City of Los Angeles

Recycled Water Master Planning

Los Angeles Department of Water and Power
and
Department of Public Works

Groundwater Replenishment Treatment Pilot Study Report

Prepared by:

RMC in association with CDM Smith

March 2012

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Title: Groundwater Replenishment Treatment Pilot Study
Report - *Pilot Testing from February 18, 2010 to June 30, 2011*

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Date: March 2012

Reference: Task 3b GWR Treatment Pilot Study
Subtask 3.6.4 Pilot Testing Reporting

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List of Acronyms

AFY – Acre-Feet Per Year

AOP – Advanced Oxidation Process

AWPF – Advanced Water Purification Plant

C – Celsius

CDPH – California Department of Public Health

CEB – Chemically Enhanced Backwash

CEC – Constituent of Emerging Concern

CIP – Clean-in-Place

DBP – Disinfectant Byproduct

DCTWRP – Donald C. Tillman Water Reclamation Plant

EDC – Endocrine Disrupting Compound

EFM – Enhanced Flux Maintenance (also CEB)

ES – Executive Summary

gfd – gallons per day per square foot

gpm – gallons per minute

GWR – Groundwater Replenishment

HAA5 – Five Regulated Haloacetic Acids

LADPW – Los Angeles Department of Public Works

LADWP – Los Angeles Department of Water and Power

MCL – Maximum Contaminant Level

MF – Microfiltration

MIT – Membrane Integrity Test

MTC – Mass Transfer Coefficient

NA – Not Applicable

NDMA – N-nitrosodimethylamine

NDP – Net Driving Pressure

NF – Nanofiltration

NL – Notification Level

NTU – Nephelometric Turbidity Units

O&M – Operation and Maintenance

OCWD – Orange County Water District

ORP – Oxidation Reduction Potential

P&ID – Process and Instrumentation Diagram

PPCP – Pharmaceuticals and Personal Care Products

psi – pounds per square inch

PVDF – Polyvinylidene Fluoride

QA/QC – Quality Assurance/ Quality Control

RO – Reverse Osmosis

TCEP – Tris (2-carboxyethyl)phosphine

TCPP – Tris (chloroisopropyl) phosphate

TDCPP – Tri(2,3-dichloropropyl) phosphate

TDS – Total Dissolved Solids

TFC – Thin Film Composite

TM – Technical Memorandum

TMP – Transmembrane Pressure

TOC – Total Organic Carbon

TTHM – Total Trihalomethanes

UV – Ultraviolet Light

VGS – Valley Generating Station

VFD – Variable Frequency Drive

Definitions and Equations

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

- Antiscalant – a chemical used to inhibit scaling (i.e., precipitation or crystallization of salt compounds)
- Clean-in-Place (CIP) – the in-situ chemical cleaning of membranes that consists of soaking membranes in one or more chemical solutions (typically acid and caustic solutions) to remove accumulated foulants and restore permeability
- Concentrate – a continuous waste stream, typically containing concentrated dissolved solids, from the membrane process. Sometimes referred to as retentate or brine
- Element – an encased spiral-wound or hollow-fiber membrane module
- Flux – the unit rate at which water passes through the membrane expressed as flow per unit of membrane area (e.g., gallons per square foot per day (gfd))
    - Flux = Flow/Membrane Area
- Fouling – the accumulation of contaminants on the membrane surface, within membrane pores, or media surface that inhibits the passage of water
- Microfiltration (MF) – a pressure-driven membrane filtration process that employs hollow-fiber membranes with a pore size range of approximately 0.1 to 0.2 µm (nominally 0.1 µm)
- Mass Transfer Coefficient (MTC) – See Permeability
- Net Driving Pressure (NDP) – the pressure available to force water through a semi-permeable membrane, accounting for osmotic forces. For microfiltration, NDP is equal to TMP.
    - NDP = TMP – Osmotic Pressure
- Normalization – the process of evaluating membrane system performance at a given set of reference conditions (e.g., at standard temperature, per unit pressure, etc.) to directly compare and trend day-to-day performance independent of changes to the actual system operating conditions
- Osmotic Pressure – the amount of pressure that must be applied to stop the natural osmosis-driven flow of water across a semi-permeable membrane.
- Permeate – a continuous stream of water that passes through membrane. Also referred to as filtrate or product.

- Permeability – the ability of the membrane to allow the passage or diffusion of water
    - Permeability =Flux * Temperature Correction Factor/ NDP
- Recovery – the volumetric percent of feed water that is converted to permeate
    - Recovery = Average Permeate Flow Rate/Average Feed Flow Rate
- Reverse Osmosis (RO) – the pressure-driven membrane separation process that employs the principles of reverse osmosis (i.e., the passage of water through a semi-permeable membrane against the concentration gradient, achieved by applying pressure greater than the osmotic pressure) to remove dissolved contaminants from water
- Scaling – the precipitation or crystallization of salts on a surface (e.g., on the feed side of a membrane)
- Stage – a group of membrane units operating in series. In a two-stage configuration, concentrate from the first stage travels to the second where more water is produced.
- Transmembrane Pressure (TMP) – the difference in pressure from the feed (or feed-concentrate average) to the permeate across the membrane
    - TMP for MF = Feed Pressure – Permeate Pressure
    - TMP for RO= [(Feed Pressure + Concentrate Pressure)/2] – Permeate Pressure

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Executive Summary

ES-1 Introduction

The Los Angeles Department of Water and Power (LADWP), in partnership with the Los Angeles Department of Public Works (LADPW) Bureau of Sanitation (BOS) and Bureau of Engineering (BOE), developed the **Recycled Water Master Planning** (RWMP) documents. Specifically, the RWMP process identified projects that will significantly increase the City's recycled water use locally. Recycling more water within the Los Angeles metropolitan area provides a number of benefits. For each acre-foot of recycled water used, an equal amount of imported water is saved. As a local source of water, recycled water is more reliable than imported water and is drought-resistant.

Since the early 1900s, Los Angeles has tapped into a variety of water sources. Today, the City's water comes from Northern California (California Aqueduct); Owens Valley and Mono Lake Basin (Los Angeles Aqueduct); Colorado River (Colorado River Aqueduct); and several local water sources including groundwater aquifers, stormwater capture, and recycled water. But securing water from distant sources has become more restricted and unreliable. LADWP's 2010 Urban Water Management Plan (UWMP) outlines a goal of increasing recycled water to 59,000 acre feet per year (AFY) by 2035 to reduce dependence on imported water.

The RWMP documents include an evaluation of alternatives – strategies that take into account forward-looking groundwater replenishment (GWR) options as well as the more familiar form of recycling water for non-potable reuse (NPR) purposes, such as for irrigation and industry. This Groundwater Replenishment Treatment Pilot Study Report is one element of the RWMP documents. It describes the pilot scale testing which was conducted to evaluate advanced water purification (AWP) processes being considered for treatment of recycled water for GWR supply.

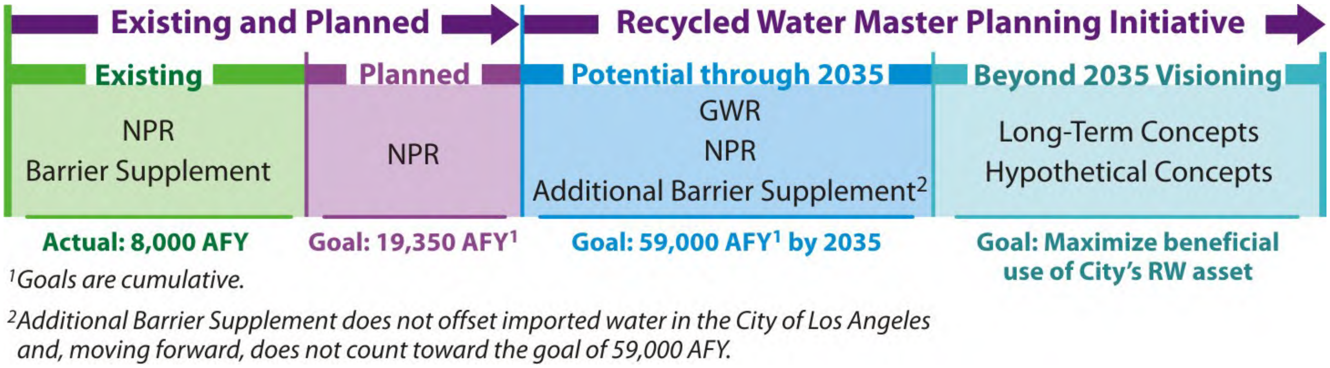
The results of this testing will be combined with findings and recommendations of several other technical studies being completed for the RWMP effort. When implemented, the RWMP will provide project alternatives to deliver 59,000 AFY of recycled water in the near-term to offset imported water and potential implementation strategies for long-term concept projects.

ES.2 Background

LADWP is implementing its multi-faceted 2010 UWMP to ensure a safe and reliable water supply for future generations of Angelenos. This is a blueprint for L.A.'s water future, and many elements go into such an important plan, such as the RWMP effort.

Figure ES-1 summarizes the City of Los Angeles' RWMP Initiative, which is guiding the development of recycled water planning for the near-term and long-term. The 2010 UWMP includes a near-term goal to develop 59,000 AFY of recycled water by 2035 as a sustainable source of local water. Of this amount, approximately 8,000 AFY is currently used for NPR and for barrier supplement in the Dominguez Gap Barrier. An additional 11,350 AFY of NPR projects are in development. The focus for the near-term is to develop the remaining 39,650 AFY (30,000 AFY from GWR and 9,650 AFY from NPR) of recycled water in Los Angeles to offset 59,000 AFY of imported water. The focus of the long-term is to offset imported water to the extent possible (up to 168,000 AFY) by 2085, fifty years after 2035.

Figure ES-1: Overview of RWMP Components

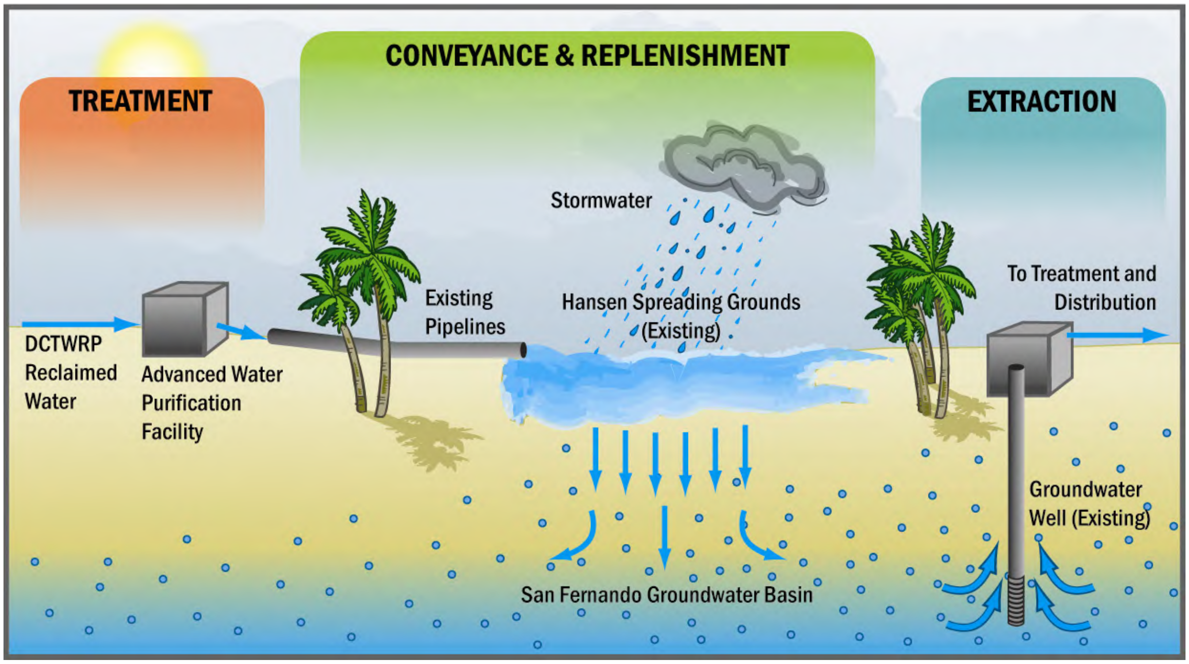


[1] *Goals are cumulative.*

[2] *Additional Barrier Supplement does not offset imported water in the City of Los Angeles and, moving forward, does not count toward the goal of 59,000 AFY.*

One method of expanding recycled water use is by indirect potable reuse through groundwater replenishment (GWR). Groundwater replenishment is a practical, proven way to increase the availability of a safe, reliable, locally-controlled water supply. As shown on **Figure ES-2** below, using state-of-the-art technology, the GWR system would include treating recycled water from the Donald C. Tillman Water Reclamation Plant (DCTWRP) to near-distilled water quality using advanced water purification (AWP) processes. This purified recycled water would be conveyed to spreading grounds, where it would percolate into natural underground aquifers. This water replenishes the aquifers, to be used as an additional local source of water supply for the city. After the minimum required residence time within the aquifer, the water would be extracted (or pumped) from the existing groundwater basins for treatment and distribution to LADWP drinking water customers.

Figure ES-2: GWR Concept



LADWP and LADPW performed a 16-month pilot study to test AWP processes. The pilot study was conducted from February 2010 through June 2011 and was located at the DCTWRP.

ES.3 Purpose of Groundwater Replenishment Treatment Pilot Study

The purpose of the pilot study was to evaluate the treatment efficacy of using AWP processes on the alternative source waters available at the DCTWRP. AWP is used to remove pathogens, salts, and organic compounds from treated wastewater, creating purified recycled water that can be used indirectly to supplement potable water supplies. Typical advanced purification consists of microfiltration (MF), reverse osmosis (RO), and advanced oxidation. For this study, the two advanced oxidation processes (AOPs) were evaluated, including ultraviolet light (UV) with hydrogen peroxide and ozone with hydrogen peroxide.

ES.4 Recycled Water Master Planning Approach

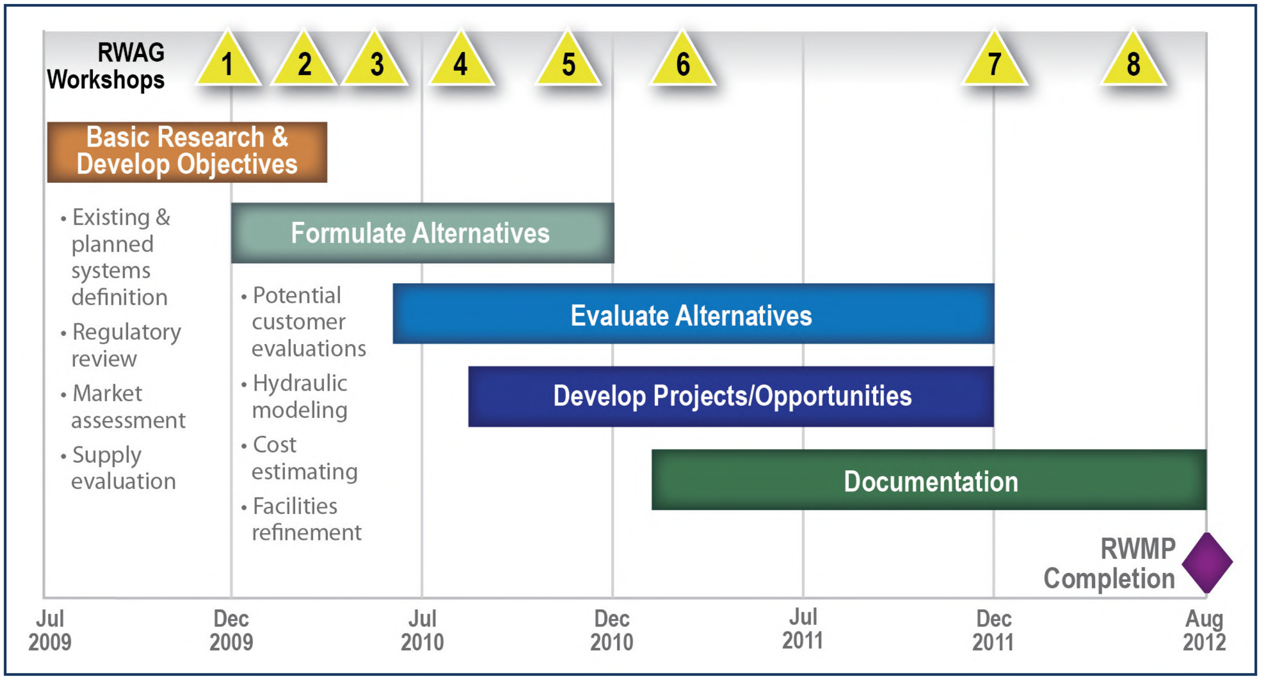
The RWMP multi-year planning process has focused on four major steps:

- Perform basic research and develop planning objectives;
- Formulate alternatives, based upon the research and objectives;

- Evaluate alternatives; and,
- Develop viable projects and opportunities.

Stakeholders have been involved in discussions with the recycled water planning team since late 2009. Their input has been folded into each of these major steps, resulting in viable projects and opportunities that include insights and interests of a very diverse cross-section of the Los Angeles community. **Figures ES-3** illustrates the main RWMP steps and timeline.

Figure ES-3: Recycled Water Master Planning Approach and Schedule



ES.5 Organization of GWR Treatment Pilot Study Report

The GWR Treatment Pilot Study Report is organized into the following sections:

- Executive Summary
- Section 1 - Introduction
- Section 2 – Pilot Testing Goals and Project Start-up
- Section 3 – Operating Conditions
- Section 4 – Source Water Evaluation Results
- Section 5 – Microfiltration Results
- Section 6 – Reverse Osmosis Results
- Section 7 – Advanced Oxidation Process Results
- Section 8 – Product Water Quality Results

- Section 9 – Conclusions and Recommendations
- Section 10 - References

ES.6 Pilot Testing Goals and Project Set-up

Pilot testing was conducted in three phases. Phase 1 validated the proposed processes used at existing AWP facilities in California, including MF, RO, and UV/peroxide, considered the baseline treatment process. Phase 2 evaluated ozone/peroxide as an alternative to UV/peroxide, with both AOPs tested side-by-side and with target contaminants spiked into the AOP supply. Phase 3 confirmed the recommended operating conditions from Phases 1 and 2 and also evaluated two alternative RO membranes.

ES.7 Operating Conditions

The pilot plant evaluated various operating conditions to aid in process optimization and to determine recommended design criteria for a future treatment facility. The primary conditions that were varied include:

- Source of water supply
- Chlorination approach
- MF flux
- MF chemically enhanced backwash usage
- RO flux
- RO recovery
- RO membrane configuration
- RO membrane type
- Advanced oxidation approach

The baseline operating conditions were chosen based on operational information at existing facilities, such as the Orange County Water District (OCWD) GWR System, Terminal Island Water Reclamation Plant's Advanced Water Treatment Facility, West Basin Municipal Water District's Edward C. Little Water Reclamation Plant, and Water Replenishment District's Vander Lans plant. By optimizing these operating conditions through the pilot testing, a more efficient, more effective treatment process can be designed for the future DCTWRP facility.

ES.8 Source Water Evaluation

Pilot testing included a source water evaluation to determine the most appropriate supply for the AWP facility (AWPF). Source waters considered at the beginning of the testing included: 1) secondary effluent before chlorination, 2) tertiary effluent before chlorination, and 3) tertiary effluent after the chlorine contact tank. Preliminary bench testing and water quality monitoring for n-nitrosodimethylamine (NDMA) were conducted, resulting in a recommendation that source water not be taken after the chlorine contact tank due to the presence of NDMA levels 10 times higher than the levels before chlorine addition. Pilot testing was therefore conducted using both secondary effluent and tertiary effluent, drawn before chlorine addition. During Phase 2 of the pilot testing, tertiary effluent after chlorination was used only when a source of high NDMA water was needed to evaluate the AOP alternatives.

Pilot testing results demonstrated that for the DCTWRP water, there were no significant differences in MF, RO, or AOP performance when secondary or tertiary effluents were used. MF and RO fouling rates were comparable for both source waters. While NDMA levels were slightly lower in the tertiary effluent, NDMA formation (after chlorine addition) was slightly higher, such that the levels of NDMA in the RO feed water and the RO product were the same for both source waters.

Since neither source water showed clear advantages in operating efficiency or water quality for the DCTWRP water, it was recommended that the full-scale facility be designed to allow flexibility for either secondary or tertiary effluent source water, taken before chlorine addition. Chlorine and ammonia addition and contact time should be carefully controlled through the AWP process to prevent biofouling on the membranes, while minimizing the formation of NDMA.

ES.9 Microfiltration

The primary function of the MF system is to provide adequate pretreatment for sustainable operation of the RO process. The MF also provides the first barrier against protozoa and bacteria, which should be undetectable in the MF product. The pilot testing objectives were to maintain reliable performance, achieving filter run lengths of at least 30 days between chemical cleanings, while meeting water quality goals for turbidity, silt density index (SDI), protozoa, and bacteria. Several different operating conditions were tested to determine the optimal system performance, including:

- Chemically enhanced backwash frequency
- Source of water supply
- Flux
- Disinfection method

Each of these conditions was tested independently to confirm operation with a minimum 30-day cleaning frequency. The study found that chemically enhanced backwashes were not needed to meet this goal, however, a filter run in excess of 200 days was achieved without a full chemical clean-in-place when chemically enhanced backwashes were employed. Chemically enhanced backwashes were discontinued at the end of the Phase 1 testing to evaluate the impact of other operating conditions on chemical cleaning frequency.

The MF flux was varied from 25 to 48 gallons per square foot per day (gfd). It was found that a maximum 35 gfd flux was required to achieve a minimum 30-day cleaning frequency, when no chemically enhanced backwashes were employed. It was recommended that a flux of 35 gfd be assumed in the planning process for full-scale operation, however, pilot testing should be conducted with alternative membrane filtration systems before recommending maximum operating fluxes for each system.

Two disinfection methods were tested during the study. The first, traditional chloramination, involved adding sodium hypochlorite and ammonium hydroxide at the same process location, immediately upstream of the MF feed tank. This allowed a chloramine residual to prevent biological growth in the MF and RO membranes, while preventing a free chlorine residual, which can damage RO membranes, reducing their ability to remove salts and dissolved organic compounds. The second method, sequential chlorination, added the sodium hypochlorite before the MF, but added the ammonium hydroxide downstream of the MF membranes. A free chlorine residual was maintained within the MF membranes, but was converted to chloramines with the ammonia addition after the MF.

It was anticipated that sequential chlorination would result in improved operation with the MF membranes, while reducing the formation of NDMA. The results, however, did not indicate a significant improvement in MF performance or a reduction in NDMA formation. Significant damage of the RO membranes occurred during the period when sequential chlorination was employed, due to the repeated loss of ammonia feed during evenings, which allowed a free chlorine residual to reach the RO membranes. Sequential chlorination also required a chlorine dose 2.5 times higher than the dose required for traditional chloramination, and resulted in increased formation of trihalomethanes (THMs). Sequential chlorination is not recommended for use in the full-scale facility.

ES.10 Reverse Osmosis

The primary function of the RO process is to provide adequate removal of dissolved salts and organic contaminants. The specific operating objectives for the RO system were to:

- Confirm that the water quality produced by the RO system meets the water quality goals, removes constituents of emerging concern (CECs), and is comparable with other operational AWPFs.
- Achieve stable operation with minimal fouling and projected run lengths of at least 6 months between chemical cleanings. To meet this goal, the RO must sustain permeabilities with no more than 5 percent permeability loss per month under optimized operating conditions.
- Determine if a 2-stage or 3-stage RO configuration provides more efficient, reliable performance at an 85 percent hydraulic recovery rate.
- Determine whether operation at a flux greater than 12 gfd provides an advantage or is a detriment to membrane fouling.
- Determine if membranes from any of three selected manufacturers provides improved performance or contaminant removal.

Testing results demonstrated that the RO system effectively met the water quality goals, while removing CECs to non-detectable levels for all but 11 compounds. Removal of these compounds was greater than 98 percent for all but NDMA, which was removed to non-detectable levels by the downstream UV/peroxide process. The testing demonstrated that RO provides an exceptional water quality for GWR.

Stable operation was achieved during Phases 2 and 3, with less than 5 percent permeability decline per month in a two-stage configuration with 85 percent recovery and a flux of 14 gfd. Testing found that the selection of source water had no impact on the RO system. No improvement in performance was seen with 3-stage operation over 2-stage, however, optimization of the 3-stage system using a different antiscalant was not attempted. Higher feed pressures were required for 3-stage operation, making it less desirable, as 2-stage operation was maintained without fouling.

Testing found that fouling in the second stage was higher when operating at 12 gfd compared with 14 gfd. It is believed that the higher fouling rate seen at 12 gfd is related to poor hydraulic conditions in the second stage membranes when operating at 85 percent recovery.

Membranes from three RO manufacturers (Hydranautics, CSM, and Toray) were compared side-by-side to observe their capabilities for performance. Permeabilities, fouling rates, and removal efficiencies for all three membranes were nearly identical, providing three nearly interchangeable membrane alternatives for the future facility. It was recommended that the full-scale facility be designed to incorporate a flux of 14 gfd at 85 percent recovery using any of the three membranes tested.

ES.11 Advanced Oxidation Process Results

The primary function of the AOP system is to break down trace organic compounds not completely removed by the RO membranes. Two alternative AOPs were evaluated during pilot testing, including UV/peroxide and ozone/peroxide. The AOP testing had the following, process-specific objectives:

- Evaluate the effectiveness of the UV/peroxide process to destroy trace organic compounds not completely removed by RO, comparing results with existing operational facilities.
- Compare ozone/peroxide with UV/peroxide in terms of effectiveness at destroying NDMA and other CECs, meeting the minimum requirement of 1.2-log NDMA reduction and 0.5-log 1,4-dioxane reduction.

The pilot testing results support the conclusion that UV/peroxide is an effective method for removing trace organic compounds, which are only partially removed by the RO membranes. UV/peroxide was effective at reducing NDMA by greater than 1.2-log units, reducing 1,4-dioxane by greater than 0.5-log, and meeting all regulatory requirements for groundwater recharge.

The pilot testing also demonstrated that ozone/peroxide is promising for the removal of 1,4-dioxane and Tris (2-carboxyethyl)phosphine (TCEP), two compounds that are more difficult to oxidize than most other constituents of emerging concern. Removal for 1,4-dioxane, TCEP, and chloramines was significantly better when using ozone/peroxide, when an ozone dose greater than 6 mg/L was employed. A 1.2-log reduction in NDMA, however, was not achieved, even with ozone doses reaching 14 mg/L. The higher NDMA removal achieved with UV/peroxide is the result of direct photolysis from the UV light rather than from oxidation.

The results demonstrated that ozone/peroxide can potentially be used in place of UV/peroxide to meet all regulatory requirements except for the current 1.2-log NDMA reduction requirement. NDMA levels less than the 10 ng/L notification level, however, were achieved by both processes. In the event that the regulations are modified to relax or remove the NDMA log reduction requirement, the use of ozone/peroxide could provide a benefit when compared with UV/peroxide, in terms of lower energy usage and greater removal of CECs. Additional study and testing of ozone/peroxide is required to refine design criteria, such as ozone dose and contact time.

ES.12 Product Water Quality

Water quality results from the pilot testing confirmed that all existing and draft drinking water and recycled water regulations can be met using the proposed treatment processes. All of the regulated compounds had average and maximum values in the product water below their regulatory limits, with the vast majority already below regulatory limits in the source water.

In addition to the regulated parameters, all but ten non-regulated pharmaceuticals and personal care products were removed to concentrations below detection levels by the RO process. All but three of these (TCEP, Tris (chloroisopropyl) phosphate (TCPP), and 1,3-Dichloro-2-propanol phosphate (TDCPP)) were removed to below detection levels by the UV/peroxide process, and all but two by the ozone/peroxide.

Overall, the removal of the three remaining personal care products (all flame retardants) was greater than 99 percent, with their concentrations in the final product water averaging less than 5 ng/L. No significant health risks have been suggested for these compounds at these concentrations. TCEP data from imported State Project Water (NWRI, 2010) was found to be higher than the levels measured in either the ozone or UV product during the pilot testing. Measurable concentrations of other CECs, such as carbamazepine, sulfamethoxazole, caffeine, primidone, and gemfibrozil have also been found in imported State Project Water, but were all below detection levels in the DCTWRP AWP product. It is concluded that the advanced water purification processes tested here provided an exception water quality for use in groundwater replenishment.

ES.13 Acknowledgments

The RWMP process was commissioned in 2009 through the vision of LADWP, in partnership with the BOS and BOE. Critical to the development of the RWMP documents was a diverse team of contributors and reviewers. The following individuals have dedicated significant time and effort to shaping a reliable, sustainable water future for Los Angeles.

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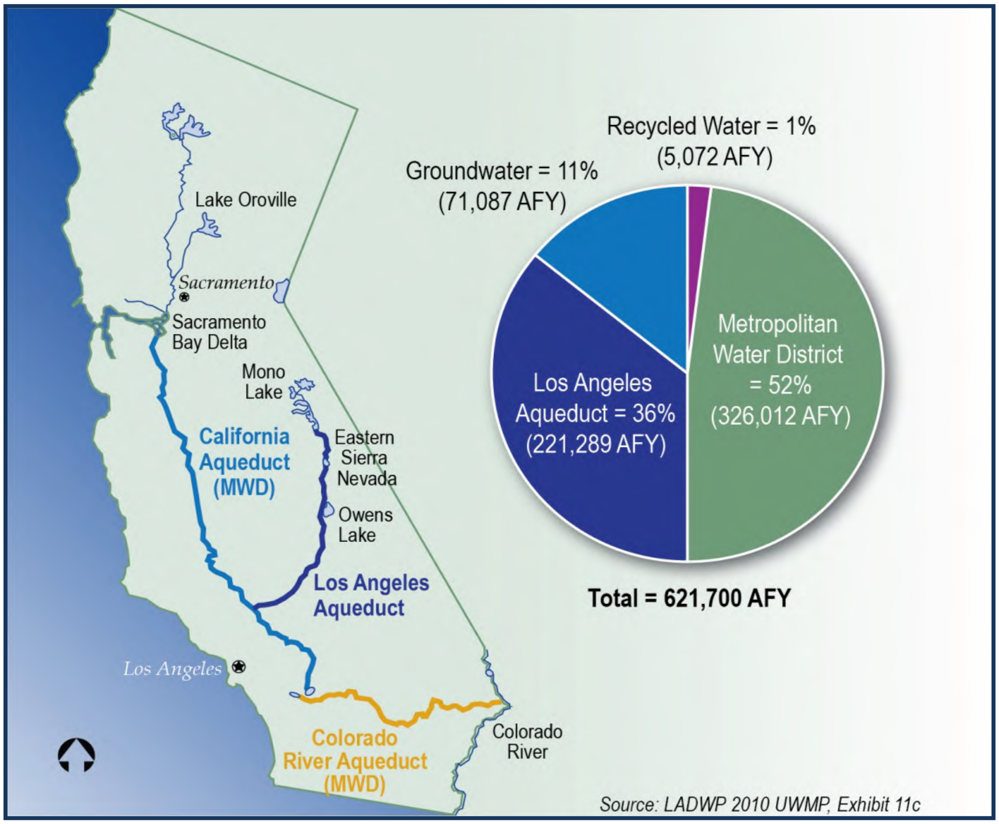
1. Introduction

1.1 Background

The City of Los Angeles (the City), with its location in a naturally dry area with warm temperatures, little rainfall, and few local sources of water, relies heavily on imported water from the Sacramento Delta (California Aqueduct), Eastern Sierra Nevada (Los Angeles Aqueduct), and Colorado River (Colorado River Aqueduct). More recently, local groundwater sources have only accounted for 11 percent of the total supply. These sources of water for the City, and annual average source water distribution for fiscal years (FY) 2006 to 2010, are illustrated in **Figure 1-1**.

Figure 1-1: Current Sources of Water for City of Los Angeles (FY 2006 to 2010)



Source: LADWP 2010 UWMP, Exhibit 11c

The City's imported supplies have been significantly cut in recent years – some by as much as half - due to periods of dry weather and low snowpack, environmental commitments, and judicial decisions. In addition, the City's ability to utilize limited groundwater supplies has been impacted by contamination.

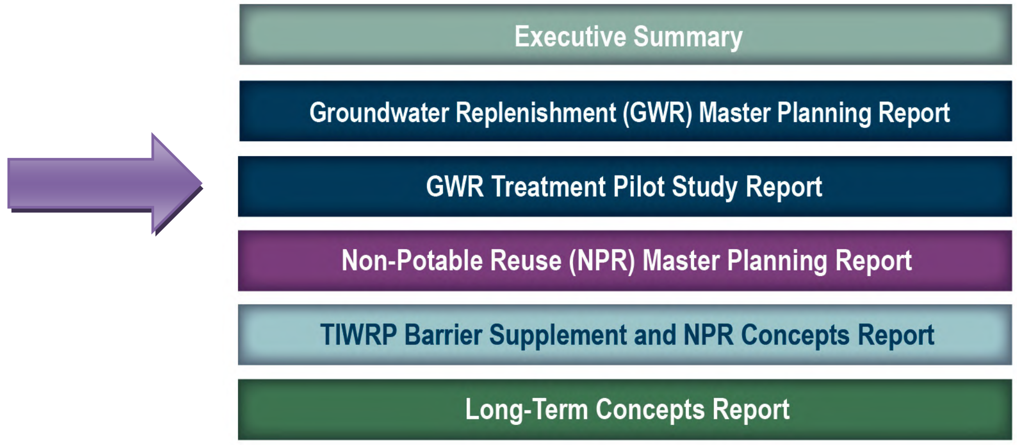
Conservation has helped Angelenos maintain about the same total water use since 1980, despite a population growth of 1 million people. However, conservation alone cannot meet future demands.

The City developed key strategies to secure a more reliable water supply for the City: 1) Increase water conservation, 2) Increase water recycling, 3) Enhance stormwater capture, 4) Accelerate groundwater cleanup, and 5) Green Building Initiatives. These strategies are being implemented through a number of parallel efforts and are documented in the 2010 Urban Water Management Plan (UWMP) for the City. The Los Angeles Department of Water and Power's (LADWP) 2010 UWMP outlines a goal of increasing recycled water to 59,000 acre feet per year (AFY) to offset imported water by 2035. The City currently delivers approximately 8,000 AFY for non-potable reuse (NPR) and for barrier supplement in the Dominguez Gap Barrier.

LADWP, in partnership with the City of Los Angeles Department of Public Works (LADPW), Bureau of Sanitation (BOS) and Bureau of Engineering (BOE), developed the Recycled Water Master Planning (RWMP) documents to outline strategies to offset imported water demand by utilizing recycled water. Specifically, the RWMP process identified projects to significantly increase the City's recycled water use. Originally, the RWMP was to identify groundwater replenishment (GWR) and NPR projects to achieve 50,000 AFY. But after adoption of the 2010 UWMP, the goal of the RWMP was modified to identify, evaluate, and set a course for achieving 59,000 AFY[1] by 2035, as well as developing a plan to maximize reuse.

The RWMP documentation includes a series of volumes comprised of an Executive Summary, GWR Master Planning Report, GWR Treatment Pilot Study Report, NPR Master Planning Report, TIWRP Barrier Supplement and NPR Concepts Report, and Long-Term Concepts Report, as well as a series of supporting technical memoranda (TMs). **Figure 1-2** illustrates the organization of these volumes.

Figure 1-2: RWMP Documentation



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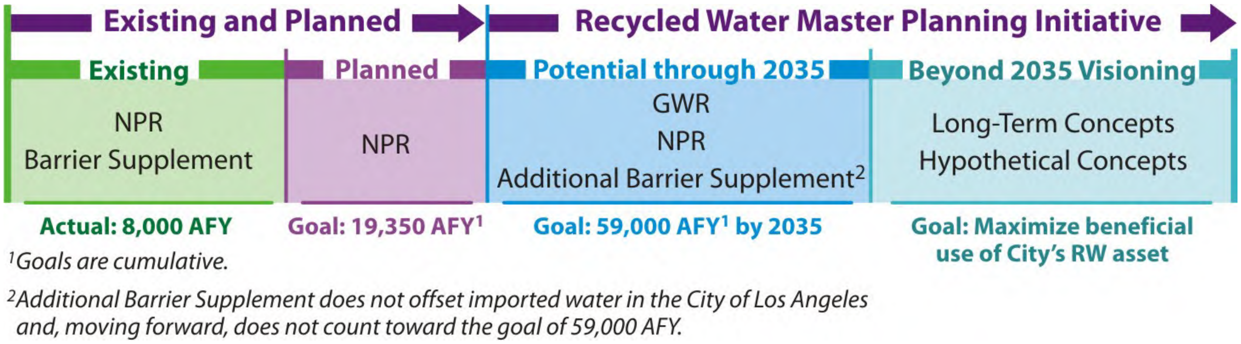
[1] LADWP has 8,000 AFY of existing recycled water customers, including both NPR and barrier supplement in the Dominguez Gap Barrier. LADWP has identified 11,350 AFY of new customers (19,350 AFY total), which are a portion of the overall 59,000 AFY goal. Therefore, the RWMP documents identify the additional 39,650 AFY of recycled water to meet the overall 59,000 AFY goal.

Figure 1-3 illustrates the breadth and linkage of the various RWMP components.

Figure 1-3: Overview of RWMP Components



[1] *Goals are cumulative.*

[2] *Additional Barrier Supplement does not offset imported water in the City of Los Angeles and, moving forward, does not count toward the goal of 59,000 AFY.*

1.2 Purpose of GWR Treatment Pilot Study

The purpose of the pilot study was to evaluate the treatment efficacy of using AWP processes on the alternative source waters available at the DCTWRP. AWP is used to remove pathogens, salts, and organic compounds from treated wastewater, creating purified recycled water that can be used indirectly to supplement potable water supplies. Typical advanced purification consists of microfiltration (MF), reverse osmosis (RO), and advanced oxidation. For this study, the two advanced oxidation processes (AOPs) were evaluated, including ultraviolet light (UV) with hydrogen peroxide and ozone with hydrogen peroxide.

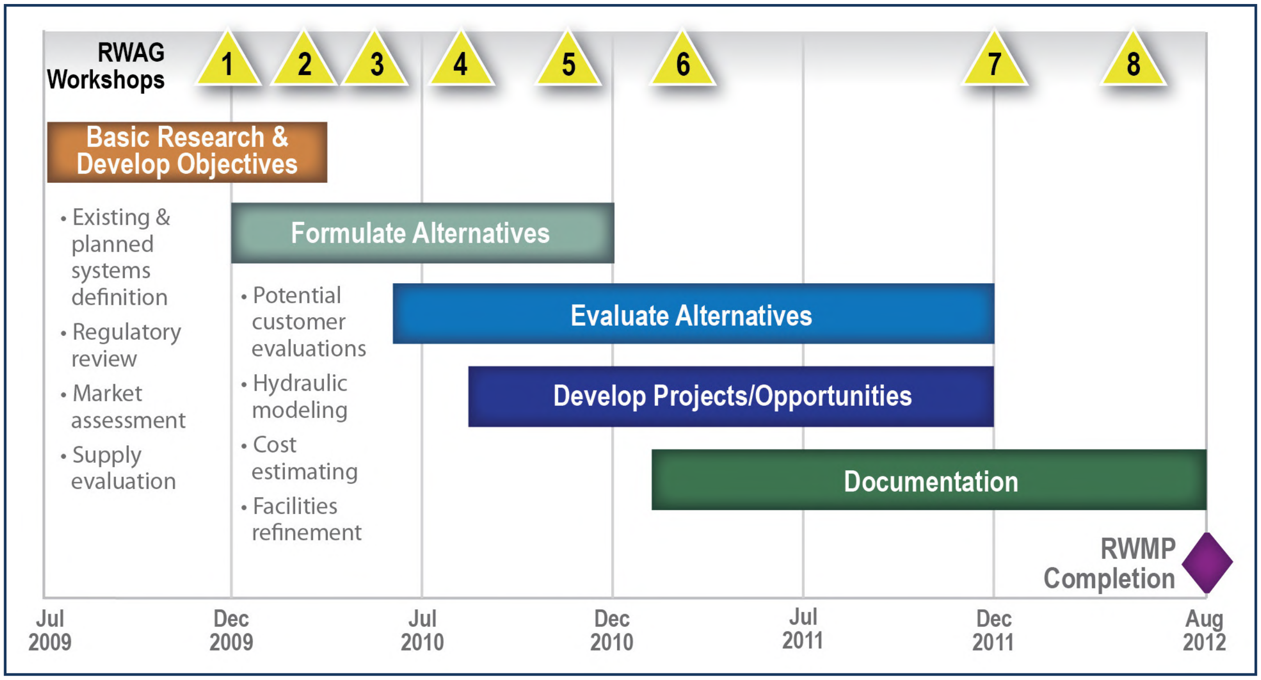
1.3 Recycled Water Master Planning Approach

The overall approach for the RWMP was to develop objectives, conduct basic research for GWR and NPR, formulate and evaluate integrated alternatives that include varying amounts of GWR and NPR, and from that analysis develop specific projects/opportunities and the associated master planning reports to implement the opportunities. **Figure 1-4** illustrates the main master planning steps and the timeline.

An important part of the RWMP is including stakeholders in the development process. In parallel to the RWMP, the City established a Recycled Water Advisory Group (RWAG) comprised of key public stakeholders representing neighborhood councils, environmental groups, industry, homeowners associations, and others. At key steps in the RWMP, the team held workshops with the RWAG to present information and seek feedback, which was then incorporated into the RWMP documents. In addition, Recycled Water Forums were held throughout the City to inform and receive input from the general public.

In 2010, the City contracted with the National Water Research Institute to establish an Independent Advisory Panel (IAP). Using an IAP increases the credibility of the project by providing an independent evaluation of the technical, regulatory, and health-related elements of the RWMP projects. By establishing the IAP early in the process, the City will have additional flexibility with the project implementation and facility planning issues that may arise during the engineering report.

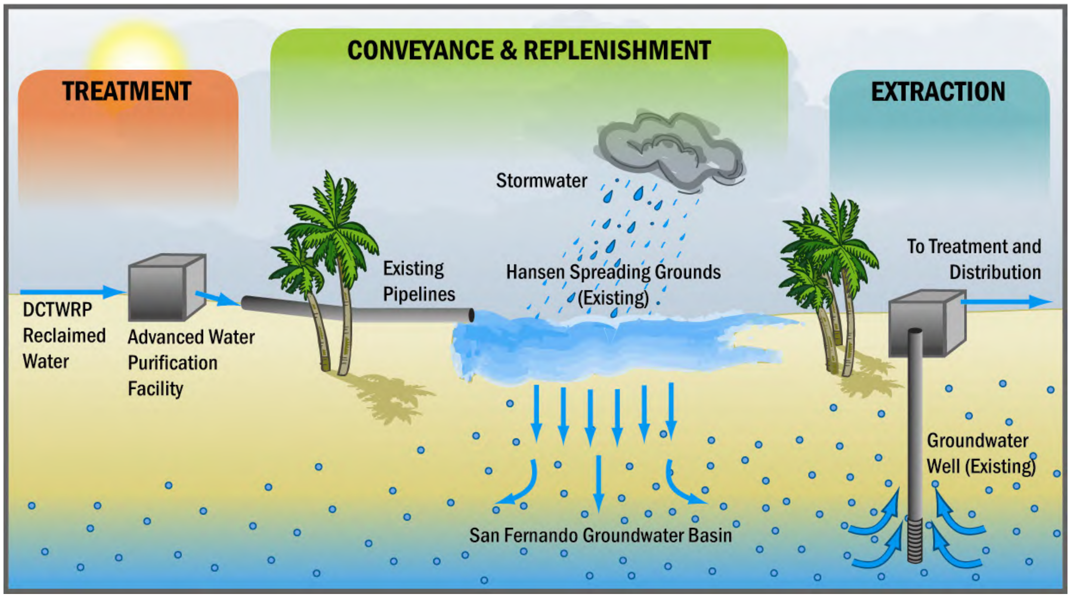
Figure 1-4: Recycled Water Master Planning Approach and Schedule



Groundwater replenishment is a practical, proven way to increase the availability of a safe, reliable, locally-controlled water supply. As shown on **Figure 1-5** below, using state-of-the-art technology, the GWR system would include treating recycled water from the DCTWRP to produce purified recycled water using advanced water purification (AWP) processes. This purified recycled water would be conveyed to “spreading grounds”, where it would percolate into natural underground groundwater, and potentially injection wells to inject the water into the groundwater. This water replenishes the aquifers that feed the City’s water supply production wells. After the minimum required blend time within the aquifer, the water would be extracted (or pumped) from the existing groundwater basins for treatment and distribution to the LADWP drinking water customers.

This report contains a description of activities and results from the GWR Treatment Pilot Study.

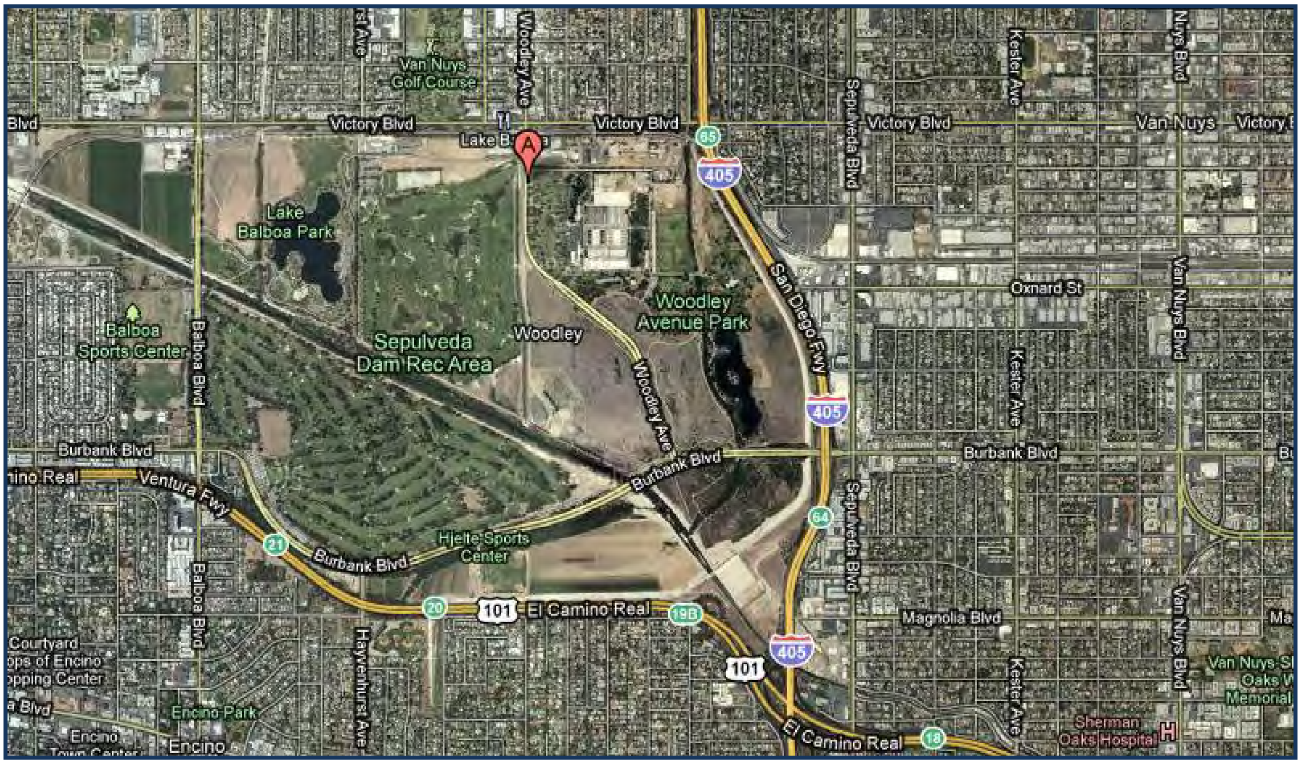
Figure 1-5: GWR Concept



1.4 GWR Treatment Pilot Study Overview

The purpose of the GWR Treatment Pilot Study was to conduct pilot scale testing to evaluate AWP processes being considered for treatment of recycled water for GWR supply. The GWR Master Planning Document, being completed as part of the RWMP, includes a facilities plan to implement an AWP facility (AWPF) with groundwater replenishment using high-quality recycled water in the San Fernando Valley at the Hansen Spreading Basin. The AWPF will be fed with secondary or tertiary effluent from the DCTWRP. The pilot testing is intended to support the implementation of the GWR Master Planning Report. The pilot facility was located at DCTWRP, immediately south of the decommissioned chlorination building (see **Figure 1-6** and **Figure 1-7** below), and was operated between February 18, 2010 and June 30, 2011.

Figure 1-6: Vicinity Map of DCTWRP



Source: Google Maps

Figure 1-7: Site Location Map

The GWR Treatment Pilot Study included three phases of pilot testing over a 16-month period, with each phase focusing on a different aspect of the treatment process. The purpose of each phase is described below:

- Phase 1 (Baseline Process Evaluation) included 6 months of testing to validate the proposed AWPF processes, including microfiltration (MF), reverse osmosis (RO), and advanced oxidation using ultraviolet (UV) light with hydrogen peroxide. Phase 1 testing was conducted between February 18 and August 18, 2010.
- Phase 2 (Alternative Advanced Oxidation Testing) included 6 months of testing to evaluate ozone/peroxide as an alternative to UV/peroxide, while looking to optimize performance of both advanced oxidation processes (AOPs). In addition, Phase 2 testing looked at optimizing performance of the MF and RO processes while defining the anticipated water quality of a future treatment facility. Phase 2 testing was conducted between August 19, 2010 and February 28, 2011.

- Phase 3 (Process Optimization) included 4 months of testing to confirm the recommended operating conditions from the Phase 1 and Phase 2 testing, while evaluating alternative RO membranes. Phase 3 testing was conducted between March 1 and June 30, 2011.

This report details the results and recommendations of all three phases of testing. It is intended that the pilot testing results be used as the basis for planning and design criteria development for the future AWPF.

1.5 Overview of Document

The GWR Treatment Pilot Study Report is organized into the following sections:

- Executive Summary
- Section 1 - Introduction
- Section 2 – Pilot Testing Goals and Project Start-up
- Section 3 – Operating Conditions
- Section 4 – Source Water Evaluation Results
- Section 5 – Microfiltration Results
- Section 6 – Reverse Osmosis Results
- Section 7 – Advanced Oxidation Process Results
- Section 8 – Product Water Quality Results
- Section 9 – Conclusions and Recommendations
- Section 10 – References

Appendices include supplemental information and reports related to the project.

2. Pilot Testing Goals and Project Set-up

This section summarizes the goals and objectives of the project, provides background information on the source water quality, describes the pilot testing equipment, and defines the water quality monitoring conducted during pilot testing.

2.1 Background

The purpose of the pilot study is to evaluate the proposed advanced water purification processes being considered for the GWR supply. Advanced water purification is used to remove pathogens, salts, and organic compounds from treated wastewater, creating a safe product water that can be used indirectly to supplement potable water supplies. These technologies are currently being used in several water recycling and indirect potable reuse facilities in Southern California. These projects generally include microfiltration or ultrafiltration (MF/UF), reverse osmosis (RO), and advanced oxidation using ultraviolet light (UV) and hydrogen peroxide; however, advanced oxidation is being used at only two and UV with no peroxide is being used at a third of these facilities. Table 2-1provides a summary of the source water, treatment processes, and operating conditions for these treatment facilities. It should be noted that of these facilities, only the Water Replenishment District (WRD) Vander Lans plant treats a nitrified source water similar to DCTWRP.

Table 2-1: Technologies Employed in Southern California Advanced Water Treatment Facilities

Facility	Source Water	Capacity (mgd)	MF/UF		RO		UV/AOP	Use
			Membranes	Flux (gfd)	Membranes	Flux (gfd)		
Terminal Island	TE(2)	4.5	Siemens PP	22	ESPA2	10	None	GWR(3)
OCWD(1) GWR	SE(2)	70	Siemens PP	20	ESPA2	12	Trojan UV	GWR
WRD Vander Lans	TE	3	Pall PVDF	33	ESPA2	10	Trojan UV (UV only)	GWR
WBMWD(1) El Segundo Ph I, II & IV	SE	12.5	Siemens PP	18-20	ESPA2	12	Trojan UV	GWR
WBMWD El Segundo Ph III	SE	4.6	Siemens PP	18	ESPA2	12	None	NPR(4)
WBMWD Carson	TE	5.0	Siemens PP	22	ESPA 2	12	None	NPR
WBMWD Exxon-Mobil	TE	3.2	Siemens PP	22	ESPA2	10	None	NPR
Yucaipa Valley WD	SE	8.0	Pall PVDF	28	None		None	NPR

Footnotes:

1) *OCWD = Orange County Water District. WRD = Water Replenishment District. WBMWD = West Basin Municipal Water District*
2) *SE = secondary effluent. TE = tertiary effluent*
3) *GWR = groundwater replenishment/seawater barrier.*
4) *NPR = non-potable reuse for industrial or irrigation use*

2.2 Overall Pilot Testing Objectives

The GWR Treatment pilot plant included all of the advanced treatment processes described above, utilizing MF membranes followed by RO and AOP. Desktop studies were also used to evaluate source water alternatives (e.g., secondary versus tertiary effluent), chlorination approaches, and post-treatment product water stabilization at DCTWRP.

The overall objectives of the pilot testing were to:

1. Demonstrate stable and reliable performance of proposed treatment technologies on secondary and tertiary wastewater effluent.
2. Demonstrate that the selected processes achieve the performance expectations and anticipated regulatory requirements.
3. Familiarize plant operations staff with the proposed treatment processes.
4. Obtain data that can be used to compare operation at DCTWRP with known operating conditions of similar equipment at other existing facilities.
5. Confirm design parameters for each pilot process, including chemical dosage rates.
6. Evaluate an alternative advanced oxidation process for minimizing NDMA, 1,4-dioxane, and other constituents of emerging concern (CECs).

2.3 Water Quality

To meet the project objectives, it was necessary to characterize the source wastewater effluent quality and confirm that the treated water quality complies with existing and proposed regulations and other project goals. Specific monitoring and water quality objectives are listed below.

2.3.1 Source Water Quality

Source water for testing included DCTWRP secondary effluent before chlorination, tertiary effluent before chloramination, and tertiary effluent after chloramination. Task 1.2 of the RWMP provided a summary of historical DCTWRP flow and water quality data. Technical Memorandum (TM) 1.2 , DCTWRP Data Summary (RMC/CDM,2010), assembled the historic water quality data for both the secondary and tertiary effluent and showed that the existing effluent water quality was in compliance with primary drinking water standards for the historically measured inorganic and organic constituents. Historical measurements were not available for the full suite of regulated chemicals with drinking water maximum contaminant levels (MCL). Section 4.4 of TM 1.2 listed the additional secondary and tertiary water quality sampling needed as part of the RWMP. These included seven parameters with primary MCLs, as well as additional information on NDMA levels within the DCTWRP. The following sampling locations and compounds were added to the pilot testing monitoring:

- NDMA sampling in primary, secondary, and tertiary effluent
- Tertiary effluent sampling for bromate, chlorite, ethylene dibromide, specific conductance, radium 226 and 228, Tritium, and Uranium.

Results from this additional sampling are included in Sections 4 and 8 of this Report.

2.3.2 Water Quality Treatment Goals and Regulatory Compliance

Regulatory related water quality requirements for the future AWPF are discussed in detail in the Regulatory Assessment revised TM (Task 1.1 TM, RMC/CDM, Dec 2011). GWR projects are regulated by the California Department of Public Health (CDPH), the Los Angeles Regional Water Quality Control Board (RWQCB), and the State Water Resources Control Board (SWRCB). Under Title 22, CDPH has the authority to approve GWR projects on a case-by-case basis, but the regulations do not include specific provisions for treatment or water quality for GWR projects. To date, CDPH has used a series of draft groundwater recharge regulations that serve as guidance for reviewing and approving projects. The draft regulations include specific treatment and water quality conditions. GWR projects must also comply with the numeric and narrative water quality objectives set forth in the RWQCB's Water Quality Control Plan (Basin Plan) for protection of groundwater. Requirements are different when surface water spreading is used for GWR rather than direct injection, however, LADWP and LADPW have chosen to treat to the higher standards required for direct injection, independent of the replenishment methods to be employed.

The requirements considered relevant for the pilot project can generally be described as:

- Compliance with the GWR permit for the West Coast Basin Barrier Project (this is the most recent and relevant permit for the proposed Los Angeles GWR project, but may not be applicable in whole);
- Compliance with water quality objectives for groundwater contained in the RWQCB's Basin Plan for minerals and for constituents with current and anticipated primary and secondary drinking water maximum contaminant levels; and
- Compliance with the 2008 draft California Department of Public Health (CDPH) groundwater recharge regulations. In accordance with recent amendments to the California Water Code (CWC), CDPH must adopt groundwater recharge regulations on or before December 31, 2013 (CWC 13562(a) (1)). It should be noted that revised draft groundwater recharge regulations were released in November 2011, after the initial drafting of this pilot report. These 2011 draft regulations include significant changes from the previous 2008 draft regulations, however, the discussions, analyses, and conclusions within this pilot report have been based on the 2008 draft regulations, which were in place when this report was written.

Water quality for the tertiary treated water at the DCTWRP facility already met the majority of the existing requirements, and the RO membranes employed in the AWP process would reduce most remaining constituents to levels well below their regulated limits. A small number of organic constituents may require treatment with advanced oxidation to fully comply with regulatory treatment requirements, specifically for NDMA. Therefore, the pilot study evaluated the effectiveness of the combined treatment processes for removing or destroying regulated water quality contaminants as well as CECs, including n-nitrosodimethylamine (NDMA), endocrine disrupting compounds (EDCs) and pharmaceuticals and personal care products (PPCPs).

Table 2-2 presents the primary water quality goals for the pilot, which were generated with consideration of the draft requirements for groundwater recharge. While these constituents were the primary focus for the treatment processes, all regulated and potentially regulated constituents were monitored during the pilot testing. In addition, the list of CECs, which were evaluated, was based on compounds monitored for at other AWPFs, including OCWD's Groundwater Replenishment System, West Basin's Edward C. Little Water Recycling Facility, and WRD's Leo J. Vander Lans Water Treatment Facility. See Section 8 for a complete list of the constituents tested.

Table 2-2: Pilot Testing Primary Water Quality Goals

Constituent	Units	Regulated Limit
Total Organic Carbon (TOC)	mg/L	< 0.5[a]
Total Nitrogen	mg/L	< 5[a]
NDMA	--	> 1.2 log reduction[a]
1,4-Dioxane	--	> 0.5 log reduction[a]
TTHM	µg/L	< 80[c]
HAA5	µg/L	< 60[c]
Turbidity	NTU	< 0.2[b]
Chloride	mg/L	< 100[d]
TDS	mg/L	< 500[c]

Footnotes:

a. *2008 Draft Groundwater Recharge Regulations. The total organic carbon goal is based on achieving authorization for a recycled water contribution as high as 100%.*
b. *Existing Title 22 Water Recycling Regulations for disinfected tertiary recycled water treated using membranes.*
c. *CDPH drinking water limits (primary and secondary maximum contaminant levels)*
d. *Basin Plan Objectives for groundwater.*

2.4 Unit Process Performance Goals

This subsection includes specific performance, operational, and water quality goals for each of the three unit processes tested.

2.4.1 Microfiltration System

The primary function of the MF system is to provide adequate pretreatment of the process stream for sustainable operation of RO. Water quality performance for the MF system was primarily measured as turbidity and silt density index (SDI), which should remain below 0.2 NTU and 3, respectively, to prevent fouling on the RO membranes. The MF also provides the first barrier against protozoa and bacteria, which should remain at undetectable levels in the MF product. The pilot testing objectives were to maintain reliable performance, achieving filter run lengths of at least 30 days between chemical cleanings, while meeting water quality goals for turbidity, SDI, bacteria, and protozoa.

2.4.2 RO System

The primary function of the RO process is to provide adequate removal of dissolved salts and organic contaminants. All of the pilot testing water quality goals were expected to be met in the RO product, with the exception of NDMA and 1,4-dioxane, which are addressed by the AOP. The specific operating objectives for the RO system were to:

- Confirm that the water quality produced by the RO system meets the water quality goals, removes CECs, and has comparable performance with other operational AWPFs.
- Achieve stable operation with minimal fouling and projected run lengths of at least 6 months between chemical cleanings. To meet this goal, the RO must sustain permeabilities with no more than 5 percent permeability loss per month under optimized operating conditions.
- Determine if a 2-stage or 3-stage RO configuration provides more efficient, reliable performance at an 85 percent hydraulic recovery rate.
- Determine whether operation at a flux greater than 12 gallons per day per square foot (gfd) provides an advantage or is a detriment to membrane fouling.
- Determine if membranes from any of three selected manufacturers provides improved performance or contaminant removal.

2.4.3 Advanced Oxidation System

The primary function of the AOP system is to destroy trace organic compounds not completely removed by the RO membranes. Two alternative AOPs were evaluated during pilot testing, including UV/peroxide and ozone/peroxide. The AOP testing had the following, process-specific objectives:

- Evaluate the effectiveness of the UV/peroxide process at destroying trace organic compounds not completely removed by RO, comparing results with existing operational facilities.
- Compare ozone/peroxide with UV/peroxide in terms of their effectiveness at destroying NDMA and other CECs, meeting the minimum requirement of 1.2-log NDMA reduction and 0.5-log 1,4-dioxane reduction.

2.5 Pilot System Design, Equipment Procurement, and System Construction

2.5.1 Advanced Oxidation Background

Advanced oxidation processes utilize hydroxyl radicals (HO•) to oxidize and sometimes completely mineralize trace organic compounds and constituents of emerging concern, CECs. This is represented in the following formula.

$$\text{CEC} + \text{HO}\bullet \rightarrow H_2O + CO_2 + \text{mineral acids/salts}$$

It should be noted, however, that incomplete mineralization can also result in the formation of different organic byproducts rather than mineral salts, making the upstream RO process an important step in the removal of CECs.

Hydroxyl radicals are increasingly being evaluated or employed to remove CECs that may pose a public health and/or environmental threat. Of the commercially available AOP options, only ozone/hydrogen peroxide and photolysis of hydrogen peroxide have been applied at full-scale drinking water or reuse facilities in California (note that the full-scale ozone/peroxide system is designed for drinking water rather than water reuse). The production pathway of HO• is different for ozone/peroxide and UV/peroxide. However, HO• induced destruction of CECs is similar for both AOP options. The low levels of natural organic matter (NOM) and alkalinity, which compete with target constituents for hydroxyl radicals, in RO product water (associated with groundwater recharge projects) make advanced oxidation an ideal candidate for application in water reuse projects.

UV/Peroxide

Target contaminant destruction pathways via the UV/peroxide process is accomplished through direct photolysis:

$$\text{CEC} + \text{UV radiation} \rightarrow \text{Products}$$

and by oxidation with hydroxyl radicals that are produced through the photolysis of hydrogen peroxide:

$$\text{UV} + H_2O_2 \rightarrow \text{HO}\bullet$$

$$\text{CEC} + \text{HO}\bullet \rightarrow H_2O + CO_2 + \text{mineral acids/salts (or other organic compounds)}$$

The dominant destruction mechanism (direct photolysis versus HO• oxidation) depends on the target contaminant of interest. In most cases, degradation is markedly improved in the presence of HO• and often accounts for the majority of the destruction pathway, as is the case with 1,4-dioxane. However, contaminants with high quantum yields and extinction coefficients (e.g., NDMA) are amenable to direct photolysis.

Ozone/Peroxide

For the ozone/peroxide system, hydroxyl radicals (HO•) are the drivers for the destruction of trace contaminants. Hydroxyl radicals are generated through a set of chain reactions that are initiated through the interaction between the anion of peroxide and aqueous ozone.

$$HO_2^- + O_{3(aq)} \rightarrow \text{OH}\bullet$$

The overall production of HO• is highly dependent on pH. At a higher pH, the dissociation of hydrogen peroxide is more favorable, thereby providing higher concentration of the anion of peroxide, which can then react with aqueous ozone to produce HO•. The HO• then reacts with target constituents by the same mechanism as in the UV/peroxide process discussed above.

$$\text{CEC} + \text{HO}\bullet \rightarrow H_2O + CO_2 + \text{mineral acids/salts (or other organic compounds)}$$

Ozone/Peroxide was selected as an alternative advanced oxidation process because of its proven effectiveness at removing CECs in other facilities and the possibility for cost or energy savings as opposed to UV/peroxide. A more extensive discussion of the rationale for selecting ozone/peroxide as an alternative AOP can be found in the Pilot Testing Protocol (Appendix G)

2.5.2 Design and Equipment Procurement

Pilot design began in mid-2009, in conjunction with the development of the testing protocol. A workshop was held on August 12, 2009 to identify and select major process components, including the MF, RO, and UV equipment. Final selection of equipment vendors was based on cost and availability among the preferred vendors identified during the August workshop. A second workshop was held on October 8, 2009, focusing on finalizing the testing protocol and selecting the alternative advanced oxidation process. Equipment procurement began in October; however, design of the Phase 2 process equipment continued through April 2010. Table 2-3 presents a summary of the major process equipment selected for each phase.

Table 2-3: System Equipment Summary

Treatment Process	Equipment	Capacity	Phases of Testing
Microfiltration	Pall Microza PVDF	50 gpm	Phase 1, 2 and 3
Reverse Osmosis	Hydranautics,	15-17 gpm	Phase 1 & 2
	Toray and CSM	15-17 gpm	Phase 3
Advanced Oxidation Process	UV/Peroxide by Trojan Technologies	15-350 gpm	Phases 1 & 2
	Ozone/Peroxide by CDM Smith		
		5-10 gpm	Phase 3

Section 2.7 provides additional detail on the installed equipment. Vendors were selected for the pilot study only and do not preclude other vendors from participating once the full-scale project is implemented. Discussion on alternative equipment considered for pilot testing can be found in the Pilot Testing Protocol (Appendix G). Some of the advantages of the selected equipment included:

- Microfiltration – the Pall MF system is used at the Vander Lans advanced treatment facility to treat a similar source water for RO pretreatment. Unlike several of the alternative membrane filtration manufacturers, the Pall membranes have not changed significantly during the last decade, making it easier to compare operating results with other full-scale facilities.
- RO Elements – The Hydranautics membranes selected for baseline operation are used at all of the operational indirect potable reuse facilities in southern California. Alternative membranes from CSM Products (Woongjin Chemical Company) and Toray Industries were selected based on review of positive operating performance published in literature for wastewater applications. It should be noted that these represent only three of several membrane alternatives that should be considered for the future facility.
- Advanced Oxidation – The Trojan UVPhox system was selected for Phase 1 and 2 testing to allow the comparison of results with other full-scale facilities utilizing UVPhox

systems, including the OCWD GWR System and the West Basin Edward C. Little facility. Ozone/peroxide was selected as an alternative AOP because of its proven effectiveness as a reliable oxidation approach.

While Phase 1 testing focused on the baseline treatment process of MF, RO, and UV/peroxide, Phase 2 testing evaluated an alternative AOP, while evaluating UV/peroxide under more efficient hydraulic conditions to better represent conditions during full-scale operation. Phase 2 operation for AOP was done in batch mode, rather than continuous flow, in order to provide high flow, fully turbulent conditions for the UV equipment. To accommodate these conditions, additional storage and pumping was required at the project site. In addition, ozone generation, injection, and contact equipment were provided for both the Phase 2 and Phase 3 testing. The design for these facilities was performed during the Phase 1 testing. The equipment is further discussed below.

2.5.3 Equipment Installation and System Construction

Initial construction for the pilot facility began in December, 2009 and was completed in early February, 2010. After the initial construction of the pilot facility, several construction modifications were made including:

- Installation of two additional submersible pumps within the DCTWRP Phase II facilities (on the east half of DCTWRP). After the pilot study was in operation, the DCTWRP operators notified the pilot staff that DCTWRP shuts off flow to half of the plant for a portion of the year. New pumps were needed to provide source water to the pilot on a continuous basis. The pumps were installed during the week of April 12, 2010.
- Relocation of the original submersible pump in the DCTWRP Phase I secondary effluent channel to a point upstream. The purpose of this was to pump secondary effluent from upstream of a new chlorine injection point that had begun feeding chlorine upstream of the tertiary filters.
- Installation of the Phase 2 pilot equipment required to operate the UV unit in fully turbulent conditions. This included electrical work, piping, chemical addition, VFD programming, and tank installation. (Work was completed on August 5, 2010.)
- Installation of the Phase 2 Ozone generation and feed equipment. This included a generator, ozone column with destruct unit, ozone contactor, peroxide contactor, and chemical feed equipment for peroxide and caustic soda. (Work was completed in September 2010.)

2.6 System Equipment Description

2.6.1 Microfiltration Equipment

The MF skid used was a pressurized Pall Microza USV with four chlorine resistant, polyvinylidine fluoride (PVDF) membranes that are identical to those used in full-scale facilities. Each membrane contains 538 square feet (sf) of membrane area functioning in an outside-in flow configuration. The nominal pore size in the membranes is 0.1 micron. This pilot skid included an automated control system, pumps, valves, controls, and the additional tankage required for backwash water and clean in place (CIP) procedures. **Figure 2-1** shows a photo of the MF pilot equipment.

Figure 2-1: Microfiltration Pilot Equipment

A membrane integrity test (MIT) was performed daily to verify integrity of the membranes and to ensure high quality RO feed water. MITs occurred automatically at the time set in the control system and could be performed manually if desired by the operators.

A complete description of the operation of the MF system was provided by the supplier in the system operation and maintenance (O&M) manual, included with the Pilot Testing Protocol, RMC/CDM, 2010. The documentation includes a flow schematic of the process, a description of each mode of operation (service, backwash, flush, clean-in-place, etc.), as well as all necessary instrumentation and controls.

2.6.2 Reverse Osmosis Equipment

The RO system was designed to be operated as either a 2-stage or 3-stage process:

- The first stage included fourteen 4-inch elements (seven in each parallel set of vessels, with each set consisting of two pressure vessels in series),
- The second stage included seven 4-inch elements split between two vessels in series, and

- The third stage included seven 2.5-inch elements, also split between two vessels in series.

This represents a standard 4x2x1 cascading array, similar to the arrays utilized at full-scale RO facilities. Photos of the RO equipment used in the testing are included as **Figures 2-2** and **2-3**.

Figure 2-2: Reverse Osmosis Equipment (1 of 2)

Figure 2-3: Reverse Osmosis Equipment (2 of 2)

Figures 2-4 and **Figure 2-5** illustrate the configurations for a 2-stage system and 3-stage system, respectively. The RO pilot skid was designed for up to 23 gpm of product flow and 300 psi of operating pressure. An interstage booster pump was included upstream of the third stage to increase the flux of this final stage; however, flow balancing between the first and second stage was done using permeate throttling of the first stage permeate. Hydranautics ESPA2 elements were used for all membrane stages during Phases 1 and 2. These were replaced during Phase 3 with CSM FEn membranes in half of the first stage and the second stage and Toray TML20 membranes in the other half of the first stage.

Figure 2-4: Two-Stage RO Configuration

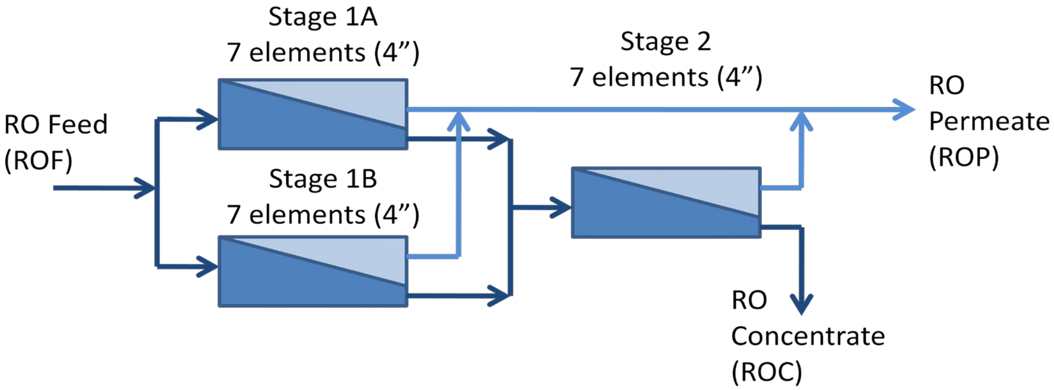
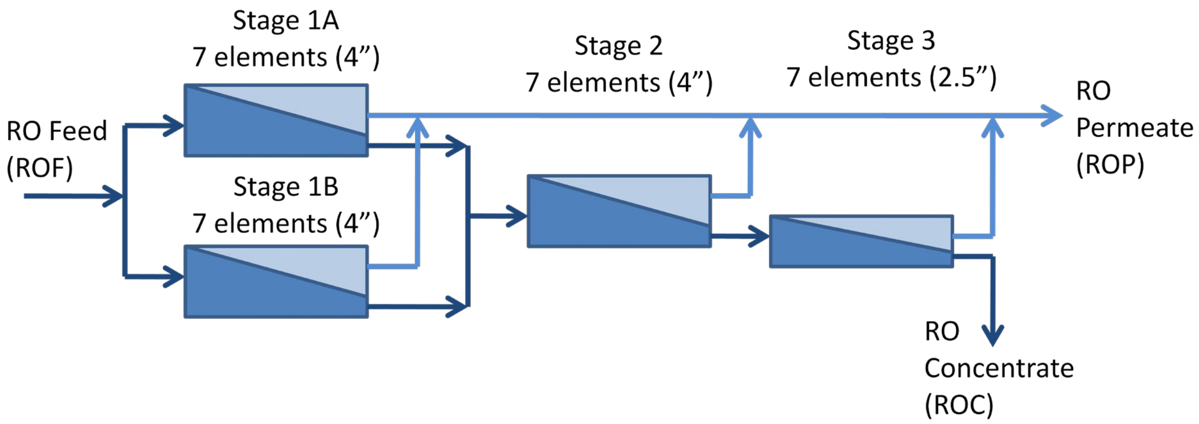


Figure 2-5: Three-Stage RO Configuration



An oxidation/reduction potential (ORP) and a total chlorine analyzer were provided to monitor the RO feed for free chlorine or excessive chloramines carryover. Antiscalant chemical was added at all times to prevent scaling of the RO system. Sulfuric acid addition was employed to reduce the pH of the feed water; however, pH adjustment was only done to reach a pH of 6.9 in order to offset a small pH increase resulting from the ammonium hydroxide addition. pH adjustment was discontinued during the Phase 3 testing. Operating conditions for the RO equipment are identified in Section 3.3.

The RO equipment was mounted within a portable trailer that included the necessary pumps, valves, chemical addition systems, automated controls and cartridge filters.

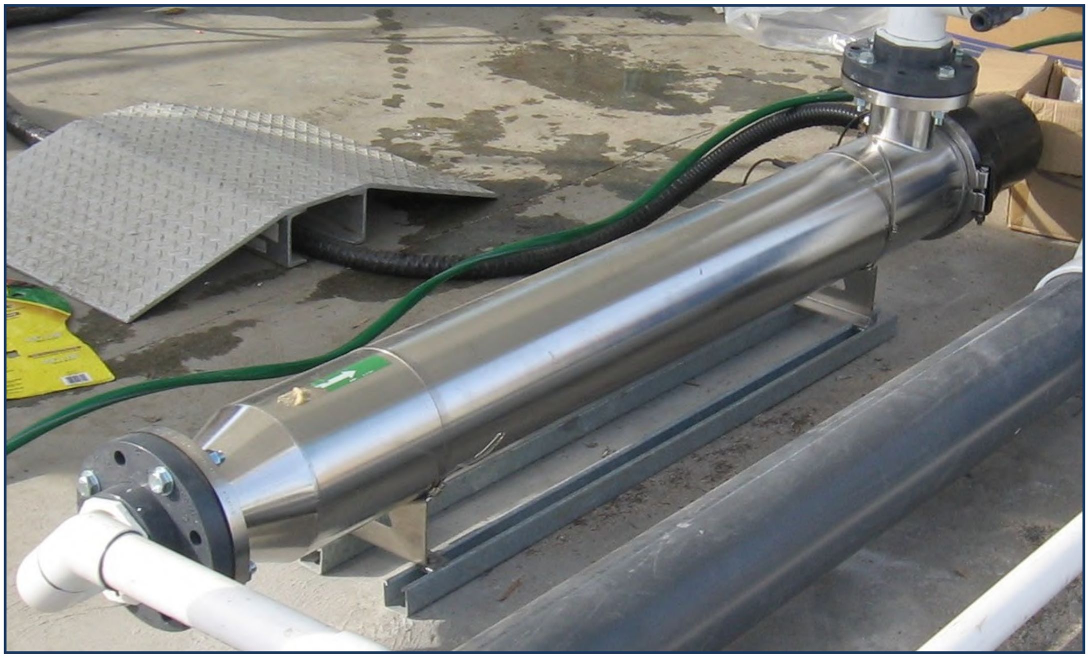
2.6.3 AOP Equipment

Two advanced oxidation systems were utilized at the pilot, one testing the same type of UV/peroxide system used at existing AWP facilities, and one testing an alternative ozone/peroxide system. Each of these systems is described briefly below:

UV/Peroxide

During Phase 1 of the pilot study, a Trojan 8AL20 UV reactor, an 8-lamp UV reactor with 8-inch diameter, was utilized at a flow rate of less than 20 gpm, matching the production flow from the RO membranes. This is shown in **Figure 2-6** below.

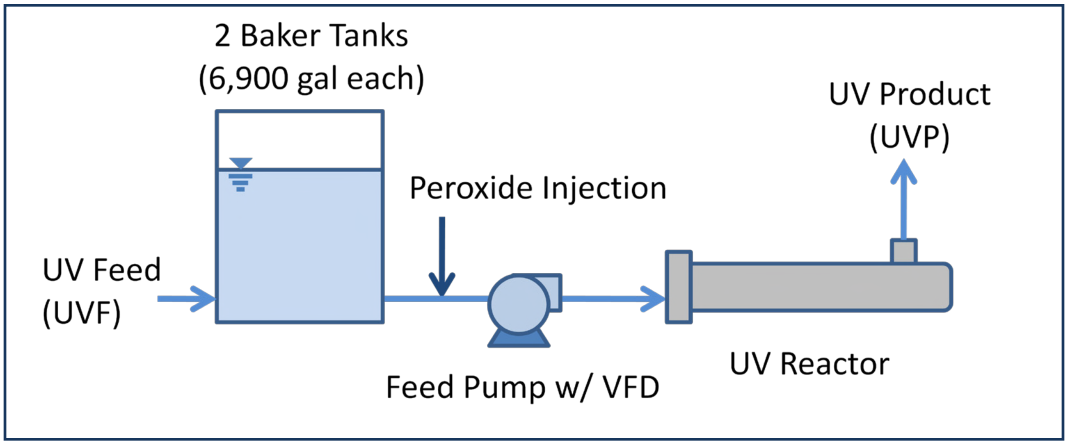
Figure 2-6: Pilot Testing UV Reactor



When used at such a low flow rate, the hydraulic conditions for the 8AL20 reactor are not representative of the fully turbulent flow conditions as utilized in full-scale applications and required for efficient photolysis. During pilot studies, it is common to operate systems at low flow rates while evaluating performance parameters that can be applied to full-scale systems; however, hydraulic conditions in UV reactors have a large influence on reactor efficiency making it advantageous to conduct pilot testing at higher flow rates that are more representative of full-scale conditions.

During Phase 2 testing, the UV/peroxide system configuration was modified to allow for higher flow rates, testing the efficiency and modeling hydraulics of the reactor at varying flows. The system configuration used during Phase 2 is shown in **Figure 2-7**.

Figure 2-7: UV/Peroxide Pilot Configuration for Phase 2 Testing



The pilot system was equipped with two Baker tanks, each 6,900 gallon in capacity, to collect RO permeate during evenings and to allow for batched operation with 1,4-dioxane (dosed at approximately 177 µg/L) which was spiked into the baker tank. A photo of the Phase 2 UV/peroxide set-up is included as **Figure 2-8**.

Figure 2-8: UV/Peroxide Equipment for Phase 2 Testing

Peroxide Injection, Feed Pump with VFD, UV Reactor

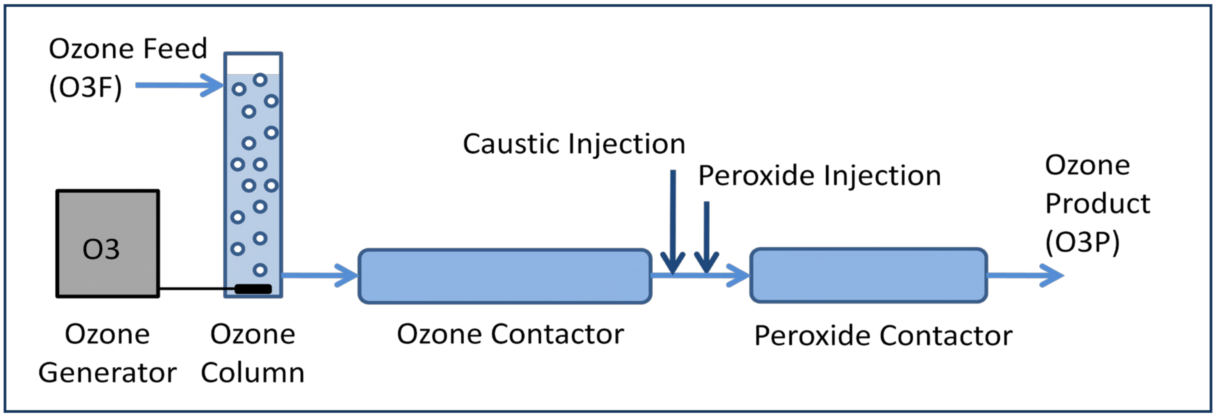
Feed water to the RO system was switched during evenings when the Baker tanks were being filled to draw water from the DCTWRP tertiary product water after the chlorine contact tanks, where NDMA levels were highest. Drawing water from this location allowed for evaluation of the treatment effectiveness of the UV/peroxide system at differing flow rates. A VFD-controlled pump and a flow control setup were utilized to operate the reactor at constant flow rates between 50 and 350 gpm with inline hydrogen peroxide injection.

Ozone/Peroxide

A photo of the ozone/peroxide system used during Phases 2 and 3 is included as **Figure 2-9**. The system configuration is shown schematically in **Figure 2-10**. The ozone/peroxide system was equipped with an ozone column/bubble diffuser and metering pumps to deliver caustic soda (NaOH), to raise pH, and hydrogen peroxide. The system was operated at a flow rate of 4 gpm and influent ozone concentrations between 5 and 14 ppm. The initial ozone reactor column was used before peroxide addition to simulate ozone disinfection required for CDPH Title 22 disinfection, based on 4-log virus inactivation. Following this process, caustic soda and hydrogen peroxide were added before a peroxide contactor, where advanced oxidation occurred. The average residence time in the ozone contactor was 2.9 minutes at 4 gpm flow. As an ozone CT of 1.0 mg/L-min is required for 4-log virus inactivation at a minimum 10°C, this contact time was in excess of what would be required for the ozone doses employed, however, these doses were not known at the time of initial system design. The residence time in the peroxide contactor was 1.5 minutes.

Figure 2-9: Ozone/Peroxide Equipment

Figure 2-10: Ozone/Peroxide Pilot Configuration



2.7 Data Monitoring

Test procedures for the Phase 1 and 2 testing followed the pilot study testing protocol. The water quality and performance monitoring conducted is described in detail below.

2.7.1 Recording Field Data

Field engineers recorded pilot field data daily. On weekends, DCTWRP staff recorded some key field measurements. Field data included basic measurement such as pressures, flows and temperatures as well as measurements such as pH, free and total residual chlorine, conductivity, oxidation reduction potential (ORP), silt density index (SDI), total organic carbon (TOC), turbidity, and UV-254. Specific feed data was recorded for each of the unit processes.

Microfiltration

The field engineer monitored and documented operational parameters for membrane filtration to confirm that sustainable operation was maintained. The majority of flow and pressure data for the MF system was collected by the system programmable logic controller (PLC), however, some parameters were also assessed by observation (e.g., gauge readings, tank levels, chemical feed rates, sample flow rates, and secondary field instruments). Key running parameters and conditions that were manually logged and reviewed daily include:

- Feed Flow (gpm)
- Filtrate Flow (gpm)
- Membrane Integrity Test Results
- Operation Time (hours)
- Feed Water Pressure (psi)
- Backwash Frequency, Flow Rate and Duration (minutes)
- Feed and Filtrate Turbidity (NTU)

Operational data were manually logged daily by onsite operations staff. The MF System operations logbook included a record of events (equipment starts, stops, maintenance, instrument calibrations, etc.) and description of any problems or issues. The original data sheets were stored on-site; copies of the daily data and log entries were emailed to the task leader on a weekly basis.

Reverse Osmosis

The field engineer monitored and adjusted daily the operating parameters for the RO unit. The permeate flow was adjusted to maintain the desired operating flux. The concentrate flow was adjusted to maintain the established system recovery. Maintaining an even flow distribution between stages and pressure vessels required daily fine tuning of multiple valves and the feed pump VFD. Backpressure was maintained on the first stage permeate to balance permeate flux between the first and second stage.

Key running parameters that were recorded daily to evaluate RO operation included:

- Total Permeate Flow
- Permeate Flow per Stage
- Feed Water Pressure
- Permeate Pressure per Stage

- Total Concentrate Flow
- Permeate Conductivity from Each Pressure Vessel
- Final Concentrate Pressure
- Inter-Stage Pressure

A daily operating log and conductivity profile were taken by the field engineers. The RO System operations logbook includes a record of events (e.g., equipment starts, stops, maintenance, and instrument calibrations) and description of any problems or issues. Data from the log sheets were entered into the project spreadsheet on a weekly basis to calculate operating parameters such as flux, permeability, and salt passage.

Advanced Oxidation

During Phase 2 testing the advanced oxidation systems were operated in batch mode. Performance monitoring was conducted during the 45 to 60 minute operating periods. Parameters monitored included flow rate, total chlorine in feed, total chlorine in product, UV transmittance, ozone dose, ozone residual, pH, and temperature.

Additional Field Measurements

Additional water quality monitoring was done using field equipment to characterize diurnal patterns for TOC, turbidity, chlorine demand, and temperature. This testing was conducted over 24 hour cycles with samples taken hourly. One test was conducted per quarter for each of these parameters.

2.7.2 Sampling for Laboratory Testing

All water quality measurements not performed with field equipment were stored in sample bottles and sent to Weck Laboratories for analysis.

Routine Sampling

Laboratory testing was split up into weekly, monthly and quarterly sets. Each week, one or more of these sets was delivered to Weck Labs for testing. Each sample location is described in Table 2-4.

In general, parameters that were most critical for monitoring or characterizing unit process performance were measured on a weekly or more frequent basis. Field measurements using field analytical equipment were made daily for several key parameters. Monthly and quarterly sampling was completed for regulated parameters, non-regulated parameters of potential concern, and for quality control on various field monitored parameters.

The frequency and schedule for water quality data collection is summarized in Table 2-5.

Table 2-4: Description of Sample Locations

Location	Facility	Description of Location	Method of Sampling	Notes
Primary Effluent	DCTWRP	Downstream of primary treatment	Channel	
Secondary Effluent	DCTWRP	Downstream of secondary treatment but before addition of chlorine and polymer	Channel/Sample Tap	These three sample locations shared one sample point. Operators adjusted valves and flushed the sample tap for 10 minutes before taking samples from these locations. Before this sample point was available, these samples were taken directly from their corresponding channels.
Tertiary Effluent before Chloramination	DCTWRP	Downstream of tertiary treatment but before chloramination	Channel/ Sample Tap	
Chloraminated Effluent	DCTWRP	Downstream of chlorine contact basins and before sodium bisulfite addition	Channel/ Sample Tap	
Source Water	Pilot/ DCTWRP	Source of water for pilot plant	Sample Tap	This sample location was always either secondary effluent or tertiary effluent before chloramination. The term 'Source Water' was used since these waters fed directly into the pilot system.
MF Effluent	Pilot	Downstream of MF system before storage tank	Sample Tap	
RO Feed	Pilot	Downstream of RO cartridge filters but upstream of RO membranes	Sample Tap	
RO Filtrate	Pilot	Mixed collection from permeate side of each RO membrane	Sample Tap	
RO Concentrate	Pilot	Collected from reject side of RO membranes	Sample Tap	
AOP Influent	Pilot	Downstream of RO membranes and immediately upstream of AOP systems.	Sample Tap	
UV Effluent	Pilot	Downstream of all treatment (when using UV/peroxidee as AOP)	Sample Tap	
Ozone Effluent	Pilot	Downstream of all treatment (when using ozone/peroxide as AOP)	Sample Tap	

Table 2-5: Pilot Water Quality Monitoring

Parameter	Method	Source Water	MF/UF Effluent	RO Feed	RO Filtrate	RO Concentrate	AOP Influent	AOP Effluent	
								UV	O_3
Temperature (F)	field	WD	WD	WD	WD	WD	WD	WD	WD
pH	field	WD	WD	D	WD	WD	WD	WD	WD
Free Residual Chlorine (mg/L)	field	WD	WD	WD	-	-	-	-	-
Total Residual Chlorine (mg/L)	field	WD	WD	WD	D	-	WD	-	WD
Color (Pt-Co)	field	W	W	W	-	W	M	-	-
Conductivity (µS/cm)	field	WD	-	D	WD	WD	W	W	WD
ORP	field	-	WD	D	WD	-	-	-	WD
Dissolved Oxygen (mg/L)	field	W	-	-	-	-	W	-	WD
SDI	field	-	W	WD	-	-	-	-	-
TOC (mg/L)	field	WD	W	M	WD	W	M	-	WD
Turbidity (NTU)	field	WD	WD	WD	WD	WD	-	-	WD
UV254	field	WD	WD	-	WD	-	WD	WD	WD
UV Intensity	field	-	-	-	-	-	WD	WD	-
Alkalinity (mg/L)	SM2320B	-	W	W	W	W	W	W	W
Barium (mg/L)	EPA200.7	-	-	M	M	M	-	-	-
Boron (mg/L)	-	M	-	M	M	M	-	-	-
Bromate (mg/L)	EPA300.1	Q	-	-	-	-	-	-	W
Bromide (mg/L)	EPA320.1	M	-	S	M	-	-	-	-
Calcium (mg/L)	EPA200.7	-	-	W	W	W	S	-	-
Chloride (mg/L)	EPA300.0	S	-	M	M	M	-	-	Q
1,4-Dioxane	EPA8270M	W	S	-	S	-	M	W	W
Fluoride (mg/L)	EPA300.0	S	S	W	W	W	-	-	-
Total Iron (mg/L)	EPA200.8	M	S	M	M	M	-	-	-
Magnesium (mg/L)	EPA200.7	Q	-	W	W	W	S	-	-
Manganese (mg/L)	EPA200.8	M	-	M	M	M	-	-	-
NDMA	EPA1625M	W	W	W	W	-	W	W	W
TKN (mg/L)	EPA351.2	M	W	M	W	M	S	M	M
NH_3 (mg/L)	EPA350.1	M	W	W	W	M	-	M	M
NO_2 (mg/L)	EPA353.2	S	W	Q	W	M	S	M	M
NO_3 (mg/L)	EPA353.2	S	W	Q	W	M	Q	M	M
Orthophosphate (mg/L)	EPA365.1	W	M	M	W	W	M	M	-
Total Phosphorus (mg/L)	EPA365.1	W	M	Q	W	W	-	-	-

Parameter	Method	Source Water	MF/UF Effluent	RO Feed	RO Filtrate	RO Concentrate	AOP Influent	AOP Effluent	
								UV	O_3
Potassium (mg/L)	EPA200.7	M	-	M	M	M	-	-	-
Silica (mg/L)	EPA200.7	-	-	W	W	W	S	-	-
Sulfate (mg/L)	EPA300.0	-	S	W	W	W	-	-	-
TDS (mg/L)	SM2540C	W	S	W	W	W	W	W	W
Sodium (mg/L)	EPA200.7	-	-	W	W	W	S	-	-
Strontium (mg/L)	EPA200.8	-	-	W	W	W	S	-	-
TOX (total organic halogens) (µg/L)	SM5320B	M	-	S	M	S	M	-	-
507 Compounds	EPA525.2	M	S	M	S	S	Q	-	-
Fumigants (EDB, DBCP)	EPA504.1	-	-	Q	S	-	-	-	-
Volatile Organic Compounds	EPA524.2	M	-	M	-	S	Q	-	-
Trihalomethanes, Total (TTHM) (µg/L)	EPA525.2	M	-	M	M	S	Q	-	M
Haloacetic Acids, five (HAA5) (µg/L)	EPA524.2	M	-	M	M	S	Q	-	M
Cryptosporidium & Giardia	EPA1623	Q	Q	-	-	-	-	-	-
Indigenous Coliphage	SM1602	M	-	-	-	-	Q	-	-
Total Cultural Virus - Enterovirus (EPA R-95/178)	EPA ICR 6000	Q	-	-	-		S	-	-
Organochlorine Pesticides & PCBs	EPA508	Q	-	Q	-	-	Q	-	Q
Oil and grease (mg/L)	EPA1664A	M	M	-	-	-	-	-	-
Emerging Contaminants									
Pharmaceuticals & Personal Compounds	-	Q	-	-	Q	-	Q	S	Q
TCEP	-	W	-	M	M	S	M	M	M
Chlorinated Acid Herbicides	EPA515.3	Q	-	-	-	-	Q	-	-

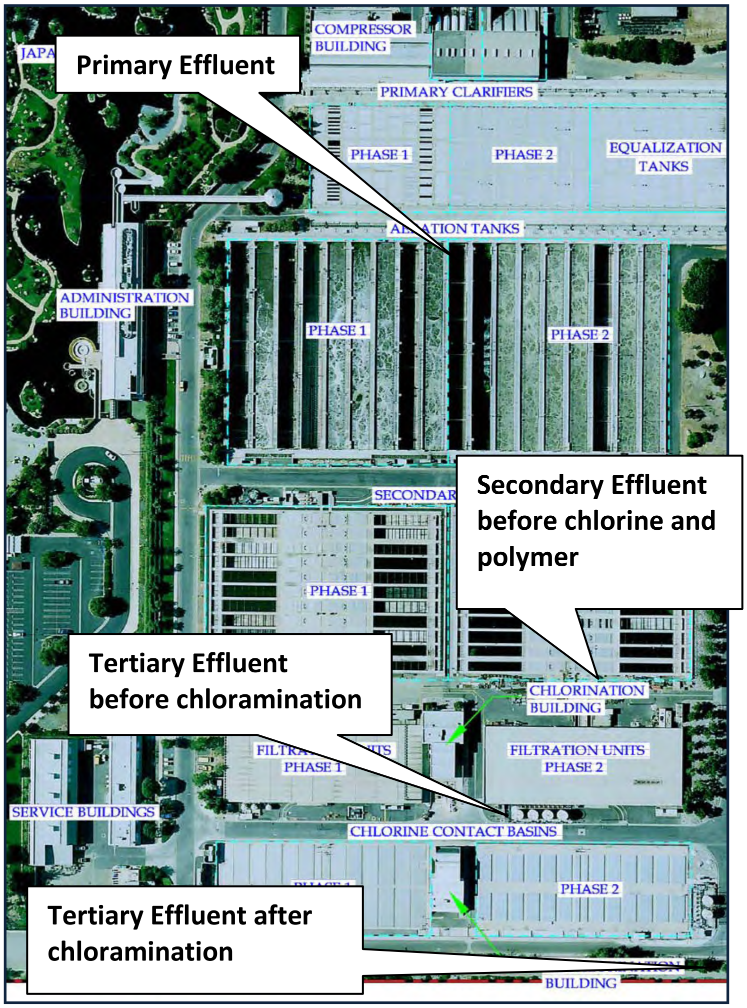
Footnotes:

a. D = daily, WD = weekdays only, W = weekly; M = monthly, Q = quarterly, S = sporadic
b. Continuous on line monitoring instruments are not included in this table.
c. Composite samples will be used for monitoring of the parameters for the primary and secondary drinking water standards.
d. Unless indicated otherwise, all other parameters will be sampled using grab samples.
e. Note that numerous changes during testing caused the frequency of some samples to vary for some source locations. As an example, the ozone effluent 1,4-dioxane is listed as a monthly sample, but this was taken only on a quarterly basis during Phases 1 and 2.
f. In addition to the sample points above, two additional sample points were tested during Phase 3. These were RO permeate taps downstream of the first stage Toray and CSM membranes, respectively. They have been omitted from this table for clarity.

Routine DCTWRP NDMA Testing

NDMA samples at several DCTWRP process locations were included as part of the routine weekly laboratory samples. These samples provide background information regarding trends in NDMA levels in the DCTWRP primary effluent, secondary effluent before chlorine and polymer addition, tertiary effluent before chloramination, and tertiary effluent after chloramination and sodium bisulfite addition. **Figure 2-11** shows the locations where these samples were taken.

Figure 2-11: DCTWRP NDMA Sample Locations



NDMA Bench Testing

During Phase 1 testing, two rounds of NDMA bench testing were performed. The purpose of this testing was to measure the difference in NDMA and TTHM disinfectant byproduct formation between various disinfection methods for detention times of 5 minutes to 24 hours During the first round of testing, free chlorine was compared with chloramination. During the second round of testing, traditional chloramination (ammonia addition followed by chlorination) was compared to sequential chlorination (breakpoint chlorination followed by ammonia addition to form chloramines).

Diurnal NDMA Sampling

During Phases 1 and 2, four rounds of diurnal sampling were performed. These occurred on April 14, 2010, August 9, 2010, November 19, 2010 and January 31, 2011. The purpose of these samplings was to investigate the variations in NDMA over a 24-hour period. The rounds of sampling were performed during different seasons to see whether or not the diurnal NDMA trends vary by season. Discussion and results from this sampling are included in Section 4 and Appendix B.

2.8 Data Evaluation

Field and laboratory data were input into a master spreadsheet on a weekly basis, tabulating trends in data and calculating various performance measurement parameters for the unit processes. These parameters and trends were monitored to evaluate performance and to determine whether or not operating conditions needed to be modified or membrane cleanings needed to be conducted. Monthly progress reports describing the data evaluation were sent to LADWP and LADPW. The performance measurement parameters and formulas used to calculate them are listed below.

- MF Flux – Measures the filtration rate of the MF membranes
  $J_{MF} = Q_p / A_m$
  Where:
  J_{MF} = MF permeate flux (gfd)
  Q_p = Permeate flow (gpd)
  A_m = Membrane area (sf)

- Normalized MF Flux (25°C) – Applies temperature correction factor to the MF based to account for changes in water viscosity.
  $J_{MF}\ (25°C) = J_{MF} * TCF$
  Where:
  $J_{MF}\ (25°C)$ = Normalized MF Flux
  TFC = Temperature Correction Factor = $e^{(2600/T - 8.72)}$
  T = Absolute Temperature (Kelvin)

- MF Transmembrane Pressure (TMP) – Average pressure loss across the membranes
  $TMP_{MF} = P_f - P_p$
  Where:
  TMP_{MF} = MF Transmembrane Pressure (psi)
  P_f = Feed Pressure (psi)
  P_p = Permeate Pressure (psi)

- MF Permeability – Normalized measure of how easily water flows through membrane. Significant permeability declines require membrane cleaning to reverse.
  $k_{MF} = J_{MF}\ (25°C) / TMP_{MF}$
  Where:

k_{MF} = MF Permeability (gfd/psi)

- RO Flux – Measures the filtration rate of the RO membranes. Can be calculated for RO system as a whole or for each individual RO stage.
  $J_{RO} = Q_p / A_m$

- Recovery – Hydraulic recovery rate of RO system. Can be calculated for system as a whole or for each individual RO stage.
  $R = (Q_p / Q_f)*100$
  Where:
    R = Hydraulic recovery (percent)
    Q_p = RO Permeate Flow (gpm)
    Q_f = RO Feed Flow (gpm)

- RO TMP – Average pressure loss across the membranes. Can be calculated for system as a whole or for each individual RO stage.
  $TMP_{RO} = (P_f + P_c)/2 - P_p$
  Where:
    TMP_{RO} = RO Transmembrane Pressure (psi)
    P_f = Feed Pressure (psi)
    P_c = Concentrate Pressure (psi)
    P_p = Permeate Pressure (psi)

- Net Driving Pressure – Similar to TMP, while accounting for osmotic pressure gradient across membranes. This represents the pressure available to drive water through the RO membranes.
  $NDP = TMP_{RO} - \Pi$
  Where:
    Π = Osmotic Pressure Differential (psi) = $2.31\text{x}10^{-5} \text{ x } T \text{ x } ((C_f + C_c)/2 - C_p)$
    T = Absolute Temperature (Kelvin)
    C_f = Feed Conductivity (µS/cm)
    C_c = Concentrate Conductivity (µS/cm)
    C_p = Permeate Conductivity (µS/cm)

- RO Permeability - Normalized measure of how easily water flows through membrane. Can be calculated for individual RO stage using flux and NDP from single stage. Permeability decline in first stage is typically an indication of organic or colloidal fouling, while permeability decline in second stage is an indication of inorganic scale.
  $k_{RO} = J_{RO}\,(25°C)/NDP$

- Salt Rejection – Measures the average rate of conductivity rejection across the membrane. A loss in salt rejection indicates fouling or damage to the membranes. Can be calculated for individual stages or for system as a whole.

  $\text{Rejection} = 1 - C_p/(C_f/2 + C_c/2)$

- Silt Density Index – Measures the rate of pressure increase across a permeable membrane. This indicator is typically used to determine is a source water is suitable to be used as RO feed water.

  $SDI_T = (\%_P30)/T =$

  $[(1\text{-}ti/tf) \times 100]/T$

  Where:

  $\%_P30$ =Plugging at 30 psi
  T=Total test time in minutes
  t_i= Initial time in seconds required to collect a 500 ml sample
  t_f= Time in seconds required to collect a 500 ml sample after 15 minutes.

3. Operating Conditions

The pilot plant evaluated various operating conditions to aid in process optimization and to determine recommended design criteria for a future treatment facility. The primary conditions which were varied include:

- Source of water supply
- Chlorination approach
- Microfiltration (MF) flux
- MF chemically enhanced backwash usage
- Reverse osmosis (RO) flux
- RO recovery
- RO configuration
- Advanced oxidation approach

This section discusses the potential impacts of each of these operating parameters and identifies the schedule of operation under each condition. These conditions were also compared against operations at existing advanced treatment facilities, such as Orange County Water District's GWR System, Terminal Island Water Reclamation Plant's AWTF, West Basin Municipal Water District's Edward C. Little Water Reclamation Plant, and Water Replenishment District's Vander Lans plant.

3.1 Source of Supply and Chlorination Approach

Two source water alternatives are available for the future full-scale treatment facility. Either non-chlorinated secondary effluent or non-chlorinated tertiary effluent could be utilized as the source. A third source initially considered was chlorinated tertiary effluent, which was evaluated through bench testing. This source was not evaluated at pilot scale, due to high NDMA levels measured in this water, which would significantly increase treatment costs. This issue is discussed further in Section 4.1.

3.1.1 Source Water Evaluation

A source water evaluation was conducted to determine the impact of varying source water alternatives on future plant design conditions. The evaluation included water quality monitoring at multiple points in the existing DCTWRP facility, bench testing, diurnal water quality sampling, and operation of the pilot using both secondary and tertiary effluent. Table 3-1 presents a summary of the various components of the source water evaluation conducted during the Phase 1 and Phase 2 testing.

Table 3-1: Source Water Evaluation Components

Activity	Description	Time Frame
Water Quality Sampling	Monitored NDMA levels in primary effluent, secondary effluent, tertiary effluent, and post-contact tank	Weekly throughout pilot testing
Bench Testing	Evaluated impact of using secondary effluent or tertiary effluent with various disinfectant contact times on disinfection byproduct formation	September 10, 2009 and May 19, 2010
Diurnal Testing	Monitored NDMA, temperature, pH, turbidity, TOC, and chlorine demand over 24 hour period	April 13-14, 2010 August 9-10, 2010 November 8-9, 2010 January 31-February 1, 2011
Tertiary Effluent Pilot Testing	Operated pilot using tertiary effluent as source water, monitoring impact on MF and RO performance	Varied.
Secondary Effluent Pilot Testing	Operated pilot using secondary effluent as source water, monitoring impact on MF and RO performance	Varied. July 21, 2010 sequential chlorination

A major focus of the source water evaluation was the monitoring of disinfection byproduct formation, including n-Nitroso-dimethylamine (NDMA) and trihalomethanes (THMs), using different source waters and chlorination approaches. The bench testing was intended to provide an estimate of the disinfection byproduct formation potential under each alternative, while the pilot testing would later confirm whether conditions seen in the bench testing could be maintained. The purpose of the diurnal testing was to evaluate whether significant variability in source water quality could be seen over the course of a 24 hour day.

3.1.2 Chlorination Approach

Three chlorination approaches were evaluated using bench testing, to determine the impact that these alternatives would have on disinfection byproduct formation, including THMs and NDMA. The chlorination approaches included traditional chloramination, breakpoint chlorination, and sequential chlorination, as defined below:

- *Traditional Chloramination* - Ammonia addition, followed by sodium hypochlorite, maintaining a chlorine to ammonia mass ratio of less than 5:1, with a monochloramine residual maintained at all times.
- *Breakpoint Chlorination* - Sodium hypochlorite addition beyond breakpoint (greater than 7.5:1 Cl2:NH3-N mass ratio) resulting in a measurable free chlorine residual.
- *Sequential Chlorination* - Breakpoint chlorination is used to maintain a free chlorine residual for a specified time period (5 minutes during this testing), followed by ammonia addition to convert the free chlorine to monochloramine.

Traditional chloramination was employed for the majority of the Phase 1 pilot operation, however, this was changed to sequential chlorination on July 21, 2010. Sequential chlorination was continued through the Phase 2 operation until December 20, 2010, when operation was returned to traditional chloramination. When sequential chlorination was employed, a free chlorine residual was maintained through the MF process, with ammonia added in the MF product water before the RO break tank. It was necessary to add ammonia before the RO process to prevent oxidation damage to the RO membranes. While the material used in the MF membranes is resistant to free chlorine, the thin film composite (TFC) material used in RO membrane can only tolerate 1 mg/L of free chlorine for 100 hours before significant damage occurs.

Existing advanced treatment facilities in southern California all currently employ traditional chloramination, with combined chlorine residuals between 3 and 4 mg/L to enhance RO performance. The nitrification-denitrification process maintained at the DCTWRP facility, along with control of the entire treatment process, provides a relatively unique opportunity to evaluate sequential chlorination as an approach to both reduce NDMA formation and improve performance of the MF system.

3.2 Microfiltration Operating Conditions

The primary variables which were evaluated with the MF equipment were flux and chemically enhanced backwash usage. Each of these is discussed briefly below. The MF operating conditions employed during the pilot testing are listed in Table 3-2.

3.2.1 MF Flux

Membrane flux is a measure of filtration rate, usually expressed as gallons per day per square foot (gfd). Sustainable operating flux varies considerably based on the membranes used, source water quality, and desired cleaning frequency. The Pall MF membranes employed in this pilot are used for treating wastewater at the Water Replenishment District (WRD) Vander Lans plant and at the Yucaipa wastewater reclamation plant. Design flux at these facilities is 33 gfd for Vander Lans and 28 gfd for Yucaipa. These membranes are also used at drinking water treatment plants throughout the country, typically at higher fluxes than those used in wastewater treatment. The Encino and Stone Canyon treatment facilities operated by LADWP, for instance, utilize Pall microfiltration membranes operated at a flux of 80 gfd for treating water from open reservoirs prior to introduction into the drinking water distribution system. Operating membranes at a higher flux will result in less membrane area, requiring a smaller plant footprint and lower construction cost, however, the higher flux may also result in more rapid membrane fouling, requiring more frequent chemical cleanings and a higher operating cost. Typically, MF systems are designed for a flux that allows 20 to 30 day cycles between chemical cleanings, however, 60 to 90 day cycles are sometimes maintained when frequent chemically enhanced backwashes are employed. The flux for the MF system was adjusted between 25 and 48 gfd during pilot testing, and a minimum 30 day cleaning cycle was sought.

Table 3-2: MF Operating Conditions

Start	End	MF Run	Flux (gfd)	Source Water	Disinfection	CEBs
2-Feb	31-Mar	0	28	Tertiary Effluent	Chloramines	Daily
1-Apr	14-May	1	25	Tertiary Effluent	Chloramines	None
15-May	20-Jul	2	25	Secondary Effluent	Chloramines	2/wk
21-July	2-Aug	3a	25	Secondary Effluent	Free Chlorine	2/wk
3-Aug	29-Aug	3b	32	Tertiary Effluent	Free Chlorine	2/wk
30-Aug	25-Oct	4	48	Tertiary Effluent	Free Chlorine	None
26-Oct	14-Nov	5	40	Tertiary Effluent	Free Chlorine	None
15-Nov	19-Dec	6	35	Tertiary Effluent	Free Chlorine	None
20-Dec	26-Jan	7	35	Tertiary Effluent	Chloramines	None
27-Jan	27-Feb	8	35	Secondary Effluent	Chloramines	None
28-Feb	15-Mar	9a	35	Tertiary Effluent	Chloramines	None
16-Mar	19-May	9b	35	Secondary Effluent	Chloramines	None
20-May	30-Jun	10	35	Tertiary Effluent	Chloramines	None

3.2.2 Chemically Enhanced Backwashes

Chemically enhanced backwashes (CEBs) are performed on the MF equipment to remove foulants from the membranes, reduce operating pressures, and extend periods between the more time consuming membrane clean-in-place (CIP) procedures. A CEB may be done with either moderate doses of chlorine or with citric acid. Caustic soda may also be combined with the chlorine CEBs to improve organics removal. Chemical doses for a CEB are typically lower than a CIP, with the duration of a CEB generally between 5 and 40 minutes, compared with 2 to 8 hours for a full CIP. CEB and CIP frequencies vary between operational advanced treatment facilities in California. None of the existing facilities currently utilize CEBs, with the exception of the Vander Lans facility, which utilizes a 5 to 10 mg/L chlorine dose in every backwash. The Terminal Island facility, Orange County GWR system, and the West Basin plants in El Segundo employ polypropylene MF membranes which cannot tolerate free chlorine, reducing the benefits of CEBs. CIPs for these facilities are typically conducted every 3 to 5 weeks. A West Basin facility in Carson employs the same Pall MF membranes used at Vander Lans, but does not employ CEBs.

The CEB procedure utilized during pilot operation is detailed below:

1. Dose 500 mg/L sodium hypochlorite and 5,000 mg/L sodium hydroxide into backwash water supply, achieving a pH of 11 to 11.5.
2. Soak for 5 minutes
3. Drain and flush
4. Repeat steps 1-3 with 5,000 mg/L citric acid (pH approximately 3)

CEB frequency varied from once per day to once per week. During some CEB sequences, the second citric acid cleaning was not conducted. CEB's were also discontinued for much of the Phase 2 testing period.

While CEBs can be fully automated and remove the MF membranes from service for only a short period of time, the chemical use can be high, particularly when CEBs are performed daily. An optimized MF design must therefore balance the flux, CEB frequency, and CIP frequency to minimize overall lifecycle cost for the facility. It should be noted that Pall typically refers to their CEBs as "Enhanced Flux Maintenance" or EFMs, however, the term CEB will be used in this report as a more universal term among membrane vendors.

3.3 Reverse Osmosis Operating Conditions

The primary variables, which were evaluated with the RO system were recovery, flux, and RO configuration. Each of these is discussed briefly below.

3.3.1 RO recovery

RO system recovery is a measure of the production efficiency reported as the product water flow divided by the feed water flow. Operation at a higher recovery will result in a smaller waste stream flow, but will also concentrate the salts and organic compounds in the source water, increasing the risk of scaling and fouling in the latter membrane stages. Recoveries for existing advanced treatment facilities are shown in Table 3-3. The highest recovery currently achieved by these facilities is 85 percent, however, the WRD Vander Lans facility has plans for expansion and increasing RO system recovery to 92 percent. The increased recovery for the Vander Lans plant is driven by limitations in local sewer capacity unique to their facility; however, the facility has experienced significant challenges with fouling in the past even when operating at 85 percent. For the DCTWRP facility, the sustainable flux will be driven by the concentrations of sparingly soluble salts and the ability of antiscalant to control their precipitation. Preliminary RO projections have indicated that a recovery of 85 percent should be sustainable based on historic source water quality, however, these projections do not model all potential foulants, and system recovery is best determined based on successful pilot performance. Recovery was varied between 80 and 85 percent during the pilot testing.

3.3.2 RO Flux

Similar to MF flux, the RO flux is a measure of filtration rate, expressed as gallons per day per square foot (gfd). Sustainable RO flux depends heavily on the source water quality, however, the fluxes utilized at RO facilities are much more uniform than with MF facilities. For reuse applications, design flux is typically maintained between 10 and 12 gfd, with most major RO manufacturers recommending that flux not exceed 12 gfd due to fouling concerns with higher fluxes. For groundwater RO facilities, design flux is typically between 15 and 16 gfd, often using the same membranes employed in reuse applications. Typical operating conditions for existing reuse facilities are listed in Table 3-3.

Table 3-3: RO Operating Conditions at Existing Reuse Facilities

Facility	Design Flux	Design Recovery	No. of Stages
Orange County GWR	12 gfd	85%	3
Terminal Island	10 gfd	75-80%	2
West Basin Barrier Water Facility	12 gfd	70-85%	2
West Basin Boiler Feed Facility (First Pass)	12 gfd	70-85%	3
Water Replenishment District Vander Lans	10 gfd	85%	2

Fluxes for RO systems are generally expressed as the average flux between the stages, however, in 2-stage or 3-stage systems, the flux is often highest in the first stage and lowest in the last, due to the loss in driving pressure and increasing salt concentrations as the water passes through each stage. At the Orange County GWR facility, for instance, an overall average flux of 12 gfd is maintained, however, the first stage flux often exceeds 16 gfd, while the third stage often runs below 5 gfd. These large fluxes in the first stage can result in excessive organic fouling when crossflow velocities are not sufficient to prevent concentration polarization on the membrane surface. One way to avoid this large change in flux between stages is to add interstage booster pumps or energy recovery devices, which provide additional pressure to the latter stages, balancing the flow more evenly. For the pilot plant, backpressure was applied to the first stage permeate, forcing more flow to the second stage and simulating the flow balancing conditions that would be seen if energy recovery devices were used. By using this approach it was believed it would be possible to sustainably operate at an overall average flux higher than the 12 gfd typically employed at reuse facilities.

Benefits of operating at a higher flux are reduced membrane area, reduced capital cost, and reduced concentration of organic compounds (NDMA, 1,4-dioxane) in the permeate (higher fluxes provide more water to dilute the salts which pass by diffusion across the membrane at a constant rate). Higher crossflow velocities along the membrane surface could also reduce concentration polarization and fouling in the membranes. Operating flux for the pilot was therefore varied between 12 and 14 gfd to determine the optimal operating condition for the DCTWRP facility. Table 3-4 presents the RO operating conditions during for the pilot testing.

Table 3-4: RO System Operating Conditions

Date Range		RO Run	Source Water	Recovery	Flux (gfd)	# Stages
3/10/2010	4/15/2010	0	Tertiary	80%	14	2
4/16/2010	5/14/2010	0	Tertiary	85%	12	2
5/15/2010	6/14/2010	1	Secondary	85%	12	2
6/15/2010	8/1/2010	2	Secondary	85%	12	3
8/3/2010	10/14/2010	3	Tertiary	85%	14	2
10/15/2010	12/20/2010	4	Tertiary	85%	14	2
12/21/2010	1/27/2011	5	Tertiary	85%	12	2
1/28/2011	2/27/2011	6	Secondary	85%	12	2
2/28/2011	6/30/2011	7	Secondary and Tertiary	85%	14	2

3.3.3 RO Configuration

The RO system was operated in both 2-stage and 3-stage configuration. In a 2-stage configuration, the concentrate or reject from the first stage is sent to a second stage to produce more product water and reduce the waste flow. The second stage typically contains half the number of membrane pressure vessels as the first stage, allowing higher crossflow velocities to be maintained with the lower flow conditions seen in the second stage. These crossflow velocities are necessary to maintain proper scouring of membrane surface, preventing fouling. In a 3-stage configuration, the concentrate from the second stage is sent to a third stage, typically containing half the number of pressure vessels as the first. In the pilot system, this configuration was modified slightly, using smaller diameter (2.5-inch) elements in the third stage rather than reducing the number of 4-inch pressure vessels. While a 3-stage configuration allows for higher scouring velocities than a 2-stage, the operating pressures are also higher, and the third stage may produce only a very small percentage of the product water flow. The purpose of operating the pilot in both 2-stage and 3-stage is to determine the operating efficiencies and fouling rates with each mode of operation.

3.3.4 RO Membranes

Three different RO membranes were used during the pilot testing. During Phases 1 and 2, Hydranautics ESPA2 Elements were used in all RO stages. During Phase 3, these were replaced with Toray TML membranes in half of the Stage 1 vessels (Stage 1a) and CSM FEn membranes in the other half of the Stage 1 vessels (Stage 1b), as well as all the Stage 2 vessels. The purpose of varying the RO membranes was to evaluate the performance of each in terms of permeability, fouling, salt rejection, and removal of constituents of emerging concern. All three membranes have been used successfully on wastewater at other facilities. Anticipated performance for each membrane, based on vendor projection software, is listed in Table 3-5. It should be noted that the software projects all three membranes to have very similar performance, in terms of permeability, TDS, and chloride reduction.

Table 3-5: RO Membrane Projected Performance

	Hydranautics *ESPA2*	Toray *TML*	CSM *FEn*
Permeability (gfd/psi)	*0.15*	*0.15*	*0.15*
TDS Rejection	*99.8%*	*99.7%*	*99.7%*
Chloride Rejection	*99.8%*	*99.8%*	*99.7%*

Footnote:

**Based on RO projections using vendor proprietary software designed at 14 gfd average flux, 85% recovery, 2-stage design*

3.4 Advanced Oxidation Process Operating Conditions

During Phase 1 testing, only UV/peroxide was used for advanced oxidation. No operating conditions were varied, but flow was kept constant at 15 gpm, while the hydrogen peroxide dose remained constant at 3 mg/L. All eight lamps remained in service, providing a constant UV output of 9 mW/cm^2. Given the dimensions of the UV unit and the average flow rate, the approximate contact time within the UV unit was 30 seconds.

During Phase 2 testing, the advanced oxidation processes were operated in batch mode, with constituents of concern spiked within the batch tank to evaluate performance of two alternative oxidation processes: UV/peroxide and ozone/peroxide. For the UV/ peroxide system, the main parameter that was varied was flow rate, which impacted both residence time and reactor efficiency, however, additional testing was conducted using a collimated beam tester to evaluate the impact of ozone dose on key organic parameters. For the ozone/peroxide system, the primary parameters evaluated were ozone dose and pH.

During Phase 3, UV/peroxide was discontinued and ozone/peroxide was operated in continues mode. All operating parameters remained relatively constant during Phase 3 testing, however, ozone dose varied somewhat based on ambient water and temperatures at the time of sampling.

4. Source Water Evaluation Results

Source water for the pilot testing included two sources: 1) secondary effluent before chlorination, 2) tertiary effluent before chlorination. In addition, tertiary effluent after chlorination was used during some evening hours to provide a high NDMA source water for AOP testing. This post-chlorination tertiary effluent was collected in large Baker tanks during the evenings to allow for batch testing with AOP.

4.1 NDMA Sampling at DCTWRP

NDMA concentration monitoring was conducted at multiple points in the existing DCTWRP facility to characterize background concentrations and to aid in selection of the highest quality source water for a future advanced water treatment facility.

NDMA results measured during pilot testing after the chlorine contact tank were comparable, but moderately higher than historic results measured between January 2007 and 2009. On average, NDMA levels were at least 30 to 50 percent higher during the entirety of pilot testing than average levels reported from six previous sampling events. While only this moderate difference was seen in the average numbers, the maximum NDMA levels measured during the pilot testing period were nearly double the maximum levels measured previously. Monitoring of NDMA on a weekly basis during the pilot testing demonstrated that variability can be extremely high in product water NDMA levels, ranging from 14 to 590 ng/L. Weekly NDMA monitoring results from the DCTWRP facility are shown in Table 4-1. A plot showing the weekly NDMA results for each of the monitoring points is included as **Figure 4-1**.

Table 4-1: DCTWRP NDMA Sampling Results During Pilot Testing

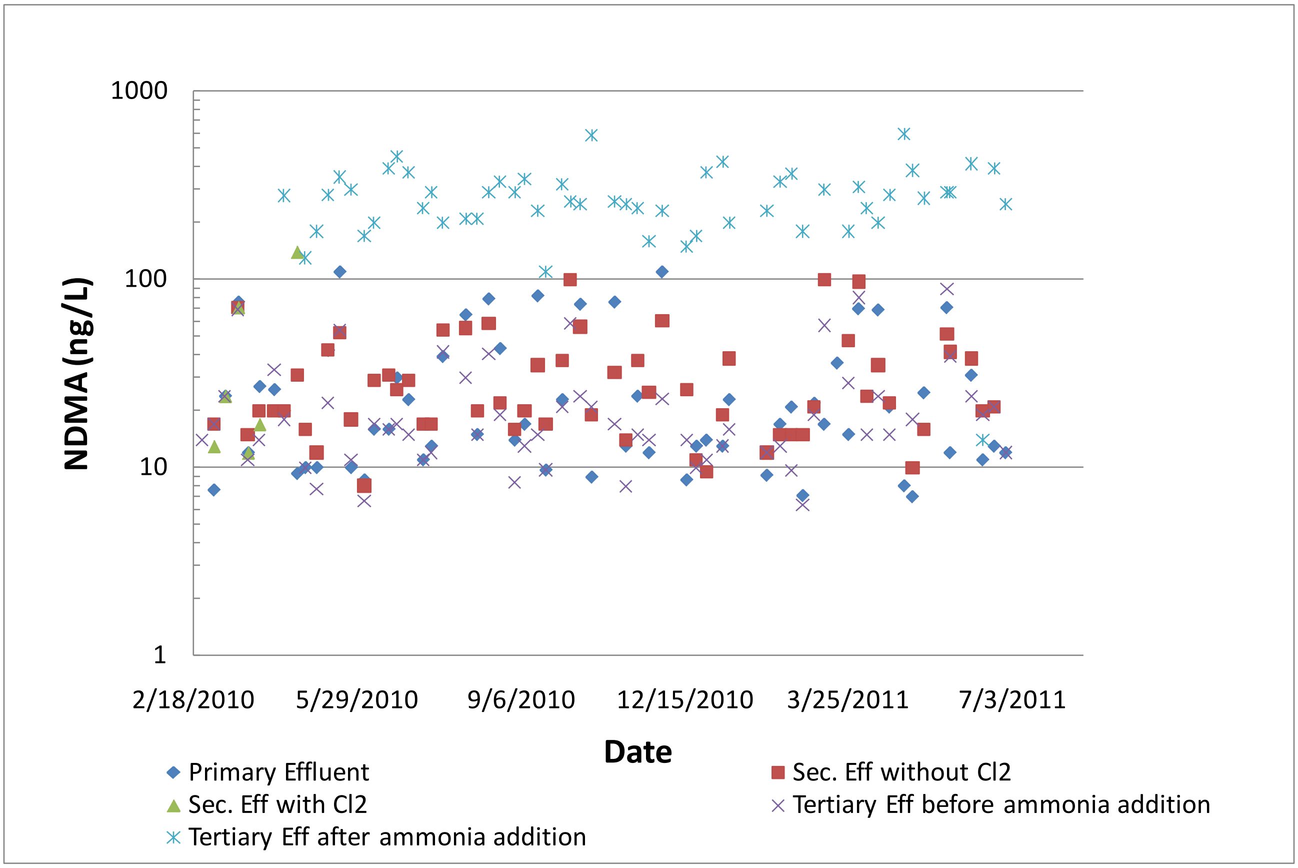
Process Location	Units	Median	Average	Min	Max	# of Samples
Primary Effluent[a]	ng/L	17	30	7	110	63
Secondary Effluent[a]	ng/L	22	31	8	100	60
Tertiary Effluent (before chlorination)[a]	ng/L	16	22	6	89	61
Tertiary Effluent (after chlorine contact)[a]	ng/L	270	276	14	590	55
Historic Data (after chlorine contact)[b]	ng/L	180	203	140	300	6

Footnotes:

a. Samples taken between February 18, 2010 and June 30, 2011

b. Historic sampling results between January 2007 and February 2009

Figure 4-1: DCTWRP NDMA Sampling Results



NDMA levels after the contact tank averaged 13 times higher than NDMA levels upstream of the contact basin. Median NDMA levels in the tertiary effluent were 16 ng/L (lower than the 22 ng/L average), while median levels after the contact tank were 270 ng/L (higher than the 276 ng/L average). These results demonstrate that significant NDMA formation is occurring within the chlorine contact basin downstream of the tertiary filters. NDMA levels were unchanged between the primary effluent and the secondary effluent. Although a small chloramine residual of typically less than 0.5 mg/L as Cl_2 is maintained through the tertiary filters, the results show that this small dose of chlorine did not increase NDMA levels, as would be expected. On the contrary, the average NDMA levels in the tertiary effluent were 29 percent lower than average levels in the secondary effluent. Median levels were also lower, by 27 percent. It is not clear why the levels were repeatedly lower in the tertiary effluent, however, the consistency of these data suggests that a mechanism of NDMA destruction may be present between the secondary effluent and tertiary effluent sampling points.

Table 4-2 presents the log reduction value that would be required to reduce NDMA from the levels measured in the secondary effluent, tertiary effluent, and post-chlorine contact to below the notification level of 10 ng/L.

Table 4-2: NDMA Reduction to meet Notification Limit

Process Location	Notification Level (ng/L)	Average (ng/L)	Reduction to reach NL	90% Value[a] (ng/L)	Reduction to Reach NL
Secondary Effluent	10	31	0.5-log	56	0.7-log
Tertiary Effluent (before chlorination)	10	22	0.3-log	41	0.6-log
Tertiary Effluent (after chlorine contact)	10	276	1.4-log	390	1.6-log

Footnotes:

a. The 90% value represents the NDMA concentration for which 90% of the samples were less than. This shows that in 90% of cases in the secondary effluent, for instance, a 0.7-log removal would reach the NDMA notification level.

These results suggest that using either secondary effluent or tertiary effluent before chlorination could allow for the NDMA notification level to be met even without the full 1.2-log reduction required by the 2008 Draft Groundwater Recharge Regulations. Utilizing tertiary effluent after chlorination, however, would require as much as 1.6-log reduction to maintain levels below the notification level for at least 90 percent of the time.

4.2 Diurnal Sampling Results

Four rounds of quarterly diurnal water quality testing were performed during pilot testing. The primary goal of these tests was to determine whether diurnal patterns in NDMA or NDMA formation could be observed and whether such patterns could be correlated to changes in other water quality parameters. Since NDMA cannot be accurately measured using 24 hour composite samplers, the diurnal testing was meant to confirm that the weekly grab samples were reliably characteristic of the actual NDMA levels in the DCTWRP water.

In addition to NDMA, the parameters monitored during the diurnal sampling events were ammonia, chlorine residual, plant flow, pH, temperature, TKN, TOC and turbidity.

Each round of diurnal sampling followed a detailed testing protocol. Some details were changed between the different diurnal sampling events. Please refer to Appendix B to for a representative diurnal sampling protocol and summary of diurnal testing results.

Results

Results from the four diurnal sampling events are summarized in Table 4-3. The results show that both temperature and pH remained relatively unchanged throughout the 24 hour sampling period, resulting in a variance coefficient of between 1 and 3 percent on all sampling days (pH was not measured during the spring sampling event). TOC and turbidity variances were also relatively low, ranging from 4 to 7 percent for TOC and 4 to 15 percent for turbidity. These results suggest that general water quality characteristics did vary considerably over 24 hours in the tertiary effluent. Similar results were seen for secondary effluent and for both unchlorinated and chlorinated tertiary effluent.

While general water quality characteristics did not vary, ammonia concentrations in both secondary and tertiary effluent resulted in variance coefficients of greater than 100 percent during the fall and winter sampling events, and 73 percent during the summer sampling event. A relatively high coefficient of variance was also seen for NDMA, ranging from 13 percent during the summer to 38 percent during the winter and spring. The diurnal changes in NDMA and ammonia concentrations are discussed further below.

Table 4-3: Average Water Quality in Tertiary Effluent during Diurnal Testing

Parameter	Spring 4/14/10	Summer 8/9/10	Fall 11/9/10	Winter 2/1/11
Temperature (°C)	23 (± 1%)[(a)]	30 (± 1%)	25 (± 1%)	21 (± 3%)
pH	-- [(b)]	7.0 (± 1%)	6.9 (± 1%)	7.3 (± 2%)
TOC (mg/L)	6.5 (± 6%)	7.8 (± 7%)	6.5 (± 5%)	7.8 (± 4%)
Turbidity (NTU)	0.9 (± 8%)	0.38 (± 4%)	0.5 (± 13%)	0.86 (± 15%)
Ammonia (mg/L)	--[(b)]	0.27 (± 73%)	0.4 (± 168%)	0.3 (± 140%)
NDMA (ng/L)	278 (± 38%)	195 (± 13%)	223 (± 30%)	181 (± 38%)

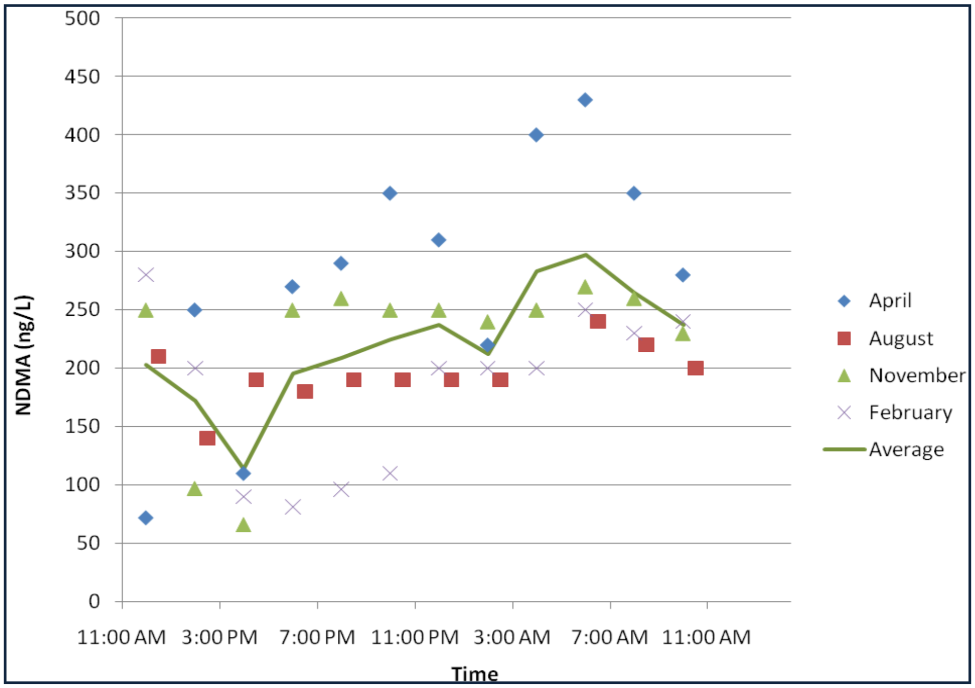
Footnotes:

a. Numbers in parentheses represents coefficient of variance

b. "--" = not measured

Figure 4-2 shows NDMA levels measured in the post-chlorine contact product water on the four sampling days, as well as a composite average for the four days.

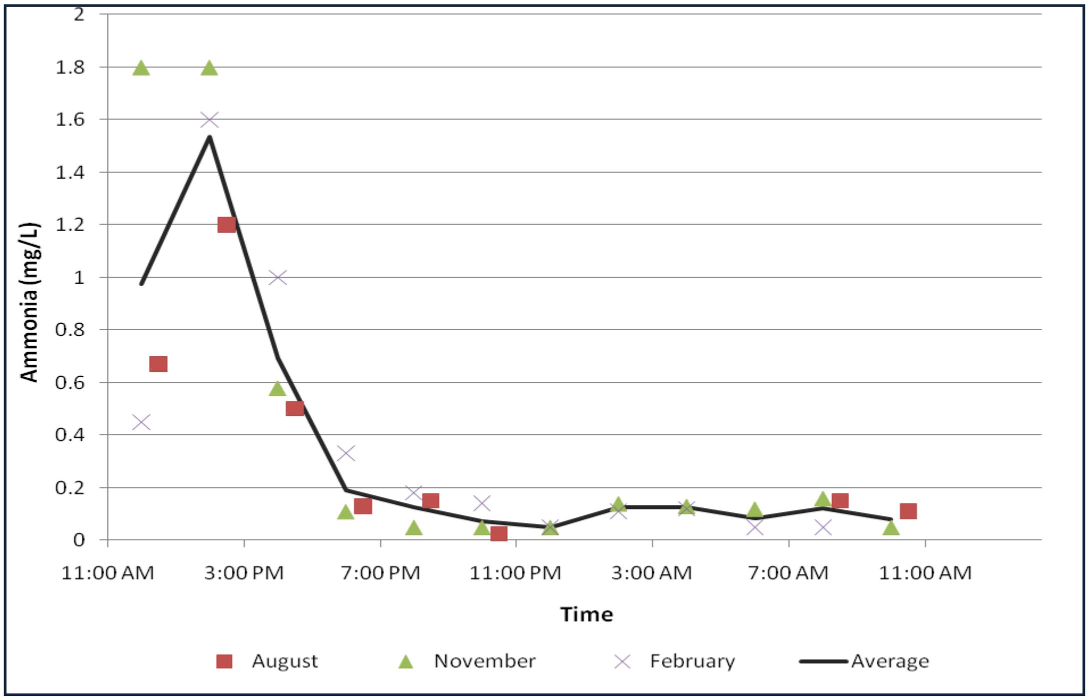
Figure 4-2: Diurnal NDMA Concentrations in DCTWRP Chlorinated Tertiary Effluent



The results demonstrate a substantial variation in NDMA levels during the April and February sampling events, resulting in a 3 to 4-fold increase between lowest and highest measured values. NDMA levels also varied during the August and November sampling events, however, variability was lower, and all but two or three of the NDMA samples for these days were within 10 percent of the average values. On all four days a notable decrease in NDMA can be observed between 2:00 and 5:00 in the afternoon. Similarly, an increase can be observed near 7:00 am, although this increase is less significant in the August and November sampling results.

Figure 4-3 shows ammonia levels measured in the secondary effluent before chlorination. These results show a clear increase in ammonia levels during the early afternoon for all of the sample days in which ammonia was measured. Similar trends were seen in the tertiary effluent results.

Figure 4-3: Diurnal Ammonia Concentrations in DCTWRP Secondary Effluent



The increase observed in the ammonia levels generally coincides with the timing of the decrease in NDMA observed during the afternoons. There is a two hour delay between the peak in the secondary effluent ammonia composite curve at 2:00 pm (**Figure 4-3**) and the low point in the chlorinated tertiary effluent NDMA composite curve at 4:00 pm (Figure 4-2). Residence time within the covered chlorine contact basins is approximately 2 hours under full flow conditions, where the plant was operated during the afternoons of these sampling days. These coinciding changes seen on all four sampling days suggest that the decrease in NDMA may be related to the increase in ammonia concentration.

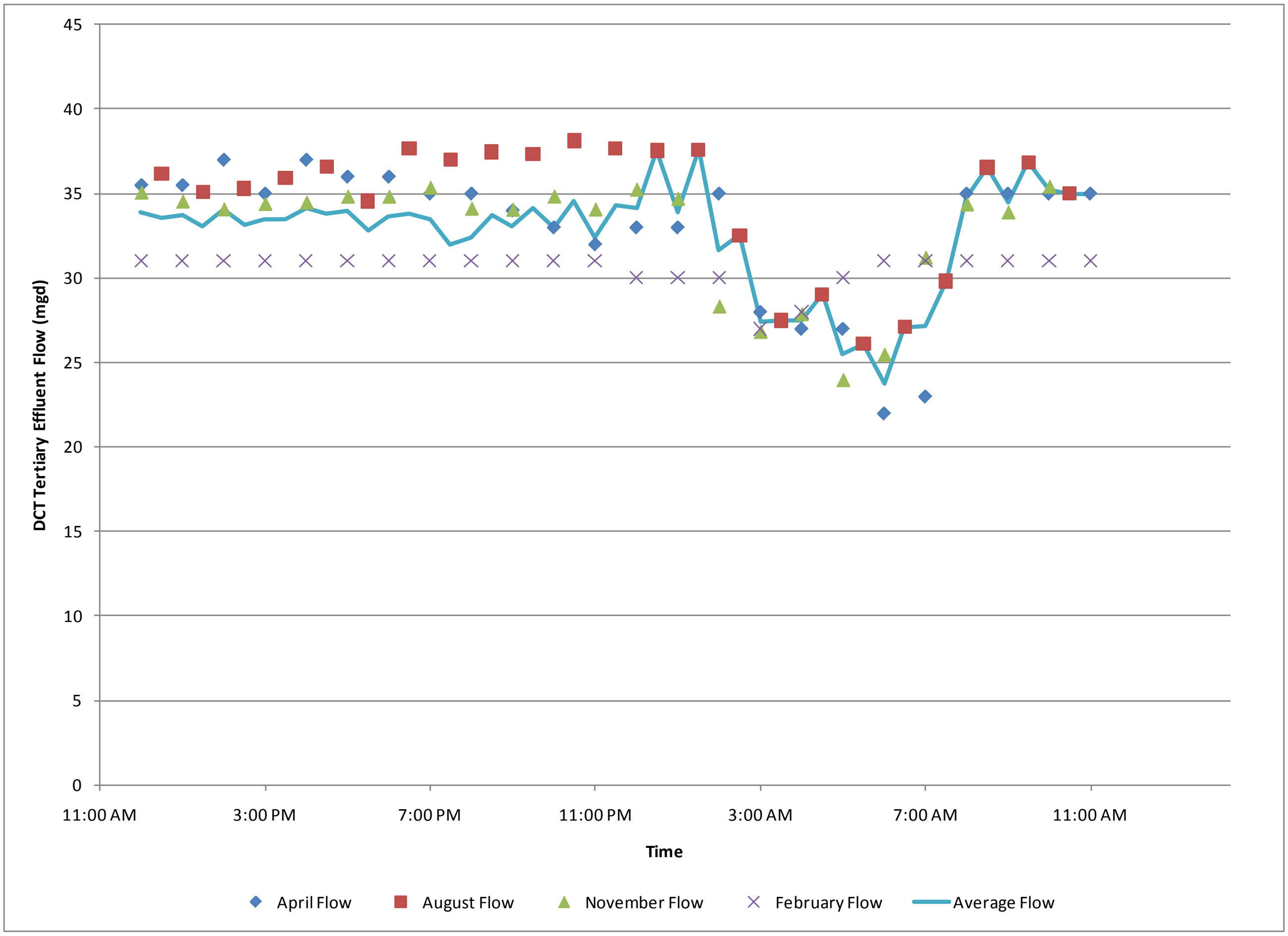
Based on discussions with plant operators, the daily ammonia increase is the result of the nitrification system becoming overloaded at mid-day, resulting in a bleed-through of ammonia. Ammonia is monitored at the plant on a continuous basis using online ammonia analyzers.

When bleed-through of the ammonia begins to be seen, plant operators reportedly turn off the ammonium hydroxide feed system, which is required for chloramine formation at other times of the day. In contrast to the ammonia feed rates, polymer feed rates to the tertiary filters did not vary during the day. Records provided by DCTWRP operators showed polymer feed rates remaining within 5 percent of average over the course of each sampling day. Polymer feed rates were a concern, because the Mannich polymer used for foam control and as a filtration aid is a known precursor for NDMA.

At this time it is not known how an increase in ammonia levels would have reduced NDMA formation or whether these changes are related in any way. One possible explanation for the correlation would be an increased biological breakdown of compounds to create more NDMA precursors during the hours of the day when full nitrification is occurring, however, additional research is needed to fully understand NDMA formation mechanisms and the impacts of plant operating conditions on its formation.

Another variable which changed during each 24 hour day was plant flow rate. **Figure 4-4** shows the diurnal flow patterns on the four sampling days.

Figure 4-4: Diurnal Sampling Results- DCTWRP Tertiary Effluent Flow



The DCTWRP tertiary effluent flow decreases in the early morning, due to decreases in collection system flows. This decreased flow, between 3:00 am and 7:00 am, coincides with an increase in NDMA concentrations, which peaks at 6:00 am in the composite curve shown on Figure 4-2. Lower plant flows result in greater residence time within the chlorine contact basin. These higher residence times would be expected to cause more NDMA formation. Residence time increased approximately 27 percent during these early morning hours, while average NDMA formation increased 34 percent, suggesting that the increase in NDMA formation is directly related to the decrease in flow.

Reduction in NDMA Between Secondary and Tertiary Effluent

In addition to comparing the diurnal trends of water quality constituents against one another, testing was also done to compare diurnal trends of NDMA at multiple process locations. Early pilot results showed that NDMA concentrations were consistently decreased by an average of 29 percent between the secondary effluent channel and the tertiary effluent channel. Diurnal NDMA testing was performed on two occasions during the spring of 2011 to determine whether this 29 percent reduction was consistent over a 24-hour period or if it only occurred during daylight hours, when natural UV light could interact with the water in an open channel between secondary and tertiary treatment processes. Results of these additional tests indicated that greater NDMA reduction was occurring at night than during the day, suggesting that some type of biological processes may be responsible for the NDMA reduction.

4.3 Chlorination Bench Testing Results

Bench testing was conducted to evaluate disinfection byproduct (DBP) formation from secondary effluent and tertiary effluent using varying chlorination approaches. The bench testing measured both NDMA and trihalomethane (THM) formation, using either breakpoint chlorination, traditional chloramination, or sequential chlorination (defined previously in Section 3.1.2). Formation of NDMA and THMs were of key concern, because both are poorly rejected by RO membranes, but are formed by the reaction of dissolved organic matter with either free chlorine or chloramines.

The first round of bench testing was conducted on September 11, 2009, prior to the beginning of pilot testing in order to evaluate source water alternatives to be used during piloting. A second round of testing was conducted on May 19, 2010. Protocol for the testing is included as Appendix A to this document.

Bench Testing Results

Figure 4-5 presents the 24 hour NDMA formation when traditional chloramination was used with either secondary or tertiary effluent. The results include both days of sampling and demonstrate that the NDMA concentrations varied nearly ten-fold on the two sampling days, increasing from 13 to 37 ng/L for the tertiary effluent on the first sampling day and from 110 to 360 ng/L on the second. These results suggest that NDMA formation can be extremely high when using traditional chloramination with either source water. The results also demonstrate that the NDMA formation was slightly higher on both sampling days when treating tertiary effluent, when compared with secondary effluent, however, the difference in formation between the two source water alternatives was less than 30 percent.

Figure 4-5: Bench Testing Results- NDMA Formation with Traditional Chloramination

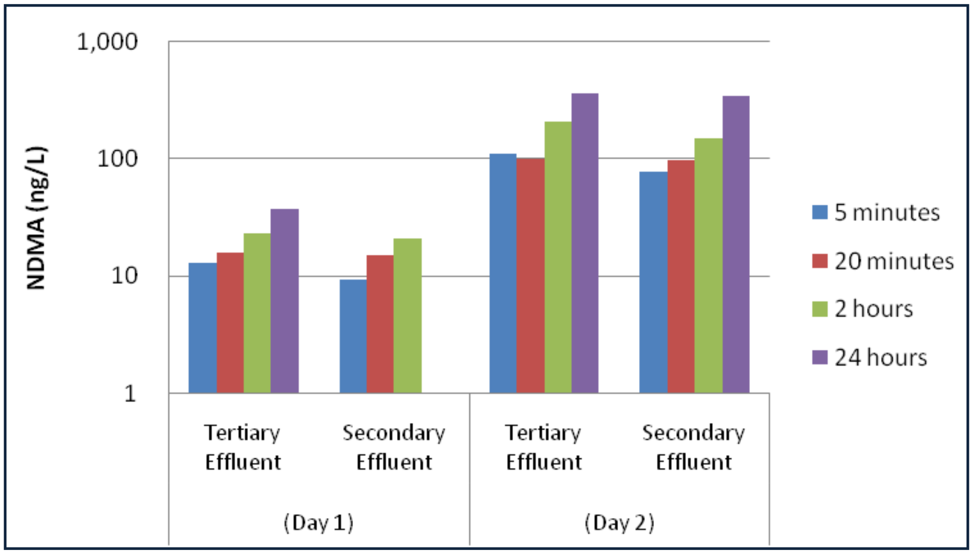
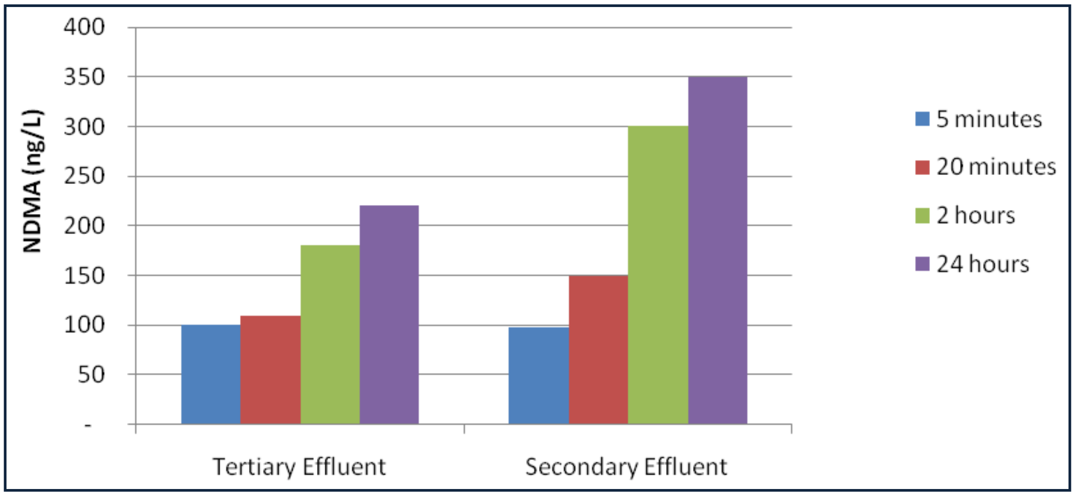


Figure 4-6 presents the 24 hour NDMA formation when sequential chlorination was used with both secondary and tertiary effluent. These results only include data from the second sampling day, since sequential chlorination was not used during the initial bench testing experiments. In contrast to when traditional chloramination was used, these results show higher NDMA formation with secondary effluent than with tertiary, suggesting that neither source water offers a clear advantage in reducing the formation of NDMA.

Figure 4-6: Bench Testing Results- NDMA Formation with Sequential Chlorination



Figures 4-7 and **Figure 4-8** present the formation of NDMA and THMs, respectively, when treating tertiary effluent with either free chlorine (breakpoint chlorination), traditional chloramination, or sequential chlorination. The figures are based on results from the second

sampling day, when data was available for this day, however, NDMA results for free chlorine, and THM results for chloramines were both based on the first testing day, since this tests were not repeated on the second day. All results are presented as a percent of initial values in order to normalize the results between the two sampling days. Initial NDMA levels were 17 ng/L on the first sampling day and 94 ng/L on the second. Initial THM levels were 1 µg/L on both sampling days.

Figure 4-7: Bench Testing Results- NDMA Formation Tertiary Effluent

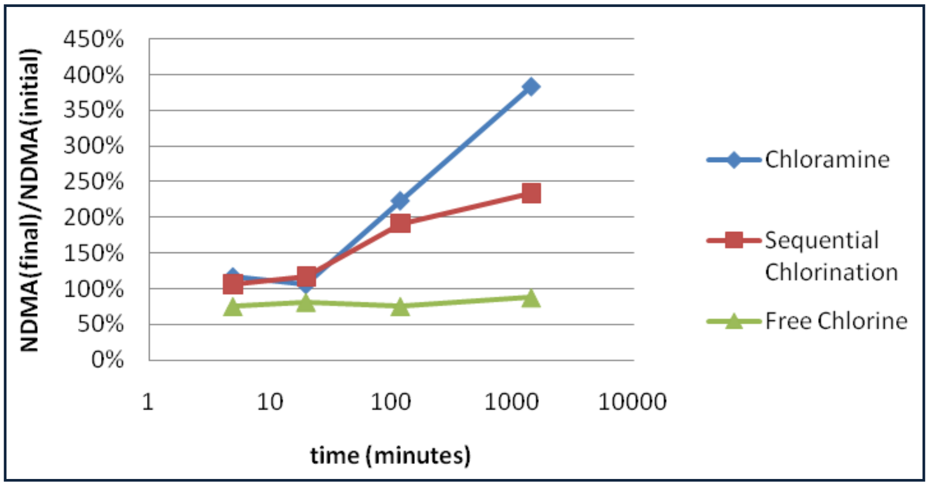
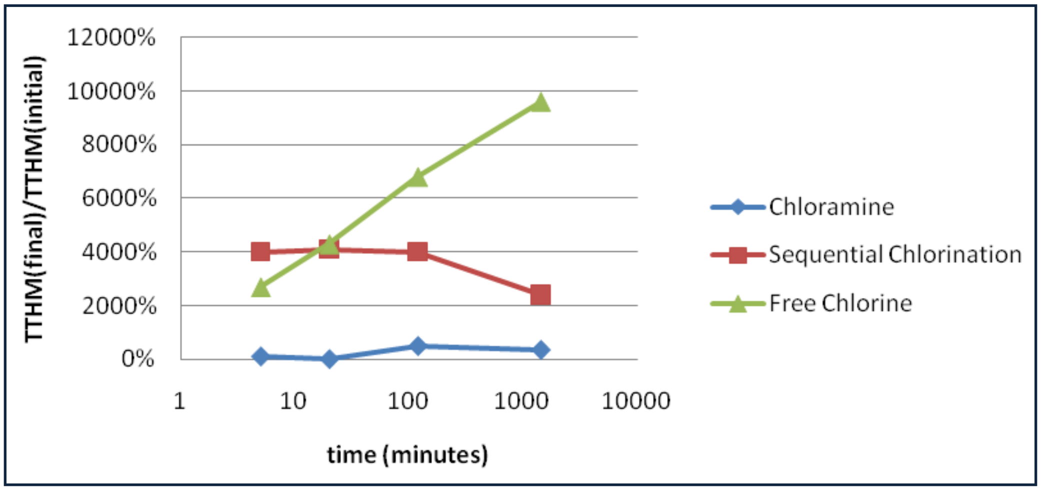


Figure 4-8: Bench Testing Results- THM Formation with Tertiary Effluent



These results confirmed that while traditional chloramination resulted in high levels of NDMA formation, the same chlorination approach resulted in no formation of THMs. In contrast, the breakpoint or free chlorination approach resulted in no formation of NDMA, but considerable THM formation was seen, exceeding the 80 µg/L MCL after more than 2 hours of reaction time. These results support the hypothesis that a trade-off exists in wastewater reuse between NDMA formed from chloramination, and THMs formed from free chlorine. The sequential chlorination approach resulted in a decrease in both THM and NDMA formation; however, both types of DBP were formed in this bench testing when sequential chlorination was utilized. These data also suggest that NDMA formation was relatively flat for the first 20 minutes of reaction time, regardless of the chlorination approach, with significant formation of NDMA occurring after 2 to 24 hours of reaction time.

4.4 Other Water Quality Results

Water quality constituents currently regulated by CDPH were monitored during pilot testing. Constituents with detectable levels measured in the source water at any time during pilot testing are listed in Table 4-4 below. Of these constituents, only nitrate and the sum of nitrate plus nitrite exceeded maximum contaminant levels during pilot testing.

Table 4-4: CDPH Regulated Constituents Detected in Pilot Source Water

	CDPH MCL	Detection Limit (c)	Pilot Average	Pilot Maximum	Number of Samples
Chemicals with MCLs in 22 CCR §64431—Inorganic Chemicals (mg/L)					
Aluminum (a)	1	0.05	ND	0.056	46
Fluoride (a)	2	0.1	0.76	1.1	59
Nitrate (as NO3) (b)	45	2	29	47	62
Nitrate + Nitrite (as N) (b)	10	--	6.6	10.9	62
Radionuclides with MCLs in 22 CCR §64441 and §64443—Radioactivity (pCi/L)					
Gross alpha particle activity	15	3	ND	6.5	7
Gross beta particle activity	50	4	15.1	18	7
Chemicals with MCLs in 22 CCR §64444—Organic Chemicals (mg/L)					
(a) Volatile Organic Chemicals (VOCs)					
1,2-Dichlorobenzene	0.6	0.0005	ND	ND	6
1,4-Dichlorobenzene (p-DCB)	0.005	0.0005	ND	ND	6
(b) Non-Volatile Synthetic Organic Chemicals (SOCs)					
2,3,7,8-TCDD (dioxin)	$3x10^{-8}$	$5x10^{-9}$	ND	$5x10^{-9}$	3
Chemicals with MCLs in 22 CCR §64533—Disinfection Byproducts (mg/L)					
Total Trihalomethanes (a)	0.08	--	0.0030	0.010	-
Bromodichloromethane (a)	--	0.001	ND	0.002	13
Bromoform (a)	--	0.001	ND	ND	13
Chloroform (a)	--	0.001	0.0017	0.005	14
Dibromochloromethane (a)	--	0.001	ND	0.002	13
Total Haloacetic Acids (a)	0.06	--	0.006	0.014	10
Monochloroacetic acid (a)		0.001	ND	0.001	9
Dichloroacetic acid (a)		0.001	0.003	0.009	10
Trichloroacetic acid (a)		0.001	0.003	0.006	9

Footnotes:

a. Samples were taken from the RO Feed.
b. Samples were taken from the MF Filtrate.
c. Detection limits listed are as defined by USEPA for all regulated compounds.

Table 4-5 presents constituents regulated with secondary MCLs by CDPH and detected in the source water. Secondary MCLs are in place primarily for aesthetic concerns, but generally must be complied with for groundwater replenishment reuse projects. The monitoring conducted during pilot testing demonstrates that the pilot source water, which varied between secondary effluent and tertiary effluent, exceeded secondary MCLs for only color, and the recommended MCL range for TDS, and conductivity (the concentrations were below the upper MCL range).

Further monitoring of unregulated constituents is discussed further in Section 8.

Table 4-5: Constituents with Secondary MCLs Detected in Pilot Source Water

Parameter		CDPH SMCL	Pilot Average	Pilot Maximum	Number of Samples
Aluminum[b]	mg/L	0.2	0.01613	0.056	46
Color	c.u.	15	44	165	49
Iron	mg/L	0.3	0.028	0.041	13
Manganese	mg/L	0.05	0.018	0.042	10
Silver	mg/L	0.1	0.0013	0.002	3
Turbidity	NTU	5	1.1	7.8	312
TDS	mg/L	500[a]	498	640	63
Conductivity	mg/L	900[a]	834	1025	315
Chloride[b]	mg/L	250	114	150	13
Sulfate[b]	mg/L	250	97	190	59

Footnotes:
a. This value is the recommended MCL range.
b. Samples were taken from the RO Feed.

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5. Microfiltration Results

This section describes the two main criteria that were used to gauge MF system performance: permeability and contaminant removal. Permeability for the MF system describes the ability of the filter to allow the passage of water through the filter pores. A lower permeability requires more energy or more membrane area to produce the same quantity of water. Contaminant removal for the MF system involves effective reduction of some key water quality parameters including pathogens, turbidity, and silt density index (SDI). Permeability is therefore a measure of how efficiently the MF system operates, while the contaminant removal is a measure of the effectiveness of the MF system as a pretreatment mechanism for RO.

Pressure hold integrity tests were performance daily on the MF membranes to confirm whether or not damage to membrane fibers had occurred. A broken fiber would result in a loss of pressure exceeding 1.2 psi/min, during a 5 minute pressure hold test, and could allow for short-circuiting of contaminants around the membranes. Integrity testing results averaged 0.30 psi/min during the pilot testing, with a maximum single result of 0.79 psi/min. These results indicate that fiber breakage did not occur during the pilot testing.

5.1 Phase 1 and 2 Operating Performance

The operating conditions for the MF system were changed during testing to test the impact of the following parameters on MF performance:

- Chemically Enhanced Backwash Frequency
- Source Water
- Flux
- Disinfection Method

Table 5-1 below details changes in the MF operating conditions during pilot testing. The table also lists the maximum transmembrane pressure (TMP) reached during each test run and the estimated chemical clean in place (CIP) frequency based on a maximum TMP of 30 psi and the average rate of TMP increase measured during the test run.

Table 5-1: MF Operating Conditions

Run	*Duration (days)*	*Flux (gfd)*	*Source Water*	*Disinfection*	*CEBs*	*Max TMP (psi)*	*Estimated CIP Cycle (days)*
0	57	28	TE	Chloramines	Daily	7	>30
1	43	25	TE	Chloramines	None	10	>30
2	66	25	SE	Chloramines	2/wk	5	>30
3a	12	25	SE	Free Chlorine	2/wk	4	>30
3b	26	32	TE	Free Chlorine	2/wk	6	>30
4	56	48	TE	Free Chlorine	None	29	12
5	19	40	TE	Free Chlorine	None	37	15
6	34	35	TE	Free Chlorine	None	22	>30
7	37	35	TE	Chloramines	None	13	>30
8	31	35	SE	Chloramines	None	11	>30
9a	11	35	TE	Chloramines	None	11	>30
9b	48	35	SE	Chloramines	None	12	>30
10	40	36	TE	Chloramines	None	12	>30

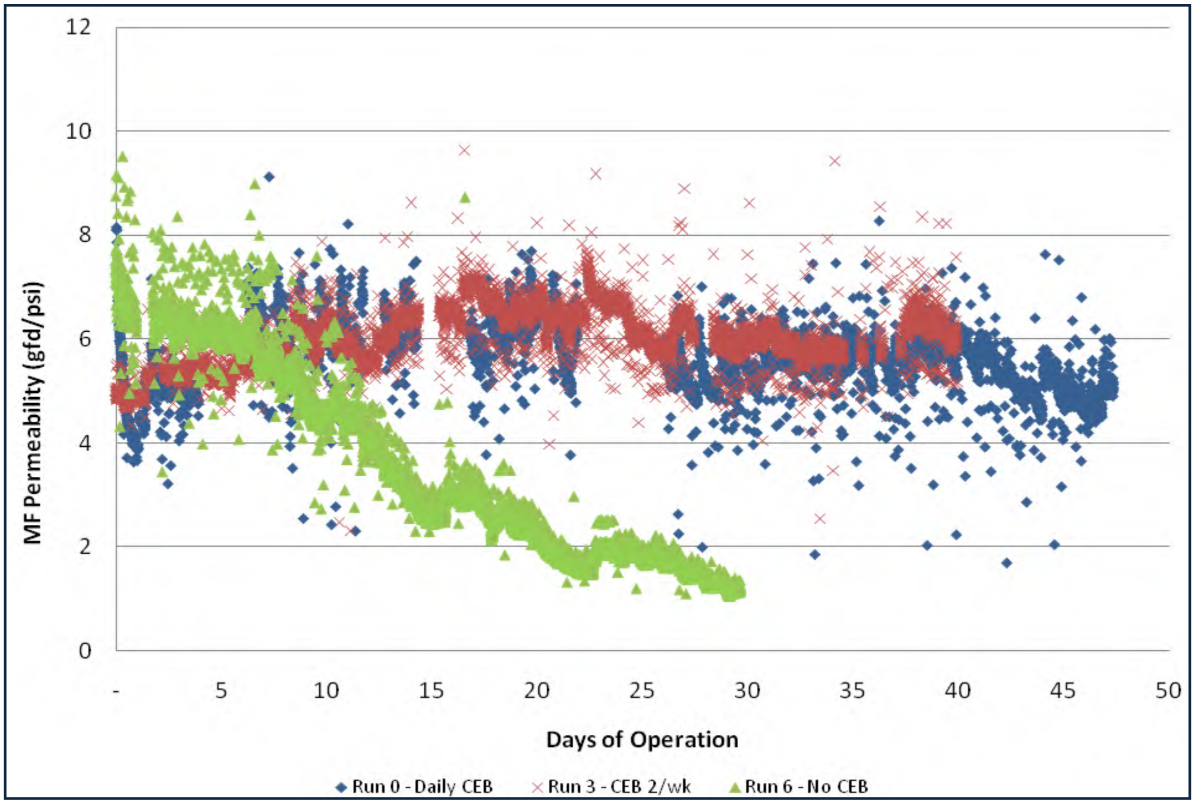
The following subsections compare the MF operational results from multiple runs, highlighting which operating conditions produced the most beneficial results.

Chemically Enhanced Backwash Frequency

At the beginning of testing, the MF system was pre-programmed to run a chemically enhanced backwash (CEB) daily, which included a rinse of the filters with a 500 mg/L sodium hypochlorite solution (Run 0). On March 22, these daily CEB cleans were stopped to see how the MF system would perform with no routine cleanings (Run 1). A steady decline in permeability was seen for two months, after which routine CEBs were recommenced. During Runs 2 & 3, CEBs were carried out two times per week. The first CEB of the week was the same as the aforementioned chlorine cleanings (500 mg/L), however, the second CEB each week included multiple chemicals. First, a CEB was performed with a 500 mg/L solution of chlorine and 1.25 L of 50 percent caustic soda solution, then a following CEB was conducted with a 0.5 percent solution of citric acid.

Runs 4 through 8 were conducted without any CEBs to determine whether or not a 30 day run cycle could be achieved without a chemical cleaning, using the varying chlorination approaches and fluxes tested during those runs. During Runs 4 through 8 a full chemical clean in place (CIP) was conducted between each run and whenever a transmembrane pressure (TMP) of 30 psi was reached. A CIP differs from a CEB in both chemical dose and duration. The CIP began with a citric acid clean, where a 2 percent citric acid solution was circulated through the membranes and soaked for 2 hours before the membranes were drained and flushed. After the citric acid clean, a hypochlorite clean was carried out using a 1,000 mg/L solution of sodium hypochlorite and enough caustic soda to achieve a pH of 13. This solution was circulated and soaked for an additional two hours, before the membranes were drained, flushed, and put back into operation. The impact of cleaning approach on MF performance is presented in **Figure 5-1**, showing the MF permeability during Runs 0, 3, and 6.

Figure 5-1: Impact of CEBs on MF Permeability

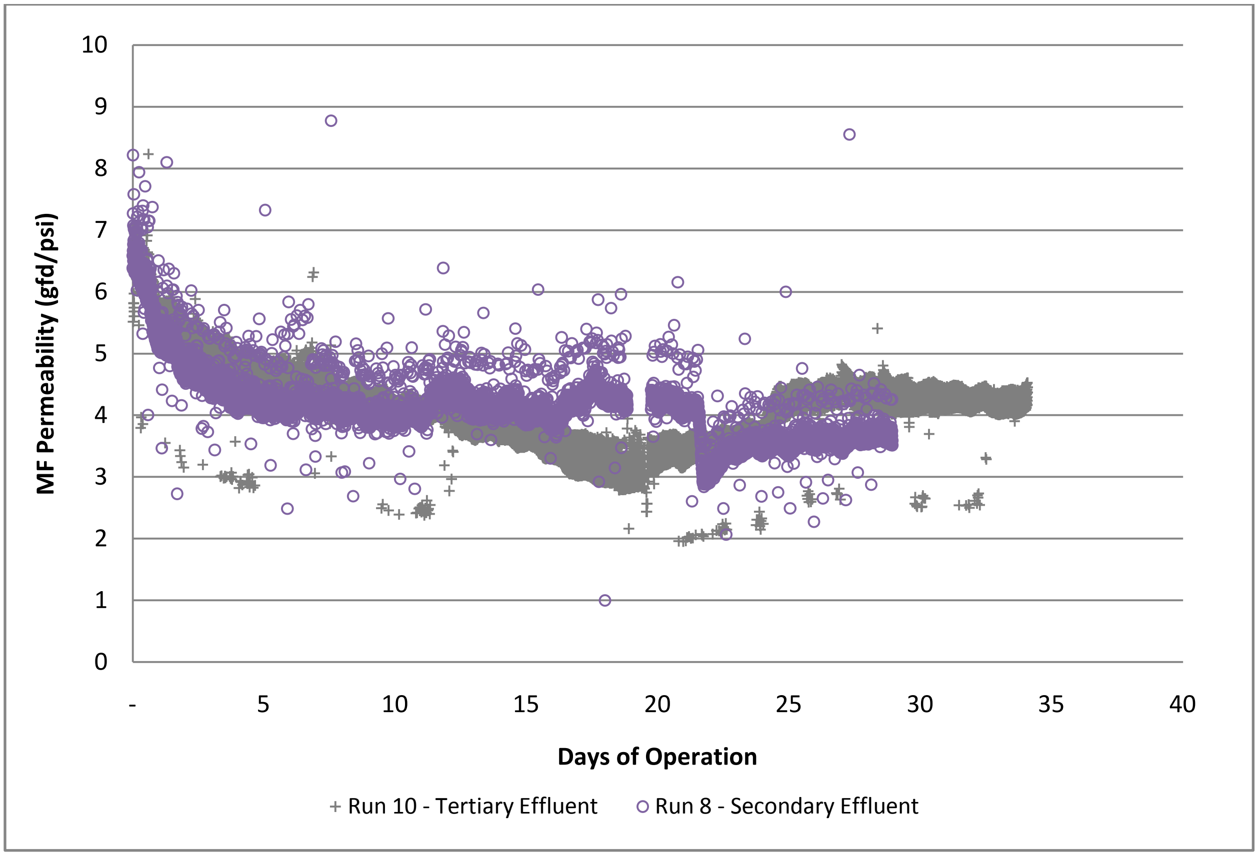


The figure demonstrates that no decline in permeability, associated with membrane fouling, was observed when CEBs were conducted either daily or two times per week. It should be noted that the MF system was operated at a flux between 25 and 28 gfd during Runs 0 and 3. A decline in permeability should be expected when operating at a significantly higher flux, even with the use of CEBs, however, it is not known at what flux permeability decline would begin. The data presented from Run 6 demonstrates the permeability loss for a run cycle where 30 days were achieved before reaching the maximum TMP without reliance on CEBs.

Source Water

The pilot source water was alternated between secondary and tertiary effluent before chloramination. Chlorine and ammonia were both added within the pilot facility. **Figure 5-2** compares MF permeability during operation with each source water.

Figure 5-2: MF Permeability with Alternative Source Waters



Runs 8 and 10 were run under the same conditions and achieved similar rates of permeability. Both source waters show a sharp permeability decline at the beginning of testing, but then level out over at least 30 days of testing. It is not clear why the permeability declined rapidly during Run 8 on February 18. There was no significant change in turbidity, TOC, flow, or temperature during this time period that might explain the rapid decline. It is also not clear why the permeability remained generally stable during the latter 20 days of Run 8 after declining 50 percent during the initial 10 days. Overall, however, the two trend lines match each other very closely which indicates that both source waters can operate effectively with at least 30-day cycle times. The initial assumption of the pilot study was that operation with tertiary effluent could potentially show less permeability decline than operation with secondary effluent. This was not the case during our testing, since the two source waters performed similarly overall.

Table 5-2 presents average source water quality conditions during operation with secondary and tertiary effluent for parameters commonly associated with MF fouling or changes in MF permeability. While turbidity was considerably higher in the secondary effluent, other parameters were similar between the two source waters. TOC averaged slightly higher in the tertiary effluent on the days when it was used as the source water. Similarly, oil and grease were also higher in the tertiary effluent, while color was highest in the secondary effluent. No differences were seen in average temperature or iron. The minor discrepancies in water quality of the two source waters has not shown to be a significant factor in affecting the MF system performance.

Table 5-2: Source Water Quality during MF Operation

Parameter	Secondary Effluent [(a)] (Average)	Tertiary Effluent [(b)] (Average)
Temperature (deg C)	24.7	25.1
Turbidity (NTU)	1.5	0.8
TOC (mg/L)	8.3	8.7
Color (c.u.)	46	37
Iron (mg/L)	0.027	0.028
Oil and grease (mg/L)	1.4	2.0

Footnotes:

a. *Secondary effluent shows average values of measurements made at pilot facilities between May 15 and August 2, 2010 and between January 27 and February 28, 2011.*

b. *Tertiary effluent shows average values of measurements made at pilot facilities between February 18 and May 14, 2010 and between August 3, 2010 and January 26, 2011.*

Flux

MF flux was varied between 35 and 48 gfd during Runs 4, 5, and 6, with no CEBs conducted, a free chlorine residual of 3 mg/L maintained, and tertiary effluent used for all three runs. The MF permeability and TMP for these test runs are shown in **Figures 5-3** and **Figure 5-4**, respectively.

Figure 5-3: MF Permeability with Varying Flux

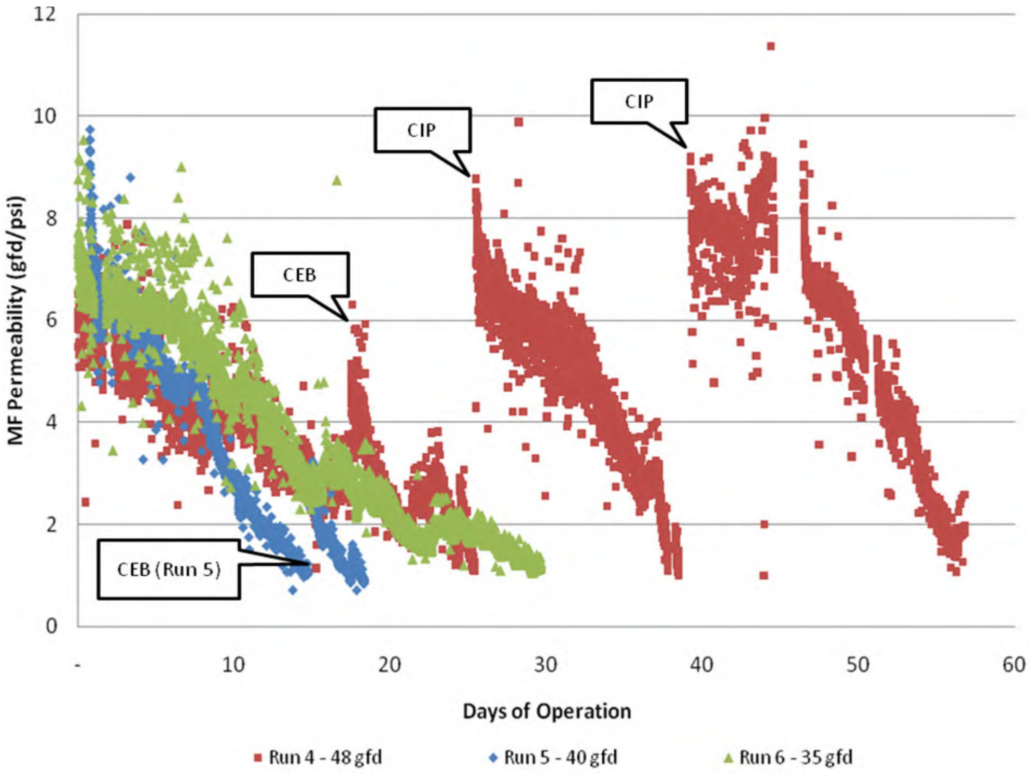
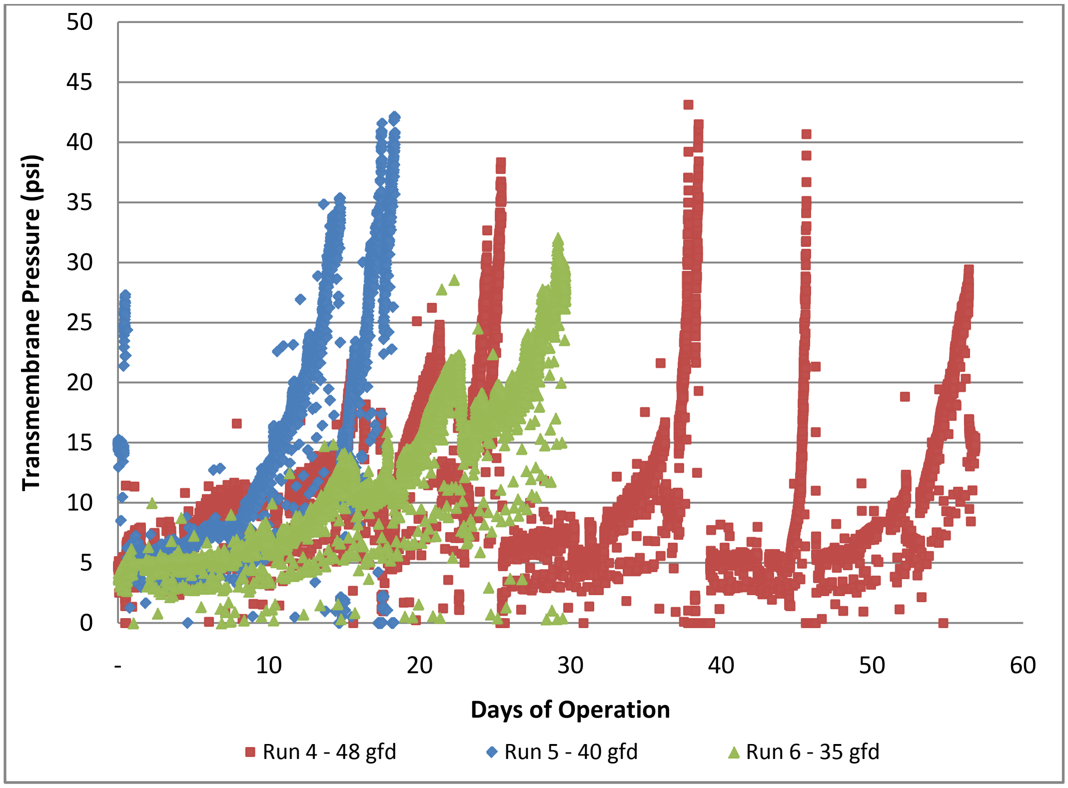


Figure 5-4: MF Transmembrane Pressure with Varying Flux



Rapid losses in permeability and increases in TMP were seen in Run 4, when a 48 gfd flux was employed. As a result, a total of 4 CEBs were carried out during the first 25 days of operation (Run 4a), before conducting a full chemical clean in place (CIP) on day 25. Filter runs after each CIP remained short, with 14 days before the second CIP (Run 4b), 7 days before the third (Run 4c), and 10 days before the last (Run 4d). CIPs were generally performed when the TMP exceeded 30 psi. These run lengths did not meet the goal of maintaining a minimum of 30 days between CIPs. As a result, the MF flux was reduced to 40 gfd for Run 5.

Rapid permeability loss and increase in TMP continued during Run 5 with the reduced flux of 40 gfd. After 14 days the maximum TMP of 30 psi was exceeded and a CIP was conducted. The test run continued for an additional 6 days until the maximum TMP was reached again and a full CIP was conducted. Performance of the MF system did not meet the minimum 30 day run cycle at 40 gfd. As a result, the MF flux was reduced to 35 gfd for Run 6.

During Run 6, no CEBs nor CIP was performed. A total run length of 30 days was achieved before reaching the maximum TMP of 30 psi. Operation of the MF system at 35 gfd met the goal of a 30 day run cycle without chemical cleaning. As a result, all remaining operation of the MF system was maintained at 35 gfd membrane flux.

Disinfection Method

The chlorination approach was varied between Runs 6 and 7, with tertiary effluent used in both runs, no CEBs, and a flux of 35 gfd. **Figure 5-5** shows the MF permeability for Runs 6 and 7.

Figure 5-5: MF Permeability with Varying Chlorination Approach and Flux at 35 gfd

Run 6 utilized breakpoint chlorination to achieve a free chlorine residual between 3 and 4 mg/L through the MF membranes. A total run length of 30 days was achieved before reaching the maximum TMP of 30 psi. Run 7 utilized traditional chloramination, with both ammonia and chlorine added before the MF to achieve a combined chlorine residual between 3 and 4 mg/L through the MF membranes. During the first 18 days of Run 7, permeability declined at a rate that was comparable to Run 6. Permeability after 18 days of operation was approximately 10 percent lower when a chloramine residual was maintained (Run 7) when compared with free chlorine (Run 6), however, permeability appeared to stabilize during Run 7 after approximately 13 days.

After 18 days a power failure occurred on January 7, 2011, causing the pilot unit to remain offline for 3 days until the unit was restarted Monday morning. The unit operated for a day and a half before another shut-down occurred on January 12, due to a VFD failure on the MF unit. The unit remained offline for an additional 15 days until the VFD could be replaced. When the system was restarted, the permeability had improved by over 50 percent (increasing from 2 gfd/psi to more than 3 gfd/psi), making it impossible to determine the run length required before reaching the maximum TMP of 30 psi. It was concluded that the fouling rate on the MF membranes was higher for operation with chloramines than with free chlorine, but the difference in fouling rate between the two runs was less than initially anticipated.

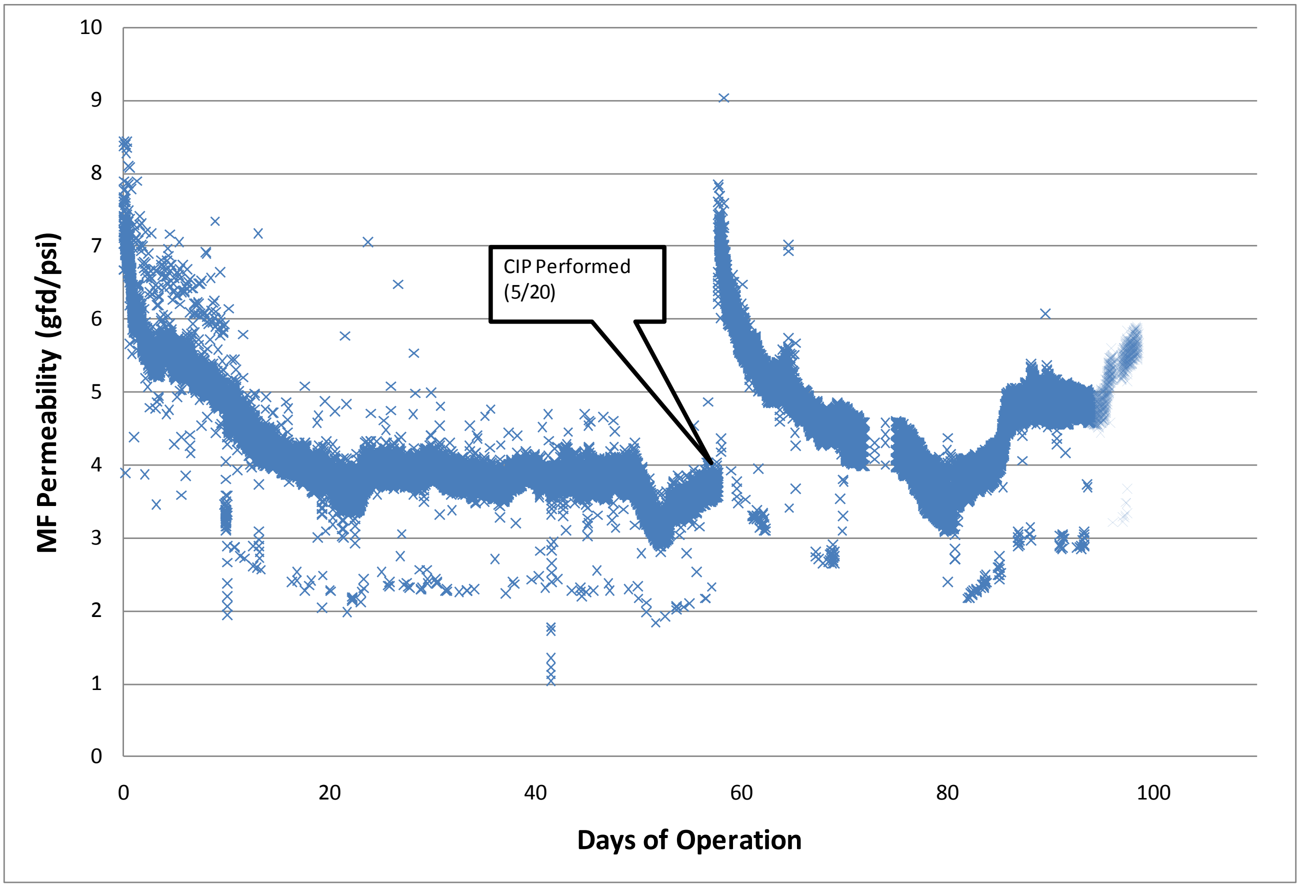
Based on the results from Phases 1 and 2 of testing, the following conditions were chosen for extended testing during Phase 3:

- Chemically enhanced backwash frequency – None
- Source water - secondary effluent or tertiary effluent
- Flux - 35 gfd
- Disinfection method - traditional chloramination

5.2 Phase 3 Operating Performance

Phase 3 testing was conducted to confirm that the recommended operating conditions could be reliably sustained over a minimum 90 day operation. This testing was extended beyond the original plans, such that a total of 103 days of MF operation were maintained during Phase 3. A single MF CIP was required after 60 days of operation. Source water was varied between secondary and tertiary effluent during the Phase 3 testing (secondary effluent before the CIP and tertiary effluent after), again confirming that both source waters will produce stable operation. MF flux remained at 35 gfd with no chemically enhanced backwashes and a recovery rate of 95 percent. Membrane permeability during the Phase 3 testing is shown in **Figure 5-6**.

Figure 5-6: MF Permeability with Optimized Operating Conditions (Runs 9a and 9b)



This performance demonstrates that the recommended MF operating conditions maintained acceptable run times of greater than 30 days between cleanings.

5.3 Water Quality Performance

The water quality performance of the MF system can be evaluated based on how well the system removes pathogens (Giardia, Coliform, Cryptosporidium and E. Coli), turbidity, and, to a lesser extent, organic material (TOC and UV254), while providing a silt density index (SDI) of 3 or less for the RO feed. Table 5-3 presents the averages for these key parameters.

Table 5-3: MF Water Quality Performance

Type	Parameter	Unit	Source Water		MF Effluent	
			Average [b]	Sample Count	Average	Sample Count
Pathogen	Coliform (Fecal)	#/100mL	7,000/ 2,000	4	<0.1	4
	Coliform (Total)	#/100mL	27,000/ 6,000	4	<0.1	7
	Cryptosporidium	#/L	1.6	8	<0.1	8
	E. Coli	#/100mL	3,600/1,700	4	<0.1	7
	Giardia	#/L	62	8	<0.1	8
General	Turbidity	NTU	1.1	312	0.056	>100,000
General	SDI	N/A	3.4	2	2.0 (a)	180
Organic	TOC	mg/L	8.9	308	8.0	21
Organic	UV 254	cm^{-1}	0.15	288	0.14	272

Footnotes:

a. Silt Density Index measure in RO feed after cartridge filters.

b. For coliform (fecal), coliform (total), and E. Coli, two values are shown. The first is the average of four secondary effluent samples. The second is the average of four tertiary effluent samples, before chloramination.

The targeted pathogen removal was complete during the testing with no samples showing any positive hits in the MF product during the 16 month testing period. Approved MF systems are granted 4-log (99.99%) removal credits for *Giardia* and *Cryptosporidium* by the California Department of Public Health (CDPH), when used for drinking water supplies. The pilot results demonstrate that greater than 4-log removal of coliform bacteria was achieved, which is consistent with the projected performance for pathogen removal.

Reduction in turbidity was good, with MF effluent turbidity averaging less than 0.06 NTU , and less than 0.1 NTU in 95 percent of the measurements. Turbidity measurements were recorded automatically every five minutes by a turbidimeter mounted on the MF unit.

Organic removal with MF membranes is limited, as they will generally remove only non-dissolved TOC and organic matter (material larger than the 0.1 micron pore size). Results of the pilot testing suggest that an average 10 percent of TOC was removed with a 7 percent reduction in UV254.

SDI measures the colloidal fouling potential of the MF product for the downstream RO membranes. Results from the MF product suggest that a high quality source water for the RO system has been produced. RO membrane manufacturers recommend an average SDI no greater than 4 when feeding standard RO membranes. Average SDI in the MF product was 2.0 during daily testing, with 95 percent of SDI values below 4.0.

5.4 Conclusions

Table 5-4 lists MF operating conditions at existing AWPFs in Southern California along with the operating conditions tested at the DCTWRP pilot. Existing facilities include both secondary and tertiary effluent as source waters, design fluxes ranging from 18 to 33 gfd, and a variety of different chemical cleaning approaches. Facilities utilizing polypropylene (PP) membranes, such as the Terminal Island facility, do not utilize CEBs, due to intolerance of this membrane material to free chlorine. The WRD Vander Lans treatment facility utilizes the same polyvinylidene fluoride (PVDF) membranes used in the DCTWRP pilot. These membranes are resistant to free chlorine, allowing the Vander Lans facility to use a small dose of free chlorine (10 mg/L) in each backwash. By using this CEB approach, the facility maintains an MF flux of 33 gfd, considerably higher than the 18 to 22 gfd used at plants operating with PP membranes.

Table 5-4: MF Operating Conditions at AWPFs

Facility	MF System	Source Water	Design Flux	Disinfection	Cleaning
Terminal Island	Siemens PP	Tertiary	22	Chloramines	CEB: None CIP: 1-2/mo
OCWD GWR	Siemens PP	Secondary	20	Chloramines	CEB: None CIP: 1-2/mo
WBMWD Barrier Water	Siemens PP	Secondary	18-20	Chloramines	CEB: None CIP: 1-2/mo
WRD Vander Lans	Pall PVDF	Tertiary	33	Chloramines	CEB: Every backwash CIP: 1/mo
Yucaipa Valley WD	Pall PVDF	Secondary	28	None	CEB: 1/day CIP: 1/mo
DCTWRP Pilot	Pall PVDF	Secondary and Tertiary	25-48	Chloramines and free chlorine	None to 1/day

Results from the pilot testing demonstrated that daily or semiweekly CEBs could be utilized to maintain stable MF permeabilities for periods in excess of 200 days (Runs 0 through 3) without utilizing the more time intensive CIPs, however, chemical usage under such an approach would be high. MF flux during these first four runs varied between 25 and 32 gfd, and it should be anticipated that a significantly higher flux would result in a more rapid decline in permeability.

When CEBs were not employed, a flux of 35 gfd was found to be sustainable with a 30 day run length between chemical cleanings (CIPs). While this flux is higher than the flux used at many operational advanced treatment facilities, it is comparable to the flux employed at the WRD Vander Lans plant, which uses the same membranes tested here. It is therefore recommended that an MF flux of 35 gfd be used for GWR treatment facility planning, but that future pilot testing be conducted with alternative membrane suppliers before identifying allowable design fluxes for the various proprietary systems.

Pilot testing results demonstrated that both tertiary effluent and secondary effluent are suitable source waters to use for GWR facility planning and there is not a significant difference between them. Pilot results were consistent that tertiary effluent did not provide for improved performance when compared with secondary effluent.

While operation using free chlorine had a lower rate of fouling than operation with chloramines, the rate of permeability decline differed by only 10 percent. It had been anticipated that the use of free chlorine would have a beneficial impact on MF performance, allowing a considerably higher flux than operation with chloramines, however, this was not apparent from the testing. Disinfection with chloramines was used for Phase 3 of the testing to protect the RO membranes from free chlorine. Disinfection with free chlorine can potentially produce slightly higher performance but with added chemical costs and the potential danger of membrane damage. Since the potential danger of membrane damage can be mitigated by implementing fail-safes in full-scale facility design either of these disinfection methods could feasibly be used in GWR treatment facility planning, however, the added costs of chemicals for the free chlorine approach makes it less advantageous.

Water quality monitoring suggests that the MF system provided a high quality source water for the downstream RO process, reducing turbidities to less than 0.06 NTU and SDI measurements to 2. Organic rejection with the MF membranes was low, suggesting that the majority of organic material in the source water was dissolved in nature. Removal of organic matter occurs primarily within the RO process; with trace organic compounds destroyed using AOP.

6. Reverse Osmosis Results

This section describes RO testing results based on the two primary criteria used to gauge system performance: operational and water quality performance. Operational performance is typically gauged by membrane permeability; whereas water quality is gauged by the ability of the membranes to reject certain compounds. Permeability for the RO system describes the ability of the membranes to allow the diffusion of water. A low permeability requires more energy or more membrane area to produce the same quantity of water, making the treatment more costly. As membranes become fouled or scaled, permeability decreases. A chemical clean-in-place (CIP) is typically conducted after permeability declines by more than 30 percent, with a goal of operating 6 months between membrane cleanings. The permeability is calculated from the flux, a temperature correction factor, and the net driving pressure.

Water quality performance for the RO system is based on contaminant removal, including effective reduction of TDS, conductivity, TOC, viruses, and other organic and inorganic parameters. While the permeability represents the efficiency at which the RO system operates, the contaminant removal represents how effective the actual treatment is.

6.1 RO Operating Performance

Operating conditions were altered during testing to stress the RO membranes in different conditions (as discussed previously in Section 3). The primary variables evaluated included chlorination approach, source water, recovery rate, flux, RO configuration, and RO membrane. In addition, the salt passage and permeability of the membranes were impacted by the upstream chlorination approach. Table 6-1 lists the sequence in which operating conditions were changed and gives average permeability results for the first stage along with the estimated 30 day loss in permeability for the second stage.

Table 6-1: RO Operating Conditions

Run	Days	Flux (gfd)	Source Water	Antiscalant	Membrane	# Stages	Average 1st Stage Permeability (gfd/psi)	Est. 30 day 2nd Stage Permeability loss
0	65	14/12	TE	Avista Technologies, Inc. (Avista)	ESPA2 (original)	2	0.12	6%
1	30	12	SE	Avista	ESPA2 (original)	2	0.14	37%
2a	20	12	SE	Avista	ESPA2 (original)	3	0.13	47%
2b	25	12	SE	Avista	ESPA2 (original)	3	0.15	39%
3a	22	14	TE	Avista	ESPA2 (original)	2	0.16	26%
3b	28	14	TE	Avista	ESPA2 (original)	2	0.17	37%
4	66	14	TE	King Lee Technologies (King Lee)	ESPA2 (original)	2	0.18	3%
5	37	12	TE	King Lee	ESPA2 (2nd set)	2	0.13	10%
6	23	12	SE	King Lee	ESPA2 (2nd set)	2	0.13	19%
7	113	14	TE/SE	King Lee	FEn and TML	2	0.12	7%

The estimated 30 day loss in permeability was calculated based on the total decline during each run. As an example, a cycle where second stage permeability declined 14 percent over 65 days would have had an estimated 30 day loss in permeability of 6 percent (14x30/65=6). To adjust for scattered data, the average of the first three days of each run was considered as the starting point and the average of the last three days was considered to be the end point.

In addition to the variable operating conditions listed above, the following operating conditions remained constant throughout the testing:

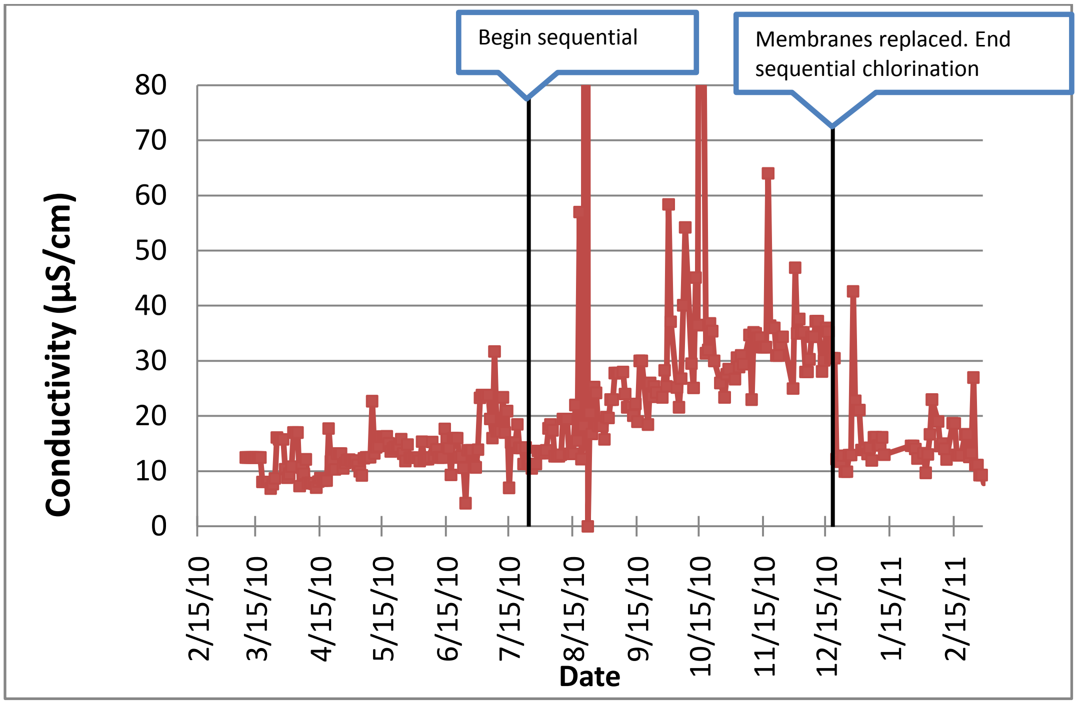
- The RO feed pH was held to an average 7.0 using a manually adjusted dose of sulfuric acid (dosed at approximately 6 to 12 mg/L). Actual RO feed pH varied from 6.8 to 7.2, and was approximately 0.2 units lower than the source water pH. The primary purpose of pH adjustment was to offset a small pH increase that occurred with the injection of ammonium hydroxide, dosed at 2.0 mg/L. pH adjustment was discontinued during Phase 3 of the testing, allowing the feed water pH to increase to an average 7.2.
- Antiscalant was dosed between 3.0 to 3.3 mg/L, however, antiscalant was inadvertently underdosed at a rate of 0.3 mg/L between June 22 and July 6, 2010 (Run 2a). This test run was therefore repeated with the correct antiscalant dose (Run 2b).
- Total chlorine in the RO feed averaged 2.4 mg/L, varying between 1.2 and 3.7 mg/L in 90 percent of the samples.

Impact of Chlorination Approach

Alternative chlorination approaches were evaluated to determine if sequential chlorination would be effective at both reducing formation of NDMA and improving performance of the MF system. When sequential chlorination was used, a high dose of chlorine was added to the source water to achieve breakpoint chlorination, providing a free chlorine residual through the MF membranes. After the MF membranes, ammonia was added to combine with the free chlorine, providing a chloramine residual for the RO membranes. Since RO membranes are not resistant to free chlorine, it was essential that the free chlorine be eliminated by adding ammonia to convert to chloramines to avoid membrane damage.

The alternative to sequential chlorination was traditional chloramination, where ammonia was added before chlorine, avoiding breakpoint chlorination, and providing the chloramine residual before the MF membranes. The chlorine dose required to achieve a 3.0 mg/L residual using traditional chloramination was approximately 3.5 mg/L, while the dose required to achieve the same residual with sequential chlorination was 9.0 mg/L. It was not anticipated that the chlorination approach would have an impact on RO performance, since the chloramine residual was identical in the two alternatives by the time the water hit the RO membranes. Results of the pilot testing, however, demonstrated that the membranes were damaged significantly during the period when sequential chlorination was used. **Figure 6-1** presents the conductivity measured in the permeate of the first pressure vessel.

Figure 6-1: RO Permeate Conductivity for First Pressure Vessel



Electrical conductivity is a commonly used surrogate measurement for TDS and should remain relatively constant in the membrane permeate. The conductivity remained steady during the first four and a half months of operation, corresponding to an average salt rejection of 98.6 percent, when traditional chloramination was used. After operation was changed to sequential chlorination on July 20, 2010, a sharp increase in conductivity was seen, with conductivities increasing above 36 µS/cm compared to the initial 12 µS/cm. This is a 300 percent increase from the initial levels, representing a salt rejection of 97 percent before sequential chlorination was discontinued.

While both membrane fouling and membrane damage can increase conductivity, no fouling was observed in the first stage pressure vessels, suggesting that the increase in conductivity can be attributed to oxidant damage from the chlorine. It is believed that the damage to the RO membranes is the result of intermittent loss of ammonia metering pump flows, which resulted in significant free chlorine contact with the membranes.

One challenge often experienced with pilot plant operation comes from the very low flow rates used for chemical metering pumps. The ammonium hydroxide feed system used at this pilot was particularly problematic, often producing bubbles in the metering pump tubing which would restrict flow to the injection port. The ammonia feed rate was overdosed to 2 mg/L (for a required dose of 0.8 mg/L) to reduce loss of ammonia feed, however, daily operating procedures still required purging of these bubbles from the tubing, and on many days operators would arrive in the morning to find the ammonia feed system air locked. This created more of a problem when sequential chlorination was used, because it allowed a 3 to 4 mg/L dose of free chlorine to have contact with the RO membranes for whatever period the metering pump was air locked. When traditional chloramination was employed, a loss of ammonia generally resulted in a total loss of chlorine residual, due to the high chlorine demand in the water. It is believed that this intermittent loss of ammonia feed is responsible for the damage observed in the RO membranes. This conclusion is supported by results of a membrane autopsy, included in Appendix D, which found evidence of oxidant damage on the last element of the second stage pressure vessels.

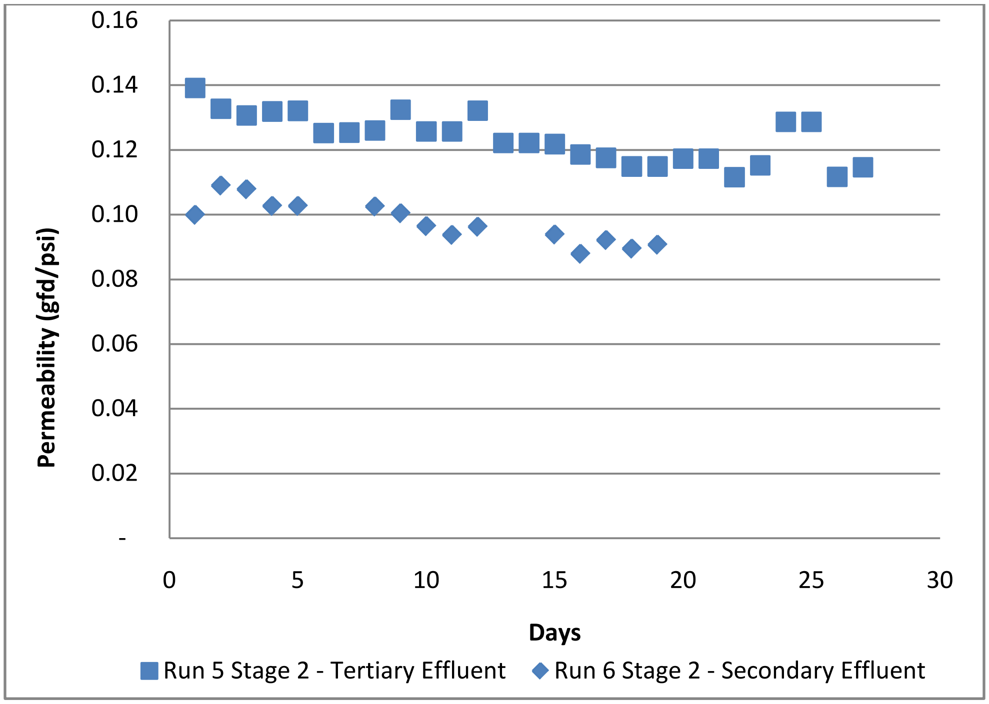
On December 20, 2010 the original membranes were replaced and the chlorination approach was changed back to traditional chloramination for the remainder of the testing.

Source Water

Pilot testing began with tertiary effluent. The anticipated benefit of secondary effluent was expected to be a slightly reduced NDMA formation, as was determined during bench testing discussed in Section 4. It was not anticipated that the tertiary effluent would provide advantages for the RO system, since both source waters pass through MF and should have identical water qualities in terms of turbidity, TOC, and other water quality parameters associated with RO performance.

RO Runs 5 and 6 compared the two source waters with all other operating conditions identical (12 gfd flux, 85 percent recovery). This is presented in **Figure 6-2** below, where second stage RO permeability is shown for both test runs. It should be noted that the RO membranes were replaced immediately before beginning Run 5 and no chemical cleaning was carried out between Runs 5 and 6.

Figure 6-2: RO Permeability in Second Stage for Alternative Source Waters



The second stage permeability for both runs declines at approximately the same rate, equating to a 15 percent permeability decline over 20 days. The results confirm that there was not a significant difference in operating performance for the two source waters tested. It should be noted that permeability decline for Runs 5 and 6 was higher than desired and would not achieve the goal of 6 months between membrane cleanings.

The study also tested whether NDMA levels increased when using tertiary effluent, as had been observed in the bench testing discussed previously. Table 6-2 shows average NDMA levels measured in both source waters and in the RO feed when using these source waters during periods in which traditional chloramination was used for disinfection.

Table 6-2: NDMA formation with Varying Source Water Using Traditional Chloramination

Source Water	NDMA in Source Water (ng/L)	NDMA in RO Feed (ng/L)
Secondary Effluent [a]	26	26
Tertiary Effluent [b]	19	25

Footnotes:

a. Values are averages for RO Runs 1,2 & 6, which used secondary effluent.

b. Values are averages for RO Runs 0 & 3-5, which used tertiary effluent.

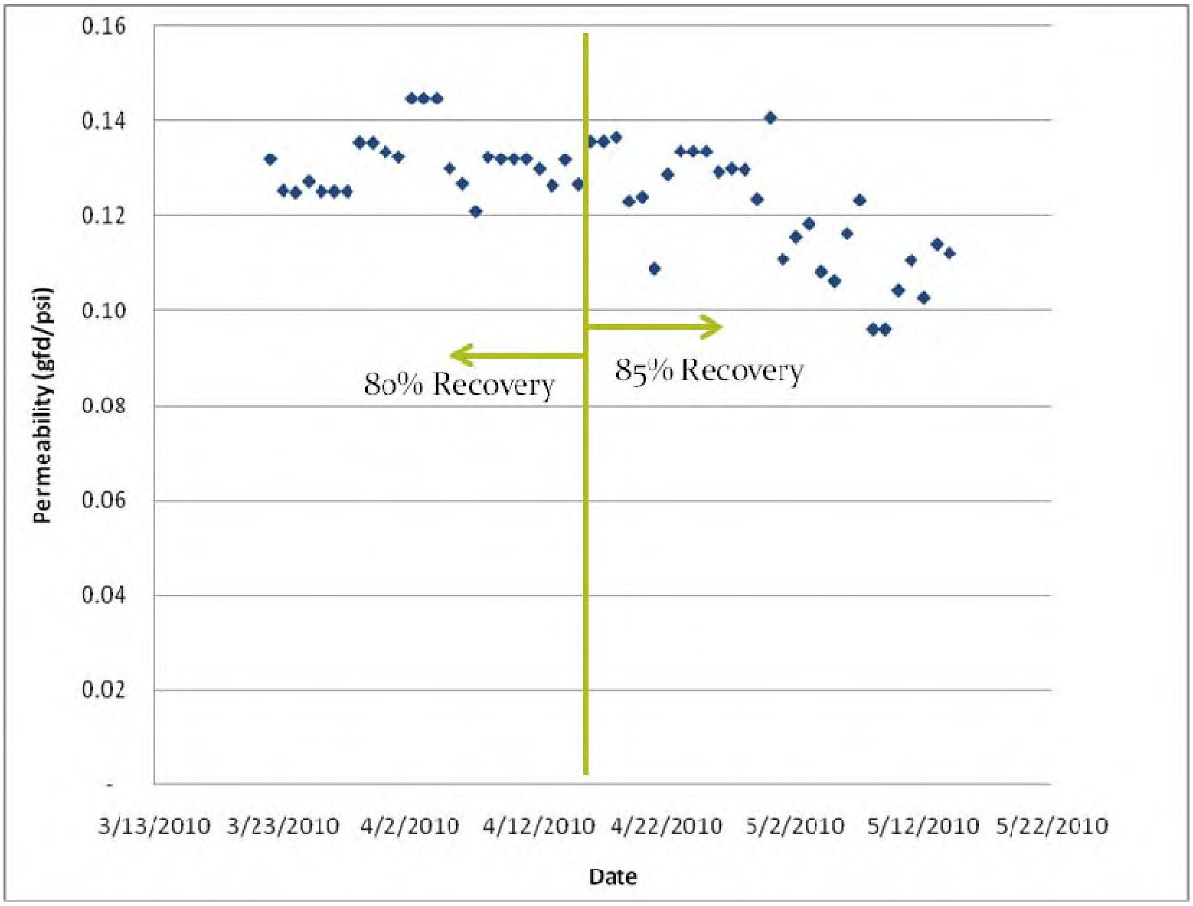
These results indicate that while NDMA levels in the source water were lower when using tertiary effluent, NDMA formation was larger, resulting in NDMA levels in the RO feed that were nearly identical for the two source water alternatives. These results suggest that the source of supply should not have a significant impact on NDMA levels in the water when it reaches the RO process.

Based on these NDMA results and the common rate of permeability decline, either secondary or tertiary effluent would be an appropriate source water for the RO treatment process.

Recovery

RO recovery was initially set at 80 percent during the early stages of Run 0, increasing to 85 percent on April 16, 2010 after stable operation at 80 percent recovery had been confirmed. At the same time that the recovery was increased from 80 to 85 percent, RO flux was also decreased from 14 to 12 gfd to simulate typical operating conditions for existing full-scale facilities. RO permeability was stable in both the first and second stages during the initial operating period before the recovery and flux were changed, however, permeability loss in the second stage began soon after increasing recovery to 85 percent. **Figure 6-3** presents the RO permeability in the second stage during this preliminary filtration run.

Figure 6-3: RO Permeability for Second Stage During Preliminary Run (Run 0)



Antiscalant

An initial analysis of potential foulants in the source water was conducted to determine whether or not an 85 percent recovery would be expected to be sustainable. Table 6-3 identifies some common inorganic foulants with projected saturation levels in the concentrate based on 85 percent recovery and average source water quality during the Phase 1 testing. Maximum allowable saturation levels were identified based on Avista Advisor v3 simulation software using Avista Vitec 4000 antiscalant, as had been employed at the pilot during initial operation.

This analysis did not suggest that levels of any potential scalants in the concentrate were at levels approaching allowable limits for the antiscalant. Nonetheless, scaling was observed in the second stage, and continued to occur during Runs 1, 2, and 3, when operating at 85 percent recovery.

To evaluate the source of this fouling, the tail end element from the second stage was sent to Avista Technologies for autopsy. The autopsy report is included with Appendix D of this document. Autopsy analysis determined that both silica and aluminum were present on the membrane surface, suggesting that some form of aluminum silicate could be responsible for the fouling seen. Aluminum had not initially been monitored in the source water and was subsequently added to the protocol. Results of aluminum monitoring suggest that levels in the concentrate exceed typical saturation levels for aluminum hydroxide, however, the levels are well within the maximum concentrations suggested by the antiscalant manufacturer. Silica levels, in contrast, were below saturation limits in the concentrate, even without the use of antiscalant, suggesting that silica alone was unlikely to be responsible for the loss in second stage permeability.

Table 6-3: Potential Inorganic Scalants for RO Membranes

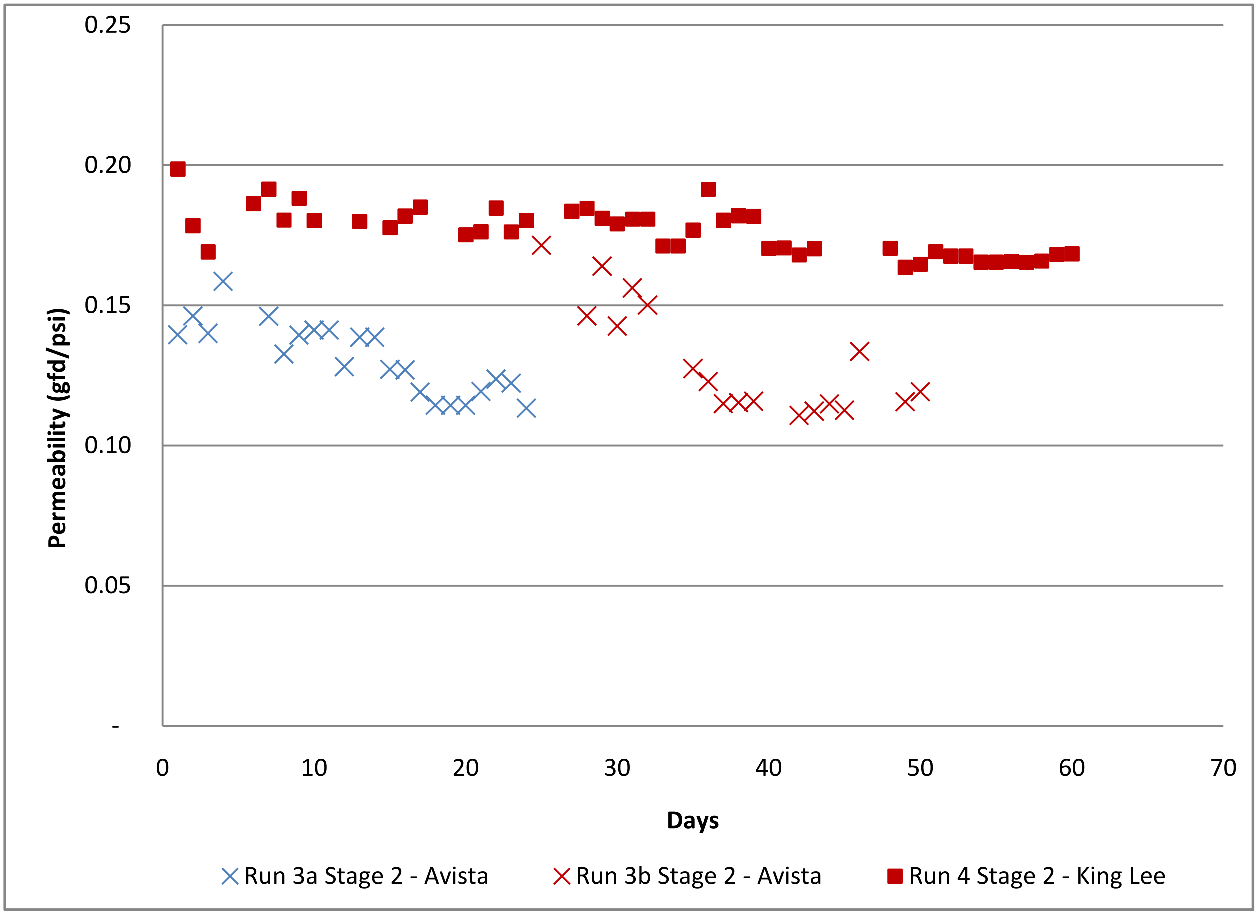
Potential Scalant	Saturation Level at 85% Recovery [(a)]	Maximum Saturation with Antiscalant [(b)]
Calcium Carbonate	LSI = 1.7	LSI < 2.5
Calcium Sulfate	17%	< 300%
Calcium Phosphate	250%	< 600%
Calcium Fluoride	475%	< 5,000%
Magnesium Phosphate	6%	< 600%
Aluminum Hydroxide	333%	<4,500%
Silica	44%	< 150%
Barium Sulfate	630%	< 4,000%
Strontium Sulfate	7%	< 3,000%

Footnotes:

a. *Saturation levels are based on average source water quality measured during Phase 1 pilot operation.*
b. *Target Saturation limits based on use of Avista Vitec 4000.*

Scaling in the second stage RO membranes continued until October 13, 2010, when the antiscalant was changed to PreTreat Plus Y2K, from King Lee Technologies. **Figure 6-4** compares the second stage permeability before and after the antiscalant was changed (Runs 3 and 4, respectively).

Figure 6-4: RO Permeability in Second Stage with Varying Antiscalants



Footnotes:

a. *Only the second stage for each run is shown since the first stage did not experience permeability decline during these runs.*

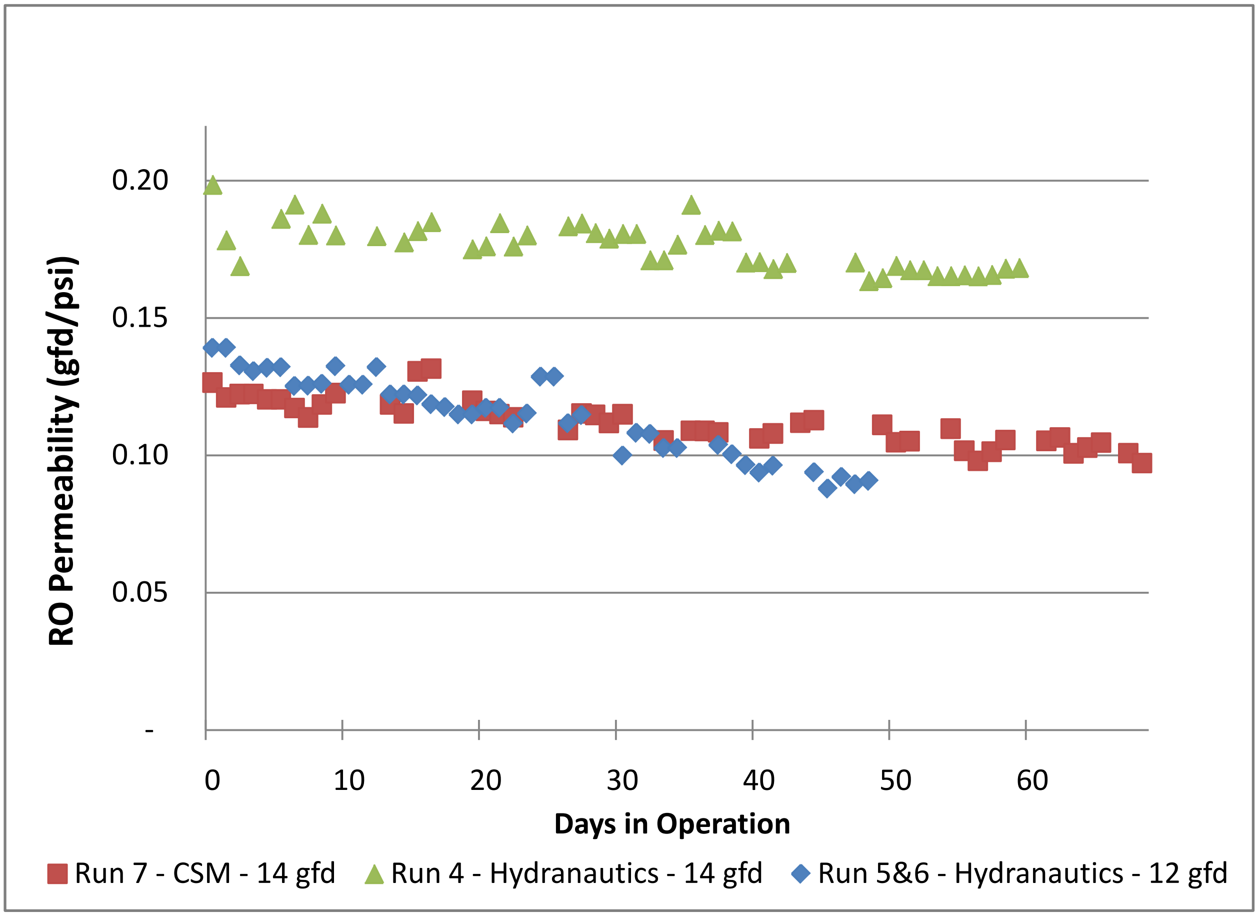
b. *Runs 3a and 3b were operated under identical conditions. A CIP was performed on the membranes following runs 3a and 3b.*

During Runs 3a and 3b rapid fouling caused the permeability to decrease by more than 30 percent in less than 30 days. This rate of fouling was repeated over two cleaning cycles. After changing the antiscalant the fouling rate decreased to less than 10 percent over 60 days. These results suggest that operation at 85 percent recovery can be sustainable, however, the initial antiscalant used in the pilot testing did not adequately address the scalants at this higher recovery rate.

Flux

The RO system average flux was varied between 12 and 14 gfd during the testing to evaluate whether a higher flux could improve plant performance. **Figure 6-5** shows second stage permeability for Run 4, operated at 14 gfd, Runs 5 & 6, operated at 12 gfd, and Run 7, operated at 14 gfd. It should be noted that Run 4 operation employed Hydranautics membranes, which had been damaged from contact with free chlorine, resulting in a higher initial permeability than would normally be seen with these membranes. Run 5 & 6 operation employed new Hydranautics membranes, which had not been damaged from contact with free chlorine, and Run 7 employed CSM membranes in the second stage. These varying membranes resulted in different initial permeability conditions, however, the change in permeabilities for each operating condition can be compared to evaluate the impact of flux on RO fouling.

Figure 6-5: RO Permeability in Second Stage with Varying Flux



Footnotes:

a. *Runs 5 and 6 are shown in one continuous run since a CIP cleaning was not done between them. The only difference in operating conditions between them was the source water, which was not shown to significantly affect the RO membrane performance.*

The rate of fouling during Run 4 (14 gfd) resulted in a permeability decline of less than 10 percent over 60 days. In contrast, when the flux was reduced to 12 gfd, the fouling rate increased, with a permeability decline of 36 percent over 60 days. Subsequent testing at 14 gfd in Run 7 showed similar results as Run 4, with less than 12 percent permeability decline over 60 days.

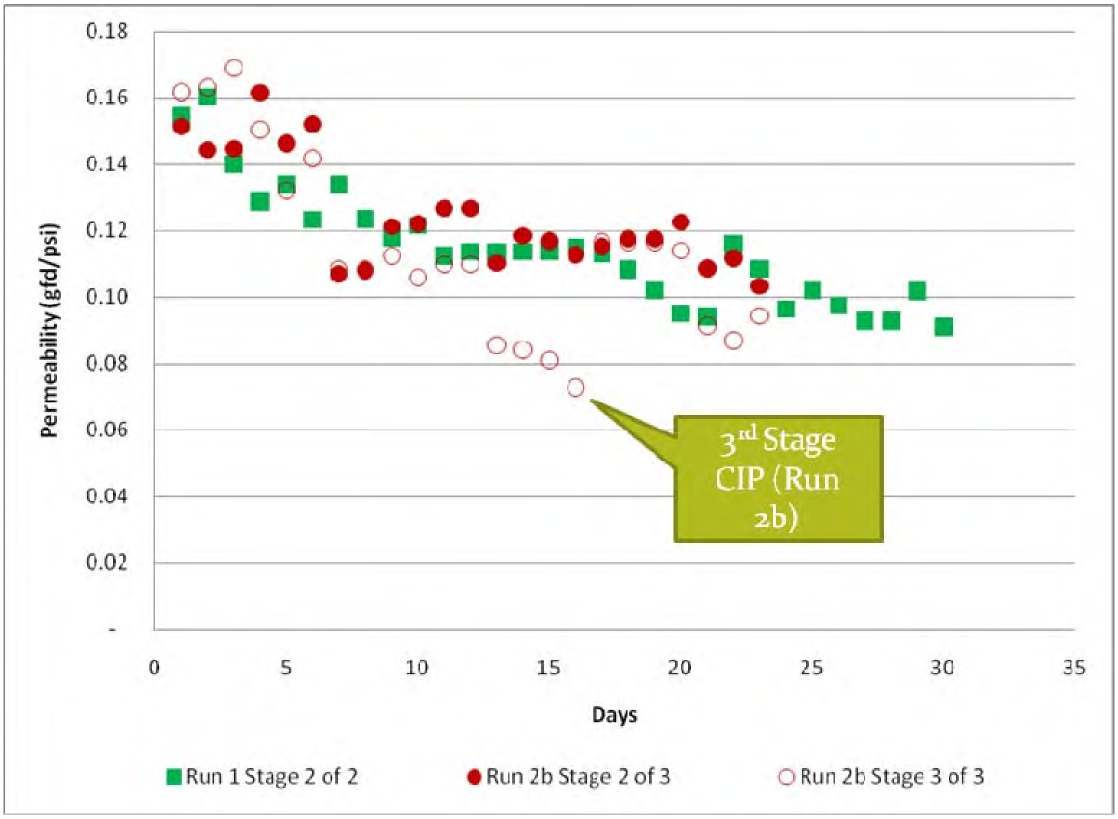
It should be noted that the concentrate flow rate during 12 gfd operation was 2.7 gpm, which is lower than the 3.0 gpm recommended minimum flow for the 4-inch RO elements, based on design criteria built into the Hydranautics IMSDesign software. These minimum flows are recommended to maintain proper scouring of the membrane surface to prevent scale build-up. By increasing the average flux to 14 gfd, the concentrate flow increased to 3.1 gpm, providing improved hydraulics and reduced fouling. While 14 gfd is higher than the maximum average flux officially recommended by Hydranautics for treating reclaimed water, results of the pilot testing suggest that the higher flux is advantageous to plant performance and should be considered for the full scale facility. It should be noted that this issue has been discussed with representatives of Hydranautics, who have indicated that they have seen similar performance in separate testing at fluxes as high as 16 gfd. They did not indicate any concern about warranting operation at an average flux of 14 gfd for this water. A more thorough discussion on RO flux and system hydraulics is included in Appendix J.

RO Configuration (Number of Stages)

Pilot testing evaluated the RO system with either two stages or three stages to determine whether improved performance could be seen with additional membrane stages. In a three-stage configuration, concentrate from the second stage is sent to a third stage to produce additional product water. The benefit of using three stages is that it provides improved hydraulics compared with a two-stage configuration, which should result in less fouling of the downstream stages. Poor cross-flow velocities in a two-stage configuration can result in scale build-up in the second stage. This issue was discussed previously in regards to membrane flux. It was suggested that increasing the flux from 12 to 14 gfd could improve crossflow velocities in the second stage, decrease scale build-up and permeability loss. In the same way, a three-stage configuration allows higher cross-flow velocities, which should reduce the risk of scale. An advantage of using a two-stage configuration is that it reduces the feed pressure required to produce the same volume of water, making the process more efficient, provided the membranes do not foul.

In practice, existing advanced treatment facilities employ both two-stage configurations (Vander Lans, Terminal Island, and West Basin Barrier Water Facility) and three-stage configurations (OCWD GWR and West Basin Boiler Feed Facility), and all of the existing facilities have experienced repeated problems with membrane fouling in the latter RO stages. **Figure 6-6** shows second and third stage permeabilities for Runs 1 & 2b, comparing operation between a two-stage configuration (Run 1) with three-stage (Run 2b) under identical operating conditions (85 percent recovery, 12 gfd flux, Vitec 4000 antiscalant).

Figure 6-6: RO Permeability in Second and Third Stages with Varying Configurations



2-stage and 3-stage operation showed similar second stage permeability decline during testing, indicating that using additional membrane stages was insufficient for reducing permeability loss in the second stage. The results indicate that fouling in the third stage was more severe than fouling in the second, suggesting that the use of three stage configuration provided no benefit to pilot plant operation. Run 2b was stopped after 16 days of operation (July 22, 2010) to clean the third stage elements. After the third stage was cleaned, operation was resumed for an additional nine days. Run 2b was discontinued after 25 days, due to excessive fouling in the second and third stage. A previous run using the three stage configuration (Run 2a) had seen a similar fouling trend to Run 2b, however, it was discovered that the antiscalant dose had been inadvertently reduced from 3.0 mg/L to 0.3 mg/L. When this error was discovered, the RO membranes were cleaned and the test run repeated (Run 2b).

During the pilot testing it was found that operation using a 3-stage configuration provided no benefit to reducing fouling in the second stage, while fouling in the third stage was significantly worse. 3-stage operation was only carried out using a single antiscalant product, which was later found to be insufficient for preventing fouling at 85 percent recovery. It is possible that stable operation could be achieved at 85 percent recovery with a 3-stage system when using a different antiscalant product, however, the results of the pilot demonstrate that a 3-stage system provided no inherent benefits over a 2-stage, when operated under identical conditions. In addition, the feed pressures and energy required for 3-stage operation are higher than for 2-stage, independent of the fouling rates.

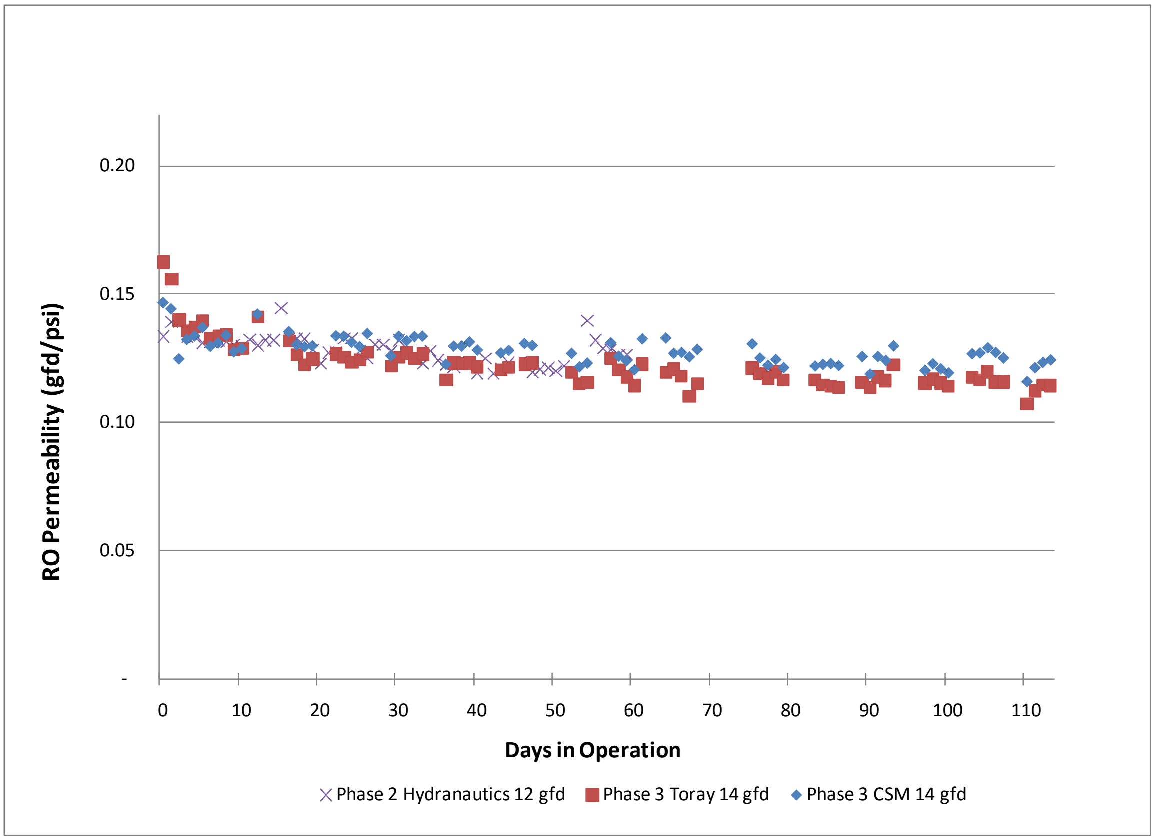
Based on the results from Phases 1 and 2 of testing, the following conditions were chosen for extended testing during Phase 3:

- Source water - secondary effluent or tertiary effluent
- Recovery – 85%
- Antiscalant – King Lee PreTreat Plus Y2K
- Flux - 14 gfd
- RO Configuration – 2-stage

6.2 Phase 3 Operating Performance

The Phase 3 testing focused on evaluating the performance of alternative RO membranes under the recommended operating conditions. Because only the first stage of the RO unit could be equally divided between parallel membrane types, the three alternative membranes can only be compared in their first stage performance. **Figure 6-7** therefore compares the first stage permeability for Toray and CSM membranes during Phase 3 (RO Run 7) and for Hydranautics membranes (RO Runs 5 & 6).

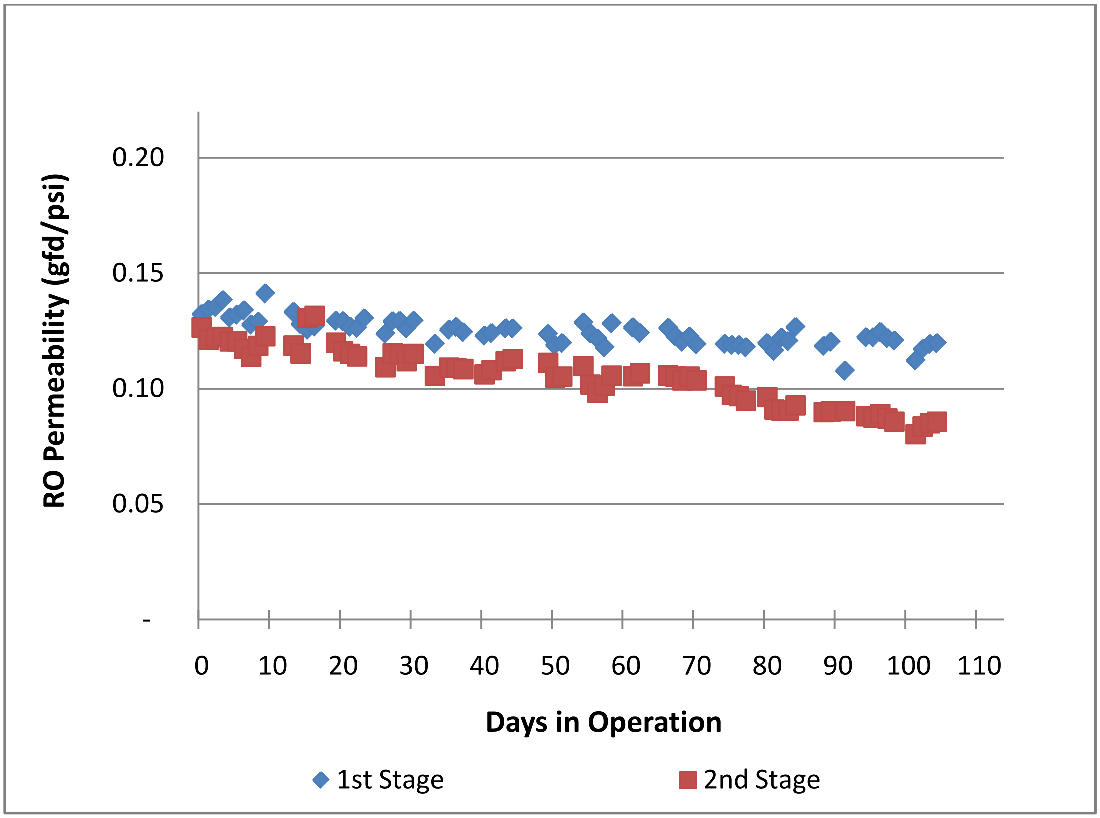
Figure 6-7: 1^{st} Stage RO Permeability with Alternative RO Membranes



The results show similar permeabilities for all three membranes, averaging 0.13 gfd/psi for the Hydranautics and CSM membranes and 0.12 gfd/psi for the Toray. Toray membrane permeability was initially higher than the other two membranes, but declined more rapidly, resulting in the lowest permeability after 60 hours of operation. Overall, permeabilities varied less than 5 percent between the three membranes tested. Projected permeability for all three membranes was 0.15 gfd/psi, suggesting that the membrane projection software provided by each vendor may under estimate stable operating pressures by 15 to 25 percent. Planning for the full scale facility should therefore assume that these higher pressures will be required for initial operation, with further increasing pressures as the membranes age.

Phase 3 testing also confirmed that performance could be maintained at the recommended operating conditions for a minimum of 90 days. A total of 104 operating days were achieved for the RO unit during Phase 3 without any chemical cleaning. **Figure 6-8** shows both the first stage and second stage permeabilities during the Phase 3 testing.

Figure 6-8: RO Permeability Using Recommended Operating Conditions



Permeability in both stages was relatively flat over the first 70 days of operation. After 70 days a decline in second stage permeability can be seen continuing until around 80 days, after which the permeability appears to have leveled off again. This decline after 70 days can be attributed to an operational error made on May 12, 2011, when a field engineer mistakenly filled the RO antiscalant feed tank with the Avista Technologies antiscalant, rather than the King Lee product previously recommended for the Phase 3 testing. The tank was refilled again on May 25, using the recommended antiscalant.

Overall, the Phase 3 second stage membranes showed an average 7 percent permeability decline per 30 days, which equates to a 42 percent decline over 6 months. This does not meet the goal of less than a 30 percent decline in permeability over 6 months, however, a significant portion of the permeability decline was related to the feeding of the incorrect antiscalant over a 10 day period. Permeability decline during the first 70 days of operation averaged 5 percent permeability decline per 30 days, which equates to a 30 percent decline over 6 months.

6.3 Water Quality Performance

RO water quality performance is measured by the membrane's ability to reduce key parameters and remove contaminants from the feed water. These results are discussed below in terms of overall RO system performance and in terms of performance of the individual RO membranes tested.

Overall Removal of RO System

Table 6-4 shows RO system removal of key constituents over the entire test duration and during the period after December 20, 2010, when the original RO membranes were changed. RO membranes worked well to remove a wide variety of contaminants. In most cases, the contaminant concentrations were reduced by greater than 98 percent. Table 6-4 shows results for key constituents that are typically not well removed by RO membranes or are important for regulatory considerations.

The table covers two testing durations. One column covers the entire testing duration, including a time period when the membranes had been damaged from repeated exposure to free chlorine. The other column includes only data after December 20, 2010, when membrane damage did not occur. Results from after December 20, 2010 includes data from all three membranes tested: Hydranautics, CSM, and Toray.

Table 6-4: RO Water Quality Results

		Undamaged Membranes (12/20/10 through 6/30/11)			Entire Pilot Study (2/18/10 through 6/30/11)			
Constituent	Units	RO Feed	RO Product	Reduction	RO Feed	RO Product	Reduction	Regulated Limit
TOC	mg/L	8.4	0.11	99%	8.4	0.29	97%	< 0.5 [a]
Total Nitrogen	mg/L	8.9	0.72	92%	8.9	1.6	82%	< 5 [a]
NDMA	µg/L	0.025	0.013	48%	0.025	0.015	40%	1.2 log reduction [a]
1,4-Dioxane	µg/L	1.2	0.36	70%	1.2	0.38	68%	0.5 log reduction [a]
TTHM	µg/L	10.4	5.7	45%	19	12	36%	< 80 [c]
HAA5	µg/L	15.8	ND	>97%	25	6.6	74%	< 60 [c]
TCEP	µg/L	0.30	0.005	98%	0.30	0.02	92%	NA
Chloride	mg/L	104	2.3	98%	114	13.7	88%	< 100 [b]
TDS	mg/L	528	13	98%	502	27	94%	< 500 [c]

Footnotes:

a. 2008 Draft Groundwater Recharge Regulations, assumes recycled water contribution may be as high as 100% for TOC limit. 1.2-log reduction = 94%, 0.5-log reduction = 68%
b. Existing Title 22 Water Recycling Regulations
c. CDPH drinking water limits (primary and secondary MCLs)

All of the water quality goals for the pilot project were met in the RO product before advanced oxidation, with the exception of NDMA, which requires advanced oxidation to remove. 2008 draft recharge regulations require that 1.2-log reduction (94 percent) of NDMA and 0.5-log reduction (68 percent) of 1,4-dioxane be achieved, regardless of the concentrations in the source water. The focus of these requirements is on the advanced oxidation process, since these compounds are generally not well removed by RO membranes, however, the RO rejection for 1,4-dioxane was sufficient to meet 0.5-log removal before advanced oxidation. NDMA was poorly rejected by the membranes, averaging 48 percent reduction during the time period when undamaged membranes were used.

Average rejections for most compounds were impacted by the membrane damage that began after July 20, 2010 and continued until the membranes were replaced on December 20, 2010. RO product water quality parameters were significantly lower when using non-damaged membranes, however, water quality goals were achieved even during the period when membrane damage was worst (November and December of 2010).

The compounds resulting in the poorest rejection were total trihalomethanes (THMs), which were reduced by only 36 percent on average, however, concentrations of these compounds were well below the 80 μg/L drinking water MCL.

During the pilot protocol development, TCEP was suggested as a surrogate species for evaluating the performance of the advanced oxidation processes, however, the results of the testing suggest that the removal effectiveness of TCEP by the membranes may be too high for this to be a practical surrogate. Removal effectiveness of TCEP averaged 92 percent, however, removal was 98 percent during the periods where membranes were not damaged by free chlorine. The detected levels in the RO product averaged 5 ng/L when membranes were undamaged. Test results this low are considered to be non-detectable by many laboratories.

TOC levels while using the undamaged membranes averaged 0.11 mg/L, which is considerably lower than the limit of 0.5 mg/L. Even the damaged membranes were able to remove TOC to below 0.5 mg/L, reaching an average of 0.22 mg/L during November and December 2010.

While virus removal is not specifically required for the RO process, indigenous coliphage measurements were made for the source water and RO product. These results are presented in Table 6-5 and indicate that the bacteriophage was completely removed by the RO membranes.

Table 6-5: Removal of Bacteriophage by the RO Membranes

Constituent	Units	Source Water	RO Product	Removal
Indigenous Coliphage (Male Specific)	pfu/100 mL	264	< 1.0	> 2.4 log
Indigenous Coliphage (Somatic)	pfu/100 mL	680	< 1.0[a]	> 2.8 log

Footnotes:

a. Somatic average for RO Product excludes positive hit on 5/12/2010, which is believed to be the result of a laboratory error.

One somatic indigenous coliphage sample returned a positive hit of 58 pfu/100 mL in an RO permeate sample on May 12, 2010, however, it is believed that this single positive reading is the result of a laboratory error. The RO product coliphage samples were all taken downstream of the RO product tank, allowing for the possibility of contamination within the tank, however, initial reporting for the May 12 coliphage results had been miscoded and corrected by the laboratory, raising doubts on the validity of results for this sampling day. In addition, the 58 pfu/100 mL somatic coliphage results reported for the RO product matched the 58 pfu/100mL male specific coliphage results reported in the source water on the same day. It is believed that the positive coliphage hit in the RO permeate on May 12 is therefore an incorrectly coded result for the source water that was not fully corrected by the bacteriological laboratory. Male specific coliphage results for May 12 were negative in the RO product, supporting the conclusion that the positive hit in somatic indigenous coliphage had been miscoded. Apart from this single positive result, removal effectiveness for the two types of indigenous coliphage measurement consistently exceeded 2-log.

Comparison of Different RO Membranes

Three membrane types were tested during the study: Hydranautics ESPA2, CSM TML and Toray FEn. To compare the performance of the three membranes, rejection rates were compared for key constituents, which were only partially removed by the membranes. Rejection rates differ from the reduction rates listed in Table 6-4, as rejection is calculated using the average concentration between the feed and concentrate, while reduction numbers look only at how much a contaminate is reduced between the feed and permeate. For instance, a constituent which is reduced by 75 percent between the feed and permeate, will be increased to 5.25 times its feed concentration in the RO concentrate, when the RO system is operated at 85 percent recovery. The actual rejection across the membrane is based on the average concentration between the feed and concentrate, and would be 92 percent under these conditions. Membrane rejection in the first stage should be identical to rejection in the second, provided that the same membranes are used at the same average flux for each stage. Calculating the rejection rate for contaminants makes it possible to compare performance of the Hydranautics membranes in a two stage configuration with the single stage water quality results for the CSM and Toray membranes. Formulas used to calculate percent rejection were included in Section 2. Table 6-6 compares calculated rejection rates of key constituents for the three membranes tested.

Rejections of constituents were similar for the three membranes tested. The Hydranautics membranes saw the highest calculated rejection of ammonia, TCEP, HAA5, and overall TDS, but the lowest rejection of nitrate. Toray membranes had the best rejection of NDMA, boron, and nitrate, but the lowest rejection of TCEP. CSM membranes were generally lower or equivalent to the other membranes in rejection. Overall there was little difference between the water qualities from the three membranes tested.

Membrane projection software for each of the vendors estimated chloride and TDS rejections between 99.7 and 99.8 percent for the operating conditions tested here. Actual rejections calculated from the pilot results were lower for all membranes, however, the concentrations of TDS and chloride measured in the first stage permeate were extremely low. TDS measured for the Toray and CSM membranes, for instance, averaged less than 10 mg/L, which is generally considered the reliable detection limit for TDS. The membrane projections therefore represent a reasonable estimate for the water quality produced by the membranes used during this pilot study.

Table 6-6: Rejection of Constituents by Three RO Membranes

Parameter	Percent Rejection		
	Hydranautics ESPA2 [(a)]	CSM FEn [(b)]	Toray TML [(b)]
Ammonia	95%	82%	85%
Boron	64%	55%	70%
Calcium	99.9%	99.9%	99.8%
Chloride	99.2%	99.4%	99.3%
Haloacetic Acids (HAA5)	99%	98%	98%
Dibromoacetic acid	Below detection	81	80
Dichloroacetic acid	98	97	97
Trichloroacetic acid	95	95	95
N-Nitrosodimethylamine (NDMA)	66%	59%	70%
Nitrate (as NO3)	97.8%	98.0%	98.4%
TCEP	99.8%	99.6%	99.5%
TDS	99.3%	98.9%	98.9%

Footnotes:

a. *Hydranautics data based on operation between 12/20/10 and 2/27/11. Percent rejection based on system recovery of 85% over both stages, using average measured concentrations in the feed and permeate and calculated concentrate values based on mass balance calculations (see Section 2 for formula).*
b. *CSM and Toray data based on operation between 2/28/11 and 6/30/11. Percent rejection based on first stage recovery of 57% for CSM and 53% for Toray, using average measured concentrations in the feed and first stage permeate and calculated first stage concentrate values, based on mass balance calculations.*

Table 6-7 presents projected and average concentrations of several inorganic constituents based on the Hydranautics membranes. The software projections were slightly high for some parameters and slightly low for others, but are reasonably accurate approximations of the pilot results. Membrane projections for all three vendors are included in Appendix I.

Table 6-7: Projected and Measure Permeate Water Quality Using Hydranautics Membranes

Constituent	Concentration (mg/L)	
	Projected [(a)]	Measured [(b)]
Calcium	0.2	0.1
Sodium	2.5	4.1
Potassium	0.4	0.4
Sulfate	0.3	0.4
Chloride	1.3	3.4
Nitrate	2.8	2.1
Boron	0.6	0.4

Footnotes:

a. *Based on projections using IMSDesign Software v. 2009*
b. *Average RO permeate values measured between December 20, 2010 and February 28, 2011*

6.4 Comparison with Full Scale Treatment Plants

Table 6-8 compares RO performance from the pilot testing with water quality reported for existing full-scale facilities.

Table 6-8: Comparison of Pilot Results with Similar Full-Scale Treatment Plants

Parameter	Units	Pilot RO Results (average)[a]	OCWD GWR (b)	Terminal Island	West Basin
RO Flux	gfd	12-14	12	10	12
TOC	mg/L	0.11	0.06	0.6	0.5
Total Nitrogen	mg/L	0.72	1.7	7.9	0.07
NDMA	µg/L	0.013	0.017	0.022	ND
1,4-Dioxane	µg/L	ND	ND	ND	ND
TTHM	µg/L	5.7	5.8	51	ND
HAA5	µg/L	ND	ND	19	ND
TCEP	µg/L	0.005	-	-	ND
Turbidity	NTU	0.11	0.03	0.04	0.05
Chloride	mg/L	2.3	4.3	59	31
TDS	mg/L	13	21	108	192

Footnotes:

a. Constituent averages are from either the UV Effluent sample tap, the RO permeate tap or the AOP influent tap. Includes average data between December 20, 2010 and June 30, 2011.

b. From OCWD 2010 Annual Report except for total nitrogen, which is from the November 2008 Monthly Operating Report

6.5 Conclusions

Pilot testing considered the impact of various operating parameters on RO performance. These included: source water, flux, number of stages, recovery, antiscalant, and membrane type. Operational recommendations for these conditions are discussed below:

- Chlorination Approach – Excessive membrane damage was observed during the period when sequential chlorination was utilized. It is believed that repeated loss of ammonia feed during the evenings allowed free chlorine concentrations greater than 3 mg/L to damage the membranes before sequential chlorination was discontinued and the membranes were replaced. During full-scale operation, automatic quenching of the chlorine can be done to prevent such damage, however, the risk of membrane damage will be higher with sequential chlorination than with traditional chlorination.
- Source Water - No difference was seen in RO performance between operation with tertiary effluent or secondary effluent as the source water.
- Flux – Stable operation was not achieved at 12 gfd operating flux and 85 percent recovery, even when operating in a 3-stage configuration. Stable operation was achieved at 14 gfd.

- Number of Stages – No difference was seen in first stage or second stage fouling between a 2-stage or 3-stage configuration, however, a high fouling rate was seen in the third stage when operating in a 3-stage mode. Higher feed pressures were required to maintain a 3-stage system. It is therefore recommended that a 2-stage configuration be used for the full-scale facility.
- Recovery – At 80 percent recovery, no fouling was observed with the initial antiscalant and a flux of 12 gfd. At 85 percent recovery fouling was observed in the second stage when the initial antiscalant was used and when flux was 12 gfd. Stable operation was achieved at an 85 percent recovery with the second antiscalant and an operating flux of 14 gfd. It is therefore recommended that a design recovery of 85 percent be used for the full-scale facility.
- Antiscalant – The RO membranes performed well with PreTreat Plus Y2K as the antiscalant, allowing for run times exceeding 60 days, but an unacceptably high rate of fouling was observed with Vitec 4000 as the antiscalant when recoveries greater than 80 percent were employed. Antiscalants can be purchased easily from multiple vendors after full-scale plant construction is complete. It is therefore not necessary to recommend a specific antiscalant at this point in the planning process.
- All three RO membranes tested performed nearly identically, in terms of fouling rate, permeability, and product water quality. It is recommended that all three membranes be considered for inclusion in the future facility.

Water quality results demonstrated that the RO system was able to meet all water quality requirements for the advanced water purification facility, with the exception of NDMA destruction, which must be achieved in the downstream advanced oxidation process. In addition, the 4-log virus inactivation requirements must be achieved through a disinfection/oxidation process.

7. Advanced Oxidation Process Results

This section summarizes the results of testing with two alternative advanced oxidation systems: UV/peroxide and ozone/peroxide. Although the equipment for these systems is very different, both generate hydroxyl radicals to break down organic matter. The UV system has an additional mechanism of direct photolysis, where UV light directly breaks down organic matter. Unlike the microfiltration and reverse osmosis processes, whose performance was measured by both operating pressures and water quality, the performance of the AOP systems was gauged solely by contaminant removal. The AOP systems were operated separately in each of the three testing phases, as described below:

- Phase 1: Continuous operation using UV/peroxide only. Secondary effluent or tertiary effluent used as source water, taken before chlorination.
- Phase 2: Batch operation using both UV/peroxide and ozone/peroxide. Tertiary effluent used as source water, taken after the chlorine contact tank.
- Phase 3: Continuous operation using ozone/peroxide only. Secondary effluent or tertiary effluent used as source water, taken before chlorination.

7.1 Influent Water Quality

During Phases 1 and 3, the AOP systems were operated continuously, with source water taken from the RO product, and the pilot source water was either secondary effluent or tertiary effluent before chloramination. The RO permeate break tank was used between the RO and UV/peroxide systems during Phase 1 testing, however, this tank was bypassed during Phase 3 testing. Following the microfiltration and reverse osmosis treatment steps, the vast majority of constituents in the water had been removed or destroyed. Since the purpose of the AOP system is to remove trace organic compounds and CECs, these are the only water quality parameters that will be discussed in this section.

For NDMA and 1,4-Dioxane, the CDPH draft Groundwater Recharge Reuse Regulations (CDPH, Aug. 2008) require 1.2-log and 0.5-log removal, respectively. Since the source water concentration of these constituents is so close to the minimum recordable limit, adjustments were made during the Phase 2 testing to demonstrate the required amounts of removal. To demonstrate removal of NDMA, the pilot source water was changed during Phase 2 to tertiary effluent after chloramination, which has NDMA levels approximately ten times higher than that of the typical pilot source waters. This was achieved by switching pilot influent water to tertiary effluent after choloramination during the evening after all regular pilot samples had been taken. During the night, storage tanks were filled which were used for UV/peroxide and ozone/peroxide testing. In the morning the pilot source water was changed back to either secondary effluent or tertiary effluent before chloramination. AOP influent NDMA concentrations during experimentation ranged from 88 to 350 ng/L. It should be noted that the AOP systems were operated in batch mode for short periods of time (less than 1 hour) during Phase 2 testing, while they were operated continuously during Phases 1 and 3.

To show removal of 1,4-Dioxane during Phase 2, this compound was dosed directly into the batch AOP influent storage tanks. Average measured levels of 1,4-dioxane in the AOP influent with and without spiking were 177 µg/L and non-detect, respectively. This high AOP influent concentration made it possible to measure the desired 0.5-log removal.

Separate from the typical continuous testing operation, Phase 2 testing involved numerous specific testing experiments, run under various conditions. The AOP influent water quality for each of these experiments is summarized in Table 7-1 below.

Table 7-1: AOP Influent Characteristics During Phase 2 Testing [a,b]

	Units	16-Nov	23-Nov	1-Dec	8-Dec		22-Dec	7-Jan		11-Jan		28-Jan	3-Feb	22-Feb	24-Feb	25-Feb
TDS	mg/L	NM (c)	65	65	68	New RO Membranes	15	13	NM	18	NM	NM	14	13	31	21
pH	-	7.89	6.68	6.35	6.24		NM	5.92	5.82	5.73	5.56	6.35	6.49	6.06	6.18	6.40
UV absorbance	Abs	0.019	0.015	0.021	0.016		0.010	0.013	0.006	0.007	0.001	0.015	0.015	0.014	0.033	0.030
Alkalinity	mg/L $CaCO_3$	32	14	15	12		5	6	NM	6	NM	NM	4	6	8	7
TOC	mg/L	0.49	0.37	0.23	0.19		0.13	0.12	0.13	0.12	0.12	0.21	0.18	0.27	0.16	0.20
Nitrate	mg/L NO_3	NM	9.5	NM	NM		NM	2.3	NM	NM	NM	NM	2.6	3.0	2.6	2.3
Total chlorine	mg/L	1.31	1.88	1.98	1.23		0.20	2.41	0	1.36	0	3.45	2.71	2.9	0	0
TCEP	ng/L	NM	NM	NM	NM		NM	NM	NM	NM	NM	NM	22	71	31	20
NDMA	ng/L	350	210	230	280		130	220	220	150	140	140	117	88	95	100
1,4-dioxane	µg/L	410	480	16	NM		42	NM	NM	110	120	120	145	140	NM	NM
Phenazone	ng/L	NM	NM	NM	NM		NM	NM	NM	NM	NM	NM	NM	NM	65	3900
Quinoline	ng/L	NM	NM	NM	NM		NM	NM	NM	NM	NM	NM	NM	NM	51	910

Footnotes:

a. New RO membranes installed on December 20th

b. Gray shading indicates experiments for which chloramines were quenched with sodium bisulfite on Dec 22, Jan 7 and 11 and with sodium thiosulfate on Feb 24 and 25

c. NM = not measured

As a result of the damage to the RO membranes by free chlorine, new RO membranes were installed on December 20, 2010, allowing the RO product water quality to degrade below acceptable levels. It can be observed from the water quality data shown in Table 7-1, that the TOC, alkalinity, TDS, and UV absorbance in the AOP feed were all lower after December 20, indicating that the new RO membranes resulted in immediate improvement in AOP feed water quality.

During Phase 3, the UV/peroxide system and batch tanks were removed and only ozone/peroxide was utilized. The ozone peroxide system was operated in a continuous manner, treating RO product water without utilizing the RO permeate break tank. Source water quality during the Phase 1 and 2 testing were as presented in Section 6.

7.2 UV/Peroxide

During Phase 1 of the pilot study, the UV reactor was operated at a flow rate of 15 to 17 gpm. Parameters monitored in the AOP product during Phase 1 included NDMA, 1,4-dioxane, and TCEP. These results are shown in Table 7-2. NDMA and 1,4-dioxane were consistently measured below the method reporting limits after advanced oxidation. TCEP, in contrast, was not significantly reduced by the UV/peroxide process, however, this compound had been removed at a 99 percent efficiency by the RO process, reducing the need for further removal in the AOP.

Table 7-2: Phase 1 UV/Peroxide Water Quality Results

Parameter	Units	UV Feed	UV Product	Removal
TCEP	µg/L	0.004	0.003[(a)]	NA
NDMA	µg/L	0.016	< 0.002	> 88%
1,4-Dioxane	µg/L	0.73	< 0.5	> 32%

Footnotes:

a. Excludes reading from 6/2/2010, where 0.034 µg/L was measured in UV product, but only 0.006 µg/L in the UV Feed. Leaving this reading in the data set results in a 0.005 µg/L average TCEP value for UV product.

When operated at the low flow rates used during Phase 1, the hydraulic conditions for the 8AL20 reactor were not representative of fully turbulent flow conditions expected in full-scale reactors at much higher flow rates. The hydraulic conditions in UV reactors have a large influence on performance and it was advantageous to conduct pilot testing during Phase 2 at higher flow rates more representative of full-scale conditions.

To determine the effectiveness of direct photolysis alone (without hydroxyl radicals), tests were conducted during Phase 2 to determine the ability of the 8AL20 reactor to remove NDMA at various flow rates without any hydrogen peroxide addition. The results of the tests are shown in Table 7-3.

Table 7-3: NDMA Removal at Various Flowrates without Hydrogen Peroxide

Flowrate, gpm	NDMA Log Removal
50	1.44
100	0.79
225	0.49
350	0.33

With the exception of operation at 50 gpm, the UV reactor did not meet the 1.2-log NDMA reduction goal without the use of hydrogen peroxide. At the representative flow condition of 350 gpm, the NDMA removal of 0.33 logs was significantly below the goal.

Although ideal hydraulic conditions were not achieved with the UV reactor, the target removal goals could be achieved by following the recommendations provided by Trojan, including:

- Maximum flow rate of 45 gpm
- Hydrogen peroxide dose of 5.6 mg/L

The UV reactor was operated at 100 percent power, which is equivalent to a rated irradiance (or UV intensity) of 9 mW/cm^2. For a flow rate of 45 gpm and reactor residence time of 12 seconds (see Appendix E for confirmation of residence time), this corresponds to a UV dose of 106 mJ/cm^2, assuming 98 percent UV transmittance. This dose is greater than the minimum 50 mJ/cm^2 recommended for virus inactivation in the Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse (NWRI, 2003).

Hydrogen peroxide doses between 0 and 8 ppm were investigated and subsequent experiments were typically run with a flowrate of 45 gpm. A technique used to evaluate the hydraulic conditions in the UV reactor is discussed in Appendix E.

Phase 2 Water Quality Results

UV/peroxide product water quality results for the Phase 2 testing are presented in Table 7-4. NDMA reduction averaged 1.65-log units and met the removal goal of 1.2-log units on all sampling days, with the exception of November 23, 2010. Reduction of 1,4-dioxane averaged 1.78-log units and met the removal goal of 0.5-log units on all sampling days.

Table 7-4: Phase 2 Results for UV/Peroxide System[a]

	Units	16-Nov	23-Nov	1-Dec	8-Dec	22-Dec	7-Jan		11-Jan		28-Jan		3-Feb			22-Feb	24-Feb	25-Feb
Flowrate	gpm	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Chlorine quenched	Y/N	No	No	No	No	Yes	No	Yes	No	Yes	No	No	No	No	No	No	Yes	Yes
H_2O_2 dose	mg/L	5.41	8.14	6.49	4.82	6.41	6.02	6.51	6.04	7.46	2.80	6.04	0	3.13	5.60	5.85	0	0
Effluent total chlorine	mg/L	0.41	0.69	0.45	0.42	n/a	0.50	n/a	0.36	n/a	1.20	1.09	0.86	NM	NM	0.85	NM	NM
Effluent TCEP	ng/L	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	2.6	2.1	1.5	2.9	17	4.7
Effluent NDMA	ng/L	22	47	4.6	13	5.1	3.6	1.3	1.6	1.5	3	1.0	2.4	2.2	1.9	2.6	2.5	2.2
Effluent 1,4-dioxane	µg/L	43	<0.07	0.47	NM	0.15	NM	NM	0.92	<0.07	19	6.6	NM	13	4.8	6.9	NM	NM
Effluent Phenazone	ng/L	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	<2.5	70
Effluent Quinoline	ng/L	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	74	45
Chloramine removal	Log	0.50	0.44	0.64	0.47	-	0.68	-	0.58	-	0.46	0.50	0.50	-	-	0.53	-	-
TCEP removal	Log	-	-	-	-	-	-	-	-	-	-	-	0.73	-	-	1.39	0.26	0.63
NDMA removal	Log	1.20	0.65	1.70	1.33	1.41	1.79	2.23	1.97	1.97	1.67	2.15	1.69	1.72	1.79	1.53	1.58	1.66
1,4-dioxane removal	Log	0.98	>3.28	1.81	NM	2.23	-	-	2.08	>3.27	0.80	1.26	n/a	1.05	1.48	1.31	-	-
Phenazone removal	Log	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	>1.4	1.75
Quinoline removal	Log	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.31

Footnotes:

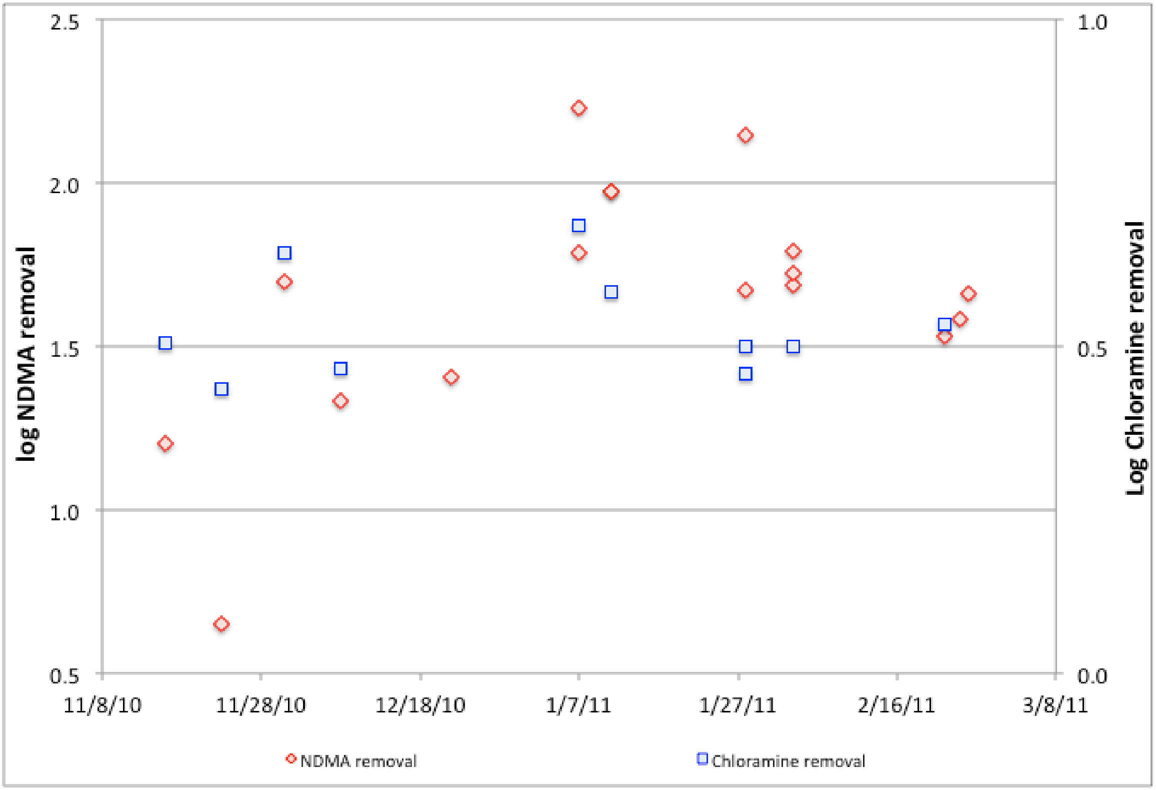
a. *New RO membranes installed on December 20*

b. *NM = not measured*

Along with the field-testing, concurrent review efforts were conducted to identify an appropriate indicator compound for NDMA to address situations when the NDMA concentration is too low in the influent to demonstrate the CDPH mandated 1.2-log reduction and avoid the spiking of NDMA. Phenazone and Quinoline showed the greatest potential as appropriate indicator compounds, because they had removal rates similar to NDMA. The details of this effort are presented in Appendix E.

An additional concurrent effort included the exploration of chloramines as a surrogate for evaluation purposes and routine monitoring. For the evaluation of NDMA removal efficacy, chloramines appear promising because this constituent is present at an adequate concentration in the RO permeate, as well as being easy and inexpensive to quantify. As shown in **Figure 7-1** below, field chloramine and NDMA removal are comparable.

Figure 7-1: Comparison of field removal of NDMA and chloramines



The final concurrent effort included a novel method, which mirrors the National Water Research Institute (NWRI) Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse (2003) approach, to estimate the actual UV dose delivered. This was done using side-by-side collimated beam (CB) experiments to develop dose-response curves for NDMA. The results for the collimated beam experiments, as well as comparisons with previous Trussell Tech (TT) CB experiments and published work are presented in Appendix E.

7.3 Ozone/Peroxide

For all the experiments during Phase 2 testing, the ozone/peroxide system consistently surpassed the required 0.5-log removal of 1,4-dioxane, however, the 1.2-log reduction goal for NDMA was not achieved under any of the test conditions. One benefit of the ozone approach is that there are essentially three oxidants in play with the hydroxyl radical, ozone and oxygen to address trace organics where UV/AOP has the hydroxyl radical and photolysis. The ozone/peroxide product water quality during Phase 2 testing is summarized in Table 7-5.

The ozone concentrations during the early experiments of Phase 2 (November 15, 23, December 1 and December 8) were likely twice what is reported, because the proper technique for measuring high ozone concentrations was not available at the time the experiments were conducted.

When operated at a dose of greater than 6 mg/L, the ozone/ peroxide system achieved above a 0.5-log reduction of NDMA. It must be noted that the feed levels of NDMA, when post-chorine contact tank water is not used, are much lower than those measured during the Phase 2 testing, allowing the product water concentration goals to be achieved with this level of NDMA reduction. NDMA concentration measured in the RO product was less than 26 ng/L in 95 percent of the weekly samples taken, indicating that an ozone dose greater of at least 6 mg/L would be capable of maintaining NDMA below the 10 ng/L notification level 95 percent of the time.

The second order reaction rate constants of 1,4-dioxane and NDMA with hydroxyl radicals (L/mole/s) are 2.8×10^9 and 4.3×10^8, respectively. This effectively means that the rate of 1,4-dioxane removal is 6.5 times greater than NDMA removal with hydroxyl radicals. On average, therefore, an 8-log reduction of 1,4-dioxane would be expected to be necessary to achieve a 1.2-log reduction of NDMA. It was initially speculated that chloramines may have been competing for hydroxyl radicals because chloramines were present at higher concentrations than NDMA or 1,4-dioxane and the second order hydroxyl radical rate constant for chloramine is reported in the literature as 2.8×10^9 L/mole/s (Johnson et al. 2002) or 5.2×10^8 L/mole/s (Poskrebyshev, Huie, and Neta 2003). For this reason, testing was conducted with AOP influent which had the chloramines quenched. It was found that quenching of chloramines did not improve the removal of NDMA or 1,4-dioxane.

Multiple ozone/peroxide systems in series or multiple ozone and peroxide injection points, a technique utilized by the HiPOx™ system, may achieve the log-removal and effluent concentration requirement for NDMA, although further experiments would be necessary to confirm this.

An additional concern for any system utilizing ozone is the potential of bromate formation. Bromate is classified by USEPA as a "probable human carcinogen" and has a current drinking water maximum contaminant limit of 10 µg/L. When the RO membranes were undamaged (after December 20, 2010), bromate was not an apparent issue and averaged 0.90 µg/L in the ozone/peroxide effluent for Phase 3. This equates to an average 72 percent increase in bromated concentration through the ozone system. When using the previous RO membranes, which had been damaged from oxidant exposure, the bromate levels were measured at 8 and 10 µg/L.

Table 7-5: Phase 2 Results for Ozone/Peroxide System a

	Units	16-Nov	23-Nov	1-Dec	8-Dec	22-Dec	7-Jan		11-Jan		28-Jan		3-Feb		22-Feb
Flowrate	Gpm	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chlorine quenched	Yes/No	No	No	No	No	Yes	No	Yes	No	Yes	No	No	No	No	No
O_3 dose	mg/L	5.7(c)	5.3(c)	4.2(c)	6.7(c)	13.9	NM	NM	13.0	12.6	9.9	5.2	12.7	5.0	5.3
O_3 prior to H_2O_2 addition	mg/L	NM(b)	NM	NM	NM	10.3	10.0	11.7	11.8	10.6	7.5	3.2	8.1	2.1	3.5
Effluent bromate	µg/L	NM	NM	10	8	0.95	1.30	1.20	3.00	ND	2.50	2.50	1.70	<0.13	2.00
Effluent H2O2	mg/L	2	1.9	1.5	2.3	2.06	1.05	1.63	1.55	2.04	0.93	0.84	0.66	0.27	0.89
Effluent pH	-	8.1	8.3	8.9	9.2	NM	6.6	8.1	6.5	6.7	9.3	8.3	7.5	7.8	7.4
Effluent total chlorine	mg/L	0.24	0.16	0.06	0.16	0	0.06	0	0.05	0	0.10	0.49	0.07	0.26	0.07
TCEP		NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	1.10	1.70	1.50
Effluent NDMA	ng/L	170	44	60	84	31	62	60	12	24	24	120	27	76	28
Effluent 1,4-dioxane	µg/L	<0.07	<0.07	0.25	NM	<0.07	NM	NM	<0.07	<0.07	<0.07	1.2	NM	1.2	<0.07
Chloramine removal	$-\log(C_{eff}/C_{inf})$	0.74	1.07	1.52	0.89	-	1.64	-	1.43	-	1.54	0.85	1.60	1.04	1.62
TCEP removal	$-\log(C_{eff}/C_{inf})$	-	-	-	-	-	-	-	-	-	-	-	1.42	-	1.68
NDMA removal	$-\log(C_{eff}/C_{inf})$	0.31	0.68	0.58	0.52	0.62	0.55	0.56	1.10	0.77	0.77	0.07	0.65	0.16	0.50
1,4-dioxane removal	$-\log(C_{eff}/C_{inf})$	>3.8	>3.8	1.8	-	>2.8	-	-	>3.2	>3.2	>3.2	2.1	-	2.1	>3.3

Footnotes:

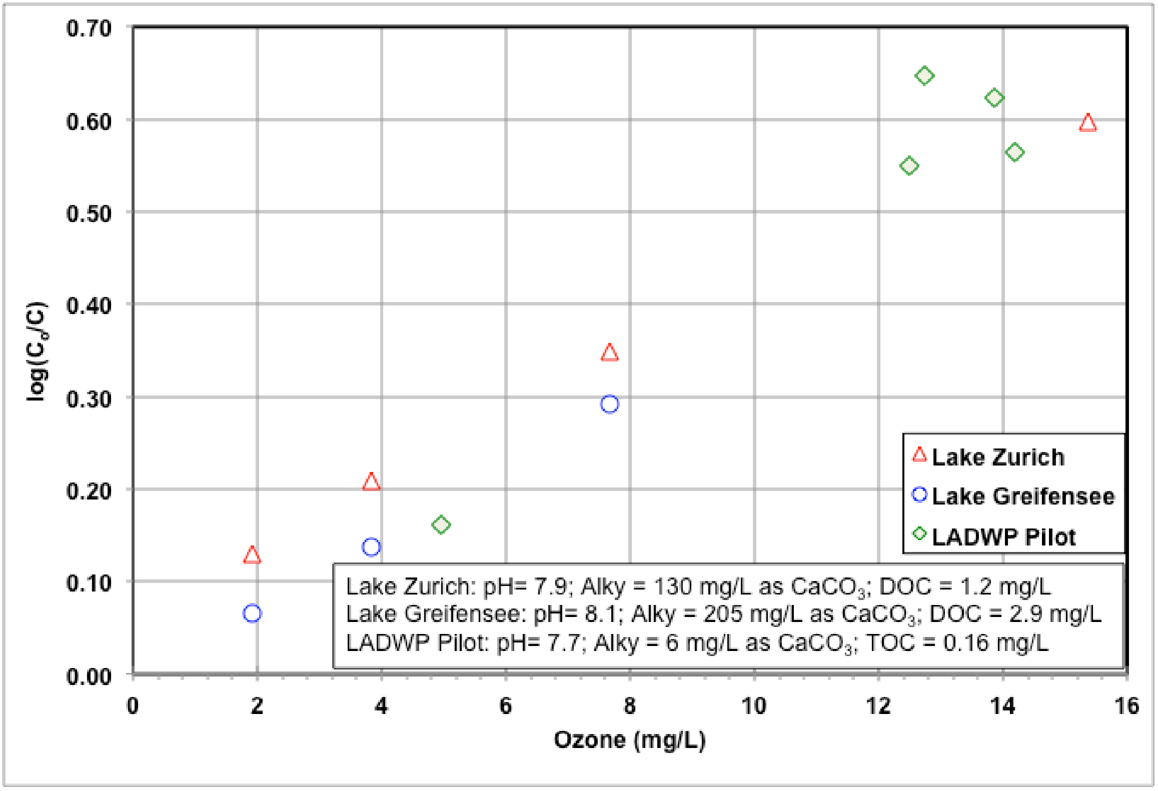
a. *New RO membranes installed on December 20*

b. *NM = not measured*

c. *Began using new O_3 detection method (gravimetric indigo procedure), more appropriate for O_3 concentrations greater than 1.5 ppm, on December 9th. As compared to the old Hach method, the new method resulted in much higher, over double, ozone concentrations than those observed under similar operating conditions.*

The results obtained for the LADWP ozone/peroxide pilot system were slightly higher than those observed by Lee and colleagues (2007). The most representative pilot data (produced after implementing the new ozone quantification method) from Table 7-5 and data from two water sources and a range of ozone concentrations (generated by Lee and colleagues (2007)) are summarized in **Figure 7-2**.

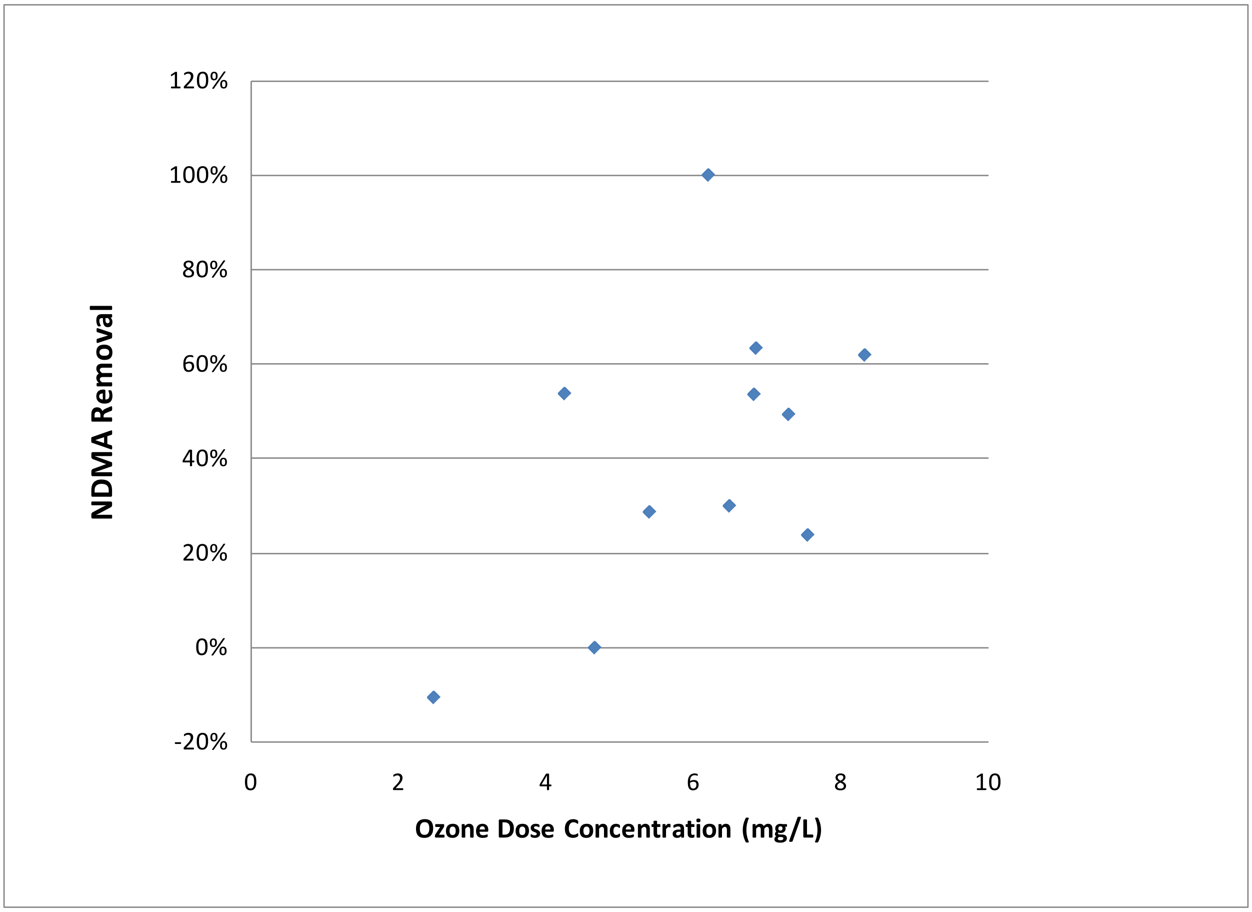
Figure 7-2: Comparison of NDMA Removal by Pilot Ozone/Peroxide System and Published Data



In general, water with lower alkalinity and organic carbon achieve higher NDMA removal, thus slightly better performance was seen with the LADWP pilot.

During Phase 3 additional testing was performed using the ozone/peroxide system in continuous operation on the RO product. These results demonstrated that ozone doses below 5 mg/L had little to no effectiveness at reducing NDMA concentrations, however, doses between 6 and 8 mg/L were able to achieve a minimum 50 percent NDMA reduction. **Figure 7-3** shows the NDMA removal at varying ozone doses measured during the Phase 3 testing period.

Figure 7-3: Phase 3 NDMA Removal with Varying Ozone Dose



Footnotes:

a. On 5/24/11, the NDMA concentration in the ozone product was measured as 270% of the ozone feed, and 138% of the RO Feed, with an ozone dose of 6.0 mg/L. Due to the anomalous nature of this data point, it was not included in the figure above.

7.4 Comparison of UV and Ozone in Batch Operation

The removal of TCEP, 1,4-dioxane, and chloramines for ozone/ peroxide was greater than the removals observed for UV/peroxide. These results are compared in Table 7-6, and suggest that ozone/peroxide may provide better removal of constituents of emerging concern than UV/peroxide.

Where ozone/peroxide did not perform as favorably was with NDMA, which was removed an average 0.6-log units during the Phase 2 testing. NDMA levels in the RO product averaged 15 ng/L and were less than 26 ng/L for 95 percent of the samples. As a result, the 0.6-log average NDMA reduction achieved by the ozone/peroxide system is more than sufficient to reduce NDMA levels to below the 10 ng/L notification level. While the ozone/peroxide system does not meet the minimum 1.2-log reduction goal for NDMA, it would provide for greater reduction of other contaminants, while maintaining NDMA levels below the current notification level.

Table 7-6: Comparison of Removal with UV/Peroxide and Ozone/Peroxide (Phase 2)

Parameter	UV/Peroxide [a]	Ozone Peroxide [a]
Chloramines (log reduction)	0.53	1.3
TCEP (log reduction)	0.75	1.4
NDMA (log reduction)	1.65	0.6
1,4-Dioxane (log reduction)	1.8	>3.0

Footnotes:

a. *Average of all Phase 2 data. Ozone dose averaged 9 mg/L.*

7.5 Comparison of UV/Peroxide and Ozone/Peroxide in Continuous Operation

During pilot testing both the UV/peroxide and ozone/peroxide systems were confirmed to effectively reduce concentrations of trace organic compounds and CECs in the RO product. In general, both systems destroyed contaminants and provided pristine-quality product water. While most compounds were not detectable in the RO product, Table 7-7 shows the removal by each AOP of organic compounds which were measured above detection limits in the RO product water. Data for the UV/peroxide system come from Phase 1 operation, when the UV system was operated continuously. Ozone/peroxide data are from Phase 3, when the ozone system was operated continuously.

Appendix H lists all water quality results for the AOP systems, identifying average values and number of samples for each monitoring location.

NDMA removal through the UV/peroxide system averaged greater than 90 percent, with concentrations below detection levels in the UV product. NDMA removal through the ozone/peroxide system averaged 55 percent, with concentrations in the ozone product averaging 5 ng/L, during the periods when the ozone dose exceeded 6 mg/L. At lower ozone doses, the NDMA removal was significantly less. These results confirm the findings from the Phase 2 testing, demonstrating that the notification level of 10 ng/L can be achieved using either AOP system, however, 1.2-log reduction could not be achieved without the use of UV.

Flame retardants, such as TCEP, TCPP, TDCPP are typically not well removed by AOP systems since they are resistant to the effects of oxidation, by design. These compounds remained above the detection level of 1 ng/L when UV/peroxide was used for oxidation, with concentrations reduced between 66 and 93 percent. It should be noted that these removals are significantly higher than are typically seen with UV/peroxide systems, due to the high residence time within the UV unit, when operated at 15 to 17 gpm. Phase 2 testing confirmed that greater than 1.4-log NDMA destruction could be achieved at a flow rate of 50 gpm through the reactor. While decreasing the flow rate to 15 gpm would be expected to significantly reduce reactor efficiency, the three-fold increase in residence time within the reactor would result in a much higher UV dose. It is therefore likely that the destruction of flame retardants seen during the pilot testing may be higher than destructions which will be achieved under full-scale operation.

TCEP removal using ozone/peroxide was 67 percent, which is identical to the removal seen with the UV/peroxide system at the high UV dose. TCPP removal was less than with the UV/peroxide system, however, TDCPP was removed to below the method reporting limit of 1 ng/L. It should be noted that all three flame retardants can have method reporting limits that range from 1 to 10 ng/L, depending on which laboratory is doing the testing. Weck Laboratories currently uses the lowest method reporting limit of 1 ng/L, however, other laboratories have suggested that such low levels cannot be reliably measured. If the reliable detection limit is assumed to be 10 ng/L rather than 1 ng/L, all three compounds would be measured as below detection levels for both AOP alternatives. In general, it appears that removal of flame retardants using ozone/peroxide was similar to the removals seen with UV/peroxide at the elevated UV dose.

Removal of N,N-Diethyl-meta-toluamide (DEET), gemfibrozil, sulfamethoxazole, and meprobamate was achieved to levels below the method reporting limits, making it difficult to compare the effectiveness of the AOP approaches at removing these compounds.

Table 7-7: Water Quality Comparison of UV/Peroxide and Ozone/Peroxide Under Continuous Operation

Constituent	UV/Peroxide Removal	Ozone/Peroxide Removal
	%	%
NDMA	>90	51
Total Chlorine	--	74
TCEP	67	67
TCPP	93	43
TDCPP	66	>28
TTHMs	--	37
DEET	>33	--
Gemfibrozil	>49	>12
Sulfamethoxazole	>52	>49
Meprobamate	>90	>41

Footnotes:

a. *Values taken from instances when AOP feed and AOP product samples were taken on the same day. They are not the removal between overall averages of AOP feed and AOP product water samples.*

b. *Values with a 'greater than' sign show that on average the AOP system reduced the constituent to below its detectable limit.*

c. *No value is shown for locations where no data is available, or concentrations in the RO permeate and AOP influent were below detection levels*

7.6 Conclusions

The pilot testing results support the conclusion that UV/peroxide is an effective method for removing trace organic compounds, which are only partially removed by the RO membranes. While most compounds were removed to below detection levels by the RO membranes, a few compounds, including NDMA, DEET, gemfibrozil, sulfamethoxazole, meprobamate, and three flame retardants (TCEP, TCPP, and TDCPP), were measured in the RO permeate in low concentrations, and were effectively reduced through UV/peroxide. In most cases these were removed to levels below detection limits, however, concentrations of the three flame retardants remained above the 1 ng/L method reporting limit. There is currently no consensus among commercial labs on the most appropriate reporting limit for these compounds, with reporting limits ranging from 1 to 10 ng/L. All three flame retardants would be considered below detection limits if a 10 ng/L limit were used. The results from the pilot testing demonstrated that UV/peroxide was effective at reducing NDMA by greater than 1.2-log units, reducing 1,4-dioxane by greater than 0.5-log, and meeting all regulatory requirements for groundwater recharge.

The Phase 2 pilot testing demonstrated that ozone/peroxide is promising for the removal of 1,4-dioxane and TCEP, two compounds with low hydroxyl radical rate constants that are difficult to oxidize compared with other constituents of emerging concern. 1,4-dioxane was removed at levels well in excess of the 0.5-log reduction requirement for groundwater recharge. Removal for 1,4-dioxane, TCEP, and chloramines was significantly better when using ozone/peroxide compared with UV/peroxide. Phase 3 testing confirmed the testing results from Phase 2, under continuous pilot operation. These results demonstrated that ozone/peroxide can potentially be used in place of UV/peroxide to meet all regulatory requirements with the exception of the requirement to provide 1.2-log NDMA reduction. In the event that the regulations are modified to relax or remove this requirement in the future, the use of ozone/peroxide could provide a benefit when compared with UV/peroxide, in terms of lower energy usage and greater removal of constituents of emerging concern.

8. Product Water Quality Results

This section summarizes the product water quality results for the entire pilot treatment system, comparing results to pilot goals and regulated limits and evaluating the impact of the treatment processes on unregulated organic compounds.

8.1 Pilot Testing Goals

Table 8-1 lists the pilot testing water quality goals identified in Section 2 along with testing results for the RO and advanced oxidation product water. Water quality goals were achieved during pilot testing, meeting anticipated regulatory limits for all of these key water quality parameters.

Table 8-1: Pilot Testing Primary Water Quality Goals

Constituent	Units	Source Water	RO Product	UV Product	UV Log Reduction	Ozone Product	Ozone Log Reduction	Regulated Limit
TOC	mg/L	8.9	0.29	-	-	-	-	< 0.5
Total Nitrogen	mg/L	9.3	1.6	-	-	-	-	< 5
NDMA	ng/L	15	15	ND	> 1.2	5	0.5	> 1.2-log
1,4-dioxane	µg/L	1.3	ND	ND	> 0.5	ND	> 0.5	>0.5-log
TTHM	µg/L	19	12.1	-	-	3.2	0.1	< 80
HAA5	µg/L	25	6.6	-	-	ND	-	< 60
Turbidity	NTU	1.1	0.1	-	-	-	-	< 0.2
Chloride	mg/L	114	14	-	-	-	-	< 100
TDS	mg/L	502	27	-	-	-	-	< 500

Footnotes:

a. *Constituent averages are from either the UV Effluent sample tap, the RO permeate tap or the AOP influent tap. Note that HAA5 results are from the RO permeate tap.*
b. *2008 Draft Groundwater Recharge Regulations, assumes recycled water contribution may be as high as 100%for TOC limit. 1.2-log reduction = 94%, 0.5-log reduction = 68%*
c. *Existing Title 22 Water Recycling Regulations*
d. *CDPH drinking water limits (primary and secondary MCLs)*

It should be noted that the data shown in Table 8-1 includes the entire pilot testing period, including a period between July and December 2010, when the RO membranes became damaged from exposure to free chlorine. Excluding the periods, the TDS in the RO product was half the concentration shown, with correspondingly lower levels for TOC, total nitrogen, and chloride. These results were listed previously in Table 7-4.

8.2 Regulated Compounds

All of the regulated compounds had average and maximum values in the product water below their regulatory limits, with the vast majority already below regulatory limits in the source water. The complete list of water quality results is shown in Table 8-2, showing average values for the pilot source water and before and after each unit process.

Pathogens

As discussed previously, *Giardia*, *Cryptosporidium*, coliform, and bacteriophage results confirmed the product water quality during the pilot, with all measurements returning non-detect results. *Giardia*, *Cryptosporidium*, and coliforms were removed in the microfiltration process, while coliphages were removed primarily in the reverse osmosis. Coliphage removal by the RO membranes exceeded 2-log units, however, it could not be confirmed whether the full 4-log removal required by Title 22 regulations was achieved entirely in the RO membranes, due to the limited concentrations in the source water. It is generally assumed that Title 22 virus removal credits will be achieved by the AOP system, rather than relying on the RO membranes for this removal. As a result, the removal of viruses by the AWP process could be considered in excess of 6-log units.

Disinfection Byproducts

All of the monitored disinfection byproducts (including TTHM, HAA5, Bromate, and NDMA) either remained below their MCLs or were non-detect in the product water, when UV/peroxide oxidation was used. NDMA levels in the ozone/peroxide product water averaged 5 ng/L, which is half of the current CDPH notification level, but above the detection limit. Bromate levels in the ozone product averaged 0.001 mg/L and never exceeded the 0.01 mg/L MCL during the testing.

8.3 Unregulated Compounds

Pharmaceuticals and Personal Care Products

The majority of monitored pharmaceuticals and personal care products were removed to levels below detectable limits by the RO membranes. Ten compounds remained in the RO product with concentrations at or above the laboratory method reporting limit (MRL). Removal of these compounds by the RO membranes was greater than 90 percent, however, the levels in the feed water were sufficient for low concentrations to remain detectable after the RO membranes. All of these compounds, with the exception of three flame retardants (TCEP, TCPP, and TDCPP), were removed to below detection levels by both the UV/peroxide and ozone/peroxide processes. Table 8-2 lists the ten compounds detected in the RO product. Also listed are concentrations for three of these compounds measured in State Project Water drinking water supplies in a 2010 study completed for the National Water Research Institute.

The total reduction of these flame retardants ranged from 2.2 to 3.1 log (99.3 to 99.9 percent), from the source water to the AOP product. The levels remaining in the RO product and AOP product are below method reporting limits for many laboratories, which range from 1 to 20 ng/L. It is not clear whether the concentrations are significant or what implications such low concentrations might have. TCEP concentrations measured in drinking water supplies from the State Project water were higher than the levels measure in the RO product, before oxidation, and the levels measured in the AOP product would be below the detection levels used by the Metropolitan Water District in the cited study (NWRI, 2010).

Table 8-2: Concentration of Pharmaceuticals and Personal Care Products Detected in the RO Product

Constituent	MRL[(a)] (ng/L)	Source (ng/L)	RO Product (ng/L)	UV Product (ng/L)	Ozone Product (ng/L)	State Project Water [(b)] (ng/L)
Atenolol	1	210	3	ND	ND	- [(c)]
Carbamazepine	1	224	2	ND	ND	3
DEET	1	224	1	ND	ND	<20
Meprobamate	1	788	6	ND	ND	-
Phenytoin	1	208	1	ND	ND	-
TCEP	1	337	6	5	2	7
TCPP	1	1,074	10	1	5	-
TDCPP	1	666	4	4	ND	-
Gemfibrozil	1	478	2	ND	ND	-
Sulfamethoxazole	1	2,200	2	ND	ND	-

Footnotes:

a. *MRL = Method Reporting Limit, as identified by Weck Laboratories*
b. *State Project Water numbers from Source, Fate, and Transport of Endocrine Disruptors, Pharmaceuticals, and Personal Care Products in Drinking Water Sources in California (NWRI, 2010)*
c. *Blanks shown where no information is available*

Table 8-3: Pilot Testing Water Quality Results (Average Values)

Parametera	Units	Source Watera	MF Filtratea	ROFa	ROPa	ROCa	AOPa Influent	UV Effluenta	Ozone Effluenta	MRLa,g	MCLa	Secondary MCLa	Notification Level
Regulated Compounds													
22 CCR §64431 - Inorganic Chemicals													
Aluminum	mg/L	ND	-	ND	ND	ND	-	-	ND	0.05	1	0.2	-
Antimony	mg/L	ND	-	-	ND	-	-	-	ND	0.006	0.006	-	-
Arsenic	mg/L	ND	-	0.002	ND	0.01	-	-	ND	0.002	0.01	-	-
Asbestos	MFL*	ND	-	-	0.58	-	-	-	-	0.2	7	-	-
Barium	mg/L	ND	-	ND	ND	ND	-	-	-	0.1	1	-	-
Beryllium	mg/L	ND	-	ND	ND	ND	-	-	ND	0.001	0.004	-	-
Cadmium	mg/L	ND	-	ND	ND	ND	-	-	ND	0.001	0.005	-	-
Chromium, Total	mg/L	ND	-	-	ND	-	-	-	ND	0.01	0.05	-	-
Cyanide	mg/L	ND	-	-	ND	-	-	-	-	0.1	0.15	-	-
Fluoride, Total	mg/L	0.76	0.73	0.81	ND	4.8	-	-	ND	0.1	2	-	-
Mercury (inorganic)	mg/L	ND	-	-	ND	-	-	-	-	0.001	0.002	-	-
Nickel	mg/L	ND	-	-	ND	-	-	-	ND	0.01	0.1	-	-
Nitrate (as NO3)	mg/L	28	29	34	4.4	170	4	4.6	3.4	2	45	-	-
Nitrite (as N)	mg/L	ND	ND	ND	ND	1	0.046	ND	ND	0.4	1	-	-
Nitrate + Nitrite (as N)	mg/L	<6.5	<6.6	<7.5	1	39	0.95	1.0	0.81	-	10	-	-
Perchlorate	mg/L	ND	-	ND	ND	-	-	ND	-	0.004	0.006	-	-
Selenium	mg/L	ND	-	-	ND	-	-	-	ND	0.005	0.05	-	-
Thallium	mg/L	ND	-	-	-	-	-	-	-	0.001	0.002	-	-

Parameter[a]	Units	Source Water[a]	MF Filtrate[a]	ROF[a]	ROP[a]	ROC[a]	AOP[a] Influent	UV Effluent[a]	Ozone Effluent[a]	MRL[a,g]	MCL[a]	Secondary MCL[a]	Notification Level
22 CCR §64672.3 - Copper and Lead													
Copper	mg/L	ND	-	-	ND	ND	-	-	-	0.05	1.3	1	-
Lead	mg/L	ND	-	-	ND	ND	-	-	-	0.005	0.015	-	-
22 CCR §64441 and §64443 - Radioactivity													
Gross alpha particle activity	pCi/L	ND	-	-	ND	-	-	-	ND	3	15	-	-
Gross beta particle activity	pCi/L	13	-	-	ND	-	-	-	ND	4	50	-	-
Radium-226	pCi/L	ND	-	-	-	-	-	-	-	1	--	-	-
Radium-228	pCi/L	ND	-	-	-	-	-	-	-	1	--	-	-
Radium-226 + Radium-228	pCi/L	ND	-	-	-	-	-	-	-	-	5	-	-
Strontium-90	pCi/L	ND	-	-	-	-	-	-	-	2	8	-	-
Tritium	pCi/L	ND	-	-	-	-	-	-	-	1,000	20,000	-	-
Uranium (Activity)	pCi/L	1.4	-	-	ND	-	-	-	ND	1	20	-	-
Uranium (Mass)	µg/L	2.1	-	-	ND	-	-	-	ND	0.6	30	-	-
22 CCR §64444 - Organic Chemicals													
(a) Volatile Organic Chemicals (VOCs)													
Benzene	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.001	-	-
Carbon tetrachloride	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.0005	-	-
1,2-Dichlorobenzene (o-DCB)	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.6	-	-
1,4-Dichlorobenzene (p-DCB)	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.005	-	-
1,1-Dichloroethane (1,1-DCA)	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.005	-	-
1,2-Dichloroethane (1,2-DCA)	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.0005	-	-
1,1-Dichloroethene (DCE)	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.006	-	-
cis-1,2-Dichloroethene (cis-1,2-Dichloroethylene)	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.006	-	-

Parametera	Units	Source Watera	MF Filtratea	ROFa	ROPa	ROCa	AOPa Influent	UV Effluenta	Ozone Effluenta	MRLa,g	MCLa	Secondary MCLa	Notification Level
trans-1,2-Dichloroethene (trans-1,2-Dichloroethylene)	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.01	-	-
Dichloromethane (Methylene chloride)	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.005	-	-
1,2-Dichloropropane	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.005	-	-
cis-1,3-Dichloropropene	mg/L	ND	-	-	-	-	-	-	-	5E-07	0.0005d	-	-
trans-1,3-Dichloropropene	mg/L	ND	-	-	-	-	-	-	-	5E-07	0.0005d	-	-
Ethylbenzene	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.3	-	-
Methyl tertiary butyl ether (MTBE)	mg/L	ND	-	-	-	-	-	-	-	0.003	0.013	0.005	-
Monochlorobenzene	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.07	-	-
Styrene	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.1	-	-
1,1,2,2-Tetrachloroethane	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.001	-	-
Tetrachloroethylene (PCE)	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.005	-	-
Toluene	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.15	-	-
1,2,4-Trichlorobenzene	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.005	-	-
1,1,1-Trichloroethane (1,1,1-TCA)	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.2	-	-
1,1,2-Trichloroethane (1,1,2-TCA)	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.005	-	-
Trichloroethylene (TCE)	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.005	-	-
Trichlorofluoromethane (Freon 11)	mg/L	ND	-	-	-	-	-	-	-	0.005	0.15	-	-
1,1,2-Trichloro-1,2,2-Trifluoroethane (Freon 113)	mg/L	ND	-	-	-	-	-	-	-	0.01	1.2	-	-
Vinyl chloride	mg/L	ND	-	-	-	-	-	-	-	0.0005	0.0005	-	-
Xylenes	mg/L	ND	-	-	-	-	-	-	-	0.0005	1.75	-	-
(b) Non-Volatile Synthetic Organic Chemicals (SOCs)													
Alachlor	mg/L	ND	ND	ND	ND	-	ND	-	-	0.001	0.002	-	-
Atrazine	mg/L	ND	ND	ND	ND	-	ND	-	-	0.0005	0.001	-	-

Parametera	Units	Source Watera	MF Filtratea	ROFa	ROPa	ROCa	AOPa Influent	UV Effluenta	Ozone Effluenta	MRLa,g	MCLa	Secondary MCLa	Notification Level
Bentazon	mg/L	ND	-	-	ND	-	ND	-	-	0.002	0.018	-	-
Benzo(a)pyrene	mg/L	ND	ND	ND	ND	-	ND	-	-	0.0001	0.0002	-	-
Carbofuran	mg/L	ND	-	ND	ND	-	-	ND	ND	0.005	0.018	-	-
Chlordane	mg/L	ND	-	ND	-	-	ND	-	ND	0.0001	0.0001	-	-
Dalapon	mg/L	ND	-	-	ND	-	ND	-	-	0.01	0.2	-	-
1,2-Dibromo-3-chloropropane (DBCP)	mg/L	-	-	ND	ND	-	-	-	-	0.00001	0.0002	-	-
2,4-Dichlorophenoxyacetic acid (2,4-D)	mg/L	ND	-	-	ND	-	ND	-	-	0.01	0.07	-	-
Di(2-ethylhexyl) adipate	mg/L	ND	ND	ND	ND	-	ND	-	-	0.005	0.4	-	-
Di(2-ethylhexyl)phthalate (DEHP)	mg/L	ND	ND	ND	ND	-	ND	-	-	0.003	0.004	-	-
Dinoseb	mg/L	ND	-	-	ND	-	ND	-	-	0.002	0.007	-	-
Diquat	mg/L	ND	-	ND	ND	-	-	ND	ND	0.004	0.02	-	-
Endrin	mg/L	ND	-	ND	-	-	ND	-	ND	0.0001	0.002	-	-
Endothall	mg/L	ND	-	ND	ND	-	-	ND	ND	0.045	0.1	-	-
Ethylene dibromide (EDB)	mg/L	-	-	ND	ND	-	-	-	-	0.00002	0.00005	-	-
Glyphosate	mg/L	ND	-	ND	ND	-	-	ND	ND	0.00001	0.7	-	-
Heptachlor	mg/L	ND	-	ND	-	-	ND	-	ND	0.00001	0.00001	-	-
Heptachlor epoxide	mg/L	ND	-	ND	-	-	ND	-	ND	0.00001	0.00001	-	-
Hexachlorobenzene	mg/L	ND	-	ND	-	-	ND	-	ND	0.0005	0.001	-	-
Hexachlorocyclopentadiene	mg/L	ND	-	ND	-	-	ND	-	ND	0.001	0.05	-	-
Lindane	mg/L	ND	-	ND	-	-	ND	-	ND	0.0002	0.0002	-	-
Methoxychlor	mg/L	ND	-	ND	-	-	ND	-	ND	0.01	0.03	-	-
Molinate	mg/L	ND	ND	ND	ND	-	ND	-	-	0.002	0.02	-	-
Oxamyl	mg/L	ND	-	ND	ND	-	-	ND	ND	0.02	0.05	-	-

Parametera	Units	Source Watera	MF Filtratea	ROFa	ROPa	ROCa	AOPa Influent	UV Effluenta	Ozone Effluenta	MRLa,g	MCLa	Secondary MCLa	Notification Level
Pentachlorophenol	mg/L	ND	-	-	ND	-	ND	-	-	0.0002	0.001	-	-
Picloram	mg/L	ND	-	-	ND	-	ND	-	-	0.001	0.5	-	-
Polychlorinated Biphenyls (PCB)	mg/L	ND	-	ND	-	-	ND	-	ND	0.0005	0.0005	-	-
Simazine	mg/L	ND	ND	ND	ND	-	ND	-	-	0.004	0.004	-	-
2,4,5-TP (Silvex)	mg/L	ND	-	-	ND	-	ND	-	-	0.001	0.05	-	-
2,3,7,8-TCDD (dioxin)	mg/L	ND	-	ND	ND	-	-	ND	ND	5E-09	3x10-8	-	-
Thiobencarb	mg/L	ND	ND	ND	ND	-	ND	-	-	0.001	0.07	0.001	-
Toxaphene	mg/L	ND	-	-	-	-	-	-	-	0.001	0.003	-	-
22 CCR §64533 - Disinfection Byproducts													
Total Residual Chlorine	mg/L	0.41	2.4	2.3	2.2	-	1.9	0.77	0.58	0.05	-	-	-
Total Trihalomethanes (TTHM)	mg/L	0.003	-	0.019	0.012	-	0.016	-	0.0032	0.0005	0.08	-	-
Bromodichloromethane	mg/L	ND	-	0.005	0.0032	-	0.0038	-	0.0011	0.0001	--	-	-
Bromoform	mg/L	ND	-	ND	ND	-	ND	-	ND	0.0001	--	-	-
Chloroform	mg/L	0.0017	-	0.01	0.0076	-	0.012	-	0.0019	0.0001	--	-	-
Dibromochloromethane	mg/L	ND	-	0.0026	0.0011	-	ND	-	ND	0.0001	--	-	-
Bromate	mg/L	ND	-	-	ND	-	-	-	ND	0.005	0.01	-	-
Chlorite	mg/L	ND	-	-	ND	-	-	-	ND	0.02	1	-	-
Total haloacetic acids (HAA5)	mg/L	0.0063	-	0.025	0.0066	-	0.0014	-	ND	0.001	0.06d	-	-
Bromochloroacetic acid (bcaa)	mg/L	ND	-	0.0055	-	-	ND	-	-	0.001	-	-	-
Dibromoacetic acid (dbaa)	mg/L	ND	-	ND	ND	-	ND	-	ND	0.001	-	-	-
Dechloroacetic acid (dcaa)	mg/L	0.0032	-	0.014	0.0034	-	0.0014	-	ND	0.001	-	-	-
Monobromoacetic acid (mbaa)	mg/L	ND	-	ND	ND	-	ND	-	ND	0.002	-	-	-
Monochloroacetic acid (mcaa)	mg/L	ND	-	ND	ND	-	ND	-	ND	0.001	-	-	-
Trichloroacetic acid (tcaa)	mg/L	ND	-	0.0099	ND	-	ND	-	ND	0.005	-	-	-

Parameter[a]	Units	Source Water[a]	MF Filtrate[a]	ROF[a]	ROP[a]	ROC[a]	AOP[a] Influent	UV Effluent[a]	Ozone Effluent[a]	MRL[a,g]	MCL[a]	Secondary MCL[a]	Notification Level
Compounds with Only Secondary MCLs													
Chloride	mg/L	ND	-	110	14	650	-	-	-	0.5	-	250[e]	-
Color	Pt-Co	44	23	39	19	150	ND	15	-	3	-	15	-
Iron	mg/L	ND	-	ND	ND	ND	-	-	-	10	-	0.3	-
Manganese	mg/L	0.02	-	0.015	ND	0.12	-	-	-	5	-	0.05	0.5
Silver	mg/L	ND	-	ND	ND	-	-	ND	ND	0.005	-	0.1	-
Specific Conductance	µS/cm	830	-	880	43	4300	37	50	72	2	-	900[e]	-
Sulfate	mg/L	-	98	97	0.68	840	-	-	-	0.5	-	250[e]	-
Total Dissolved Solids (TDS)	mg/L	500	480	500	27	3500	26	29	44	10	-	500[e]	-
Turbidity	NTU	1.1	0.2	0.17	0.10	0.39	0.10	-	0.11	0.10	-	5	-
Zinc	mg/L	0.011	-	-	ND	-	-	-	ND	0.005	-	5	-
Non-Regulated Compounds													
Compounds with Notification Levels													
Boron	µg/L	560	-	890	420	2300	-	-	-	10	-	-	1000
n-Butylbenzene	µg/L	ND	-	-	-	-	-	-	-	0.5	-	-	260
sec-Butylbenzene	µg/L	ND	-	-	-	-	-	-	-	0.5	-	-	260
tert-Butylbenzene	µg/L	ND	-	-	-	-	-	-	-	0.5	-	-	260
Chlorate	µg/L	63	-	-	ND	-	-	-	85	10	-	-	800
2-Chlorotoluene	µg/L	ND	-	-	-	-	-	-	-	0.5	-	-	140
4-Chlorotoluene	µg/L	ND	-	-	-	-	-	-	-	0.5	-	-	140
Dichlorodifluoromethane (Freon 12)	µg/L	ND	-	-	-	-	-	-	-	0.5	-	-	1000
1,4- Dioxane	µg/L	1.3	1.3	-	ND	-	120[h]	1.9[h]	ND	0.5	-	-	3

Parametera	Units	Source Watera	MF Filtratea	ROFa	ROPa	ROCa	AOPa Influent	UV Effluenta	Ozone Effluenta	MRLa,g	MCLa	Secondary MCLa	Notification Level
HMX	µg/L	ND	-	-	-	-	-	-	-	1.0	-	-	350
Isopropylbenzene	µg/L	ND	-	-	-	-	-	-	-	0.5	-	-	770
Methyl Isobutyl Ketone (MIBK)	µg/L	ND	-	-	-	-	-	-	-	5	-	-	120
Naphthalene	µg/L	ND	-	-	-	-	-	-	-	0.5	-	-	17
N-Nitrosodiethylamine (NDEA)	ng/L	ND	-	-	ND	-	-	-	ND	2	-	-	10
N-Nitrosodimethylamine (NDMA)	ng/L	22	25	25	15	-	37	4.2h	26h	10	-	-	10
N-Nitrosodi-n-propylamine (NDPA)	ng/L	ND	-	-	ND	-	-	-	ND	2	-	-	10
Propachlor	µg/L	ND	-	-	-	-	-	-	-	0.05	-	-	90
n-Propylbenzene	µg/L	ND	-	-	-	-	-	-	-	0.5	-	-	260
RDX	µg/L	ND	-	-	-	-	-	-	-	1.0	-	-	0.3
Tertiary Butyl Alcohol (TBA)	µg/L	ND	-	-	-	-	-	-	-	2	-	-	12
1,2,3-Trichloropropane	µg/L	ND	-	-	-	-	-	-	-	0.5	-	-	0.005
1,2,4-Trimethylbenzene	µg/L	ND	-	-	-	-	-	-	-	0.5	-	-	330
1,3,5-Trimethylbenzene	µg/L	ND	-	-	-	-	-	-	-	0.5	-	-	330
Trinitrotoluene (TNT)	µg/L	ND	-	-	-	-	-	-	-	1.0	-	-	1.0
Vanadium	mg/L	ND	-	-	ND	-	-	-	ND	0.005	-	-	0.05
Inorganic Compounds													
Ammonia as N	mg/L	1.2	1.4	2.2	0.49	7.5	-	0.11	0.1	0.1	-	-	-
Bromide	µg/L	160	-	ND	ND	-	-	-	ND	10	-	-	-
Calcium	mg/L	40	-	42	0.31	330	0.53	-	-	0.1	-	-	-
Dissolved Oxygen	mg/L	4.3	48	-	7.7	27	5.8	-	-	1	-	-	-
Free Residual Chlorine	mg/L	0.088	0.76	0.2	-	7.2	-	-	-	0.05	-	-	-
Molybdenum	mg/L	ND	-	-	ND	-	-	-	ND	0.1	-	-	-
Strontium	µg/L	230	-	270	2.1	2000	4.3	-	ND	2	-	-	-

Parametera	Units	Source Watera	MF Filtratea	ROFa	ROPa	ROCa	AOPa Influent	UV Effluenta	Ozone Effluenta	MRLa,g	MCLa	Secondary MCLa	Notification Level
Total Inorganic Nitrogen	mg/L	7.9	8.4	8.9	1.6	49	-	1.4	0.48	-	-	-	-
Orthophosphate, as P	µg/L	63	93	90	ND	490	ND	ND	-	2	-	-	-
Total phosphorous, as P	µg/L	180	130	90	ND	1500	-	-	-	10	-	-	-
Potassium	mg/L	14	-	14	1.9	100	-	-	-	0.1	-	-	-
Silica	mg/L	20	-	10	1.3	87	2.7	-	-	0.04	-	-	-
Sodium	mg/L	83	-	100	7.1	680	17	-	-	0.5	-	-	-
Pathogens and Microbial Contaminants													
Cryptosporidium	count/L	1.6	ND	-	-	-	-	-	-	0.1	-	-	-
Giardia	count/L	62	ND	-	-	-	-	-	-	0.1	-	-	-
Indigenous Coliphage (Bacteriophage, Male Specific)	pfu/100mL	250	ND	-	-	-	-	-	-	0	-	-	-
Indigenous Coliphage (Bacteriophage, Somatic)	pfu/100mL	680	ND	-	-	-	-	-	-	0	-	-	-
Enterovirus (EPA R-95/178)	MPN/100L	ND	-	-	-	-	-	-	-	10	-	-	-
E. Coli	N/A	Present	ND	-	ND	-	-	-	-	1	-	-	-
Total Coliform	N/A	Present	ND	-	ND	-	-	-	-	1	-	-	-
Organic Compounds													
1,2-Dibromo-3-chloropropane	µg/L	-	-	-	ND	-	-	-	-	0.01	-	-	-
N-Nitrosodi-n-butylamine	ng/L	ND	-	-	ND	-	-	-	ND	2	-	-	-
N-Nitrosomethylethylamine	ng/L	ND	-	-	ND	-	-	-	ND	2	-	-	-
N-Nitrosomorpholine	ng/L	10	-	-	ND	-	-	-	ND	2	-	-	-
N-Nitrosopiperidine	ng/L	2.2	-	-	ND	-	-	-	ND	2	-	-	-
N-Nitrosopyrrolidine	ng/L	ND	-	-	ND	-	-	-	ND	2	-	-	-
TKN	mg/L	1.8	1.8	1.5	0.45	11	0.38	0.15	0.11	0.1	-	-	-
TOC	mg/L	8.9	8	8.4	ND	46	ND	ND	ND	0.3	-	-	-
Total Organic Halogens (TOX)	µg/L	190	-	71	28	-	ND	-	-	20	-	-	-

Parametera	Units	Source Watera	MF Filtratea	ROFa	ROPa	ROCa	AOPa Influent	UV Effluenta	Ozone Effluenta	MRLa,g	MCLa	Secondary MCLa	Notification Level
Chlorinated Acid Herbicides													
2,4,5-T	µg/L	ND	-	-	ND	-	ND	-	-	0.2	-	-	-
2,4-DB	µg/L	ND	-	-	ND	-	ND	-	-	2	-	-	-
3,5-Dichlorobenzoic acid	µg/L	ND	-	-	ND	-	ND	-	-	1	-	-	-
Acifluirfen	µg/L	ND	-	-	ND	-	ND	-	-	0.4	-	-	-
DCPA	µg/L	ND	-	-	ND	-	ND	-	-	0.1	-	-	-
Dicamba	µg/L	ND	-	-	ND	-	ND	-	-	0.6	-	-	-
Dichloroprop	µg/L	ND	-	-	ND	-	ND	-	-	0.3	-	-	-
Pharmaceuticals													
Acetaminophen	ng/l	81	-	-	ND	-	-	ND	ND	20	-	-	-
Amoxicillin	ng/l	1200	-	-	ND	-	-	ND	ND	10	-	-	-
Atenolol	ng/l	210	-	-	4.4	-	-	ND	ND	1	-	-	-
Atorvastatin	ng/l	250	-	-	ND	-	-	ND	ND	1	-	-	-
Azithromycin	ng/l	1500	-	-	ND	-	-	ND	ND	10	-	-	-
Caffeine	ng/l	13	-	-	ND	-	-	ND	ND	1	-	-	-
Carbamazepine	ng/l	220	-	-	1.6	-	-	ND	ND	1	-	-	-
Ciprofloxacin	ng/l	1700	-	-	ND	-	-	ND	ND	5	-	-	-
Cotinine	ng/l	19	-	-	ND	-	-	ND	ND	1	-	-	-
DEET	ng/l	220	-	-	ND	-	-	ND	ND	1	-	-	-
Diazepam	ng/l	3.1	-	-	ND	-	-	ND	ND	1	-	-	-
Fluoxetine	ng/l	6.9	-	-	ND	-	-	ND	ND	1	-	-	-
Meprobamate	ng/l	790	-	-	ND	-	-	ND	ND	1	-	-	-
Methadone	ng/l	40	-	-	ND	-	-	ND	ND	1	-	-	-
Phenytoin	ng/l	210	-	-	1.4	-	-	ND	ND	1	-	-	-

Parametera	Units	Source Watera	MF Filtratea	ROFa	ROPa	ROCa	AOPa Influent	UV Effluenta	Ozone Effluenta	MRLa,g	MCLa	Secondary MCLa	Notification Level
Primidone	ng/l	190	-	-	ND	-	-	ND	ND	1	-	-	-
Sulfamethoxazole	ng/l	2200	-	-	3.7	-	-	ND	ND	1	-	-	-
TCEP	ng/L	340	-	300	6.2	-	11	5.2	1.8	1	-	-	-
TCPP	ng/l	1100	-	-	3.9	-	-	1.7	7.3	1	-	-	-
TDCPP	ng/l	670	-	-	2.9	-	-	4.1	ND	1	-	-	-
Trimethoprim	ng/l	640	-	-	4.1	-	-	ND	ND	1	-	-	-
17a-Ethynylestradiol	ng/L	ND	-	-	ND	-	-	ND	ND	10	-	-	-
17-Beta-Estradiol	ng/L	ND	-	-	ND	-	-	ND	ND	10	-	-	-
Estrone	ng/L	11	-	-	ND	-	-	ND	ND	10	-	-	-
Progesterone	ng/L	ND	-	-	ND	-	-	ND	ND	10	-	-	-
Testosterone	ng/L	ND	-	-	ND	-	-	ND	ND	10	-	-	-
Bisphenol A	ng/L	ND	-	-	ND	-	-	ND	ND	20	-	-	-
Gemfibrozil	ng/L	480	-	-	ND	-	-	ND	ND	10	-	-	-
Ibuprofen	ng/L	ND	-	-	ND	-	-	ND	ND	10	-	-	-
Iopromide	ng/L	ND	-	-	ND	-	-	ND	ND	50	-	-	-
Naproxen	ng/L	250	-	-	ND	-	-	ND	ND	10	-	-	-
Salicylic Acid	ng/L	ND	-	-	ND	-	-	ND	ND	500	-	-	-
Triclosan	ng/L	190	-	-	ND	-	-	ND	ND	20	-	-	-
Quinoline	ng/L	ND	-	-	-	-	-	ND	ND	10	-	-	-
Sucralose	ng/L	6200	-	-	-	-	-	ND	ND	50	-	-	-
Regulated and 507 Compounds													
Bromacil	µg/L	ND	ND	ND	ND	-	ND	-	-	1.0	-	-	-
Butachlor	µg/L	ND	ND	ND	ND	-	ND	-	-	0.20	-	-	-
Captan	µg/L	ND	ND	ND	ND	-	ND	-	-	1.0	-	-	-

Parameter[a]	Units	Source Water[a]	MF Filtrate[a]	ROF[a]	ROP[a]	ROC[a]	AOP[a] Influent	UV Effluent[a]	Ozone Effluent[a]	MRL[a,g]	MCL[a]	Secondary MCL[a]	Notification Level
Chloropropham	µg/L	ND	ND	ND	ND	-	ND	-	-	0.10	-	-	-
Cyanazine	µg/L	ND	ND	ND	ND	-	ND	-	-	0.10	-	-	-
Diazinon	µg/L	ND	ND	ND	ND	-	ND	-	-	0.10	-	-	-
Dimethoate	µg/L	ND	ND	ND	ND	-	ND	-	-	0.20	-	-	-
Diphenamid	µg/L	ND	ND	ND	ND	-	ND	-	-	0.10	-	-	-
Disulfoton	µg/L	ND	ND	ND	ND	-	ND	-	-	0.10	-	-	-
EPTC	µg/L	ND	ND	ND	ND	-	ND	-	-	1.0	-	-	-
Metolachlor	µg/L	ND	ND	ND	ND	-	ND	-	-	0.10	-	-	-
Metribuzin	µg/L	ND	ND	ND	ND	-	ND	-	-	0.10	-	-	-
Prometon	µg/L	ND	ND	ND	ND	-	ND	-	-	0.2	-	-	-
Prometryn	µg/L	ND	ND	ND	ND	-	ND	-	-	0.1	-	-	-
Terbacil	µg/L	ND	ND	ND	ND	-	ND	-	-	2	-	-	-
Trithion	µg/L	ND	ND	ND	ND	-	ND	-	-	0.1	-	-	-
508 Compounds													
4,4'-DDD	µg/L	ND	-	ND	-	-	-	-	ND	0.01	-	-	-
4,4'-DDE	µg/L	ND	-	ND	-	-	-	-	ND	0.01	-	-	-
4,4'-DDT	µg/L	ND	-	ND	-	-	-	-	ND	0.01	-	-	-
Aldrin	µg/L	ND	-	ND	-	-	-	-	ND	0.01	-	-	-
alpha-BHC	µg/L	ND	-	ND	-	-	-	-	ND	0.01	-	-	-
Aroclor 1016	µg/L	ND	-	ND	-	-	-	-	ND	0.1	-	-	-
Aroclor 1221	µg/L	ND	-	ND	-	-	-	-	ND	0.1	-	-	-
Aroclor 1232	µg/L	ND	-	ND	-	-	-	-	ND	0.1	-	-	-
Areclor 1242	µg/L	ND	-	ND	-	-	-	-	ND	0.1	-	-	-
Aroclor 1248	µg/L	ND	-	ND	-	-	-	-	ND	0.1	-	-	-

Parameter[a]	Units	Source Water[a]	MF Filtrate[a]	ROF[a]	ROP[a]	ROC[a]	AOP[a] Influent	UV Effluent[a]	Ozone Effluent[a]	MRL[a,g]	MCL[a]	Secondary MCL[a]	Notification Level
Aroclor 1254	µg/L	ND	-	ND	-	-	-	-	ND	0.1	-	-	-
Aroclor 1260	µg/L	ND	-	ND	-	-	-	-	ND	0.1	-	-	-
beta-BHC	µg/L	ND	-	ND	-	-	-	-	ND	0.01	-	-	-
Chlorothalonil	µg/L	ND	-	ND	-	-	-	-	ND	0.05	-	-	-
delta-BHC	µg/L	ND	-	ND	-	-	-	-	ND	0.01	-	-	-
Dieldrin	µg/L	ND	-	ND	-	-	-	-	ND	0.01	-	-	-
Endosulfan I	µg/L	ND	-	ND	-	-	-	-	ND	0.01	-	-	-
Endosulfan II	µg/L	ND	-	ND	-	-	-	-	ND	0.01	-	-	-
Endosulfan sulfate	µg/L	ND	-	ND	-	-	-	-	ND	0.01	-	-	-
Endrin aldehyde	µg/L	ND	-	ND	-	-	-	-	ND	0.01	-	-	-
Trifluralin	µg/L	ND	-	ND	-	-	-	-	ND	0.01	-	-	-
524.2 Compounds													
1,1,1,2-Tetrachloroethane	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-
1,1-Dichloropropene	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-
1,3-Dichloropropane	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-
2,2-Dichloropropane	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-
2-Butanone	µg/L	ND	-	ND	-	-	-	-	-	5	-	-	-
2-Chloroethyl vinyl ether	µg/L	ND	-	ND	-	-	-	-	-	1	-	-	-
2-Hexanone	µg/L	ND	-	ND	-	-	-	-	-	5	-	-	-
4-Methyl-2-pentanone	µg/L	ND	-	ND	-	-	-	-	-	5	-	-	-
Bromobenzene	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-
Bromochloromethane	µg/L	ND	-	ND	-	-	ND	-	-	0.5	-	-	-
Bromomethane	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-
Chloroethane	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-

Parametera	Units	Source Watera	MF Filtratea	ROFa	ROPa	ROCa	AOPa Influent	UV Effluenta	Ozone Effluenta	MRLa,g	MCLa	Secondary MCLa	Notification Level
Chloromethane	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-
Dibromomethane	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-
Di-isopropyl ether	µg/L	ND	-	ND	-	-	-	-	-	3	-	-	-
Ethyl tert-butyl ether	µg/L	ND	-	ND	-	-	-	-	-	3	-	-	-
Hexachlorobutadient	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-
m,p-Xylene	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-
m-Dichlorobenzene	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-
o-Xylene	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-
p-Isopropyltoluene	µg/L	ND	-	ND	-	-	-	-	-	0.5	-	-	-
Tert-amyl methyl ether	µg/L	ND	-	ND	-	-	-	-	-	3	-	-	-
Carbamates and Urea Pesticides													
3-Hydroxycarbofuran	µg/L	ND	-	ND	ND	-	-	ND	ND	5	-	-	-
Aldicarb	µg/L	ND	-	ND	ND	-	-	ND	ND	2	-	-	-
Aldicarb sulfone	µg/L	ND	-	ND	ND	-	-	ND	ND	2	-	-	-
Carbaryl	µg/L	ND	-	ND	ND	-	-	ND	ND	2	-	-	-
Methiocarb	µg/L	ND	-	ND	ND	-	-	ND	ND	5	-	-	-
Methomyl	µg/L	ND	-	ND	ND	-	-	ND	ND	3	-	-	-
Propoxur (Baygon)	µg/L	ND	-	ND	ND	-	-	ND	ND	2	-	-	-
Miscellaneous													
Alkalinity as CaCO3	mg/L	150	140	140	7.5	750	7.2	6.8	25	2	-	-	-
C	C	25	24	25	25	25	26	26	25	-	-	-	-
pH	N/A	7.1	7.3	7.1	6.3	7.8	6.4	6.3	7.6	-	-	-	-
Oil and grease	mg/L	ND	ND	-	-	-	-	-	-	5	-	-	-
ORP	mV	250	510	450	570	-	120	23	280	-	-	-	-

Parameter[a]	Units	Source Water[a]	MF Filtrate[a]	ROF[a]	ROP[a]	ROC[a]	AOP[a] Influent	UV Effluent[a]	Ozone Effluent[a]	MRL[a,g]	MCL[a]	Secondary MCL[a]	Notification Level
SDI	N/A	3.4	1.2	2	-	-	-	-	-	-	-	-	-
UV 254	cm-1	0.15	0.14	0.12	0.016	-	0.014	ND	0.011	0.009	-	-	-
UV Intensity	mW/cm2	-	-	6.6	6.6	-	7.2	-	-	-	-	-	-
Hydrazine	µg/L	ND	-	ND	ND	-	-	ND	ND	1.0	-	-	-
PFOS	ng/L	9.7	-	-	ND	-	-	-	ND	5	-	-	-
PFOA	ng/L	22	-	-	ND	-	-	-	ND	5	-	-	-

Footnotes:

a. *All values are composite averages over the testing duration. The following acronyms are used: Microfiltration (MF), Reverse Osmosis Feed (ROF), Reverse Osmosis Permeate (ROP), Reverse Osmosis Concentrate (ROC), Advanced Oxidation Process (AOP), Ultraviolet (UV), Method Reporting Limit (MRL), Maximum Contaminant Limit (MCL).*

b. *MFL = million fibers per liter, with fiber length > 10 microns.*

c. *ND = Not Detected, meaning that the average of all values measured for a given parameter since the beginning of testing was below the MRL.*

d. *This MCL represents a summation of several compounds which do not individually have MCLs. The non-regulated compounds are listed adjacent to this parameter.*

e. *MCLs listed are ambient levels, not upper level MCLs.*

f. *Note that some values in this table may differ from other locations in this report. The reason for this is that this table shows all data for a specific parameter at a given sample location. In the analysis of this report, some samples were not included since they did not have a corresponding data point to compare against. For example, if a section of the report describes removal through the ozone system, then any data that did not have sample results for both upstream and downstream of the ozone system were not included.*

g. *Where available, the CDPH detection limit for the purpose of reporting (DLR) is shown instead of the laboratory MRL.*

h. *This value is not representative of typical testing conditions. In the case of 1,4- Dioxane in the AOP Influent a solution of 1,4-Dioxane was batch dosed for specific testing. For the NDMA in the UV effluent, this value includes data obtained when running using tertiary effluent after chloramination, which had much higher initial NDMA values. The NDMA in the ozone effluent value includes results from when samples were taken with minimal ozone doses.*

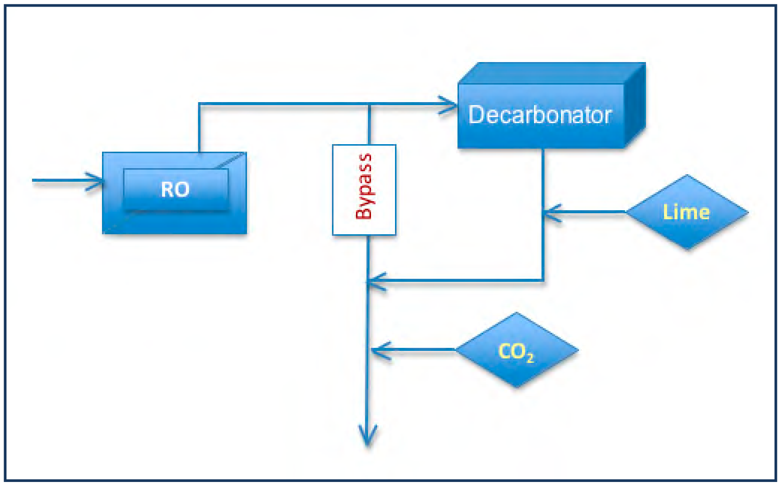
8.4 Product Water Stabilization

The objective of the product water stabilization bench scale evaluation was to identify design parameters for the stabilization of RO product water prior to recharge at the spreading grounds.

8.4.1 Desktop Evaluation

The post treatment approach was evaluated with a desktop model. The model capabilities include evaluation of a decarbonator for treatment of a fraction of the RO product water, the ability to add lime to meet a target Langelier Saturation Index (LSI), and the ability to trim with carbon dioxide to meet a desired pH target in the treated water. The reason for the decarbonator upstream of lime addition is to remove free carbon dioxide from the RO product water prior to adding lime, otherwise as lime is added, calcium carbonate will form and the turbidity of the lime-treated water may be problematic. The reason for the ability to trim with carbon dioxide downstream of the lime addition is that in achieving a target LSI of 0.06 for a given water, the pH may exceed a reasonable target for water treatment. The lime-water should be added to the stream that is treated by the decarbonator prior to blending with the fraction of the water that is not fed to the decarbonator. A process flow diagram is shown on **Figure 8-1**.

Figure 8-1: Process Flow Diagram for Potential Post Treatment System



The desktop model calculations used the following pH and LSI targets:

- LSI of 0.06
- pH < 8.5

It is recommended that 25 percent of the RO product water stream would be fed to the decarbonator to prevent turbidity problems when the lime is dosed. By adding the lime to the decarbonator outlet stream prior to blending with the decarbonator bypass water, problems with calcium carbonate scaling upon lime addition can be avoided. The lime-saturated water should be vigorously mixed with the decarbonator outlet stream prior to blending with the decarbonator bypass water; problems with calcium carbonate scaling upon lime addition can be avoided. The lime-saturated water should be vigorously mixed with the decarbonator outlet stream prior to blending with the decarbonator bypass water to avoid zones of poor mixing where calcium carbonate scaling may occur, decreasing the likelihood of turbidity problems. The required lime dose to be added to the decarbonator outlet stream to achieve an LSI of 0.06 is equal to 312 mg/L[1]. After blending the decarbonator outlet stream containing lime with the decarbonator bypass stream, it was calculated that around 19 mg/L of carbon dioxide would be needed to maintain pH < 8.5 in the conditioned water prior to distribution at the spreading grounds (see Figure 8-1). A summary of the water quality of the treated water prior to distribution at the spreading grounds, as determined from the desktop model, is provided in Table 8-4.

Table 8-4: Water Quality after Post Treatment Stabilization

Parameter	Value	Units
pH	8.50	-
LSI	0.06	-
Alkalinity	40	mg/L as CACO3

8.4.2 Bench-scale Testing

Purpose

The purpose of the post-treatment bench-scale testing was to determine the quality of three hydrated lime samples, two lime water samples out of saturators, and one calcium chloride sample from existing water reclamation facilities in Southern California. The hydrated lime samples were from Terminal Island Water Reclamation Plant, Edward Little Water Recycling Facility and Orange County Water District. The lime saturator samples were from Edward C. Little Water Recycling Facility and OCWD and the calcium chloride sample was from Terminal Island Water Reclamation Plant.

Method

Lime from each source was added to distilled (DI) water to attain the target alkalinity of 40 ppm as CaCO3. CaCl2 was added to attain a hardness of 40 ppm as CaCO3 and the pH was adjusted to approximately 8 with sodium hydroxide.

Each source was tested in duplicate for turbidity and total suspended solids (TSS). Additionally, the modified fouling index (MFI) was determined for each source.

It is important to note that the EL and OCWD hydrated lime samples were tested with commercially available SDI equipment, RO water as the carrier water and a target alkalinity of 30 ppm as CaCO3. However, MFI was difficult to measure with the commercially available unit because the apparatus often failed to maintain the necessary constant pressure of 30 psi. Due to this issue, a new SDI apparatus was developed by Trussell Technologies. The new unit was able to maintained constant pressure more consistently.

Results

The turbidity, TSS and MFI values are summarized in Table 8-5.

Table 8-5: Post-Treatment Results Summary

Lime Source	Alkalinity or Hardness (in the case of $CaCl_2$)	Turbidity	TSS	Modified Fouling Index (MFI)
	mg/L as $CaCO_3$	NTU	mg/L	s/L^2
Edward Little Water Recycling Facility Hydrated Lime	30 for turbidity and TSS batch; 24 for MFI batch	4.8	15.7	7.9[a]
Orange County Water District Hydrated Lime	29 for turbidity and TSS batch; 24 for MFI batch	2.4	7.0	13.7[a]
Terminal Island Water Reclamation Plant Hydrated Lime	40	1.3	0.9	15.9
Edward Little Water Recycling Facility Lime Water	39	0.4	0.1	0.5
Orange County Water District Lime Water	40	0.2	0.0	0.8
Terminal Island Water Reclamation Plant Calcium Chloride	37	0.1	0.0	0.1

Footnote:

a. Edward C. Little and OCWD hydrated lime samples were tested with CDM's SDI equipment, RO water as the carrier water and a target alkalinity of 30 ppm as CaCO3; all other tests were conducted with Trussell Technologies' SDI equipment, which was able to maintained constant pressure more consistently, and distilled water as the carrier water.

It is clear that the lime water out of the saturator produced dissolved lime with very little particulates, as evident from the lower turbidity, TSS and MFI as compared to the hydrated lime. Additionally, calcium chloride is very appropriate for the generation of low turbidity, TSS and MFI product water.

Conclusion

Overall, a properly functioning saturator or the use of calcium chloride makes a big difference and can help reduce turbidity, TSS and the clogging propensity of post-treated RO water.

8.5 Post-Treatment DBP Formation

Bench testing was conducted in June 2011, using ozone/peroxide product water to determine the potential for disinfection byproduct formation within the final product water. No information was available on the potential formation of NDMA and THMs when chlorinating advanced treated water, raising concerns that unacceptable levels could be produced if the final product at the future plant was chlorinated before being pumped through the pipeline to the spreading grounds.

8.5.1 Bench Testing Procedure

Product water samples from the ozone/peroxide system were collected and dosed with either 4 mg/L of sodium hypochlorite (as Cl_2) or a combination of 4 mg/L hypochlorite and 1 mg/L ammonia (as N). The chlorinated samples were allowed to sit for 24 hours in sealed, opaque containers, with samples taken at 5 minutes, 1 hour, 4 hours, and 24 hours. Samples collected included NDMA and four regulated THMs (chloroform, bromoform, bromodichloromethane, and dibromochloromethane).

8.5.2 Bench Testing Results

Figures 8-2 and **Figure 8-3** show the formation of NDMA and THMs when treating final product water with free chlorine or chloramines, respectively.

Figure 8-2: Formation of DBPs in Final Product Water with Free Chlorine

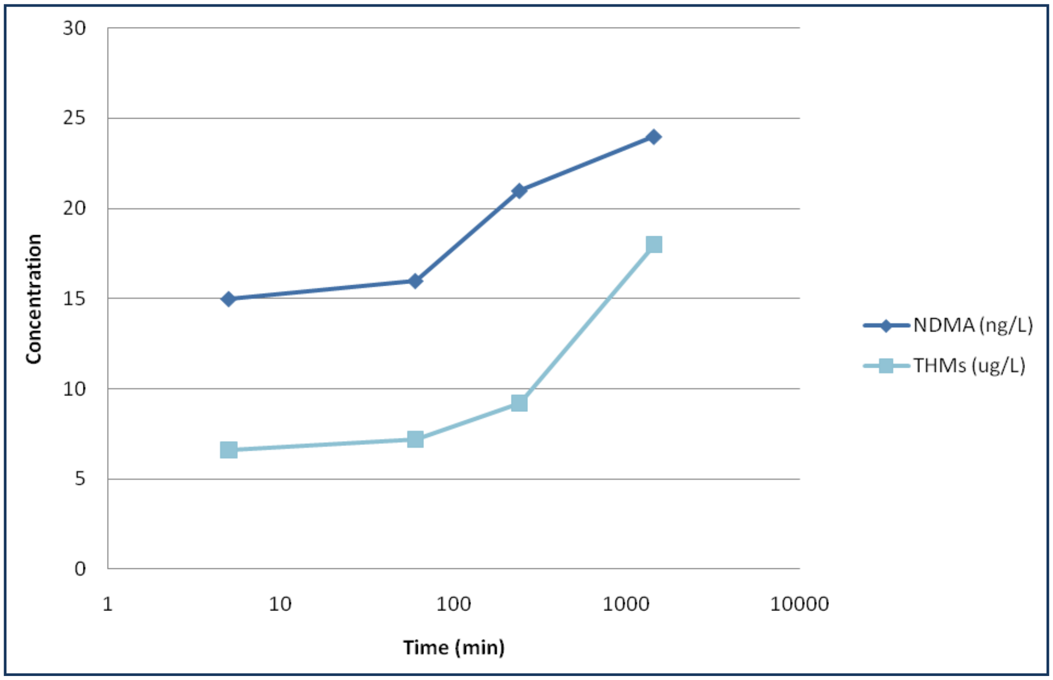
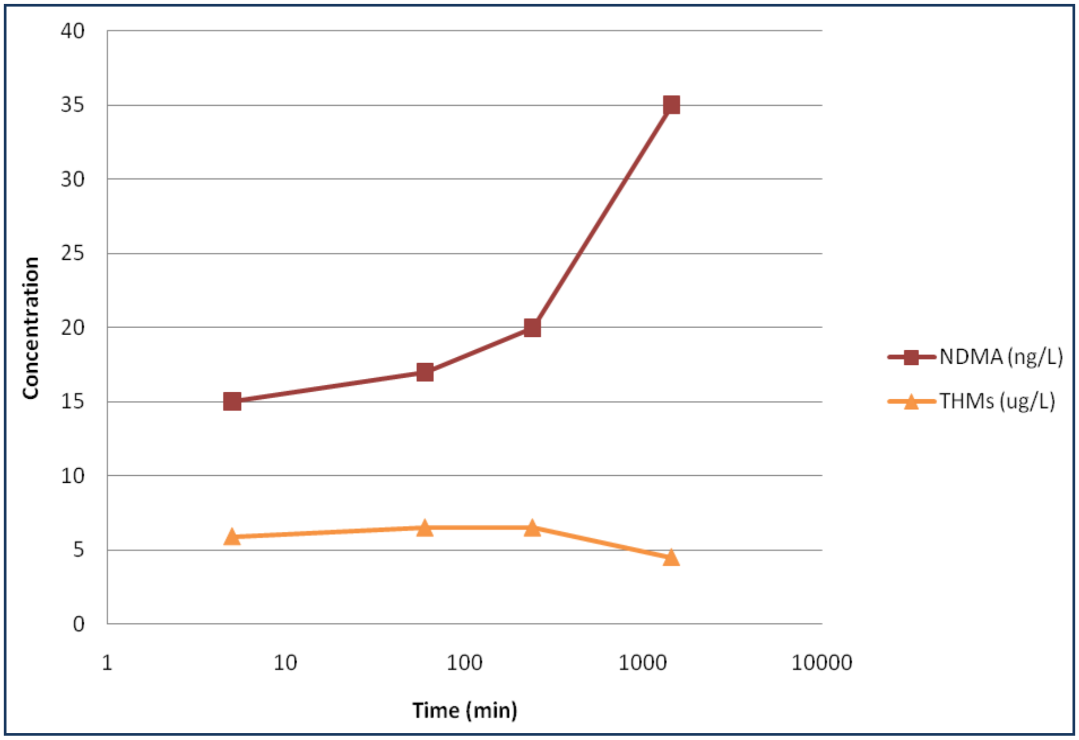


Figure 8-3: Formation of DBPs in Final Product Water with Chloramines



The results demonstrate that when free chlorine was used for post-disinfection, the NDMA increased by nearly 10 ng/L (60 percent) over 24 hours, while the THMs increased by 11 µg/L (170 percent). In contrast, when chloramines were used for post-disinfection, the NDMA increased by 20 ng/L (130 percent), while the THM concentrations remained unchanged. While the THM concentrations remained well below the 60 µg/L MCL, even after 24 hours of free chlorine contact, NDMA levels exceeded the current 10 ng/L notification level. These results suggest the post-chlorinating the advanced treatment product water, whether using free chlorine or chloramines, could result in NDMA concentrations exceeding the notification level. It is therefore recommended that post-chlorination not be utilized at the future groundwater replenishment treatment facility.

8.6 Quality Assurance/Quality Control

Quality assurance and quality control (QA/QC) was conducted to maintain high standards during pilot-scale testing.

8.6.1 Analytical Procedures

The following analytical procedures were observed for all data collection and sampling procedures:

- Calibrated the field analysis instruments, as needed, per the manufacturers' instructions. A calibration notebook was kept at the site to document all instrument calibrations.
- Followed proper sample collection and handling requirements as specified in Standard Methods and/or other relevant sampling methods (e.g., EPA, Lab specific methods for emerging contaminants, etc.).
- Duplicated samples of field analyses (e.g., TOC, conductivity) were sent periodically to an outside lab to confirm onsite testing results. Exceptions included temperature, pH, ORP, and chlorine, where laboratory analysis could not provide a significant improvement in accuracy compared to calibrated field measurements.

8.6.2 Technical Review Committee (TRC)

The TRC provided an independent review by experienced and qualified personnel. The TRC provided input and guidance so that the direction of the testing would be consistent with a sound, practical, and cost-effective treatment approach.

8.6.3 Calibration of Field Equipment

Analytical field instruments were calibrated on either a weekly or monthly basis. After calibration, each instrument was used to measure a stock solution to verify accuracy. In the case of the pH meter, the calibration slope was recorded, since the slope of the calibration curve correlates to proper calibration. The instruments routinely calibrated were the Shimadzu TOC analyzer, Hach Sension 1 pH meter, Hach Sension1 ORP meter, and Hach 2100N Turbidimeter. Table 8-6 below lists the calibration measurements.

Table 8-6: Field Calibration Results

Instrument	Shimadzu TOC Analyzer	Hach Sension1 pH analyzer	Hach Sension1 ORP meter	Hach 2100N Turbidimeter
Concentration of stock solution[a]	50 mg/L	-58 mV	475 mV	50 NTU
March 20	48.0	-56.3	455.2	50.8
April 2	49.4	-55.4	456.1	47.6
May 7	49.8	-57.2	461.1	50.3
May 14	49.6	-57.4	466.8	51.2
May 28	50.4	-56.2	485.3	51.6
June 4	50.9	-56.7	462.1	51.9
June 25	49.5	-55.0	458.6	49.2
July 2	-	-57.0	-	-
July 9	-	-56.2	-	-
July 16	50.5	-55.5	480.5	49.0
July 30	50.7	-58.1	453.4	52.6
August 6		-57.3	467.4	50.2

Footnotes:

a. pH calibration is measured by the slope of the calibration curve, not by concentration of a stock solution.

8.7 Duplicate Sampling

In order to verify accuracy of field instruments, duplicate samples were sent to the laboratory during both rounds of quarterly testing. Table 8-7 shows the results from this duplicate sampling. The results suggest show good correlation for the pH results, which generally showed discrepancies of less than five percent, in spite of potential changes to the pH during transit and storage at the lab. Total chlorine results were considerably lower in the laboratory samples, suggesting that the water samples were not capable of sustaining a chlorine residual during the transit and storage at the laboratory. Turbidity results correlated relatively well for the source water and MF Filtrate, where online turbidimeters were employed, however, the field turbidimeter used for the RO feed and RO permeate appears to have had trouble reading the low values of these low turbidity samples. Correlation was good for UV254, TOC, and conductivity data sent for duplicate sampling.

Table 8-7: Duplicate Sampling Results

	pH		Total Cl2 (mg/L)		Turbidity (NTU)		UV254		TOC (mg/L)		Conductivity	
	Field	Lab	Field	Lab	Field	Lab	Field	Lab	Field	Lab	Field	Lab
Source Water												
4/27/2010	7	7.45	0.56	0.2	0.68	-	0.141	0.123	6.9	6	834	840
7/8/2010	6.91	7.05	-	-	0.62	0.37	0.135	0.125	6.822	5.8	727	700
MF Filtrate												
4/27/2010	7.59	7.47	2.83	0.21	0.036	ND	0.133	0.108	-	-	-	-
7/8/2010	6.98	7.17	-	-	0.052	0.02	0.106	0.102	-	-	-	-
RO Feed												
4/27/2010	6.94	7.47	3.86	0.21	0.19	ND	-	-	-	-	893	860
7/8/2010	6.88	7.17	-	-	-	-	0.075	0.02	-	-	735	720
RO Permeate												
4/27/2010	6.15	5.89	-	-	-	-	0.016	ND	-	-	-	-
7/8/2010	5.94	6.03	-	-	0.17	0.002	-0.005	0.0015	-	-	-	-
AOP Influent												
4/27/2010	5.82	6.11	3.54	0.1	-	-	0.016	ND	-	-	-	-
7/8/2010	7.3	6.18			-	-			-	-	-	-
UV Effluent												
4/27/2010	5.5	6.07	-	-	-	-	0.001	ND	-	-	-	-
7/8/2010	6.3	6.23	-	-	-	-	0.001	0.002	-	-	-	-

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9. Conclusions and Recommendations

The pilot testing confirmed that the proposed treatment technologies are suitable for treatment of the DCTWRP secondary and/or tertiary effluent. In addition, it was determined that some operational changes can be made to improve reliability and decrease capital or operator costs compared with existing, operational advanced purification facilities. An alternative advanced oxidation process was tested using ozone and hydrogen peroxide, finding that it provides a viable alternative to the current advanced oxidation process used at existing advanced purification facilities. The conclusions and recommendations are summarized below for the source water evaluation, microfiltration, reverse osmosis, advanced oxidation, and product water quality.

9.1 Source Water Evaluation

Bench testing and source water monitoring conducted for the source water evaluation concluded that regardless of which water source (secondary versus tertiary effluent) and disinfection method was tested, significant levels of disinfection by-products were formed from extended chlorine contact. Utilizing chlorinated tertiary effluent as the source water would require as much as 1.6-log reduction of NDMA to maintain concentrations below the notification level of 10 ng/L. In contrast, by drawing source water before chlorine addition, NDMA levels in the pilot feed water averaged 22 ng/L, requiring only a 0.4-log reduction to reach the notification level.

It was therefore recommended that source water be taken before chlorine contact. NDMA levels were found to be slightly lower in the tertiary effluent than in the secondary effluent, however, NDMA formation after chloramines addition was slightly higher in the tertiary effluent. As a result, the levels of NDMA in the RO feed and RO product water were identical, regardless of which source water was used. It was recommended that without a compelling reason to utilize one source water over the other, flexibility should be maintained to allow for either source water to supply the future advanced purification facility.

Source water for the pilot, before advanced treatment, complied with all primary drinking water MCLs, with the exception of one sample that contained nitrate and the sum of nitrate plus nitrite concentrations above the irrespective MCLs. Monitoring also confirmed that the source water complied with the secondary drinking water MCLs with the exception of color and the recommended MCL ranges for TDS and conductivity; TDS and conductivity concentrations were less than the upper MCL ranges.

9.2 Microfiltration

Pilot testing results demonstrated that daily or semiweekly chemically enhanced backwashes (CEBs) could be utilized to maintain stable MF permeabilities for periods in excess of 200 days without utilizing the more time intensive CIPs, however, chemical usage under such an approach would be high. MF flux during the first four runs when CEBs were employed varied between 25 and 32 gfd, and it should be anticipated that a significantly higher flux would result in a more rapid decline in permeability.

When CEBs were not employed, a flux of 35 gfd was found to be sustainable with a 30 day run length between chemical cleanings (CIPs). While this flux is higher than the flux used at many operational advanced treatment facilities, it is comparable to the flux employed at the WRD Vander Lans plant, which uses the same membranes tested here, treating a similar water quality. It is therefore recommended that an MF flux of 35 gfd be assumed for GWR treatment facility planning, but that future pilot testing be conducted with alternative membrane suppliers before identifying allowable design fluxes for the various proprietary systems.

The rates of permeability decline using tertiary effluent and secondary effluent were similar; both would allow for a minimum cleaning frequency of 30 days. Using tertiary effluent did not provide for improved performance when compared with secondary effluent. Similarly, testing results did not find a significant improvement in performance when free chlorine was maintained within the MF membranes rather than the typical chloramines residual used at existing advanced purification facilities.

Water quality monitoring suggests that the MF system provided a high quality source water for the downstream RO process, reducing turbidities to less than 0.06 NTU and SDI measurements to 2. Organic rejection with the MF membranes was low, suggesting that the majority of organic material in the source water was dissolved in nature. Removal of organic matter occurs primarily within the RO process, with additional destruction accomplished using AOP.

9.3 Reverse Osmosis

Pilot testing considered the impact of various operating parameters on RO performance. These included: source water, chlorination approach, flux, number of stages, recovery, antiscalant, and membrane type. Operational recommendations for these conditions include:

- Chlorination Approach – Excessive membrane damage was observed during the period when sequential chlorination was utilized. It is believed that repeated loss of ammonia feed during the evenings allowed free chlorine concentrations greater than 3 mg/L to damage the membranes before sequential chlorination was discontinued and the membranes were replaced. During full-scale operation, automatic quenching of the chlorine can be done to prevent such damage, however, the risk of membrane damage will be higher with sequential chlorination than with traditional.
- Source Water - No difference was seen in RO performance between operation with tertiary effluent or secondary effluent as the source water.
- Flux – Stable operation was not achieved at 12 gfd operating flux and 85 percent recovery, even when operating in a 3-stage configuration. Stable operation was achieved at 14 gfd in a 2-stage configuration.
- Number of Stages – No difference was seen in first stage or second stage fouling between a 2-stage or 3-stage configuration, however, a high fouling rate was seen in the third stage when operating in a 3-stage mode. Higher feed pressures were required to maintain a 3-stage system. It is therefore recommended that a 2-stage configuration be used for the full-scale facility.
- Recovery – At 80 percent recovery, no fouling was observed with the initial antiscalant and a flux of 12 gfd. At 85 percent recovery fouling was observed in the second stage

when the initial antiscalant was used and when flux was 12 gfd. Stable operation was achieved at an 85 percent recovery with the second antiscalant and an operating flux of 14 gfd. It is therefore recommended that a design recovery of 85 percent be used for the full-scale facility.

- Antiscalant – The RO membranes performed well with PreTreat Plus Y2K as the antiscalant, allowing for run times exceeding 60 days, but an unacceptably high rate of fouling was observed with Vitec 4000 as the antiscalant when recoveries greater than 80 percent were employed. Antiscalants can be purchased easily from multiple vendors after full-scale plant construction is complete. It is therefore not necessary to recommend a specific antiscalant at this point in the planning process.
- Three alternative RO membranes were tested, including Hydranautics ESPA2, CSM FEn, and Toray TML20. All three RO membranes performed nearly identically, in terms of fouling rate, permeability, and product water quality. It is recommended that all three membranes be considered for inclusion in the future facility.

Water quality results demonstrated that the RO system was able to meet all water quality requirements for the advanced purification facility, with the exception of NDMA destruction and disinfection, which must be achieved in the downstream advanced oxidation process.

9.4 Advanced Oxidation Process

The pilot testing results support the conclusion that UV/peroxide is an effective method for removing trace organic compounds, which are only partially removed by the RO membranes. While most compounds were removed to below detection levels by the RO membranes, a few compounds, including NDMA, DEET, gemfibrozil, sulfamethoxazole, meprobamate, and three flame retardants (TCEP, TCPP, and TDCPP), were measured in the RO permeate in low concentrations, and were effectively reduced through UV/peroxide. In most cases these were removed to levels below detection limits, however, concentrations of the three flame retardants remained above the 1 ng/L method reporting limit. There is currently no consensus among commercial labs on the most appropriate reporting limit for these compounds, with reporting limits ranging from 1 to 20 ng/L. All three flame retardants would be considered below detection limits if a 5 ng/L limit were used. The results from the pilot testing demonstrated that UV/peroxide was effective at reducing NDMA by greater than 1.2-log units, reducing 1,4-dioxane by greater than 0.5-log, and meeting all regulatory requirements for groundwater recharge.

The Phase 2 pilot testing demonstrated that ozone/peroxide is promising for the removal of 1,4-dioxane and TCEP, two compounds that are difficult to oxidize compared with other constituents of emerging concern. 1,4-dioxane was removed at levels well in excess of the 0.5-log reduction requirement for groundwater recharge. Removal for 1,4-dioxane, TCEP, and chloramines was significantly better when using ozone/peroxide compared with UV/peroxide. Phase 3 testing confirmed the testing results from Phase 2, under continuous pilot operation. These results demonstrated that ozone/peroxide can potentially be used in place of UV/peroxide to meet all regulatory requirements with the exception of the requirement to provide 1.2-log NDMA reduction. In the event that the regulations are modified to relax or remove this requirement in the future, the use of ozone/peroxide could provide a benefit when compared with UV/peroxide, resulting in lower energy usage and greater removal of constituents of emerging concern. In the event that such regulatory changes occur, it is recommended that further evaluations be conducted to optimize the reaction time and operation of an ozone/peroxide system.

Bench testing using the ozone/peroxide product water suggested that chlorination, either with free chlorine or chloramines, could result in the formation of NDMA exceeding the 10 ng/L notification level. It is therefore recommended that chlorination not be utilized in the final product water when conveying the water through the pipeline to the spreading grounds.

9.5 Product Water Quality

Water quality results from the pilot testing confirmed that all existing and draft drinking water and recycled water regulations can be met using the proposed treatment processes. All of the regulated compounds had average and maximum values in the product water below their regulatory limits, with the vast majority already below regulatory limits in the source water.

In addition to the regulated parameters, all but ten non-regulated pharmaceuticals and personal care products were removed to concentrations below detection levels by the RO process. All but three of these (TCEP, TCPP, and TDCPP) were removed to below detection levels by the UV/peroxide process, and all but two by the ozone/peroxide.

Overall, the removal of the three remaining personal care products (all flame retardants) was greater than 99 percent, with their concentrations in the final product water averaging less than 5 ng/L. No significant health risks have been suggested for these compounds at these concentrations. TCEP data from imported State Project Water (NWRI, 2010) was found to be higher than the levels measured in either the ozone or UV product during the pilot testing. Measurable concentrations of other CECs, such as carbamazepine, sulfamethoxazole, caffeine, primidone, and gemfibrozil have also been found in imported State Project Water, but were all below detection levels in the DCTWRP AWP product. It is concluded that the advanced water purification processes tested here provided an exceptional water quality for use in groundwater replenishment.

10. References

DCT Data Summary TM, Final, RMC/CDM, January 29, 2010.

GWR Treatment Pilot Study Testing Protocol, RMC/CDM, January 29, 2010.

Regulatory Assessment Technical Memorandum, Revised Draft, RMC/CDM, February 5, 2010.

Ultraviolet Disinfection Guidelines for Drinking Water and Reuse, NWRI/AWWARF, 2003.

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Appendix A

Bench Testing Notes and Protocol

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City of Los Angeles

Recycled Water Master Plan

Bench-Scale Testing Protocol

Title:	NDMA Formation Bench-Scale Testing Protocol
Version:	Draft
Prepared For:	John Hinds, Project Manager, LADWP Doug Walters, Project Manager, BOS Task 3b Lead, Gary Stolarik Co-Task Lead, Al Bazzi
Prepared by:	Greg Wetterau, Task 3 Lead, CDM Eric Smith, Task 3 Field Engineer, CDM Marie Burbano, Task 3 Project Engineer, CDM
Reviewed by:	Heather Boyle VanMeter, CDM Andrea Turriciano, CDM
Date:	April 20, 2010
Reference:	Task 3b, Subtask 3.5.4

1. Introduction

To prepare Los Angeles for future water needs and plan for expanding reuse in the future, LADWP has partnered with the Department of Public Works to develop the Recycled Water Master Plan (RWMP). The RWMP includes 7 major tasks: 1 Indirect Potable Reuse Master Plan, 2 Non-Potable Reuse Master Plan, 3 Indirect Potable Reuse Pilot Study, 4 Max Reuse Concept Report, 5 Satellite Feasibility Concept Report, 6 Existing System Reliability Concept Report, and 7 Training.

The Indirect Potable Reuse Pilot Study includes pilot testing to evaluate the proposed primary treatment process, assumed to consist of microfiltration (MF) followed by reverse osmosis (RO), as well as alternate post-treatment processes, such as advanced oxidation processes (AOP) used to remove or destroy trace organic compounds that are poorly removed by RO, and other post-treatment processes used to disinfect or stabilize the product water for distribution.

The purpose of this protocol is to provide bench-scale testing procedures to evaluate NDMA (N-nitroso-dimethylamine) formation from various water sources, including secondary effluent and filter effluent. The potential to form NDMA will be used to evaluate which water source should be tested during the pilot for eventual full-scale implementation. In addition, the bench-scale testing will measure the NDMA from primary effluent to develop a baseline concentration of NDMA.

NDMA is formed by chloramines used for disinfection reacting with organic nitrogen. NDMA is an unregulated contaminant by the EPA (U.S. Environmental Protection Agency), but the CA DPH (California Department of Public Health) notification level is 10 ng/L.

2. Testing Procedures

The overall plan is to use chloramines for different amounts of reaction time. Table 1 is a summary of the sample runs to be completed.

Table 1: Sample Runs

Run #	Description	Sample	Contact time (min)	Ammonia Dose as N(mg/L)	Chlorine dose as Cl2 (mg/L)	NDMA sampling	TTHM sampling
1.	Chlorine Demand	Secondary Effluent (SE)	5	0	10	No	No
2.	Chlorine Demand	Filtered Effluent (FE)	5	0	10	No	No
3.	Chloramine Demand	SE	20	2	8	No	No
4.	Chloramine Demand	FE	20	2	8	No	No
5.	SE baseline	SE	0	0	0	Yes	Yes
6.	FE baseline	FE	0	0	0	Yes	Yes
7.	SE w/ sequential chlorination	SE	5	0	Demand + 4	Yes	Yes
8.	SE w/ sequential chlorination	SE	20	1.5*	Demand + 4	Yes	Yes
9.	SE w/ sequential chlorination	SE	120	1.5	Demand + 4	Yes	Yes
10.	SE w/ sequential chlorination	SE	1440	1.5	Demand + 4	Yes	Yes
11.	SE w/chloramines	SE	5	1.5**	Demand + 4	Yes	No
12.	SE w/chloramines	SE	20	1.5	Demand + 4	Yes	No
13.	SE w/chloramines	SE	120	1.5	Demand + 4	Yes	No
14.	SE w/chloramines	SE	1440	1.5	Demand + 4	Yes	No
15.	FE w/ sequential chlorination	FE	5	0	Demand + 4	Yes	Yes
16.	FE w/ sequential chlorination	FE	20	1.5*	Demand + 4	Yes	Yes
17.	FE w/ sequential chlorination	FE	120	1.5	Demand + 4	Yes	Yes
18.	FE w/ sequential chlorination	FE	1440	1.5	Demand + 4	Yes	Yes
19.	FE w/chloramines	FE	5	1.5**	Demand + 4	Yes	No
20.	FE w/chloramines	FE	20	1.5	Demand + 4	Yes	No
21.	FE w/chloramines	FE	120	1.5	Demand + 4	Yes	No
22.	FE w/chloramines	FE	1440	1.5	Demand + 4	Yes	No

*Add ammonia at the T=5 min mark.

**Add ammonia, stir sample vigorously for approx. 20 seconds, and then add chlorine.

Runs #1, #2, #3 and #4 – Chlorine and Chloramine Demand

1. Collect SE and FE samples.
    a. SE sample shall be taken from pilot source water location with secondary effluent pump turned on.
    b. FE sample shall be taken from pilot source water location with filtered effluent pump turned on.
2. Add chemical to 1L sample according to doses in table below.
3. Measure free chlorine residual at 2 min, 5 min, 10 min, and 20 min.
4. If residual drops below 0.5 mg/L, repeat test with increased dose (use increments of 10 mg/L).
5. Plot residual vs. time to determine chlorine demand.

	Run #1	Run #2	Run #3	Run #4
Water Source	SE	FE	SE	FE
Sodium Hypochlorite addition	0.17 mL (10 mg/L)	0.17 mL (10 mg/L)	0.14 mL (8 mg/L)	0.14 mL (8 mg/L)
Ammonia addition	0 mL	0 mL	0.06 mL (2 mg/L)	0.06 mL (2 mg/L)

Runs #5 and #6 - Baseline Testing Procedure

1. Pour FE and SE into bottles for NDMA testing.
2. Test the sample for pH, free, and total chlorine.

After background testing, tests will be performed to see if NDMA is created with free chlorine or chloramines. All mixing samples will be completed in a plastic water bucket. The bucket should be covered in aluminum foil to avoid exposure to light.

Runs #7 through #10 – SE with Free Chlorine Testing Procedure

1. Place 6L of sample in white 2 gal bucket.
2. Add ammonia to required dose.
3. Stir rapidly for 20 seconds.
4. Allow sample to sit for 5 minutes (T=5min).

5. Measure free and total chlorine, as well as pH and temperature.
6. Pour the sample into bottles for NDMA and TTHM testing.
7. Add sodium hypochlorite to required dose, and then stir vigorously.
8. Repeat steps 5 and 6 for time intervals of T=20 min, 120 min, and 1440 min.

Runs #11 through #14 – SE with Chloramines Testing Procedure

1. Place 6L of sample in white 2 gal bucket.
2. Add ammonia to required dose.
3. Stir rapidly for 20 seconds.
4. Add sodium hypochlorite to required dose.
5. Allow sample to sit for 5 minutes (T=5min).
6. Measure free and total chlorine, as well as pH and temperature.
7. Pour the sample into bottles for NDMA testing.
8. Repeat steps 6 and 7 for time intervals of T=20 min, 120 min, and 1440 min.

Runs #14 through #18 – FE with Free Chlorine Testing Procedure

1. Repeat steps for Runs #7 through #10 using FE instead of SE.

Runs #19 through #23 – FE with Chloramines Testing Procedure

2. Repeat steps for Runs #11 through #14 using FE instead of SE.

3. Analysis

For laboratory analysis, the NDMA samples are to be stored in two 500 mL amber glass bottles with sodium thiosulfite (dechlorinating agent). There is a 7-day hold time on that sample. TTHM samples are to be stored in three 40 mL VOA bottles (per sample) with sodium thiosulfite. NDMA and TTHM sample bottles will be provided by Weck Laboratories. Samples will be returned to Weck Laboratories for analysis.

Free and total chlorine residual will be measured using the HACH DR4000 with reagent in the field.

pH and temperature will be measured using the Sension 1 pH meter in the field. The pH probe should be calibrated at the beginning of the testing.

4. Materials

Table 2 shows the list of materials for the testing

Table 2: Materials

Item	Specifications	Purchase Location
Water Quality Lab Kit	• HACH DR4000 • HACH Sension 1 pH meter • HACH Sension 5 Conductivity meter • Glassware and accessories	CDM/Rancho
pH calibration solution	pH 4, 7, and 10	CDM/Rancho
Pipettes & bulb	1 mL, 5 mL, 10 mL	CDM/Los Angeles
Camera	Pilot Plant Cell Phone	CDM/ Los Angeles
Free chlorine reagent	DPD Free Chlorine Reagent, Powder packets Range: 0 to 5 mg/L	HACH
Total chlorine reagent	DPD Total Chlorine Reagent, Range: 0 to 5 mg/L	HACH
NDMA sample bottles	1-L amber glass bottles with sodium thiosulfite (dechlorinating agent)	Weck Labs
Bleach	2 liters, 5.25% solution	Hardware/grocery store
Ammonia	1 liter, 5 or 10% solution	Hardware/grocery store
Water jugs	4 gallon jugs	Hardware/grocery store
Aluminum foil	For covering the water jugs to prevent sunlight	Hardware/grocery store
Graduated cylinder or measuring cup	1-L plastic	Hardware/grocery store
5- gallon bucket with top	2 buckets	Hardware/grocery store
2- gallon buckets with top	4 buckets	Hardware/grocery store
Rod for mixing	1 rod	Hardware/grocery store
Paper Towels		Hardware/grocery store
Plastic Gloves		Hardware/grocery store
1-L jar		Hardware/grocery store
Deionized water	2 gallons	Hardware/grocery store

Appendix B

Diurnal Sampling Protocols

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Diurnal Testing Protocol

Title:	NDMA Diurnal Testing Protocol
Version:	Draft
Prepared For:	Internal Team Document
Prepared by:	Greg Wetterau, Task 3b Lead, CDM Marie Burbano, Task 3b Project Engineer, CDM Eric Smith, Task 3b Field Engineer, CDM
Reviewed by:	David Hokanson, PhD, PE, RMC
Date:	April 7, 2010
Reference:	Task 3b, Subtask 3.4

1. Introduction

The purpose of this protocol is to provide a protocol for diurnal testing to evaluate NDMA (N-nitroso-dimethylamine) formation from DCT final effluent over a 24-hour duration. The potential to form NDMA will be used to aid the eventual full-scale implementation.

NDMA is formed by chloramines used for disinfection and/or RO biofouling control reacting with organic precursors and it should be noted that NDMA levels may be influenced by additional factors including industrial sources and the Mannich polymer used to control foaming in WWTPs. NDMA is an unregulated contaminant by the EPA (U.S. Environmental Protection Agency) and CA DPH (California Department of Public Health), but the CA DPH has set a Notification Level (NL) of 10 ng/L for NDMA, which is a health-based advisory level established for select unregulated constituents.

The pilot study protocol and Task 3b scope of work stipulate that the RMC team will perform testing and sampling over a 24-hour period to monitor diurnal fluctuations of the DCT flows on a quarterly basis.

2. Testing Procedures

This section describes the procedures to be performed for diurnal testing. Parameters to be monitored are listed below:

Parameter	Sampling Frequency
TOC	Hourly
Temperature	Hourly
NDMA	Every 2 hours

Turbidity	Hourly
Chlorine Demand	Every 2 hours.

Since some parameters will be tested on an hourly basis and others will be tested on a bi-hourly basis, the procedures for testing at each hour are separated as follows:

Even-numbered hours:

1. Take NDMA sample from DCT post-chlorine contact basins.
2. Take sample from the secondary effluent before chlorine and measure turbidity, temperature, TOC, and chlorine demand.
3. Take sample from the filtered effluent before ammonia and measure turbidity, temperature, TOC, and chlorine demand.

Odd-numbered hours:

1. Take sample from the secondary effluent before chlorine and measure turbidity, temperature, TOC.
2. Take sample from the filtered effluent before ammonia and measure turbidity, temperature, TOC.

Specific procedures for testing each parameter are listed in the following table:

Parameter	Sampling Frequency
TOC	• Test using Shimadzu TOC analyzer in lab area. • Every 4 hours starting with 6pm, take a TOC sample in an 250 mL amber glass bottle to send to Weck Laboratory
Temperature	• Record temperature directly at sample location so that sample does not have a chance to cool off. • Record temperature for each sample using the pH mater in the lab area.
NDMA	• Fill up two 500mL Amber NDMA bottles per location. • Label samples properly and place in ice chest. • Send all samples to Weck labs for testing.

Turbidity	- Use 2100N Turbidimeter in lab area. - Every 4 hours starting with 6pm, take a turbidity sample in an unpreserved 500 mL clear glass bottle to sent to Weck laboratory. - Label samples properly and place in ice chest.
Chlorine Demand	- Chlorine Demand - Test using DR4000 Free Chlorine Test 'n Tube method. - Dose 0.1 mL of 10% chlorine solution to 1 L sample using pipet - To test—dose 0.1 mL of 10% chlorine solution to RO permeate and check free chlorine residual: should equal 10 mg/L - Allow sample to react for 5 minutes. - Measure chlorine residual. - Record chlorine demand as difference between dose (10 mg/L) and residual.

3. Analysis

For laboratory analysis, the NDMA samples are to be stored in two 500 mL amber glass bottles with sodium thiosulfite (dechlorinating agent). There is a 7-day hold time on that sample. NDMA sample bottles will be provided by Weck Laboratories. Samples will be returned to Weck Laboratories for analysis.

Free chlorine residual will be measured using the HACH DR4000 with reagent in the field.

Temperature will be measured using the Sension 1 pH meter in the field. The pH probe should be calibrated at the beginning of the testing.

Turbidity will be measured using a 2100N HACH Turbidimeter and also 500 mL glass sample bottles will be sent to Weck Laboratories for testing.

Diurnal Testing Protocol

Title:	NDMA Diurnal Testing Protocol
Version:	Final
Prepared For:	Internal Team Document
Prepared by:	Greg Wetterau, Task 3b Lead, CDM Marie Burbano, Task 3b Project Engineer, CDM Eric Smith, Task 3b Field Engineer, CDM
Reviewed by:	David Hokanson, PhD, PE, RMC
Date:	July 27, 2010
Reference:	Task 3b, Subtask 3.4

1. Introduction

The purpose of this protocol is to provide a protocol for diurnal testing to evaluate NDMA (N-nitroso-dimethylamine) formation from DCT final effluent over a 24-hour duration. The potential to form NDMA will be used to aid the eventual full-scale implementation.

NDMA is formed by chloramines used for disinfection and/or RO biofouling control reacting with organic precursors and it should be noted that NDMA levels may be influenced by additional factors including industrial sources and the Mannich polymer used to control foaming in WWTPs. NDMA is an unregulated contaminant by the EPA (U.S. Environmental Protection Agency) and CA DPH (California Department of Public Health), but the CA DPH has set a Notification Level (NL) of 10 ng/L for NDMA, which is a health-based advisory level established for select unregulated constituents.

The pilot study protocol and Task 3b scope of work stipulate that the RMC team will perform testing and sampling over a 24-hour period to monitor diurnal fluctuations of the DCT flows on a quarterly basis.

2. Testing Procedures

This section describes the procedures to be performed for diurnal testing. Parameters to be monitored are listed below:

Parameter	Field Test	Lab Test
TOC	Hourly	Every 4 Hours
Temperature	Hourly	N/A
Turbidity	Hourly	Every 4 Hours
pH	Hourly	N/A
TKN	N/A	Every 2 Hours
Ammonia	N/A	Every 2 Hours
NDMA	N/A	Every 2 Hours
Total Chlorine Dose	Every 2 Hours	N/A
MF Effluent Total Chlorine	Every 2 Hours	N/A
Flow	N/A	N/A

Since some parameters will be tested on an hourly basis and others will be tested on a bi-hourly basis, the procedures for testing at each hour are separated as follows:

Even-numbered hours:

1. Take NDMA from DCT post-chlorine contact basins. Measure pH at this location too.
2. Take TKN/Ammonia, Turbidity (as needed), and TOC (as needed) samples from the secondary effluent before chlorine* and measure turbidity, pH, temperature, TOC.
3. Take TKN/ Ammonia**, Turbidity (as needed), and TOC (as needed) samples from the filtered effluent before ammonia* and measure turbidity, pH, temperature, TOC. Measure total chlorine dose and MF effluent total chlorine at this location.

Odd-numbered hours:

1. Take sample from the secondary effluent before chlorine* and measure turbidity, pH, temperature, TOC.
2. Take sample from the filtered effluent before ammonia* and measure turbidity, pH, temperature, TOC.

*Note that these samples can be taken from the pilot source water location, as long as the correct source water pump has been turned on.

**The TKN/Ammonia samples must be taken from the tertiary effluent channel, not from the source water pump location.

Bottles Required for Laboratory Testing:

Parameter	Lab Test	Total Bottles Required
TOC	Every 4 Hours	6
Turbidity	Every 4 Hours	6
TKN, Ammonia	Every 2 Hours	12 (TKN and ammonia bottles can be shared)
NDMA	Every 2 Hours	12 (2 per location makes 24)

Specific procedures for testing each parameter are listed in the following table:

Parameter	Sampling Frequency
TOC	• Test using Shimadzu TOC analyzer in lab area. • Every 4 hours starting with 4pm, take a TOC sample in an 250 mL amber glass bottle with H3PO4 preservative to send to Weck Laboratory
Temperature	• Record temperature directly at sample location so that sample does not have a chance to cool off. • Record temperature for each sample using the pH meter in the lab area.
NDMA	• Fill up two 500mL Amber NDMA bottles per location. • Label samples properly and place in ice chest. • Send all samples to Weck labs for testing.
pH	• Measure using field pH meter
TKN, Ammonia	• Fill up 250 mL poly bottle with H2SO4 preservative.
Turbidity	• Use 2100N Turbidimeter in lab area. • Every 4 hours starting with 4pm, take a turbidity sample in an unpreserved 500 mL clear glass bottle to send to Weck laboratory. • Label samples properly and place in ice chest.

Total Chlorine Dose and MF Effluent Total Chlorine	• Test using DR4000 Free Chlorine Test 'n Tube method. • Measure total chlorine using reagent.

3. Analysis

For laboratory analysis, the NDMA samples are to be stored in two 500 mL amber glass bottles with sodium thiosulfite (dechlorinating agent). There is a 7-day hold time on that sample. NDMA sample bottles will be provided by Weck Laboratories. Samples will be returned to Weck Laboratories for analysis.

Free chlorine residual will be measured using the HACH DR4000 with reagent in the field.

Temperature will be measured using the Sension 1 pH meter in the field. The pH probe should be calibrated at the beginning of the testing.

Turbidity will be measured using a 2100N HACH Turbidimeter and also 500 mL glass sample bottles will be sent to Weck Laboratories for testing.

TOC will be measured using the Non- Purgable Organic Carbon (NPOC) method with the Shimadzu TOC analyzer in the field lab area.

Diurnal Testing Results for GWR Treatment Pilot Study

April		August						November						February								Average				
Chloraminated Effluen		Secondary Effluent		Tertiary Effluent		Chloraminated Effluen		Secondary Effluent		Tertiary Effluent		Chloraminated Effluen		Secondary Effluent			Tertiary Effluent			Chloraminated Effluen		Chloraminated Effluen	Secondary Effluent		Tertiary Effluent	
NDMA	Flow	TKN	Ammonia	TKN	Ammonia	NDMA	Flow	TKN	Ammonia	TKN	Ammonia	NDMA	Flow	TKN	Ammonia	NDMA	TKN	Ammonia	NDMA	NDMA	Flow	NDMA	TKN	Ammonia	TKN	Ammonia
ng/L		mg/L	mg/L	mg/L	mg/L	ng/L		mg/L	mg/L	mg/L	mg/L	ng/L		mg/L	mg/L	mg/L	mg/L	mg/L	ng/L	ng/L		ng/L	mg/L	mg/L	mg/L	mg/L
72							36	2.1	1.8	3.2	2	250	50	2.6	0.45		0.53	0.53		280	53	203	2.1	1.0	1.5	1.0
		1.5	0.67	0.71	0.42	210																				
	36						35						50													
250	37						35	2.8	1.8	2.3	1.6	97	49	3.7	1.6	26	2.1	1.4	26	200	52	171.75	3.0	1.5	2.0	1.2
		2.6	1.2	1.5	0.61	140																				
	35						36						49													
110	37						37	1.7	0.58	1.2	0.46	66	48	3	1		2.4	0.93		90	59	114	2.2	0.7	1.6	0.5
		1.9	0.5	1.2	0.19	190																				
	36						35						48													
270	36						38	1.4	0.11	1.2	0.05	250	49	2.1	0.33	20	1.5	0.2	11	81	47	195.25	1.6	0.2	1.4	0.1
		1.3	0.13	1.5	0.13	180																				
	35						37						51													
290	35						37	1.4	0.05	1.2	0.05	260	53	2.1	0.18		1.8	0.13		96	48	209	1.6	0.1	1.5	0.1
		1.3	0.15			190																				
	34						37						51													
350	33						38	1.3	0.05	1.2	0.05	250	49	2.3	0.14	22	1.6	0.1	12	110	51	225	1.7	0.1	1.4	0.1
		1.6	0.024			190																				
	32						38						47													
310	33						38	1.3	0.05	1.1	0.05	250	47	1.9	0.05		1.4	0.12		200	53	237.5	1.6	0.1	1.3	0.1
						190																				
	33						38						42													
220	35						33	1.2	0.14	1.2	0.05	240	33	2.2	0.11	17	1.4	0.05	11	200	48	212.5	1.7	0.1	1.3	0.1
						190																				
	28						27						35													
400	27						29	1.2	0.13	0.97	0.12	250	34	1.9	0.12		2	0.05		200	41	283.3333333	1.6	0.1	1.5	0.1
	27						26						32													
430	22						27	1.3	0.12	0.78	0.12	270	34	1.8	0.05	14	1.3	0.1	11	250	38	297.5	1.6	0.1	1.0	0.1
						240																				
	23						30						44													
350	35						37	1.1	0.16	1.2	0.11	260	53	1.7	0.05		1.6	0.05		230	37	265	1.4	0.1	1.3	0.1
		1.5	0.15	1	0.12	220																				
	35						37						50													
280	35						35	1.5	0.05	0.98	0.13	230	52			10	1.3	0.05	12	240	37	237.5	1.4	0.1	1.2	0.1
		1.2	0.11	1.3	0.16	200																				
	35						36						50													

Appendix C

Chains-of-Custody for Laboratory Testing

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CHAIN OF CUSTODY RECORD

STANDARD

Page 1 Of 1

CLIENT NAME: CDM

PROJECT: GWR Treatment Pilot Study - Quarterly Sampling

ADDRESS: 523 W. Sixth St. Suite 400 Los Angeles CA 90014

PHONE: 213-457-2200

FAX:

EMAIL: smitheh@cdm.com

PROJECT MANAGER: Greg Wetterau

SAMPLER

SPECIAL HANDLING

☐ Same Day Rush 150%
☐ 24 Hour Rush 100%
☐ 48-72 Hour Rush 75%
☐ 4 - 5 Day Rush 30%
☐ Rush Extractions 50%
☑ 10 - 15 Business Days
☐ QA/QC Data Package

Charges will apply for weekends/holidays

Method of Shipment:

ANALYSES REQUESTED

ID# (For lab Use Only)	DATE SAMPLED	TIME SAMPLED	SMPL TYPE	SAMPLE IDENTIFICATION/SITE LOCATION	# OF CONT.	1,4- Dioxane (2 per location)	504.1 edb-dbcp (Fumigants)			508 Organo Pest+PCBs (2 per location)	PPCP Pharma +/- (2 per location)	515.3 Herbicides				COMMENTS
				Source Water	8					X	X	X				
				MF Effluent	1											
				RO Feed	4		X									
				RO Filtrate	0											
				RO Concentrate	0											504 has 2 per location
				AOP Influent	11	X	X				X					
				UV Effluent	0											
				O3 Effluent	0											

RELINQUISHED BY	DATE / TIME	RECEIVED BY
RELINQUISHED BY	DATE / TIME	RECEIVED BY
RELINQUISHED BY	DATE / TIME	RECEIVED BY

SAMPLE CONDITION:

Actual Temperature:

Received On Ice	Y / N
Preserved	Y / N
Evidence Seals Present	Y / N
Container Attacked	Y / N
Preserved at Lab	Y / N

SAMPLE TYPE CODE:
AQ=Aqueous
NA= Non Aqueous
SL = Sludge
DW = Drinking Water
WW = Waste Water
RW = Rain Water
GW = Ground Water
SO = Soil
SW = Solid Waste
OL = Oil
OT = Other Matrix

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CHAIN OF CUSTODY RECORD

STANDARD

Page 1 Of 1

CLIENT NAME: CDM

PROJECT: GWR Treatment Pilot Study - Monthly Samples

ADDRESS: 523 W. Sixth St. Suite 400 Los Angeles CA 90014

PHONE: 213-457-2200

FAX:

EMAIL: smitheh@cdm.com

PROJECT MANAGER: Greg Wetterau

SAMPLER:

SPECIAL HANDLING

☐ Same Day Rush 150%
☐ 24 Hour Rush 100%
☐ 48-72 Hour Rush 75%
☐ 4 - 5 Day Rush 30%
☐ Rush Extractions 50%
☑ 10 - 15 Business Days
☐ QA/QC Data Package

Charges will apply for weekends/holidays

Method of Shipment:

ANALYSES REQUESTED

ID# (For lab Use Only)	DATE SAMPLED	TIME SAMPLED	SMPL TYPE	SAMPLE IDENTIFICATION/SITE LOCATION	# OF CONT.	1x250ml P (HNO3) 200.7 K, B, 200.8 Fe, Mn	1x250ml P (HNO3) 200.7 Ba	1x40ml (EDA) 326 Bromide	1x250ml P (None) 300.0 Chloride	2x1L A (None) 1,4-Dioxane (2 each location)	1x250ml P (H2SO4) TKN	1x250ml (NH4CL) 552.2 Haloacetic Acids (HAA5)	1x250ml P (Nitrate) NO2, NO3 353.2, Ammonia-NH3	1x500ml (H2SO4) TOX SM5320B	2x1L (HCL) 525.2 Reg+507 (2 each location)	3x40ml G (HCL) 524.2 VOC:THMs only	1x1L WG (HCL) Oil and Grease	2x1L (Sodi- um Azide) PPCP Pharma Pos-TCEP only	COMMENTS
Source Water			W	Source Water	12	X	X	X			X	X		X	X	X	X		
MF Effluent			W	MF Effluent															PPCP has 2 per location
RO Feed			W	RO Feed	9	X	X		X			X				X		X	
RO Filtrate Combined			W	RO Filtrate Combined	10	X			X			X	X	X		X		X	
RO Filtrate A			W	RO Filtrate A	10	X			X			X	X	X		X		X	
RO Filtrate B			W	RO Filtrate B	10	X			X			X	X	X		X		X	
RO Concentrate			W	RO Concentrate	5	X	X		X		X		X						
AOP Influent			W	AOP Influent	2													X	
O3 Effluent			W	O3 Effluent	10					X	X	X	X			X		X	

RELINQUISHED BY	DATE / TIME	RECEIVED BY
RELINQUISHED BY	DATE / TIME	RECEIVED BY
RELINQUISHED BY	DATE / TIME	RECEIVED BY

SAMPLE CONDITION:

Actual Temperature:

Received On Ice Y / N
Preserved Y / N
Evidence Seals Present Y / N
Container Attacked Y / N
Preserved at Lab Y / N

SAMPLE TYPE CODE:
AQ=Aqueous
NA= Non Aqueous
SL = Sludge
DW = Drinking Water
WW = Waste Water
RW = Rain Water
GW = Ground Water
SO = Soil
SW = Solid Waste
OL = Oil
OT = Other Matrix

PRESCHEDULED RUSH ANALYSES WILL TAKE PRIORITY
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Page 1 Of 1

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EMAIL: smitheh@cdm.com
PROJECT MANAGER: Greg Wetterau
SAMPLER:

SPECIAL HANDLING

☐ Same Day Rush 150%
☐ 24 Hour Rush 100%
☐ 48-72 Hour Rush 75%
☐ 4 - 5 Day Rush 30%
☐ Rush Extractions 50%
☑ 10 - 15 Business Days
☐ QA/QC Data Package

Charges will apply for weekends/holidays
Method of Shipment:

						ANALYSES REQUESTED										
ID# (For lab Use Only)	DATE SAMPLED	TIME SAMPLED	SMPL TYPE	SAMPLE IDENTIFICATION/SITE LOCATION	# OF CONT.	1,4- Dioxane (2 per location)	504.1 edb-dbcp (Fumigants)			508 Organo Pest+PCBs (2 per location)	PPCP Pharma +/- (2 per location)	515.3 Herbicides				COMMENTS
				Source Water	8					X	X	X				
				MF Effluent	1											
				RO Feed	4		X									
				RO Filtrate	0											
				RO Concentrate	0											504 has 2 per location
				AOP Influent	11	X	X				X					
				UV Effluent	0											
				O3 Effluent	0											

RELINQUISHED BY	DATE / TIME	RECEIVED BY
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SAMPLE CONDITION:

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Appendix D

Membrane Autopsy Report

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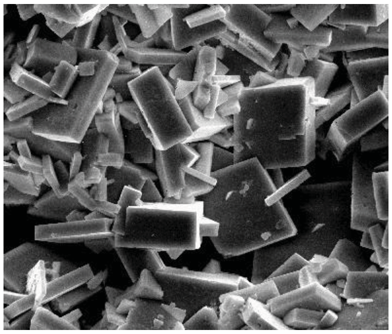
Membrane Autopsy Report

Completed for:

CDM



August 2010
WO#070210-3

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FOCUSED SOLUTIONS

CONTENTS

APPENDIX A –

APPENDIX B –

EXECUTIVE SUMMARY

CDM provided one Hydranautics ESPA2-4040 reverse osmosis membrane (SN#6008008671) to Avista Technologies for analysis. SN# 6008008671 was wet tested on San Marcos, CA tap water and data was normalized to manufacturer's standard conditions. Element SN# 6008008671 was then weighed and dissected for autopsy. Please refer to the element drawing in Appendix A for an explanation of the terms used throughout this report.

SN# 6008008671 produced no flow upon baseline wet testing and during the flat sheet pre-test. There was no evidence of mechanical failure (i.e. glue line failure or delamination) observed during internal membrane inspection.

Very little visible foulant material was observed on the membranes surfaces of SN#6008008671. Insufficient foulant material was present on the membrane surfaces to perform organic content (LOI), foulant density, microscope analysis and zeta potential. FT-IR analysis showed trace amounts of organic matter fouling (carbohydrates and polysaccharides). SEM/EDX identified silica scale with trace amounts of clay and iron oxide as the primary inorganic foulants.

RoClean L403 followed by P112 restored the water passage; however, the Fujiwara test was positive for the presence of halogen (i.e. chlorine) on SN#6008008671. High salt passage post clean is likely due to halogenation of the rejecting membrane surface.

Supporting data is included in the Procedures and Results, or Foulant Analysis sections of this report.

PROCEDURES AND RESULTS

WET TEST

The element was wet tested on dechlorinated San Marcos, CA city water. Wet test results were normalized to the manufacturer's published test conditions. Wet testing was unable to be performed due to lack of flow produced by the full element.

ELEMENT WEIGHT

Because element weight is often indicative of the degree of fouling, elements are weighed prior to the autopsy. SN# 6008008671 weighed 9 pounds; new elements of this model weigh approximately 7-9 pounds.

EXTERNAL INSPECTION

Fiberglass wrap:

The outer fiberglass casing was in satisfactory condition.

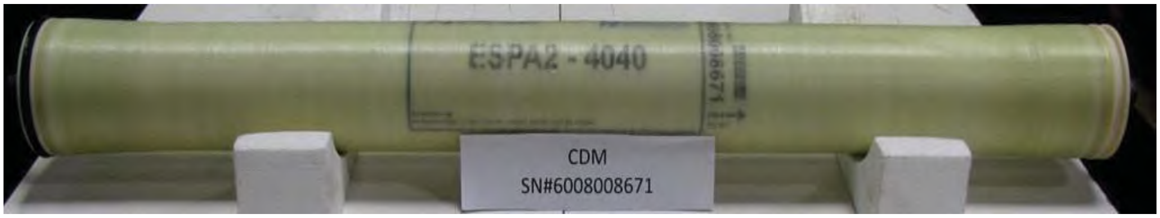


Figure 1: External fiberglass casing with damage for SN# 6008008671.

Telescoping of element leaves:

Both ends of the element were examined for signs of membrane and feed spacer extrusion. This type of damage is termed "telescoping" and is caused by the development of high differential pressure (usually greater than 12 psi) across the element. No telescoping was observed on the element.

Brine seal:

The brine seal was in good condition and showed no signs of damage that could allow bypass of the RO concentrate water around the spiral wound membrane scroll.

Anti-telescoping device (ATD):

ATD's are designed to prevent telescoping of element leaves at normal differential pressures. ATD's of SN# 6008008671 showed no signs of physical damage.

PROCEDURES AND RESULTS

Permeate tube:
No gouges were visible on the ends of the permeate tube that could allow the by-pass of feed water.

INTERNAL EXAMINATION

Membrane Surface:
Very little visible foulant material was observed on the membrane surfaces of SN# 6008008671.

Figure 2: Exposed membrane surface for SN# 6008008671.

PROCEDURES AND RESULTS

Fujiwara Test:

The Fujiwara test is used to confirm that a polyamide (PA) thin-film membrane has been exposed to an oxidizing halogen, such as chlorine, bromine, or iodine. This test analyzes qualitatively whether halogens have become part of the polymer structure through oxidative attack.

Fujiwara testing was positive for samples from element SN# 6008008671.

Feed spacer:

The feed spacer is a plastic net material (Vexar) designed to separate membrane leaves to form a flow path and to promote turbulence within feed water passages. The feed spacer for SN# 6008008671 was in good condition.

Permeate spacer:

Permeate spacer (Tricot) provides a path for permeate flow to central permeate tube which minimizes permeate-side pressure losses. Tricot was in good condition for element SN# 6008008671.

Glue lines:

Membrane leaves are glued on three sides to separate feed and permeate streams. Glue lines in element SN# 6008008671 were in good condition and showed no signs of pouching or delamination.

PROCEDURES AND RESULTS

CELL TEST & LABORATORY CLEAN-IN-PLACE STUDY

Membrane samples were tested in a cell test apparatus with dechlorinated San Marcos, CA city water to determine membrane performance characteristics.

The permeate flow constant is expressed as the "A" value, and the salt passage constant is expressed by a "B" value. Both constants are functions of the chemical-physical properties of the membrane plus any fouling layer present.

"A" and "B" value constants are also independent of operating parameters such as pressure, temperature, and salt content of the feed stream. "A" value units are cm/sec/atm. "B" value units are cm/sec. The table below shows performance data before and after cleaning. RoClean L403 and P112 solutions were used at standard dilution (2% by weight in RO/DI water) and heated to 40-45˚C for 2 hours before rinsing. Rinsing occurred between subsequent treatments of L403 and P112.

Hydranautics ESPA2-4040 SN#6008008671	**"A" Value**	**"B" Value**
Baseline Flat Sheet Membrane	No flow	No flow
L403 & P112 Post-Cleaning	1.57 E-04 116% of Normal	29.8 E-06 403% of Normal
Manufacturer's original specifications	1.00 to 1.35 E-04 Normal Range	5.46 to 7.39 E-06 Normal Range

FOULANT ANALYSIS

Loss on ignition:
Loss on ignition gives an approximation of the organic content of the foulant. Values in excess of about 35% represent a significant organic content. Insufficient foulant material was present on the membrane surface to perform organic content (LOI).

Membrane foulant density:
Membrane foulant density is the weight of dry foulant per area of membrane surface. Foulant densities determined from past autopsies range from 0.04 to 1.6 mg/cm^2 and average 0.203 mg/cm^2. Insufficient foulant material was present on the membrane surface to perform foulant density.

Acid test:
Several drops of dilute hydrochloric acid were placed on the foulant surfaces. Bubbles indicate the presence of carbonates. No bubbles were observed on the membrane surface of element SN#6008008671.

Microbiological examination:
Microscope analysis is performed by staining the foulant samples and examining the foulant material with a light microscope (1000x). Gram positive bacteria are stained blue while Gram negative bacteria are stained red. The foulant material on SN#6008008671 adhered too tightly to the membrane surface to perform microscope analysis.

FOULANT ANALYSIS

ZETA POTENTIAL:

Most naturally occurring colloids are negatively charged and surrounded by a double layer of counter ions. Zeta potential is the charge that resides at the double layer boundary, which we can conveniently measure with a zeta potential meter.

Electrostatic repulsion becomes significant when two colloids approach each other and their charged double layers begin to interfere. Because of this mutual repulsion, coagulation and flocculation are difficult to accomplish and coagulants are often overfed into the RO system resulting in a positive zeta potential. Samples that show a near zero or neutral zeta potential represent the optimum coagulant dosage.

In order to perform a zeta potential 2 grams of wet foulant must be suspended in 200 mL of deionized H_2O + 10 ppm NaCl. Insufficient foulant material was present on the membrane surface to perform zeta potential.

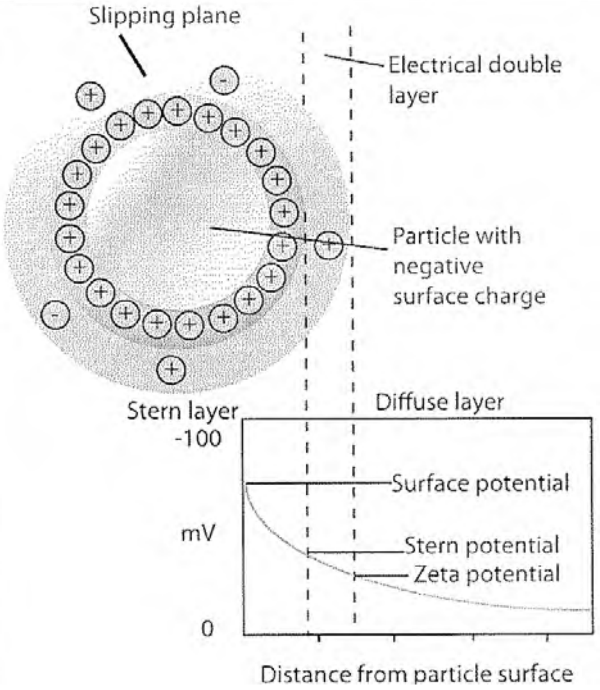


Figure 3: Image from Particle Characterization Laboratories, Inc. in Novato, CA.

PROCEDURES AND RESULTS

Fourier Transformed Infrared (FT-IR) analysis:
FT-IR analysis identifies organic foulant constituents. FT-IR is a measurement technique whereby spectra are collected based on measurements of the temporal coherence of a radiative source, using time-domain measurements of the electromagnetic radiation or other type of radiation. Spectra are compared against a library of more than 71,000 known constituents (FtirSearch.com).

Foulant was analyzed with a Perkin-Elmer 1600 FT-IR with a HATR (ZnSe crystal) attachment. FT-IR spectrum of foulant from SN# 6008008671 displayed trace amounts of organics (carbohydrates, and polysaccharides).

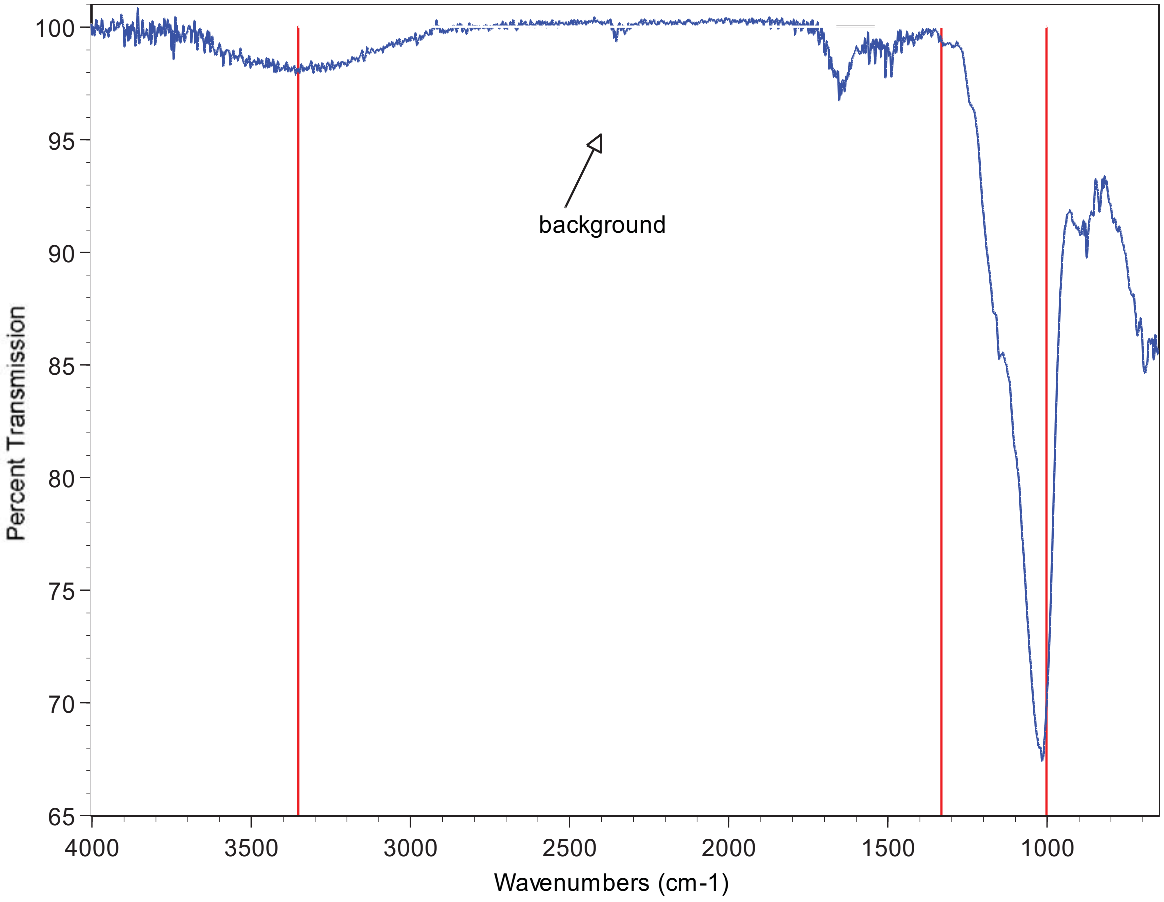


Figure 4: FT-IR spectral image of foulant material from SN# 6008008671.

FOULANT ANALYSIS

Scanning Electron Microscopy /Energy Dispersive X-ray Analysis (SEM/EDX):
EDX analysis is conducted in conjunction with scanning electron microscopy (SEM) to identify inorganic foulant constituents. In this technique, a Phillips XL30 FEG field emission microscope with an energy dispersive X-ray spectrometer is used for analysis. The electron beam in the microscope causes specimens to emit x-rays including those from the k, l and m atomic shells. Spectrometer counts of these x-rays, which are said to be "characteristic" of the elements present in the specimen, can be used to calculate composition for a full qualitative analysis. The analysis is non-destructive and is accurate to ~1%. This technique determined the elements silicon, aluminum, calcium, and iron to be the primary inorganic foulants. All inorganic constituents are listed in the table below and an SEM image of this foulant can be viewed in Appendix B, Figure 1.

Elements (wt. %)	**SN#6008008671**
Carbon	10.5
Nitrogen	<0.2
Oxygen	40.4
Sodium	0.6
Magnesium	0.6
Aluminum	**8.2**
Silicon	**34.8**
Phosphorous	<0.2
Sulfur	0.3
Chlorine	<0.2
Potassium	0.9
Calcium	**2.9**
Iron	**0.3**

APPENDIX A

Spiral Wound Membrane Construction

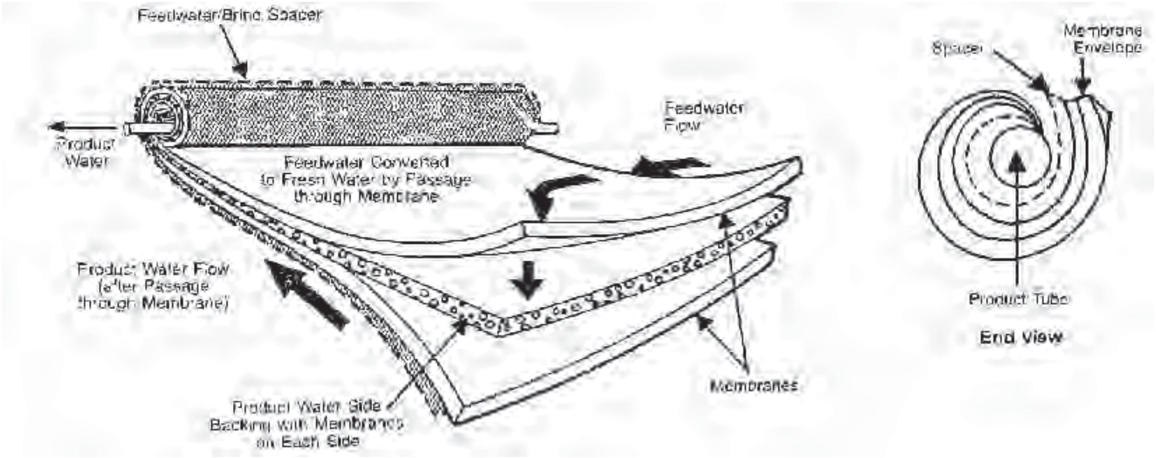


Diagram of a Spiral Wound Reverse Osmosis Element

APPENDIX B

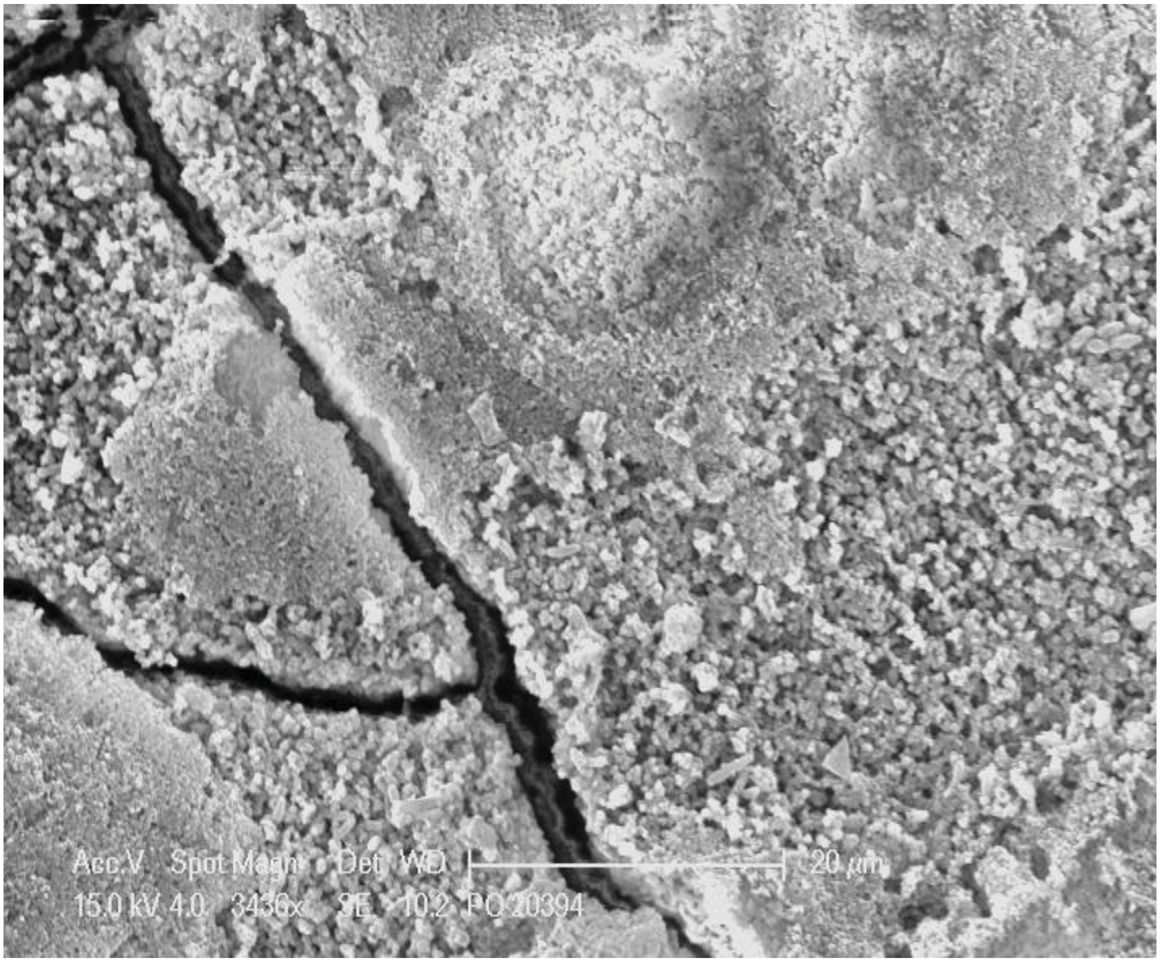


Figure 1: SEM image of foulant from SN# 6008008671.

O.S.C.A.R. RESULTS

Customer Information:

Name:	CDM
End User:	
Date:	7/14/10
Customer PO:	86538-71984
Work Order No:	070210-3
Membranes Cleaned:	1

Hydranautics
ESPA2-4040

Normalized Conditions:

Temperature, °C:
Net Driving Pressure, psig: 133.5
Norm Recovery, %: 15

OEM Specifications:

Flow Rate: 1.1 to 1.3
% Rejection: 99.4% to 99.6%

Serial Number	Test	Delta Pressure psi	Normalized Results		Notes
			Flow, gpm	Rejection, %	
6008008671	Pre Clean	3			No flow
	Post Clean				

Thank You For Your Business!

Reverse Osmosis Membrane Element

Foulant Study

for

CDM Rancho Cucamonga

September 2011

September 13, 2011

Greg Wetterau
9220 Cleveland Ave #100
Rancho Cucamonga, CA 91730
909-579-3500
wetteraugd@cdm.com

Subject: Reporting Results of Autopsy and Foulant Analysis

Dear Mr. Wetterau:

We are pleased to report our Foulant Study findings based on testing CSM model RE4040-FEN and Toray model TML 10.

This report was done under CDM Rancho Cucamonga PO# 86538-71984 .

Background

Both elements were used in a pilot test during which they were cleaned one or two times, and may have some exposure to chlorine due to injection of chloramines upstream.

Goal of the Study

Verify the elements' performance and determine the nature of foulant on the membrane.

Wet Test

Upon arrival the test element productivity was characterized using the manufacturer's wet test conditions. See Appendix A. The CSM element manufacturing specifications are 2100 gpd and 99.7% salt rejection. The CSM test element had productivity of 2792 gpd (133% of nominal flow) and 99.2% salt rejection (0.5% less than spec).

The Toray element manufacturing specifications are 1850 gpd and 99.7% salt rejection. The Toray test element had 2346 gpd (127% of nominal flow) and 98.9% salt rejection (0.8% less than spec).

Autopsy

The CSM element serial number BAJAAO45A003 was examined upon arrival and before the membrane scroll was unrolled. See Appendix B, Figure 1. No exterior defects were seen. No foulant was seen on the feed end of the element. The element was opened for examination by removing the outer wrap and unrolling the membrane scroll. See Figure 2. The membrane surface appeared clean as shown in Figure 3. To gather sufficient foulant for analysis, all membrane leaves were flooded and the rinse collected. A sample of the rinse is shown in Figure 4.

No mechanical defects were seen.

The Toray element serial number 101022871 was examined in the same way as the CSM element. As was seen with the first membrane there was no foulant on the feed end of the element (see Figure 5) or on the surface of the membrane (see Figures 6 and 7). Again entire surface of membrane was flooded and rinse collected. See Figure 8.

No mechanical defects were seen.

Foulant Analysis

Representative foulant from the surface of the element was harvested, and washed several times with RO permeate water by mixing and decantation. After drying at 120-130 ^{0}C, the dried foulant was analyzed quantitatively for absolute % by weight of carbon, hydrogen and nitrogen and ash, and by Scanning Electron Microscopy with Energy Dispersive X-Ray (SEM-EDX) for relative % composition of all elements with atomic number of magnesium and higher.

For the CSM element, the C, H, N results (Appendix C) showed that the foulant is composed of 87% of organic material and 13% of inorganic material. The SEM-EDX results (Appendix D) on inorganic components showed 7.8% aluminum, and smaller percentages of silicon, calcium, iron, sodium, magnesium and sulfur.

For the Toray element, the C, H, N results (Appendix C) showed that the foulant is composed of 93% of organic material and 7% of inorganic material. The SEM-EDX results (Appendix D) on inorganic components showed small percentages of silicon, calcium, sulfur, iron, chlorine, magnesium, aluminum and sodium.

Conclusions and Recommendations

The membrane surfaces were, for practical consideration, perfectly clean. The majority of the small amount of foulant present was the ubiquitous bacteria slime found on all membranes.

Both elements had slightly low salt rejection and approximately 130% of nominal productivity. Elements with this ‘looseness’ typically have been exposed to a small amount of oxidant. It is possible that some free chlorine exposure occurred during the injection of chloramine upstream. Also if the membranes were cleaned when there was little or no foulant present, some chemical aging of the membrane may have occurred.

Please feel free to call us if you have any questions.

Sincerely,

Tom Troyer, MS

Appendix A

Element Cleaning Results

King Lee Technologies Cleaning Data Sheet

Commercial Information			**Technical Information**			**Manufacturing Test Specifications**		
Date Element Rec'd	8/23/2011		Element Manufacturer	CSM	Toray	Net Pressure	200	Psig
Client	CDM		Element Model	RE4040-FEN	TML 10	Recovery	15%	
Contact	Greg Wetterau		Productivity, GPD	2100	1850	Temperature	77	
PO#	86538-71984	Rancho Cau.	%Rejection	99.7%	99.7%	Test Solution	2000	ppm NaCl

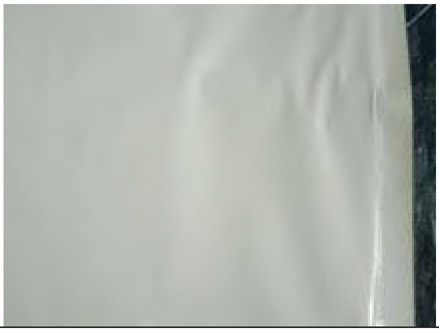
Date	S/N	Cleaner	Soak Time	Circ Time	Differential Pressure DP	Perm Pressure Pp	Feed Pressure Pc	Feed Temp Tf	Perm Flow Fp	Conc Flow Fc	Feed Cond. Cf	Perm Cond. Cp	Norm GPD	Norm %Rej	% Nominal Productivity
23-Aug	BAJAAO45A003	Pretest					200	78.8	1.740	8.000	850	5	2792	99.2%	132.9%
23-Aug	101022871	Pretest					200	78.8	1.460	8	850	8	2346	98.9%	126.8%

Notes:

Appendix B

Pictures of Autopsied Element

Serial Number BAJAAO45A003

Figure 1 Feed End 	**Figure 2 Unrolled Element** 
Figure 3 Membrane Closeup 	**Figure 4 Collected Foulant** 

Serial Number 101022871

Figure 5 Feed End 	**Figure 6 Unrolled Element** 
Figure 7 Membrane Closeup 	**Figure 8 Collected Foulant** 

Appendix C

Carbon, Hydrogen, Nitrogen and Ash Analyses For the Organic Portion of the Foulant (Absolute % By Weight)

Serial Number BAJAAO45A003

Carbon	38.15
Hydrogen	6.26
Nitrogen	4.28
Residual*	38.3
Ash	13.01
Total	100.0

*Residual volatile elements not analyzed mostly composed of oxygen.

Serial Number 101022871

Carbon	43.78
Hydrogen	7.44
Nitrogen	5.33
Residual*	36.8
Ash	6.63
Total	100.0

*Residual volatile elements not analyzed mostly composed of oxygen.

Appendix D

Scanning Electron Microscopy with Energy Dispersive X-Ray (SEM-EDX) (Relative weight % composition of all elements with atomic numbers between magnesium-12 and molybdenum-42)

Serial Number BAJAAO45A003

Element	% of Ash	% of Foulant
Aluminum	60.0	7.81
Silicon	13.3	1.73
Calcium	11.1	1.45
Iron	6.7	0.87
Sodium	4.4	0.58
Magnesium	2.2	0.29
Sulfur	2.2	0.29

Total	100.0	13.01

Serial Number 101022871

Element	% of Ash	% of Foulant
Silicon	27.3	1.81
Calcium	25.0	1.66
Sulfur	20.5	1.36
Iron	9.1	0.60
Chlorine	6.8	0.45
Magnesium	4.5	0.30
Aluminum	4.5	0.30
Sodium	2.3	0.15

Total	100.0	6.63

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Appendix E

AOP Background Information

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Attachment G:

Section G.1: Flow Regime Characterization

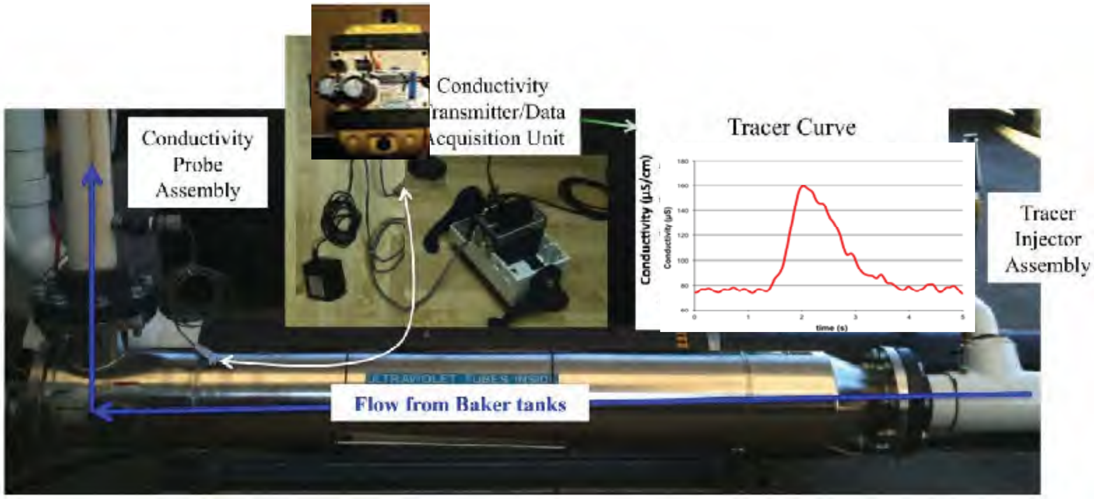
It is imperative to achieve adequate flow conditions at the pilot-scale so the knowledge gained during pilot testing is scalable and can be used to accurately predict the performance expectations of a full-scale treatment system. In an effort to simulate full-scale hydraulic conditions the pilot UV/peroxide is equipped with two Baker tanks (6900 gallon capacity each), a VFD pump and a flow control setup to operate the reactor at flowrates (100-350 gpm) that result in higher Reynold's numbers and a greater degree of turbulence.

The goal is that for the unit to achieve plug flow and that all the flow leaving the reactor receives the same UV exposure. In order to achieve plug flow, the design of the reactor must minimize axial mixing and dispersion. Axial dispersion is characterized by longitudinal mixing along the length of the UV reactor that distorts the flat velocity profile perpendicular to the direction of flow that is assumed for an ideal plug flow reactor. Because dispersion effects are dominated by turbulence at the macroscale, they are identical for all constituents and tracer tests can be conducted to characterize axial dispersion with any substance, including salt (Crittenden et al., 2005).

In order for all the flow to have the same UV exposure, the design of the reactor must maximize radial mixing, which occurs radially from the center line of the reactor to the reactor walls. Both of these objectives are more likely obtained under conditions of fully turbulent flow. Methods to measure each of these flow characteristics are described in the following paragraphs.

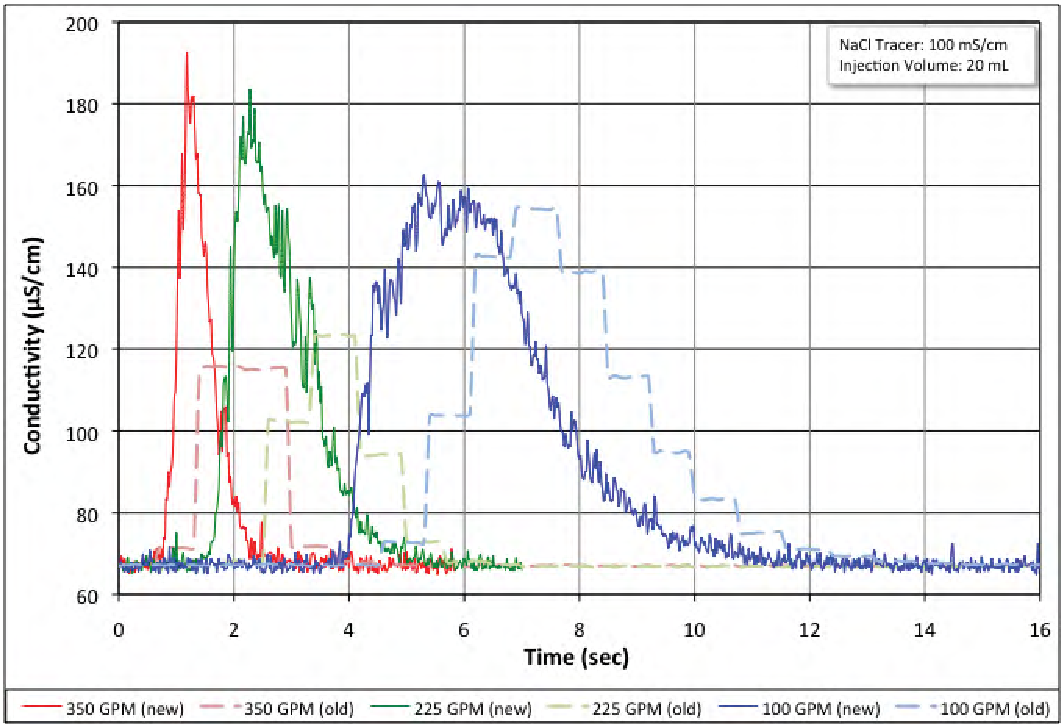
To quantify axial mixing, tracer studies with sodium chloride as a pulse of tracer are utilized. The overall procedure involves the injection of sodium chloride solution, upstream of the UV reactor, and subsequent measurement of the conductivity at the reactor outlet using a recording conductivity meter, as shown in Figure G.1-1. As will be shown below, the tracer test for UV reactors is complicated by short contact times in the UV reactor on the order of seconds, necessitating an automated way to transmit the measured conductivity data on the order of milliseconds. Tracer tests with rhodamine dye were ruled out because there was no equipment available to collect and record the data in an automated fashion with the necessary response time.

Figure G.1-1. Tracer Study Setup



Based on the tracer study results, the extent of axial mixing can be approximated. Preliminary, unfiltered results using the high-speed conductivity transmitter, along with the commercial transmitter results, are shown in Figure G.1-2.

Figure G.1-2: Preliminary Tracer Study Results Using the High-Speed Conductivity Transmitter



As evident from Figure G.1-2, the high-speed transmitter is able to capture the flow regime more accurately than the commercial unit. Further improvements were subsequently made to the high-speed transmitter, as discussed below.

With the improved conductivity transmitter (Figure G.1-3a) and an air-powered injector (Figure G.1-3b), the results obtained were more representative than those collected using the old configuration.

Figure G.1-3: Improved Conductivity Transmitter (a) and Air-Powered Injector (b)

(a) (b)

Results from this round of tracer testing are shown in Figure G.1-4 and G.1-5 for the UV/peroxide and ozone/peroxide systems, respectively. Each tracer test was repeated three times.

Figure G.1-4: Improved Tracer Study Results for UV/Peroxide System at Various Flowrates

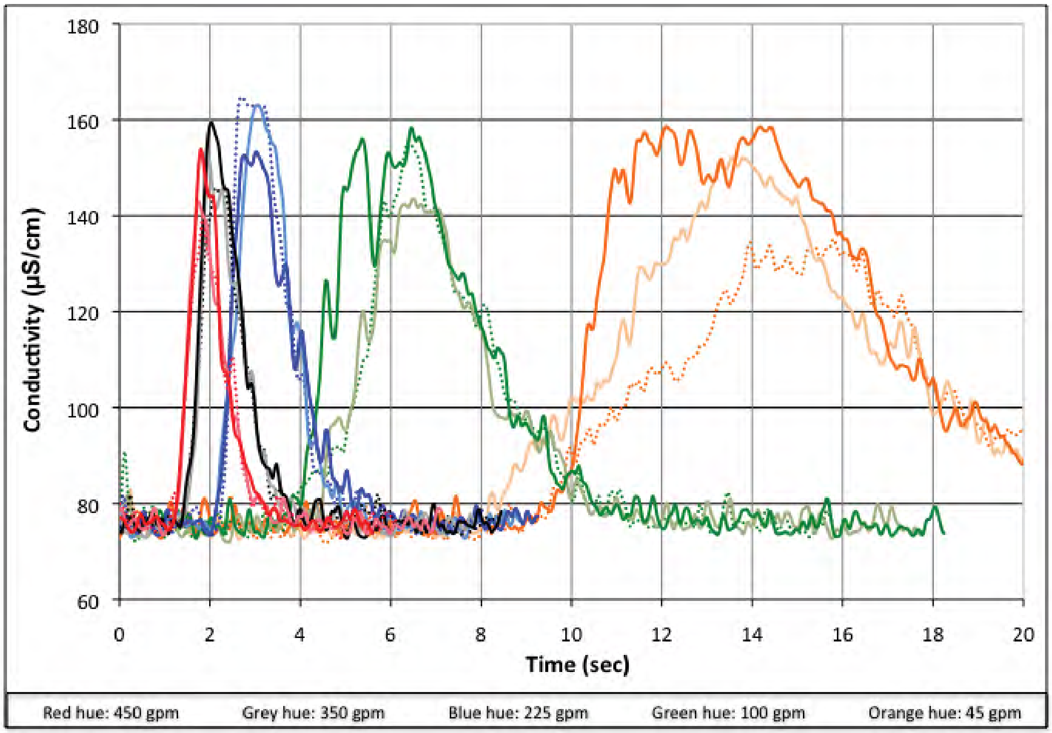
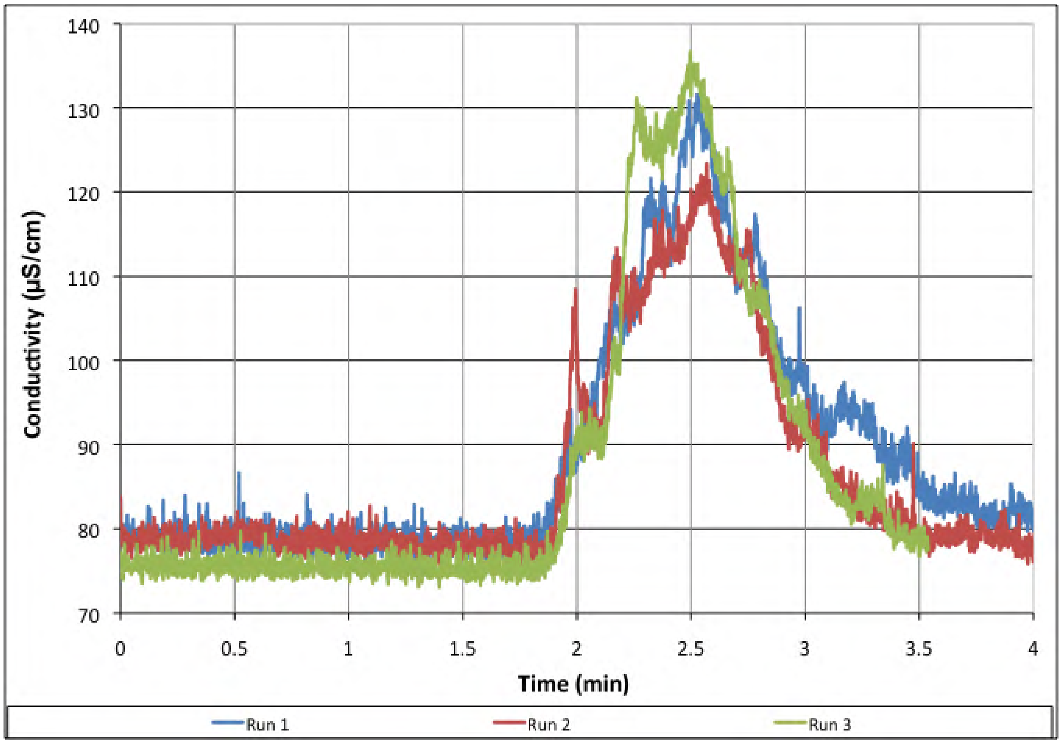


Figure G.1-5: Improved Tracer Study Results for the Ozone Contactor

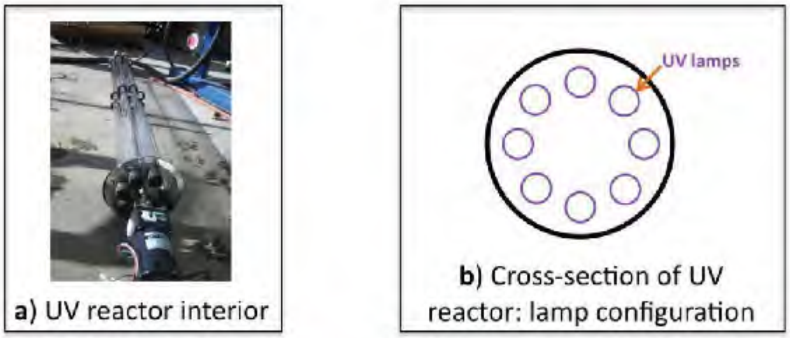


As evident from the tracer results for the ozone contactor, the contact time is slightly under 2 minutes and should suffice in the event CDPH requests a demonstration to prove that the ozone contactor meets the minimum regulated modal contact time (Figure G.1-5).

The same type of tracer test system can also be used to test the full-scale reactor (e.g., for the Trojan 72AL75 reactor) to assure adequate plug flow conditions. *This test can be an important part of confirming that the reactor provided by the UV manufacturer meets specified hydraulic characteristics.*

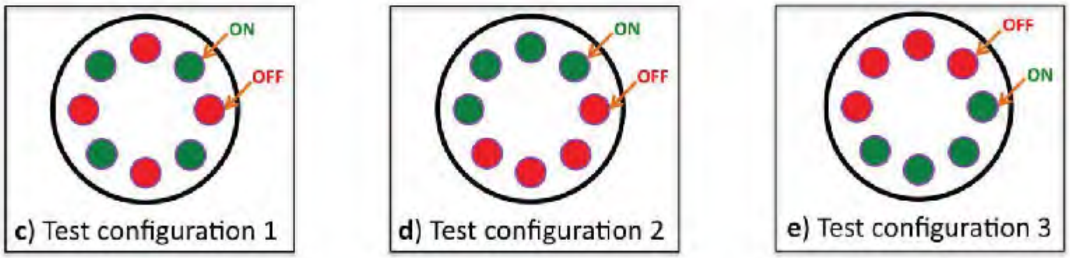
The UV reactor at the pilot site consisted of 8 lamps configured radially, shown in Figure G.1-6a and G.1-6b. The effectiveness of the UV reactor in achieving radial mixing was examined by comparing performance with different combinations of lamps on and off. The UV lamp configurations used to test the extent of radial mixing involve turning different lamps off in each test and are shown in Figure G.1-6c, G.1-6d and G.1-6e.

Figure G.1-6. Longitudinal Testing



a) UV reactor interior

b) Cross-section of UV reactor: lamp configuration



c) Test configuration 1

d) Test configuration 2

e) Test configuration 3

Theoretically, if there is good radial mixing, the contaminant removal under all test configurations should be equal. If radial mixing is poor, then performance will be different, depending on the combination of lamps on. Preliminary tests at 100 gpm resulted in chloramine log removals of 0.13, 0.12 and 0.12, respectively, for test configurations 1, 2 and 3. The lack of significant differences among the configurations tested suggests that radial mixing is adequate at 100 gpm.

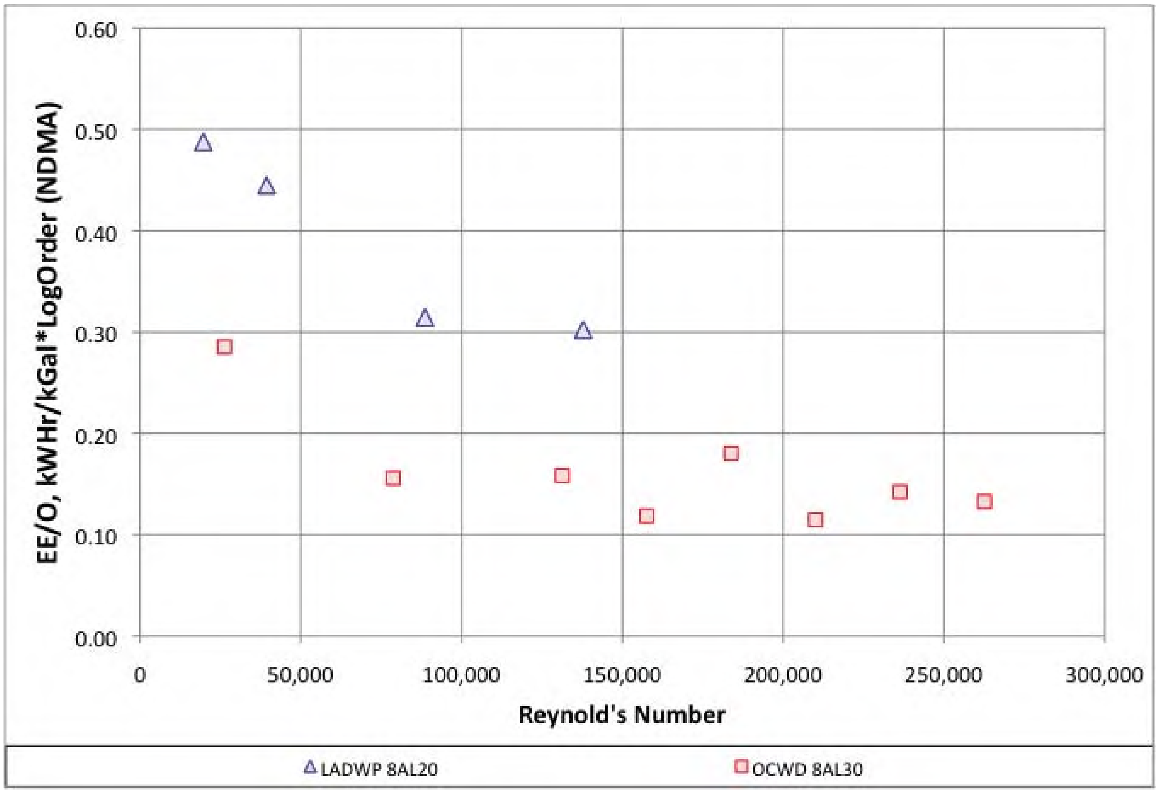
To evaluate if turbulent flow conditions were being realized within the UV reactor, the electrical efficiency[1] per log order reduction (EE/O) was assessed. The EE/O of a target constituent is typically expressed in kWh/1000 gal and defined for the UV/peroxide process as:

$$\mathrm{EE/O} = \frac{\text{Lamp Power Output}}{\text{Flowrate} \times \log\left(C_o/C_e\right)}$$

Work done during the development of the OC GWRS can be used to demonstrate that as the reactor is operated under increasingly turbulent conditions, as reflected by the Reynolds number or N_{RE}, the EE/O asymptotically approaches a minimum value. This characteristic is demonstrated in Figure G.1-7, which is based on work conducted by Murray and colleagues (2002) at the Orange County Water District (OCWD). Based on this work, it would appear that the EE/O reaches a minimum once the N_{RE} rises above approximately 100,000.

In accordance with EE/O and its relation to Reynold's number, adequate flow conditions were observed when the UV reactor was operated at flowrates of 225 gpm and above, as evident in Figure G.1-7.

Figure G.1-7: LADWP and OCDW EE/O and Reynold's Number



The EE/O asymptotically approaches a minimum value of 0.30 for the 8AL20 when the system is operated at Reynolds numbers greater than 90,000, which corresponds to flowrates above 225

---

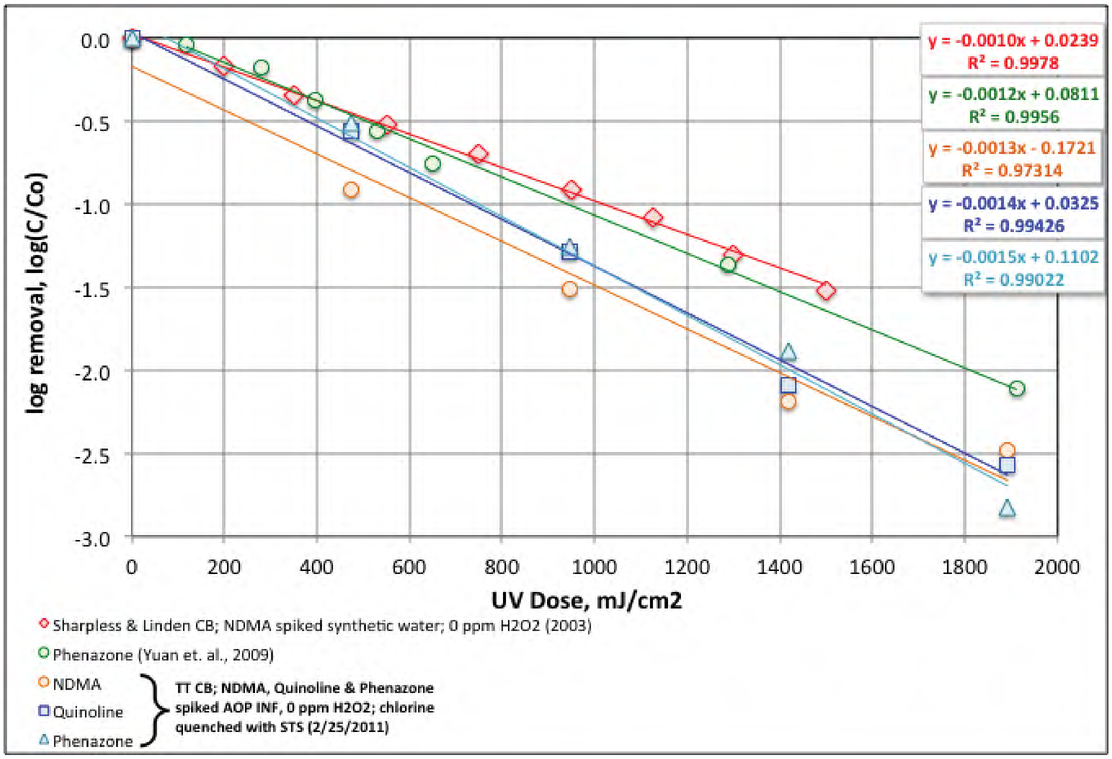
[1] The employment of energy usage of the lamps rather than light intensity is preferable, because light intensity meters within UV reactors have proven highly unreliable.

gpm. Figure G.1-7 aids in the development of the flow conditions that the manufacturer must deliver to minimize power consumption for a given log removal goal.

Section G.2: Assessment of Candidate Indicator Compounds

As the addition of toxic organics is not a good practice in field tests, additional bench-scale and field-scale testing of possible process calibration surrogates, such as quinoline and phenazone, will make it possible to conduct full-scale testing at a later time to determine if installed units meet specified UV dose requirements. As shown below, the dose-response curve for NDMA and Quinoline and Phenazone are very similar for the LADWP pilot AOP influent.

Table G.2-1. Dose Response Curves Generated for Potential Indicator Compounds and Comparison with NDMA and Published Values



Section G.3: Determination of Delivered Dose

Where establishing the specified UV dose is concerned, it is recommended that the NWRI approach for specification of disinfection reactors be adapted to use it for photolysis reactors designed to remove organic contaminants. Such an approach would include the use of bench-scale testing with a collimated beam (CB) apparatus in parallel with field-scale testing to confirm the delivered dose. The configuration for each of the 11 CB experiments are summarized in Table G.3-1.

Table G.3-1: Summary of Collimated Beam Experimental Configuration

Date	**1-Oct**	**16-Nov**	**23-Nov**	**8-Dec**	**16-Dec**	**16-Dec**	**3-Feb**	**22-Feb**	**24-Feb**	**25-Feb**
Matrix	AOP INF	AOP INF	AOP INF	DI water	AOP INF	DI water	AOP INF	AOP INF	AOP INF	AOP INF
H_2O_2, ppm	0	5.4	8.1	0	5.6	0	0	5.3	0	0
Chloramines quenched	No	No	No	n/a	Yes	n/a	No	No	Yes	Yes
NDMA spiked	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1,4-dioxane spiked	No	Yes	No	No	Yes	No	No	Yes	No	No
Other spike	No	No	No	No	Yes (Baker tank was spiked with a mixture of chemicals[1])	Yes (mixed chemical spiked[1])	No	No	Yes (Quinoline)	Yes (Phenazone & Quinoline)

[1] Spiked with Triclosan, Phenazone, Clofibric Acid, Quinoline and Sucralose

The following section presents a series of dose-response plots resulting from the CB experiments listed in Table G.3-1. Also, because typical water quality laboratories are not accustomed to analyzing high NDMA concentrations, there is potential for measurement errors due to issues related with extensive dilutions and the saturation of the cartridge used to extract NDMA from the sample. This issue became evident when it was observed that the recovery of one of the benchmarks used by the lab was below an acceptable level. These issues were addressed in a stepwise fashion. All samples analyzed after November 16th were diluted prior to extraction to mitigate cartridge saturation and all samples after Dec 16th utilize lower NDMA concentrations (appx. 700 ng/L) as compared to the original target concentration of 5000 ng/L. The most reliable data sets are considered below (Dec 8 and Feb 3 to 25).

NDMA CB

Figure G.3-1 provides a comparison between CB data for the direct photolysis of NDMA generated by Trussell Tech (TT) with a distilled water matrix and Sharpless and Linden (2003) with a synthetic water matrix.

Figure G.3-1: Collimated Beam Results using a Distilled Water Matrix Spiked with NDMA and Published Literature

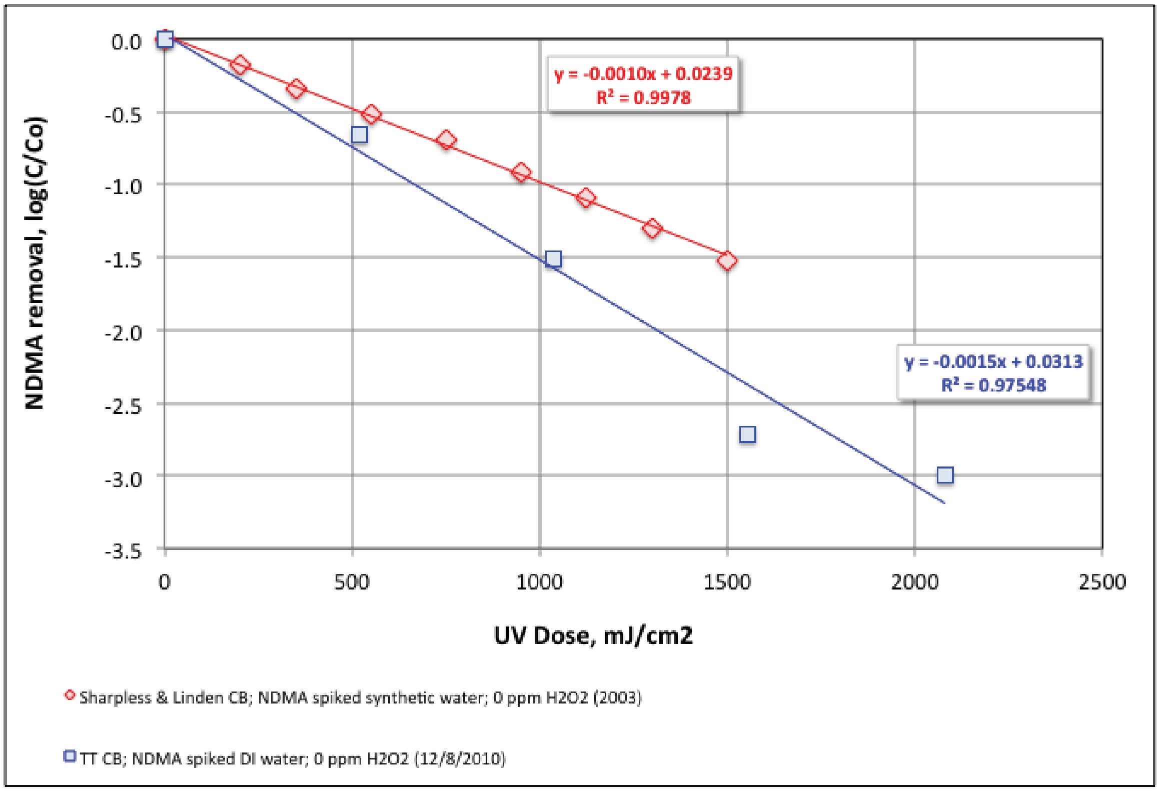

NDMA removal, log(C/Co)
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
0
500
1000
1500
2000
2500
UV Dose, mJ/cm2
y = -0.0010x + 0.0239
R² = 0.9978
y = -0.0015x + 0.0313
R² = 0.97548
Sharpless & Linden CB; NDMA spiked synthetic water; 0 ppm H2O2 (2003)
TT CB; NDMA spiked DI water; 0 ppm H2O2 (12/8/2010)

Figure G.3-2 provides a comparison between CB data for the direct photolysis of NDMA generated by Trussell Tech (TT) with a pilot RO permeate water matrix and again Sharpless and Linden (2003) with a synthetic water matrix.

Figure G.3-2: Collimated Beam Results using a Pilot RO Permeate Water Matrix Spiked with NDMA and Published Literature

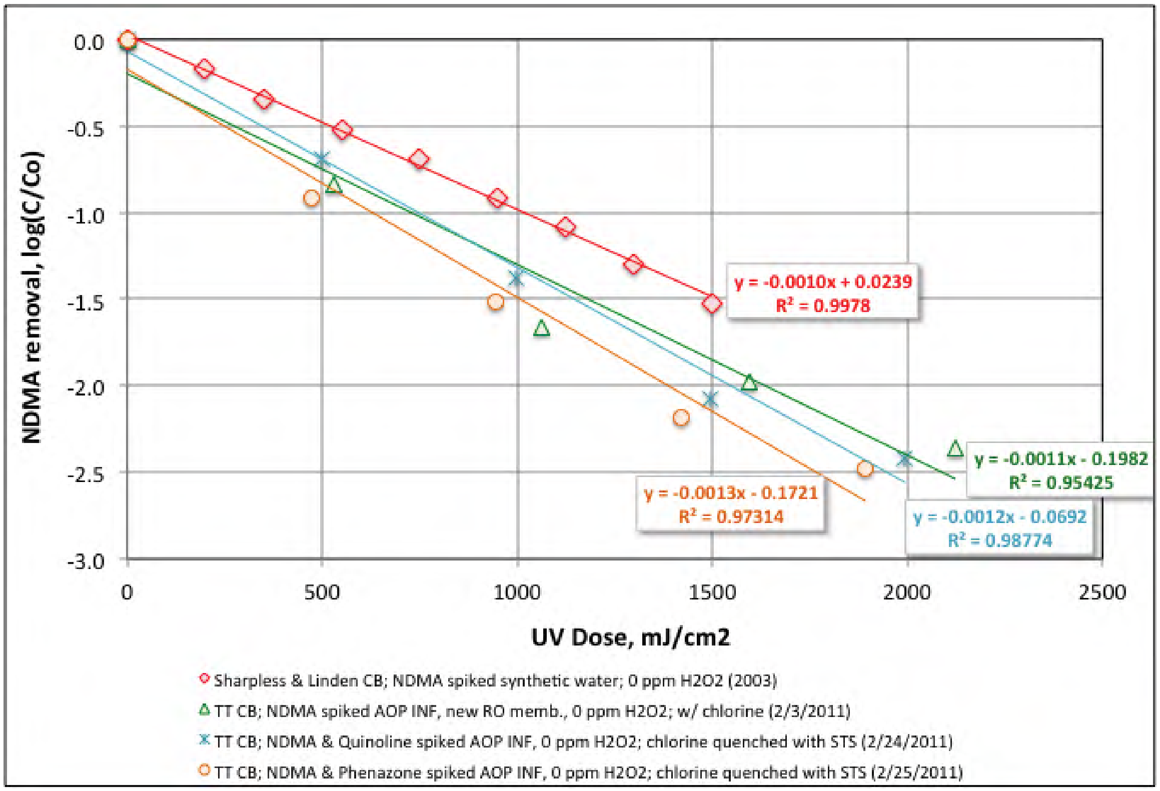
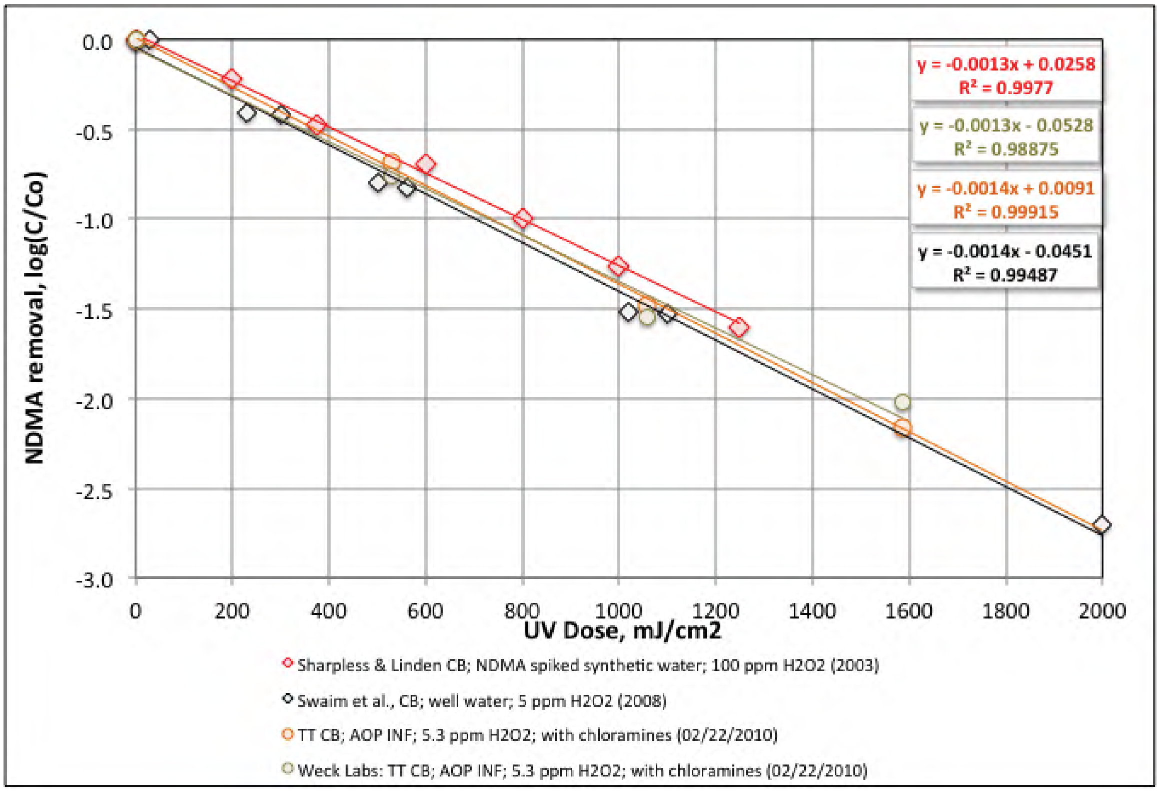


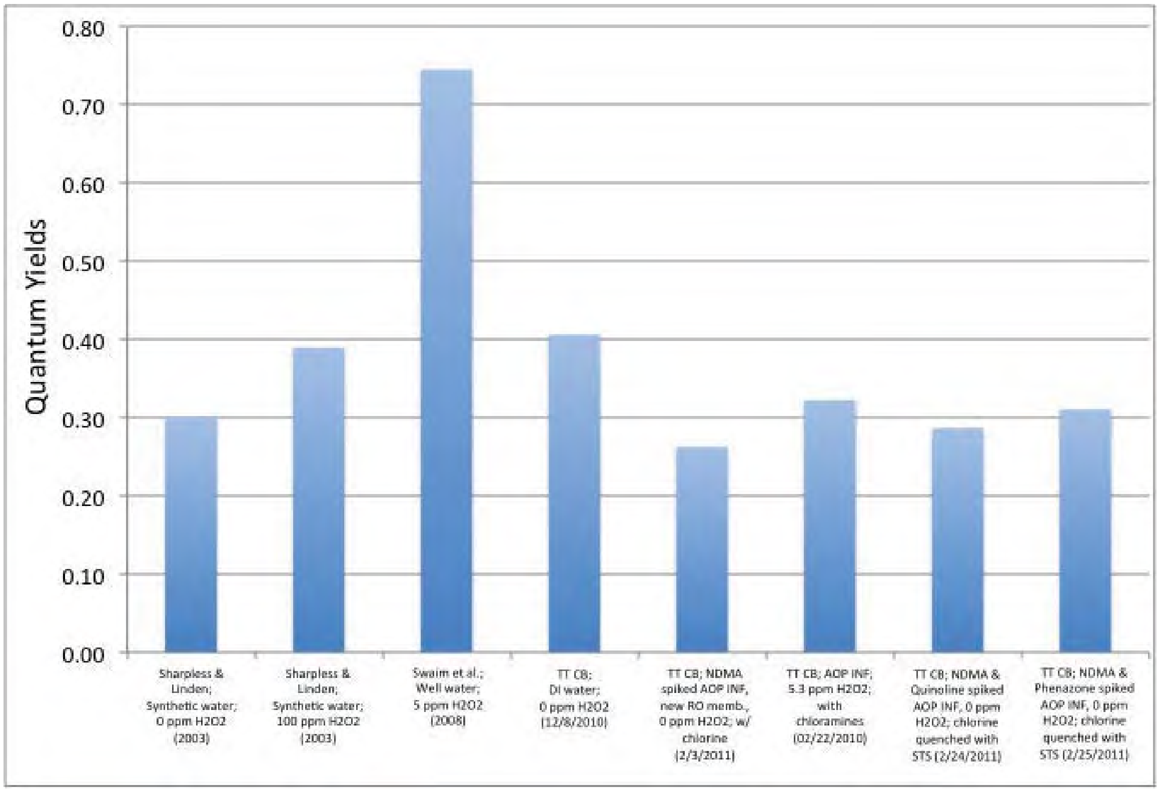
Figure G.3-3 provides a comparison between CB data in the presence of H_2O_2 for NDMA removal generated by Trussell Tech (TT) with a pilot RO permeate water matrix and published work by Sharpless and Linden (2003) with a synthetic water matrix and Swaim and colleagues (2008) with a well water matrix.

Figure G.3-3: Collimated Beam Results using a Pilot RO Permeate Water Matrix with H_2O_2 Spiked with NDMA and Published Literature



Observed quantum yields for NDMA based on experimental data are presented in Figure G.3-4.

Figure G.3-4: Computed Quantum Yields for NDMA



The quantum yields obtained from all experiments are comparable to the literature.

1. Methodology for the Evaluation of O_3/ H_2O_2 AOPs at the Bench Scale

For the ozone/hydrogen peroxide (O_3/H_2O_2) advanced oxidation process (AOP), it is beneficial to understand the removal kinetics via the O_3 and hydroxyl radical (•OH) pathways. An important element in the development of a kinetic model is the concentration of the O_3 and •OH oxidizers during the course of treatment. However, hydroxyl radicals are difficult to quantify because they are short-lived and present in low quasi-steady-state concentrations.

In an effort to overcome this shortcoming, Elovitz and von Gunten (1999) developed a novel bench-scale approach using perchlorobenzoic acid (pCBA) as a marker for the reaction with hydroxyl radicals to gain better understanding of the oxidative processes involving ozone and hydroxyl radicals. The pCBA reacts rapidly with hydroxyl radicals but has a comparatively low rate of reaction with ozone. The principal finding was that the oxidation of pCBA (utilization of hydroxyl radicals or $\bullet OH_{ct}$), had a linear relationship with ozone exposure, or ozone$_{CT}$ ($O_{3\text{-}ct}$). This finding is illustrated in a plot in Figure 1.

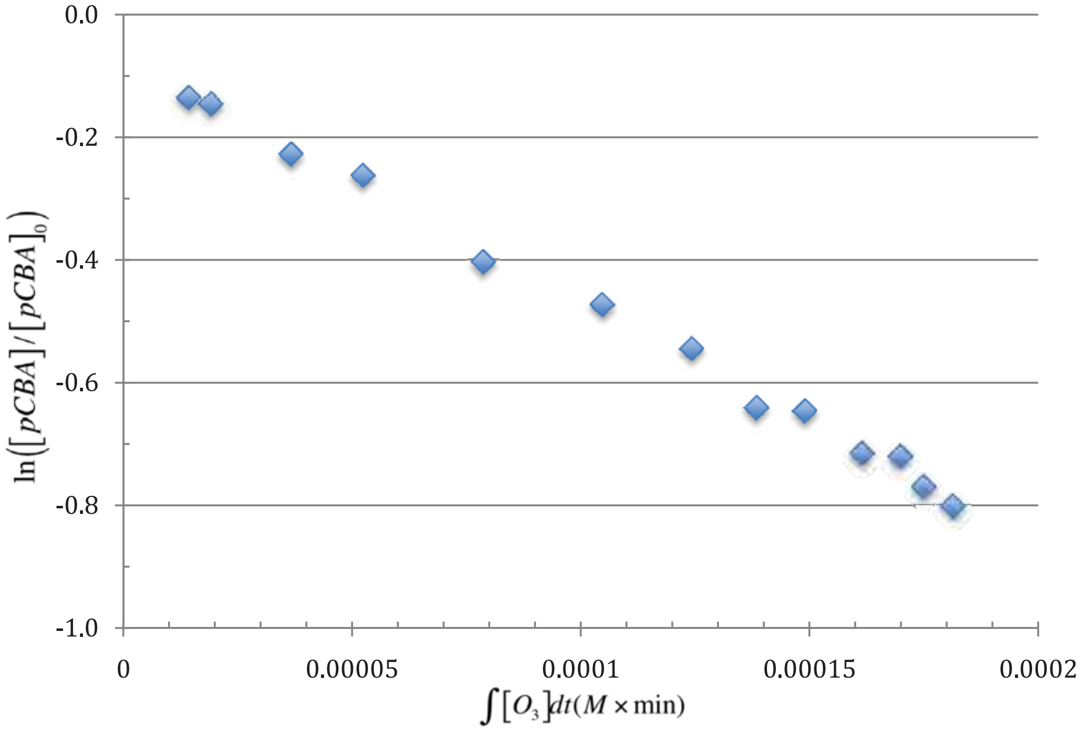


Figure 1. Linear Relationship Between Removal and Ozone Exposure, $O_{3\text{-}ct}$ ***(From*** Elovitz and von Gunten, 1999)

The best fit line of the plot in Figure 1 is as follows, with an assumed intercept of zero:

$$\ln\left(\frac{pCBA}{pCBA_0}\right)=m\times \mathrm{O_{3\text{-}ct}} \tag{1}$$

Equation 1 is clearly linked to secondary reaction kinetics. The degradation of pCBA and most micropollutants via the •OH and O_3 pathways follow the following equation:

$$\frac{d[P]}{dt}=k_{\bullet OH}[\bullet OH][P]+k_{O_3}[O_3][P] \tag{2}$$

The integrated form of this equation is as follows:

$$\ln\left(\frac{P}{P_0}\right)=-\left[\left(k_{\bullet OH/P}\right)\times\left(\bullet OH_{ct}\right)+k_{O_{3/P}}\times\left(\mathrm{O_{3\text{-}ct}}\right)\right] \tag{3}$$

In the case of pCBA, the •OH -probe:

$$k_{\bullet OH/pCBA}=5x10^{9}M^{-1}s^{-1}>>k_{O_{3/pCBA}}=0.15M^{-1}s^{-1}$$

This means that the dominant degradation pathway is via •OH and the degradation of pCBA can be simplified to:

$$\ln\left(\frac{[pCBA]}{[pCBA]_0}\right)=k_{\bullet OH/pCBA}\int[\bullet OH]\,dt \tag{4}$$

Setting Equation 4 equal to the equation of the best fit line from the plot in Figure 1 results in the following equation:

$$k_{\bullet OH/pCBA}\times OH_{ct}=m\times \mathrm{O_{3\text{-}ct}} \tag{5}$$

In their publication, Elovitz and von Gunten (1999) introduce the R_{ct} term, which they define as

$$R_{ct}=\frac{\bullet OH-\exp osure}{O_3-\exp osure}=\frac{\int[\bullet OH]dt}{\int[O_3]\,dt}=OH_{ct}/\mathrm{O_{3\text{-}ct}} \tag{6}$$

R_{ct} can be extracted from the resulting slope in the plot shown in Figure 1. Thus, combining Equation 5 and 6 results in the following:

$$\mathrm{R}_{ct}=m/k_{\bullet OH/pCBA} \tag{7}$$

Since the slope and $k_{\bullet OH/pCBA}$ are constant, it implies that R_{ct} is constant as well. With R_{ct} established, the OH_{ct} (from Equation 6) can be substituted into Equation 3 or 4 to result in the following equations containing terms that can be easily quantified:

$$\ln\left(\frac{[pCBA]_t}{[pCBA]_0}\right)=-k_{\bullet OH/pCBA}R_{ct}\int_0^t[O_3]\,dt \tag{8}$$

$$\ln\left(\frac{[P]_t}{[P]_0}\right) = -\left(\int_0^t [O_3]\,dt\right)\left(k_{\cdot OH}R_{ct} + k_{O_3}\right) \tag{9}$$

With Equation 9, it is possible to predict removals of a given constituent as long as the rate constants for •OH and O_3 are known, as well as R_{ct} for the water source of interest.

Elovitz and von Gunten's study was with the application of ozone without H_2O_2 using the hydroxyl radicals that are generated by the reaction of ozone with the organic matter naturally present in the water. However RO permeate, such as that produced at an AWTP, does not have much natural organic matter and requires the addition of a promoter, such as H_2O_2 (as discussed in the TM on AOP alternatives). Acero and von Gunten (2001) conducted some experiments to show that the R_{ct} concept can also be applied to the O_3/H_2O_2 AOP option. However, such work has not been applied to RO permeate. However, the Elovitz and von Gunten's protocol can be further extended to better understand the O_3/H_2O_2 process at the LADWP AWT pilot.

The protocol includes spiking the water sample with pCBA and atrazine, as well as pH adjustment and buffering the system. Similar to the method used by Elovitz and von Gunten (1999), the test method used for measuring ozone residual in the water is a modification of the Solution Ozone Test (SOT) developed by Rakness (2005). The equipment setup is shown in the Figure 2 below.

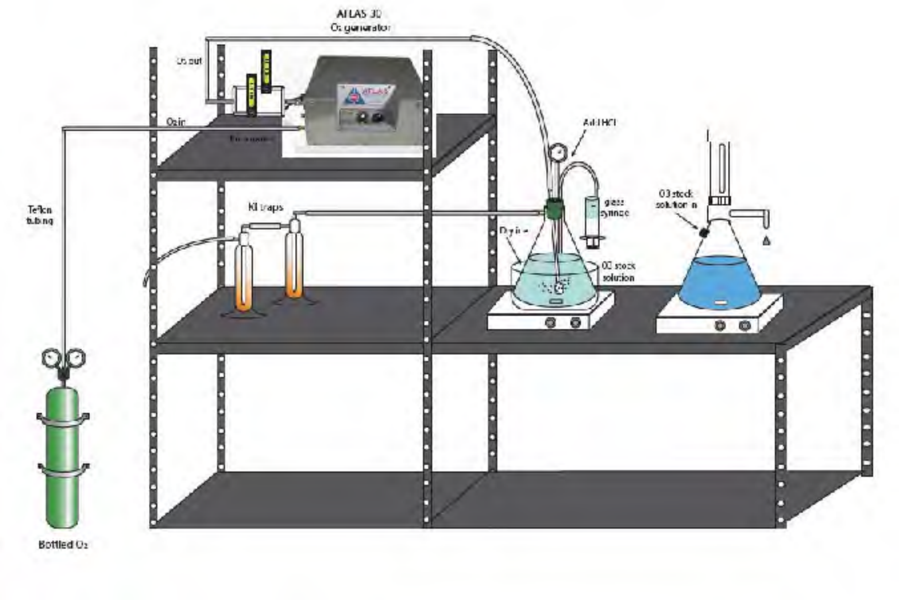


Figure 2. Solution Ozone Test Apparatus.

For analysis with ozone alone, a stock ozone solution was prepared by bubbling ozone through deionized (DI) water. Oxygen was used for the feed gas to the ozone generator. By reducing the pH of the DI water to 3.4-3.6 with hydrochloric acid and maintaining a water temperature just below 0°C (using a water-bath containing dry ice), a stock solution containing up to 70 mg/L ozone was prepared.

To perform the test, a known volume of the ozone stock solution was added to a known volume of sample and stirred for about 10 seconds. Samples of the ozonated sample were withdrawn (using a dispenser system) into flasks containing indigo solution. The ozone reacted with the indigo solution, reducing its blue color in relation to the concentration of ozone in the sample. The indigo concentration of each sample was measured with a spectrophotometer, from which the residual ozone concentrations were calculated. The volume of ozonated sample dispensed into the indigo solution was determined gravimetrically, and was used in the calculation of residual ozone concentration.

This procedure delivers ozone to the test sample in the form of an aqueous solution rather than as a gas stream bubbled through the test sample. As such, the applied ozone dose was the same as the transferred ozone dose, and ozone gas transfer efficiency did not have to be taken into account in determining the transferred ozone dose. For the analysis of O_3/H_2O_2, H_2O_2 is added to the prepared water prior to O_3 addition.

1.1 Bench Scale Testing Results for Ozonation (O_3) alone:

Table 1 provides a summary comparison of Trussell Tech (TT) and Acero and von Gunten (2001) results for bench-scale testing that was conducted with ozonation alone (no hydrogen peroxide addition):

Table 1. Water Quality Summary for Ozone Alone Experiments[***]

	Acero & von Gunten, 2001		**Trussell Technologies**
Water source	0.45µM filtered GW	0.45µM filtered SW	AWT Pilot ROP
DOC, ppm	1	3.2	0.60
Alkalinity, ppm	317	232	7.2
Borate buffer, µM	10	10	5
pH	7	7	8.3
pCBA, µg/L	39	39	9*
Atrazine, µg/L	54	54	135**
Ozone stock solution, mg/L	58	58	76
Temperature	11	11	20
Ozone dose, mg/L	1.0	1.0	7.0
k_{O3}, s-1	1.5×10^{-4}	2.5×10^{-3}	6.9×10^{-4}
pCBA elimination, %	44	28	not measured
Atrazine elimination, %	15	not measured	93

*56 µg/L was the target concentration, however there was incomplete dissolution of pCBA solids, thus potentially resulting in the lower measured concentration

**111µg/L was the target concentration

***Note the ozone in the RO effluent was unusually high, indicating possible membrane degradation.

The TT results indicate that ozone decay was slightly faster than observed by Acero and von Gunten (2001) for groundwater (GW) , as evident in Figure 3. For RO permeate (ROP) and GW, k was 7×10^{-4} s^{-1} and 2×10^{-4} s^{-1}, respectively.

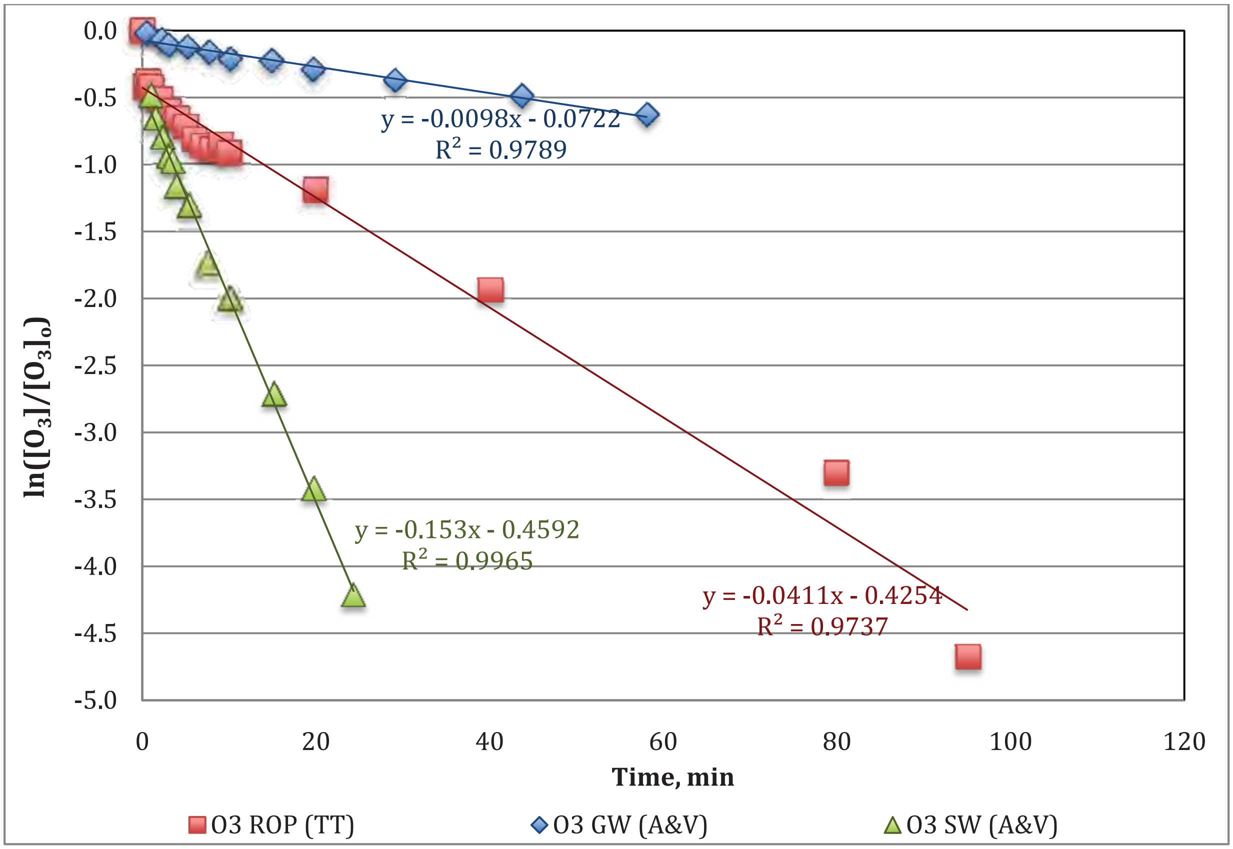


Figure 3. Ozone Decay for Ozonation Experiments in the Absence of Hydrogen Peroxide Addition

This higher rate is most likely explained by the differences in the experimental protocols, namely the higher pH, ozone dose and temperature at which the TT experiments were operated, all of which contribute to more rapid degradation of O_3.

Because atrazine is similar to pCBA, in that $k_{\bullet\bullet OH/atrazine} = 3\times10^9\ M^{-1}s^{-1} >> k_{O3/atrazine} = 6\ M^{-1}s^{-1}$, the R_{ct} can be estimated for our system with ozonation alone. The slope of the ln([atrazine]/[atrazine]$_o$) versus $O_{3\text{-}ct}$ plot was used to determine R_{ct} for ozonation alone. Using a $k_{\bullet OH/atrazine}$ of $3\times10^9\ M^{-1}s^{-1}$, and a slope of 44, the R_{ct} was computed to be 2×10^{-8}. This is about an order of magnitude higher than that computed by Acero and von Gunten (2001) for pCBA (3×10^{-9}). This is again most likely due to differing operating conditions, especially higher pH, temperature and ozone dose, which all result more efficient conversion of O_3 to •OH.

1.2 Bench Scale Testing for Ozone/Hydrogen Peroxide (O_3/H_2O_2):

A slightly different strategy was used for the O_3/ H_2O_2 bench scale testing, as compared to Acero and von Gunten (2001). Acero and von Gunten (2001) dosed peroxide at a level that resulted in residual ozone. However, the strategy used by TT mimicked the strategy used in the field. This strategy was to dose peroxide such that there was complete and nearly instantaneous O_3 decay and •OH production. The water source and experimental characteristics are summarized in the Table 2.

Table 2. Water Quality Summary for Ozone and Hydrogen Peroxide Experiments

	Acero & von Gunten, 2001		**Trussell Technologies**
Water source	0.45µM filtered GW	0.45µM filtered SW	ROP
DOC, ppm	1	3.2	0.60
Alkalinity, ppm	317	232	7.2
H_2O_2/O_3, g/g	0.34	0.34	0.57
Peroxide, mg/L	0.34	0.34	4.04
Borate buffer, µM	10	10	5
pH	7	7	8.3
pCBA, µg/L	39	39	9*
Atrazine, µg/L	54	54	135**
Ozone stock solution, mg/L	57.6	57.6	76
Temperature	11	11	20
Ozone dose, mg/L	1.0	1.0	7.0
pCBA elimination, %	66	29	92
Atrazine elimination, %	16	not measured	88
Change in peroxide, mg/L	0.22	0.04	3.82
Peroxide elimination, %	65	12	95

*56 µg/L was the target concentration, however there was incomplete dissolution of pCBA solids, thus potentially resulting in the lower measured concentration

**111µg/L was the target concentration

Some significant differences include the use of a higher H_2O_2/O_3 ratio, temperature, O_3 dose and pH in the TT experiments. These differences resulted in the complete ozone decay within 30 seconds as shown in Figure 4 (green triangles).

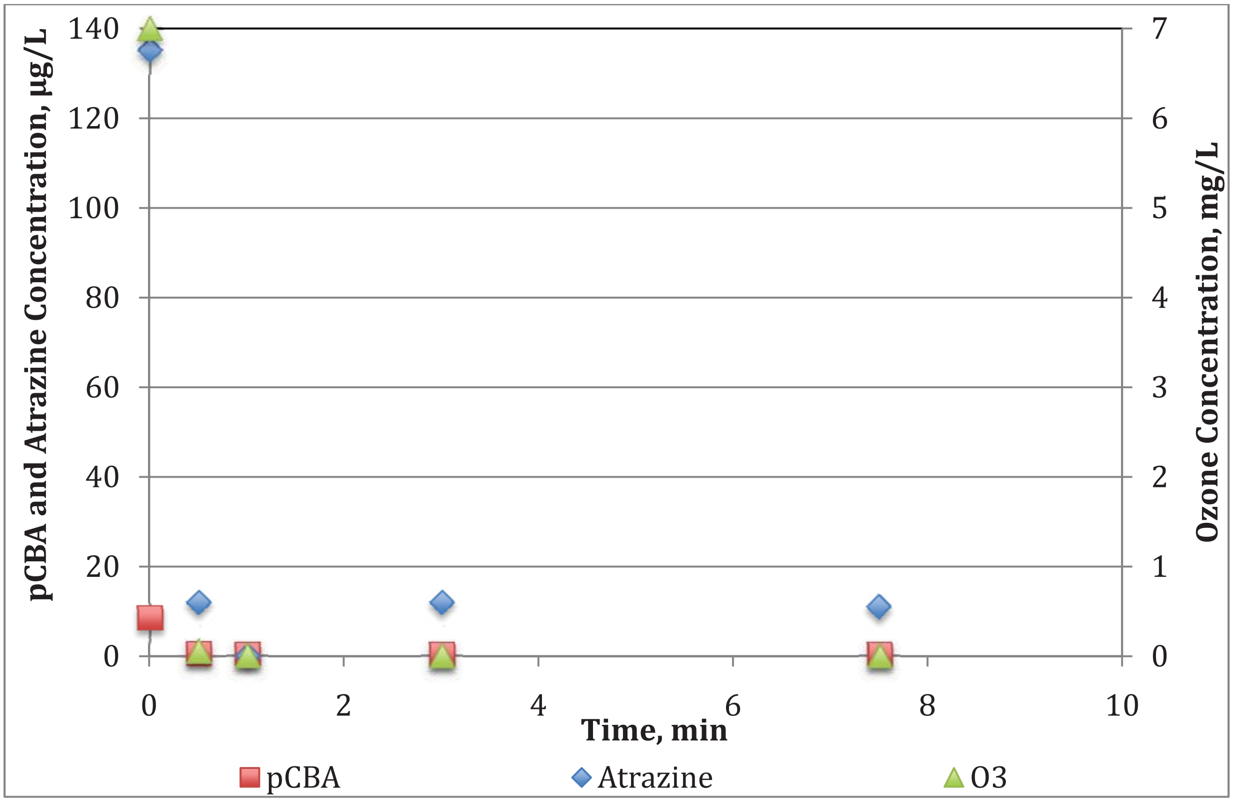


Figure 4. Raw Concentrations Observed during Bench-Scale Testing

The results from the application of the R_{ct} concept are summarized in Table 3.

Table 3. Summary of R_{ct} Values Experimentally Determined by TT and Acero and von Gunten (2001)

	TT		**Acero and von Gunten, 2001**			
H_2O_2/O_3 ratio (w/w)	0	0.57	0	0.19	0.34	0.7
Rct (pCBA-basis)	no data	$>2\times10^{-7}$	3×10^{-9}	1×10^{-8}	2×10^{-8}	4×10^{-8}
Rct (atrazine-basis)	2×10^{-8}	$>4\times10^{-7}$	no data	no data	no data	no data

It is evident that the TT system had significantly higher level of •OH activity than Acero and von Gunten (2001), given that the TT R_{ct} was nearly 1 order of magnitude higher than Acero and von Gunten (2001). Again this is attributed to the combination of a higher H_2O_2/O_3 ratio, O_3 dose, and pH in TT experiments.

Overall, the TT bench scale system was more effective at removing pCBA and utilizing a greater percentage of the hydrogen peroxide, which translates to the presence of more hydroxyl radicals than Acero and von Gunten (2001) findings. The effectiveness is also attributed to the use of a higher O_3 concentration, coupled with a higher H_2O_2/O_3 ratio. An explanation of the higher percentage of H_2O_2 usage is that natural organic matter was nearly absent and did not exert competition for the ozone. Additionally, higher pH promotes faster decay of O_3, as well as the generation of the anion of peroxide that then readily reacts with O_3 to produce hydroxyl radicals.

1.2.1 NDMA Results

An experiment with NDMA was also conducted. The results with RO permeate are compared to results presented in Lee, Yoon, and von Gunten (2007) with Lake Zurich water, which have similar ozone dosages.

Table 4. Water Quality Summary for Ozone and Hydrogen Peroxide Experiments

	Lee, Yoon, and von Gunten, 2007	**Trussell Technologies**
Water source	Lake Zurich (LZ)	ROP
DOC, ppm	1.2	0.60
Alkalinity, ppm	131	7.2
H_2O_2/O_3, g/g	0.35	0.57
Peroxide, mg/L	2.7	4.04
pH	7.9	8.3
Temperature, °C	21	20
Ozone dose, mg/L	7.7	7.0

As an example, the R_{ct} determined by TT is used to predict the removal of NDMA. The values used to compute the predicted natural-log removal of NDMA are summarized in Table 5.

Table 5. NDMA Study Summary

	Lee et al. O_3/H_2O_2	TT[a] O_3/H_2O_2
$NDMA_o$, ng/L	74000	28
$NDMA_f$, ng/L	33000	18
Ozone dose, mg/L	7.7	7.0
H_2O_2 dose, mg/L	2.7	4.04
pH	7.9	8.30
Temperature, deg C	21	20
TOC_o	1.2	0.60
k_{OH}, M^{-1} S^{-1}	4.5×10^8	4.5×10^8
k_{O3}, M^{-1} S^{-1}	5.2×10^{-2}	5.2×10^{-2}
R_{ct}, unitless	$>6\times10^{-7}$	$>2\times10^{-7}$
O_3-exposure, M-sec	-	$>2\times10^{-3}$
NDMA Computed -log(C/Co)	-	>0.1
NDMA Measured -log(C/Co)	>0.4	>0.2

[a] R_{ct} computed for atrazine used here

The computed level of NDMA removal was less than the measured levels. This potentially indicates the presence of NDMA forming precursors that react with O_3 and actually form NDMA during the O_3/H_2O_2 process.

1.3 Reference

Acero, J. L. and U. Von Gunten (2001). "Characterization of oxidation processes: Ozonation and the AOP O3/H2O2." Journal American Water Works Association **93**(10): 90-100.

Elovitz, M. S. and U. Von Gunten (1999). "Hydroxyl radical/ozone ratios during ozonation processes. I. The R(ct) concept." Ozone: Science and Engineering: The Journal of the International Ozone Association **21**(3): 239 - 260.

Lee, C., J. Yoon, and U. von Gunten (2007). "Oxidative degradation of N-nitrosodimethylamine by conventional ozonation and the advanced oxidation process ozone/hydrogen peroxide," *Water Res.*, **41**(3): 581-590.

Rakness, K.L. (2005) Ozone in drinking water treatment: process design, operation and optimization, American Water Works Association, Denver, CO.

Appendix F

Contaminant Removal through RO Membranes

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Removal of Target Constituents by Three RO Membrane Types

Parameter	Unit	12/20/10 through 2/27/2011					2/28/2011-6/30/2011										
		Selected Feed Location	Selected Feed Average	Hydranautics			Selected Feed Location	Selected Feed Average	Combined CSM and Toray			CSM (1st stage only)			Toray (1st stage only)		
				RO Permeate	Rejection (%)	Number of Samples			RO Permeate	Rejection (%)	Number of Samples	RO Permeate	Rejection	Number of Samples	RO Permeate	Rejection	Number of Samples
Dissolved Oxygen	mg/L	Source	3.6	-	-	0	Source	6.7	7.7	54	11	-	-	0	-	-	0
TOC	mg/L	ROF	8.6	ND	99.5	32	ROF	7.9	ND	99.6	68	-	-	0	-	-	0
UV 254	cm-1	MF Filtrate	0.15	0.021	86	32	MF Filtrate	0.16	ND	95	67	-	-	0	-	-	0
Alkalinity as CaCO3	mg/L	ROF	140	6.6	98.7	8	ROF	130	3.9	99.1	17	4.1	99.1	14	4.3	99	13
Bicarbonate Alkalinity as HCO3	mg/L	ROF	23	5.8	98.9	3	ROF	160	4.7	99.2	17	5	99.1	14	5.2	99.1	13
Boron	µg/L	ROF	2500	360	82	2	ROF	720	440	71	3	420	73	2	290	81	2
Calcium	mg/L	ROF	42	0.1	99.9	7	ROF	49	ND	100	17	ND	100	14	0.13	99.9	14
1,4- Dioxane	µg/L	Source	1.2	ND	79	1	Source	1.3	ND	71	8	-	-	0	-	-	0
Fluoride, Total	mg/L	ROF	0.87	-	-	0	ROF	0.79	ND	98.3	4	-	-	0	-	-	0
Manganese	µg/L	ROF	7.8	0.1	99.7	2	ROF	25	0.19	99.7	2	0.26	99.6	2	0.29	99.6	2
N-Nitrosodimethylamine (NDMA)	µg/L	ROF	0.023	0.015	34	8	ROF	0.022	0.012	46	17	0.012	47	14	0.009	59	14
TKN	mg/L	MF Filtrate	3.1	0.38	96	8	MF Filtrate	2	0.3	95	17	0.55	91	14	0.32	95	14
Ammonia as N	mg/L	ROF	3	0.53	93	8	ROF	1.6	0.31	93	17	0.44	90	14	0.35	92	14
Nitrite (as NO2)	µg/L	MF Filtrate	180	150	51	1	MF Filtrate	280	150	92	9	150	92	2	130	93	2
Nitrate (as NO3)	mg/L	MF Filtrate	26	2.1	96	7	MF Filtrate	30	1.5	98.5	17	0.99	99	14	0.76	99.2	14
Potassium	mg/L	ROF	14	0.43	99.3	2	ROF	15	0.42	99.3	3	0.32	99.5	2	0.39	99.3	2
Silica	mg/L	ROF	9.1	0.18	99.5	7	ROF	13	0.13	99.7	17	0.093	99.8	14	ND	99.9	14
Sulfate	mg/L	ROF	100	ND	99.9	7	ROF	120	ND	99.9	17	ND	100	14	ND	99.9	14
Total Dissolved Solids (TDS)	mg/L	ROF	510	13	99.4	8	ROF	540	13	99.4	18	ND	99.5	14	ND	99.6	14
Sodium	mg/L	ROF	100	4.1	99	7	ROF	94	2.7	99.3	17	2.1	99.5	14	1.9	99.5	14
Strontium	µg/L	ROF	270	0.76	99.9	7	ROF	290	0.58	99.9	17	ND	100	14	0.46	100	14
Total Organic Halogens (TOX)	µg/L	Source	140	ND	93	2	Source	180	ND	94	3	ND	94	1	ND	94	2
TCEP	ng/L	ROF	290	2	99.3	2	ROF	310	5.4	98.2	10	8.6	97	2	11	97	2
1,2-Dibromo-3-chloropropane	µg/L	ROF	0.014	ND	64	1	ROF	-	-	-	0	-	-	0	-	-	0
Bromodichloromethane	µg/L	ROF	0.86	1	-18	2	ROF	4.7	1.5	68	3	1.8	61	2	1	78	2
Dibromochloromethane	µg/L	ROF	0.67	0.61	9	2	ROF	3.5	0.69	80	3	ND	88	2	ND	86	2
Total Trihalomethanes (TTHM)	µg/L	ROF	4.5	7.8	-72	2	ROF	14	4.4	70	3	4.4	70	2	3	79	2
Acetaminophen	ng/l	Source	100	ND	90	1	Source	100	ND	90	2	-	-	0	-	-	0
Amoxicillin	ng/l	Source	1900	ND	99.7	1	Source	1300	ND	99.6	2	-	-	0	-	-	0
Atenolol	ng/l	Source	230	4.4	98.1	1	Source	260	ND	99.8	2	-	-	0	-	-	0
Atorvastatin	ng/l	Source	120	ND	99.6	1	Source	520	ND	99.9	2	-	-	0	-	-	0
Azithromycin	ng/l	Source	2900	ND	99.8	1	Source	1300	ND	99.6	2	-	-	0	-	-	0
Primidone	ng/l	Source	2800	3.7	99.9	1	Source	1900	2	99.9	2	-	-	0	-	-	0

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Appendix G

Pilot Testing Protocol

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City of Los Angeles

Recycled Water Master Plan

Technical Memorandum

Title: GWR Treatment Pilot Study Testing Protocol TM

Version: Draft

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Date: January 10, 2012

Reference: Task 3a GWR Treatment Pilot Study
Subtask 3.1.1 Protocol Development

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1. Introduction

The Los Angeles Department of Water and Power (LADWP) has partnered with the Los Angeles Department of Public Works (LADPW) to develop a Recycled Water Master Planning document (RWMP), which facilitates implementation of the 2010 Urban Water Management Plan (UWMP). LADWP's UWMP outlines a goal of increasing recycled water use citywide to 59,000 acre feet per year (AFY) by 2035.

One method of expanding recycled water use is by indirect potable reuse through groundwater replenishment (GWR). Groundwater replenishment is a practical, proven way to increase the availability of a safe, reliable, locally-controlled water supply. As shown on Figure ES-1, using state-of-the-art technology, the GWR system would include treating recycled water from the Donald C. Tillman Water Reclamation Plant (DCTWRP) to near-distilled water quality using advanced water purification (AWP) processes. This purified recycled water would be conveyed to spreading grounds, where it would percolate into natural underground aquifers. This water replenishes the aquifers, to be used as an additional local source of water supply for the city. After the minimum required residence time within the aquifer, the water would be extracted (or pumped) from the existing groundwater basins for treatment and distribution to LADWP drinking water customers.

1.1 Task 3 Overview

The purpose of Task 3 is to conduct pilot testing to evaluate the proposed advanced water purification facility (AWPF) processes to be employed for treatment of the GWR supply. The GWR Master Plan, being completed as part of the RWMP, will include a capital improvement program to implement an AWPF and groundwater replenishment using high-quality recycled water in the San Fernando Valley in the Hansen, Pacoima, and possibly in the Strathern Pit and injection wells. The AWPF will be fed with effluent from the Donald C. Tillman Water Reclamation Plant (DCTWRP). The pilot testing will support the implementation of the GWR Master Plan.

Task 3 is being conducted in two parts: Task 3a and Task 3b. Task 3a includes the initial planning for the pilot testing, including development of this Testing Protocol, the pilot plant design and equipment procurement, and installation and construction. Task 3b will include the pilot plant operations and summary reports. The pilot testing will be conducted in three primary phases:

- Phase 1 will validate the proposed AWPF processes, including microfiltration (MF), reverse osmosis (RO), and advanced oxidation using ultraviolet light (UV) with hydrogen peroxide (H_2O_2);
- Phase 2 will evaluate alternative advanced oxidation processes (AOPs) for potential use in future AWPF expansions; and,
- Phase 3 will focus on process optimization.

1.2 TM Purpose

This GWR Treatment Pilot Study Testing Protocol TM (Protocol) sets forth the overall goals for the pilot study, as well as the procedures and policies that will be followed during the pilot testing operations. This Protocol will direct the activities of the pilot plant operations staff.

1.3 TM Overview

This document contains the following sections:

- Section 1 – Introduction
- Section 2 – Background and Objectives
- Section 3 – Equipment, Operations and Data Management
- Section 4 – Water Quality Monitoring Plan
- Section 5 – Quality Assurance/Quality Control (QA/QC)
- Section 6 – Staffing and Communications
- Section 7 – Health and Safety
- Section 8 – References
- Attachments

2. Background and Objectives

The DCTWRP currently produces Title 22 recycled water through tertiary treatment. Aqua Diamond cloth filters were recently installed for tertiary filtration. Chlorine is added before the filters and bothchlorine and ammonia are added after the filters. The plant employs nitrification-denitrification, producing a product with ammonia concentrations less than 0.2 mg/L. Ammonia must therefore be added to maintain a stable chloramine residual. The pilot will test advanced purification processes to treat either secondary effluent or tertiary effluent drawn ahead of the chlorine injection. A thorough discussion of the advanced purification process can be found in the Draft Advanced Water Treatment Technology Assessment TM (Task 1.4 TM). The three primary processes to be tested include MF, RO, and AOP.

2.1 Pilot Plant Objectives

The GWR Treatment Pilot Plant will consist of MF membranes for pretreatment followed by RO membranes as the primary treatment process. Additional processes include AOP to remove or destroy trace organic compounds that are poorly removed by RO. Desktop studies based upon the water quality results developed from the pilot testing will be utilized to evaluate post-treatment product water stabilization steps.

The overall objectives of the pilot plant are to:

- Demonstrate stable and reliable performance of proposed treatment technologies on secondary and tertiary wastewater effluent.
- Demonstrate that the selected processes achieve the performance expectations and anticipated regulatory requirements.
- Familiarize plant operations staff with the proposed treatment processes.
- Evaluate alternative AOP processes on reliability, effectiveness, operational requirements, and costs.
- Compare operation at DCTWRP with known operating conditions of similar equipment at other existing facilities.
- Develop design parameters for each pilot process, including the types and doses of chemicals.

2.2 Pilot Plant Overview

2.2.1 Schedule

Development of the pilot testing program involved four separate workshops to develop the protocol, meet with regulatory agencies, and train City staff on the treatment processes to be employed. These workshops included:

- Workshop #1: Protocol development workshop, August 12, 2009
- Workshop #2: Treatment process decision workshop, October 8, 2009
- Workshop #3: Regulatory review workshop, November 18, 2009

- Workshop #4: Operator training workshop (to be conducted in three sessions), March 10, 16 and 24, 2010

Installation of the pilot equipment will begin in December 2009, with operation beginning by mid-February 2010. Operation will consist of three phases, lasting a total of 15 months. Phase 1 will last 6 months and will include baseline operation using a treatment process selected to match existing advanced water purification facilities at the Orange County Water District, the West Basin Municipal Water District, and other operational facilities in California and outside the state. This baseline testing will include MF, RO and UV/H_2O_2 maintained at similar operating conditions to existing full-scale facilities. Phase 2 will include 6 months of evaluating two alternative RO membranes and one alternative advanced oxidation processes discussed in Attachment H. The alternative oxidation process to be evaluated will be ozone with H_2O_2. Phase 3 will provide 3 months of additional testing for process optimization and selection of the full-scale design criteria. The testing phases are outlined in Table 2-1.

Table 2-1 Testing Phases

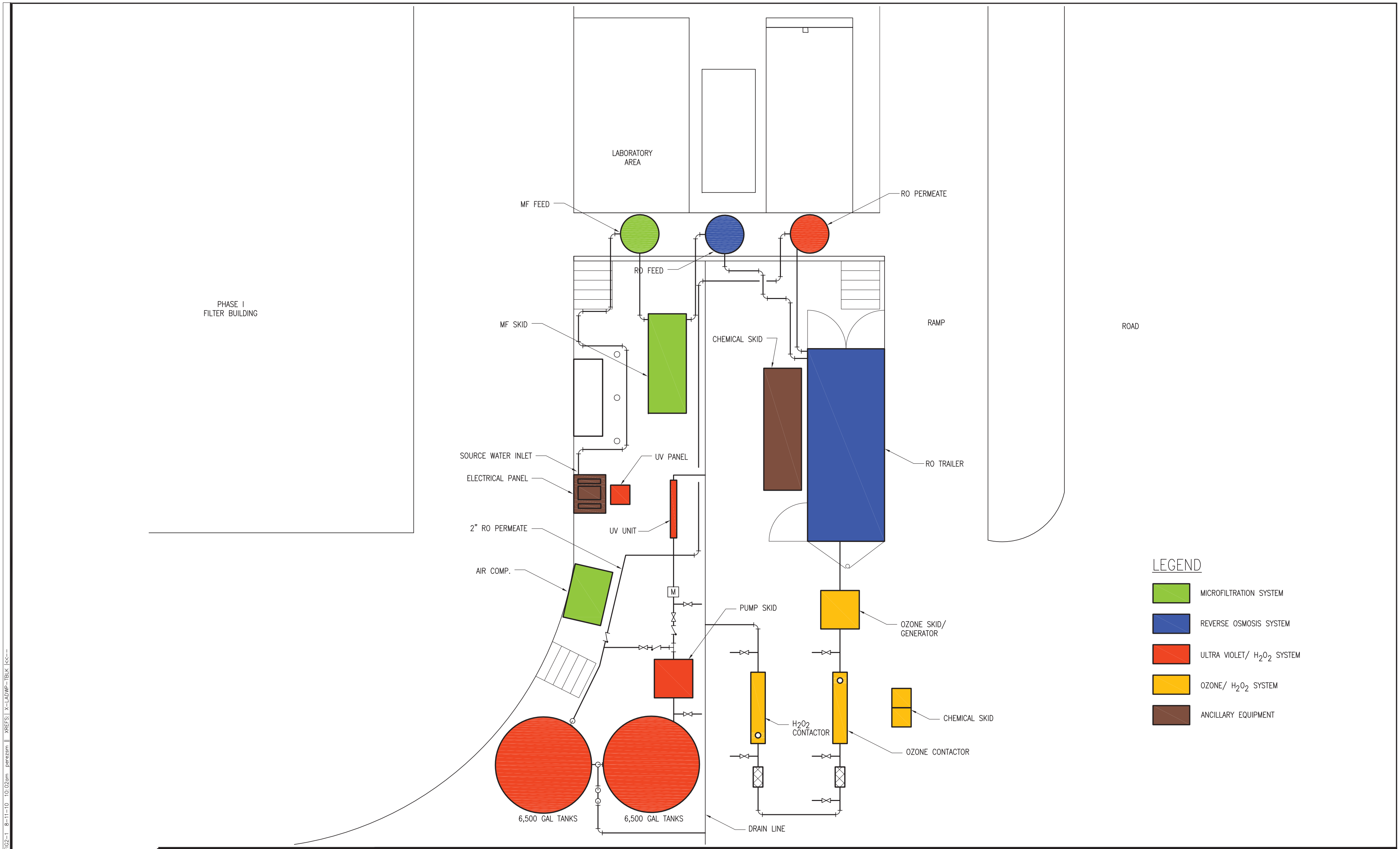
Phase	Description	Treatment Process	Duration	Expected Dates
1	Baseline Evaluation	MF, RO, and UV/H_2O_2	6 months	2/18/10 to 8/17/10
2	Advanced Oxidation Process Evaluation	MF, RO, and UV/ H_2O_2 and/bor Ozone/H_2O_2	6 months	8/18/10 to 2/17/11
3	Process Optimization	MF, RO, and Selected AOP	3 months	2/18/11 to 5/17/11

2.2.2 Location

The pilot plant will be located at the DCTWRP plant, directly south of the decommissioned chlorination building, between the east and west bank of tertiary filters. The proposed equipment layout is shown in Figure 2-1. The process equipment will be modular with break tanks and temporary polyvinyl chloride (PVC) piping connecting each of the treatment processes. A laboratory testing area will be used for bench testing and lab analyses. Temporary canvas awnings will provide shade for process equipment and field engineers.

2.2.3 Feed Water

The pilot plant will test water from two separate sources at the DCTWRP plant, including 1) after the secondary clarifiers, and 2) after tertiary filtration, before chlorination. The two sources will be tested to determine whether the differing source water has an impact on MF or RO performance or on the rate of disinfection byproduct (DBP) formation. Preliminary bench testing was conducted to determine whether a significant difference in DBP formation could be seen between the two sources. Results of this testing are presented in Attachment G and indicate that a small difference in formation potential may exist, however, further testing is recommended to confirm any trends. Temporary PVC piping will supply up to 40 gallons per minute (gpm) of either secondary effluent or tertiary effluent to the pilot feed water tank. Submersible pumps will be used to supply water from either the filter effluent channel upstream of chemical injection or the secondary effluent channel upstream of the filters. The pilot plant product water and all waste streams will be drained to the sewer. Locations of the feed water and drain connections are shown in Figure 2-2.



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CITY OF LOS ANGELES - RECYCLED WATER MASTER PLAN

GWR PILOT

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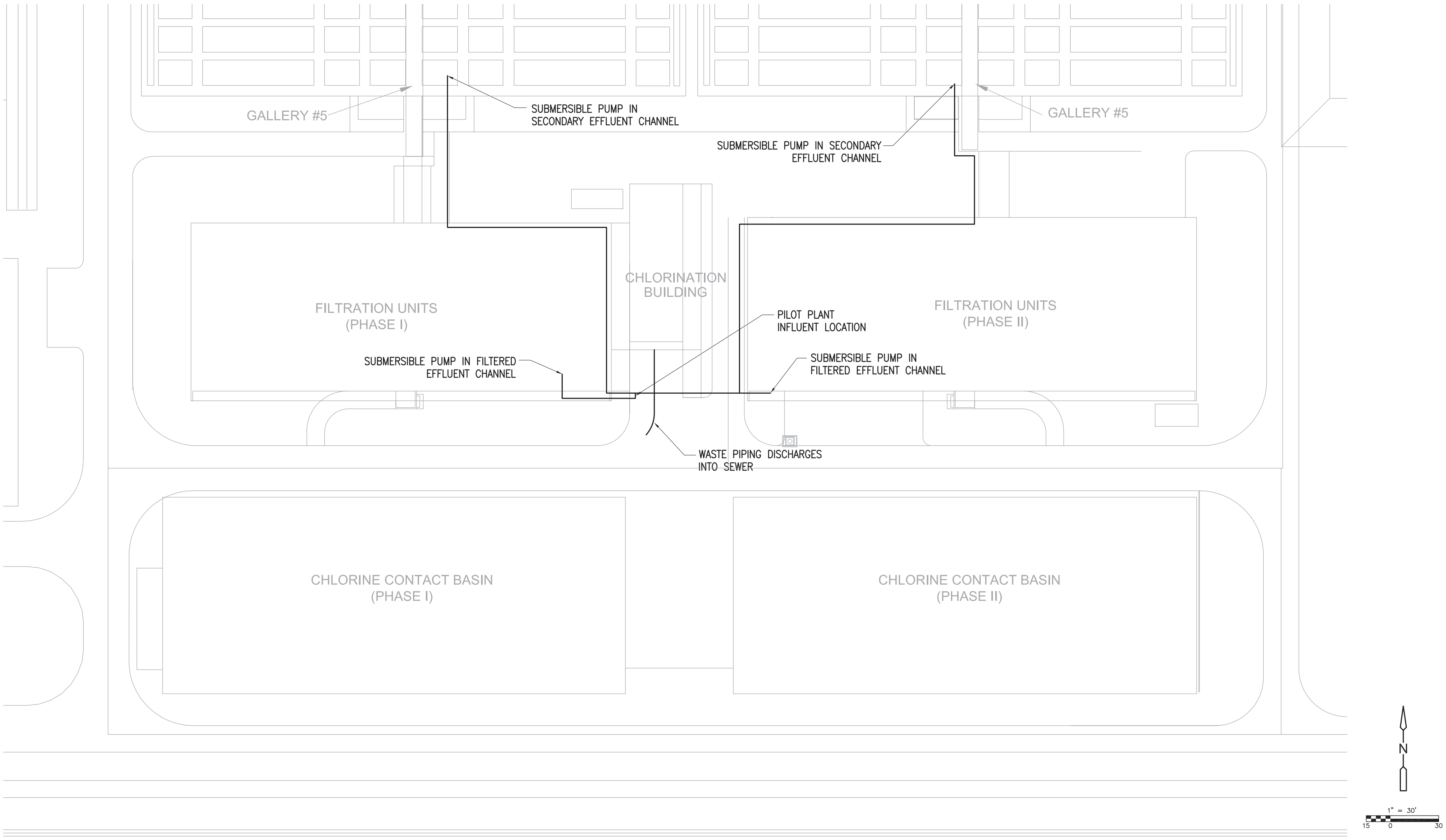

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CITY OF LOS ANGELES - RECYCLED WATER MASTER PLAN

FIGURE 2-2
INFLUENT AND DISCHARGE
PIPING PLAN

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2.3 Water Quality Goals

Regulatory related water quality requirements for the future DCTWRP AWPF are discussed in detail in the Draft Regulatory Assessment TM (Task 1.1 TM). These requirements take into consideration the waste discharge permit for the West Coast Basin Barrier Project; water quality objectives for groundwater contained in the Regional Water Quality Control Board's Basin Plan for minerals and constituents with current and anticipated drinking water maximum contaminant levels; and the 2008 draft California Department of Public Health (CDPH) groundwater recharge regulations. Water quality for the tertiary treated water at the DCTWRP facility already meets the majority of these requirements, and the AWPF will have little trouble meeting most of the remaining requirements. Some constituents, however, will require process optimization to ensure that they are adequately removed or reduced by the treatment processes. These constituents will be the primary water quality focus and specific goals of the pilot testing.

Table 2-2 presents the performance expectations for the pilot testing along with established or proposed regulated limits for these parameters. It should be noted that the performance expectations differ from the regulated limits and have been established to ensure optimization of the various treatment processes rather than to establish specific goals for the future AWPF.

Table 2-2: Pilot Water Quality Goals and Expected Performance

Constituent	Units	Pilot Performance Expectations (average)	Regulated Limit (maximum)
TOC	mg/L	0.2	0.5[a]
Total Nitrogen	mg/L	2	5[a]
NDMA	µg/L	0.005	1.2 log reduction[a]
1,4-Dioxane	mg/L	0.0015	0.5 log reduction[a]
TTHM	µg/L	40	80[c]
HAA5	µg/L	30	60[c]
TCEP	µg/L	0.0015	NA
Turbidity	NTU	0.1	O.2[b]
Chloride	mg/L	80	100[d]
TDS	mg/L	250	500[c]

Footnotes:

a. 2008 Draft Groundwater Recharge Regulations, assumes recycled water contribution may be as high as 100%for TOC limit
b. Existing Title 22 Water Recycling Regulations
c. CDPH drinking water limits (primary and secondary maximum contaminant levels)
d. Basin Plan Objectives

Both total organic carbon (TOC) and total nitrogen have established and proposed criteria in the CDPH draft recharge regulations, but the performance expectations have been identified to promote optimization of the treatment processes. In addition to challenging the pilot AWPF with low product water N-nitrosodimethylamine (NDMA) and 1,4-dioxane concentrations, tris(2-

chloroethyl) phosphate (TCEP) has been chosen as an indicator parameter because it has been found to be ubiquitous in wastewater and it is known that it passes through the reverse osmosis process. The complete discussion on the importance of TCEP to the AWPF train can be found in the section on constituents of concern under the Draft Advanced Water Treatment Technology Assessment TM (Task 1.4 TM). Performance expectations for NDMA and 1,4-dioxane have been set at half of the current CDPH notification levels, since no regulated limits exist in the current regulations, and the draft recharge regulations are based on log removal of these compounds (1.2-log for NDMA and 0.5-log for 1,4-dioxane), rather than product water quality. The goal for TCEP is based on 150 percent of the current analytical detection level, since no regulated limits or notification levels are currently in place for this compound. Performance expectations for total dissolved solids (TDS), total trihalomethanes (TTHM), and the sum of five regulated haloacetic acids (HAA5) have been set at half of the CDPH regulated limits.

2.4 Process Description

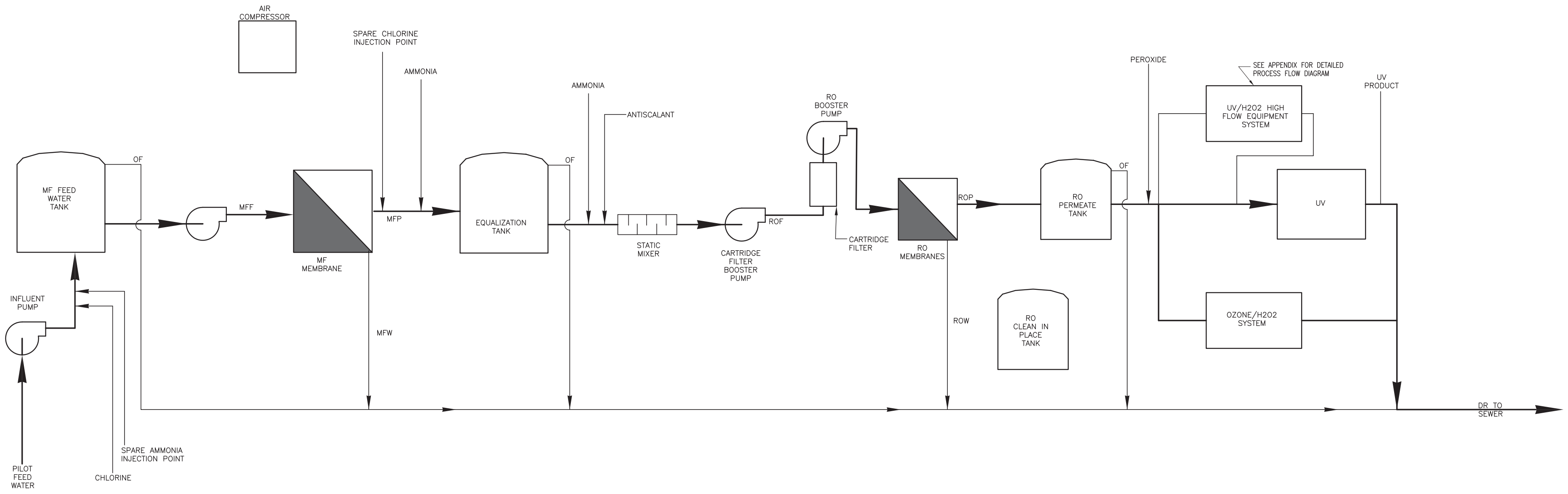
The pilot treatment process will consist of three systems: (1) the pretreatment system, including MF (2) the RO system, and (3) advanced oxidation. The specific equipment to be used during the baseline pilot testing (first 6 months) was selected during Workshop #1. The equipment was selected to represent, to the extent possible, typical process equipment used at existing full-scale facilities, allowing the results of this pilot test to be compared with operational facilities before proceeding with design of future AWPF.

The pretreatment system will include 500-micron strainers, an MF system, and chemical addition, including chlorination, to remove suspended solids and microorganisms to reduce the fouling potential of the RO feedwater. The RO system will include 5-micron cartridge filters to protect the RO membranes from debris. Chemical addition to the RO feedwater is necessary to control RO membrane fouling and maintain a stable RO performance. RO membranes are intolerant to free chlorine, requiring that ammonia be added to create a stable chloramine residual ahead of the membranes. The RO membranes will remove the majority of dissolved contaminants, minerals, nutrients and salts, including many pharmaceuticals and personal care products (PhPCPs) and other endocrine disruptors (EDCs). The AOP will include hydrogen peroxide addition and a UV reactor. The AOP will oxidize and break down trace organic contaminants not completely removed by the RO process. Desktop modeling of the post-treatment process will provide information on how best to condition the product water for recharge at the spreading basins. The alternative AOP (ozone/H_2O_2) will also be testing during Phase 2 of the pilot testing, and is discussed in Attachment H.

The pilot plant process flow diagram is presented in Figure 2-3.

LEGEND

RW	RAW WATER
MF	MEMBRANE FILTRATION
MFF	MF FEED
MFP	MF PRODUCT
MFW	MF WASTE
ROF	REVERSE OSMOSIS FEED
ROP	REVERSE OSMOSIS PRODUCT
ROW	REVERSE OSMOSIS WASTE
DR	DRAIN
OF	OVERFLOW
UV	ULTRAVIOLET LIGHT
AOP	ADVANCED OXIDATION PROCESS



PROCESS STREAM	DESIGN FLOW	DESIGN PRESSURE
MF FEED	45 GPM	30 PSI
MF PRODUCT	40 GPM	<25 PSI
RO FEED	20 GPM	200 PSI
RP PRODUCE	17 GPM	<5 PSI
RO WASTE	3 GPM	180 PSI

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CITY OF LOS ANGELES - RECYCLED WATER MASTER PLAN

FIGURE 2-3
PROCESS FLOW DIAGRAM

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The equipment will consist of the following units:

- The MF pilot system will be supplied by Pall, a chlorine resistant polyvinyl difluoride (PVDF) membrane used at other reuse facilities at the Water Replenishment District, Yucaipa Valley Water District, East Bay Municipal Utilities District, and Fountain Hills, Arizona. The MF membrane vessels, automated control system, pumps, ancillary equipment for operation and cleaning will be mounted onto a single skid. Additional items required onsite include an air compressor to supply air for control valve operation and integrity testing and bulk chemicals to supply the cleaning chemical day tanks.
- The RO pilot system will be supplied by the CDM pilot plant group and has been designed to utilize RO membranes for advanced purification of wastewater. The RO system will include three stages, with the first two stages using 4-inch elements in a 2:1 array, and the third stage using 2.5-inch elements. A booster pump will be used between the second and third stage. The cartridge filters, pumps, automated controls, pressure vessels, and ancillary equipment for operation will be mounted onto a single skid within a portable trailer. The clean-in-place system will be mounted on a separate area within the trailer. The RO pressure vessels will initially include Hydranautics ESPA2 membranes, which are common RO membranes used for advanced water purification in California, including use by the Orange County Water District, Water Replenishment District, and at the Terminal Island facility. Alternative RO membranes will be tested during Phase 2 and will include Koch TFC-HR and Toray TMG, as selected during Workshop #2.
- The AOP which will be utilized during Phase 1 is UV/H_2O_2, manufactured by Trojan Technologies Inc. UV/ H_2O_2 is the only AOP which has been used for large indirect potable reuse in California up to the present time and it will be used as the baseline process for comparison with the alternative AOP (ozone/H_2O_2). The AOP pilot system will be procured by the project team and efforts will be made to replicate a full-scale system. As necessary, the results from the AOP pilot system will be modeled to allow for a full-scale system evaluation.
- Post-treatment will be conducted using bench-scale experiments and desktop modeling which will determine the proper means for achieving product water stabilization. Model runs will be based upon the water quality data generated from the product water at the pilot AWPF. This approach simulates the full-scale approaches of using a lime saturator or a limestone contactor for post-treatment prior to recharge at the spreading grounds. The bench-scale experiments themselves will be focused on the significance of inerts in commercial lime products and on the lime water from full-scale saturators operating in Southern California.
- Four storage tanks will initially be used at the pilot plant for water storage and flow equalization. Seismic tie-downs will be used for all storage tanks. The tanks include a raw water storage tank which will also be used for chlorine contact time prior to MF filtration, an MF filtrate equalization tank, an RO permeate storage tank prior to the AOP process, and a waste tank to neutralize waste cleaning solutions prior to disposal. In addition, two 6,500 gallon tanks will be used during Phase 2 and 3 testing to allow the high flow rates needed to optimize the UV equipment.

Process and instrumentation diagrams (P&IDs) for all process equipment are included in Attachment B. Ancillary equipment will include process water transfer pumps, water quality instrumentation, the air compressor for the MF skid, the clean-in-place equipment for the RO system, chemical storage and feed systems, health and safety equipment, and a small laboratory counter and sink. The following is a list of chemicals that will be purchased, delivered onsite, and added to the treatment process. All chemicals will be stored in secondary containment and Material Safety Data Sheets (MSDS) will be located both in a binder at the pilot plant and at near the chemical storage locations.

- Sodium hypochlorite: a sodium hypochlorite (NaOCl) solution will be used for disinfection prior to MF filtration and will be injected before the raw water storage tank. It will also be used intermittently for MF membrane cleaning. A third injection point may be used before or after the MF break tank to reduce the formation of disinfection byproducts. The bulk chemical will be delivered and stored onsite in a 55 gallon drum of 10 to 12 percent solution.
- Ammonia: an ammonium chloride (NH_3Cl) or ammonium hydroxide (NH_3OH) solution will be added either before or after MF filtration to convert free chlorine to chloramines. It is essential that ammonia be added prior to the RO system because free chlorine will rapidly damage the RO membranes. The bulk chemical will be delivered and stored onsite as a 55 gallon drum of 19 percent solution or in 50 pound bags of dry chemicals.
- Sodium bisulfite: sodium bisulfite ($NaHSO_3$) will be used for dechlorination as needed prior to the disposal of washwater. It may also be used prior to the RO system to protect the RO membranes from free chlorine when aqueous ammonia is not added. Sodium bisulfite will be delivered and stored onsite in 15 or 55 gallon drums of 38 percent to 40 percent solution. The specific gravity will be approximately 1.33.
- Antiscalant: antiscalant is used for RO pretreatment to prevent scaling on the membranes. The antiscalant to be used in this pilot will be Avista 4000 provided by Avista Technologies or Pretreat Y2K by King Lee Technologies. The antiscalant will be delivered and stored onsite in a 5 gallon drum at 100 percent strength and will be dosed continuously at 2 to 4 mg/L. The specific gravity will be between 1.1 and 1.2.
- Sulfuric Acid: sulfuric acid (H_2SO_4) is used for RO pretreatment to prevent scaling on the membranes; however, testing is required to confirm if it is needed for this application. If used, the sulfuric acid will be delivered and stored onsite in a 15 gallon drums of 50 percent solution. The specific gravity will be approximately 1.4.
- Citric Acid: citric acid is used to clean MF and RO membranes. The citric acid will be delivered and stored onsite in 5 gallon containers of 50 percent solution. The specific gravity will be approximately 1.7.
- Hydrogen Peroxide: hydrogen peroxide is added to the process stream immediately upstream of the UV reactor in the AOP process. Adding hydrogen peroxide will enhance the effectiveness of the processes to oxidize and breakdown organic contaminants. The peroxide will be delivered and stored onsite in 15 or 55 gallon drums of 30 percent solution. The specific gravity will be approximately 1.13.
- Sodium hydroxide: sodium hydroxide (NaOH) may also be added upstream of the UV reactor and/or alternative AOPs to enhance the AOP process. NaOH will also be used intermittently for MF membrane cleaning and neutralization of acidic cleaning solutions. The specific gravity will be approximately 1.28. The sodium hydroxide will be delivered and stored onsite in 15 or 55 gallon drums of 25 percent solution.

3. Equipment, Operations, and Data Management

3.1 Membrane Filtration Pretreatment

3.1.1 MF Pilot Test Program Objectives

The primary function of the MF membrane filtration system will be to provide adequate pretreatment of the process stream for sustainable operation of reverse osmosis. The MF will also provide an additional barrier against protozoa and bacteria. The pilot testing objectives are to provide reliable feed water to the downstream processes and to compare the performance of the MF system with existing full-scale facilities.

3.1.2 MF Process Description

The MF skid that will be used is a Pall Microza USV which functions identically to systems at full-scale facilities. The unit will employ a low pressure microfiltration membrane with a nominal pore size of 0.1 microns. This skid will include an automated control system, all necessary pumps, controls and valves, and additional tankage required for backwash water and clean in place (CIP) procedures.

A membrane integrity test (MIT) will be performed daily to verify integrity of the membranes which ensures a high quality RO feedwater and the CDPH pathogen removal credits allowed for the Pall Microza membrane as an alternative filtration technology. MITs will occur automatically at the time set in the control system or can be performed manually if desired by the operator.

A complete description of the operation of the MF system will be provided by the supplier in the system operation and maintenance (O&M) manual. The documentation will include a flow schematic of the process, a description of each mode of operation (service, backwash, flush, clean-in-place, etc.), as well as all necessary instrumentation and controls. A process and instrumentation diagram (P&ID) for the pilot MF unit is included in Attachment B.

The membrane performance is measured in terms of target production (e.g., flux and recovery), effluent quality (e.g., Silt Density Index (SDI) and turbidity), cleaning frequency, chemical usage, and maintenance of integrity.

3.1.3 MF Test Plan Overview

Once all equipment problems have been corrected and the pilot plant has been fully functional for a minimum of two days, routine flow, pressure, and water quality monitoring of the pilot plant will begin. Each pilot testing phase will be completed by performing a chemical cleaning on the membranes and operating the pilot units for a minimum of 6 hours after completion of cleaning to determine the degree of flux recovery.

Phase 1: Baseline Operations and Optimization (6 months)

Routine operations will be carried out for six months to establish the baseline operating conditions. Initial testing will be performed on tertiary treated water. Additional testing will be performed to assess the impact of using secondary effluent on MF operations and reliability.

Typically, an MF system that is running at a sustainable flux rate can operate with backwash and cleaning intervals that provide a target overall system recovery of greater than 92 percent (i.e., 8 percent of the total flow is used for backwash and cleanings) at a reasonable rate of transmembrane pressure (TMP) increase. Routine cleanings are either referred to as Chemical –Enhanced Backwashes (CEBs) or Enhanced Flux Maintenance (EFM). Both terms describe the same cleaning process. The term EFM will be used in this report. Cleaning intervals vary with source water. For initial operating conditions, EFMs will be discontinued to see if this causes a negative effect on the MF TMP level. It is expected that when the source water switches from filtered effluent to secondary effluent, EFMs will be required twice per week. The first EFM each week will include first a backwash with sodium hypochlorite and sodium hydroxide followed by an EFM with acid; the second EFM each week will use just sodium hypochlorite. More intensive CIP cleanings (a.k.a. recovery cleans) will be performed once per month (see the membrane cleaning section below for more information on EFMs and CIPs).

The initial flux and backwash intervals will be set at the recommendation of the membrane supplier based on full-scale operation at other similar facilities, and free chlorine will be added upstream of the MF system to maintain a residual between 2 and 4 mg/L. It is expected that the MF system will be able to achieve greater than 92 percent recovery with gradually increasing TMP at these operating parameters. If not, then the cleaning scheme will be adjusted as necessary (i.e., chemicals, doses, soak/recirculation time, and cleaning interval) for this source water. If the target recovery rate and cleaning interval can still not be achieved, then the membrane flux will be decreased in 5 to 10 percent increments to identify the baseline flux rate for this source water using free chlorine. Conversely, if the TMP does not increase for more than 7 days, then the membrane flux will be increased in 5 to 10 percent increments. Initial operating flux is assumed to be between 25 and 50 gallons per day per square foot of membrane area (gfd).

Phases 2 and 3: Alternative AOP Evaluation and Design Criteria Optimization (Remaining 9 months)

Once the operating parameters using free chlorine have been determined, the second variable to assess will be to determine whether or not chloramination prior to the MF system can achieve similar operating conditions without generating excessive NDMA (Note: the chemistry and kinetics associated with chloramination impacts the formation of NDMA within the process). If the target recovery rate and cleaning interval are not initially achieved, then the cleaning scheme and flux rate will be adjusted to identify the baseline flux rate for this source water using chloramines. The EFM interval may be increased to no more than once per day and the flux may be decreased as low as 30 gfd.

The flux, recovery, and cleaning parameters will be logged and monitored to evaluate the performance and stability of the MF system. Final optimization will determine the optimum range of flux rates, backwash intervals, and cleaning schemes for reliable operation to include in the design criteria for the full-scale facility.

3.1.4 MF Operations Overview

Sustainable Membrane Operation for Optimization

The MF system will be operated to determine sustainable operating conditions for the full-scale facility. This will include recovery of permeability by prescribed cleaning schemes and maintenance of the membrane module's integrity to assure protection of downstream process equipment.

Membrane integrity verification is required during the pilot testing to ensure that the membrane surface continuously provides an uncompromised and integral pretreatment to the RO system. Verification of membrane integrity will be a critical aspect of the pilot testing, to ensure the validity of removal performance data and demonstrate the reliability of the membrane process. Membrane integrity testing will be performed daily. The integrity monitoring method will be an air pressure holding test (e.g., "pressure decay test") identical to that of full-scale systems. Membrane integrity testing will ensure reliable removal of microorganisms that could promote fouling of the downstream RO membranes.

During the testing period, it is not anticipated that a significant amount of fiber breaks will occur, however, occasional repair of fibers may be required to maintain the required integrity. Fiber repairs will be done by removing the membrane element from operation and manually inserting pins into any broken fibers.

Membrane Cleaning

Two types of chemical cleaning regimens will be performed and evaluated in this study – EFMs to maintain the day by day membrane permeability and CIPs to restore the membrane permeability between phases or when the TMP reaches the terminal value (approximately 35 psi).

EFMs are preventive cleans performed in place at specified regular intervals to maintain the permeability of the membrane at an acceptable level. To start, EFMs will not beutilized, will begin if needed. During these types of cleanings, the membranes will be exposed to chemicals for a short period of time (<15 minutes); initially these chemicals will include sodium hypochlorite, citric acid, and caustic soda; other chemicals including strong acids may be used depending on the supplier's membrane chemical compatibility and foulants of concern. Chemical concentrations will depend on the severity of the organic or inorganic membrane fouling. Before resuming production, chemical residuals must be flushed out from the membrane tank. The supplier is responsible for providing input for the optimization of the EFM cleaning regimen.

CIP cleans are an intensive chemical cleaning used to restore the membrane permeability to pre-fouled conditions. This intensive cleaning will be performed as needed,.. The chemicals used for recovery cleanings will depend on the severity of the organic or inorganic membrane fouling. The initial chemicals will be sodium hypochlorite and sodium hydroxide. This cleaning is performed in place, requires a significant soaking or recirculation time (>4 hours), and typically uses higher chemical concentrations than EFMs. The permeability will be closely monitored throughout the duration of the cleaning, and compared to the permeability which was recorded at the beginning of the study. After a CIP, an integrity test will be conducted to confirm integrity. CIP waste will be neutralized and disposed of in the sewer with the other pilot residuals.

MF Filtrate Water Quality

MF filtered water quality is typically very consistent in terms of removal of suspended solids (measured as turbidity). The turbidity should be approximately less than 0.2 NTU during operation; an increase above 0.2 NTU may indicate an integrity breach and troubleshooting (such as membrane integrity testing) will be necessary to determine the reason for the increase, however, increased turbidity can also be a result of bubbles in the product water, which often occur after a backwash. If high turbidities are observed, the bubble trap should be checked first to ensure that container is full and water is not being short-circuited directly to the turbidimeter.

Even though turbidity is typically low in the filtered water, the filtered water may have a relatively high potential for fouling the RO membranes. The parameter which is used to assess the fouling potential for RO membranes is the silt density index (SDI). The SDI test includes timing how long 500 mL of filtered water takes to pass through a paper filter at different time intervals. The SDI after 15 minutes or SDI_{15} is used by the RO membrane manufacturers as the standard. The target for treated wastewater is an SDI_{15} of less than 3.0 for ninety percent of the time and less than 4.0 for one hundred percent of the time. If the SDI_{15} is greater than 3.0, repeat the test to confirm the result, and begin troubleshooting the MF process and upstream processes to see if there is a cause to the increased values. Potential causes include, breaches in MF membrane integrity, increases in dissolved organics, or upsets in the upstream treatment processes (e.g., secondary clarification, tertiary filtration, chlorine addition).

The monitoring of organics will be useful in assessing fouling of the MF and RO membranes. Values such as TOC and UV_{254} will be monitored to assess the impact on membrane fouling. Monitoring frequency for each of these parameters is discussed in Section 4 of this memorandum.

Run Parameters and Data Logging

Run parameters for membrane filtration must be monitored and documented by the Field Engineer to confirm that sustainable operation is achieved. Even though the majority of flow and pressure data will be collected by the MF system programmable logic controller (PLC), some parameters will be assessed by observation (e.g., gauge readings, tank levels, chemical feed rates, sample flow rates, and secondary field instruments). Key running parameters and conditions that should be manually logged and reviewed include:

- Feed Flow (gpm)
- Filtrate Flow (gpm)
- Membrane Integrity Test Results
- Operation Time (hours)
- Pretreatment Chemical Addition (mg/L)
- Water Quality Parameters in Section 4
- Water Pressure (psi)
- Cleaning Parameters and Frequency
- Backwash Frequency, Flow Rate and Duration (minutes)
- CIP Chemical Usage (gallons)
- CIP Frequency (days)
- Feed and Filtrate Turbidity (NTU)

Operational data and laboratory data will be collected during the membrane filtration testing process. Operational data will be manually logged daily by onsite operations staff. The MF System operations logbook will include a record of events (equipment starts, stops, maintenance, instrument calibrations, etc.) and description of any problems or issues. The original data sheets will be stored on-site; copies of the daily data and log entries will be emailed to the lead operations Engineer on a weekly basis.

Monitoring, Data Collection and Reporting

Much of the data will be monitored and recorded through the online instrumentation; however, routine monitoring and sampling activities for additional and redundant parameters will be performed by the operating engineer on a daily, weekly and monthly basis. Laboratory analyses and data collection will be performed for the membrane filtration pilot with the frequency and schedule as described in Section 4 until the end of the test. Samples will include the feed, filtrate and backwash streams. The samples will be analyzed by Weck Laboratories.

Digital outputs of the feed flow, transmembrane pressure, and trouble alarm status will be sent to the DCTWRP control room for remote monitoring. A brief, general description of MF operations and equipment status will be provided in weekly email updates. A summary of the key water quality parameters: SDI, turbidity and operations parameters: TMP and cleaning frequency will be included in monthly progress reports.

3.2 Reverse Osmosis System

3.2.1 RO Pilot Test Program Objectives

The primary function of the RO process is to provide adequate removal of dissolved salts and organic contaminants. The objectives of the pilot testing will be to:

- Evaluate the operation of the RO membranes in terms of fouling and to adjust the pretreatment and RO parameters as necessary for cost-effective operation.
- Determine if a 2-stage or 3-stage configuration will be optimal for a typical 85 percent recovery.
- Determine if higher recoveries can be achieved with a 3-stage system.
- Determine the impact of different membrane types on energy use and rejection of target contaminants (Phase 3 testing).

3.2.2 RO Process Description

The reverse osmosis equipment system will be mounted within a portable trailer that includes the necessary pumps, valves, chemical addition systems, automated controls and cartridge filters. The RO system is designed to be operated as either a two stage or three stage process; the first stage includes fourteen to sixteen 4-inch elements (7 or 8 in each parallel set of vessels, with each set consisting of two pressure vessels in series), the second stage includes seven or eight 4-inch elements split between two vessels in series, and the third stage includes seven or eight 2.5-inch elements, also split between two vessels in series. The RO pilot skid is designed for use up to 23 gpm of product flow and 300 psi of operating pressure. The process and instrumentation diagram (P&ID) of the RO pilot system is presented in Attachment B.

The optimized recovery rate and flux rate will be determined during testing. The initial flux will be 12 gfd, based on proven operation at the Orange County Water District, Terminal Island Water Reclamation Plant, and West Basin Municipal Water District. The recovery rate will be raised gradually from 70 to 85 percent using a 2-stage design with eight elements in each set of vessels; this configuration will be tested for 3 months.

An additional 3 months of testing will be performed to determine if a 3-stage design can result in lower fouling rates or if higher recoveries can be achieved with a three stage system. When the 3-stage configuration is employed, 7 elements per vessel will be used. The initial set of RO membranes will be Hydranautics ESPA2-4040 (4-inch element) and ESPA-2540 (2.5-inch element).

Additional membranes will be tested in Phase 3 based on recommendations from Workshop #2, and will include Koch TFC-HR and Toray TMG.

Either ammonium chloride or sodium bisulfite will be added at all times prior to the RO system to protect the RO membranes from damage due to free chlorine. An oxidation/reduction potential (ORP) and a total chlorine analyzer will be provided to automatically shut off the RO system in case of free chlorine or excessive chloramines carryover. This will require careful attention of upstream processes to minimize the occurrence of shutdowns. Antiscalant chemical also must be added at all times to prevent scaling of the RO system. Sulfuric acid addition to reduce the pH of the feed water may also be employed, however, it is not currently anticipated that acid addition will be required, based on preliminary operational projections.

3.2.3 RO Test Plan Overview

Phase 1: Baseline Operations and Optimization (6 months)

The start-up period will consist of running the pretreatment and RO units to make sure all automation is working correctly. Start-up is expected to last between seven and fourteen days, depending on the time required for the RO membrane permeability to stabilize after an initial conditioning period.

During baseline testing, the pilot unit will initially operate at an average system flux of 12 gfd and 70 percent recovery in two-stage operation mode, with 7 elements in each pressure vessel. Parameters of specific flux, differential pressure, and salt rejection will be normalized to assess operation and fouling of the system. The normalized specific flux is expected to decline within the first 1 to 2 weeks, but then stabilize. If the specific flux does not stabilize during the first 4 weeks, then the RO system will be cleaned and the flux may be reduced to 10 gfd and operated for an additional 2 to 4 weeks. Once the sustainable flux has been achieved, the recovery will be increased to 85 percent and the testing period will begin. After completion of the 2-stage operation, the third stage will be brought online at the same flux and recovery rate.

Phases 2: Design Criteria Optimization (6 months)

Phase 2 operation will continue the comparison of 2-stage vs. 3-stage operation, and will look at the impact of increased recovery on 3-stage operation. Maintaining a flux of 12 gfd, the hydraulic recovery will be increased to 88 percent and then to 90 percent, to determine whether stable operation can be maintained. Increasing the recovery rate decreases the volume of brine that must be discharged, but also increases pressure and the potential for scaling. Pilot testing confirmation is required to assess the impact on the fouling rate and cleaning interval.

Phases 3: Alternative RO Membrane Evaluation (Remaining 3 months)

Phase 3 will look at the impact of different RO membranes on contaminant rejection, operating pressure, and fouling. The ESPA2 membranes in the first two stages of the RO skid will be replaced with Koch TFC-HR membranes on one side of the skid (Side A) and Toray TMG on the other side (Side B). Each side will be isolated and operated in parallel, such that 7 first stage membranes supply 4 identical second stage membranes, with each side run at 85 percent recovery and 12 gfd.

3.2.4 RO Operations Overview

Sustainable Membrane Operation for Optimization

Sustainable operation will be measured by graphing RO membrane fouling trends and salt rejection, and comparing this data to the projected performance of the membranes from RO membrane projection software. The threshold parameters for fouling trends are as follows: the RO membranes will be cleaned 1) with every 10 percent decrease in normalized permeability, or 2) with every 10 percent increase in differential pressure (DP). If the flux or DP is not recovered by at least 5 percent, then a membrane will be sent for autopsy to determine the correct cleaning solution for the observed foulants.

The key RO fouling trends are:

Membrane Permeability (gpm/psi) = permeate flow per day ÷ membrane surface area ÷ net driving pressure[1] *(NDP)*

- Quantifies permeability of RO membrane elements within a train.
- The slope of membrane permeability decreasing over time is an indicator of membrane fouling rate.

Differential Pressure (psi) = RO feed pressure – RO concentrate pressure

- Quantifies pressure drop across the feed/brine channel of RO membrane elements within a train.
- The slope of differential pressure increasing over time is an indicator of membrane fouling rate.

Normalized Salt Passage % = 100% - salt rejection = permeate conductivity ÷ RO feed conductivity x 100%

- Indicates salt passage through RO membrane elements within a train. Conductivity data will be correlated with chloride and TDS sampling data.
- The slope of normalized permeate conductivity increasing over time is an indicator of membrane fouling rate.

RO Membranes will also be cleaned between phases to prevent compounding of fouling agents from the previous phase. Membrane cleaning will be done using a clean-in-place system using mild acid and base solutions, according to recommended cleaning procedures from the membrane supplier.

Run Parameters and Data Logging

The run parameters for the pilot unit will be based upon the active area of the elements chosen for the RO system demonstration. The permeate flow will be adjusted to attain an average system flux rate of 12 gfd. The concentrate flow will be adjusted to attain a system recovery of 85 percent. Initial flow conditions will be established using RO vendor design software, such as IMSDesign from Hydranautics, however, first stage permeate backpressure, concentrate throttling, and feed water pump pressure will be adjusted manually by field engineers to maintain the desired flow

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[1] Net driving pressure is equal to the transmembrane pressure minus the osmotic pressure.

conditions. Preliminary flow conditions for two stage and three stage operation are presented in Table 3-1, with the full membrane projections included in Attachment C.

Table 3-1: Projected Flow Conditions for RO Pilot

Parameter	2-Stage	3-Stage
Recovery	85%	85%
Average Flux	12 gfd	12 gfd
Feed Flow	17 gpm	18.8 gpm
1st Stage Permeate	9.6 gpm	10.2 gpm
2nd Stage Permeate	5 gpm	4.8 gpm
3rd Stage Permeate	--	1.6 gpm
Total Permeate	14.6 gpm	16.5 gpm
Concentrate	2.4 gpm	2.3 gpm

Key running parameters that will be logged or recorded daily to assess achievement of program objectives are:

- Water Quality Parameters in Section 4
- Total Permeate Flow
- Permeate Flow per Stage
- Total Concentrate Flow
- Inter-Stage Conductivity
- Feed Water Pressure
- Permeate Pressure per Stage
- Final Concentrate Pressure
- Inter-Stage Pressure
- Permeate Conductivity per Stage

A daily operating log and conductivity profile will be taken by the field engineers. The RO System operations logbook will include a record of events (e.g., equipment starts, stops, maintenance, and instrument calibrations) and description of any problems or issues. The original data sheets will be stored on-site. Each item logged will be entered into the project spreadsheet.

Monitoring, Data Collection and Reporting

Some of the data will be monitored and recorded through the online instrumentation; however, routine monitoring and sampling activities for additional and redundant parameters will be performed by the operating engineer on a daily, weekly and monthly basis. Laboratory analyses and data collection will be performed with the frequency and schedule as described in Section 4 until the end of the test. Samples will include the feed, filtrate, and concentrate streams. The samples will be analyzed by Weck Laboratories.

Digital output of the feed flow, permeate flow, transmembrane pressure, recovery, and trouble alarm status will be sent to the DCTWRP control room for remote monitoring. A brief, general description of RO operations and equipment status will be provided in weekly email updates. A summary of the key water quality parameters: salt rejection and operations parameters: RO fouling trends will be included in monthly progress reports.

3.3 Advanced Oxidation Process

UV/H_2O_2 is an established process for advanced oxidation in reuse applications in California, and is in use at the Orange County Water District Groundwater Replenishment System, among other facilities. A thorough discussion of AOP alternatives and the rationale for selecting UV/H_2O_2 for the baseline process is included as Attachment H. A Trojan UV/H_2O_2 system will be used during Phase 1 of the pilot test and UV/H_2O_2 will be evaluated as the baseline for comparison along with the selected AOP, ozone/hydrogen peroxide (O_3/H_2O_2). The AOP pilot testing protocol is described below.

3.3.1 AOP Pilot Test Program Objectives

The objectives of the AOP pilot testing are:

- Demonstration of UV/H_2O_2 treatment for destruction of target constituents, including NDMA, 1,4-dioxane and selected, non-regulated indicator compounds gemfibrozil, sufamethoxazole, and TCEP (see the Task 1.4 TM for rationale of selecting these compounds). One potential challenge is sufficient NDMA in the feed. It is possible that the AOP feed NDMA concentration at DC Tillman will not be high enough to demonstrate 1.2-log removal, in which case spiking will be necessary. It is possible that the NDMA concentration observed at Hansen spreading grounds will be orders of magnitude higher than those observed at DCTWRP. Because of this uncertainty, it will be important to ensure high levels of feed NDMA during pilot testing to account for possible variation in AOP feed NDMA concentrations and demonstrate removal. Ensuring high levels of NDMA will be addressed during Phases 2 and 3 of the pilot study.
- Demonstration of the alternative advanced oxidation process for destruction of target constituents. If O_3/H_2O_2 is selected to be pursued at the full-scale, it may be necessary to demonstrate effective pathogen removal under Title 22 recycled water requirements.
- Comparison of AOP alternatives including processes in consideration of factors including, but not limited, to energy requirements (e.g., electrical efficiency per log order reduction, or EE/O) and chemical costs.

If the indicator compounds identified above or any other emerging contaminants sampled are detected during sampling for EDCs/PhPCPs in the feed to the AOP, their removal in the AOP will be considered as part of the pilot study.

3.3.2 AOP Process Description

The advanced oxidation treatment step will include the application of UV light and hydrogen peroxide to destroy small molecular weight organic compounds not completely removed by the RO membranes. Low pressure UV/H_2O_2 technology is being applied to meet the advanced purification requirements in the draft CDPH Groundwater Recharge Reuse Regulations at the GWRS in Orange County and at the Edward C. Little Recycling Facility at West Basin MWD. Because this process is already in place at a full-scale facility in California, it is recommended as the baseline technology for Phase 1.

Recommended AOP Technology for Pilot Test: Low pressure UV with H_2O_2

Based on recent AOP experience, it is not likely that a pilot-scale version of the UV/H_2O_2 process technology suitable for application at the full-scale will be available for the target flow range (flow ~ 5-20 gpm). For this reason, a phased approach to the pilot testing will be followed. During Phase 1, the UV/H_2O_2 pilot reactor will be run at low flow (< 20 gpm) and, while demonstrating removal of target constituents to levels meeting the performance expectations, the Phase 1 hydraulic conditions will be considerably different than those in full-scale and will not be directly scalable. For this reason, in Phases 2 and 3, the flow rate will be increased to levels representative of a turbulent flow regime (100-350 gpm) to obtain results suitable for process optimization and scale-up to the full-scale conditions. Note that at this flowrate, the system may not achieve a 1.2 log reduction of NDMA. However, results from this high flow testing will be used to develop a model for use in design of the full-scale system. The suitable reactor is anticipated to employ lamps with the same output spectrum as the full-scale reactor. The reactor to be implemented for Phase 1 is Trojan's 8AL20 reactor. Vendor information on this reactor is included in Attachment B.

A pump and control setup will be implemented that has the ability to consistently maintain a 350 gpm flow without significant variation as the Baker tank empties and the pressure drop, ΔP, changes during the experiments to maintain turbulent flow conditions. Ideally this will be a system with the ability to (1) "dial in" flows between 100 gpm and 350 gpm; (2) to set the flow to the required level pretty quickly (1 or 2 min.) as only a short time is available for testing; and (3) to maintain the flow within 5 percent variability as the Baker tank empties. This will be done either with a variable frequency drive (vfd) pump or an automatically actuating control valve. Location and control of the UV feed reservoir and pump have not yet been established, and will be addressed in a future draft of this protocol.

As discussed in the Task 1.4 TM, an advanced oxidation process simulation model, AdOx™, will be used to evaluate the pilot testing results for the pilot-scale reactor and to predict the performance of the full-scale reactor. While it is expected that the pilot-scale and full-scale reactors will use lamps with the same output spectrum, the hydrodynamics of each reactor are likely to differ. A tracer study will be conducted to evaluate the mixing condition for the reactor at the pilot. Based on the data collected during Phases 2 and 3 of the pilot study and through application of AdOx™, it will be possible to develop a bid document that considers key issues like power requirements, wavelength, and mixing condition, which may be used to qualify other vendors beyond Trojan for the full-scale application. It is also considered that an alternative vendor LPUV technology (e.g., Wedeco or Ozonia) may be tested in Phases 2 and 3 of the pilot study. In addition to modeling with AdOx™, the UV dose delivered by the AL20 will be determined following an adaptation of the protocol in the NWRI Guidelines.

It is anticipated that the tracer study for the pilot will be conducted using a pulse of tracer (e.g., sodium chloride) injected upstream of the UV reactor in a manner designed to assure proper mixing prior to entering the UV reactor and by measuring conductivity at the reactor outlet using a recording conductivity meter. As discussed in the Task 1.4 TM, the AdOx model has the capability to evaluate the tracer curve obtained from the tracer study to calibrate performance to that of a real reactor based on the dye curve.

Electrical efficiency per log order reduction (EE/O) of a target constituent is typically expressed in kWh/1000 gal and defined for the UV/H_2O_2 process as:

$$\mathrm{EE/O} = \frac{\text{Lamp Power Output}}{\text{Flowrate} \times \log(C_i/C_e)}$$

By accounting for mixing condition in the manner discussed above it will be possible using the AdOx modeling approach to predict electrical efficiency per log order reduction (EE/O) for target constituents like NDMA, 1,4-dioxane, and the EDC/PhPCP indicator compound(s) and compare them to experimental data collected during the pilot study. AdOx will also allow for evaluation of the optimum hydrogen peroxide dosage to achieve removal of target constituents.

It will then be possible to apply AdOx to the full-scale reactor using tracer study data for the full-scale reactor to account for the mixing condition. It is expected that the EE/O achieved during the pilot study will differ from the full-scale because of the differences in the pilot- and full-scale reactors including the differences in mixing condition discussed above. In this way, energy efficiency and hydrogen peroxide dosage can be optimized to meet the water quality objectives for target constituents for the full-scale. EE/O can also be determined in a similar manner for the alternative AOP, O_3/H_2O_2, in consideration of the energy requirements and used as a basis for comparing the alternative along with other factors including chemical costs.

A summary of conditions that it is envisioned will be evaluated in the pilot study provided below.

3.3.3 AOP Test Plan Overview

The testing plan is intended to demonstrate the effectiveness of the baseline process at removing the target contaminants and provide an evaluation of an alternative AOP technology to achieve the same objectives.

Phase 1: Baseline Operations and Optimization (6 months)

During baseline operations, the Trojan UV/H_2O_2 process will be evaluated to demonstrate that the MF/RO/AOP process can achieve the performance expectations. The UV reactor will not require manual or automatic adjustment; however, it will require monitoring of the display to confirm that the unit is on or if there is an indication that the UV lamp requires cleaning or replacement. The hydrogen peroxide dose will be set to achieve the target rates of contaminant removal. Further discussion of the UV/H_2O_2 AOP is provided in Attachment H.

Phases 2 and 3: Alternative AOP Evaluation and Design Criteria Optimization (Remaining 9 months)

During Phase 2, an alternative AOP technology will also be evaluated. Continued monitoring of the UV/ H_2O_2 system may be necessary to determine any variations in effectiveness as the lamps begin to foul. The flow rate during Phases 2 and 3 will be 100-350 gpm for the UV/H_2O_2 tests as discussed above.

Ozone/hydrogen peroxide will be the alternative AOP evaluated during Phase 2. The unit will treat a flow rate of 4 gpm. During Phase 3, process parameters will be optimized to determine the full-scale design criteria for the process. Further discussion of the O_3/H_2O_2 AOP is provided in Attachment H.

3.3.4 AOP Operations Overview

Sustainable Operation for Optimization

Sustainable operation is confirmed by monitoring the dose of UV light in the reactor. This will be confirmed by monitoring for the UV absorbance of the feed and filtered water at a wavelength of 254 nm using a benchtop spectrophotometer and by monitoring the power consumption of the UV system. The UV lamps will be cleaned when necessary to provide the target dose based on the UV absorbance monitoring and/or the automatic indicator that indicates when cleaning is required by measuring the output within the reactor. Cleaning is not expected to be required.

Run Parameters and Data Logging

The destruction of contaminants by UV/ H_2O_2 AOP involves a complex series of chemical reactions interacting with the amount of energy input into a unit volume of water. During UV radiation, the photons of light activate hydrogen peroxide and generate highly reactive hydroxyl radicals, which destroy the organic contaminants. The UV dose can be viewed in two ways: as the reduction equivalent dose (RED, mJ/cm^2) or as the electrical energy dose (EED, KWh/1000 gal). The RED will be determined by ADOx™ and by the use of an adaptation of the NWRI Guidelines. The EED will be determined by monitoring the energy usage of the lamps rather than by using light intensity meters, which have proven highly ineffective at other sites. The run parameters for this process unit will be based upon the UV dose and hydrogen peroxide addition.

Other important parameters include power range, guaranteed lamp life (hrs), lamp operating temperature range, power consumption/lamp (Watts), UV output/Lamp (Watts), number of lamps, efficiency and time to cool down to restart.

The following parameters are necessary to evaluate the performance of the UV equipment:

- Feed Water Temperature (°C)
- Feed Water pH
- UV Transmittance (%)
- Number of Lamps in operation
- Feed Water Turbidity (NTU)
- Feed Water Flow (gpm)
- Energy Dose (kWh/1,000 gal)
- Cleaning Requirements

A daily operating log and turbidity profile is to be taken by the Engineer operating staff. The UV-A System operations logbook will include a record of events (e.g. equipment starts, stops, maintenance, instrument calibration, etc.) and description of any problems or issues. The original data sheets will be stored on-site; daily data and log entries will be entered into the project spreadsheet.

Sampling and Laboratory Data

The target contaminants which will be monitored regularly after the AOP process include: NDMA, 1,4-Dioxane, and several EDCs/PhPCP compounds including gemfibrozil, sulfamethoxazole, TCEP, and other EDCs/PhPCPs detected in AOP feed.

Data Collection and Reporting

Much of the data will be monitored and recorded through the online instrumentation; however, routine monitoring and sampling activities for additional and redundant parameters will be performed by an operator on a daily, weekly and monthly basis.

The sampling and monitoring schedule is discussed in Section 4. This schedule may be modified during operation based on raw water quality and other operating conditions. All data will be recorded on the daily, weekly and monthly log sheets provided in Attachment D.

3.4 Product Stabilization (Bench-scale Testing and Desktop Evaluation)

3.4.1 Product Stabilization Testing Objective

The objective of this testing is to identify the design parameters for the most appropriate post-treatment approach for the effluent stabilization for distributing the product water and for recharge at the spreading grounds.

3.4.2 Product Stabilization Process Description

The product water from the RO pilot units is very soft and corrosive because the RO process removes the majority of salts and minerals from the water that provide hardness and alkalinity. Therefore, post-treatment stabilization will be required to: (1) limit corrosion during distribution and conveyance and (2) ensure a stable long-term soil hydraulic conductivity at the spreading grounds.

To meet these objectives, the post-treatment process will most likely be partial decarbonation of the RO permeate followed by lime addition to meet calcium and alkalinity goals. A portion of the RO permeate will by-pass the decarbonator to provide the necessary carbonic acid (soluble carbon dioxide) for pH adjustment. The result will be a combined balance of alkalinity, calcium and pH that is suitable for $CaCO_3$ stabilization. Previous experience has shown that this approach successfully controls corrosion of water conduits and helps to prevent sodicity (i.e. maintain reasonable groundwater infiltration rates). However, depending on the final RO product water quality, the amount of water sent through the decarbonators may vary from zero percent to more than 75 percent.

3.4.3 Product Stabilization Test Plan Overview

The desktop evaluation is intended to determine the requirements for stabilization and the impact of process control and design decisions on those requirements. A desktop model of the stabilization technology will be built that can simulate performance and allow the exploration of changes in permeate water quality, or changes in operating conditions, on the requirement for the stabilization process. The model will be based on spreadsheet software similar in function to WaterPro or the RTW model.

As delivered, most lime products contain a significant amount of inert material. Moreover it is generally difficult to dose lime without introducing a certain amount of debris in the product water and these inerts are thought to interfere with the permeability of formations receiving injected water. As a result, at the present time, most installations using lime to stabilize the AWPF product water use lime saturators to produce lime-water that is free of inert materials. Bench-scale testing will be conducted in order to assess the impact of alternative methods of lime delivery on inert particulates in the product water. This testing will include examination of the quality of lime waters currently being produced at full-scale installations in Southern California, including evaluation of the modified fouling index (MFI) for lime adjusted water from the pilot plant.

Run Parameters and Data Logging

The corrosion tendency can be approximated by calculating the Langelier Saturation Index (LSI) on the RO effluent. The LSI can be calculated by monitoring for pH, TDS, calcium, alkalinity, and temperature.

For reference LSI = pH - pH_s

Where pH = measured pH in the water sample

pH_s = saturation pH for calcium carbonate

The criteria for the LSI are:

- LSI > 0 Water is supersaturated with respect to calcium carbonate ($CaCO_3$) and scaling may occur
- LSI < 0 Water is undersaturated with respect to calcium carbonate with tendency to remove existing calcium carbonate scale.
- LSI = 0 Neutral water. Scale is neither precipitated nor dissolved

Note that although the LSI is commonly used as a corrosion index, it is not a direct indicator of corrosiveness, rather it is an indicator of the tendency to form $CaCO_3$ scale, which is sometimes connected to corrosion. Many utilities target a slightly positive LSI and some may use additional indices or parameters. Many pipes are mortar-lined and as mortar linings cure, pockets of lime are formed which can dissolve, exposing greater surface area to aggressive water. In such a circumstance, a positive LSI means that pores containing lime solution will tend to be self-sealing (e.g. $CaCO_3$ will form). It is important to note that many municipalities successfully control corrosion while delivering a treated water with a negative LSI (e.g. Seattle, Portland and New York).

The water quality impacts on soil infiltration are measured through a combination of the sodium adsorption ratio (SAR) and the electrical conductivity (EC_w). Figure 3-1 illustrates the ranges of SAR and EC_w values that have severe, moderate, and negligible impacts on soil infiltration. In general, the likelihood of infiltration problems increases as the electrical conductivity of the water decreases. Because all product water from the AWPF at DCTWRP is currently destined for infiltration via spreading grounds and the current limitations to IPR capacity from water produced at this facility are limited by the capacity of these spreading grounds, the need to consider final water quality objectives that ensure future spreading ground capacity is critical. The SAR is calculated using the following equation:

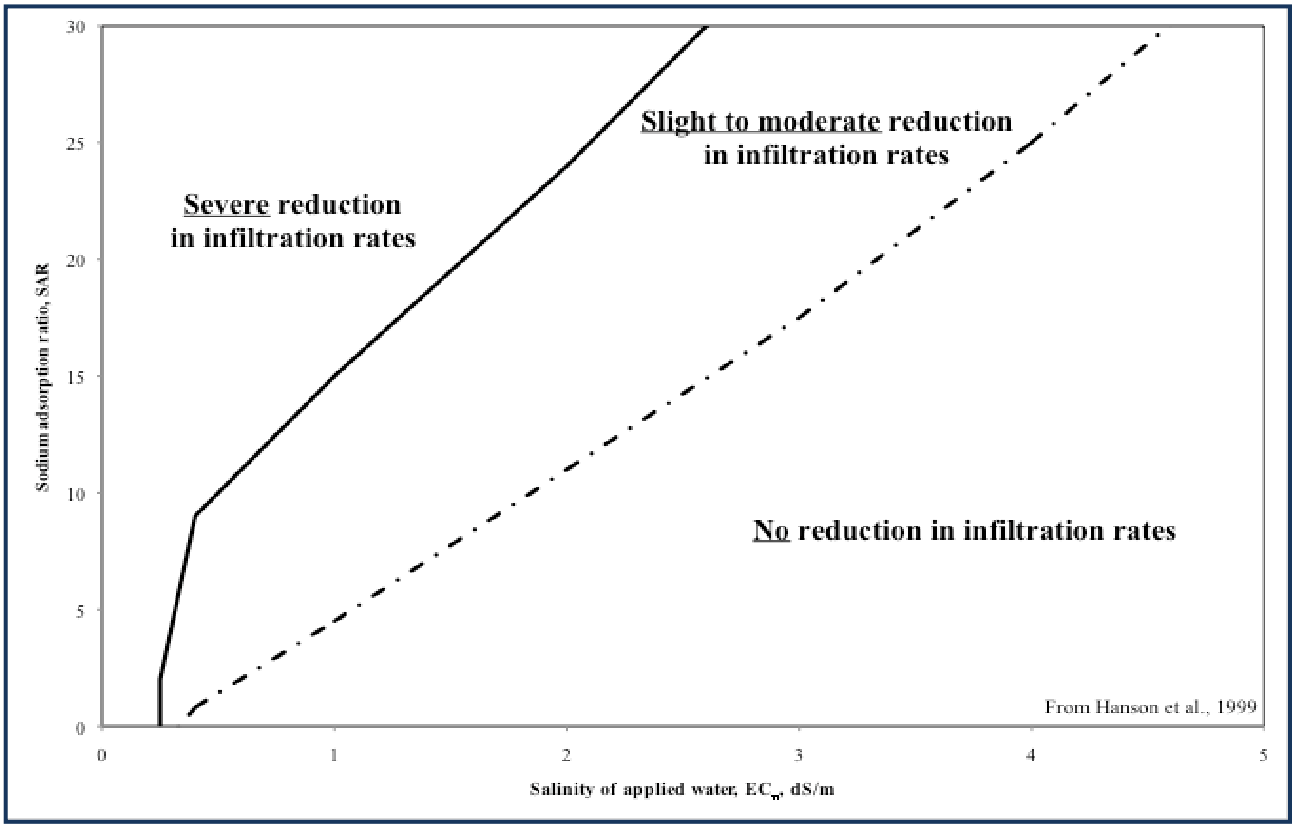
$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\left[\mathrm{Ca}^{2+}\right]+\left[\mathrm{Mg}^{2+}\right]/2}}$$

where $[Na^+]$ = concentration of sodium ion, meq/L

$[Ca^{2+}]$ = concentration of calcium ion, meq/L

$[Mg^{2+}]$ = concentration of calcium ion, meq/L

Figure 3-1: Impact of Product Water SAR and Conductivity on Water Sodicity or Infiltration Rates



Monitoring, Data Collection and Reporting

Laboratory analyses will be performed on the product water following bench-scale testing for the following parameters:

- Chemical Dose
- pH
- Bicarbonate
- LSI
- Calcium
- Chloride
- Temperature
- Carbon Dioxide
- Carbonate
- TDS
- Electrical Conductivity
- Sulfate

3.5 Summary of Operations Schedule

Table 3-2 summarizes the proposed testing schedule and operating conditions for the various unit processes discussed above.

Table 3-2: Projected Operating Schedule

Month	Pretreatment	Reverse Osmosis	Advanced Oxidation
1	FE source water 3 mg/L total Cl_2 50 gfd MF flux 3-day EFM cycle	70-85% recovery 12 gfd RO flux 2-Stage ESPA2	UV/peroxide 15gpm Continuous operation
2			
3	SE source water 3 mg/L free Cl_2 50 gfd MF flux EFM No EFMs	85% recovery 2-Stage	
4		85% recovery 3-Stage	UV/peroxide 100-350 gpm Intermittent operation
5	FE source water 3 mg/L free Cl_2 50 gfd MF flux No EFMsEFM	85% recovery 3-Stage	
6		85% recovery 2-Stage	
7	FE source water 3 mg/L chloramines	88% recovery 3-stage ESPA2	UV/peroxide + O_3/peroxide
8			
9	FE source water 3 mg/L sequential chloramination		
10		90% recovery 3-stage ESPA2	UV/peroxide + TiO_2
11	FE source water 3 mg/L chloramines		
12			
13	To be determined	85% recovery 2-stage TFC-HR & Toray TMG	To be determined
14			
15			

4. Water Quality Monitoring Plan

4.1 Water Quality Monitoring Objectives

The objective of the water quality monitoring is to: 1) demonstrate that the treatment process will produce water that is suitable for groundwater replenishment, 2) demonstrate that the process can achieve regulatory compliance, 3) provide information on fouling potential of water and performance of unit processes for full scale facility design, and 3) demonstrate removal of emerging contaminants (discussed in detail in the Task 1.4 TM). The primary product water performance expectations for the pilot, defined previously in Section 2, include:

- TOC – 0.2 mg/L
- Total Nitrogen – 2 mg/L
- NDMA – 0.005 µg/L
- 1,4-Dioxane – 0.0015 mg/L
- TTHMs – 40 µg/L
- HAA5 – 30 µg/L
- TCEP – 0.0015 µg/L
- Turbidity – 0.1 NTU
- TDS – 250 mg/L
- Chloride – 80 mg/L

4.2 Frequency and Schedule of Analytical Data Collection

The frequency and schedule for water quality data collection is summarized in Table 4-1.

Table 4-1 Proposed Pilot Water Quality Monitoring

Parameter	Method	Source Water	MF/UF Effluent	RO Feed	RO Filtrate	RO Concentrate	AOP Influent	AOP Effluent		
								UV	O_3	TiO_2
Temperature (F)	field	D	WD	D	-	-	WD	-	-	-
pH	field	D	WD	D	WD	WD	WD	WD	WD	WD
Free Residual Chlorine (mg/L)	field	WD	WD	WD	-	-	-	-	-	-
Total Residual Chlorine (mg/L)	field	WD	WD	D	-	-	WD	-	-	-
Color (Pt-Co)	field	W	W	W	-	W	W	-	-	-
Conductivity (uS/cm)	field	WD	-	D	D	WD	W	W	W	W
ORP	field		WD	D	WD					
Dissolved Oxygen (mg/L)	field	W					W		W	
SDI	field	-	W	WD	-	-	-	-	-	-
TOC (mg/L)	field	WD	W	-	WD	W	-	-	-	-
Turbidity (NTU)	field	WD	D	WD	WD	WD	-	-	-	-
UV254	field	WD	WD	-	WD	-	WD	WD	WD	WD
UV Intensity	field	-	-	-	-	-		WD		
Alkalinity (mg/L)	SM2320B	-	W	W	W	W	W	W	W	W
Barium (mg/L)	EPA200.7			M	M	M				

Parameter	Method	Source Water	MF/UF Effluent	RO Feed	RO Filtrate	RO Concentrate	AOP Influent	AOP Effluent		
								UV	O_3	TiO_2
Boron (mg/L)		M		M	M					
Bromate (mg/L)	EPA300.1								W	
Bromide (mg/L)	EPA320.1	M			M					
Calcium (mg/L)	EPA200.7	-	-	W	W	W	-	-	-	-
Chloride (mg/L)	EPA300.0	-	-	M	M	M	-	-	-	-
1,4-Dioxane	EPA8270M	Q	-	-	-	-	Q	Q	M	M
Fluoride (mg/L)	EPA300.0	-	-	W	W	W	-	-	-	-
Total Iron (mg/L)	EPA200.8	-	-	M	M	M	-	-	-	-
Magnesium (mg/L)	EPA200.7	-	-	W	W	W	-	-	-	-
Manganese (mg/L)	EPA200.8	-	-	M	M	M	-	-	-	-
NDMA	EPA1625M	W	W	W	W	-	W	W	W	W
TKN (mg/L)	EPA351.2	M	W	-	W	M	-	M	M	M
NH_3 (mg/L)	EPA350.1	-	W	W	W	M	-	M	M	M
NO_2 (mg/L)	EPA353.2	-	W	-	W	M	-	M	M	M
NO_3 (mg/L)	EPA353.2	-	W	-	W	M	-	M	M	M
NO_3 + NO_2 (mg/L)	calculation	-	W	-	W	M	-	M	M	M
Orthophosphate (mg/L)	EPA365.1	W	-	-	W	W	-	-	-	-
Total Phosphorus (mg/L)	EPA365.1	W	-	-	W	W	-	-	-	-
Potassium (mg/L)	EPA200.7	-	-	M	M	M	-	-	-	-
Silica (mg/L)	EPA200.7	-	-	W	W	W	-	-	-	-
Sulfate (mg/L)	EPA300.0	-	-	W	W	W	-	-	-	-
TDS (mg/L)	SM2540C	W	-	W	W	W	W	W	W	W
Sodium (mg/L)	EPA200.7	-	-	W	W	W	-	-	-	-
Strontium (mg/L)	EPA200.8	-	-	W	W	W	-	-	-	-
TOX (total organic halogens) (ug/L)	SM5320B	M	-	-	-	-	M	-	-	-
Regulated 3 & 507 Compounds	EPA525.2	M	-	-	-	-	-	-	-	-
Di(2-ethylhexyl) phthalate (ug/L)										
Fumigants (EDB, DBCP)	EPA504.1	-	-	Q	-	-	Q	-	-	-
Dibromochloropropane (DBCP) (ug/L)										
Ethylene dibromide (EDB) (ng/L)										

Parameter	Method	Source Water	MF/UF Effluent	RO Feed	RO Filtrate	RO Concentrate	AOP Influent	AOP Effluent		
								UV	O_3	TiO_2
Volatile Organic Compounds	EPA524.2	M	-	-	-	-	-	-	-	-
1,2-Dichlorobenzene										
1,4-Dichlorobenzene (ug/L)										
Chlorobenzene (mg/L)										
Chloroform (ug/L)										
cis-1,2-Dichloroethylene (ug/L)										
Dichloromethane (ug/L)										
Ethylbenzene (mg/L)										
Tetrachloroe thylene (ug/L)										
Toluene										
Trichloroethylene (ug/L)										
Trihalomethanes, Total (TTHM) (ug/L)	EPA525.2	M	-	M	M	-	M	M	M	M
Haloacetic Acids, five (HAA5) (ug/L)	EPA524.2	M	-	M	M	-	M	M	M	M
Cryptosporidium & Giardia	EPA1623	Q	Q	-	-	-	-	-	-	-
Indigenous Coliphage	SM1602	M	-	-	-	-	M	-	-	-
Enterovirus (EPA R-95/178)	EPA ICR 6000	Q	-	-	-		Q	-	-	-
Organochlorine Pesticides & PCBs	EPA508	-	-	Q	-	-	Q	-	-	-
Oil and grease (mg/L)	EPA1664A	M	M	-	-	-	-	-	-	-
Emerging Contaminants										
Pharmaceuticals Pharma +, -		Q	-	-	Q	-	Q	Q	Q	Q
Organochlorine Pesticides & PCBs	EPA508	Q	-	-	-	-	-	-	-	-
Chlorinated Acid Herbicides	EPA515.3	Q	-	-	-	-	-	-	-	-
TCEP		M	-	M	M		M	M	M	M

Footnotes:
a. D = daily, WD = weekdays only, W = weekly; M = monthly, Q = quarterly
b. Continuous on line monitoring instruments are not included in this table.
c. Composite samples will be used for monitoring of the parameters for the primary and secondary drinking water standards.
d. Unless indicated otherwise, all other parameters will be sampled using grab samples.

4.3 Field Analysis

Field equipment will be used for all daily and weekday samples, using either bench-top or online equipment. The following field equipment will be employed during the piloting:

- Bench top spectrophotometer (Hach DR 5000)

- Handheld conductivity/pH meter (Myron L Ultrameter II)
- Handheld DO probe
- Bench top TOC analyzer (Shimadzu TOC-Vcsn)
- Bench top SDI kit
- Bench top turbidimeter (Hach turbidimeter)
- Online total chlorine analyzer (Hach CL17)
- Online ORP meter
- Online pH analyzer
- Online turbidimeter (2) (Hach 1720E and Hach 660)

4.4 Laboratory Analysis

All water quality measurements not performed with field equipment will be stored in sample bottles and sent to Weck Laboratories for analysis. The analytical methods to be employed for each parameter are listed in Attachment E. In addition, periodic duplicate samples of field analyses will be sent to the laboratory for quality control confirmation.

4.5 Additional Water Quality Monitoring

Additional water quality monitoring will be done using field equipment to characterize diurnal patterns for TOC, turbidity, chlorine demand, and temperature. This testing will be conducted over 24 hour cycles with samples taken hourly. One test will be conducted per quarter for each of these parameters.

5. Quality Assurance/ Quality Control

Quality assurance and quality control (QA/QC) is a system for maintaining desired standards during pilot-scale testing and is particularly important for analytical procedures during the operation of a pilot plant.

5.1 Analytical Procedures

The following analytical procedures should be observed for all data collection and sampling procedures:

- Calibrate the field analysis instruments, as needed, per the manufacturers' instructions. A calibration notebook will be kept at the site to document all instrument calibrations.
- Follow proper sample collection and handling requirements as specified in Standard Methods and/or other relevant sampling methods (e.g., EPA, Lab specific methods for emerging contaminants, etc.). A list of methods is included in Attachment E.
- Duplicate samples of field analyses (e.g., TOC, conductivity) will be sent periodically to an outside lab to confirm onsite testing results. Exceptions include temperature, pH, ORP, and chlorine, where laboratory analysis would not provide a significant improvement in accuracy compared to calibrated field measurements.

5.2 Weekly Updates

Weekly updates on the pilot operation will be sent with the RWMP weekly reports providing frequent updates on equipment status, process performance, schedule, and unforeseen issues that may need to be addressed by the team and/or the technical review committee.

5.3 Technical Review Committee (TRC)

The TRC will provide an independent review by experienced and qualified personnel. The TRC provides input and guidance so that the direction of the testing is consistent with a sound, practical, and cost-effective treatment approach. The work of the consultant TRC will be directed by the Project Manager. Meeting minutes with recommendations from TRC membranes shall be provided to team members for response or incorporation into project documents.

5.4 City Reviews

The City will review project reports and deliverables. Review comments shall be consolidated by the City prior to forwarding the review comments to the consultant for response or incorporation into project documents.

6. Staffing and Communications

6.1 Staffing

The following is a summary of the City and consulting project teams. A contact list for pertinent team members is included in the Health and Safety Plan in Attachment F.

6.1.1 City Project Team

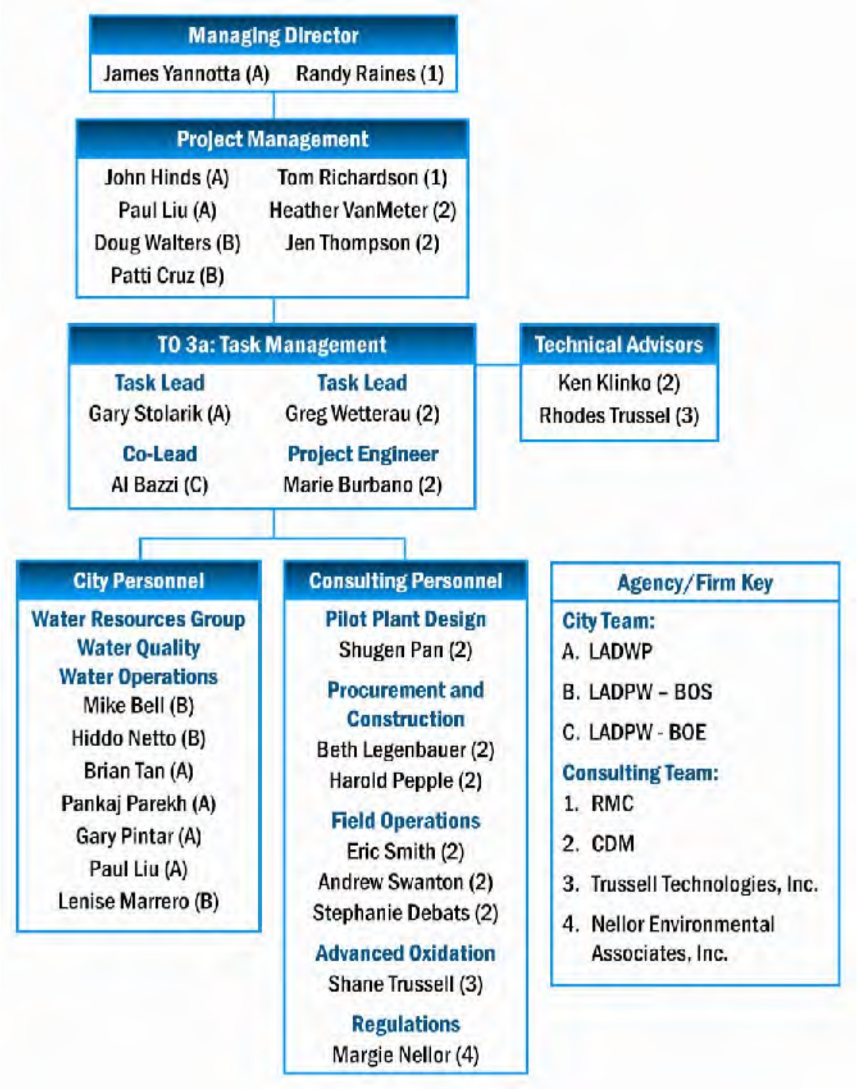
The Los Angeles project team is under the overall direction of James Yannotta, Assistant Director of Water Resources, LADWP. The following is a list of team members from the City.

- Paul Liu - LADWP
- John Hinds –LADWP
- Doug Walters -Los Angeles Bureau of Sanitation (BOS)
- Patti Cruz – BOS
- Gary Stolarik – LADWP
- Al Bazzi – Los Angeles Bureau of Engineering (BOE)

6.1.2 Consultant Project Team

The consultant project team organization is shown in Figure 6-1. The consultant team is headed by the project manager, Tom Richardson with RMC and the task leader, Greg Wetterau with CDM.

Figure 6-1: Task 3a Organization Chart



6.1.3 Field Engineers and Weekend Operations Staff

Daily operations (M-F) will be conducted by the consultant team through the end of operation. Eric Smith, Daniel Berokoff and Andrew Swanton will rotate operating the pilot.

BOS will provide staff to collect samples on the weekends (Sat-Sun) and holidays.

6.1.4 City Responsibilities

BOS will provide the following support for installation and operation:

- Connection of electrical power supply to the pilot plant units
- Assistance during equipment delivery, unloading, and siting
- Assisting with labor during start-up, commissioning, and weekend operations
- Notifying the operating engineer on call of equipment malfunctions and process issues
- Providing the operating engineer on call with data and information observed over the weekend

6.1.5 Consultant Team Responsibilities

The consultant team will provide the following services for pilot plant:

- Start-up, commissioning, and adherence to the testing protocol
- Equipment and instrument procurement
- Labor for installation, startup, and equipment replacement
- Labor for week day operations (assumes an average of 40 hours per week)
- Determining chemical cleaning solutions, schedules and procedures
- Supplying chemicals for operations and cleaning
- Normalizing and reviewing the operating data
- Preparing weekly and monthly progress reports
- Preparing final pilot report

6.2 Communications

The objective is to provide proactive, clear, and open communications between the consultant project team and the City. Updates on the pilot will be given at monthly RWMP progress meetings between the consultant team, LADWP and LADPW staff. The consultant team will provide weekly and monthly progress reports to LADWP providing updates of pilot operation and current testing conditions.

A project eRoom has been set up for team members. An eRoom is a web-based project delivery system that will be used to store and review all project documents. The system can be accessed by both City and consultant team personnel. Users will be granted access to the eRoom and given a login ID and password.

7. Health and Safety

The Health and Safety Plan for the Pilot Study includes key personnel contacts, emergency contacts, a catalog of potential hazards, and the means to control those hazards and is included in Attachment F.

7.1 Health and Safety Equipment

The pilot plant will be equipped with the following safety equipment at all times:

- Chemical spill cleanup/control kits.
- Personal Protective Equipment including face shields, goggles, aprons and gloves.
- First aid kit.
- Hazard identification labels (using NFPA rating numbers) on each chemical storage tank and dry chemical storage area.

Emergency eyewash/drench hoses and fire extinguishers are located in adjacent DCTWRP buildings.

7.2 Chemical System Training

Pilot operators and field engineers will receive training on chemical handling and general safety before operating pilot plant equipment and will review the DCTWRP emergency response plan on a quarterly basis.

7.3 Chemical Storage and Deliveries

The pilot plant will use several chemicals, both liquid and dry, at various stages of the treatment process. Liquid chemical will be stored on-site will 55 gallon containers or smaller. Dry chemicals will be delivered in 50 or 100 pound bags, and the aggregate amount of each dry chemical on-site will be less than 500 lbs. Upon receipt, these chemicals will be placed on spill containment pallets. Non-compatible chemicals will not be stored on the same spill containment pallet.

Deliveries are estimated to occur on a monthly basis and will be coordinated with plant operating staff; empty containers will be collected during delivery by the chemical supplier for disposal.

With exception of the strong acid, which will be fed neat, diluted chemical feed solutions will be prepared and fed from mini-bulk tanks constructed of high density polyethylene (HDPE) capable of storing up to 20 gallons. The mini-bulk tanks and chemical feed pumps will be placed in secondary containment. The chemical feed tubing will be secondarily contained with larger diameter tubing so that drips or leaks will be transferred back to the containment.

MSDS sheets for each chemical on-site will be posted next to the chemical storage areas and will also be kept in a binder stored along with the pilot plant equipment operation and maintenance manuals.

8. References

1. RWMP Draft Regulatory Assessment Technical Memorandum (Task 1.1 TM), RMC/CDM, updated revised versions dated December 2011
2. RWMP Draft Advanced Water Treatment Technology Assessment Technical Memorandum (Task 1.4 TM), RMC/CDM, updated revised versions dated December 2011
3. 2008 Draft Groundwater Recharge Regulations (CCR Title 22)

Attachments

Attachment A Equipment Data

Attachment B P&IDs

Attachment C RO Projections

Attachment D Data Log Sheets

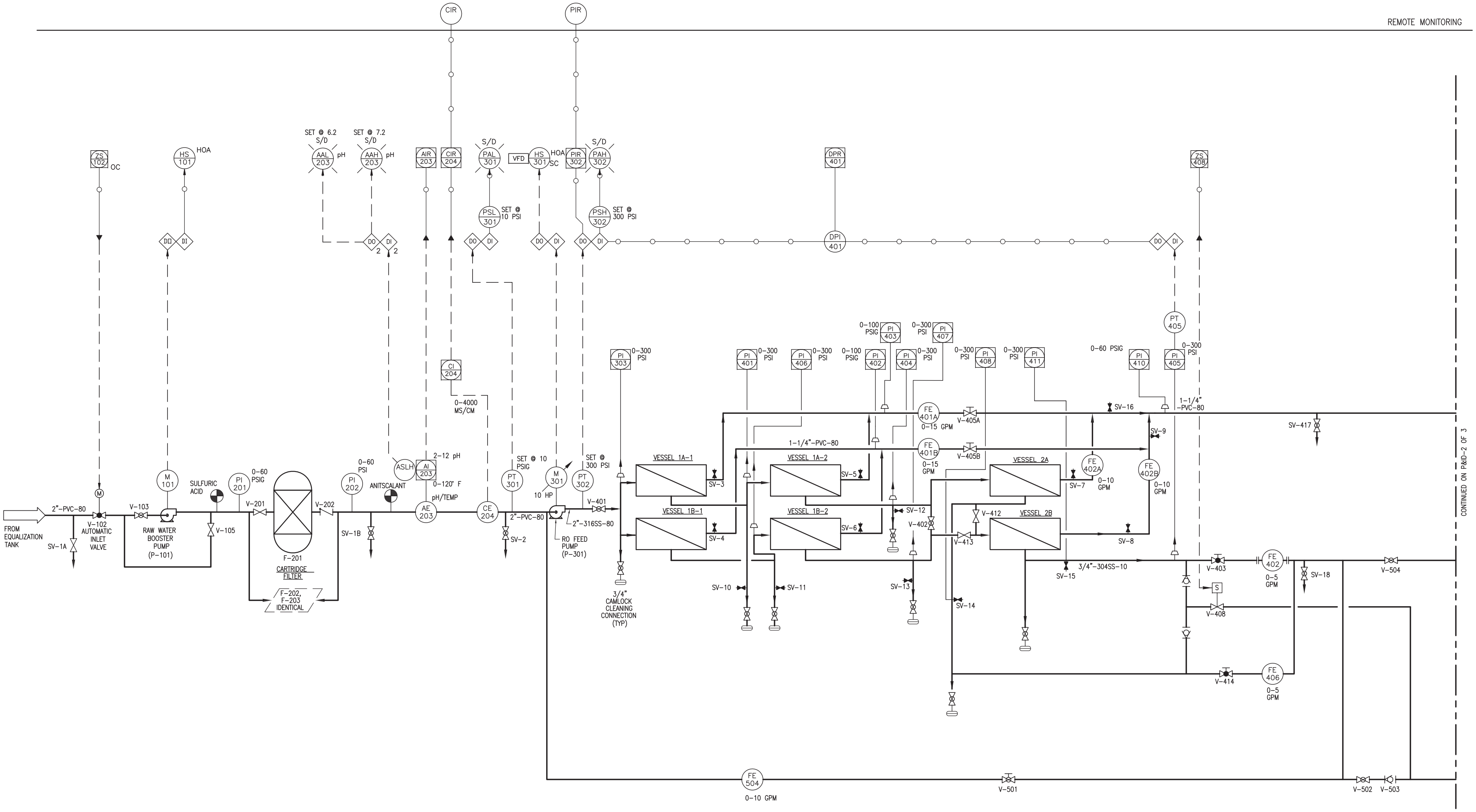
Attachment E Analytical Methods

Attachment F Health & Safety Plan

Attachment G Bench Scale Testing

Attachment H Alternative Advanced Oxidation Processes

Attachment A
Equipment Data



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CITY OF LOS ANGELES - RECYCLED WATER MASTER PLAN

RO SKID (1 OF 3)

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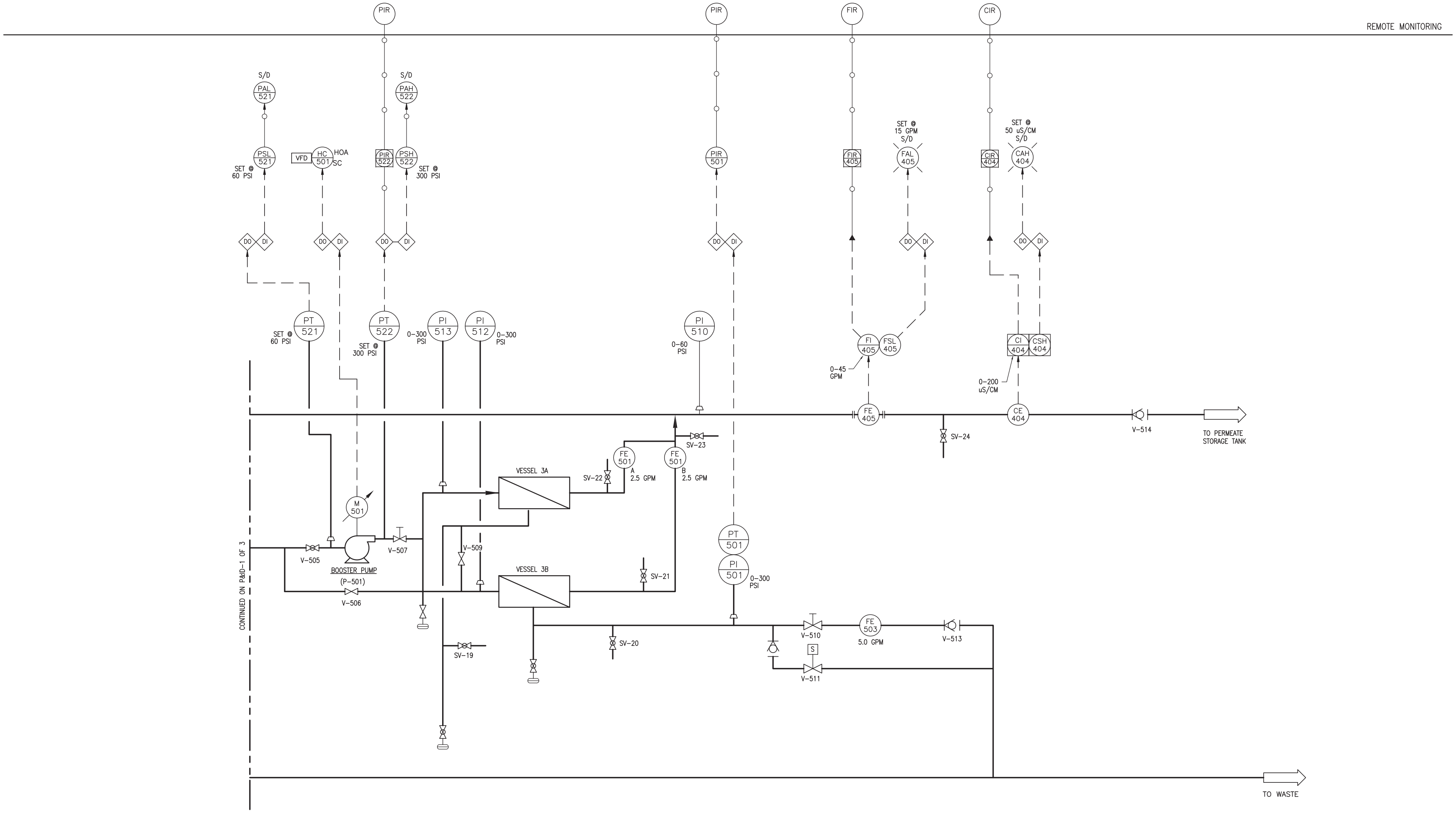

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CITY OF LOS ANGELES - RECYCLED WATER MASTER PLAN

RO SKID (2 OF 3)

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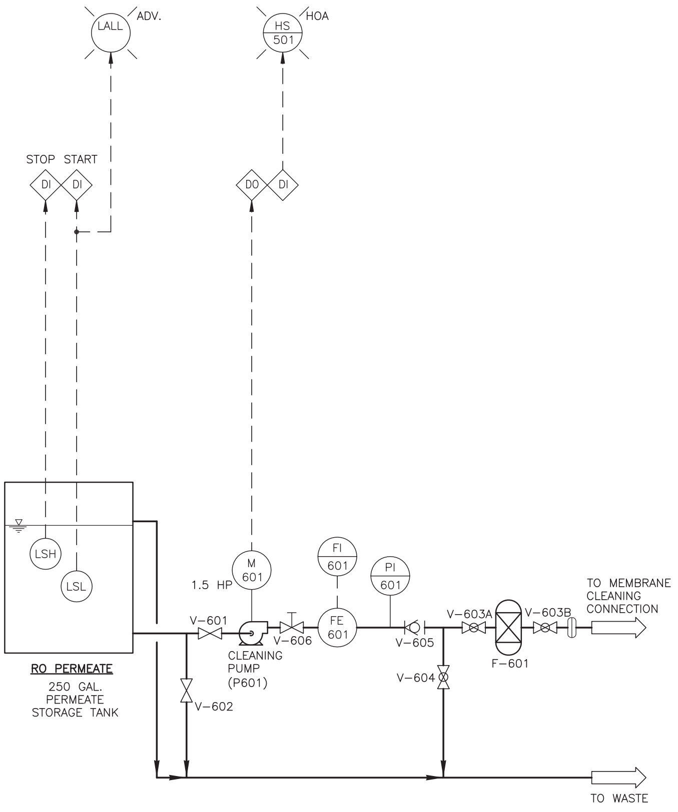

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CITY OF LOS ANGELES - RECYCLED WATER MASTER PLAN

RO CIP SYSTEM (3 OF 3)

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Attachment B

Process & Instrumentation Diagrams

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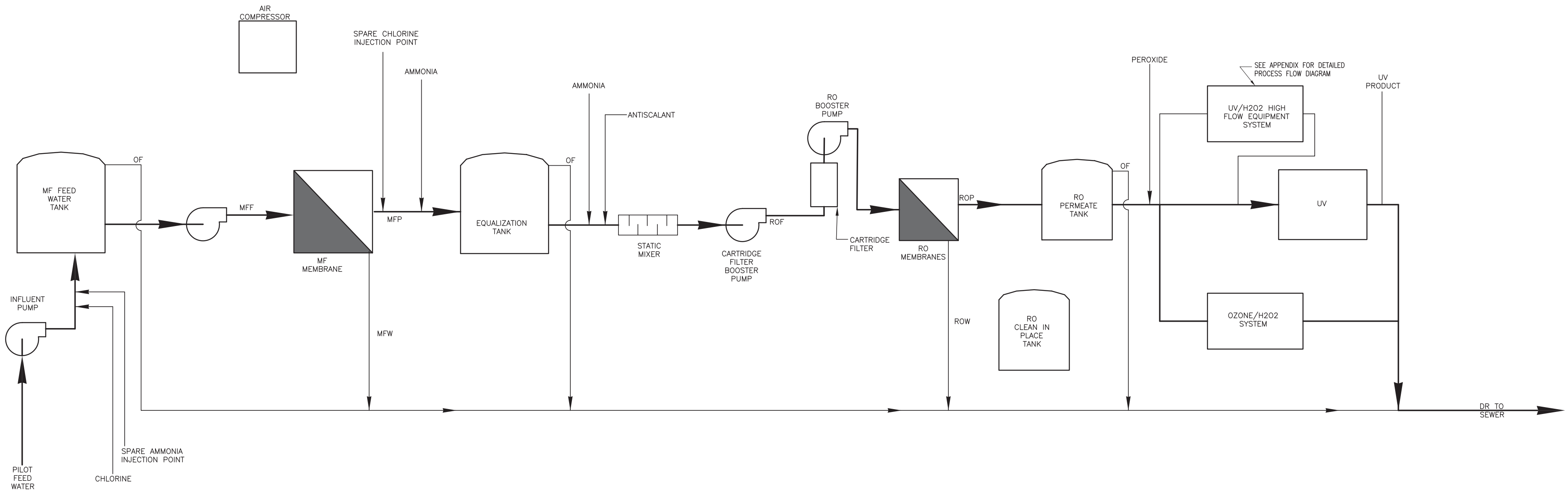
LEGEND

RW	RAW WATER
MF	MEMBRANE FILTRATION
MFF	MF FEED
MFP	MF PRODUCT
MFW	MF WASTE
ROF	REVERSE OSMOSIS FEED
ROP	REVERSE OSMOSIS PRODUCT
ROW	REVERSE OSMOSIS WASTE
DR	DRAIN
OF	OVERFLOW
UV	ULTRAVIOLET LIGHT
AOP	ADVANCED OXIDATION PROCESS



PROCESS STREAM	DESIGN FLOW	DESIGN PRESSURE
MF FEED	45 GPM	30 PSI
MF PRODUCT	40 GPM	<25 PSI
RO FEED	20 GPM	200 PSI
RP PRODUCE	17 GPM	<5 PSI
RO WASTE	3 GPM	180 PSI

FINAL

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CITY OF LOS ANGELES - RECYCLED WATER MASTER PLAN

FIGURE 2-3
PROCESS FLOW DIAGRAM

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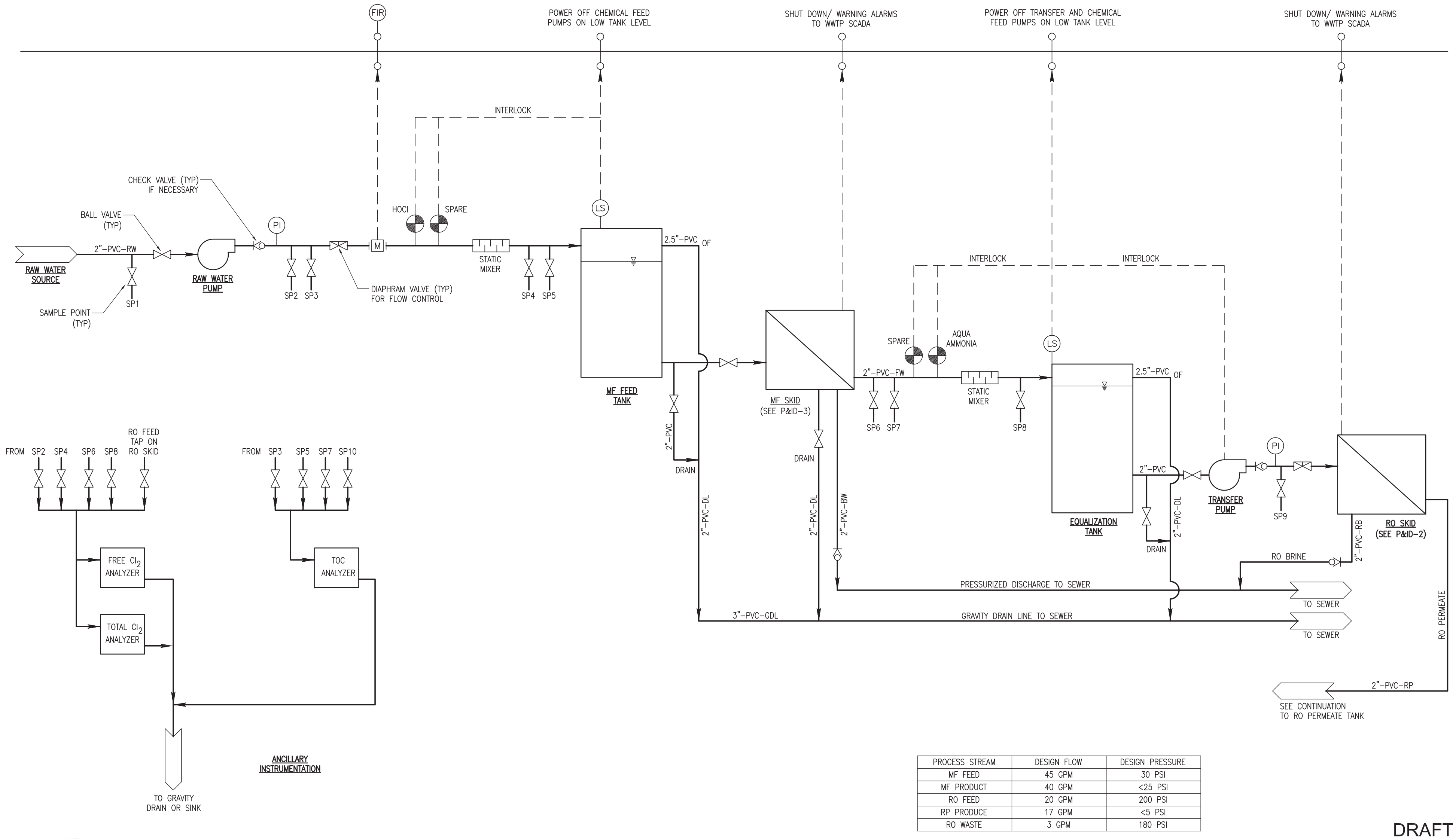

PROCESS STREAM	DESIGN FLOW	DESIGN PRESSURE
MF FEED	45 GPM	30 PSI
MF PRODUCT	40 GPM	<25 PSI
RO FEED	20 GPM	200 PSI
RP PRODUCE	17 GPM	<5 PSI
RO WASTE	3 GPM	180 PSI

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CITY OF LOS ANGELES - RECYCLED WATER MASTER PLAN

PILOT PLANT P&ID
(1 OF 2)

DWG NO P&ID-1
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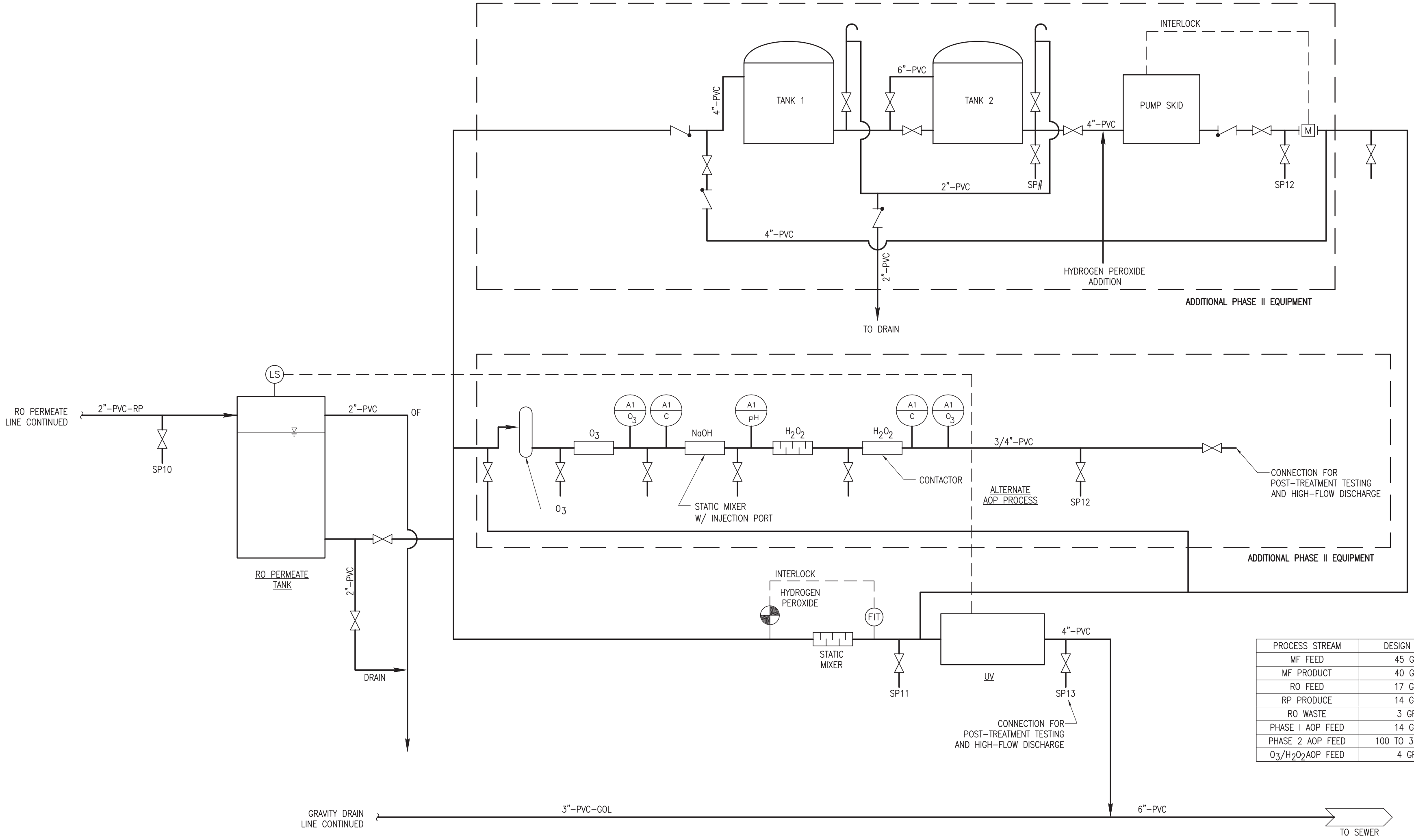

PROCESS STREAM	DESIGN FLOW	DESIGN PRESSURE
MF FEED	45 GPM	30 PSI
MF PRODUCT	40 GPM	<25 PSI
RO FEED	17 GPM	200 PSI
RP PRODUCE	14 GPM	<5 PSI
RO WASTE	3 GPM	180 PSI
PHASE I AOP FEED	14 GPM	<5 PSI
PHASE 2 AOP FEED	100 TO 350 GPM	TBD
O_3/H_2O_2AOP FEED	4 GPM	3 PSI

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CITY OF LOS ANGELES - RECYCLED WATER MASTER PLAN

PILOT PLANT P&ID
(2 OF 2)

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SHEET NO OF .
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Attachment C

RO Projections

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Permeate THROTTLING(1ST STAGE)

RO program licensed to:					
Calculation created by:	GDW				
Project name:	Tillman AWTP - 2-Stage		Permeate flow:	17.00	gpm
HP Pump flow:	20.0	gpm	Raw water flow:	20.0	gpm
Recommended pump press.:	156.4	psi	Permeate throttling(1st st.)	30.0	psi
Feed pressure:	127.4	psi	Permeate recovery:	85.0	%
Feedwater Temperature:	25.0	C(77F)			
Feed water pH:	7.4		Element age:	0.0	years
Chem dose, ppm (100%):	0.0	H2SO4	Flux decline % per year:	15.0	
Acidified feed CO2:	8.05		Salt passage increase, %/yr:	10.0	
Average flux rate:	12.0	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	11.9	10.0	4.0	12.6	1.13	98.9	30.0	ESPA2-4040	16	2x8
1-2	5.1	8.1	3.0	10.8	1.14	75.8	0.0	ESPA2-4040	8	1x8

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3
Ca	44.0	109.7	44.0	109.7	0.229	0.6	292.0	728.3
Mg	13.0	53.5	13.0	53.5	0.068	0.3	86.3	355.1
Na	121.7	264.6	121.7	264.6	3.017	6.6	794.2	1726.6
K	14.0	17.9	14.0	17.9	0.433	0.6	90.9	116.5
NH4	1.2	3.3	1.2	3.3	0.037	0.1	7.8	21.6
Ba	0.020	0.0	0.020	0.0	0.000	0.0	0.133	0.1
Sr	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.0
CO3	0.2	0.3	0.2	0.3	0.000	0.0	1.3	2.2
HCO3	130.0	106.6	130.0	106.6	3.277	2.7	848.1	695.2
SO4	124.0	129.2	124.0	129.2	0.439	0.5	824.2	858.5
Cl	134.0	189.0	134.0	189.0	1.886	2.7	882.6	1244.9
F	0.8	2.1	0.8	2.1	0.022	0.1	5.2	13.7
NO3	27.0	21.8	27.0	21.8	2.731	2.2	164.5	132.7
B	0.51		0.51		0.506		0.53	
SiO2	8.6		8.6		0.12		56.7	
TDS	619.0		619.0		12.8		4054.6	
pH	7.4		7.4		5.9		8.2	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	2%	2%	23%
SrSO4 / Ksp * 100:	0%	0%	0%
BaSO4 / Ksp * 100:	89%	89%	888%
SiO2 saturation:	6%	6%	40%
Langelier Saturation Index	-0.43	-0.43	1.90
Stiff & Davis Saturation Index	-0.38	-0.38	1.75
Ionic strength	0.01	0.01	0.08
Osmotic pressure	5.2 psi	5.2 psi	34.0 psi

Permeate THROTTLING(1ST STAGE)

RO program licensed to:					
Calculation created by:	GDW				
Project name:	Tillman AWTP - 2-Stage		Permeate flow:	17.00	gpm
HP Pump flow:	20.0	gpm	Raw water flow:	20.0	gpm
Recommended pump press.:	156.4	psi	Permeate throttling(1st st.)	30.0	psi
Feed pressure:	127.4	psi	Permeate recovery:	85.0	%
Feedwater Temperature:	25.0	C(77F)			
Feed water pH:	7.4		Element age:	0.0	years
Chem dose, ppm (100%):	0.0	H2SO4	Flux decline % per year:	15.0	
Acidified feed CO2:	8.05		Salt passage increase, %/yr:	10.0	
Average flux rate:	12.0	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	psi	Element Type	Elem. No.	Array
1-1	11.9	10.0	4.0	12.6	1.13	98.9	30.0	ESPA2-4040	16	2x8
1-2	5.1	8.1	3.0	10.8	1.14	75.8	0.0	ESPA2-4040	8	1x8

Stg	Elem no.	Feed pres psi	Pres drop psi	Perm flow gpm	Perm Flux gfd	Beta	Perm sal TDS	Conc osm pres	Concentrate saturation levels				
									CaSO4	SrSO4	BaSO4	SiO2	Lang.
1-1	1	127.4	5.64	0.92	15.6	1.09	3.56	5.7	2	0	100	7	-0.3
1-1	2	121.7	4.90	0.86	14.6	1.10	3.77	6.3	3	0	113	7	-0.2
1-1	3	116.8	4.25	0.81	13.6	1.10	4.08	7.0	3	0	128	8	-0.1
1-1	4	112.6	3.69	0.76	12.8	1.10	4.45	7.8	4	0	146	9	0.1
1-1	5	108.9	3.16	0.71	12.1	1.11	4.87	8.7	4	0	167	10	0.2
1-1	6	105.7	2.68	0.67	11.4	1.11	5.36	9.8	5	0	193	12	0.4
1-1	7	103.1	2.26	0.63	10.7	1.12	5.94	11.1	6	0	226	13	0.5
1-1	8	100.8	1.88	0.60	10.1	1.13	6.62	12.7	7	0	267	15	0.7
1-2	1	95.9	4.17	0.82	14.0	1.10	6.87	14.3	8	0	304	17	0.8
1-2	2	91.8	3.55	0.77	13.0	1.10	7.27	15.9	9	0	347	19	1.0
1-2	3	88.2	3.03	0.71	12.1	1.10	7.77	17.9	10	0	400	21	1.1
1-2	4	85.2	2.58	0.66	11.2	1.12	8.41	20.2	12	0	464	24	1.3
1-2	5	82.6	2.17	0.61	10.4	1.12	9.20	22.9	14	0	541	27	1.4
1-2	6	80.4	1.81	0.56	9.5	1.13	10.19	26.1	17	0	635	31	1.6
1-2	7	78.6	1.50	0.51	8.6	1.13	11.43	29.8	20	0	750	35	1.7
1-2	8	77.1	1.23	0.45	7.6	1.14	12.99	34.2	23	0	888	41	1.9

Permeate THROTTLING(1ST STAGE)

RO program licensed to:					
Calculation created by:	GDW				
Project name:	Tillman AWTP - 2-Stage		Permeate flow:	17.00	gpm
HP Pump flow:	20.0	gpm	Raw water flow:	20.0	gpm
Recommended pump press.:	156.4	psi	Permeate throttling(1st st.)	30.0	psi
Feed pressure:	127.4	psi	Permeate recovery:	85.0	%
Feedwater Temperature:	25.0	C(77F)			
Feed water pH:	7.4		Element age:	0.0	years
Chem dose, ppm (100%):	0.0	H2SO4	Flux decline % per year:	15.0	
Acidified feed CO2:	8.05		Salt passage increase, %/yr:	10.0	
Average flux rate:	12.0	gfd	Feed type:	Wastewater	

****

**** THE FOLLOWING PARAMETERS EXCEED RECOMMENDED DESIGN LIMITS: ***

****

Concentrate Langelier Saturation Index too high (1.90)

The following are recommended general guidelines for designing a reverse osmosis system using Hydranautics membrane elements. Please consult Hydranautics for specific recommendations for operation beyond the specified guidelines.

Feed and Concentrate flow rate limits

Element diameter	Maximum feed flow rate	Minimum concentrate rate
4.0 inches	16 gpm (60.6 lpm)	3 gpm (11.3 lpm)
4.0 inches(Full Fit)	16 gpm (60.6 lpm)	8 gpm (30.3 lpm)

Concentrate polarization factor (beta) should not exceed 1.2 for standard elements

Saturation limits for sparingly soluble salts in concentrate

Soluble salt	Saturation
BaSO4	6000%
CaSO4	230%
SrSO4	800%
SiO2	100%

Langelier Saturation Index for concentrate should not exceed 1.8

The above saturation limits only apply when using effective scale inhibitor. Without scale inhibitor, concentrate saturation should not exceed 100%.

BOOSTER PUMP AND PERMEATE THROTTLING(VARIABLE)

RO program licensed to:					
Calculation created by:	GDW				
Project name:	Tillman AWTP - Pilot 3 ph		Permeate flow:	16.50	gpm
HP Pump flow:	18.8	gpm	Raw water flow:	18.8	gpm
Recommended pump press.:	150.3	psi	Booster pump pressure:	35.0	psi
Feed pressure:	121.3	psi	Permeate throttling(All st.)	30.0	psi
Feedwater Temperature:	25.0	C(77F)	Permeate recovery:	88.0	%
Feed water pH:	7.2		Element age:	0.0	years
Chem dose, ppm (100%):	4.4	H2SO4	Flux decline % per year:	15.0	
Acidified feed CO2:	11.22		Salt passage increase, %/yr:	10.0	
Average flux rate:	12.0	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel		Flux gfd	Beta	Conc.&Throt. Pressures		Element Type	Elem. No.	Array
		Feed gpm	Conc gpm			psi	psi			
1-1	10.2	9.4	4.3	12.3	1.13	97.1	30.0	ESPA2-4040	14	2x7
1-2	4.8	8.6	3.8	11.5	1.13	73.2	0.0	ESPA2-4040	7	1x7
1-3	1.6	3.8	2.3	11.6	1.06	71.9	0.0	ESPA-2540	7	1x7

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3
Ca	71.0	177.1	71.0	177.1	1.817	4.5	578.3	1442.2
Mg	20.0	82.3	20.0	82.3	0.512	2.1	162.9	670.4
Na	78.2	170.0	78.2	170.0	9.433	20.5	582.5	1266.3
K	6.0	7.7	6.0	7.7	0.889	1.1	43.5	55.7
NH4	1.2	3.3	1.2	3.3	0.178	0.5	8.7	24.2
Ba	0.020	0.0	0.020	0.0	0.001	0.0	0.163	0.1
Sr	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.0
CO3	0.2	0.3	0.1	0.2	0.000	0.0	1.1	1.8
HCO3	120.0	98.4	114.7	94.1	14.707	12.1	848.4	695.4
SO4	124.0	129.2	128.3	133.6	1.517	1.6	1057.8	1101.9
Cl	134.0	189.0	134.0	189.0	4.722	6.7	1082.0	1526.2
F	0.8	2.1	0.8	2.1	0.072	0.2	6.1	16.1
NO3	27.0	21.8	27.0	21.8	10.284	8.3	149.6	120.6
B	0.51		0.51		0.508		0.52	
SiO2	15.0		15.0		1.62		113.1	
TDS	597.9		596.9		46.3		4634.8	
pH	7.4		7.2		6.3		8.0	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	3%	3%	49%
SrSO4 / Ksp * 100:	0%	0%	0%
BaSO4 / Ksp * 100:	84%	87%	1138%
SiO2 saturation:	11%	11%	81%
Langelier Saturation Index	-0.26	-0.48	2.04
Stiff & Davis Saturation Index	-0.21	-0.43	1.82
Ionic strength	0.01	0.01	0.10
Osmotic pressure	4.7 psi	4.7 psi	36.1 psi

BOOSTER PUMP AND PERMEATE THROTTLING(VARIABLE)

RO program licensed to:					
Calculation created by:	GDW				
Project name:	Tillman AWTP - Pilot 3 ph		Permeate flow:	16.50	gpm
HP Pump flow:	18.8	gpm	Raw water flow:	18.8	gpm
Recommended pump press.:	150.3	psi	Booster pump pressure:	35.0	psi
Feed pressure:	121.3	psi	Permeate throttling(All st.)	30.0	psi
Feedwater Temperature:	25.0	C(77F)	Permeate recovery:	88.0	%
Feed water pH:	7.2		Element age:	0.0	years
Chem dose, ppm (100%):	4.4	H2SO4	Flux decline % per year:	15.0	
Acidified feed CO2:	11.22		Salt passage increase, %/yr:	10.0	
Average flux rate:	12.0	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	10.2	9.4	4.3	12.3	1.13	97.1	30.0	ESPA2-4040	14	2x7
1-2	4.8	8.6	3.8	11.5	1.13	73.2	0.0	ESPA2-4040	7	1x7
1-3	1.6	3.8	2.3	11.6	1.06	71.9	0.0	ESPA-2540	7	1x7

Stg	Elem no.	Feed pres psi	Pres drop psi	Perm flow gpm	Perm Flux gfd	Beta	Perm sal TDS	Conc osm pres	Concentrate saturation levels CaSO4	SrSO4	BaSO4	SiO2	Lang.
1-1	1	121.3	5.2	0.9	14.7	1.09	3.1	5.2	4	0	98	12	-0.4
1-1	2	116.2	4.5	0.8	13.7	1.10	3.4	5.7	4	0	111	13	-0.2
1-1	3	111.7	3.9	0.8	12.9	1.10	3.7	6.3	5	0	126	14	-0.1
1-1	4	107.8	3.4	0.7	12.2	1.10	4.1	7.0	6	0	143	16	0.0
1-1	5	104.5	2.9	0.7	11.5	1.11	4.5	7.9	7	0	165	18	0.2
1-1	6	101.6	2.4	0.6	10.8	1.12	4.9	8.9	8	0	191	20	0.3
1-1	7	99.2	2.0	0.6	10.2	1.13	5.4	10.2	9	0	224	23	0.5
1-2	1	94.2	4.5	0.8	14.1	1.10	5.6	11.3	10	0	253	26	0.6
1-2	2	89.6	3.9	0.8	13.2	1.10	5.9	12.5	12	0	288	29	0.8
1-2	3	85.7	3.4	0.7	12.3	1.10	6.2	14.0	14	0	329	32	0.9
1-2	4	82.3	2.9	0.7	11.5	1.11	6.7	15.7	16	0	378	36	1.0
1-2	5	79.4	2.5	0.6	10.7	1.11	7.2	17.6	18	0	437	40	1.2
1-2	6	77.0	2.1	0.6	9.9	1.12	7.9	20.0	21	0	509	46	1.3
1-2	7	74.9	1.7	0.5	9.1	1.13	8.8	22.8	25	0	596	52	1.5
1-3	1	105.2	6.5	0.3	15.9	1.08	13.6	24.8	28	0	661	56	1.6
1-3	2	98.7	5.8	0.3	14.2	1.08	18.4	26.7	31	0	730	60	1.7
1-3	3	92.9	5.2	0.2	12.7	1.07	23.6	28.6	34	0	804	65	1.8
1-3	4	87.8	4.6	0.2	11.3	1.07	29.2	30.6	38	0	882	69	1.8
1-3	5	83.1	4.2	0.2	10.0	1.07	35.3	32.6	41	0	963	73	1.9
1-3	6	79.0	3.8	0.2	8.8	1.06	41.9	34.5	45	0	1047	77	2.0
1-3	7	75.2	3.4	0.1	7.7	1.06	49.0	36.3	49	0	1132	80	2.1

BOOSTER PUMP AND PERMEATE THROTTLING(VARIABLE)

RO program licensed to:					
Calculation created by:	GDW				
Project name:	Tillman AWTP - Pilot 3 ph		Permeate flow:	16.50	gpm
HP Pump flow:	18.8	gpm	Raw water flow:	18.8	gpm
Recommended pump press.:	150.3	psi	Booster pump pressure:	35.0	psi
Feed pressure:	121.3	psi	Permeate throttling(All st.)	30.0	psi
Feedwater Temperature:	25.0	C(77F)	Permeate recovery:	88.0	%
Feed water pH:	7.2		Element age:	0.0	years
Chem dose, ppm (100%):	4.4	H2SO4	Flux decline % per year:	15.0	
Acidified feed CO2:	11.22		Salt passage increase, %/yr:	10.0	
Average flux rate:	12.0	gfd	Feed type:	Wastewater	

****

**** THE FOLLOWING PARAMETERS EXCEED RECOMMENDED DESIGN LIMITS: ***

****

Concentrate Langelier Saturation Index too high (2.04)

The following are recommended general guidelines for designing a reverse osmosis system using Hydranautics membrane elements. Please consult Hydranautics for specific recommendations for operation beyond the specified guidelines.

Feed and Concentrate flow rate limits

Element diameter	Maximum feed flow rate	Minimum concentrate rate
4.0 inches	16 gpm (60.6 lpm)	3 gpm (11.3 lpm)
4.0 inches(Full Fit)	16 gpm (60.6 lpm)	8 gpm (30.3 lpm)

Concentrate polarization factor (beta) should not exceed 1.2 for standard elements

Saturation limits for sparingly soluble salts in concentrate

Soluble salt	Saturation
BaSO4	6000%
CaSO4	230%
SrSO4	800%
SiO2	100%

Langelier Saturation Index for concentrate should not exceed 1.8

The above saturation limits only apply when using effective scale inhibitor. Without scale inhibitor, concentrate saturation should not exceed 100%.

Attachment D
Data Log Sheets

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Recycled Water Master Plan: GWR Treatment Pilot Study

City of Los Angeles

Daily Data Log Sheet

Date:

Time:

Operator:

Shaded boxes are to remain blank.

Source Water: Secondary Effluent | Filtered Effluent (Circle One)

DCT Operations: Phase I | Phase II (Circle One)

Tank Levels (% full):

MF Feed	
RO Feed	
RO Permeate	

Parameter	**Units**	**Method**	**Source Water**	**MF Feed**	**MF Filtrate**	**Cartridge Filter Feed**	**Cartridge Filter Filtrate**	**RO Feed**	**RO Filtrate**	**RO Concentrate**	**AOP Influent (for Phase II)**	**UV Effluent**	**O_3 Effluent**
Flow	(gpm)	field				▨	▨		▨	▨		▨	▨
Pressure	(psi)	field	▨						▨	▨	▨	▨	▨
Pressure Decay Rate	(psi/min)	field	▨	▨		▨	▨	▨	▨	▨	▨	▨	▨
Temperature	(F)	field		▨		▨	▨						▨
pH		field		▨		▨	▨						▨
Free Residual Chlorine	(mg/L)	field		▨		▨	▨		▨	▨	▨	▨	▨
Total Residual Chlorine	(mg/L)	field		▨		▨	▨		▨	▨		▨	▨
Conductivity	(uS/cm)	field		▨	▨	▨	▨		▨	▨	▨	▨	▨
ORP		field	▨	▨		▨	▨			▨	▨	▨	▨
SDI (15 minute, 500mL)		field	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨
TOC	(mg/L)	field		▨	▨	▨	▨	▨		▨	▨	▨	▨
Turbidity	(NTU)	field		▨		▨	▨				▨	▨	▨
UV254		field		▨		▨	▨	▨		▨			▨
UV Transmittance		field	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨

Clean Strainers	yes/no	
Blowoff Compressor	yes/no	
MF Backwash Freque	(min)	
MF Recovery	(%)	
MF Recirculation	(%)	
Chemical leakage from tanks, platforms or pumps?	(yes/no)	

% Plugged:

RO Trailer		**1A-1**	**1B-1**	**1A-2**	**1B-2**	**2-1**	**2-2**	**Combined**
Permeate	Flow	▨	▨					
	Pressure	▨	▨					▨
	Conductivity							
Concentrate	Flow	▨	▨	▨	▨			
	Pressure	▨	▨					▨
	Conductivity							
Feed	Pressure	▨	▨	▨	▨			▨

Question? Call Eric Smith (CDM) at 213-457-2200

Comments:

Recycled Water Master Plan: GWR Treatment Pilot Study

City of Los Angeles
Weekend Data Log Sheet

Date:
Time:
Operator:
Shaded boxes are to remain
Source Water: Secondary Effluent / Filtered Effluent (Circle One)

Tank Levels (% full):

MF Feed	
RO Feed	
Permeate	

Parameter	Units	Source Water	MF Feed	MF Filtrate	Cartridge Filter Feed	Cartridge Filter Filtrate	RO Feed	RO Filtrate	RO Concentrate	AOP Influent (for Phase II)	UV Influent	UV Effluent	O_3 Effluent
Total Chlorine	mg/L	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨
ORP (Oxidation	mV	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨
Flow	(gpm)		▨		▨	▨	▨	▨	▨			▨	▨
Pressure	(psi)	▨									▨	▨	

MF Alarms?	yes/no	
UV Intensity	(mW/cm2)	
UV system okay?	yes/no	
Chemical leakage from platforms or pumps?	yes/no	
Leakage from tanks, piping or skids?	yes/no	

If leakage or alarm is observed, describe below:

Question? Call Eric Smith (CDM) at 213-457-2200

Comments:

Recycled Water Master Plan: GWR Treatment Pilot Study
City of Los Angeles

Weekly Data Log Sheet

Date:
Time:
Operator:
Shaded boxes are to remain blank.
Source Water: Secondary Effluent/ Filtered Effluent (Circle One)

Finished Water Flow (gal)
Time to fill 5 gal (sec)
Calculated flow (gpm)

Cumulative Flow through MF:

Parameter	Units	Method	Bottle Type	Label	Source Water	MF/UF Effluent	RO Feed	RO Filtrate	RO Concentrate	AOP Influent	UV Effluent	O_3 Effluent
Temperature	(F)	field	N/A	N/A	▨	▨	▨	▨	▨	▨	▨	▨
pH		field	N/A	N/A	▨	▨	▨	▨	▨	▨	▨	▨
Free Residual Chlorine	(mg/L)	field	N/A	N/A	▨	▨	▨	▨	▨	▨	▨	▨
Total Residual Chlorine	(mg/L)	field	N/A	N/A	▨	▨	▨	▨	▨	▨	▨	▨
Color	(Pt-Co)	field	N/A	N/A				▨			▨	▨
Conductivity	(uS/cm)	field	N/A	N/A	▨	▨	▨	▨	▨			
ORP		field	N/A	N/A	▨	▨	▨	▨	▨	▨	▨	▨
Dissolved Oxygen	(mg/L)	field	N/A	N/A		▨	▨	▨	▨		▨	
SDI		field	N/A	N/A	▨		▨	▨	▨	▨	▨	▨
TOC	(mg/L)	field	N/A	N/A	▨		▨	▨		▨	▨	▨
Turbidity	(NTU)	field	N/A	N/A	▨	▨	▨	▨	▨	▨	▨	▨
UV254		field	N/A	N/A	▨	▨	▨	▨	▨	▨	▨	▨
UV Transmittance		field	N/A	N/A	▨	▨	▨	▨	▨	▨	▨	▨

Parameter	Units	Method	Bottle Type	Label	Source Water	MF/UF Effluent	RO Feed	RO Filtrate	RO Concentrate	AOP Influent	UV Effluent	O_3 Effluent
1,4 Dioxane		EPA8270M	Two 1L Amber Glass per location	14Dioxane		▨	▨	▨	▨	▨		▨
1,4 Dioxane		EPA8270M	Two 1L Amber Glass per location	14Dioxane		▨	▨	▨	▨	▨		▨
Alkalinity, Orthophosphate	(mg/L)	SM2320B	Unpreserved 250mL poly	Unpreserved 250mL poly								
Bromate	(mg/L)	EPA300.1	40 mL VOA Amber Vial	Bromate	▨	▨	▨	▨	▨	▨	▨	
Calcium, Magnesium, Sodium, Strontium, Silica	(mg/L)	EPA 200.7 and EPA 200.8	250 mL poly-HNO3	200.7 and 200.8 metals	▨	▨				▨	▨	▨
Fluoride, Sulfate	(mg/L)	EPA300.0	250 mL poly	300	▨	▨				▨	▨	▨
NDMA (pilot)		EPA1625M	Two 500mL Amber Glass per location -Na2S2O3	NDMA	▨				▨			
NDMA (pilot)		EPA1625M	Two 500mL Amber Glass per location -Na2S2O3	NDMA	▨				▨			
TKN , NH3, total phosphorous	(mg/L)	EPA351.2 and 350.1	250mL poly with H2SO4 Nutrients	Ammonia/TKN	▨				▨	▨	▨	▨
NO_2 NO_3	(mg/L)	EPA353.2	250mL poly Nutrients	Nitrates	▨		▨		▨	▨	▨	▨
$NO_3 + NO_2$	(mg/L)	calculation	N/A	N/A	▨	N/A	▨	N/A	▨	▨	▨	▨
TDS	(mg/L)	SM2540C	500 mL poly	TDS		▨						
TCEP (2 per location)			1lAmber with sodium azide	TCEP		▨	▨	▨	▨	▨		▨
TCEP (2 per location)			1lAmber with sodium azide	TCEP		▨	▨	▨	▨	▨		▨

NDMA Sampling at Tillman	Unit	Method	Bottle	Label	Bottle sampled?
Primary Effluent	ug/L	EPA1625M	Two 500mL Amber Glass per location -Na2S2O3	NDMA	
Primary Effluent					
Secondary Effluent before chlorine/ polymer					
Secondary Effluent before chlorine/ polymer					
Tertiary Effluent before chloramination					
Tertiary Effluent before chloramination					
Tertiary Effluent after chloramination					
Tertiary Effluent after chloramination					

Clean Strainers	yes/no	
Blowoff Compressor	yes/no	

% Plugged:

Question? Call Eric Smith (CDM) at 213-457-2200

Comments:

Recycled Water Master Plan: GWR Treatment Pilot Study
City of Los Angeles

Monthly Data Log Sheet

Date:
Time:
Operator:
Shaded boxes are to remain blank.
Source Water: Secondary Effluent/ Filtered Effluent (Circle One)
Replace Cartridge Filters? (yes/no)
Finished Water Flow (gal)
Time to fill 5 gal (sec)
Calculated flow (gpm)

Parameter	Units	Method	Bottle Type	Label	Source Water	MF/UF Effluent	RO Feed	RO Filtrate	RO Concentrate	AOP Influent	UV Effluent	O_3 Effluent
Barium, Total Iron, Manganese, Potassium, Boron	(mg/L)	EPA200.7 and EPA 200.8	250 mL poly-HNO3	200.7 and 200.8 metals		▨				▨	▨	▨
Bromide	(mg/L)	EPA320.1 (or 326.0?)	40 mL VOA Amber Vial-300.1/326 EDA	Bromide		▨	▨		▨	▨	▨	▨
Chloride	(mg/L)	EPA300.0	All 300.0 anions share same bottle -250 mL poly	300 anions	▨	▨				▨	▨	▨
1,4-Dioxane		EPA8270M	Two 1L Amber Glass per location	14Dioxane	▨	▨	▨	▨	▨	▨	▨	
1,4-Dioxane		EPA8270M	Two 1L Amber Glass per location	14Dioxane	▨	▨	▨	▨	▨	▨	▨	
TKN	(mg/L)	EPA351.2	250mL poly with H2SO4 Nutrients	Ammonia/TKN		▨	▨	▨		▨		
NH3	(mg/L)	EPA350.1			▨		▨			▨		
NO_2, NO_3	(mg/L)	EPA353.2	250mL poly Nutrients	Nitrates	▨	▨	▨	▨		▨		
$NO_3 + NO_2$	(mg/L)	calculation	N/A	N/A	▨	▨	▨	▨	▨	▨	N/A	N/A
TOX (total organic halogens)	(ug/L)	SM5320B	500mL Amber Glass	TOX		▨	▨	▨	▨		▨	▨
Regulated 3 & 507 Compounds		EPA525.2	Two 1L Amber Glass per location	525 w/ HCl		▨		▨	▨		▨	▨
Regulated 3 & 507 Compounds		EPA525.2	Two 1L Amber Glass per location	525 w/ HCl		▨		▨	▨		▨	▨
Volatile Organic Compounds		EPA524.2	Three 40mL VOA Vials per location	524 HCl		▨		▨	▨		▨	▨
Volatile Organic Compounds		EPA524.2	Three 40mL VOA Vials per location	524 HCl		▨		▨	▨		▨	▨
Volatile Organic Compounds		EPA524.2	Three 40mL VOA Vials per location	524 HCl		▨		▨	▨		▨	▨
Indigenous Coliphage		SM1602	125 mL poly with sodium thiosulfate, two per location			▨	▨	▨	▨		▨	▨
Indigenous Coliphage		SM1602	125 mL poly with sodium thiosulfate, two per location			▨	▨	▨	▨		▨	▨
Oil and grease	(mg/L)	EPA1664A	1L clear glass wide mouth with HCl	Oil and Grease			▨	▨	▨	▨	▨	▨
TCEP			1lAmber with sodium azide	TCEP	▨	▨			▨		▨	

Clean Strainers	yes/no	
Blowoff Compressor	yes/no	

% Plugged:

Question? Call Eric Smith (CDM) at 213-457-2200

Comments:

Recycled Water Master Plan: GWR Treatment Pilot Study
City of Los Angeles
Quarterly Data Log Sheet

Date:

Time:

Operator:

Shaded boxes are to remain blank.

Source Water: Secondary Effluent/ Filtered Effluent (Circle One)

Replace Cartridge Filters? (yes/no)

Finished Water Flow (gal):

Time to fill 5 gal (sec):

Calculated flow (gpm):

Parameter	Units	Method	Bottle Type	Label	Source Water	MF/UF Effluent	RO Feed	RO Filtrate	RO Concentrate	AOP Influent	UV Effluent	O_3 Effluent
1,4-Dioxane		EPA8270M	Two 1L Amber Glass per location	14Dioxane	▨	▨	▨	▨	▨		▨	▨
1,4-Dioxane		EPA8270M	Two 1L Amber Glass per location	14Dioxane	▨	▨	▨	▨	▨		▨	▨
Fumigants (EDB, DBCP)	ug/L and n	EPA504.1	40 mL VOA Vial	504	▨	▨		▨	▨		▨	▨
Cryptosporidium & Giardia		EPA1623	10 L Cubitainer	EPA 1623			▨	▨	▨	▨	▨	▨
Enterovirus (EPA R-95/178)		EPA ICR 6000	Filtration Sampling Kit			▨	▨	▨	▨		▨	▨
Organochlorine Pesticides & PCBs		EPA508	Two 1L Amber Glass per location	508		▨		▨	▨		▨	▨
Organochlorine Pesticides & PCBs		EPA508	Two 1L Amber Glass per location	508		▨		▨	▨		▨	▨
Pharmaceuticals Pharma +, -		EPA1694M-E	two 1 L Amber	PPCP+/-		▨	▨	▨	▨		▨	▨
Pharmaceuticals Pharma +, -		EPA1694M-E	two 1 L Amber	PPCP+/-		▨	▨	▨	▨		▨	▨
Chlorinated Acid Herbicides		EPA515.3	250 mL Amber Glass	515		▨	▨	▨	▨		▨	▨

Clean Strainers	yes/no	
Blowoff Compressor	yes/no	

% Plugged:

Question? Call Eric Smith (CDM) at 213-457-2200

Comments:

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Attachment E

Analytical Methods

Analytical Method Details - Weck Laboratories, Inc

					Surr.	DUP	Matrix Spike		Blank Spike		
Method	**Analyte**	**MDL**	**MRL**	**Units**	**%R**	**RPD**	**%R**	**RPD**	**%R**	**RPD**	CASNumber
1,4-Dioxane Low Level by isotopic dilution GC/MS											
in Water											
EPA 8270M	1,4-Dioxane	0.13	0.50	ug/l	-	30	67-138	30	76-131	30	123-91-1
Anions by EPA Method 300.0/300.1/326											
in Water											
EPA 300.0	Fluoride, Total	0.013	0.10	mg/l	-	20	79-109	20	90-110	20	16984-48-8
EPA 300.0	Chloride	0.079	0.50	mg/l	-	20	72-118	20	90-110	20	7647-14-5
EPA 300.0	Sulfate as SO4	0.038	0.50	mg/l	-	20	84-114	20	90-110	20	148-08-798
EPA 300.1	Bromate	1.6	5.0	ug/l	-	20	78-130	20	85-115	20	15541-45-4
EPA 300.1	Chlorite	2.3	10	ug/l	-	20	85-124	20	85-115	20	14998-27-7
EPA 300.1	Dichloroacetate			Surrogate	90-115	-	-	-	-	-	13425-80-4
Carbamates and Urea Pesticides											
in Water											
EPA 531.1	Aldicarb sulfoxide	0.33	2.0	ug/l	-	30	65-135	30	80-120	30	1646-87-3
EPA 531.1	Aldicarb sulfone	0.36	2.0	ug/l	-	30	65-135	30	80-120	30	1646-88-4
EPA 531.1	Oxamyl	0.57	2.0	ug/l	-	30	65-135	30	80-120	30	23135-22-0
EPA 531.1	Methomyl	0.34	2.0	ug/l	-	30	65-135	30	80-120	30	16752-77-5
EPA 531.1	3-Hydroxycarbofuran	0.43	2.0	ug/l	-	30	65-135	30	80-120	30	16655-82-6
EPA 531.1	Aldicarb	0.70	2.0	ug/l	-	30	65-135	30	80-120	30	116-06-3
EPA 531.1	Propoxur (Baygon)	0.43	5.0	ug/l	-	30	65-135	30	80-120	30	114-26-1
EPA 531.1	Carbofuran	0.63	5.0	ug/l	-	30	65-135	30	80-120	30	1563-66-2
EPA 531.1	Carbaryl	0.97	2.0	ug/l	-	30	65-135	30	80-120	30	63-25-2
EPA 531.1	Methiocarb	1.4	3.0	ug/l	-	30	65-135	30	80-120	30	2032-65-7
Chlorinated Pesticides and/or PCBs											
in Water											
EPA 508	Aldrin	0.0037	0.010	ug/l	-	25	51-121	25	58-120	25	309-00-2
EPA 508	alpha-BHC	0.0053	0.010	ug/l	-	25	57-127	25	62-125	25	319-84-6
EPA 508	beta-BHC	0.0053	0.010	ug/l	-	25	60-130	25	54-139	25	319-85-7
EPA 508	delta-BHC	0.0046	0.010	ug/l	-	25	67-137	25	63-142	25	319-86-8
EPA 508	gamma-BHC (Lindane)	0.0050	0.010	ug/l	-	25	54-124	25	61-128	25	58-89-9
EPA 508	4,4´-DDD	0.0056	0.010	ug/l	-	25	72-142	25	47-147	25	72-54-8
EPA 508	4,4´-DDE	0.0048	0.010	ug/l	-	25	64-134	25	54-130	25	72-55-9
EPA 508	4,4´-DDT	0.0046	0.010	ug/l	-	25	77-147	25	42-143	25	50-29-3
EPA 508	Dieldrin	0.0044	0.010	ug/l	-	25	52-122	25	52-130	25	60-57-1
EPA 508	Endosulfan I	0.0047	0.010	ug/l	-	25	52-122	25	44-119	25	959-98-8
EPA 508	Endosulfan II	0.0047	0.010	ug/l	-	25	57-127	25	39-120	25	33213-65-9
EPA 508	Endosulfan sulfate	0.0046	0.010	ug/l	-	25	67-137	25	63-158	25	1031-07-8
EPA 508	Endrin	0.0050	0.010	ug/l	-	25	53-123	25	57-148	25	72-20-8
EPA 508	Endrin aldehyde	0.0056	0.010	ug/l	-	25	53-123	25	53-123	25	7421-93-4
EPA 508	Heptachlor	0.0052	0.010	ug/l	-	25	63-133	25	56-142	25	76-44-8
EPA 508	Heptachlor epoxide	0.0058	0.010	ug/l	-	25	52-122	25	57-124	25	1024-57-3
EPA 508	Methoxychlor	0.0064	0.010	ug/l	-	25	70-140	25	45-165	25	72-43-5
EPA 508	Chlorothalonil	0.011	0.050	ug/l	-	25	56-126	25	61-121	25	1897-5-6
EPA 508	Hexachlorobenzene	0.0020	0.010	ug/l	-	25	65-135	25	65-135	25	118-74-1
EPA 508	Hexachlorocyclopentadiene	0.016	0.050	ug/l	-	25	65-135	25	65-135	25	77-47-4
EPA 508	Propachlor	0.014	0.050	ug/l	-	25	68-138	25	73-133	25	1918-16-7
EPA 508	Trifluralin	0.0070	0.010	ug/l	-	25	68-138	25	73-133	25	1582-09-8
EPA 508	Chlordane (tech)	0.045	0.10	ug/l	-	25	64-134	25	69-129	25	57-74-9
EPA 508	Toxaphene	0.031	1.0	ug/l	-	25	65-135	25	65-135	25	8001-35-2
EPA 508	PCB-1016	0.097	0.10	ug/l	-	25	65-135	25	65-135	25	12674-11-2
EPA 508	PCB-1221	0.084	0.10	ug/l	-	-	-	-	-	-	11104-28-2
EPA 508	PCB-1232	0.064	0.10	ug/l	-	-	-	-	-	-	11141-16-5
EPA 508	PCB-1242	0.070	0.10	ug/l	-	-	-	-	-	-	53469-21-9
EPA 508	PCB-1248	0.049	0.10	ug/l	-	-	-	-	-	-	12672-29-6
EPA 508	PCB-1254	0.068	0.10	ug/l	-	-	-	-	-	-	11097-69-1
EPA 508	PCB-1260	0.069	0.10	ug/l	-	25	70-130	25	65-135	25	11096-82-5
EPA 508	PCBs, Total	0.049	0.50	ug/l	-	-	-	-	-	-	1336-36-3
EPA 508	Tetrachloro-meta-xylene			Surrogate	70-130	-	-	-	-	-	877-09-8
EPA 508	Decachlorobiphenyl			Surrogate	70-130	-	-	-	-	-	2051-24-3

Analytical Method Details - Weck Laboratories, Inc

					Surr.	DUP	Matrix Spike		Blank Spike		
Method	**Analyte**	**MDL**	**MRL**	**Units**	**%R**	**RPD**	**%R**	**RPD**	**%R**	**RPD**	CASNumber
Chlorinated Herbicides											
in Water											
EPA 515.3	Dalapon	0.040	0.40	ug/l	-	30	70-130	30	70-130	30	75-99-0
EPA 515.3	3,5-Dichlorobenzoic acid	0.080	1.0	ug/l	-	30	70-130	30	70-130	30	51-36-5
EPA 515.3	Dicamba	0.080	0.60	ug/l	-	30	70-130	30	70-130	30	1918-00-9
EPA 515.3	Dichloroprop	0.060	0.30	ug/l	-	30	70-130	30	70-130	30	120-36-5
EPA 515.3	2,4-D	0.050	0.40	ug/l	-	30	70-130	30	70-130	30	94-75-7
EPA 515.3	Pentachlorophenol	0.020	0.20	ug/l	-	30	70-130	30	70-130	30	87-86-5
EPA 515.3	2,4,5-TP (Silvex)	0.020	0.20	ug/l	-	30	70-130	30	70-130	30	93-72-1
EPA 515.3	2,4,5-T	0.050	0.20	ug/l	-	30	70-130	30	70-130	30	93-76-5
EPA 515.3	2,4-DB	0.42	2.0	ug/l	-	30	70-130	30	70-130	30	94-82-6
EPA 515.3	Dinoseb	0.050	0.40	ug/l	-	30	70-130	30	70-130	30	88-85-7
EPA 515.3	Bentazon	0.23	2.0	ug/l	-	30	70-130	30	70-130	30	25057-89-0
EPA 515.3	DCPA	0.020	0.10	ug/l	-	30	70-130	30	70-130	30	1861-32-1
EPA 515.3	Picloram	0.34	0.60	ug/l	-	30	70-130	30	70-130	30	1918-02-1
EPA 515.3	Acifluorfen	0.050	0.40	ug/l	-	30	70-130	30	70-130	30	50594-66-6
EPA 515.3	Chloramben		1.0	ug/l	-	-	-	-	-	-	133-90-4
EPA 515.3	2,4-DCAA			Surrogate	70-130	-	-	-	-	-	19719-28-9
Conventional Chemistry/Physical Parameters by APHA/EPA/ASTM Methods											
in Water											
EPA 140.1	Threshold Odor Number		1.0	T.O.N.	-	20	-	-	-	-	NA
EPA 1664A	Oil & Grease (HEM)	2.0	5.0	mg/l	-	18	78-114	18	78-114	18	NA
EPA 180.1	Turbidity	0.040	0.10	NTU	-	10	-	-	90-110	10	NA
EPA 335.4	Cyanide, Total	2.7	5.0	ug/l	-	10	90-110	20	90-110	20	57-12-5
EPA 350.1	Ammonia as N	0.048	0.10	mg/l	-	10	90-110	10	90-110	10	7664-41-7
EPA 351.2	TKN	0.074	0.10	mg/l	-	10	90-110	10	90-110	10	7727-37-9
EPA 353.2	Nitrate as NO3	0.097	0.50	mg/l	-	20	90-110	20	90-110	20	14797-55-8
EPA 353.2	Nitrite as N	33	100	ug/l	-	20	90-110	20	90-110	20	14797-65-0
EPA 353.2	Nitrite as NO2	100	300	ug/l	-	20	90-110	20	90-110	20	14797-65-0
EPA 353.2	NO2+NO3 as N	33	100	ug/l	-	20	90-110	20	90-110	20	NA
EPA 365.1	Phosphorus, Total as P	1.4	10	ug/l	-	10	90-110	10	90-110	10	7723-14-0
EPA 365.1	o-Phosphate as P, dissolved	0.22	2.0	ug/l	-	20	80-120	20	90-110	10	14265-44-2
EPA 420.4	Phenolics	0.0016	0.010	mg/l	-	20	90-110	20	90-110	20	NA
SM 2320B	Alkalinity as CaCO3		2.0	mg/l	-	15	-	-	94-108	15	NA
SM 2320B	Carbonate Alkalinity as CaCO3		2.0	mg/l	-	-	-	-	-	-	NA
SM 2320B	Bicarbonate Alkalinity as HCO3		2.0	mg/l	-	15	-	-	94-108	15	NA
SM 2320B	Hydroxide Alkalinity as CaCO3		2.0	mg/l	-	-	-	-	-	-	NA
SM 2330B	Langelier Index @ 60 C	-10.0	-10.0	N/A	-	-	-	-	-	-	NA
SM 2330B	Langelier Index @ Source Temp	-10.0	-10.0	N/A	-	-	-	-	-	-	NA
SM 2330B	Langelier Index @ 20 C	-10.0	-10.0	N/A	-	-	-	-	-	-	NA
SM 4500 Cl G	Chlorine Residual, Total	0.0016	0.050	mg/l	-	15	65-128	15	82-112	15	7782-50-5
SM 5210 B	Carbonaceous BOD	0.10	2.0	mg/l	-	20	-	-	85-115	20	NA
SM 5540 C	MBAS	0.019	0.050	mg/l	-	20	77-118	20	79-113	20	NA
SM2120B	Color		3.0	Color Units	-	10	-	-	95-105	10	NA
SM2510B	Specific Conductance (EC)	0.23	2.0	umhos/cm	-	4.28	-	-	95-105	5	NA
SM2540C	Total Dissolved Solids	4.0	10	mg/l	-	10	-	-	91-104	10	NA
SM2540D	Total Suspended Solids	5.0	5.0	mg/l	-	20	-	-	-	-	NA
SM4500 H+ B	pH			Units	-	3.24	-	-	96.7-102	-	NA
SM5310C	Total Organic Carbon (TOC)	0.032	0.30	mg/l	-	20	84-107	20	90-110	20	NA
SM5320B	Total Organic Halides	3.4	20	ug/l	-	20	65-141	20	78-131	20	NA
Diquat and Paraquat by EPA 549.2											
in Water											
EPA 549.2	Diquat	0.90	4.0	ug/l	-	30	52-130	30	54-135	30	2764-72-9
Endothall By EPA 548.1											
in Water											
EPA 548.1	Endothall	3.5	45	ug/l	-	30	3.5-137	30	3.5-143	30	145-73-3
Field determinations											
in Water											
Field	Temperature, degrees F			°F	-	-	-	-	-	-	NA

Analytical Method Details - Weck Laboratories, Inc

					Surr.	DUP	Matrix Spike		Blank Spike		
Method	**Analyte**	**MDL**	**MRL**	**Units**	**%R**	**RPD**	**%R**	**RPD**	**%R**	**RPD**	CASNumber
Fumigants by EPA Method 504.1											
in Water											
EPA 504.1	1,2-Dibromoethane (EDB)	0.0049	0.020	ug/l	-	30	65-135	30	70-130	30	106-93-4
EPA 504.1	1,2-Dibromo-3-chloropropane	0.0030	0.010	ug/l	-	30	65-135	30	70-130	30	96-12-8
Glyphosate by EPA 547											
in Water											
EPA 547	Glyphosate	1.8	5.0	ug/l	-	30	68-134	30	71-137	30	1071-83-6
HAAs by EPA 552.2											
in Water											
EPA 552.2	Monochloroacetic acid (mcaa)	0.32	2.0	ug/l	-	30	70-130	30	70-130	30	79-11-8
EPA 552.2	Monobromoacetic acid (mbaa)	0.21	1.0	ug/l	-	30	70-130	30	70-130	30	79-08-3
EPA 552.2	Dichloroacetic acid (dcaa)	0.41	1.0	ug/l	-	30	70-130	30	70-130	30	79-43-6
EPA 552.2	Trichloroacetic acid (tcaa)	0.22	1.0	ug/l	-	30	70-130	30	70-130	30	140-41-0
EPA 552.2	Dibromoacetic acid (dbaa)	0.13	1.0	ug/l	-	30	70-130	30	70-130	30	631-64-1
EPA 552.2	HAA5, Total		1.0	ug/l	-	-	-	-	-	-	NA
EPA 552.2	2,3-Dibromopropionic acid			Surrogate	70-130	-	-	-	-	-	600-05-5
Metals by EPA 200 Series Methods											
in Water											
EPA 200.7	Barium, Total	0.00092	0.0020	mg/l	-	30	70-130	30	85-115	30	7440-39-3
EPA 200.7	Calcium, Total	0.016	0.10	mg/l	-	30	70-130	30	85-115	30	7440-70-2
EPA 200.7	Iron, Total	1.1	10	ug/l	-	30	70-130	30	85-115	30	7439-89-6
EPA 200.7	Potassium, Total	0.081	0.10	mg/l	-	30	70-130	30	85-115	30	7440-09-7
EPA 200.7	Magnesium, Total	0.012	0.10	mg/l	-	30	70-130	30	85-115	30	7439-95-4
EPA 200.7	Sodium, Total	0.015	0.50	mg/l	-	30	70-130	30	85-115	10	7440-23-5
EPA 200.7	Silicon, Total	0.0040	0.040	mg/l	-	30	70-130	30	85-115	30	7440-21-3
EPA 200.8	Beryllium, Total	0.022	0.10	ug/l	-	30	70-130	30	85-115	20	7440-41-7
EPA 200.8	Aluminum, Total	0.19	5.0	ug/l	-	30	70-130	30	85-115	20	7429-90-5
EPA 200.8	Chromium, Total	0.012	0.20	ug/l	-	30	70-130	30	85-115	20	7440-47-3
EPA 200.8	Manganese, Total	0.019	0.20	ug/l	-	30	70-130	30	85-115	20	7439-96-5
EPA 200.8	Nickel, Total	0.011	0.80	ug/l	-	30	70-130	30	85-115	20	7440-02-0
EPA 200.8	Copper, Total	0.022	0.50	ug/l	-	30	70-130	30	85-115	20	7440-50-8
EPA 200.8	Strontium, Total	0.069	0.20	ug/l	-	30	70-130	30	85-115	20	7440-24-6
EPA 200.8	Zinc, Total	0.30	5.0	ug/l	-	30	70-130	30	85-115	20	7440-66-6
EPA 200.8	Arsenic, Total	0.014	0.40	ug/l	-	30	70-130	30	85-115	20	7440-38-2
EPA 200.8	Selenium, Total	0.017	0.40	ug/l	-	30	70-130	30	85-115	20	7782-49-2
EPA 200.8	Silver, Total	0.0080	0.20	ug/l	-	30	70-130	30	85-115	20	7440-22-4
EPA 200.8	Cadmium, Total	0.013	0.10	ug/l	-	30	70-130	30	85-115	20	7440-43-9
EPA 200.8	Antimony, Total	0.0080	0.50	ug/l	-	30	70-130	30	85-115	20	7440-36-0
EPA 200.8	Barium, Total	0.024	0.50	ug/l	-	30	70-130	30	85-115	20	7440-39-3
EPA 200.8	Thallium, Total	0.020	0.20	ug/l	-	30	70-130	30	85-115	20	7440-28-0
EPA 200.8	Lead, Total	0.017	0.20	ug/l	-	30	70-130	30	85-115	20	7439-92-1
EPA 245.1	Mercury, Total	0.0039	0.050	ug/l	-	20	70-130	20	85-115	20	7439-97-6
Microbiological Parameters by APHA Standard Methods											
in Water											
SM 9215 B	Heterotrophic Plate Count		1.0	CFU/ml	-	-	-	-	-	-	NA
SM 9221 E	Fecal Coliform		2.0	MPN/100 m	-	-	-	-	-	-	NA
Nitrosamines by isotopic dilution GC/MS CI Mode											
in Water											
EPA 1625M	N-Nitrosodimethylamine	0.00023	0.0020	ug/l	-	-	70-130	30	70-130	30	62-75-9
PPCPs - Pharmaceuticals by LC/MSMS-ESI+											
in Water											
EPA1694M-ESI	Acetaminophen	1.4	20	ng/l	-	-	70-130	30	70-130	30	103-90-2
EPA1694M-ESI	Morphine	0.53	2.0	ng/l	-	-	50-150	30	50-150	30	57-27-2
EPA1694M-ESI	Atenolol	0.20	1.0	ng/l	-	-	70-130	30	70-130	30	29122-68-7
EPA1694M-ESI	Atorvastatin	0.11	1.0	ng/l	-	-	70-130	30	70-130	30	134523-00-5
EPA1694M-ESI	Azithromycin	2.2	10	ng/l	-	-	70-130	30	70-130	30	83905-01-5
EPA1694M-ESI	Caffeine	0.31	1.0	ng/l	-	-	70-130	30	70-130	30	58-08-2
EPA1694M-ESI	Carbamazepine	0.080	1.0	ng/l	-	-	70-130	30	70-130	30	298-46-4
EPA1694M-ESI	Ciprofloxacin	1.4	5.0	ng/l	-	-	70-130	30	70-130	30	85721-33-1

Analytical Method Details - Weck Laboratories, Inc

					Surr.	DUP	Matrix Spike		Blank Spike		
Method	**Analyte**	**MDL**	**MRL**	**Units**	**%R**	**RPD**	**%R**	**RPD**	**%R**	**RPD**	CASNumber
EPA1694M-ESI	Cotinine	0.35	1.0	ng/l	-	-	70-130	30	70-130	30	486-56-6
EPA1694M-ESI	DEET	0.060	1.0	ng/l	-	-	70-130	30	70-130	30	134-62-3
EPA1694M-ESI	Diazepam	0.14	1.0	ng/l	-	-	70-130	30	70-130	30	439-14-5
EPA1694M-ESI	Fluoxetine	0.080	1.0	ng/l	-	-	70-130	30	70-130	30	59333-67-4
EPA1694M-ESI	Methadone	0.040	1.0	ng/l	-	-	70-130	30	70-130	30	76-99-3
EPA1694M-ESI	Primidone	0.60	1.0	ng/l	-	-	70-130	30	70-130	30	125-33-7
EPA1694M-ESI	Sulfamethoxazole	0.19	1.0	ng/l	-	-	70-130	30	70-130	30	723-46-6
EPA1694M-ESI	TCEP	0.34	1.0	ng/l	-	-	70-130	30	70-130	30	115-96-8
EPA1694M-ESI	TCPP	0.27	1.0	ng/l	-	-	70-130	30	70-130	30	13674-84-5
EPA1694M-ESI	TDCPP	0.47	1.0	ng/l	-	-	70-130	30	70-130	30	13674-87-8
EPA1694M-ESI	Trimethoprim	0.24	1.0	ng/l	-	-	70-130	30	70-130	30	738-70-5
EPA1694M-ESI	Amoxicillin		10	ng/l	-	-	70-130	30	70-130	30	26787-78-0
EPA1694M-ESI	Phenytoin		1.0	ng/l	-	-	70-130	30	70-130	30	57-41-0
EPA1694M-ESI	Hydrocodone-d3			Surrogate	50-150	-	-	-	-	-	NA
GCMS SIM	PBDE-47	0.0070	0.050	ug/l	-	-	70-130	30	70-130	30	5436-43-1
GCMS SIM	PBDE-99	0.0090	0.050	ug/l	-	-	70-130	30	70-130	30	60348-60-9
GCMS SIM	PBDE-100	0.012	0.050	ug/l	-	-	70-130	30	70-130	30	189084-64-8
GCMS SIM	PBDE-153	0.0090	0.050	ug/l	-	-	70-130	30	70-130	30	68631-49-2
GCMS SIM	PBDE-154	0.011	0.050	ug/l	-	-	70-130	30	70-130	30	207122-15-4
GCMS SIM	Perylene-d12			Surrogate	70-130	-	-	-	-	-	1520-96-3
GCMS SIM	Triphenyl phosphate			Surrogate	70-130	-	-	-	-	-	115-86-6
PPCPs - Pharmaceuticals by LC/MSMS-ESI- in Water											
EPA1694M-ESI	Bisphenol A	0.27	1.0	ng/l	-	-	70-130	30	70-130	30	80-05-7
EPA1694M-ESI	Gemfibrozil	0.080	1.0	ng/l	-	-	70-130	30	70-130	30	25812-30-0
EPA1694M-ESI	Ibuprofen	0.39	1.0	ng/l	-	-	70-130	30	70-130	30	15687-27-1
EPA1694M-ESI	Naproxen	0.25	1.0	ng/l	-	-	70-130	30	70-130	30	22204-53-1
EPA1694M-ESI	Salicylic Acid	0.86	50	ng/l	-	-	70-130	30	70-130	30	69-72-7
EPA1694M-ESI	Triclosan	1.2	2.0	ng/l	-	-	70-130	30	70-130	30	3380-34-5
EPA1694M-ESI	Iopromide		5.0	ng/l	-	-	70-130	30	70-130	30	73334-07-3
PPCPs - Hormones by LC/MSMS-APCI in Water											
EPA1694M-APC	17a-Ethynylestradiol	0.56	1.0	ng/l	-	-	70-130	30	70-130	30	57-63-6
EPA1694M-APC	Estradiol	0.31	1.0	ng/l	-	-	70-130	30	70-130	30	50-28-2
EPA1694M-APC	Estrone	0.20	1.0	ng/l	-	-	70-130	30	70-130	30	53-16-7
EPA1694M-APC	Progesterone	0.17	1.0	ng/l	-	-	70-130	30	70-130	30	57-83-0
EPA1694M-APC	Testosterone	0.14	1.0	ng/l	-	-	70-130	30	70-130	30	58-22-0
PPCPs - Alkyl Phenols by GC/MS SIM in Water											
GCMS SIM	Nonylphenol	0.30	0.90	ug/l	-	-	70-130	30	70-130	30	25154-52-3
GCMS SIM	Nonylphenol diethoxylate	2.1	6.0	ug/l	-	-	70-130	30	70-130	30	20427-84-3
GCMS SIM	Nonylphenol monoethoxylate	0.87	2.0	ug/l	-	-	70-130	30	70-130	30	27986-36-3
GCMS SIM	4-tert-Octylphenol	0.080	0.20	ug/l	-	-	70-130	30	70-130	30	140-66-9
GCMS SIM	Bisphenol A	0.25	0.30	ug/l	-	-	70-130	30	70-130	30	80-05-7
GCMS SIM	4-Nonylphenol			Surrogate	70-130	-	-	-	-	-	104-40-5
Radiological Parameters by APHA/EPA Methods in Water											
EPA 200.8	Uranium, Total	0.019	0.13	pCi/L	-	30	70-130	30	85-115	20	7440-61-1
EPA 900.0	Gross Alpha			pCi/L	-	-	70-130	30	70-130	30	NA
EPA 900.0	Gross Alpha counting error (+/-)			pCi/L	-	-	-	-	-	-	NA
EPA 900.0	Gross Alpha MDA95			pCi/L	-	-	-	-	-	-	NA
EPA 900.0	Gross Beta			pCi/L	-	-	70-130	30	70-130	30	NA
EPA 900.0	Gross Beta counting error (+/-)			pCi/L	-	-	-	-	-	-	NA
EPA 900.0	Gross Beta MDA95			pCi/L	-	-	-	-	-	-	NA
Semivolatile Organic Compounds by GC/MS in Water											
EPA 525.2	Benzo (a) pyrene	0.073	0.10	ug/l	-	30	29-153	30	54-136	30	50-32-8
EPA 525.2	Bis(2-ethylhexyl)adipate	0.23	5.0	ug/l	-	30	28-147	30	50-145	30	103-23-1
EPA 525.2	Bis(2-ethylhexyl)phthalate	1.1	3.0	ug/l	-	30	23-154	30	54-142	30	117-81-7
EPA 525.2	Alachlor	0.070	0.10	ug/l	-	30	58-177	30	58-164	30	15972-60-8

Analytical Method Details - Weck Laboratories, Inc

					Surr.	DUP	Matrix Spike		Blank Spike		
Method	**Analyte**	**MDL**	**MRL**	**Units**	**%R**	**RPD**	**%R**	**RPD**	**%R**	**RPD**	CASNumber
EPA 525.2	Atrazine	0.047	0.10	ug/l	-	30	53-142	30	68-133	30	1912-24-9
EPA 525.2	Bromacil	0.90	1.0	ug/l	-	30	71-182	30	43-177	30	314-40-9
EPA 525.2	Butachlor	0.10	0.20	ug/l	-	30	67-181	30	55-178	30	23184-66-9
EPA 525.2	Captan	0.86	1.0	ug/l	-	30	45-182	30	20-215	30	133-06-2
EPA 525.2	Chloropropham	0.010	0.10	ug/l	-	30	76-137	30	74-133	30	101-21-3
EPA 525.2	Cyanazine	0.020	0.10	ug/l	-	30	26-145	30	69-131	30	21725-46-2
EPA 525.2	Diazinon	0.051	0.10	ug/l	-	30	43-219	30	42-212	30	333-41-5
EPA 525.2	Dimethoate	0.10	0.20	ug/l	-	30	39-120	30	24-110	30	60-51-5
EPA 525.2	Diphenamid	0.020	0.10	ug/l	-	30	86-130	30	82-144	30	957-51-7
EPA 525.2	Disulfoton	0.030	0.10	ug/l	-	30	24-133	30	71-122	30	298-04-4
EPA 525.2	EPTC	0.23	1.0	ug/l	-	30	67-119	30	75-110	30	759-94-4
EPA 525.2	Metolachlor	0.056	0.10	ug/l	-	30	53-178	30	55-170	30	51218-45-2
EPA 525.2	Metribuzin	0.074	0.10	ug/l	-	30	64-155	30	44-149	30	21087-64-9
EPA 525.2	Molinate	0.051	0.10	ug/l	-	30	68-125	30	76-116	30	2212-67-1
EPA 525.2	Prometon	0.16	0.20	ug/l	-	30	5-148	30	6-110	30	1610-18-0
EPA 525.2	Prometryn	0.074	0.10	ug/l	-	30	44-169	30	34-152	30	7287-19-6
EPA 525.2	Simazine	0.083	0.10	ug/l	-	30	53-152	30	54-156	30	122-34-9
EPA 525.2	Terbacil	0.55	2.0	ug/l	-	30	56-159	30	66-140	30	5902-51-2
EPA 525.2	Thiobencarb	0.11	0.20	ug/l	-	30	71-160	30	57-162	30	28249-77-6
EPA 525.2	Trithion	0.010	0.10	ug/l	-	30	86-144	30	62-149	30	786-19-6
EPA 525.2	1,3-Dimethyl-2-NB			Surrogate	73-136	-	-	-	-	-	81-20-9
EPA 525.2	Perylene-d12			Surrogate	48-141	-	-	-	-	-	1520-96-3
EPA 525.2	Triphenyl phosphate			Surrogate	71-150	-	-	-	-	-	115-86-6
Subcontracted Analyses											
in Water											
EPA 100.2	Asbestos		0.200	MFL	-	-	-	-	-	-	1332-21-4
EPA 1613	2,3,7,8-TCDD (Dioxin)	0.543	5.00	pg/l	-	-	-	-	-	-	1746-01-6
EPA 1623	Cryptosporidium Occysts		0.10	Organisms/	-	-	-	-	-	-	NA
EPA 1623	Giardia Species Cysts		0.10	Organisms/	-	-	-	-	-	-	NA
EPA 903.1	Radium 226			pCi/L	-	-	-	-	-	-	13982-63-3
EPA 903.1	Radium 226 counting error			pCi/L	-	-	-	-	-	-	NA
EPA 903.1	Radium 226 MDA			pCi/L	-	-	-	-	-	-	NA
EPA 905.0	Strontium 90			pCi/L	-	-	-	-	-	-	10098-97-2
EPA 905.0	Strontium 90 counting error			pCi/L	-	-	-	-	-	-	NA
EPA 905.0	Strontium 90 MDA			pCi/L	-	-	-	-	-	-	NA
EPA 906.0	Tritium			pCi/L	-	-	-	-	-	-	10028-17-8
EPA 906.0	Tritium counting error (+/-)			pCi/L	-	-	-	-	-	-	NA
EPA 906.0	Tritium MDA			pCi/L	-	-	-	-	-	-	NA
EPA ICR 600/R-	Total Culturable Virus Assay	0.10	0.10	MPN/L	-	-	-	-	-	-	NA
EPA Ra-05	Radium 228			pCi/L	-	-	-	-	-	-	15262-20-1
EPA Ra-05	Radium 228 counting error (+/-)			pCi/L	-	-	-	-	-	-	NA
EPA Ra-05	Radium 228 MDA			pCi/L	-	-	-	-	-	-	NA
EPA 625/R-92/0	Helminth Parasites										
Volatile Organic Compounds by EPA Method 524.2											
in Water											
EPA 524.2	Dichlorodifluoromethane (Freon 12)	0.26	0.50	ug/l	-	30	-	-	70-130	30	75-71-8
EPA 524.2	Chloromethane	0.20	0.50	ug/l	-	30	-	-	70-130	30	74-87-3
EPA 524.2	Vinyl chloride	0.18	0.50	ug/l	-	30	-	-	70-130	30	75-01-4
EPA 524.2	Bromomethane	0.21	0.50	ug/l	-	30	-	-	70-130	30	74-83-9
EPA 524.2	Chloroethane	0.18	0.50	ug/l	-	30	-	-	70-130	30	75-00-3
EPA 524.2	Trichlorofluoromethane	0.20	5.0	ug/l	-	30	-	-	70-130	30	75-69-4
EPA 524.2	Freon 113	1.6	5.0	ug/l	-	30	-	-	70-130	30	76-13-1
EPA 524.2	1,1-Dichloroethene	0.21	0.50	ug/l	-	30	70-130	30	70-130	30	75-35-4
EPA 524.2	Methylene chloride	0.15	0.50	ug/l	-	30	-	-	70-130	30	75-09-2
EPA 524.2	trans-1,2-Dichloroethene	0.18	0.50	ug/l	-	30	-	-	70-130	30	156-60-5
EPA 524.2	Methyl tert-butyl ether (MTBE)	1.1	3.0	ug/l	-	30	-	-	70-130	30	1634-04-4
EPA 524.2	1,1-Dichloroethane	0.15	0.50	ug/l	-	30	-	-	70-130	30	75-34-3
EPA 524.2	Di-isopropyl ether	1.3	3.0	ug/l	-	30	-	-	70-130	30	108-20-3
EPA 524.2	Ethyl tert-butyl ether	1.3	3.0	ug/l	-	30	-	-	70-130	30	637-92-3
EPA 524.2	2-Butanone	1.9	5.0	ug/l	-	30	-	-	70-130	30	78-93-3
EPA 524.2	2,2-Dichloropropane	0.16	0.50	ug/l	-	30	-	-	70-130	30	594-20-7
EPA 524.2	cis-1,2-Dichloroethene	0.18	0.50	ug/l	-	30	-	-	70-130	30	156-59-2
EPA 524.2	Bromochloromethane	0.20	0.50	ug/l	-	30	-	-	70-130	30	74-97-5

Analytical Method Details - Weck Laboratories, Inc

					Surr.	DUP	Matrix Spike		Blank Spike		
Method	**Analyte**	**MDL**	**MRL**	**Units**	**%R**	**RPD**	**%R**	**RPD**	**%R**	**RPD**	CASNumber
EPA 524.2	Chloroform	0.17	0.50	ug/l	-	30	-	-	70-130	30	67-66-3
EPA 524.2	1,1,1-Trichloroethane	0.15	0.50	ug/l	-	30	-	-	70-130	30	71-55-6
EPA 524.2	Carbon tetrachloride	0.18	0.50	ug/l	-	30	-	-	70-130	30	56-23-5
EPA 524.2	1,1-Dichloropropene	0.16	0.50	ug/l	-	30	-	-	70-130	30	563-58-6
EPA 524.2	Benzene	0.15	0.50	ug/l	-	30	70-130	30	70-130	30	71-43-2
EPA 524.2	1,2-Dichloroethane	0.14	0.50	ug/l	-	30	-	-	70-130	30	107-06-2
EPA 524.2	Tert-amyl methyl ether	1.2	3.0	ug/l	-	30	-	-	70-130	30	994-05-8
EPA 524.2	Trichloroethene	0.18	0.50	ug/l	-	30	70-130	30	70-130	30	79-01-6
EPA 524.2	1,2-Dichloropropane	0.15	0.50	ug/l	-	30	-	-	70-130	30	78-87-5
EPA 524.2	Dibromomethane	0.18	0.50	ug/l	-	30	-	-	70-130	30	74-95-3
EPA 524.2	Bromodichloromethane	0.13	0.50	ug/l	-	30	-	-	70-130	30	75-27-4
EPA 524.2	cis-1,3-Dichloropropene	0.16	0.50	ug/l	-	30	-	-	70-130	30	10061-01-5
EPA 524.2	4-Methyl-2-pentanone	1.5	5.0	ug/l	-	30	-	-	70-130	30	108-10-1
EPA 524.2	2-Chloroethyl vinyl ether	0.35	1.0	ug/l	-	30	-	-	70-130	30	110-75-8
EPA 524.2	Toluene	0.15	0.50	ug/l	-	30	70-130	30	70-130	30	108-88-3
EPA 524.2	trans-1,3-Dichloropropene	0.17	0.50	ug/l	-	30	-	-	70-130	30	10061-02-6
EPA 524.2	1,1,2-Trichloroethane	0.22	0.50	ug/l	-	30	-	-	70-130	30	79-00-5
EPA 524.2	Tetrachloroethene	0.26	0.50	ug/l	-	30	-	-	70-130	30	127-18-4
EPA 524.2	1,3-Dichloropropane	0.14	0.50	ug/l	-	30	-	-	70-130	30	142-28-9
EPA 524.2	Dibromochloromethane	0.19	0.50	ug/l	-	30	-	-	70-130	30	124-48-1
EPA 524.2	2-Hexanone	0.18	5.0	ug/l	-	30	-	-	70-130	30	591-78-6
EPA 524.2	Chlorobenzene	0.16	0.50	ug/l	-	30	70-130	30	70-130	30	108-90-7
EPA 524.2	1,1,1,2-Tetrachloroethane	0.17	0.50	ug/l	-	30	-	-	70-130	30	630-20-6
EPA 524.2	Ethylbenzene	0.17	0.50	ug/l	-	30	-	-	70-130	30	100-41-4
EPA 524.2	m,p-Xylene	0.37	0.50	ug/l	-	30	-	-	70-130	30	1330-20-7
EPA 524.2	o-Xylene	0.19	0.50	ug/l	-	30	-	-	70-130	30	95-47-6
EPA 524.2	Styrene	0.16	0.50	ug/l	-	30	-	-	70-130	30	100-42-5
EPA 524.2	Bromoform	0.17	0.50	ug/l	-	30	-	-	70-130	30	75-25-2
EPA 524.2	Isopropylbenzene	0.17	0.50	ug/l	-	30	-	-	70-130	30	98-82-8
EPA 524.2	Bromobenzene	0.18	0.50	ug/l	-	30	-	-	70-130	30	108-86-1
EPA 524.2	1,1,2,2-Tetrachloroethane	0.18	0.50	ug/l	-	30	-	-	70-130	30	79-34-5
EPA 524.2	1,2,3-Trichloropropane	0.15	0.50	ug/l	-	30	-	-	70-130	30	96-18-4
EPA 524.2	n-Propylbenzene	0.15	0.50	ug/l	-	30	-	-	70-130	30	103-65-1
EPA 524.2	2-Chlorotoluene	0.18	0.50	ug/l	-	30	-	-	70-130	30	95-49-8
EPA 524.2	4-Chlorotoluene	0.17	0.50	ug/l	-	30	-	-	70-130	30	106-43-4
EPA 524.2	1,3,5-Trimethylbenzene	0.15	0.50	ug/l	-	30	-	-	70-130	30	108-67-8
EPA 524.2	tert-Butylbenzene	0.14	0.50	ug/l	-	30	-	-	70-130	30	98-06-6
EPA 524.2	1,2,4-Trimethylbenzene	0.16	0.50	ug/l	-	30	-	-	70-130	30	95-63-6
EPA 524.2	sec-Butylbenzene	0.15	0.50	ug/l	-	30	-	-	70-130	30	135-98-8
EPA 524.2	m-Dichlorobenzene	0.21	0.50	ug/l	-	30	-	-	70-130	30	541-73-1
EPA 524.2	p-Isopropyltoluene	0.17	0.50	ug/l	-	30	-	-	70-130	30	99-87-6
EPA 524.2	p-Dichlorobenzene	0.17	0.50	ug/l	-	30	-	-	70-130	30	106-46-7
EPA 524.2	o-Dichlorobenzene	0.17	0.50	ug/l	-	30	-	-	70-130	30	95-50-1
EPA 524.2	n-Butylbenzene	0.15	0.50	ug/l	-	30	-	-	70-130	30	104-51-8
EPA 524.2	1,2,4-Trichlorobenzene	0.19	0.50	ug/l	-	30	-	-	70-130	30	120-82-1
EPA 524.2	Hexachlorobutadiene	0.16	0.50	ug/l	-	30	-	-	70-130	30	87-68-3
EPA 524.2	Naphthalene	0.21	0.50	ug/l	-	30	-	-	70-130	30	91-20-3
EPA 524.2	1,2,3-Trichlorobenzene	0.16	0.50	ug/l	-	30	-	-	70-130	30	87-61-6
EPA 524.2	Xylenes (total)	0.37	0.50	ug/l	-	-	-	-	-	-	1330-20-7
EPA 524.2	1,3 Dichloropropene (Total)	0.17	0.50	ug/l	-	-	-	-	-	-	542-75-6
EPA 524.2	Carbon Disulfide	0.21	0.50	ug/l	-	30	-	-	70-130	30	75-15-0
EPA 524.2	Acetone	1.7	5.0	ug/l	-	30	-	-	70-130	30	67-64-1
EPA 524.2	Acrylonitrile	1.1	2.0	ug/l	-	30	-	-	70-130	30	107-13-1
EPA 524.2	THMs, Total		0.50	ug/l	-	-	-	-	70-130	-	NA
EPA 524.2	1,2-Dichlorobenzene-d4			Surrogate	70-130	-	-	-	-	-	2199-69-1
EPA 524.2	4-Bromofluorobenzene			Surrogate	70-130	-	-	-	-	-	460-00-4

Attachment F

Health and Safety Plan

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City of Los Angeles
Recycled Water Master Plan

Pilot Health and Safety Plan - Task 3a - DRAFT

General Information

This task-specific health and safety plan (HASP) provides safety-related information and requirements specific to the task and work location(s) described. General requirements contained in the CDM Health and Safety Program along with those described in this task-specific HASP will be implemented except where noted. Significant changes to this HASP shall be documented by resubmittal of a revised task-specific HASP.

Project Name:	Recycled Water Master Plan, Task 3-Indirect Potable Reuse Pilot Study	Client:	City of Los Angeles
Project No.:	86538-71984	Date:	9/25/2009

Performing Organization(s):	RMC, CDM Inc, CDM Constructors Inc.
Planned Duration of Field Activities:	18 months (10/2010-4/2011)
Project Location :	Site is within the Donald C. Tillman Water Reclamation Plant (DCT) (6100 Woodley Ave. Van Nuys, CA 91406)

Key Personnel

Project Manager:	Greg Wetterau	Telephone:	909-579-3500(o) 503-267-5812(c)
Project Health and Safety	Pat Dentler	Telephone:	505-661-8386

Project Field Personnel	Responsibilities	Telephone
Greg Wetterau	Consultant Team Task Lead	909-579-3500 (o)
Marie Sedran	Project Engineer	213-457-2200 (o)
Usingama Mvuemba	Field Operations	909-579-3467
Eric Smith	Field Operations	213-457-2200(o) 760-715-3349(c)
Daniel Berokoff	Field Operations	213-457-2200(o) 562-217-8603 (c)
Mike Bell	DCT Primary Contact	818-778-4108(o) 800-309-0676(c)
Gary Stolarik	City Team Task Lead	
Al Bazzi	City Team Task Co-Lead	

Project Site Description	Site is within the Donald C. Tillman Water Reclamation Plant (DCT).

CDM Activity Hazard Analysis

Project Name: Recycled Water Master Plan, Task 3-Indirect Potable Reuse Pilot Study **Project No.:** 86538-71984

Analyzed by: Marie Burbano **Date:** 06/04/10 **Reviewed by:** Pat Dentler **Date:**

Description of Work Activity

Construct, install, and operate a skid mounted reverse osmosis pilot plant to treat effluent water from the Donald C. Tillman Water Reclamation Plant (DCT). This will include installation of membrane filters, UV reactor, and additional advanced oxidation processes. Water samples will be collected at pre-determined points in the system and analyzed on-site for pre-determined constituents.

Potential Hazards	Hazard Controls
On-site pilot construction	Personal Protection equipment (PPE) including hard hats, safety glasses, gloves, long pants, and close-toed shoes.
General pilot plant operations	Personal Protection equipment (PPE) including hard hats, safety glasses, gloves, long pants, and close-toed shoes.
Hazard Control (laboratory analytical chemicals and equipment)	Wear and dispose of gloves after handling. Eyewash onsite (equipment required). If working directly with acid, use splash apron, heavy acid resistant gloves, & face shield.
On-site traffic	Equipment is located outside of traffic. Security fencing, where appropriate to show limit of area

Training Required	Equipment Required
Right to Know training including a review of applicable MSDS's will be conducted	Required and optional PPE listed above. MSDS's for chemical to be used are attached to this plan

Emergency Plan and Information

Basic Approach:	In an emergency situation, the Consultant Team will rapidly, but without haste, withdraw to a safe location and notify the appropriate emergency agencies listed below.
Police:	911
Fire:	911
CDM H & S Manager	**Pat Dentler** **(505) 780-0381**
Poison Control Center	**Nationwide** **(800) 222-1222**
State Spill Number:	**California** **(800) 852-7550**
Ambulance:	911
Client's Emergency Number:	
Nearest Medical Facility:	Valley Presbyterian Hospital
Address:	15107 Vanowen St. Van Nuys, CA 91405
Telephone:	(818) 782-6600
Driving Directions: (Attach Map)	1. Head north on Woodley Ave toward Victory Blvd. 0.7 miles 2: Turn right at Vanowen St. 1.0 miles 3: Turn left at Sepulveda Blvd. 0.1 miles 4: Turn right at Bassett St. 0.2 miles 15107 Vanowen St. Van Nuys, CA 91405 (See map attached)

Reviews

Project Manager:	Greg Wetterau	Date:	6/4/2010
Health and Safety Manager:	Pat Dentler	Date:	6/4/2010

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Attachment G

Bench Scale Testing

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Attachment G. Bench-Top Testing Results

G.1 Introduction

The Los Angeles Department of Water and Power (LADWP) has partnered with the Los Angeles Department of Public Works (LADPW) to develop a Recycled Water Master Planning document (RWMP), which facilitates implementation of the 2010 Urban Water Management Plan (UWMP). LADWP's UWMP outlines a goal of increasing recycled water use citywide to 59,000 acre feet per year (AFY) by 2035.

One method of expanding recycled water use is by indirect potable reuse through groundwater replenishment (GWR). Groundwater replenishment is a practical, proven way to increase the availability of a safe, reliable, locally-controlled water supply. As shown on Figure ES-1, using state-of-the-art technology, the GWR system would include treating recycled water from the Donald C. Tillman Water Reclamation Plant (DCTWRP) to near-distilled water quality using advanced water purification (AWP) processes. This purified recycled water would be conveyed to spreading grounds, where it would percolate into natural underground aquifers. This water replenishes the aquifers, to be used as an additional local source of water supply for the city. After the minimum required residence time within the aquifer, the water would be extracted (or pumped) from the existing groundwater basins for treatment and distribution to LADWP drinking water customers.

G.1.1   Purpose

This TM attachment is being completed as part of Task 3a. The purpose of this write-up is to summarize the results of bench-top testing and water quality analyses performed at the Donald C. Tillman Water Reclamation Plant (DCTWRP) on September 10, 2009. These results were used in development of the testing protocol documented in the GWR Treatment Pilot Study Protocol TM.

G.1.2   Overview

This TM attachment is organized in the following sections:

- Section G.1 – Introduction
- Section G.2 – Overview of Testing
- Section G.3 – Regulated DBP Limits
- Section G.4 – Testing Protocol
- Section G.5 – Testing Results
- Section G.6 – Conclusions and Recommendations for Future Testing

G.2 Overview of Testing

Bench-scale sampling was performed at DCTWRP on September 10, 2009 to evaluate disinfection byproduct (DBP) formation, including n-Nitroso-dimethylamine (NDMA) and total trihalomethanes (TTHMs), from the secondary effluent (SE) and filter effluent (FE). The data regarding the potential of DCTWRP's effluent to form these DBPs was used in the development of the Pilot Testing Protocol, particularly in regards to which sources (secondary effluent or filtered effluent) should be used during the testing and what types of disinfection approaches should be employed. Existing advanced wastewater purification facilities maintain a chloramine residual through the membrane processes to help mitigate biological fouling. However, it is well documented that NDMA can be produced through a reaction between chloramines (particularly dichloramine) with organic precursors in wastewater effluent. Since DCTWRP produces a nitrified effluent (e.g. low effluent ammonia concentrations), it may be possible to carry a free chlorine residual through the pretreatment membrane filtration process, then adding ammonia to form chloramines prior to feeding the water to the reverse osmosis (RO) process. Work performed by the Sanitation Districts of Los Angeles County has demonstrated that this sequential chlorination actually reduces the NDMA formation. There can be issues if there is too much free chlorine contact time, or too high of a concentration, as total trihalomethanes (TTHMs) are known to form from a reaction between free chlorine and organic matter. Neither NDMA nor TTHMs are well removed by the RO membranes typically employed in reuse applications. A trade-off may therefore exist between disinfection time with either free chlorine or chloramines in order to minimize the formation of both types of DBP while preventing organic fouling of the membranes.

The bench-scale testing measured the NDMA from primary effluent, secondary effluent, and tertiary filtrate before chlorine addition to develop a baseline concentration to compare with NDMA formed under different disinfection approaches. TTHM concentration in the source water was assumed to be negligible and was therefore not measured. Samples from the secondary effluent and tertiary effluent where then dosed with either free chlorine or chlorine and ammonia and allowed to react in a sealed, dark container for up to 24 hours. 5.25 percent sodium hypochlorite solution was used for chlorine injection with 10 percent ammonium hydroxide used for ammonia. Free chlorine residual was maintained by dosing chlorine beyond breakpoint conditions. For chloramine addition, ammonia was injected and thoroughly mixed prior to addition of chlorine. DBPs were measured at multiple reaction times to determine the rate of formation for both THMs and NDMA.

G.3 Regulated DBP Limits

NDMA is not currently regulated with a maximum contaminant level (MCL) by the Environmental Protection Agency (EPA) or the California Department of Public Health (CDPH). CDPH does have an existing notification level of 10 ng/L and a response level of 300 ng/L. In addition, draft groundwater recharge regulations include a requirement to removal a minimum 1.2-log units of NDMA through advanced water purification. TTHMs are regulated based on an MCL of 80 µg/L, for the locational running annual average (LRAA) in the drinking water distribution system. The application of this limit to groundwater recharge can be debated, however, compliance with this MCL has been established as a treatment goal for the pilot.

G.4 Testing Protocol

The primary and secondary effluent samples were retrieved by placing a sampling bucket into the process stream, whereas the filtered effluent was retrieved by opening a valve from an active turbidimeter sample line. Before the filtered effluent sample was taken, the turbidimeter was allowed to drain so any stagnant water within the turbidimeter piping could be drained. All samples were stored in sealed 2.5-gallon plastic containers, wrapped in aluminum foil prior to and after chlorine addition.

Table G-1 is a summary of the sample runs completed. Note that the chlorine dose of 10 mg/L for free chlorine and 4.5 mg/L for chloramines was based on chlorine demand testing and a goal of a 4.0 mg/L total chlorine residual.

Table G-1: Sample Runs

Run #	Description	Sample	Contact time (min)	Ammonia Dose as N(mg/L)	Chlorine dose as Cl_2 (mg/L)
1.	Baseline	Primary Effluent (PE)	0	0	0
2.	SE baseline	Secondary Effluent (SE)	0	0	0
3.	FE baseline	Filtered Effluent (FE)	0	0	0
4.	SE w/chloramines	SE	5	1.0	4.5
5.	SE w/chloramines	SE	20	1.0	4.5
6.	SE w/chloramines	SE	80	1.0	4.5
7.	SE w/chloramines	SE	90	1.0	4.5
8.	FE w/free chlorine	FE	6	0	10
9.	FE w/free chlorine	FE	20	0	10
10.	FE w/free chlorine	FE	90	0	10
11.	FE w/free chlorine	FE	1440	0	10
12.	FE w/chloramines	FE	5	1.0	4.5
13.	FE w/chloramines	FE	20	1.0	4.5
14.	FE w/chloramines	FE	90	1.0	4.5
15.	FE w/chloramines	FE	1440	1.0	4.5

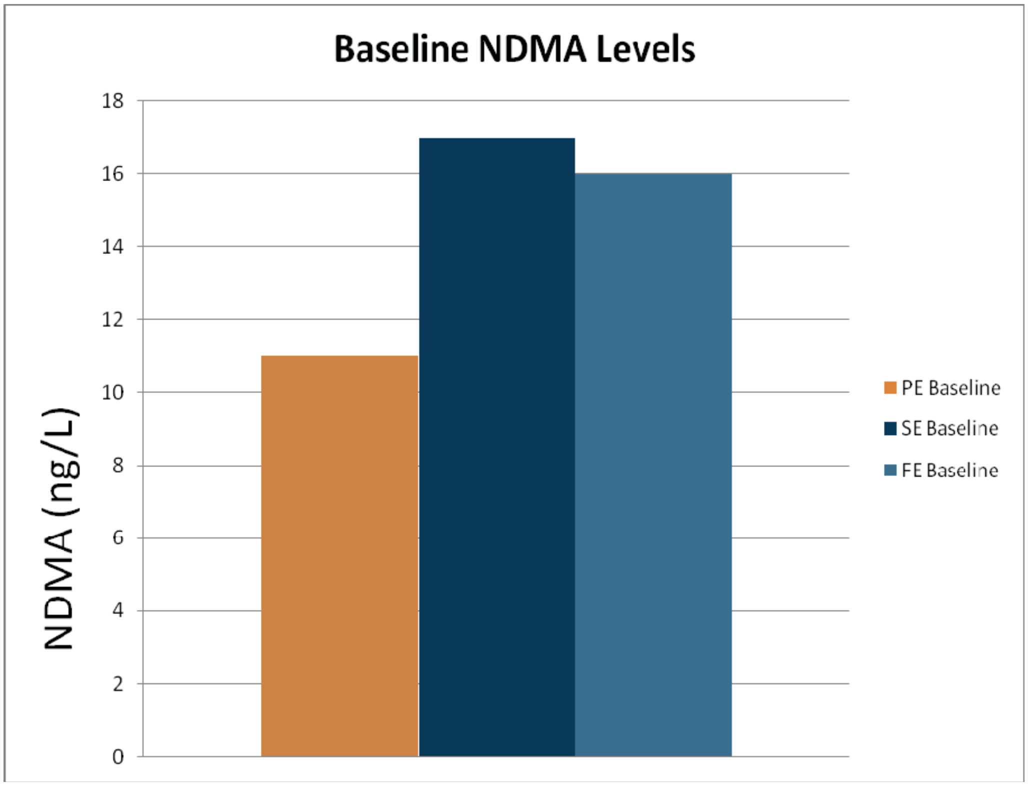
For laboratory analysis, the NDMA samples were stored in duplicate 500 mL amber glass bottles with sodium thiosulfate (dechlorinating agent). TTHM samples were stored in duplicate 100 mL clear glass vials, headspace free with sodium thiosulfate. All sample bottles were provided by Weck Laboratories, and samples were returned to Weck Laboratories for analysis.

Free and total chlorine residual were measured in the field, using the DPD method with a HACH DR890. pH and temperature were measured in the field using a Sension 1 pH meter.

G.5 Testing Results

Results of the baseline NDMA testing, prior to disinfectant addition, are presented in Figure G-1.

Figure G-1: Baseline NDMA Levels



A small increase in NDMA was seen between the primary effluent and the secondary and tertiary effluent, increasing from 11 ng/L in the PE to 17 ng/L in the SE. Given that only a single sample was taken for each, it cannot be known whether this represents a significant increase within the wastewater treatment plant or just the variability of NDMA levels with time. The PE sample was taken at 11:30 am, while the SE and FE samples were taken at 8:00 am. Baseline levels of NDMA should be established by frequent analysis of the primary, secondary, and tertiary effluent composite samples. The results of this limited testing indicate that NDMA levels coming into the DCTWRP facility are slightly above the notification level of 10 ng/L. No significant difference was seen between the NDMA levels in the secondary effluent and those in the filtered effluent, as should be expected in a facility that does not regularly chloraminate ahead of the tertiary filters. It should be noted that previous testing of DCTWRP final product water (after chloramine contact time) conducted on three dates in 2008 resulted in NDMA levels ranging from 160 to 260 ng/L, a full order of magnitude higher than the levels seen in this bench testing before chloramination.

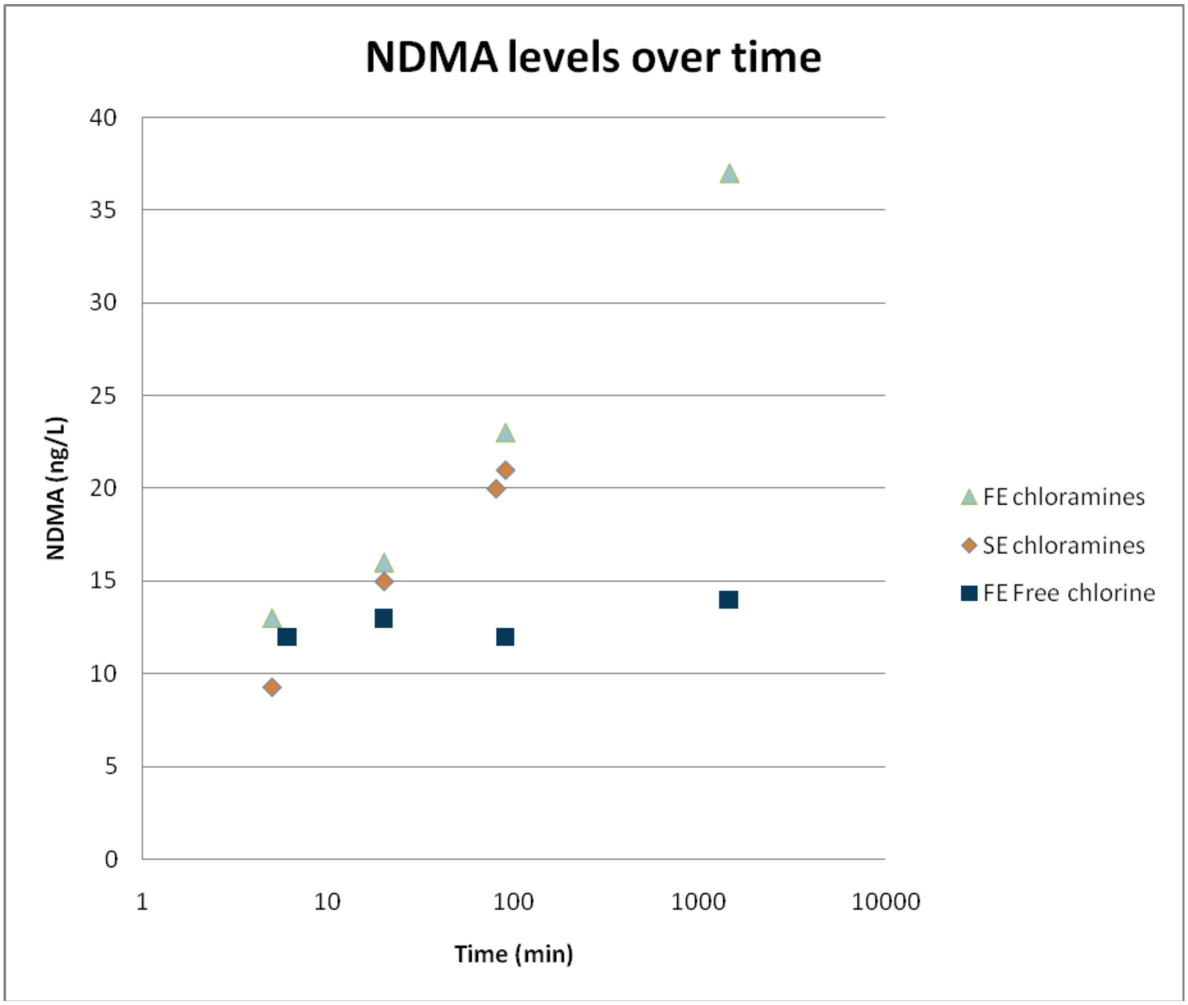
Table G-2 presents the measured chlorine residual, temperature, and pH for each of the tested samples.

Table G-2: Measured Test Conditions for Samples

Run #	Description	Sample	Temperature (deg C)	pH	Total Chlorine residual (mg/L as Cl_2)
1.	Baseline	PE	28	7.1	0
2.	SE baseline	SE	26	7.2	0
3.	FE baseline	FE	26	7.3	0
4.	Chloramines (5 min)	SE	27	7.5	4.5
5.	Chloramines (20 min)	SE	27	7.4	4.3
6.	Chloramines (90 min)	SE	28	7.7	3.7
7.	Free Chlorine (6 min)	FE	27	7.6	7.6
8.	Free Chlorine (20 min)	FE	27	7.5	7.0
9.	Free Chlorine (90 min)	FE	27	7.4	5.2
10.	Free Chlorine (24 hr)	FE	31	7.8	0.3
11.	Chloramines (5 min)	FE	27	7.6	3.8
12.	Chloramines (20 min)	FE	27	7.8	4.1
13.	Chloramines (90 min)	FE	28	7.9	3.5
14.	Chloramines (24 hr)	FE	32	8.1	2.3

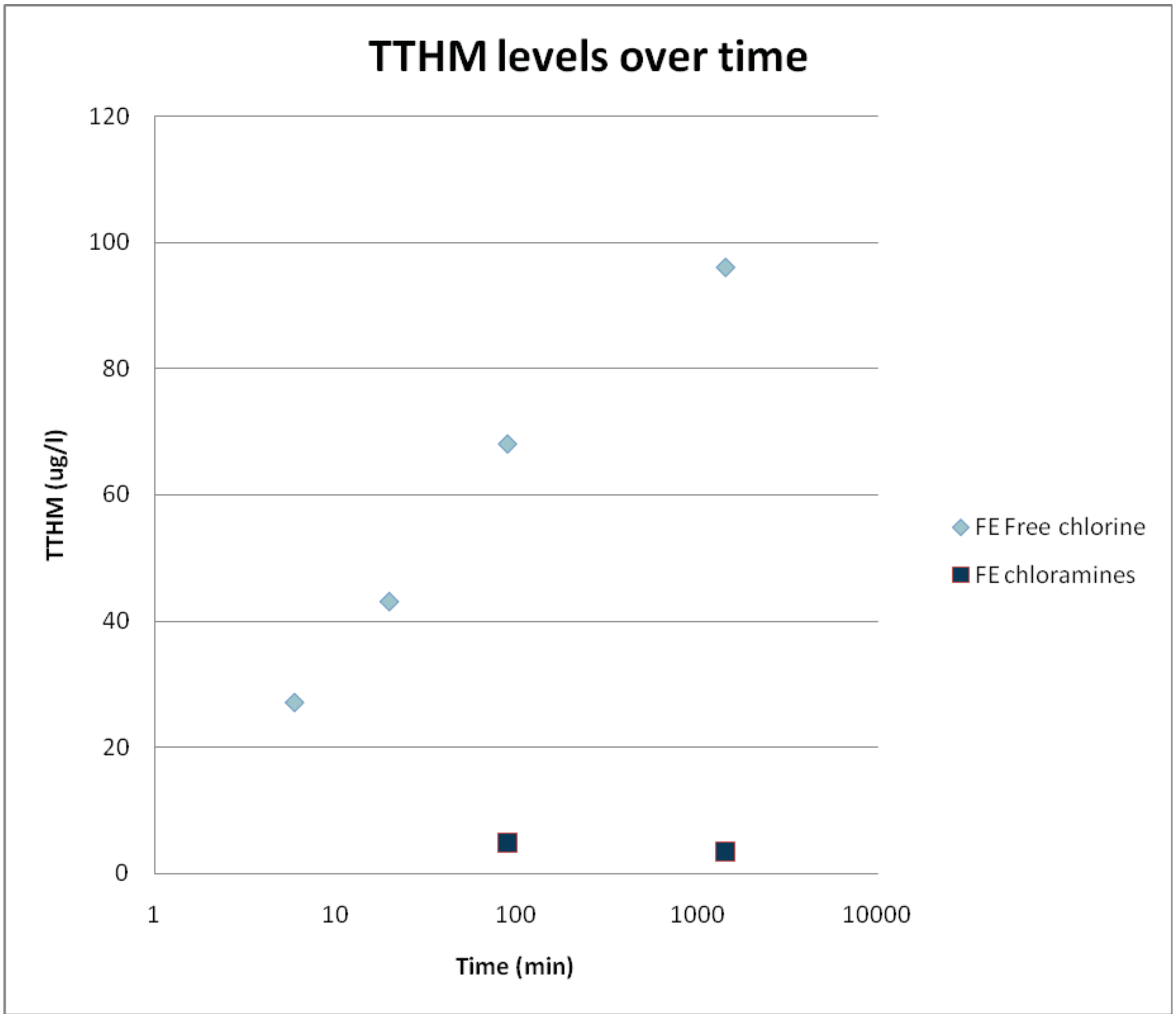
Figure G-2 shows the NDMA formation over time for the filtered effluent with chloramines, the secondary effluent with chloramines, and the filtered effluent with free chlorine samples.

Figure G-2: NDMA Levels over Time



These results indicate that no NDMA formation was seen over the 24-hour testing period when free chlorine was used as the disinfectant. NDMA levels in the free chlorine sample remained at or below the levels seen in the filtered effluent prior to chlorine addition. A significant increase in NDMA was seen in both the secondary and filtered effluent, increasing to a maximum of 37 ng/L in the filtered effluent after 24 hours of contact time, however, these levels were still much lower than the NDMA levels recorded in 2008 for the DCTWRP final product water. A slightly higher increase in NDMA may have been seen in the filtered effluent compared with the secondary effluent, possibly attributable to the addition of Mannich polymer, a known NDMA precursor, ahead of the tertiary filters. However, the difference appears to be less than 10 percent between the NDMA levels seen in the FE and SE, and may not be a significant variance. Further testing should be done to confirm whether reduced NDMA formation can be obtained using secondary effluent rather than filtered effluent and whether this difference is significant. Figure G-3 presents the TTHM levels measured in the free chlorine and chloraminated samples of filtered effluent.

Figure G-3: TTHM Levels over Time



These results indicate that no formation of trihalomethanes was seen when chloramines were used for disinfection. Only two TTHM samples were taken for the chloraminated samples, however, these data indicated a similar and low TTHMs concentration (~5 µg/L) after 90 minutes and 24 hours of chloramination. In contrast, a significant amount of TTHMs formation was observed in the filtered sample with free chlorine, which approached the 80 µg/L MCL after only 90 minutes and exceeded the MCL after 24 hours. In addition to the significance of contact time, the concentration of free chlorine is critical to TTHMs formation and it should be noted that all of this work was performed at a relatively high chlorine dose of 10 mg/L. Future work will consider different free chlorine doses and their respective TTHM formation with time.

G.6 Conclusions and Recommendations for Future Testing

The bench testing conducted at the DCTWRP facility indicates that disinfection byproducts formation, such as NDMA and TTHMs, can be significant when free chlorine or chloramines are used. Chloramine addition to both the secondary and filtered effluents formed significant levels of NDMA, increasing to more than double the current notification level of 10 ng/L after 90 minutes and approaching four times the notification level after 24 hours. No NDMA formation resulted from the addition of free chlorine. In contrast, TTHMs formation was significant when free chlorine was used, approaching the MCL of 80 µg/L after 90 minutes and exceeding the MCL after 24 hours. No TTHMs formation was observed with the addition of chloramines.

With the current disinfection contact time at the DCTWRP facility exceeding 90 minutes, considerable formation of either NDMA or TTHMs will be generated, dependent on the type of chlorination employed. Previous sampling for NDMA in DCTWRP product water showed levels ranging from 160 to 260 ng/L, much higher than those seen during this single day bench testing. It is therefore recommended that any future advanced water purification facility at the DCTWRP site treat a source water prior to the chlorine contact basins to reduce the formation of disinfection byproducts and the treatment requirments for the advanced water purification facility.

If a site other than DCTWRP is utilized for a future advanced water purification facility, additional treatment to remove disinfection byproducts will be necessary, regardless of the type of chlorination employed. Pilot testing at DCTWRP should focus on the following areas of DPB formation and removal:

- Impacts of sequential chlorination or chloramination at various doses and contact times through the advaced water treatment train on NDMA and TTHM formation
- Removal of various levels of NDMA and TTHMs through various RO membranes and advanced oxidation processes

It is recommended that additional bench testing be performed at different seasons throughout the year and possibly at different times of day if grab samples are used again in future work. The goal is to develop consistent trends for the DBP formation in the secondary and filtered effluents, and provide design engineers with a broader picture of the anticipated DBP formation at the full-scale advanced water purification facility.

Attachment H

Alternative Advanced Oxidation Processes

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Attachment H. Alternative Advanced Oxidation Processes

H.1 Overview

As discussed in the Task 1.1 Regulatory Assessment TM and in Section 2 of this Testing Protocol, the CDPH draft groundwater recharge requirements specify the log-removal required for NDMA and 1,4-dioxane and also provide an approach for the consideration of emerging contaminants like endocrine disruptors, pharmaceuticals, and personal care products (EDCs/PhPCPs) (CDPH, 2008). NDMA and 1,4-dioxane are low molecular weight compounds not well-suited for removal by RO. UV/H_2O_2 represents the baseline advanced AOP to meet the 1.2-log removal of NDMA and 0.5-log removal of 1,4-dioxane in the draft CDPH groundwater recharge requirements in the near term as UV/H_2O_2 represents the AOP recently permitted by CDPH for the water reuse application at the GWR System. These levels of removal of NDMA (1.2-log) and 1,4-dioxane (0.5-log) are required regardless of whether NDMA and/or 1,4-dioxane are present in the feed water to the advanced purification train, as discussed in the Task 1.1 Regulatory Assessment TM. For the reasons discussed in the Task 1.4 Advanced Water Treatment Technology Assessment TM, TCEP was selected as a suitable surrogate representing the EDCs/PhPCPs that may be present in the secondary effluent feed to the advanced purification train.

The removal requirement for NDMA in the draft CDPH Groundwater Recharge Requirements was the log reduction achieved at the GWR System for its site-specific conditions. Through source control methods, it may be possible to effectively control the level of NDMA in the secondary effluent to lower levels than experienced in other recharge projects and this should reduce the cost of all AOP alternatives, including UV/H_2O_2. Given that UV/H_2O_2 is energy intensive, alternative AOP technologies may be attractive to achieve the reduction of NDMA, 1,4-dioxane, and other emerging contaminants that may be required longer term. The UV dose required to achieve 1-log removal of NDMA is ~ 1000 mJ/cm^2 (Mitch et al., 2003) and for 2-log reduction is ~ 1400 to 1700 mJ/cm^2 (Sharpless and Linden, 2003) compared to a UV Dose less than ~ 100 mJ/cm^2 for UV disinfection.

A list of AOPs in current practice is provided in Table H-1.

Table H-1: List of AOPs in Current Practice

Technologies	Vendors	Application
H_2O_2 / UV	Rayox™, Calgon Carbon; UVPhox™, Trojan	Water reuse, water/wastewater, Remediation
O_3/H_2O_2	HiPOx™, Applied Process Technology Conventional methods using O_3/H_2O_2 are also available in the public NOMain	water/wastewater, remediation Conventional O_3/H_2O_2 processes are extensively used in drinking water treatment for taste and odor removal
O_3/UV	WETCO, Zimpro (US Filter)	Drinking water
O_3/High pH	N/A	
O_3/H_2O_2/UV	Ultrox™, US Filter	Industry wastewater
H_2O_2 / Fe^{2+},Fe^{3+}/UV (Fenton/Photo-Fenton)	N/A	Soil, high concentration waste water
H_2O_2 / catalyst / UV	N/A	Soil, high concentration waste water
TiO_2 / H_2O_2 / UV	PhotoCat™, Purifics Inc.	Remediation, industry wastewater

Only two of the AOPs listed in Table H-1 have been operated at full-scale drinking water treatment facilities in California: O_3/H_2O_2 and UV/H_2O_2. Conventional preozonation processes without hydrogen peroxide have been provided as a prefiltration step at the full-scale for disinfection in California, such as the application at the Los Angeles Aqueduct Filtration Plant (LAAFP). Conventional O_3/H_2O_2 processes are in widespread use at the full-scale in California for the removal of taste and odor compounds, such as MIB and geosmin. As discussed above and in the Regulatory Assessment, UV/H_2O_2 processes are in place at the full scale in California in reuse applications for removal of NDMA and 1,4-dioxane. Research over the last 20 years has resulted in increasing interest in additional AOP applications like titanium dioxide photocatalysis and Fenton's reactions with iron.

The following alternatives will be considered during the project: (1) baseline AOP: UV/H_2O_2, (2) ozone alone as an AOP (preozonation and ozonation of RO permeate), (3) ozone/H_2O_2 treatment of RO permeate, (4) titanium dioxide photocatalysis treatment of RO permeate, and (5) Fenton's reagent treatment of RO permeate. It is anticipated that a detailed evaluation of the baseline AOP (UV/H_2O_2) and two AOP alternatives will be evaluated during the pilot-phase of the project to determine the most cost-effective AOP in terms of minimizing energy requirements.

The second order ozone, k_{O3}, and hydroxyl radical rate constants, $k_{HO\bullet}$, for the target compounds, NDMA, 1,4-dioxane, and TCEP are shown in Table H-2. It is observed that the second order hydroxyl radical rate constant for NDMA is lower than the second order hydroxyl radical rate constant for 1,4-dioxane and TCEP, suggesting that an AOP designed to meet 1.2-log removal of NDMA will also achieve a greater log reduction of 1,4-dioxane or TCEP, provided the AOP is providing the full removal of the NDMA (not the case when UV photolysis is involved).

Table H-2: Rate Constants for Target Compounds

Compound	K_{O3}	K_{HO}
NDMA [a, b]	5.2×10^{-2}	4.3×10^{8}
1,4-Dioxane [c]	3.2×10^{-1}	2.8×10^{9}
TCEP [d]		5.6×10^{8}

Footnotes:

a. Source: Lee et al., 2007
b. Source: Nakonechny et al., 2008
c. Source: Adams et al., 1994
d. Source: Watts et al., 2009

The baseline AOP approach (UV/H_2O_2) will be discussed in Section H.1.1. The AOP alternatives under consideration will be discussed in Sections H.2 to H.5. Selection of AOP alternatives in addition to the baseline approach recommended for evaluation at the pilot-scale will be provided in Section H.6.

H.1.1 Baseline AOP: UV/H_2O_2

During the pilot-phase of the work, the UV/H_2O_2 baseline approach will be compared to alternative AOPs that are selected for pilot testing. In the pilot-phase, the project team will take advantage of its own recent experience with evaluation of UV/H_2O_2 technology performed on a recent project that compared removal of MtBE and tBA with an Advanced Oxidation Process Simulation Software (AdOx™) package (Li et al., 2008) for a 10 percent design case. That project compared energy requirements for several different pretreatment options including an evaluation/optimization of electrical efficiency per log order reduction (EE/O) predicted by the AdOx model for low pressure versus medium pressure UV/H_2O_2 AOP.

As appropriate, the AdOx model will be employed during the pilot phase to further the design of experiments, evaluation of results, and scale-up to a full-scale process. The capabilities of AdOx are summarized below (Li et al., 2002; Crittenden et al., 1999):

- AdOx can be used to determine optimal reactor type, optimum hydrogen peroxide dosage, and optimal electrical efficiency per log order reduction (EE/O). In this manner, AdOx™ provides insight into the impact of key design and operational variables on UV/H_2O_2 process performance
- AdOx can analyze tracer (dye) study results and determine the appropriate number of tanks-in-series (NTIS) to describe non-ideal mixing in a photochemical reactor
- AdOx can dynamically simulate parent compound destruction and hydrogen peroxide consumption in completely mixed batch reactors (CMBRs), completely mixed flow reactors (CMFRs), CMFRs in series, and plug flow reactors (PFRs)
- AdOx includes all identified and reasonably proposed photochemical and chemical reactions with regard to the degradation of parent organic compounds
- AdOx can simulate the destruction of all target compounds whose reaction mechanisms and rate constants are known
- AdOx can account for the formation of secondary by-products

H.2 Ozone (O_3)

Ozonation has been an indispensable unit process to the overall treatment train for the past twenty years at the 600-MGD LAAFP. Dedicated in 1987, this facility was the first large-scale ozonation plant in the United States. The plant incorporated a high-rate direct filtration process enhanced by ozone pretreatment, or pre-ozonation. The ozonation system had a design capacity of 7900 lbs per day at that time and now has a design capacity of 13,000 lbs per day. LAAFP is a world-class example of a large-scale ozonation system and these years of ozone experience provides a unique perspective to LADWP for considering alternative AOPs for the AWP train at DCTWRP, particularly alternatives involving ozone.

H.2.1 Science, Chemistry and Use as a Disinfectant

Ozone for disinfection, taste and odor control, and target compound destruction has been broadly used at the water treatment plants in the Untied States. Ozone is an effective disinfectant and can be used to inactivate Giardia lamblia and Crytosporidium. In addition, the use of ozone reduces the formation of chlorinated by-products such trihalomethanes (THMs) and other disinfection by-products (DBPs) (Hodges Jr et al. 1979). Besides using O_3 as a disinfectant, ozone also has a role in oxidation.

The ozonation process is classified as an AOP because the process generates hydroxyl radicals and target compounds are oxidized both by the direct reaction with ozone and by reaction with hydroxyl radicals. Ozone begins to form hydroxyl radical (HO•) once dissolved in water (Trussell and Najm 1999). The reaction with hydroxyl radicals is important because the rate constant for the reaction of the target compound with hydroxyl radicals is typically several orders of magnitude higher than the apparent rate constant for the reaction of the target compound with ozone. For some recalcitrant compounds present in certain water qualities, it is necessary to add hydrogen peroxide to increase the production of hydroxyl radicals, which is discussed in Section H.3. Ozone reacts in two ways: (1) by direct oxidation with target compounds (as shown in Reaction H-1 and H-2) and (2) through the action of hydroxyl radicals generated during its decomposition (Reaction H-3) (MWH 2005).

$$\mathbf{O_3 + R \xrightarrow{k_1} Products} \qquad \text{H-1}$$

$$\mathbf{O_3 \rightarrow HO\cdot + R \xrightarrow{k_2} Products} \qquad \text{H-2}$$

where k1 and k2 are rate constants, L/mole·s.

In high pH (≈ 11) solution, formation of HO· radicals is directly from O_3.

When O_3 reacts with certain functional groups on the surface of nature organic matter (NOM), it also produces HO• as shown in Reaction H-3 (MWH 2005).

$$\mathbf{O_3 + NOM \rightarrow HO\cdot + byproducts} \qquad \text{H-3}$$

The functional groups that participate in this reaction are called "promoters". The HO• produced from Reaction H-3 may also be scavenged by the reaction with other functional groups on the NOM to produce some by-products (Reaction H-4).

$$\mathrm{HO\cdot + NOM \xrightarrow{k_3} byproducts} \qquad \text{H-4}$$

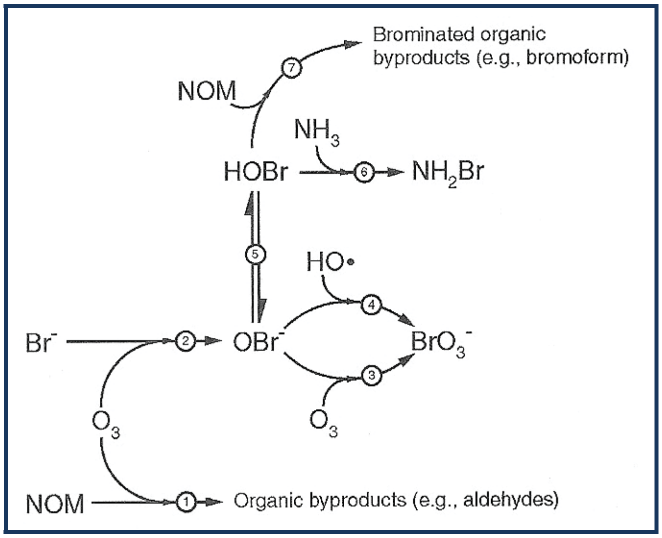
where k_3 is second-order rate constant between hydroxyl radical and NOM, L/mole·s

These functional groups are called scavengers. The net HO• produced by reactions H-3 and H-4 depends on the relative distribution of these functional groups on the NOM. The mechanism of Reaction H-3, ozone with NOM producing HO•, is the most important mechanism to destroy a target compound (MWH 2005).

H.2.2 Potential Bromate Formation

Bromate is a DBP of the ozonation of bromide-containing waters (the production of halogenated by-products). Much of the recent attention has focused on the presence of bromate ion resulting from ozonation. Bromate is classified by the USEPA as a "probable human carcinogen" and has a current drinking water maximum contaminant limit of 10 µg/L. Processes involving ozonation can produce bromate (BrO_3^-) according to the pathways shown in Figure H-1 (MWH, 2005). All the pathways between Br- and BrO_3^- require ozone (O_3) to be present.

Figure H-1: Pathways for Bromate Formation (MWH, 2005)



As shown in Figure H-1, bromate formation resulted from a complex combination of molecular ozone and free radical mechanisms initiated by the hydroxyl radical (HO•) formed through ozone decomposition. When bromide is present in a source water, it oxidizes by ozone to form hypobromous acid (HOBr). At common drinking water pH levels, HOBr is in equilibrium with the hypobromite ion, OBr^-. HOBr reacts with organic precursors to form bromoform and other brominated organic by-products, and OBr^- can be oxided by ozone to bromate (BrO_3^-).

Methods for controlling bromate formation include: (1) pH depression to shift the balance between HONr and BrO^- and (2) ammonia addition to tie up the HOBr (MWH, 2005, Gillogly et al., 2001) and, more recently 3) the chlorine-ammonia process, which seeks to tie the ammonia up as bromamine, which reacts very slowly with ozone (von Guten, 2005).

H.2.3 Pre-Ozonation

One potential application point for ozone (O_3) as an AOP at DCTWRP is to the AWP source water, either secondary or tertiary treated effluent, prior to MF and RO treatment processes. There is evidence that the application of ozone at this point in the process may: 1) facilitate the formation of hydroxyl radicals (HO•) without the need H_2O_2 addition, 2) oxidize NDMA precursors, and 3) reduce membrane fouling of the MF pretreatment.

Early work done, first by LADWP, UCLA and James M. Montgomery Consulting Engineers (JMM) (Aieta et al. 1988) and later by MWD, JMM and UCLA (Ferguson et al. 1991; Glaze et al. 1990) demonstrated that the addition of hydrogen peroxide (H2O2) during the ozonation of San Fernando groundwater, Colorado River Water and State Project Water increased the production of HO•, making AOP more efficient. The concentration of NOM in these waters ranges from 0.5 to 4 mg/L. Later work by JMM (Trussell 1989), and more recently by the Southern Nevada Water Authority (SNWA) (Wert et al. 2009), demonstrated that the addition of H2O2 to waters with higher NOM concentrations, particularly treated wastewaters, often does little to enhance treatment performance. These observations are thought to be due to the action of "promoters" on the NOM molecules themselves (Trussell and Najm 1999).

In fact, ozone, without peroxide, has been shown to possess AOP properties that effectively oxidize many of the emerging contaminants of concern (Buffle et al. 2006; Wert et al. 2009). The reason that so many compounds can be effectively oxidized is because when ozone is added to wastewater, there is an abundance of NOM and this NOM possesses functional groups that act as the "promoters" described above, generating HO•. In fact, recent research has demonstrated that the levels of HO• ($>10^{-10}$ M) produced can actually exceed the concentrations of HO• in typical AOP applications with R_{ct} ratios ($=\int[HO\bullet]dt/\int[O3]dt$) $>10^{-6}$. This AOP behavior oxidizes many emerging contaminants (Snyder et al. 2006) and has been shown to effectively reduce the estrogenic activity of the treated wastewater (Huber et al. 2004; Snyder et al. 2006). Researchers that have added H_2O_2 in an attempt to generate additional emerging contaminant oxidation have observed little improvement because the quantity of HO• generated by the NOM promoters was so significant (Snyder et al. 2006).

In addition to oxidizing the wastewater contaminants of concern, pre-ozonation will oxidize NDMA precursors and effectively reduce the NDMA formation potential of the water (Lee et al. 2007). Although the formation of NDMA through the AWP train cannot be avoided altogether, it can be dramatically reduced by (1) minimizing the chloramine contact time which is required for biofouling control of the RO membranes and (2) reducing the ultimate NDMA formation potential of the water. Pre-ozonation allows for an engineered treatment train that brings these goals to fruition. A potential concern with pre-ozonation is that bromate formation will be significant, but research has shown that bromate is well rejected (Gyparakis and Diamadopoulos 2007) and it is anticipated that these results would be confirmed at the pilot, if tested. If the rejection of bromate by the RO process is inadequate, considerations would need to be made to control bromate formation through the methods detailed in the previous section.

Despite the promise of pre-ozonation in AWP facilities, there are a few reasons that make this alternative AOP less attractive for application at DCTWRP. The first reason is that the required ozone dose would be quite significant (e.g., 8 to 12 mg/L) to achieve effective emerging contaminant oxidation and this makes this particular application likely to be as costly as other AOP alternatives. Another important consideration is the fact that the wastewater at DCTWRP is completely nitrified. This means that the effluent average pH will be closer to 7 which will slow down reaction rates and, more importantly, a nitrified effluent means that free chlorine can be dosed to the source water. The ability to carry free chlorine through the MF process will greatly enhance the sustainable membrane flux through the pretreatment process and will also have the benefit of reducing the water's NDMA formation potential by oxidizing NDMA precusors (Huitric, et al. 2007). Free chlorine is also known to effectively oxidize estrogens. The fact that a low free chlorine residual is a cost-effective means of reducing NMDA formation potential and enhancing MF performance at future AWPF makes pre-ozonation an alternative that deserves consideration only at AWP facilities that are treating a wastewater without nitrification, such as at HTP. Finally, the pre-ozonation chemistry is extremely complex and the mechanistic understanding of the reaction sequence and influence of key water quality parameters is still in its infancy (Buffle et al. 2006). In summary the following are recommended for consideration:

- For non-nitrified effluents (HTP): preozonation ahead of MF, preformed chloramines between MF and RO.
- For nitrified effluents (DCTWRP, LAGWRP & TIWRP): free chlorine ahead of MF, ammonia to form chloramines after MF, but before RO.

H.2.4 Post-Ozonation

The other potential application point for O_3 at the future AWPF is to the RO product water, possibly after additional post-treatment processes designed to stabilize the water quality, which might enhance performance. A simple model of a plug flow reactor (PFR) or a completely mixed batch reactor can be used to determine the required time for destruction of target compounds as shown in Equations H-5 to H-8 (MWH 2005).

$$\frac{d[O_3]}{dt} = -k[O_3] \qquad \text{H-5}$$

$$[O_3] = [O_3]_0 e^{-kt} \qquad \text{H-6}$$

$$\frac{d[R]}{dt} = -(cR + k_{O_3}[R])[O_3]_0 e^{-kt} \qquad \text{H-7}$$

$$[R] = [R]_0 e^{[([O_3]_0/k)(k_{HO\cdot} C_{[HO\cdot]/[O_3]} + k_{O_3})(e^{-kt} - 1)]} \qquad \text{H-8}$$

where k is the pseudo-first-order rate constant for ozone, s^{-1},

$[O_3]_0$ is the initial concentration of ozone, mole/L,

$[R]_0$ is the initial concentration of target compound R, mole/L

This simplified model requires that experimental tests be performed to determine *k* and $C_{[HO\bullet]/[O3]}$. Bench-scale testing is required for better model calibration for all potential O_3 application points, but extensive testing with the pre-ozone application point would be required as detailed in the previous section. In order to develop the pseudo first order rate constant, *k*, and $C_{[HO\bullet]/[O3]}$, the following steps would need to be performed using a batch-test method (MWH, 2005):

1. Add ozone to the water and measure the initial ozone concentration as well as the concentration of ozone as a function of time.
2. Calculate the k for ozone by fitting Eq. H-6 to the ozone-versus-time data.
3. Measure the concentration of target compounds as a function of time.
4. Determine the best-fit $C_{[HO\bullet]/[O3]}$ value by fitting the target compounds data using Eq. H-8. It is recommended that an objective function (OF) as shown in Equation H-9 be used to find the best fit using a spread sheet and making $C_{[HO\bullet]/[O3]}$ the target cell.

$$\mathrm{OF} = \sqrt{\frac{1}{\mathrm{n}-1}\sum_{i=1}^{n}\left(\frac{C_{\mathrm{data},i} - C_{\mathrm{model},i}}{C_{\mathrm{data},i}}\right)^2} \qquad \text{H-9}$$

where OF is the objective function, dimensionless

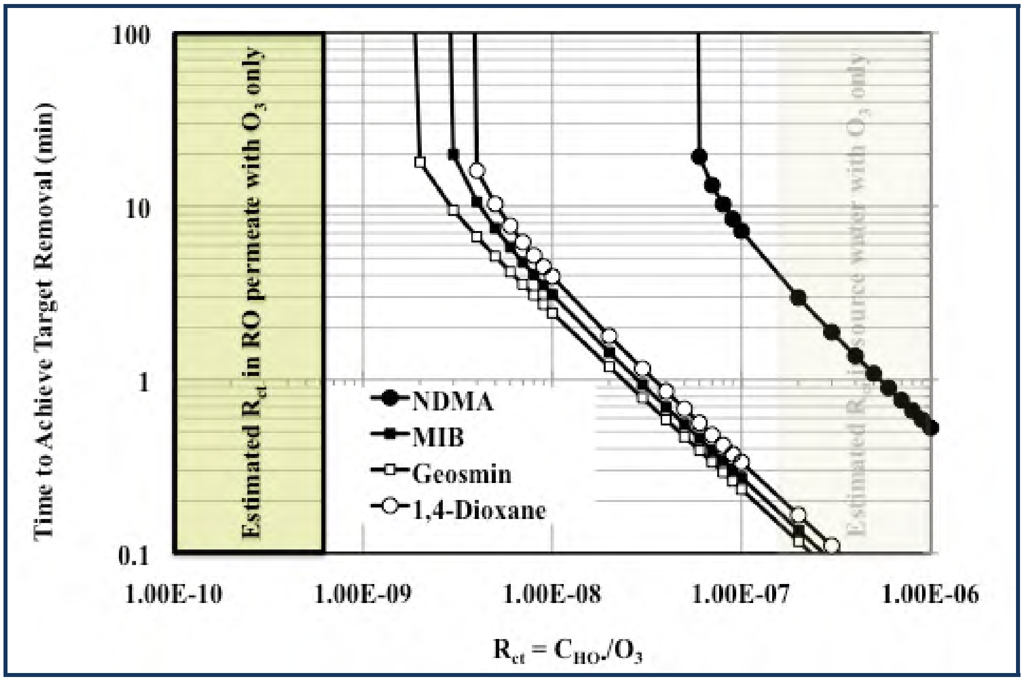
n is the number of data points, dimensionless

$C_{data,i}$ is the measured concentration of data point i, mg/L

$C_{model,i}$ is the predicted concentration of data point i, mg/L

However, even without these specific batch ozonation experiments, reasonable estimates of the required oxidation time can be generated using a typical first order rate constant of $k = 0.1\ \mathrm{min}^{-1}$. Using this approach and contaminant specific rate constants from the literature, modeling was performed using equations H-5 to H-8 to generate Figure H-2. Figure H-2 presents the time required to oxidize 1.2-log of NDMA and 0.5-log of 1,4-dioxane as a function of R_{ct}, or the ratio of $HO\bullet/O_3$. For comparison purposes, the time required to oxidize 1.2-log of MIB and Geosmin is also presented as these are common taste and odor compounds. Because the RO permeate has a low concentration of NOM (e.g., less than 0.2 mg/L), there will be very little HO• generated and it is estimated that the R_{ct} will be close to 10^{-10} when ozone is dosed to the RO permeate. Observing Figure H-2, it is evident that O_3 alone will not suffice for application to the RO permeate. In fact, any R_{ct} less than 10^{-7} will not allow our 1.2-log NDMA removal objective to be achieved regardless of how much contact time is provided. For comparison purposes, it is important to highlight the promise of O_3 as an AOP on the source water when treating non-nitrified waters with the R_{ct} approaching 10^{-6} (as discussed in the previous section). Significantly, this figure also highlights the fact that if 1.2-log of NDMA removal is achieved with an AOP unit then the 0.5-log 1,4-dioxane removal will be easily achieved.

Figure H-2: Modeling results for the removal of NDMA, 1,4-Dioxane, Geosmin and MIB



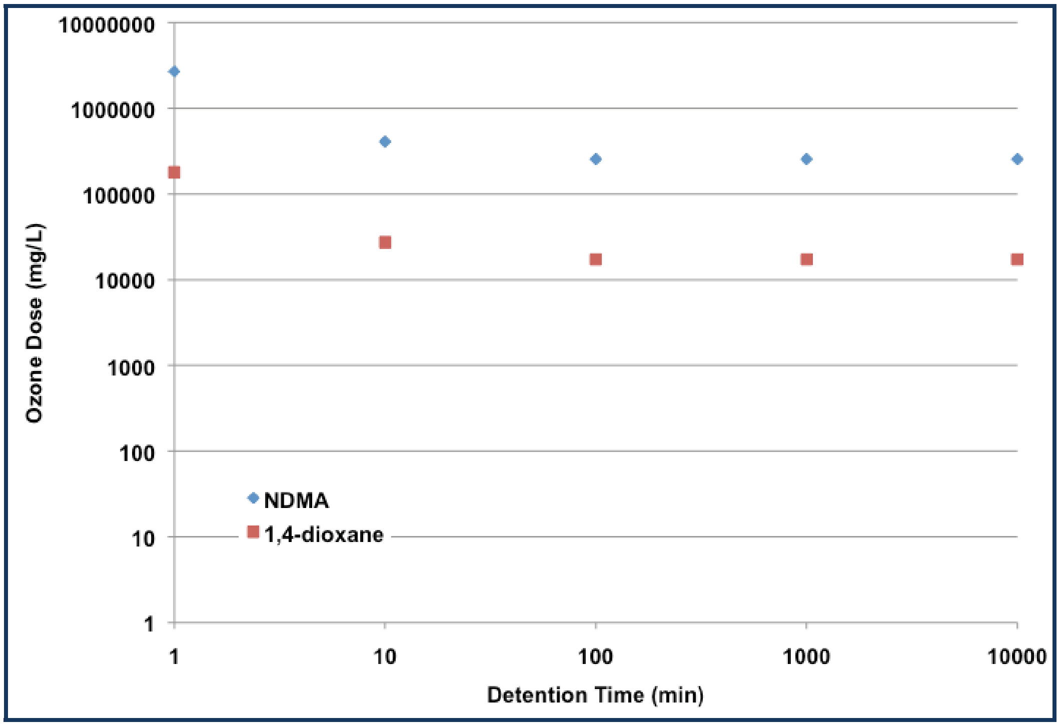
As noted in the discussion of Figure H-2, the HO• production from the reaction of O_3 with low NOM concentrations will be almost negligible. Assuming that HO• production in the RO permeate is negligible, then Eqs. H-7 and H-8 simplify to the following:

$$\frac{d[\mathrm{R}]}{dt} = -k_{O_3}[\mathrm{R}][\mathrm{O}_3]_0 e^{-kt} \qquad \text{H-10}$$

$$[R] = [R]_0 e^{[([\mathrm{O}_3]_0/k)k_{\mathrm{O}_3}(e^{-kt}-1)]} \qquad \text{H-11}$$

Using these modified equations (H-10 and H-11), Figure H-3 was constructed that presents the required ozone dose to achieve the required log removals (1.2-log NDMA and 0.5-log 1,4-dioxane) as a function of the required detention time. It is clear from the data presented in Figure H-3 that a reasonable O_3 dose cannot be achieved regardless of the detention time and there is no detention time that could be provided to make these oxidation goals feasible. Hence, with our AOP objectives in mind, the application of O_3 to the RO permeate is not an alternative that deserves any additional consideration.

Figure H-3: Required O_3 dosage to achieve the target log-removal with time



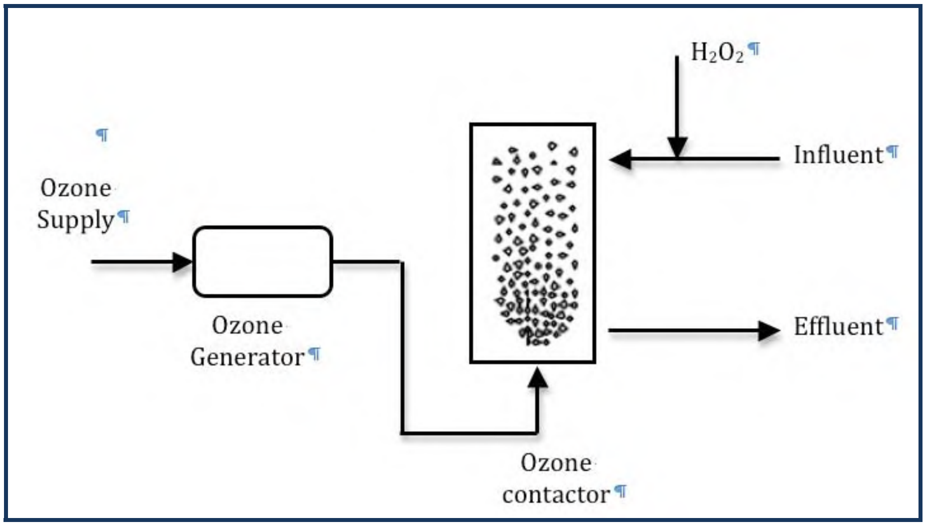
H.3 Ozone (O_3)/Peroxide (H_2O_2)

H.3.1 Science and Chemistry of HO• formation, and HO• Oxidation Power

In advanced oxidation processes, often a combination of ozone and hydrogen peroxide are applied because deprotonated hydrogen peroxide (HO_2^-) acts as initiator for the chain reactions that transform ozone into hydroxyl radicals (Gunten et al., 1994). The O_3/H_2O_2 AOP is widely and successfully used in full-scale water treatment plants to remove taste and odor compounds, as well as to treat contaminated groundwater for TCE, PCE and MtBE. In the Ozone/Hydrogen Peroxide process, ozone reacts with hydrogen peroxide to generate hydroxyl radicals. The hydroxyl radicals oxidize target organics. With hydrogen peroxide addition, the activation of NOM with ozone is ignored because it is insignificant. The O_3/H_2O_2 alternative is under consideration for treatment of the RO permeate where the extremely low TOC and alkalinity downstream of the RO make application of the O_3/H_2O_2 AOP a particularly attractive option given the lack of competition for HO• from NOM and carbonate species compared to AOP treatment of other water sources. Applying O_3/H_2O_2 AOP on the RO permeate is also attractive because bromide will be rejected by the RO eliminating the potential problem of bromate formation in ozonation processes that was discussed above.

A schematic of a typical O_3/H_2O_2 reactor is shown in Figure H-4.

Figure H-4: Schematic of O_3/H_2O_2 process



The O_3/H_2O_2 elementary reactions are (MWH, 2005):

$$HO_2^- + O_3 \xrightarrow{k_1} O_3^- + HO_2 \cdot \qquad \text{H-12}$$

$$HO^- + O_3 \xrightarrow{k_2} HO_2^- \cdot + O_2 \qquad \text{H-13}$$

$$O_2^- \cdot + O_3 \xrightarrow{k_3} O_3^- \cdot + O_2 \qquad \text{H-14}$$

$$O_3 + H^+ \xrightarrow{k_4} HO_3 \cdot \qquad \text{H-15}$$

$$HO_3 \cdot \xrightarrow{k_5} HO \cdot + O_2 \qquad \text{H-16}$$

$$O_3 + R \xrightarrow{k_6} \text{Product} \qquad \text{H-17}$$

$$HO \cdot + HO_2^- \xrightarrow{k_9} OH^- + HO_2 \cdot \qquad \text{H-18}$$

$$HO \cdot + H_2O_2 \xrightarrow{k_{10}} H_2O + HO_2 \cdot \qquad \text{H-19}$$

$$HO \cdot + HCO_3^- \xrightarrow{k_{11}} CO_3^- \cdot + H_2O \qquad \text{H-20}$$

$$HO \cdot + R \xrightarrow{k_{12}} \text{Product} \qquad \text{H-21}$$

$$HO \cdot + NOM \xrightarrow{k_{13}} \text{Product} \qquad \text{H-22}$$

Where k_1, k_2, k_3, k_4, k_6, k_9, k_{10}, k_{11}, k_{12}, and k_{13} are the second-order rate constants, L/mole·s, and k_5 is the first-order rate constant, s^{-1} (see MWH, 2005).

The overall reaction for the formation of HO· in the O_3/H_2O_2 process is:

$$\mathrm{H_2O_2 + 2O_3 \rightarrow 2HO\cdot + 3O_2} \qquad \text{H-23}$$

While ozone can react directly with target organics to form products (Reaction H-1), this will not be significant compared to the reaction of HO• with target organics to form products (Equation H-21) given that the HO• rate constant for a given organic is typically several orders of magnitude higher than the apparent rate constant for the reaction of the organic with ozone.

To provide an estimate of the destruction rates of the parent compound and hydrogen peroxide in the case of when H_2O_2 is added to water containing O_3, a simplified model of the H_2O_2/O_3 process was employed (adapted from MWH, 2005). A net rate of formation of hydroxyl radicals is given by the following expression:

$$\begin{aligned} \mathrm{r_{HO\cdot}} &= \mathrm{k_5[HO_3\cdot] - k_9[HO\cdot][HO_2^-] - k_{10}[HO\cdot][H_2O_2]} \\ &\quad \mathrm{- k_{11}[HO\cdot][HCO_3^-] - k_{12}[HO\cdot][R] - k_{13}[HO\cdot][NOM]} \end{aligned} \qquad \text{H-24}$$

Equation H-24 can be rearranged to obtain the following expression for the pseudo-steady-state concentration of HO•, where radical species other than HO• can be eliminated:

$$\mathrm{[HO\cdot]}_{ss} = \frac{\mathrm{2k_1[HO_2^-][O_3]}}{\mathrm{k_{11}[HCO_3^-] + k_{12}[R] + k_{13}[NOM]}} \qquad \text{H-25}$$

where $[HO\bullet]_{ss}$ is the pseudo-steady-state concentration of HO•, mole/L

According to Eq. H-25, the initial pseudo-steady-state concentration of HO• can be calculated by the following equation (MWH, 2005):

$$\mathrm{[HO\cdot]}_{ss,0} = \frac{\mathrm{2k_1[H_2O_2]_0} \times 10^{(pH - pK_{H_2O_2})}[O_3]_{res}}{\mathrm{k_{11}[HCO_3^-]_0 + k_{12}[R]_0 + k_{13}[NOM]_0}} \qquad \text{H-26}$$

Based on equation H-23, $\mathrm{[H_2O_2]_0} \times 10^{(pH - pK_{H_2O_2})} = \mathrm{[HO_2^-]_0}$.

Applying a tanks-in-series (TIS) approach to determine removal:

$$\frac{C_{i,e}}{C_{i,o}} = \frac{1}{(1 + k_R \tau / n)^n} \qquad \text{H-27}$$

where τ is the hydraulic detention time of the reactor, s; n is the number of tanks; and k_R is the pseudo-first-order rate constant for target compound R, s^{-1}:

$$\mathrm{k_R = k_{12}[HO\cdot]_{ss,0}} \qquad \text{H-28}$$

where k_{12} is the second-order rate constant between hydroxyl radical and target organic compound R, L/mole·s.

To to examine the effectiveness of H_2O_2/O_3 post-RO treatment in achieving the target log-removal of 1.2 for NDMA, the model described above was used to estimate the removal of NDMA. Several assumptions were made: 1) H_2O_2 dosed after contact time (Ct) for ozone disinfection credit achieved; 2) 4 tanks in series describes the mixing condition; 3) H_2O_2 concentration constant equal to initial concentration; 4) O_3 concentration constant equal to disinfection residual.

The following assumptions were made about feed water quality in the analysis (values in bold represent values used in analysis):

TOC = 0.15 to 0.20 mg/L (based on typical RO permeate)

Target compound concentrations:

NDMA = 30 ng/L (based on levels observed at Orange County's GWRS);

1,4-dioxane = 1.8 to 3.3 µg/L (based on levels observed at Orange County's GWRS);

TCEP = 10 ng/L (based on Snyder et al., 2007)

Two Scenarios of AOP Feed pH / alkalinity

1. Typical RO permeate water quality:
   pH = 6 to 6.5, alkalinity = 2 to 10 mg/L as $CaCO_3$
2. Water quality after post-treatment with decarbonator(s) and caustic addition
   pH =8, alkalinity = 14 mg/L as $CaCO_3$

The results for detention time required to achieve 1.2-log removal of NDMA are presented in Table H-3 for various hydrogen peroxide and ozone concentrations.

Table H-3: Detention time required for 1.2-log NDMA removal with varying AOP feed conditions

(a) Typical permeate water quality (pH 6, alkalinity = 10 mg/L as $CaCO_3$):

H_2O_2 (mg/L)	Detention Time Required for 1.2-log NDMA Removal (min) Ozone Residual (mg/L) 1	2	5	10
1	135	67	27	14
2	68	34	14	6.8
5	27	14	5.4	2.7
10	14	6.8	2.7	1.4

(b) After post-treatment with CO_2 stripping and caustic (pH 8, alkalinity = 14 mg/L as $CaCO_3$):

H_2O_2 (mg/L)	Detention Time Required for 1.2-log NDMA Removal (min) Ozone Residual (mg/L) 1	2	5	10
1	1.53	0.76	0.31	0.16
2	0.76	0.38	0.16	0.076
5	0.31	0.16	0.061	0.031
10	0.16	0.076	0.031	0.016

It is observed from Table H-3 that adjusting the AOP feed to pH 8 greatly reduces the time required to achieve 1.2-log NDMA removal. For example, at an ozone dose of 5 mg/L and a hydrogen peroxide dose of 5 mg/L, the time required decreases from 5.4 min to 0.061 min (a reduction by a factor of ~100). For the scenario of feeding RO permeate post-treated prior to AOP feed (pH 8), a greater extent of removal was achieved than for NDMA:

- 3.6 log-removal for 1,4-dioxane and
- 1.5 log-removal for TCEP.

The same trend would be expected for the pH 6 scenario.

The simplified O_3/H_2O_2 model discussed above represents a useful tool to evaluate the ability of the process to remove NDMA, 1,4-dioxane, and TCEP. As needed during the evaluation of this process at the pilot stage, the project team has available to it a dynamic O_3/H_2O_2 model recently developed by Professor John Crittenden, now at Georgia Tech (formerly of Arizona State and Michigan Tech), and his colleagues. The modeling approach for this O_3/H_2O_2 model is similar to the approach discussed above for UV/H_2O_2.

Following the example of the LAAFP's ozonation process and subsequent work done by LADWP on PCE removal from San Fernando groundwater via H_2O_2/O_3, the Metropolitan Water District of Southern California (MWD) also began to consider the application of ozonation technology to their water treatment process with combined of H_2O_2 addition for the purpose of removing trace organics that cause taste and odor in water from the Colorado Aqueduct and the California State Water Project (Glaze, et al., 1990). Using this technology, MWD also constructed a 3,500 gpm Oxidation Demonstration Plant (ODP) in Laverne. Following successful work at the ODP, MWD has nearly completed a program installing the process in all six of its water treatment plants. The process is also now widely installed in drinking water treatment plants throughout California and across the United States as a whole. Treatment plants including the technology range in size from 700 gpm to more than 600 mgd.

In summary, H_2O_2/O_3 is a proven, cost-effective AOP process and its application to the RO product water at the new AWP Facility is particularly well-suited because the water's low levels of NOM and alkalinity eliminate the major water quality components which compete for HO• activity in normal applications. Preliminary modeling suggests that both NDMA and 1,4-dioxane will be effectively removed.

H.4 Titanium Dioxide

H.4.1 Science and Commercial Process Availability

Another AOP alternative is application of titanium dioxide (TiO_2) photocatalysis. In the late 1980s and early 1990s, the American Water Works Association Research Foundation (AWWARF) invested in research on titanium dioxide photocatalysis for the destruction of DBP precursors in drinking water (Hand et al., 1993). The results were promising and showed that the effectiveness of the process depended on process variables including the properties of the TiO_2 catalyst, incident light intensity received by the catalyst, the oxygen concentration in the reactor, and contact time. At the time, a drawback of the process was the fact that the most effective removal was obtained in a slurry reactor and there was not an effective method at the time for separating the catalyst slurry from the treated water. The study demonstrated an optimum catalyst dose of 1000 mg/L and evaluated reaction times up to an hour, demonstrating increasing removal of DBP precursors with increasing reaction time (Hand et al., 1995). During the last decade, the use of TiO_2 has been the focus of additional scrutiny for photocatalytic degradation of organic compounds including emerging contaminants like endocrine disrupting compounds and pharmaceuticals and personal care products in water purification (e.g., Armon et al., 2004; Doll and Frimmel, 2004, 2005; Bahnemann et al., 2007; Benotti et al., 2009).

The mechanism of photocatalysis in the presence of TiO_2 involves the enhanced formation of hydroxyl (HO•) radicals. The following reactions describe the movement of an electron from the valance band (VB) to the conduction band (CB) produces a hole in the valence band, h^+ (MWH, 2005).

$$\mathrm{TiO}_2 \xrightarrow{hv} \mathrm{h}^+ + e_{cb} \qquad \text{H-29}$$

where e_{cb} is an electron in conduction band.

h^+ is the hole in valence band.

H_2O molecules adsorbed on TiO_2 particle surface react to form HO• radicals.

$$\mathrm{h}^+ + \mathrm{H_2O} \rightarrow \mathrm{H}^+ + \mathrm{HO}\cdot \qquad \text{H-30}$$

Excess electrons in the conduction band reduce molecular oxygen to form superoxide ions.

$$e_{cb} + O_2 \rightarrow O_2^{-} \cdot \tag{H-31}$$

which further disproportionate to form more HO• radicals (Ireland et al., 1993).

$$2\mathrm{O}_2^{-} \cdot + \mathrm{H}_2\mathrm{O} \rightarrow 2\mathrm{HO} \cdot + 2\mathrm{OH}^{-} + \mathrm{O}_2 \tag{H-32}$$

In the presence of hydroxyl radicals, target compound destruction proceeds by the same reaction as described in the O3/H_2O_2 AOP discussed above (see Eq. H-21).

Unfortunately, the majority of the holes and conduction band electrons cleaved in the reaction shown in Equation H-29 simply recombine before they participate in any reactions on the catalyst surface and the incident light intensity is wasted:

$$h^{+} + e_{cb} \rightarrow \text{photocatalyst} + \text{heat and/or light (recombination)} \tag{H-33}$$

The addition of H_2O_2 has been shown to improve the rate of reaction:

$$e_{cb} + H_2O_2 \rightarrow OH^{-} + HO\bullet \tag{H-34}$$

At the same time, UV photolysis of hydrogen peroxide generates hydroxyl radicals:

$$H_2O_2 + h\nu \rightarrow 2\,HO\bullet \tag{H-35}$$

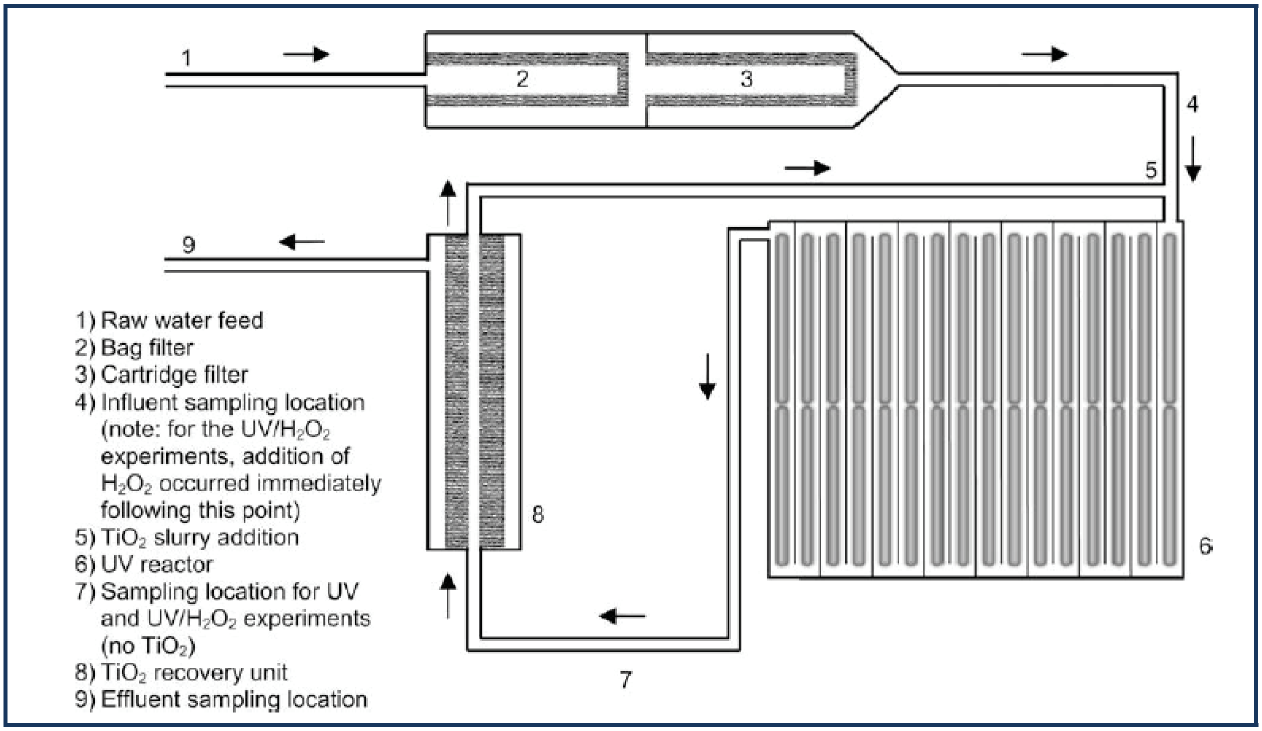
Photolysis of the target compound, such as NDMA, may also occur in UV/TiO_2 with or without H_2O_2 and photolysis of NDMA is a demonstrated approach for NDMA removal (and the same approach used in the baseline AOP approach for this reason):

$$NDMA + h\nu \rightarrow products \tag{H-36}$$

In this AOP alternative, it is not desired to repeat the UV/H_2O_2 approach for removal of NDMA by photolysis but rather to assess whether a UV/TiO_2/(with or without H_2O_2) process can be optimized for NDMA destruction at lower energy and present worth costs than the UV/H_2O_2 baseline approach (i.e., at much lower incident light intensity given the presence of the TiO_2 photocatalyst in addition to the UV light). For this application, it is assumed NDMA will be removed by the mechanism shown in Eq. H-21 (noting it is uncertain how much might be removed by Eq. H-36 at the same time).

In the past decade, Purifics ES has developed a UV/TiO_2 photocatalysis process to effectively destroy organic pollutants in water, disinfect and kill biological matters, and remove metals and particles from water. This patented process (PhotoCat® Process) involves photocatalytic oxidation and reduction process that utilizes low-pressure, high output ultraviolet (UV) light including bands at 254 nm and 185 nm to activate the TiO_2 catalyst as opposed to the photons cleaving chemical bonds to create hydroxyl radicals as well as filtration and recycling of the photocatalyst by ceramic microfiltration membrane (as shown in Figure H-5). The ceramic microfiltration membrane is the method to separate the slurry from the treated water.

Figure H-5: General PhotoCat® pilot system schematic (Benotti et al., 2009).



Flow (point 1) enters the unit passing the influent chamber to a pre-filter consisting of both a bag (point 2) and cartridge filter (point 3). It is then mixed with nanoparticle TiO_2-water slurry (point 5 - rejected TiO_2 from point 8), and passed through the UV reactor (point 6). After exposing to the UV lamps, flow enters to a cross-flow ceramic membrane (Point 8) and TiO_2 is being removed from the flow stream, and the treated water exits the unit (Point 9).

Both pilot and bench-scale studies have proved that the TiO_2/UV technology or PhotoCat® technology (1) is able to remove high percentage of pharmaceuticals and endocrine disrupting compounds from contaminated water (Benotti et al., 2009, Doll et al., 2004) and has promising destruction of common emerging contaminants such as triclosan, TCEP, hexachlorobenzene, bisphenol-A, carbamazapine, and ethinyl estradiol (Hart et al., 2008); (2) can effectively inactivate pathogens such as Cryptosporidium parvum (Ryu et al., 2008), total coliform, MS2 coliphage and adenovirus (Hart et al., 2008). Hart et al. (2008) reported that even with 0.15 kW/gallon of UV strength, total coliform was removed below detection limits of 1 MPN/100mL

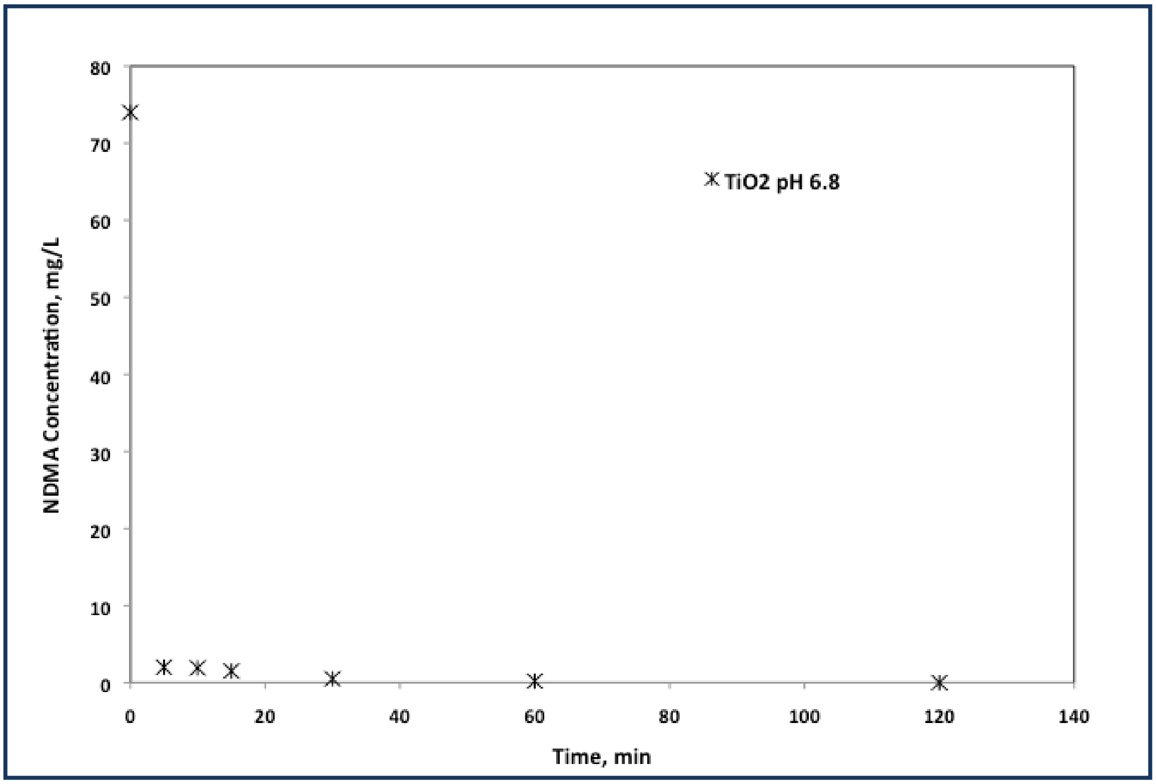
In Benotti et al. (2009)'s pilot study on spiked Colorado River Water from Lake Mead prechlorinated to control quagga mussels, it is reported that eleven of the 32 compounds were easily removed, with concentrations below or approaching MRLs with 0.53 kWh/m^3 (4 lamps) of treatment: estrone, estradiol, ethinylestradiol, bisphenol A, octylphenol, butylated hydroxyanisole (BHA), atorvastatin, triclosan, diclofenac, sulfamethoxazole, and naproxen; and 17 compounds required higher amounts of treatment (0.80–4.24 kWh/m3 or 6–32 lamps) to achieve a greater than 70 percent reduction in compound concentration; and three of them: PFOS, tris(2-chloroethyl) phosphate (TCEP), and tris(1-chloro-2-propyl) phosphate (TCPP), were less than 50 percent removed but required 4.24 kWh/m^3 (32 lamps) UV treatment. The recalcitrance of TCEP in the UV/TiO_2 process supports it is choice as a sentinel.

A conclusion of Benotti et al. (2009) was that UV/H_2O_2/TiO_2 may represent a preferred treatment approach in terms of electrical efficiency per log order reduction compared to UV/TiO_2 alone, but the approach was not considered in their study. The work of Benotti et al. (2009) also was limited to a catalyst dosage of 50 mg/L at the recommendation of Purifics but noted that alternative studies used much higher dosages on the order of 1000 mg/L as discussed in other works above. Another difference of the Benotti et al. (2009) study noted by the authors was their reaction time of less than a minute exposure to the UV light compared to reaction times on the order of minutes to hours to achieve destruction in other studies.

The work of Bahnemann et al. (2007) demonstrated that the effectiveness of UV/TiO_2 can be affected by pH and showed competing effects depending on the compound. Bahnemann's work also showed that the type of catalyst makes a difference, that optimum catalyst dose depends on target compound and that increasing the dose beyond a certain point may be detrimental due to increasing turbidity in the water interfering with the ability of the UV lamps to activate the photocatalyst, and that the addition of hydrogen peroxide can have a positive effect by reducing the recombination effect discussed above.

With adding TiO_2 alone as a catalyst, Jahan et al. (2008) reported that with 0.015 grams of TiO_2 added into a NDMA concentrations of 74 mg/L, the NDMA is completely removed after 2 hours of detention time as shown in Figure H-6.

Figure H-6: NDMA destruction by TiO_2 (data adapted from Jahan et al., 2008)



TiO_2 based photocatalysts such as a commercial P25, a synthesized magnetic photocatalyst and an immobilized sol-gel system can completely mineralizes 1,4-dioxane to CO_2 (Coleman et al., 2007).

Based on the discussion in this section, the TiO_2 photocatalyis process shows great promise for the destruction of the target compounds, but the process is less proven than other alternatives being considered. For this reason, the pilot study should be designed to carefully evaluate key process variables including catalyst dosage, incident light intensity, pH, dissolved oxygen concentration in the feed, and effectiveness of the process for NDMA, 1,4-dioxane, and TCEP removal with and without hydrogen peroxide.

H.5 Fenton's Reagent

Fenton's reagent is a mixture of ferrous ion and hydrogen peroxide and it has long been known as a powerful oxidant for organic contaminants. It catalyses the formation of hydroxyl radicals as shown in Reaction H-37 (MWH, 2005) which is a typical reaction scheme in the Fenton system:

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^{-} + HO\bullet \quad \text{H-37}$$

The ferric ions from the reaction can then produce $HO_2\bullet$ although the oxidation process slows down after the conversion of ferrous to ferric ion (MWH, 2005).

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + HO_2\bullet + H^{+} \quad \text{H-38}$$

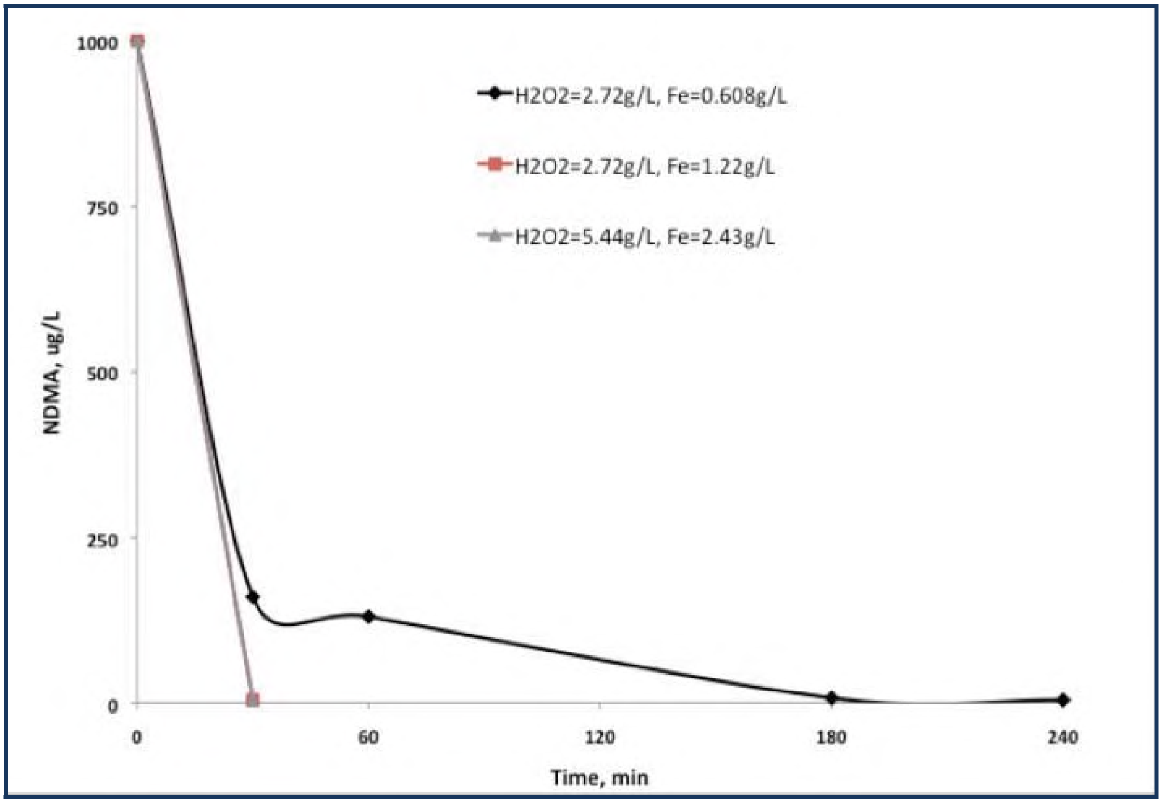
There have been many of studies into the application of Fenton or modified Fenton oxidation processes to water and wastewater treatment in the last two decades (Safarzadeh-amiri et al., 1997, Namkung et al., 2004, Liu et al., 2007, Son et al., 2009, So et al., 2009). In past years, both bench-scale and pilot studies are being carried out on treating textile industry effluent by using Fenton oxidation process (Fe^{2+}/H_2O_2) and Photo-Fenton (Fe^{2+}/H_2O_2/UV) (Riga et al.,2007). With Fenton alone, this method was slightly slower than the photo-Fenton's method but was suitable for compounds that are subject to direct photolysis, such as hexachlorocyclopentadiene and picloram (Haag, et al.,1992). However, the destruction efficiency of Fenton's reagents depended on hydrogen peroxide concentration. In Riga et al. 2007's dye study, three different combinations of H_2O_2 and Fe^{2+} were tested and the decolorization rates observed.

Results demonstrated that with both H_2O_2 and $FeSO_4$ at a 0.01 percent concentration and a 1/1 weight ratio, the destruction is most efficient and effective.

In Kim et al., (2006)'s study, it is reported that photo-Fenton process was able to remove a 95 percent and a 100 percent of 1,4-dioxane in two different polyester wastewater samples. The Fe(II):H_2O_2 dosages were 200:300 and 100:200 respectively. Later research found that photo-Fenton process with post-treatment could only achieve 90 percent removal of 1,4-Dixoane for polyester manufacturing wastewater (So et al., 2009). Fenton reactions, like all AOP reactions are strongly influenced by water quality, particularly pH, alkalinity, and the presence of competing organics, especially TOC, so this may be the explanation.

In terms of NDMA destruction by Fenton's reagents, Kommineni et al. 2003 has conducted a bench-scale experiment in a homogeneous system and the results are presented in Figure H-7.

Figure H-7: Rate of NDMA destruc-tion by Fenton's reagents in a homogeneous system $NDMA_0$=1000ug/L, pH=1.9 (data from Kommineni et al. 2003)



As shown from Figure H-7, Fenton-driven destruction of NDMA occurs rapidly in the homogeneous system. Kommineni et al. 2003 reported that NDMA destruction by Fenton's reagent is most efficient at low pH (near 2).

In fact, there are many process parameters that affect the efficiency of the Fenton oxidation such as pH, dosage and ratio of Fenton's reagent, concentration of hydroxyl radicals, concentration of inorganic materials forming complexes with iron species, temperature, mixing, concentration of dissolved oxygen (DO), characteristics and concentration of organic pollutants, and TOC (Namkung et al., 2004). Because of many unknown factors and its relatively high cost for practical applications (Namkung et al., 2004), substantial additional research is still required to support a more cost effective and reliable process design. Also important in the case of the Los Angeles reuse project, is the fact that Fenton reactions would be most efficient in the RO effluent and yet they would introduce significant amounts of ferric ion which must be subsequently removed. For these reasons, the Fenton reaction will not be considered further.

H.6 Recommendations for AOP Alternatives to Evaluate in Addition to the Baseline AOP Approach (UV/H_2O_2)

Based on the analysis provided in the previous sections, the following recommendations can be made for the AWP train at DCTWRP:

1. AWP train and AOP design objectives should be developed based upon the observed concentrations of NDMA, 1,4-dioxane and TCEP in collaboration with CDPH. It is anticipated that NDMA and TCEP will control the process design and represent the most effective sentinels for AOP evaluation.
2. Influent for the AWP Plant should be taken from the DCTWRP before chloramination in order to avoid further NDMA formation.
3. Sequential chlorination, free chlorine addition prior to the MF pretreatment process followed by ammonia addition prior to the RO process, should be employed regardless of the AOP selection to minimize NDMA formation through the AWP train and enhance the sustainable MF design flux.
4. Ozone alone does not merit any further evaluation for application at as an alternative AOP on the nitrified effluent at DCTWRP or RO permeate.
5. O_3/H_2O_2 treatment applied to RO permeate should be further evaluated at the bench- and pilot-scale to refine the optimum treatment train and develop an appropriate treated cost of water comparison. Most significant, consideration must be given to the interplay between necessary post-stabilization processes and the optimal location of this AOP technology.
6. UV/TiO_2 treatment applied to RO remains a possible alternative to more traditional AOP alternatives. Further evaluation of this alternative at the pilot-scale may help to refine design criteria, optimize the required TiO_2 and UV dose, and verify manufacturer design reliability and sizing, but further testing is not anticipated.

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Appendix H

Water Quality Comparison of UV/Peroxide and Ozone/Peroxide Systems

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Water Quality Comparison of UV/Peroxide and Ozone/Peroxide Systems

Parameter	Unit	Phases 1 and 2												Phase 3										
		ROP			AOP Influent			UV Effluent			Removal			ROP			AOP Influent			Ozone Effluent			Removal	
		Average	Max	Count	Average	Max	Count	Average	Max	Count	Removal from ROP (%)	Removal from AOP Influent (%)		Average	Max	Count	Average	Max	Count	Average	Max	Count	Removal from ROP (%)	Removal from AOP Influent (%)
Bromate	µg/L	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A		ND	ND	7	N/A	N/A	0	0.892	1.600	14	-72	N/A
TOC	mg/L	0.25	2.2	145	ND	ND	3	ND	0.68	39	>53	N/A		ND	0.36	68	ND	ND	2	ND	0.33	40	N/A	N/A
NDMA	ng/L	16	54	33	20.2	220	22	1.8	18	24	89	91		10.7	16.5	9	11.0	17.0	9	9.96	45.50	9	6.7	9.2
Total Chlorine	mg/L	N/A	N/A	0	0.92	0.92	1	0.77	0.77	1	N/A	16		2.2	3.4	60	0.46	0.52	2	0.58	4.41	46	73.5	N/A
1,4-Dioxane	µg/L	ND	ND	1	0.57	1.4	3	ND	ND	20	N/A	>89		ND	1.5	8	ND	ND	1	ND	ND	10	>33	N/A
TCEP	ng/L	39	340	10	11.4	31	6	5.16	34	26	67	16		5.4	24	10	10	20	4	1.8	3.4	10	67	59.8
UV 254 Absorbance	Abs	0.017	0.26	184	0.014	0.06	94	ND	0.035	95	>71	>65		ND	0.043	56	0.019	0.025	2	0.011	0.093	52	-12	N/A
TCPP	ng/L	8.0	12	2	22	22	2	1.65	2.8	2	79	93		12.8	22.0	2	N/A	N/A	0	7.30	13.00	2	43	N/A
TDCPP	ng/L	7.0	11	2	12	12	2	4.05	8.4	4	58	66		1.4	1.6	2	N/A	N/A	0	ND	ND	2	>49	N/A
DEET	ng/L	1.5	3	2	3	3	2	ND	ND	2	>67	>85		0.9	1.0	2	N/A	N/A	0	0.16	0.16	2	83	N/A
Gemfibrozil	ng/L	2.0	2.3	2	N/A	N/A	0	ND	ND	2	>74	N/A		1.1	1.3	2	N/A	N/A	0	ND	ND	2	>56	N/A
Sulfamethoxazole	ng/L	2.1	3.7	2	ND	ND	2	ND	ND	2	>76	N/A		2.0	3.0	2	N/A	N/A	0	ND	ND	2	>75	N/A
Meprobamate	ng/L	10	20	2	13	13	2	ND	ND	2	>95	>96		1.7	2.2	2	N/A	N/A	0	ND	ND	2	>71	N/A

Footnotes:

- *a.* *Note that the NDMA values in the Phase 3 portion of this table represent only the data from 4/29/11 through 6/30/11, and not all of Phase 3. Before this time the ozone dose was unreliable.*
- *b.* *The Phase 1 and Phase 2 NDMA and 1,4 dioxane data shown in this chart include only samples taken while the system was in the continuous-operation mode. It does not include any sampling done on batch tests (sampling dates from 9/16/10 through 12/22/10).*
- *c.* *UV Effluent TOC data from two consecutive days (7/1 and 7/2 during Phases 1 and 2 had extremely high values. It is likely that a decimal point was misplaced in the field data sheet since these values were approximately ten times higher than the average TOC value.*
- *d.* *ROP and AOP Influent values for TOC do not include all of Phase 1 and 2 data. This data begins on 6/24/10 and lasts through 2/27/11 since settings on the TOC analyzer were changed on 6/24 to more accurately record low measurements.*
- *e.* *Additional AOP Influent Total Chlorine data was available, but only the data point corresponding to the one UV Effluent data point is shown. Overall, all AOP Influent Phase 1 and 2 total chlorine results are 2.0 mg/L average, 4.3 mg/L max, and 87 total samples.*
- *f.* *Since bromate levels were non-detect in the ROP, the bromate formation through the ozone system is the increase from half the detection limit to the ozone effluent value.*
- *g.* *The Phase 3 NDMA removal covers a wide range of ozone doses.*
- *h.* *Although the Phase 3 1,4-Dioxane averages in the ROP and Ozone Effluent are both beneath the MRL, the ROP had several samples which were greater than the MRL. Because of this, a percent removal can be calculated.*
- *i.* *Removal values are calculated only for data values on corresponding dates.*

Appendix I

RO Membrane Projections

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PERMEATE THROTTLING(1ST STAGE)

RO program licensed to:					
Calculation created by:	GDW				
Project name:	Tillman AWTP - Pilot Data		Permeate flow:	17.40	gpm
HP Pump flow:	20.5	gpm	Raw water flow:	20.5	gpm
			Permeate throttling(1st st.)	35.0	psi
Feed pressure:	154.1	psi	Permeate recovery:	85.0	%
Feedwater Temperature:	25.0	C(77F)			
Feed water pH:	7.0		Element age:	1.0	years
Chem dose, ppm (100%):	0.0	H2SO4	Flux decline % per year:	15.0	
			Salt passage increase, %/yr:	10.0	
Average flux rate:	14.0	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	11.8	10.2	4.4	14.2	1.15	127.4	35.0	ESPA2-4040	14	2x7
1-2	5.6	8.7	3.1	13.7	1.19	104.8	0.0	ESPA2-4040	7	1x7

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3
Ca	41.4	103.2	41.4	103.2	0.211	0.5	274.8	685.3
Mg	16.0	65.8	16.0	65.8	0.081	0.3	106.2	437.1
Na	105.0	228.3	105.0	228.3	2.550	5.5	685.5	1490.3
K	14.6	18.7	14.6	18.7	0.442	0.6	94.8	121.6
NH4	1.5	4.2	1.5	4.2	0.045	0.1	9.7	27.1
Ba	0.016	0.0	0.016	0.0	0.000	0.0	0.106	0.1
Sr	0.280	0.3	0.280	0.3	0.001	0.0	1.859	2.1
CO3	0.1	0.2	0.1	0.2	0.000	0.0	0.8	1.3
HCO3	169.0	138.5	169.0	138.5	3.389	2.8	1107.5	907.8
SO4	88.0	91.7	88.0	91.7	0.247	0.3	585.3	609.7
Cl	114.0	160.8	114.0	160.8	1.276	1.8	752.8	1061.7
F	0.8	2.1	0.8	2.1	0.018	0.0	5.2	13.8
NO3	34.0	27.4	34.0	27.4	2.751	2.2	211.1	170.2
B	0.59		0.59		0.583		0.63	
SiO2	9.3		9.3		0.11		61.4	
CO2	26.37		26.37		26.37		26.37	
TDS	594.6		594.6		11.7		3897.7	
pH	7.0		7.0		5.3		7.9	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	2%	2%	17%
SrSO4 / Ksp * 100:	1%	1%	7%
BaSO4 / Ksp * 100:	54%	54%	535%
SiO2 saturation:	7%	7%	44%
Langelier Saturation Index	-0.74	-0.74	1.71
Stiff & Davis Saturation Index	-0.69	-0.69	1.58
Ionic strength	0.01	0.01	0.07
Osmotic pressure	5.0 psi	5.0 psi	33.1 psi

PERMEATE THROTTLING(1ST STAGE)

RO program licensed to:					
Calculation created by:	GDW				
Project name:	Tillman AWTP - Pilot Data		Permeate flow:	17.40	gpm
HP Pump flow:	20.5	gpm	Raw water flow:	20.5	gpm
			Permeate throttling(1st st.)	35.0	psi
Feed pressure:	154.1	psi	Permeate recovery:	85.0	%
Feedwater Temperature:	25.0	C(77F)			
Feed water pH:	7.0		Element age:	1.0	years
Chem dose, ppm (100%):	0.0	H2SO4	Flux decline % per year:	15.0	
			Salt passage increase, %/yr:	10.0	
Average flux rate:	14.0	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	psi	Element Type	Elem. No.	Array
1-1	11.8	10.2	4.4	14.2	1.15	127.4	35.0	ESPA2-4040	14	2x7
1-2	5.6	8.7	3.1	13.7	1.19	104.8	0.0	ESPA2-4040	7	1x7

Stg	Elem no.	Feed pres psi	Pres drop psi	Perm flow gpm	Perm Flux gfd	Beta	Perm sal TDS	Conc osm pres	Concentrate saturation levels CaSO4	SrSO4	BaSO4	SiO2	Lang.
1-1	1	154.1	5.8	1.0	16.5	1.09	3.7	5.6	2	1	61	7	-0.6
1-1	2	148.3	5.0	0.9	15.6	1.10	4.0	6.2	2	1	69	8	-0.5
1-1	3	143.3	4.3	0.9	14.8	1.11	4.4	6.9	2	1	79	9	-0.4
1-1	4	139.0	3.7	0.8	14.1	1.11	4.8	7.8	3	1	91	10	-0.2
1-1	5	135.3	3.1	0.8	13.4	1.12	5.3	8.8	3	1	106	12	0.0
1-1	6	132.2	2.6	0.8	12.8	1.13	5.8	10.1	4	2	125	13	0.1
1-1	7	129.6	2.1	0.7	12.2	1.15	6.5	11.8	4	2	151	16	0.3
1-2	1	124.5	4.6	1.0	16.2	1.11	6.7	13.3	5	2	174	17	0.5
1-2	2	119.9	3.9	0.9	15.3	1.10	7.1	15.0	6	3	202	20	0.6
1-2	3	116.0	3.3	0.9	14.5	1.13	7.7	17.1	7	3	237	23	0.8
1-2	4	112.7	2.7	0.8	13.7	1.14	8.4	19.8	9	4	282	26	1.0
1-2	5	110.0	2.2	0.8	12.9	1.15	9.3	23.1	10	5	342	30	1.2
1-2	6	107.9	1.7	0.7	12.0	1.17	10.4	27.4	13	6	422	36	1.4
1-2	7	106.2	1.3	0.6	11.0	1.19	12.0	33.1	16	7	531	44	1.6

Stage	NDP psi
1-1	97.4
1-2	93.9

```
 *** TORAY MEMBRANE REVERSE OSMOSIS SYSTEM DESIGN ***   page  1

Project name : AWTP     Case: 001     Date: 9/10/2011 1:57:
Project title: SD AWTP
----------------------------------------------------------------------
Prog-Version: 1.1.66 * Update: 8-SEP-2009 ** El-Version: 2539 * Update: 19.Aug.2009

1. RO-SYSTEM DATA
----------------------------------------------------------------------
Feed water type                  Tertiary Waste MF/UF
Feed temperature            25.00 deg.C (design)
RO feed pressure           166.86 psi after 1 years
Total diff.-pressure        27.08 psi feed - brine, incl. dP manifolds+pipe
Brine pressure             139.78 psi at exit from last bank
Design period                1.00 years
Fouling Factor               0.85 after 1 years
Salt passage increase       15.00 % after 1 years (15% per year)
Silt density index           3.00 in RO-feed (SDI_15)
System recovery             85.00 %
System feed flow         24905.88 Gpd = 17.30 Gpm
Product flow             21170.00 Gpd = 14.70 Gpm
Average system flux          0.57 m/d  =  23.77 l/m2/h  =  14.0 GFD
Brine flow                3735.88 Gpd = 2.59 Gpm
Feed salinity              595.18 mg/l as ion
Product salinity             5.77 mg/l as ion after 1 years
Brine salinity            3930.67 mg/l as ion

2. BANK DATA                1         2
------------------------------------------
Membrane Elements Type     TML10     TML10
Membrane Elements  pcs        14         7
Elements/Vessel    pcs         7         7
Pressure vessels   pcs         2         1
------------------------------------------
Recovery rate       %      56.73     65.35
Feed flow          Gpd  24905.88  10775.76
Product flow       Gpd  14130.12   7042.27
Average flux       GFD     14.02     13.97
Brine flow         Gpd  10775.76   3733.49
------------------------------------------
Feed pressure      psi    166.86    147.03
dP elements        psi      9.84      7.25
dP manifolds+pipe  psi     10.00      0.00
Brine pressure     psi    147.03    139.78
Perm. pressure     psi     33.00      0.00
------------------------------------------
Lead element
Feed flow          Gpd  12452.94  10775.76
Product flow       Gpd H 1071.55 H 1109.27
Flux rate          GFD   H 14.88   H 15.40
------------------------------------------
Last element
Product flow       Gpd    945.28    870.44
Product:Brine ratio 1:      5.70    L 4.29
Brine              Gpd   5387.88   3733.49
Net driving press. psi     98.67     91.73
------------------------------------------

WARNINGS :
Lead El specif.flux high  bank 1:   14.9 GFD    ** max:   14.7 GFD
Lead El specif.flux high  bank 2:   15.4 GFD    ** max:   14.7 GFD
Last El product:brine low bank 2:    4.3        ** min:    5.0
----------------------------------------------------------------------
```

```
Project name : AWTP     Case: 001     Date: 9/10/2011 1:57:
Project title: SD AWTP
----------------------------------------------------------------------

3. WATER ANALYSIS      Orig   Treated     Conc.      Exp.
as mg/l ion            feed      feed     Brine  Permeate
---------------------------------------------------------
Calcium               41.40     41.40    274.79      0.22
Magnesium             16.00     16.00    106.20      0.08
Sodium               105.00    105.00    694.13      1.04
Potassium             14.60     14.60     95.95      0.24
Ammonium               1.50      1.50      9.86      0.03
Barium                 0.01      0.01      0.09      0.00
Strontium              0.28      0.28      1.86      0.00
---------------------------------------------------------
Chloride             114.00    114.00    755.08      0.87
Sulfate               88.01     88.01    585.10      0.28
Nitrate               34.00     34.00    223.33      0.59
Bicarbonate          169.00    168.32   1092.93      1.85
Carbonate              0.10      0.10      4.74      0.00
Fluoride               0.80      0.80      5.27      0.01
Silica                 9.30      9.30     61.00      0.18
Boron *                0.59      0.59      1.72      0.39
Bromide                0.51      0.51      3.38      0.00
Phosphate              0.07      0.07      0.47      0.00
Free CO2              25.43     25.92     30.54     25.91
---------------------------------------------------------
Total as ion         595.18    594.85   3930.67      5.77
Total as meq/l         8.41      8.41     55.69      0.07
EC uS/cm             844.08    843.77   4938.85      9.86
CO2 EC uS/cm           5.72      5.78      6.28      5.78
pH Value               7.00      7.00      7.68      5.07
---------------------------------------------------------
Langelier Index       -0.69     -0.70      1.57     -6.72
Stiff Davis Index     -0.60     -0.61      1.45     -6.76
---------------------------------------------------------
* Boron permeate values depend on various design parameters
  and therefore shall be verified by Toray. See disclaimer.

4. PRETREATMENT
Measure against CaCO3-scale :   None
SO4- and CO3-Scale inhibitor:   None
Saturation index in brine   :   0.0 max. ()
----------------------------------------------------------

5. RECOVERY LIMITS
for        IP_Brine    Saturation   Max.Recov.
CaSO4       4.18E-5       17.1%       93.8%
BaSO4       4.04E-9      701.3%       60.3%
SrSO4       1.29E-7        9.3%       95.0%
CaF2       5.27E-10      438.9%       87.8%
Silica                    47.9%       92.8%
----------------------------------------------------------

6. POST-TREATMENT
Measure against permeate :   None
----------------------------------------------------------
```

Disclaimer:
The program is intended to be used by persons having technical skill, at their own discretion and risk. The projections, obtained with the program, are the expected system performance, based on the average, nominal element-performance and are not automatically guaranteed.
Toray shall not be liable for any error or miscalculation in the program.
The obtained results cannot be used to raise any claim for liability or warranty.
It is the users responsibility to make provisions against fouling, scaling and chemical attacks, to account for piping- and valve pressure losses, feed pump suction pressure and permeate backpressure. For questions please contact us:

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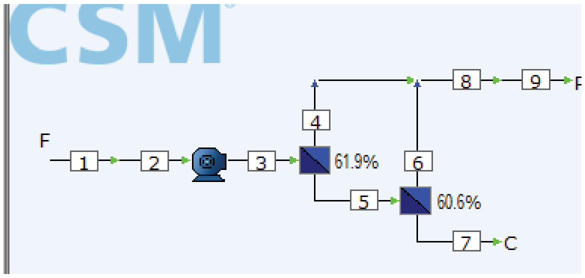
< Project Description >

Flow Diagram



Tag	1	2	3	4	5	6	7	8	9
Flow(GPM)	20.5	20.5	20.5	12.7	7.8	4.7	3.1	17.4	17.4
Press(psig)	0.0	0.0	131.9	0.0	116.6	0.0	101.8	0.0	0.0
TDS(mg/l)	595.1	595.1	595.1	7.4	1,549.7	24.3	3,896.4	12.0	12.0

System Configuration

<Pass 1>

Designated Product Flow	17.40 GPM	No. of Pressure Vessel	3
Membrane Type and Model	RE4040-FEn	No. of Element	21
Array Configuration	2 Array, 2-1 , 7 elements/pressure vessel		
Recover Ratio	85 %	Average Permeate Flux	14.04 gfd

Project Note

Qp=17.4 gpm, R=85%, 2/1 (7M), RE4040-FEn

< Projection Results >

Projection Details :

<Pass 1>

Feed flow into RO system	20.47	GPM	Membrane Age	1.00	year(s)
Permeate Flow	17.40	GPM	Flux decline rate	15.00	%/year
Pass Recovery	85.00	%	Salt passage increase	10.00	%/year
Feed TDS	595.08	mg/L	Average permeate flux	14.04	gfd
Permeate TDS	11.97	mg/L	Feed Osmotic Pressure	5.27	psig
Concentrate TDS	3,896.4	mg/L	Concentrate Osmotic Pressure	32.40	psig
Salt rejection	97.99	%	Chfem. dose	0.00	mg/L
Feed Pressure	131.90	psig	Permeate Blending	0.00	GPM
Temperature	25.00	C	Softener	No	
Feed water type	Well Water SDI<3				
Array Recycle	No				

Array	1	2
Element Model	RE4040-FEn	RE4040-FEn
No. of Pressure Vessel	2	1
Elements per PV	7	7
Boost pump pressure (psig)	0.00	0.00
Permeate back pressure (psig)	0.00	0.00

Array/	Pressure(psig)		Flow(GPM)		Rec.(%)	Flux	TDS(mg/L)		Conc.	Osm.
Element	Feed	Diff	Feed	Perm.		(gfd)	Feed	Perm.	Pol.	Press.
1	131.90	15.33	20.47	12.67	61.91	15.34	595.1	7.36	1.131	10.990
1	131.90	3.68	10.24	0.99	9.65	16.74	595.1	4.04	1.070	5.540
2	128.21	3.09	9.25	0.96	10.34	16.19	657.7	4.65	1.075	5.800
3	125.12	2.56	8.29	0.93	11.18	15.71	733.0	6.19	1.081	6.430
4	122.55	2.09	7.36	0.90	12.24	15.28	824.5	7.12	1.089	7.200
5	120.47	1.66	6.46	0.88	13.59	14.87	938.6	8.32	1.100	8.150
6	118.81	1.28	5.58	0.86	15.31	14.49	1,084.8	9.94	1.113	9.370
7	117.52	0.96	4.73	0.83	17.57	14.08	1,279.2	12.25	1.131	10.990
2	111.56	9.77	7.80	4.73	60.62	11.44	1,549.7	24.34	1.117	27.460
1	111.56	2.34	7.80	0.76	9.81	12.95	1,549.3	14.26	1.071	13.910
2	109.22	1.96	7.03	0.74	10.46	12.46	1,716.2	16.45	1.076	14.600
3	107.26	1.62	6.30	0.71	11.24	11.99	1,914.9	19.17	1.082	16.240
4	105.63	1.32	5.59	0.68	12.15	11.50	2,154.8	22.63	1.089	18.210
5	104.31	1.06	4.91	0.65	13.21	10.99	2,449.7	27.17	1.097	20.630
6	103.25	0.83	4.26	0.61	14.43	10.42	2,818.4	33.36	1.106	23.640
7	102.42	0.63	3.65	0.58	15.79	9.75	3,288.0	42.16	1.117	27.460
Total	131.90	25.10	20.47	17.40	85.00	14.04	595.1	11.97	1.131	27.460
Product (after blending, post treatement)				17.40				11.97		

< Water Quality Details >

<Pass 1>

	Unit	Raw Water	Feed Water	Concentrate		Permeate			Product
				Stage1	Stage2	Total	Stage1	Stage2	
NH4	as Ion	1.5	1.5	3.9	9.7	0.05	0.03	0.11	0.05
K	as Ion	14.6	14.6	38.0	95.5	0.33	0.20	0.67	0.33
Na	as Ion	105.0	105.0	274.0	690.0	1.76	1.06	3.66	1.76
Mg	as Ion	16.0	16.0	41.9	105.9	0.14	0.08	0.28	0.14
Ca	as Ion	41.4	41.4	108.4	274.0	0.35	0.21	0.73	0.35
Sr	as Ion	0.3	0.3	0.7	1.9	0.00	0.00	0.00	0.00
Fe	as Ion	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
Ba	as Ion	0.0	0.0	0.1	0.1	0.00	0.00	0.00	0.00
HCO3	as Ion	169.0	169.0	439.2	1,100.1	4.70	2.82	9.71	4.70
NO3	as Ion	34.0	34.0	88.1	220.0	1.18	0.71	2.43	1.18
Cl	as Ion	114.0	114.0	297.5	749.2	1.92	1.15	3.97	1.92
F	as Ion	0.8	0.8	2.1	5.3	0.01	0.00	0.01	0.01
Boron	as Ion	0.6	0.6	0.7	0.6	0.05	0.01	0.14	0.05
SO4	as Ion	88.0	88.0	230.3	582.5	0.74	0.44	1.54	0.74
SiO2	as Ion	9.3	9.3	24.3	61.0	0.18	0.11	0.36	0.18
CO2	as Ion	25.1	25.0	25.0	25.0	25.03	25.03	25.03	25.03
CO3	as Ion	0.1	0.1	0.3	0.7	0.00	0.00	0.00	0.00
pH	-	7.0	7.0	7.4	7.8	5.48	5.26	5.80	5.48
TDS	mg/L	595.1	595.1	1,549.7	3,896.4	11.97	7.36	24.34	11.97
SDI	-	0.0	-	-	-	-	-	-	-
TOC	mg/L	0.0	-	-	-	-	-	-	-
COD	mg/L	0.0	-	-	-	-	-	-	-
BOD	mg/L	0.0	-	-	-	-	-	-	-
Hardness	as CaCO3	169.43	169.43	443.50	1,121.47	1.42	0.85	2.98	1.42

< Additional Information >

Scale Calculation

	PASS 1		
	Raw Water	Feed Water	Concentrate
pH	7.000	7.000	7.762
LSI	-0.624	-0.624	1.516
Stiff & Davis Index	-1.050	-1.050	1.169
Ionic Strength (molal)	0.011	0.011	0.073
TDS (mg/L)	595.080	595.076	3,896.376
HCO3 (mg/L)	169.000	169.000	1,100.082
CO3 (mg/L)	0.112	0.112	0.741
CO2 (mg/L)	25.047	25.033	25.033
CaSO4 (%Saturation)	1.003	1.003	18.223
BaSO4 (%Saturation)	58.230	58.230	791.225
SrSO4 (%Saturation)	0.582	0.582	6.703
CaF2 (%Saturation)	0.013	0.013	0.029
SiO2 (%Saturation)	9.300	9.300	49.380

< Scale recommendation >
Warning! Concentrate BaSO4 Exceeds791.22%of Saturation
Warning! High LSI, LSI > -0.2 Scale inhibitor and/or pH adjustment is required.
Warning! High S&DSI, S&DSI > 0.0 Scale inhibitor and/or pH adjustment is required.

CHEMICAL CONSUMPTION :
No Chemical.

recommendations and Errors :
No Error.

No recommendation.

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Appendix J

Optimizing RO Design Criteria for Indirect Potable Reuse

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Optimizing RO Design Criteria for Indirect Potable Reuse

Introduction

“Securing LA’s Water Supply” is a comprehensive plan established by the Los Angeles Mayor’s office to increase the city’s water supply by 15 percent by the year 2030. In 2008, with imported water supplies becoming ever more unpredictable in southern California, the Los Angeles Department of Water and Power (LADWP) adopted the Mayor’s vision, calling for 50,000 acre-feet per year (AFY) of potable supplies to be replaced by recycled water. To meet this near-term challenge and plan for expanding reuse in the future, LADWP has partnered with the Los Angeles Department of Public Works (LADPW) to develop the Recycled Water Master Plan (RWMP). As part of the approach to meet this near-term challenge and plan for expanding reuse in the future, LADWP commissioned a groundwater replenishment (GWR) treatment pilot study at the Donald C. Tillman Water Reclamation Facility (DCTWRP). The pilot study included testing to evaluate the proposed primary treatment process, which consists of microfiltration (MF) followed by reverse osmosis (RO) and advanced oxidation to destroy trace organic compounds that are poorly removed by RO.

Pilot testing began in February 2010 and was completed in June 2011. This paper discusses testing conducted to optimize the operation of the RO system, looking at variations in operating flux, system recovery, and number of stages as a method for reducing fouling and improving operational efficiency. The paper gives an overview of operating conditions in existing wastewater RO facilities in southern California, discusses the significance of the test conditions evaluated, and presents results from the pilot testing.

Wastewater RO in Southern California

Reverse osmosis (RO) has been used in southern California to treat wastewater since the Water Factory 21 facility went online in 1976. There are currently four agencies in southern California that operate RO plants treating more than 1 million gallons per day (mgd) of wastewater effluent. These include multiple facilities owned and operated by West Basin Municipal Water District, the Terminal Island Water Reclamation Facility operated by the Los Angeles Bureau of Sanitation (LABOS), the Vander Lans Advanced Water Treatment Facility owned by the Water Replenishment District of Southern California (WRD), and the 70-mgd GWR System owned and operated by the Orange County Water District (OCWD). The operating conditions for the largest of these facilities are given in Table 1. It should be noted that actual operating conditions at the plants often differ from the original design conditions. Both fluxes and recoveries may be operated lower than the design conditions shown in Table 1.

Table 1
Design Conditions for Southern California Advanced Treatment Facilities

Facility	Flux (gfd)	Recovery (percent)	No. of Stages
Orange County GWR System	12	85	3
LABOS Terminal Island	10	80	2
WRD Vander Lans	10	85	2
West Basin El Segundo (Phases 1 & 2)	12	85	2
West Basin El Segundo (Phase 3)	12	85	3

Operating Flux

For reuse applications, average design flux is typically maintained between 10 and 12 gallons per day per square foot (gfd), with most major RO manufacturers recommending that the average flux not exceed 12 gfd when treating wastewater. While these recommended limits are established for average flux, operating flux in the first stage of a multi-stage RO system is often considerably higher than the average for the overall system. At the Orange County GWR facility, for instance, an overall average flux of 12 gfd is maintained; however, the first stage flux can exceed 16 gfd, while the third stage can run below 5 gfd. It is believed that having too high of a flux in the early stages can result in excessive organic fouling when treating wastewater with high concentrations of total organic carbon (TOC). Therefore, the recommendation for maximum average flux accounts for anticipated differences between the flux in the first stage elements and the last.

One way to avoid this large change in flux between stages is to add interstage booster pumps or energy recovery devices, which provide additional pressure to the latter stages, balancing the flow more evenly. This approach is utilized at the Terminal Island facility to maintain similar fluxes between the first and second stages. For the pilot plant at DCTWRP, backpressure was applied to the first stage permeate, forcing more flow to the second stage and simulating the flow balancing conditions that would be seen if energy recovery devices or interstage booster pumps were employed. By using this approach, it may be possible to sustainably operate at an overall average flux higher than the 12 gfd typically employed at reuse facilities.

In contrast to wastewater applications, average flux for groundwater RO facilities is commonly maintained between 15 to 16 gfd (average flux over all stages). This higher flux has proven to be sustainable even with high organic content groundwater in south Florida, where TOC levels can be similar to southern California wastewater effluent. It was therefore not certain whether or not higher fluxes can be sustainably maintained at reuse facilities under optimized hydraulic conditions.

Number of Stages

Similar to the question of flux, it is not clear whether 2 stages or 3 stages are more advantageous for a reuse facility operated at 85-percent recovery, which is the recovery rate employed by the majority of facilities in southern California. West Basin operates both 2-stage and 3-stage facilities, with both having experienced considerable fouling in all stages (Gerringer, 2011). The two-stage Vander Lans facility has reported considerable fouling in their second stage (Trussell et al, 2009); however, the three-stage OCWD GWR facility has also experienced fouling in both their second and third stages (Knoell and Patel, 2011). It is therefore not immediately clear which configuration is most advantageous for an 85-percent recovery reuse facility.

Hydraulic Considerations in RO Design

The majority of wastewater RO facilities in southern California operate at a recovery of 85 percent. The ability to operate at higher recoveries can be limited both by saturation levels of sparingly soluble salts and by hydraulic conditions within the membrane elements. To maintain optimal hydraulic conditions, membrane manufacturers typically set maximum concentration polarization coefficients, also referred to as Beta Factors. The Beta Factor for an element is a measure of the relationship between feed water velocity (parallel to the membrane) and permeate flow (perpendicular to the membrane). A high Beta Factor can result in foulant build-up on the membrane, which is not adequately removed by crossflow. Although membrane vendors may have variations in how they calculate Beta Factor, they typically recommend a maximum value of 1.2, which generally corresponds to a recovery of 20 percent for a typical 8-inch element. Beta Factor calculations are generally made within membrane vendor design software rather than being directly calculated.

In addition to maximum Beta Factors, membrane vendors typically recommend a minimum concentrate flow rate for individual elements. For the Hydranautics ESPA2 8-inch elements used at OCWD, Terminal Island, Vander Lans, and several other reuse facilities, a 12-gallon-per minute (gpm) minimum flow is recommended. This corresponds to a minimum crossflow velocity of 0.18 feet per second (fps), based on membrane element geometry provided by Hydranautics for this paper. Allowing crossflow to drop below this level could result in scale or foulant build-up, even when the recommended Beta Factor is not exceeded. It is therefore important to maintain both minimum crossflow velocity and maximum Beta Factor under all recommended operating conditions when designing RO systems.

To illustrate the sensitivity of these hydraulic parameters to varying operating conditions, Table 2 presents calculations of Beta Factor and minimum crossflow velocity for a system similar to the OCWD GWR design. The first column shows a three-stage system operated at 5 mgd, representing the OCWD design conditions. The second column shows the same system operated at a reduced flow of 3.5 mgd, and the third column shows a modified two-stage configuration operated at 5 mgd.

As this table illustrates, Beta Factor and crossflow velocity are maintained well within the recommended ranges for the OCWD design operated at 5 mgd permeate production. However, when the permeate flow drops to 3.5 mgd, the minimum crossflow velocity of 0.18 fps is reached in the second stage. While the numbers presented here are simulated based on membrane projections, actual operation of the OCWD facility is typically maintained to prevent a production of less than 4 mgd per membrane skid. The facility has reported challenges with fouling of their latter stages, which are believed to be related to low flow conditions experienced during evenings when sufficient feed water has not been available. The calculations presented in Table 2 suggest that fouling could be anticipated when production drops below 3.5 mgd per skid.

Table 2
Impact of RO Operating Conditions on Beta Factor and Crossflow Velocity
(No Energy Recovery or Flow Balancing)

	Three-Stage Design (OCWD)[1]		Two-Stage Design[1]
Flow Rate (mgd)	5 mgd	3.5 mgd	5 mgd
Recovery (%)	85	85	85
Average Flux (gfd)	12	8.3	12
Feed Pressure (psi)	168	130	135
Beta Factor			
Maximum Recommended	1.20	1.20	1.20
First Stage	1.15	1.16	**1.21**
Second Stage	1.10	1.11	1.09
Third Stage	1.02	1.03	--
Crossflow Velocity (fps)			
Minimum Recommended	0.18	0.18	0.18
First Stage	0.34	0.24	0.20
Second Stage	0.26	**0.18**	**0.18**
Third Stage	0.39	0.27	--

1. Based on 78x48x24 pressure vessel array for three-stage configuration and 100x50 pressure vessel array for two-stage configuration. Assumes 7 elements per vessel and use of 8-inch Hydranautics ESPA2 elements with no energy recovery device, interstage pressure boost, or permeate throttling for flow balance. Calculations were made using IMSDesign software from Hydranautics, with crossflow velocity calculated manually from minimum flow outputs and membrane element geometry information provided by Hydranautics.

In contrast to the three-stage design currently in use at OCWD GWR, a two-stage configuration was presented in Table 2 using the same number of pressure vessels in a 100x50 vessel array. The table illustrates that at a permeate flow rate of 5 mgd and recovery of 85 percent, the maximum Beta Factor is exceeded in the first stage, while the minimum crossflow velocity is reached in the second. These design conditions would generally not be recommended for an efficiently operated reuse facility, due to the risk of fouling in both the first and second stages.

As stated previously, a method for improving flow balance between stages is the use of an interstage boost, either through a booster pump or an energy recovery device. Energy recovery devices, such as the hydraulic TurboCharger, have seen increasing use in brackish water facilities as the cost of energy has increased; however, their use in reuse applications remains limited. Membrane projections and calculations were made for the two-stage RO configuration presented previously in Table 2, with a TurboCharger added to improve flow balance. These results are presented below in Table 3.

The first column in Table 3 shows the two-stage system from Table 2, designed for 12-gfd average flux, and operated at 5-mgd permeate production. The second column shows the same system operated at 4 mgd (the minimum recommended flow for the existing OCWD facility). The results show that while maximum Beta Factors and minimum crossflow velocities are maintained during 5-mgd operation, the minimum crossflow velocity cannot be maintained in the second stage during 4-mgd production. To improve these hydraulics, a simulation was run using 15-percent fewer membrane elements, resulting in a 14-gfd average flux during 5-mgd production. These results are shown in the third and fourth columns of Table 3, and suggest that the recommended hydraulic conditions can be maintained, even at a reduced production of 4 mgd, when a reduced number of membrane elements are employed.

Table 3
Impact of RO Operating Conditions on Beta Factor and Crossflow Velocity (Using Turbocharger for Interstage Boost)

	Two-Stage RO in 100x50 Vessel Array[1]		Two-Stage RO in 86x42 Vessel Array[1]	
Flow Rate (mgd)	5 mgd	4 mgd	5 mgd	4 mgd
Recovery (%)	85	85	85	85
Average Flux (gfd)	12	9.5	14	11
Feed Pressure (psi)	124	104	141	118
Beta Factor				
Maximum Recommended	1.20	1.20	1.20	1.20
First Stage	1.16	1.16	1.16	1.16
Second Stage	1.14	1.12	1.10	1.13
Crossflow Velocity (fps)				
Minimum Recommended	0.18	0.18	0.18	0.18
First Stage	0.24	0.19	0.28	0.22
Second Stage	**0.18**	**0.15**	0.22	**0.18**

1. Assumes 7 elements per vessel and use of 8-inch Hydranautics ESPA2 elements with use of Turbocharger to provide interstage boost. Calculations were made using IMSDesign software from Hydranautics, with crossflow velocity calculated manually from minimum flow outputs and membrane element geometry information provided by Hydranautics.

What is most notable about the operating conditions presented in the 14-gfd scenario (column 3 in Table 3) is that the projected feed pressure under these conditions is 141 pounds per square inch (psi), compared with projected feed pressures for the existing OCWD facility, which are 168 psi. This suggests that by operating at 15-percent higher flux, reducing to two stages, and adding an energy recovery device, the feed pressure could potentially be reduced by 16 percent. Stated another way, a 15-percent smaller facility could use 16-percent less energy to produce the same amount of water, generating savings in both capital and operating costs. The key question, is whether or not such a facility would truly operate without an increased rate of fouling, and whether or not these reductions in feed pressure could be realized. Determining the answer to this question became one focus of the pilot testing conducted at DCTWRP, the results of which are discussed below.

Pilot Testing Equipment

The pilot testing conducted at the DCTWRP employed a Pall MF system for pretreatment, Hydranautics ESPA2 RO membranes, and a Trojan UVPhox ultraviolet light system. During the last phase of testing, the ESPA2 elements were replaced by Toray TML elements in one half of the first stage and CSM FEn elements in the other parallel half of the first stage as well as the entire second stage. The MF unit contained four membrane modules and was operated at 25 to 40 gfd. Source water was taken from either secondary effluent or tertiary effluent before chloramine addition. Ammonia and chlorine were then added upstream of the MF unit. During a portion of the testing, ammonia was added prior to chlorine, representing a conventional chloramination approach. During other portions of the testing, chlorine was added first past breakpoint chlorination, and ammonia was added downstream of the MF unit. This second approach was referred to as sequential chlorination, and has been discussed in a recent paper presented at the AWWA Annual Conference and Exposition (Wetterau et al, 2011).

The RO system included a combination of 4-inch and 2.5-inch RO elements to simulate hydraulic conditions in either a two-stage or three-stage full-scale facility. For two-stage operation, the pilot uses two parallel sets of first-stage pressure vessels with seven 4-inch elements per set (resulting in a total of 14 first-stage elements), followed by one set of second-stage vessels with seven 4-inch elements. For three-stage operation, the two-stage equipment was followed by one set of 2.5-inch pressure vessels, with 7 elements in series. This configuration is shown schematically in Figure 1. The RO system was run at a recovery of 85 percent and an average flux varying between 12 and 14 gfd. Sulfuric acid was used to reduce the feed pH to 6.9 standard units, and a 3 mg/L dose of Vitec 4000 antiscalant was used initially for control of calcium phosphate and calcium fluoride scale. During Run 4, the antiscalant was changed to King Lee Pretreat Y2K. First stage permeate throttling was used to balance flow between the first and second stages during two-stage operation. A third-stage booster pump was employed when the third stage was in use.

Figure 1 – RO Pilot Configuration Schematic

The pilot operation can be divided into eight separate runs for the RO unit. Chemical cleanings were carried out between each run, which some runs including multiple cleanings. Operating conditions for the RO runs as summarized in Table 4.

Table 4
RO Operating Conditions

Run	Days	Flux (gfd)	Recovery	# Stages	Antiscalant	Membranes
0	65	14	80%	2	Avista	ESPA2 (original)
1	30	12	85%	2	Avista	ESPA2 (original)
2	45	12	85%	3	Avista	ESPA2 (original)
3	50	14	85%	2	Avista	ESPA2 (original)
4	66	14	85%	2	King Lee	ESPA2 (original)
5	37	12	85%	2	King Lee	ESPA2 (2nd set)
6	23	12	85%	2	King Lee	ESPA2 (2nd set)
7	113	14	85%	2	King Lee	FEn and TML

To monitor performance of the RO system, daily measurements were made for flows, pressures, conductivities, and temperatures necessary to calculate membrane permeability for each stage.

All permeabilities were normalized to 25°C to account for variations in feed water temperature. A loss in permeability generally indicates that fouling has occurred. Membranes are typically cleaned when more than 20 to 30 percent of the permeability has been lost. Full-scale wastewater RO facilities generally target 6- to 12-month cleaning intervals; however, many facilities have experienced more rapid fouling, requiring chemical cleaning every 2 to 3 months.

Pilot Testing Results

Permeability in the first stage did not show signs of fouling at any point during the pilot testing, regardless of the flux or membrane configuration employed. Some degree of oxidant damage was observed in the first stage, due to several events where ammonia feed was lost. First stage permeability increased from 0.13 gfd/psi to 0.19 gfd/psi over the first 10 months of pilot operation. During this period, the first-stage permeate conductivity increased from 10 uS/cm to 30 uS/cm. A lead element was sent to Avista Technologies for autopsy, and showed signs of oxidant damage. While the pilot testing did not suggest any impact of flux or membrane configuration on first-stage fouling, the sequential chlorination approach employed during much of the pilot testing appears to have created a greater risk of oxidant damage than the more conventional chloramination approach employed at most wastewater RO facilities.

Significant fouling was observed in the second and third stages of the pilot throughout the initial testing periods. Figure 2 presents the Stage 2 and Stage 3 permeabilities for Runs 1 and 2, contrasting the operation of the pilot using two-stage and three-stage operation, with other operating variables relatively unchanged. The figure demonstrates that during two-stage operation at 12-gfd flux (Run 1), the second stage saw a 23-percent reduction in permeability over the first 28 days. A chemical cleaning was then performed and a similar fouling rate was observed with a 29-percent reduction in permeability over the next 28 days. This is a relatively high fouling rate and would not be considered advantageous for full-scale operation.

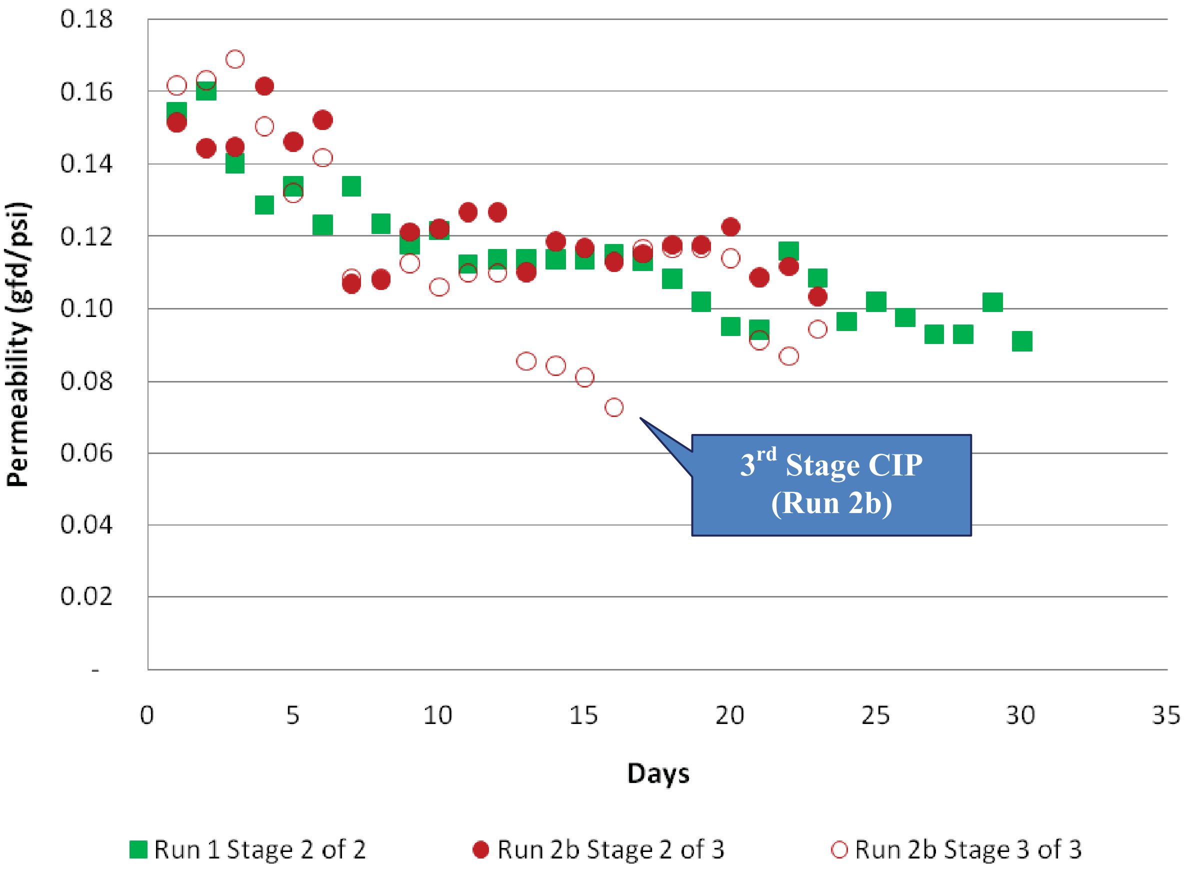

Figure 2 – RO Permeability for Two-Stage and Three-Stage Operation

In contrast to the two-stage operation, the three-stage operation (also at 12-gfd average flux) saw a higher fouling rate in both the second and third stages of the pilot unit (Run 2 in Figure 2). Both second-stage and third-stage permeabilities dropped 36 percent over the first 21 days of Run 3. A chemical cleaning was performed on all stages and the run was continued. After the chemical cleaning, fouling was less rapid than in the first 21 days, with second stage permeability dropping 17 percent during the subsequent 22 days, and third-stage permeability dropping between 25 and 30 percent. These results suggest that the improved hydraulic conditions in a three-stage configuration were not adequate to prevent fouling in the downstream stages of the pilot unit. Membrane autopsies suggested the primary foulants were silica and aluminum; however, concentrations of both parameters were relatively low and had not been anticipated to create an operational challenge at 85-percent recovery.

Figure 3 presents the normalized second-stage permeability for a two-stage configuration operated at 85 percent recovery and either 12- or 14-gfd average flux. The normalized permeability was calculated as the permeability divided by the initial permeability for the test run. Normalized permeability was used to standardized between membranes with differing initial permeabilities.

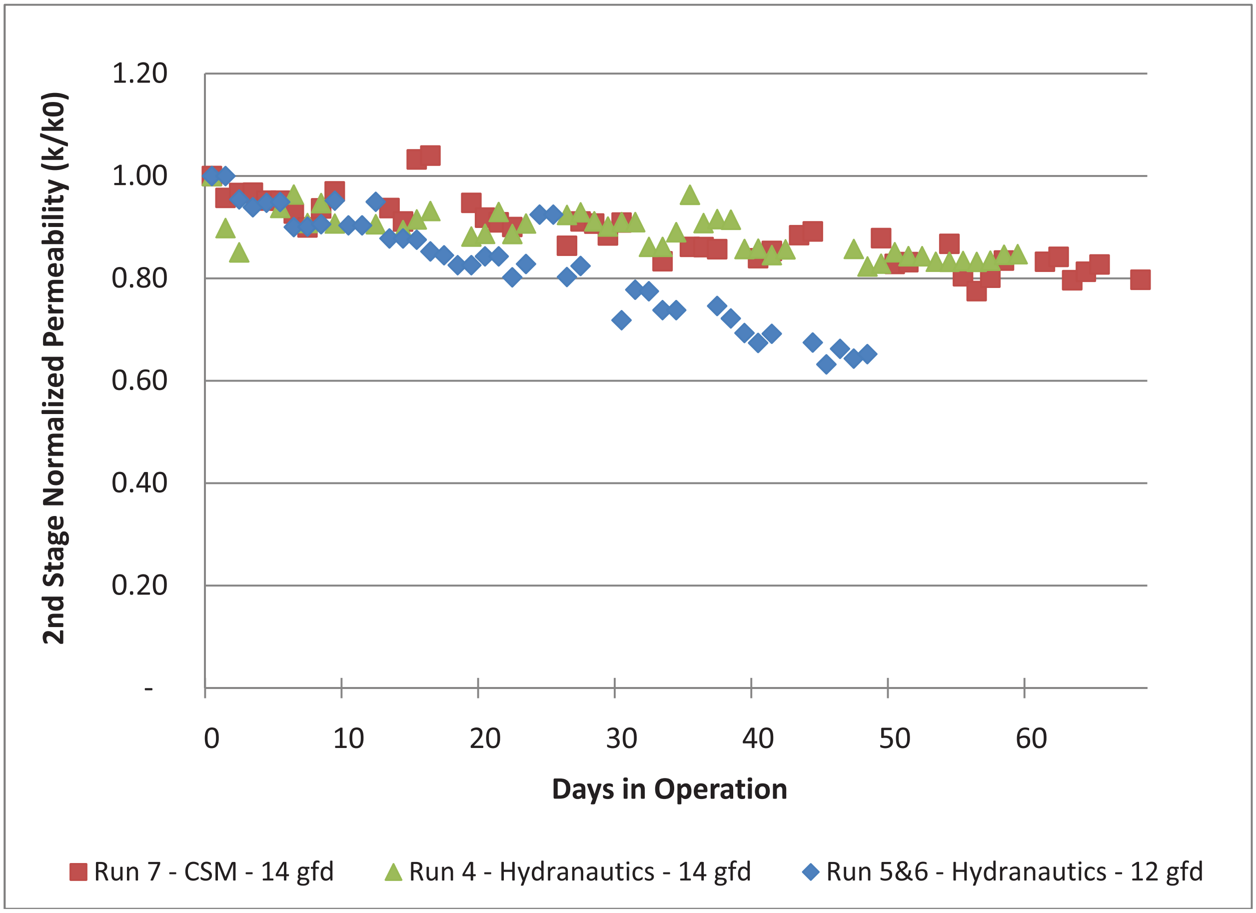

Figure 3 – Impact of RO Flux on Second-Stage Permeability (2-Stage Operation)

During Run 4, an average flux of 14 gfd was maintained using Hydranautics ESPA2 membranes. During Runs 5 and 6 the flux was reduced to 12 gfd, using a replaced set of ESPA2 membranes. During Run 7, operated again at 14 gfd, the ESPA2 membranes were replaced with CSM FEn membranes in the second stage. During Runs 5 and 6, permeability declined by 36 percent over 47 days, or an average of 23 percent decline per 30 days. During Runs 4 and 7, a 17-percent loss in permeability was observed over 60 days, or an average 8.5 percent decline per 30 days. These results suggest that operation was more stable in the two-stage configuration when a 14-gfd average flux was maintained, compared with a 12-gfd average flux.

The results support the previously discussed hypothesis that poor hydraulic conditions (high Beta values or low crossflow velocities) can contribute to fouling in a two-stage RO configuration when an overall average flux of 12 gfd is maintained.

Study Conclusions

Pilot testing was conducted at the DCTWRP to optimize the RO design and operating conditions for a future advanced water treatment facility. It is hoped that improvements in the design approach will result in both a reduced energy demand and an improved performance, making use of lessons learned from existing advanced treatment facilities in southern

California. While existing facilities and manufacturer recommendations have limited the average design flux to 12 gfd when treating wastewater, evaluation of hydraulic conditions in an 85-percent recovery RO design suggest that operating at a higher flux could improve performance and reduce the risk of fouling in a two-stage configuration. It was estimated that a two-stage system employing energy recovery and a 14-gfd flux could result in a 16-percent reduction in energy use compared with a similar three-stage system operated at 12 gfd. This suggests that both capital and operational savings could be realized using this proposed design configuration and operating flux.

Pilot results from the DCTWRP facility suggest that operation at 12 gfd, whether in two-stage or three-stage configuration, was more problematic than initially anticipated. Significant fouling was seen in the second and third stages, in spite of the relatively low concentrations of sparingly soluble salts. This fouling resulted in run lengths of less than 30 days before membrane cleaning was required. Fouling rate was improved by selection of an alternative antiscalant, however, 30 day permeability loss remained at an average 23 percent under the best operating conditions at 12 gfd flux.

Operation at 14 gfd was more stable than at the lower flux, with an average 8.5-percent per month reduction in second-stage permeability over two separate test runs. The pilot results support the initial concerns raised about poor hydraulic conditions during operation at lower fluxes. While some wastewater RO facilities have experienced fouling in the first stage elements, which can be made worse by elevated fluxes, no such fouling was observed during the 16 month pilot testing at the DCTWRP, regardless of the operating flux employed. It was recommended that the future DCTWRP advanced treatment facility be designed around an average RO flux of 14 gfd in a two stage configuration, in order to take advantage of the improved hydraulics and reduced operating pressures discussed here-in.

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