed water, *E.coli* have been present in one (1) out of 33 weekly samples and total coliform present in 11 out of 33 weekly samples.

Table 3-6. Pathogen Results

Pathogen	Units	Raw Water						
		Date	07/19/13	10/08/13	12/03/13	02/04/14	04/03/14	05/27/14
Cryptosporidium	Oocysts/100L	16.3	14.4	3.2	1.3	<1.4	1.3	
Enteroviruses	Infectious Units/ 100L	BDL	BDL	BDL	BDL	BDL	BDL	
Giardia	Oocysts/100L	2.8	12.5	7.0	22.6	<1.4	BDL	
Helminth Ova	Total ³ ova/L	45.0	27.0	26.0	12	375	324	
	Viable ova/L	BDL	BDL	BDL	BDL	BDL	BDL	
Pathogen	Units	Purified Water						
		Date	07/19/13	10/8/13 ⁽¹⁾	12/3/13 ⁽¹⁾	02/04/14 ⁽¹⁾	04/03/14 ⁽¹⁾	05/27/14 ⁽¹⁾
Cryptosporidium	Oocysts/100L	N/A ⁽²⁾	BDL	BDL	BDL	BDL	BDL	BDL
Enteroviruses	Infectious Units/ 100L	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Giardia	Oocysts/100L	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Helminth Ova	Total ⁽³⁾ ova/L	BDL	0.07	0.16	0.07	0.10	0.16	
	Viable ova/L	BDL	BDL	BDL	BDL	BDL	BDL	

Notes:¹ Sampled from membrane contactor effluent (MC-E-1) to avoid turbidity interference from lime addition.² Turbidity interference from lime addition in the purified water interfered with pathogen counts for 7/19/13.³ None of the ova were found to be viable, and therefore do not pose any infection risk.⁴ The presence of pollen, insect eggs, and larvae from insect excrement complicate the process of enumeration as they resemble microscopically the Ova that are being enumerated. Pollen, eggs, and biologicals may be misclassified as ova even by a trained person. Additionally, if insects gain access to the water system, then it is possible that they would release ova as part of the insects' natural life cycle.

3.3.2 Non-Regulated Constituents

101 additional nonregulated constituents were monitored in the purified water and the reclaimed water. These constituents included 62 unregulated microconstituents and pharmaceutically active compounds and 39 other unregulated organics. Of the 101 nonregulated constituents sampled for at the pilot facility, only two constituents, atenolol and chlorate, were detected in the purified water at any time.

Atenolol, a blood pressure medication, was detected in the purified water in one sample at 16 ng/L in January 2014. Four other samples for atenolol in the purified water were below the 5 ng/L detection limit. This is below the

risk reference level for atenolol, 70,000 ng/L². Atenolol was detected in the reclaimed water in two samples; one at 75 ng/L in January 2014 and one other at 25 ng/L in March 2014. Three (3) other samples for atenolol were below the 5 ng/L detection limit in the reclaimed water.

Among the other non-regulated constituents, chlorate, a disinfection byproduct, was detected in the purified water on three occasions with a maximum concentration of 52 µg/L, average 42 µg/L (N=3). This is below the health reference level for chlorate, 210 µg/L³. The maximum concentration in the reclaimed water was 490 µg/L with an average of 360 µg/L (N=3).

3.3.2.1 Microconstituents

The pilot water purification process was designed to be effective at removing a wide variety of unregulated organics and small molecular weight compounds, known as microconstituents. The microconstituents analyzed include compounds spanning a broad range such as pharmaceutically-active agents (drugs and antibiotics), personal care products and hormones. A summary of microconstituent concentrations in the reclaimed water and purified water are shown in Table 3-6. Over the course of five separate sampling events, 30 out of 62 microconstituents were found in the reclaimed water above the minimum reporting limit. Sampling results have indicated that the treatment train is effectively reducing nearly all microconstituents tested to below minimum reporting levels. Two compounds, atenolol and chlorate, were reported in the purified water, but were below the health and risk reference levels. The minimum reporting limit is the smallest measured concentration of a substance that can be reliably measured by using a given analytical method.

12 out of the 30 microconstituents were detected all five times, including: sucralose, iohexal, TCEP, Lopressor, TCPP, Primidone, Carisoprodol, Carbamazepine, Dehydronifedipine, Dilantin, Atrazine, and Cotanine. These compounds could potentially be used as indicators for monitoring treatment process performance.

In the aquifer water, none of the 62 microconstituents tested were found above the minimum reporting limits. A deionized water field blank was collected to identify microconstituents that may have come from the sampling technician and were not present in the water samples. It had no microconstituents above the minimum reporting limit, suggesting that field collection did not contribute significantly to detection of any microconstituents.

Atenolol is the only microconstituent that has been found above reporting limits in the purified water. Atenolol is a high blood pressure medication. In October 2013, it was not detected in the reclaimed water; however, in January 2014, it was detected in the reclaimed water at a concentration of 75 ng/L. The pilot treatment train removed 79-percent of atenolol from the water, resulting in a purified water concentration of 16 ng/L. This concentration is above the analytical laboratories minimum reporting limit of 5 ng/L. Without a regulatory limit for atenolol, some other point of reference is needed in order to understand the significance of the reported concentration.

In order to quantify the risk of adverse health effects from unregulated chemicals, the National Research Council states that a Margin of Safety (MOS) can be used. This MOS is the ratio of a contaminant-specific risk reference value and the concentration of the contaminant in the purified water. An MOS greater than one suggests that the contaminant in the water is unlikely to pose significant risk of adverse health effects. A risk reference value for atenolol of 70,000 ng/L has recently been reported in the potable reuse literature. Since the concentration of atenolol measured in the purified water was 16 ng/L, the MOS is 4,375, indicating that 16 ng/L of atenolol is not likely to pose significant risk of adverse health effects. A person would need to ingest nearly 33,000 gallons of purified water in one day to receive the minimum prescribed therapeutic dose of atenolol.

² WateReuse Research Foundation. "Potable Reuse: State of the Science Report and Equivalency Criteria for Treatment Trains."

³<http://water.epa.gov/scitech/drinkingwater/dws/ccl/upload/Preliminary-Regulatory-Determinations-3-June-16th-Public-Meeting-Slides.pdf>

Table 3-7. Microconstituent Concentrations

Item	Reporting Limit (PQL) (ng/L)	Reclaimed Water ⁽¹⁾ (ng/L)		Purified Water (ng/L)	
		Average ⁽²⁾	Maximum	Average ⁽²⁾	Maximum
Sucralose	100	47,400	56,000	ND ⁽³⁾	ND
Iohexal	10	726	980	ND	ND
TCEP	10	266	400	ND	ND
Lopressor	20	230	350	ND	ND
Hexachlorocyclopentadiene	50	211	760	ND	ND
TCPP	100	198	430	ND	ND
Acesulfame-K	20	184	740	ND	ND
Primidone	5	158	170	ND	ND
TDCPP	100	154	390	ND	ND
Carisoprodol	5	135	300	ND	ND
Carbamazepine	5	134	190	ND	ND
Dehydronifedipine	5	98	200	ND	ND
Dilantin	20	90	120	ND	ND
Meprobamate	5	70	200	ND	ND
Acetaminophen	5	46	220	ND	ND
Caffeine	5	26	120	ND	ND
Atrazine	5	23	30	ND	ND
Atenolol	5	21	75	5.2 ⁽⁴⁾	16 ⁽⁴⁾
DEET	10	20	64	ND	ND
1,7-Dimethylxanthine	10	18	71	ND	ND
Fluoxetine	10	17	28	ND	ND
Methylparaben	20	15	34	ND	ND
Cotinine	10	12	18	ND	ND
Diuron	5	8.4	32	ND	ND
Gemfibrozil	5	6.3	14	ND	ND
N-Nitroso-dimethylamine (NDMA)	2	4.7	5.5	ND	ND
DEA	5	4.0	10	ND	ND
Sulfamethoxazole	5	3.3	6.5	ND	ND
Diazepam	5	3.1	5.3	ND	ND
4-androstene-3,17-dione	0.3	0.30	0.41	ND	ND

Notes:¹ “Reclaimed water” prior to purification process.² Average calculated with observed concentrations, and observations below reporting limit counted as half the reporting limit.³ ND-Not-detected.⁴ Atenolol was below the reporting limit of 5 ng/L four times and measured at 16 ng/L on one occasion.

4.0 RECOMMENDATIONS FOR FULL-SCALE DESIGN AND CONSTRUCTION

This section describes the design recommendations for full-scale implementation of the pilot treatment process, drawing on water quality results, process optimization techniques and lessons learned during the operation of the pilot purification process.

4.1 MEMBRANE FILTRATION

Universal Pressurized UF Membrane Skid

The pressurized Dow UF module that was pilot tested is one example of several membrane manufacturers who have begun offering only membrane modules for sale in the commercial marketplace, in lieu of only selling membrane modules as part of a package system, which was previously the standard manner in which these systems were procured. Although UF modules from each manufacturer still have proprietary differences in terms of fiber type, membrane area, flow direction, connection size, and other details, there has been a significant degree of convergence towards standard module dimensions and configurations. This change in commercial UF membrane offerings has brought forth the possibility of construction of a UF system based on a “universal” UF system rack that will be compatible with multiple manufacturer’s modules. The benefits of this alternative are increased competitive pricing for membrane modules in the initial system construction (capital cost savings) as well as a reduction in the costs to change to different membrane manufacturers in the future when membrane replacement is necessary (O&M cost savings).

Source Water Withdrawal Point

The membrane filtration process should withdraw source water from before the reclaimed water storage tank or before the chlorine contact chamber. This recommendation will provide additional buffer between treatment operations and the TTHM MCL by minimizing the free chlorine reaction time with reclaimed water in order to reduce the formation of TTHMs in the reclaimed water supply.

Evaluate CEB Versus CIP Operations

A review of CEBs and CIP operations should be included as part of the preliminary and final design considerations. From pilot operations it was observed that a higher frequency of low pH CEB operations would be beneficial to maintaining low operating pressures in the UF process. A recent trend in newer UF systems is a switch from routine CEB operations for maintenance to moderate duration CIP cycles that are automated and performed on a more frequent basis. The driving force behind this change is to increase the effectiveness of routine preventative cleaning of the membranes by providing longer soak time of the membranes in the cleaning solution. Additionally, it is believed that this practice increases the effectiveness of membrane maintenance and reduces the chemical use for these operations. Additional process design considerations for this approach include extending the design offline time, which will increase the process equalization storage volume between the UF and RO processes.

Backwash Water Recovery

Limited sampling of backwash water indicated that it could be of comparable quality to the reclaimed water entering the pilot plant. The ultrafiltration membranes were operated at 94-percent recovery with 6-percent of feedwater being used for backwashing. Most of this water could be recovered for beneficial reuse by blending into the reclaimed water storage tank for public access reuse irrigation, or potentially returning it to the water reclamation facility, upstream of the tertiary media filters.

Backwash Water Tank

Low chlorine residuals in the UF pilot system backwash tank were a suspected factor contributing to periods of rapid fouling in the membrane filters. UF filtrate was used to fill the backwash tank. Several times during the pilot, the backwash tank was drained and bottom sediment removed. An evaluation of potential alternatives should be performed in the preliminary and final design to address this concern. Possible alternatives for consideration include the use of opaque tanks to avoid algae growth, use of purified water, installation of a supplemental chlorine feed system to the fill line of the tanks, and redundant backwash tanks to allow routine tank draining and cleaning without impacts to operations.

4.2 REVERSE OSMOSIS

RO Feed Water Ammonia Monochloramine Monitoring

Use of free chlorine analyzers should be avoided on the water supply to the RO system as these units are subject to interference from monochloramine. Instead, the use of an analyzer than continuously monitors free ammonia and ammonia monochloramine levels in the RO feed water should be provided upstream of the RO system to help prevent exposure of the reverse osmosis membranes to free chlorine. It should also be noted that the use of an ORP analyzer alarm for protection of the RO membranes only provided a gross order-of-magnitude indication of the presence or absence of free chlorine. In spite of these challenges the RO membranes maintained effective removal of targeted constituents during the pilot testing; however, wide variations in reclaimed water chlorine residuals presented challenges for the manual control ammonia dosing during the pilot system operations. The free ammonia monitoring provided by an on-line analyzer will ensure that a consistent chlorine to ammonia ratio can be maintained in the full scale facility.

Two Stage RO Configuration

Operation of the RO system at recovery rates of approximately 85-percent is feasible with a three stage RO treatment process, however some scaling of calcium phosphate was observed in the 3rd stage. The observed scaling was able to be mostly recovered through cleaning, however a three stage RO system would be expected to have higher capital cost and energy use than would be possible utilizing a two stage RO process. Pilot operations of a two stage RO process indicated stable operations with beneficial reductions in feed pressure and no observed scaling when operated at 80-percent recovery.

Implementation of a two-stage RO system for the full scale treatment facilities will provide benefits of lower energy use, lower initial capital costs, and simplified system control for flux balancing when compared to a three stage RO configuration. The recommended two stage RO process should be designed to operate with recovery rates ranging from 80-percent to 85-percent to allow optimization of RO operations and testing of alternate scale inhibitor chemicals to minimize membrane scaling and need for cleaning, as well as to make the best use of available reclaimed water resources.

In addition to the two-stage system, the installation of an additional “canary” pressure vessel on the total concentrate line leaving the system is recommended for the full scale facility to operate at a higher recovery for testing of recovery limits and to serve as an indicator of potential scaling in the system. Alternative, removable “black-box” systems may also be considered, which provide a similar capability to test the limits of recovery with lower construction costs.

RO Permeate Flux Balancing

The reverse osmosis pilot process utilized an interstage boost pump between the first and second stages to balance flux between the stages and account for higher osmotic pressure requirements in the 2nd stage. An interstage booster pump should be considered for the full-scale facility in order to reduce energy requirements, however acceptable membrane elements and configurations from other membrane manufacturers should also be considered when combined with alternate methods of flux balancing to provide equal performance and energy

use without the need for additional pumping equipment. The full scale design specifications should be flexible as to allow for alternate system configurations to provide the best value to the project.

4.3 UV DISINFECTION AND ADVANCED OXIDATION

Optimize UV Reactor Design and Peroxide Dose

The UV advanced oxidation process demonstrated effective removal of the spiked challenge contaminants during testing. The UV reactor design should maintain the level of treatment provided during testing, while looking for enhancements to UV reactor hydraulics or smaller sequential reactors to reduce capital and O&M costs.

The peroxide dose should be high enough to maintain effective log removal of 1,4-dioxane, verifiable through full-scale challenge testing. Excessive peroxide addition should be avoided, because it increases O&M costs for hydrogen peroxide and sodium bisulfide, while increasing capital costs by requiring a larger peroxide quenching tank. The pilot testing results indicated that two (2) mg/L of peroxide was effective for 1,4-dioxane removal; however, this should be verified as a part of full scale testing.

4.4 MEMBRANE CONTACTORS

Dissolved Oxygen Removal Basis of Design

While the membrane contactor pilot unit was capable of reducing trace dissolved oxygen to 1 part per billion (ppb), this degree of dissolved oxygen (DO) removal may not be geochemically necessary to mitigate metals mobilization in the aquifer. For example, in order to increase from 1–log (90-percent) removal to 4–log (99.99-percent) removal, the number of membrane contactors and footprint are quadrupled. When the rock core column test and geochemical modeling are complete, hydrogeologists and geochemists should provide guidance as to the necessary dissolved oxygen target that is protective of the aquifer based on available information.

Sweep Gas Considerations

The full scale membrane contactors should consider use of measures that would reduce the operating expense of the process. This would include finding the proper balance between sweep gas flow rates and vacuum pump capacity. Additionally, full scale design should compare the costs associated with refrigerated storage of bulk delivered nitrogen gas, versus on-site generation of nitrogen gas.

Dissolved Oxygen Monitoring

Optimal performance of the trace dissolved oxygen (DO) sensor was observed when the sensor was located downstream of the membrane contactor system and upstream of the lime slurry and sodium bisulfide chemical addition points. Additionally, two (2) trace DO sensors are recommended for the full-scale design, with one serving as the lead sensor and the other as backup.

Evaluate Anticipated Membrane Life

The membrane contactors provided effective removal of dissolved oxygen during the one year pilot test period, without significant signs of fouling; however, a membrane autopsy of the lead membrane element identified decreases in tensile strength of the membrane fibers that could indicate membrane oxidation or mechanical stresses to the fiber which could shorten the useful life of the membrane contactor elements. Further testing of the remaining membrane contactors is recommended to identify if the loss in mechanical strength was limited to the first membrane contactor, or was uniform through the four contactors. Depending on the findings of the investigation, possible actions may include: increased membrane replacement or adjustments to chemical addition.

4.5 POST-TREATMENT

Provide Adequate Carbon Dioxide Injection Turndown

The carbon dioxide injection system should provide adequate turndown for fine control of pH after the membrane contactors. The membrane contactors not only remove dissolved oxygen but also acted as degasifiers, removing carbon dioxide from the purified water, resulting in a water with very little buffering capacity. The carbon dioxide system on the pilot was operated manually at the lower end of the rotameter and control throttling dosing whatever valve, making it difficult to adjust the pH precisely. This factor contributed to early inconsistent pH levels that were resolved at a lower pH target with a higher, more repeatable CO₂ feed rate.

Post-Treatment Chemical Feed Automation

During the pilot study, manually controlled post-treatment chemical feed systems were used for carbon dioxide, lime slurry, and sodium bisulfide. This manual control concept for the post treatment pilot testing was partially due to the costs of providing automation of these processes and also to maintain simplicity of the pilot operations, when combined with scaling of the piping with calcium carbonate, these manually controlled chemical feed systems led to a chain reaction scaling process that is further described below.

At the onset of scale buildup within the purified water piping and valves, an increase in backpressure to the membrane contactors was followed by a decrease in purified water flow through the system. As this backpressure increased, the lime slurry and sodium bisulfide chemical feed rates remained constant from their positive displacement metering devices while the CO₂ gas feed rate (pressure regulator controlled) was decreased. Naturally, this created a positive feedback effect, increasing the lime and bisulfide doses, while decreasing or halting CO₂ addition. This led to further increases in pH and an acceleration of scaling which was rapid enough to severely constrict the purified water line in as little as one to two days.

At full scale these systems will be designed to operate as automated systems that will include flow pacing for primary control, and process feedback through the use of on-line analyzers whenever possible for fine tuning of the chemical dosing. Additional specifics are identified below:

The lime slurry feed system should shut off automatically if process flow rates decrease below a low flow alarm set point. Lime slurry feed should also be automated through feedback control using either an online calcium ion selective electrode or conductivity probe.

Sodium bisulfide feed should be automated through feedback control using online hydrogen peroxide analyzers before the first wellhead. ORP sensors could also be used as a secondary indicator of peroxide removal.

Carbon dioxide feed should also be automated through feedback control by pH, turbidity, and/or line pressure. Enough carbon dioxide should be added to maintain the pH near 7.5. Elevated turbidity and/or purified water line back pressure would be early warning indicators to trigger an increase in CO₂ feed to arrest an impending scale buildup in the line. An online turbidity meter could be set after the static mixers. The line back pressure control logic could use a pressure transducer and a field-tested system curve for flow and pressure to identify if the system curve was trending above its normal pressure for a given flow.

Lime Chemical Feed

To avoid clogging of feed tubing, the lime slurry chemical metering pumps should include provisions for automated flushing using fresh water and solenoid operated flushing valves at the end of each operational cycle, and at a minimum of once every 12 hours. Lime slurry storage tanks should be sized to allow dilution of lime to a minimum of 15-percent solution and if possible, to a 7.5-percent solution. This will allow the metering pumps to operate at higher stroke frequency and reduce pulsing of the chemical, which was found to improve control of purified water stability.

Calcium Addition Alternatives

While lime slurry is a relatively effective and low-cost stabilization option, Alternatives to lime slurry addition are available that could also provide calcium addition and pH adjustment with reduced turbidity. A calcium carbonate (calcite) contactor could be used to stabilize the purified water. A pressurized contactor vessel would be required to avoid reintroducing air to the purified water. Careful sourcing of high-purity calcite is required to avoid adding turbidity in the purified water.

Another alternative would be to inject calcium chloride and sodium hydroxide to minimize the potential for adding turbidity to the purified water. Both calcium chloride and sodium hydroxide are relatively expensive chemicals.

Post Treatment Static Mixers

During the pilot study lime slurry injection was followed by sodium bisulfide injection and then by a static mixer. For the full scale facility, dedicated static mixer should be provided for each chemical application point, with sufficient contact time between the two application points to facilitate full dissolution of the lime slurry prior to contact with bisulfide. Since sodium bisulfide can raise the pH to about pH 9, this separation will also help to minimize pH-related interactions between poorly-mixed lime slurry and sodium bisulfide. Another static mixer should be provided immediately after the bisulfide injection point to avoid creating regions of extreme pH which could lead to localized calcium carbonate scale formation within the piping.

Lime Slurry and Purified Water Turbidity

Dosing of lime slurry can result in increased turbidity in the purified water that may pose a concern to operation and maintenance of the purified water pipeline and recharge wells. Through feeding additional CO₂ the potential increase in turbidity can be minimized, however the result is purified water that is slightly below calcium saturation (slightly negative LSI). To adjust the pH to slightly above saturation, the full scale system could also incorporate additional metering pumps to feed a small dose of sodium hydroxide as the final means for pH adjustment.

Purified Water Line Maintenance

The purified water line to the injection wells should be designed to allow operators to clear the line of calcium carbonate scale buildup. During the pilot shutting off the lime feed and increasing CO₂ to lower the pH was effective in completely removing the scale. The low pH water will need to be discharged through a pipe to some location other than the injection wells. pH neutralization of the low pH water may be a requirement if the water is to be discharged to the headworks of the NEWRF. Additionally, provisions for flushing and/or pigging of the purified water piping should be considered.

Purified Water Bisulfide Contact Tank

A pressurized bisulfide contact tank that is closed to the atmosphere is recommended in order to provide adequate hold time for complete quenching of residual peroxide before aquifer injection. Closed loop testing at the pilot site demonstrated that at 6 mg/L of bisulfide, 10 minutes was adequate to quench 1.2 mg/L of peroxide within a pH range of 6 to 8. Although higher bisulfide doses were found to consume peroxide more rapidly, they would result in higher chemical use and higher sulfide levels in the purified water.

Sodium Bisulfide Chemical Aging

Use of sodium bisulfide storage containers with controlled venting is recommended to avoid oxidation of the sodium bisulfide by the atmosphere. When natural venting of storage tanks is permitted, within several weeks after delivery the NaHS solution which is a bright yellow color upon delivery is turned to red as a result of this oxidation. This effect results in a loss of chemical strength and the need for a higher pump feed rate to maintain the same effective sulfide dose. Through the use of vacuum breaker valves and pressure rupture discs on the tank vent line, the impacts of chemical exposure to air can be minimized.

4.6 PRELIMINARY COST OPINIONS

4.6.1 Preliminary Opinion of Capital Cost

The capital costs presented are conceptual in nature and based upon the design parameters for the pilot, and similar to the cost opinion provided in the original 2011 GWR Feasibility Report. The costs are escalated from October 2010 Engineering News Record Construction Cost Index (ENR CCI 8921) to an assumed midpoint of construction in July 2016, (projected ENR CCI Index 10350). The cost opinions are based on available literature, equipment manufacturer quotes, previous designs of similar processes, and the water quality sampling done during the pilot study. The preliminary capital cost opinion for the groundwater replenishment facilities is given in Table 4-1. The cost opinions represent the costs associated with design and construction of the GWR purification process, recharge wells and monitoring wells, pilot testing, and public participation program.

The capital cost for the membrane contactor system may change depending on the results from the whole rock core testing. The capital costs provided herein are for a membrane contactor system that provides up to 4-log dissolved oxygen removal. If the whole rock core testing indicates that less than 4-log dissolved oxygen removal is sufficient, then fewer membrane contactors will be needed in the full-scale system.

4.6.2 Preliminary Opinion of Operating Costs

The yearly operation and maintenance (O&M) costs presented are conceptual in nature and based upon the original estimates of the design parameters with adjustments based on operational experience during the pilot. Table 4-2 presents the preliminary opinion of O&M costs for the groundwater replenishment facilities discussed and are based on an average annual treated flow of three (3) MGD, assuming that the treatment facilities operate continuously at or near capacity. Assumptions used in this analysis are a 5-year service life for the RO membranes, a 7-year service life for the UF membranes, a 4-month service life for the cartridge filters and a UV bulb service life of 12,000 hours. This analysis assumes full plant productivity (3 MGD of recharge water) with no significant downtime. Between the original feasibility study estimate and the pilot study, there were two major changes in operating costs: an increase in membrane contactor replacement costs and an increase in sodium bisulfide costs.

Upon review of preliminary results from the membrane contactor element autopsy and comparison with other facilities utilizing membrane contactors for DO removal, the initial feasibility study replacement frequency assumption of 5 years has been revised to 2.5 years. The resulting impact on O&M costs is an increase in the annual expense from \$37,000/year to \$74,000/year. Preliminary design of the full scale facility should include evaluation of alternatives for promoting an extended membrane life by reducing oxidant exposure, including considerations for dosing of sodium bisulfite ahead of the membrane contactors.

The original feasibility study assumed a sodium hydrosulfide (i.e., sodium bisulfide) price of \$0.50/lb; based on similar prices for sodium bisulfite; however, quotations from a major sodium hydrosulfide supplier have placed the price of sodium hydrosulfide at \$2.05/lb. In addition, the study assumed a dose of 1 mg/L; however, a dose of 5 mg/L was necessary to provide for efficient quenching of peroxide. This differential resulted in an increase in cost of sodium bisulfide of nearly \$85,000/year. The operating costs for sodium bisulfide per year may change based on the results of the whole rock core testing. If the whole rock core testing indicates that higher levels of dissolved oxygen can be present in the stabilized, purified water, then the operational costs for sodium bisulfide will decrease.

4.6.3 Conceptual Cost Opinion Summary

The conceptual cost opinion for the groundwater replenishment system is provided in Table 4-3 including capital, O&M and the present worth cost based on the capital and O&M cost opinions. Costs are escalated to the assumed midpoint of construction in July 2016. The overall estimated cost per 1,000 gallons is \$4.58/kgal.

Table 4-1. Preliminary Capital Cost Opinion for GWR Facilities

Item	Cost
Process Building	\$1,900,000
UV and Membrane Contactor Building	\$350,000
Membrane Filtration System ⁽¹⁾	\$3,000,000
RO Pretreatment and High Pressure Pumping ⁽²⁾	\$730,000
RO Membrane and Cleaning System	\$2,200,000
Advanced Oxidation Process ⁽³⁾	\$900,000
Post-Treatment ⁽⁴⁾	\$900,000
Oxygen Removal System ⁽⁵⁾	\$1,680,000
Electrical, Instrumentation, and Standby Power (20%)	\$1,890,000
Site Work	\$460,000
Yard and Process Piping	\$700,000
Reclaimed Water Piping to GWR Treatment Facilities	\$220,000
Waste Pump Station and Piping	\$280,000
Transmission Piping to Recharge Wells ⁽⁶⁾	\$660,000
Recharge Wells and Monitoring Wells	\$1,210,000
Concentrate Disposal ⁽⁷⁾	\$1,890,000
<i>Subtotal</i>	<i>\$18,970,000</i>
Mobilization, Bonds, Permits, General Conditions (6%)	\$1,138,200
Contingency (20%)	\$3,794,000
Engineering, Permitting & Construction Admin. (15%)	\$2,845,500
Pilot Testing ⁽⁸⁾	\$1,584,500
Public Participation	\$1,000,000
Total	\$29,332,200

Notes:

¹ Includes strainers, membrane trains, clean-in-place system, backpulse tank and pumps, blowers, air compressors, and flow equalization tanks.

² Includes sulfuric acid and scale inhibitor storage and feed systems, cartridge filters, and high pressure pumps

³ Includes UV reactors and hydrogen peroxide storage and feed system

⁴ Includes calcium hydroxide, sodium bisulfide, ferrous sulfate, and carbon dioxide feed systems, storage tank, and booster pumps

⁵ Includes nitrogen gas storage and feed system and membrane degasification system

⁶ The cost is based on pipe sizes for 3 MGD total flow for groundwater recharge. Should future expansion of the groundwater replenishment of up to an additional 3 MGD of purified water for recharge be expected, costs for this line item are estimated to be approximately \$660,000 more.

⁷ Assumes deep well injection disposal method with dual zone monitoring well, with the well located on the NEWRF site. The deep well injection cost is based on utilizing Zone C in the Avon Park Formation as the injection zone.

⁸ Pilot testing included pilot design and construction and water sampling with the operation of the pilot performed by the City of Clearwater personnel.

Table 4-2. Preliminary O&M Cost Opinion for GWR Facilities

Item	Cost
Power ⁽¹⁾	\$380,000
Chemical Costs ⁽²⁾	\$480,000
Membrane & Cartridge Filter Replacement ⁽³⁾	\$460,000
UV Bulb Replacement	\$50,000
Maintenance & Supplies	\$150,000
Labor ⁽⁴⁾	\$400,000
WQ Monitoring	\$120,000
<i>Subtotal</i>	\$2,040,000
Contingency (20%)	\$410,000
Total	\$2,450,000

Notes:¹ Based on \$0.10/kW-hr unit power cost.....² Includes ammonium hydroxide, sulfuric acid, scale inhibitor, membrane filtration cleaning chemicals, hydrogen peroxide,

calcium hydroxide, carbon dioxide, nitrogen, sodium bisulfide, and ferrous sulfate.

³ Includes UF, RO and MC membranes⁴ Based on the assumption that 28 additional operator-hours will be required daily**Table 4-3. Conceptual Cost Opinion for GWR Facilities**

Item	Cost
Capital Cost Opinion	\$29,332,200
O&M Cost Opinion	\$2,450,000/year
Capital Cost per Thousand Gallons ⁽¹⁾	\$2.34/kgal
O&M Cost per Thousand Gallons	\$2.24/kgal
Total Cost per Thousand Gallons ⁽¹⁾	\$4.58/kgal

Notes:¹ Based on 20 years and 6% interest.

4.7 SUMMARY

The GWR Pilot Program for groundwater recharge or indirect potable reuse was subject to the requirements set by the FDEP. The results from the 12-month pilot operation indicated that the pilot testing facility produced purified water that reliably met drinking water quality standards set forth by regulatory agencies. The purified water also consistently met regulatory water quality requirements from the 2012 Full Treatment and Disinfection Requirements [FAC Chapter 62-610.563(3)].

Over 25,000 tests were performed for more than 204 constituents. These constituents included 103 regulated constituents and 101 unregulated constituents of potential significance for groundwater recharge. These tests demonstrated that the treatment system produced a purified water that met or surpassed regulated drinking water quality standards. Results from the water quality monitoring consistently met regulated primary standard maximum contaminant GWR Testing levels (MCLs) established at the Federal and State levels, except for two (2) samples for total trihalomethanes (TTHMs) during the 12-month pilot study. The 101 additional unregulated constituents monitored included some from the Environmental Protection Agency's (EPA) Unregulated Contaminant Monitoring Rule 3 List (UCMR3), organic compounds, pharmaceutically active compounds, and other microconstituents. Only two (2) of the 101 additional constituents tested, chlorate and atenolol, were found at quantifiable levels of detection in the purified water during pilot testing.

Among the non-regulated constituents, chlorate, a disinfection byproduct, was detected in the purified water on three occasions with a maximum concentration of 52 µg/L, average 42 µg/L (N=3). This is below the US EPA (2011) health reference level for chlorate, 210 µg/L. The maximum concentration in the reclaimed water was 490 µg/L with an average of 360 µg/L (N=3).

Atenolol, a blood pressure medication, was detected in the purified water in one sample at 16 ng/L. Four other samples for atenolol in the purified water were below the 5 ng/L detection limit. The sample that detected atenolol is well below the risk reference level for atenolol of 70,000 ng/L.

It was determined that the multi-barrier advanced treatment process for purification of reclaimed water is feasible relative to regulatory water quality requirements. Throughout the pilot study, several optimization techniques were also implemented and tested in order to determine more practical implementations for full-scale design. With the successful completion of the 12-month pilot testing phase and confirmation from the City of the full-scale design from a technical and financial perspective, The City can successfully begin the steps for the construction of a potable reuse project that will set the standard for future projects for years to come.

APPENDIX A OPERATIONS LOG BOOK

See CD Attachment, Appendix A for The Operations Log Book records from June 13th, 2014 to June 3rd, 2014.

APPENDIX B FIELD DATA COLLECTION SHEETS

See CD Attachment, Appendix B for field data collection sheets by treatment process.

APPENDIX C LABORATORY DATA

See CD Attachment, Appendix C for laboratory data by laboratory.

SOUTHERN ANALYTICAL LABORATORIES - WEEKLY

See CD Attachment, Appendix C for weekly laboratory analyses and backwash water analysis.

TEST AMERICA – MONTHLY AND QUARTERLY

See CD Attachment, Appendix C for monthly laboratory analyses.

EUROFINS/EATON ANALYTICAL – MICROCONSTITUENTS AND UVAOP CHALLENGE TESTING

See CD Attachment, Appendix C for quarterly microconstituent analyses and quarterly UVAOP challenge testing results.

BCS LABORATORIES – MUTAGENICITY AND PATHOGENS

See CD Attachment, Appendix C for bimonthly analyses on mutagenicity and pathogens.

APPENDIX D QUALITY CONTROL FIELD LOG

See CD Attachment, Appendix D for the quality control field logbook.

APPENDIX E DOW BULLETIN ON MEMBRANE FILTRATION CLEANING PROCEDURES

See CD Attachment, Appendix E for clean in place procedures for the DOW ultrafiltration module.

APPENDIX F ROCK CORE COLUMN TEST RESULTS – WORK BY OTHERS

See CD Attachment, Appendix F.

APPENDIX G REVERSE OSMOSIS 4TH STAGE SINGLE ELEMENT “BLACK BOX”

See CD Attachment, Appendix G for recorded data from the Avista Black Box from February 4th, 2014 to May 19th, 2014.

APPENDIX H PROCESS AUTOPSIES

See CD Attachment, Appendix H for autopsy reports.

Dow Autopsy Report Summaries

UF Conclusion: Average amount of fouling throughout the UF module, some pockets had more fouling which could be caused by lower air scour or backwash flux. To optimize the system we recommend checking the values for backwash flux, frequency and air scour velocity. These all will play a role in cleaning the module effectively. Overall, the module was in good shape. The remaining fouling was Iron and Manganese which would clean up with an acid cleaning using HCl or similar acid. This system could be further optimized by increasing the Acid CEB frequency to keep the iron fouling from building up on the fibers. The integrity of the module was in good shape and had many more years of its module life remaining.

RO Conclusion: The XFRLE-4040 element returned from the pilot study retained its original flow and rejection performance. The level of fouling on the surface of the RO membrane was not sufficient to cause any performance change but was comprised of a slight amount of silicates and very small amounts of phosphorous, aluminum, manganese and iron.

Membrana Autopsy Report

MC Conclusion: A visual inspection of the contactor indicated that the contactor was clean and in good physical condition. The maximum negative decrease in percent elongation at break was 61-percent compared to the control sample. Percent elongation measurements below 170-percent or loss of 25-percent or more is a significant loss of fiber mechanical strength and is often associated with fiber leaks. Percent elongation below 140-percent or loss of 30-percent or more signifies beginning of the end of life for fibers. Testing showed significant loss of strength in this case and believed to likely be caused by membrane oxidation. Common chemical/media cause of membrane oxidation include Chlorine, Ozone, Hydrogen Peroxide, Peracetic Acid, UV radiation, Chlorine Dioxide, Hot water in the presence of air, and Hot air.

Significant changes in the physical properties of the fiber were noted in Gurley values, which is a measure of membrane gas permeability. Gurley was found to be a maximum positive deviation of 152-percent higher than the control sample. These results indicate that the fiber was losing some of its effective gas transfer properties. Based on our experience and data collected during life analysis testing, once the Gurley value begins to increases we would expect the gas removal performance to start declining. The fiber sample testing confirms some loss of performance seen in this unit resulting from partially occluded membrane porosity.



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