# Removing Refractory Organics from Wastewater Using MF-O3-BAC Treatment

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*Submitted to*
City of Reno

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One Team. Infinite Solutions.

Contents

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## Tables

## Figures

## Appendices

# Executive Summary

Adequately treated WWTP effluent, termed “reclaimed water”, has the potential to be a reliable, high quality source of relatively drought-proof water.

Of the many possible uses of reclaimed water, one of the highest and best uses, when feasible, is groundwater replenishment for indirect potable reuse (IPR). In IPR, purified reclaimed water is injected into a groundwater aquifer serving as a future potable water supply. Public acceptance of any IPR project is of foremost concern. An IPR project is designed so that the injected reclaimed water co-mingles with, and is diluted by natural groundwater as it flows over a specified minimum distance, and minimum amount of time (often at least one year) towards the potable water supply well(s). IPR water quality concerns include presence of: 1) pathogens, 2) chemical toxicity (e.g., pharmaceuticals, hormones, carcinogenicity, etc.), 3) total dissolved solids (TDS), 4) well clogging substances (i.e., biofouling), and 5) leaching of natural contaminants (e.g., arsenic) from the aquifer formation. The time factor, dilution, and natural soil/aquifer treatment all provide a substantial margin of safety to protect public health in addition to the treatment given to the reclaimed water before it is injected. Purified reclaimed water to be injected into groundwater is treated to standards more rigorous than drinking water standards.

At present, the typical IPR projects utilize soil-aquifer treatment (SAT) in Arizona, and a reverse osmosis (RO) based treatment train in coastal locations of California. Initial hydrogeologic evaluation of soil conditions in areas north of Reno showed that SAT will be more challenging than in Arizona. With RO-based treatment, removed contaminants leave the RO unit as a “reject stream” or brine stream that constitutes up to 20 percent of the influent flow to the RO unit. RO-based treatment is more suited for coastal communities with an ocean to receive the brine stream with little to no additional treatment. When ocean discharge of the brine stream is not possible, the life cycle cost of specialized treatment and disposal of the brine stream may be up to double the life cycle cost of a project with ocean discharge.

The City of Reno elected to investigate the technical feasibility of protective groundwater replenishment IPR treatment processes other than RO that would be more suitable to Nevada’s economy, geographic location, and geology (Reno area aquifers tend to contain arsenic that may be leached into solution by a typical RO effluent). The City of Reno engineering team and Stantec Consulting Services Inc. considered several alternatives based on an extensive literature review and selected for demonstration a novel membrane filtration (MF), peroxide, ozonation (O3), and biologically active carbon (BAC) filter treatment process train (see Figure ES-1) for a 15-month, continuous flow, demonstration project. The purpose of the pilot test was to demonstrate MF-O3-BAC treatment efficacy and reliability under sustained field conditions at an actual WWTP. The results would then be made available to State of Nevada regulators and the general public for evaluation. If MF-O3-BAC treatment is determined to be acceptable for groundwater replenishment, then further demonstrations moving towards the permitting and feasibility assessment of IPR implementation may be proposed.

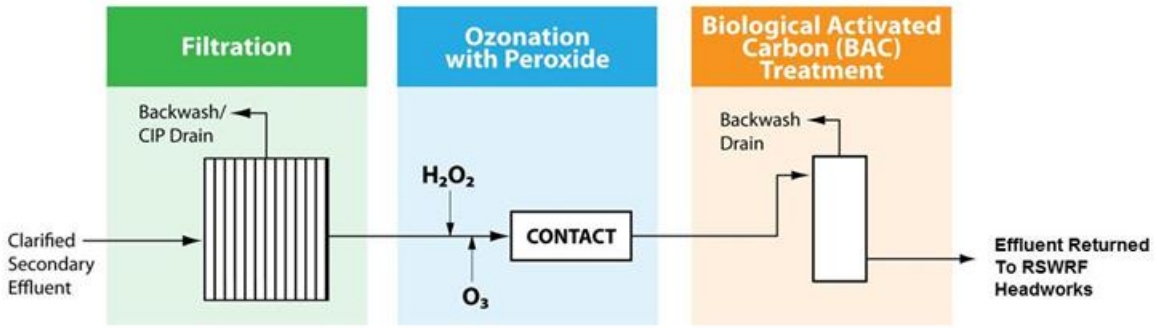


Figure ES-1
**MF-O3-BAC Treatment Process Train**

The MF-O3-BAC treatment process train with final disinfection provides multiple barriers to remove each class of contaminant of general concern as shown in Table ES-1.

Table ES-1
**Multi-Barrier Treatment**

| Constituents of Concern (COCs) | Treatment Process | | | | |
|---|---|---|---|---|---|
| | Activated Sludge | MF | Ozone | BAC | Final Disinfection |
| Nitrogen Compounds | √ | √ | | √ | |
| Total Suspended Solids and Turbidity | √ | √ | | √ | |
| Pathogens (Coliforms) | | √ | √ | | √ |
| Total Metals | √ | √ | | √ | |
| Total Organic Carbon (TOC) | √ | √ | | √ | |
| Soluble Biodegradable Organic Matter (BOM) | √ | | | √ | |
| EDCs (Hormones) | √ | √ | √ | √ | |
| PPCPs (Pharmaceuticals) | √ | √ | √ | √ | |
| Taste, Odor and Color | | | √ | √ | |
| Reduction of Biofilm Growth Potential | √ | | | √ | |

During the 15-month demonstration, major effluent sampling campaigns (each involving over 490 water quality parameters) were conducted encompassing a range of seasonal performance by the process. A summary of removals of contaminants of emerging concern (CECs) observed during the demonstration project is presented in Table ES-2.

Table ES-2
**CECs Before and After MF, O3, BAC Treatment**

| Group | Constituents | Units | Secondary Clarifier Effluent | Membrane Filter Effluent | Ozonation Effluent | BAC Effluent | Blank |
|---|---|---|---|---|---|---|---|
| Hormones | Estradiol | ng/l | 5.9 | 3.4 | 1.9 | 1.8 | 2 |
| | Estrone | ng/l | 65 | 11.9 | 0.52 | 0.5 | 0.5 |
| Pharmaceuticals | Gemfibrozil | ng/l | 45.7 | 35.3 | 0.2 | 0.2 | < 0.080 |
| | Ibuprofen | ng/l | 4.4 | 6.4 | < 0.39 | < 0.39 | < 0.39 |
| | Naproxen | ng/l | 20.5 | 17.9 | < 0.25 | < 0.25 | < 0.25 |
| | Triclosan | ng/l | 54.7 | 2.2 | < 1.2 | < 1.2 | < 1.2 |
| | Diazepam | ng/l | 2.7 | 2.8 | 0.18 | < 0.14 | < 0.14 |
| | Fluoxetine | ng/l | 3.2 | 2.4 | 2 | < 0.080 | < 0.080 |
| | Primidone | ng/l | 140 | 129 | 4.6 | < 0.6 | < 0.6 |
| | Trimethoprim | ng/l | 270 | 130 | < 2.4 | < 2.4 | < 2.4 |
| | Atorvastatin | ng/l | 14.3 | 5.5 | < 0.11 | < 0.11 | < 0.11 |
| | Azithromycin | ng/l | 323 | 102 | < 22 | < 22 | < 22 |
| | Caffeine | ug/l | 25 | 10.8 | < 0.042 | < 0.042 | < 0.042 |
| | Ciprofloxacin | ng/l | 363 | 247 | < 14 | < 14 | < 14 |
| | Cotinine | ng/l | 54.5 | 20.5 | 14 | 2.3 | 0.49 |
| | Meprobamate | ng/l | 385 | 343 | 43.5 | 3 | < 1 |
| | Sulfamethoxazole | ng/l | 930 | 833 | 6.0 | < 0.25 | < 0.25 |
| | Methadone | ng/l | 65.3 | 33 | 0.3 | 0.13 | < 0.4 |
| | Atenolol | ng/l | 953 | 890 | 10.6 | < 1 | < 1 |
| | Carbamazepine | ng/l | 258 | 247 | 0.98 | 0.8 | 0.8 |
| | Dilantin | ng/l | 253 | 150 | 3.1 | < 1 | < 1 |
| | Diclofenac | ng/l | 96 | 109 | < 0.5 | < 0.5 | < 0.5 |
| | Amoxicillin | ng/l | 1633 | 1020 | 0.74 | ND | ND |
| | Phenytoin | ng/l | 390 | 343 | 3.9 | ND | ND |
| | Salicylic Acid | ng/l | 25 | 32.67 | 28 | 20.67 | 48.67 |
| Flame Retardants | TCEP | ng/l | 620 | 545 | 445 | < 3.4 | < 3.4 |
| | TCPP | ng/l | 2100 | 2400 | 1400 | < 2.7 | < 2.7 |
| | TDCPP | ng/l | 633 | 623 | 627 | 0.695 | 3.23 |
| Industrial EDCs | Bisphenol A | ng/l | 18 | 22 | < 0.27 | < 0.27 | 2200 |
| | Octylphenol | ng/l | 31 | < 25 | < 25 | < 25 | < 25 |
| | Nonylphenol monoethoxylate | ug/l | 1.1 | 0.87 | < 0.87 | < 0.87 | < 0.87 |
| Organics | DEET | ng/l | 115 | 125 | 2.56 | < 0.60 | 1.2 |
| | Musk Ketone | ng/l | 47 | 38 | < 25 | < 25 | < 25 |
| | BHA | ng/l | 76 | 42 | < 1 | < 1 | < 1 |
| | Atrazine | ng/l | 1.3 | 1.5 | 0.5 | < 0.25 | < 0.25 |
| | Benzophenone | ng/l | 203 | 173 | < 50 | < 50 | < 50 |
| | 1,4-Dioxane | ug/l | 1.53 | 1.5 | 0.3 | 0.4 | < 0.13 |
| Ozone Byproducts | Formaldehyde | ug/l | 9.2 | 9.8 | 133.3 | 5.8 | 2.4 |
| | Acetaldehyde | ug/l | 3.5 | 2.1 | 31.0 | < 1 | < 1 |
| | Ethyl Glyoxal | ug/l | 3.3 | 3.1 | 41.3 | 3.9 | < 1.1 |
| | Methyl Glyoxal | ug/l | 3.3 | 3.4 | 27.0 | 3.7 | < 0.5 |
| | Propanal | ug/l | <0.7 | <0.7 | 3.5 | < 0.7 | < 0.7 |
| | NDMA | ng/l | 1 | 0.9 | 7.9 | < 0.28 | 0.385 |

Detected  Not Detected  QA/QC Interference

QA/QC interference referenced in Table ES-2 implies that detectable concentrations of CECs were found in blank samples (e.g., field blank, lab blank). When a lab finds detectable

concentrations in a blank sample (where none should occur), this suggests an interference in the analytical and/or sampling procedure. This same interference may also affect the validity of an ozonation effluent result or BAC effluent result, as noted in Table ES-2.

Comparative effluent quality results for these key CEC parameters for the MF-O3-BAC and the RO-based process are presented in Figure ES-2.

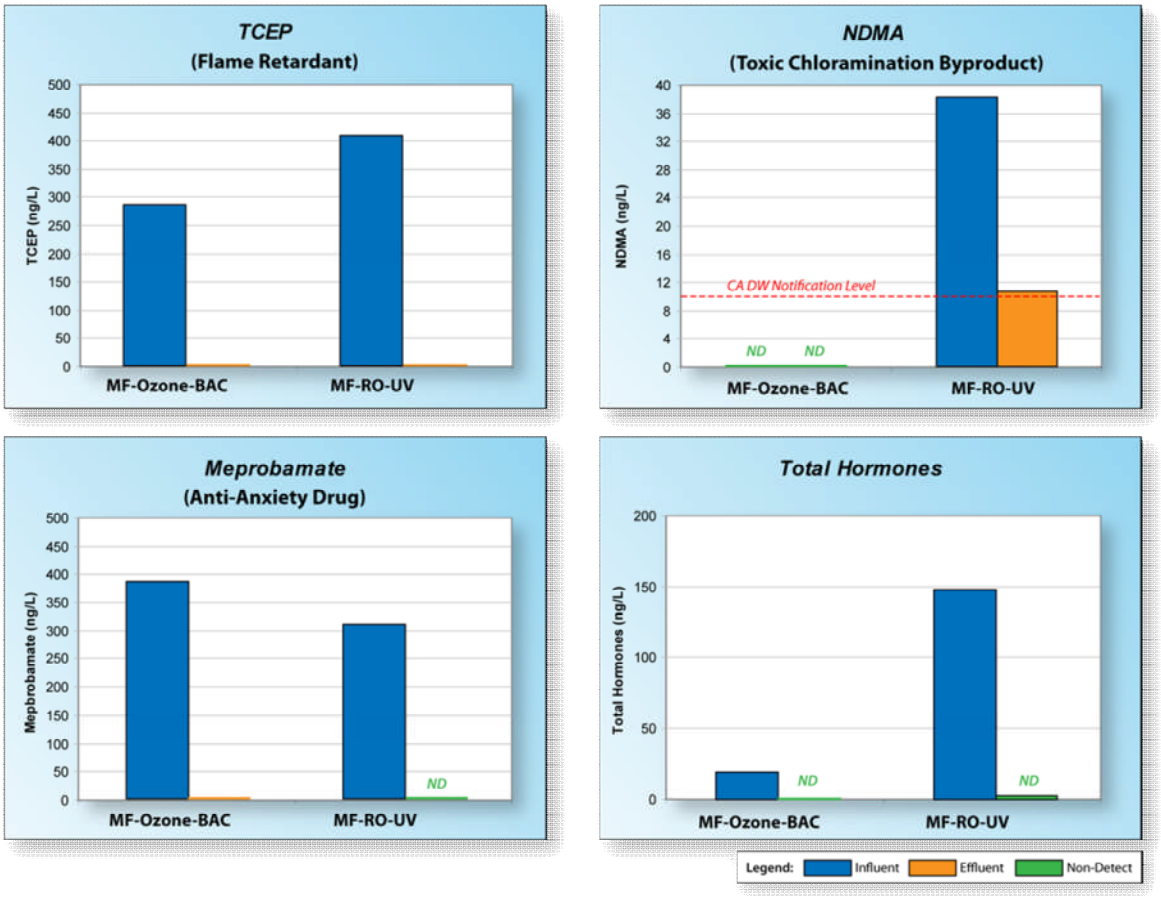


Figure ES-2
**Removal of Critical Indicator CECs by MF-O3-BAC and RO**

As shown, MF-O3-BAC results are comparable to RO results with the exceptions of TOC reduction and TDS reduction. The significance, if any, of the TOC results is unknown and needs further study. The TDS results are as expected, and underscore the premise that the primary use of RO is to remove TDS (i.e., salts). In Reno's case, TDS reduction is not required at this time as the current levels of effluent TDS are considerably lower than the published effluent TDS limitations. In other inland locations where TDS reduction is needed, installation of a small downstream RO unit treating a portion of MF-O3-BAC can be considered.

The MF-Peroxide-O3-BAC pilot project successfully demonstrated process capabilities (at much lower cost and energy usage than RO) to:

- Reduce contaminants of emerging concern (CECs) including Endocrine Disrupting Compounds (EDCs) and Pharmaceuticals and Personal Care Products (PPCPs) to very low and non-detect concentrations (see Table ES-2),
- Reduce product water estrogen activity in human cell bioassays to background levels,
- Control and/or remove ozonation transformation byproducts such as bromate and NDMA,
- Avoid increasing the corrosivity of the product water, a serious concern for groundwater replenishment and IPR in arsenic-rich aquifer formations.
- Reduce biodegradable dissolved organic carbon (BDOC) concentrations in ozonated water in order to reduce biofilm growth in aquifer injection wells and conveyance systems, and
- Provide effective disinfection by inactivating virus and coliforms.

Compared to RO-based IPR systems, MF-O3-BAC has the benefits of:

- Providing multi-barrier treatment for all major categories of contaminants of concern, which improves treatment process reliability.
- Lower capital and operation and maintenance (O&M) costs
- Lower energy use
- Eliminates treatment and disposal of RO brine.
- Destroying CECs rather than concentrating them in the RO brine.
- Reducing the amount of water resource lost for reuse via the RO brine stream.

Additional significant contributions resulting from the project include:

- Improved virus testing protocol that reduces TOC interference.
- Developed new BAC operational and performance data.
- Developed seasonal operational strategies to mitigate ozone transformation byproducts.

This study concluded that ozone dosage of 5 mg/L or more was needed for desired CEC removal. Peroxide (year-round) and ammonia (seasonal) were added to mitigate bromate formation during ozonation. Key process variables evaluated were: (1) pretreatment process, (2) addition of peroxide, (3) formation of ozonation byproducts (such as bromate and NDMA), and (4) regrowth of coliform after ozonation in downstream processes. Findings from this study indicate that reliable CEC removal is more affordable than previously thought.

Section 1

# Introduction

## 1.1 NEED FOR WATER REUSE IN STATE OF NEVADA

Affordable clean water is essential to Nevada's economy. Nevada averages only 9 inches of rainfall per year, which makes it the driest state. Water shortages forecast for the West and the possibility of extended drought pose serious challenges for Nevada. In Nevada and other states, an under-utilized water resource is municipal wastewater treatment plant (WWTP) effluent. Adequately treated municipal effluent, termed "reclaimed water", can be made into a reliable, high quality, drought-proof water resource. Potential water shortages in the immediate future can be addressed by insightful management of available freshwater resources, and recycling or banking of reclaimed water. Throughout the water industry, a broad realization is developing that reclaimed water is like any other freshwater resource and can satisfy multiple purposes if treated adequately for the specific use.

## 1.2 CONSTITUENTS OF CONCERN

### 1.2.1 CONTAMINANTS OF EMERGING CONCERN (CECS)

Industrialization and advancement in human lifestyle have resulted in increased presence of man-made organic compounds in the environment, many of which are wholly or partially resistant (i.e., refractory) to conventional wastewater treatment. Of these refractory organics, the contaminants of emerging concern (CECs) include endocrine disrupting chemicals (EDCs) and pharmaceuticals and personal care products (PPCPs). Most CECs are life improving drugs and useful household products (e.g., anti-bacterial agents and flame retardants) which makes complete source control infeasible until less refractory substitute compounds are developed. Occurrences of CECs in effluent and the environment, especially effluent-dominated streams, are well documented and reported elsewhere (Goodbred et al., 2007; Vajda et al., 2008; Jenkins et al., 2009). Releases of CECs to the environment 1) have affected aquatic organisms living in the receiving water, and 2) may affect people ingesting water and/or aquatic organisms containing CECs.

#### Aquatic Life Impacts

CEC impacts on aquatic life have been reported in various studies performed worldwide. This is of concern to stakeholders involved in projects discharging municipal WWTP effluents to water bodies, particularly water bodies providing limited dilution of the effluent. As an example, increases in intersex fish, female-biased sex ratios, and elevated levels of vitellogenin (Vtg, a female egg yolk protein) were found in white sucker fish populations living immediately downstream from an effluent discharge to Boulder Creek in Colorado (Vajda et al., 2008). Male white suckers living in the effluent plume had approximately 25 times more Vtg in spring (effluent more diluted) and 500 times more Vtg in fall (effluent less diluted, plus elevated temperature) than upstream males used as reference. Investigators also found selective uptake of anti-depressants in the brain cells of white suckers living in the effluent plume (Schultz et al., 2010). In another study, the U.S. Geological Survey (USGS) found elevated levels of Vtg

reduced sperm motility and distribution, and consistently lowered the gonadosomatic index in male common carp living in Las Vegas Bay of Lake Mead, Nevada, that receives effluent (Goodberd et al., 2007). A third study of reproductive and endocrine biomarkers in western mosquito fish at various locations in the Santa Ana River, California, showed significant evidence of endocrine disruption as a function of proximity to effluent discharges (Jenkins et al., 2009).

#### Human Impacts

Direct evidence of harmful impacts on human health from exposure to and ingestion of CECs in water resources is not known to exist. The levels of individual CECs detected in drinking water supplies, thus far, are far below their known threshold effect levels; however, possible synergistic effects of numerous CECs on the human body over a lifetime exposure in addition to medicines taken by an individual are still unclear. Considering this and the known impacts of CECs on some aquatic forms at very low concentrations, the 2010 President's Cancer Panel recommended that pregnant women and children should minimize their exposure to CECs (Reuben, 2010). A California advisory panel recommended monitoring a few key indicator CECs in groundwater recharge applications (CSWRCB, 2010). This panel excluded CEC monitoring requirements for irrigation projects due to the lesser chance of people ingesting irrigation water.

### 1.2.2 OTHER CONSTITUENTS OF CONCERN

To protect public health during various reuse scenarios, concerns related to constituents other than CECs also need to be addressed. Other constituents of concern include: 1) drinking water primary and secondary constituents, 2) pathogens, 3) various refractory organics such as dioxins, pesticides, and PCBs, 4) priority pollutants listed in 40 CFR, 5) byproducts known to be created during treatment, and 6) organic carbon concentrations.

## 1.3 TREATMENT OPTIONS

Treatment for removing CECs from wastewater has been based mainly on four mechanisms: biological metabolism, membrane separation, chemical oxidation, adsorption, and oxidation-bioadsorption. Treatment options for CEC removal are discussed below.

### 1.3.1 BIOLOGICAL SECONDARY TREATMENT

Previous studies have shown significant removals of hydrophobic CECs during secondary treatment by biological metabolism and adsorption to sludge (Clara et al., 2005). Hydrophilic and recalcitrant CECs, including organophosphate flame retardants (e.g., TCEP) and iodinated contrast media (i.e. iopromide), are not removed during secondary treatment (Snyder et al., 2007). Thus, researchers have focused their investigations on evaluating treatment technologies for removing CECs remaining in effluent after biological secondary treatment

### 1.3.2 MEMBRANE SEPARATION

Microfiltration and ultrafiltration are marginally effective in controlling CECs (Snyder et al., 2007). Reverse osmosis (RO) is successful in removing virtually all CECs by concentrating them in the RO membrane reject stream. However, RO effluent may still contain NDMA (Plumlee et al., 2008), TCEP, and iopromide (Snyder et al., 2007). In many cases, NDMA is generated during the chloramination step to prevent RO membrane biofouling (Sedlak et al,

2006). To remove these residual CECs from RO effluent, the effluent can receive advanced oxidation treatment.

With RO treatment, the bulk of the removed CECs are concentrated in the reject stream (consisting of about 15 percent of the influent flow to the RO process). To our knowledge at this time, RO with supplemented advanced oxidation treatment is the most effective method for removing the broadest range of CECs; but it involves high capital costs, high power utilizations, and creates a substantial and potentially harmful waste stream. This concentrated waste stream poses a greater threat than the original effluent being treated, and therefore may need special treatment and/or disposal.

### 1.3.3 CHEMICAL OXIDATION

Less costly and less power intensive CEC removal methods than RO have included oxidation by ozonation (without peroxide), hydroxyl radical-based advanced oxidation processes (i.e. AOPs such as ozone-peroxide and high energy UV-peroxide), and chlorination. However, all have been less effective than RO to varying degrees. Chlorination is fairly effective in removing CECs (Snyder et al., 2007) but creates carcinogenic byproducts. Chloramination is not effective in removing CECs (Snyder et al., 2007). The most effective oxidation processes, thus far, are ozonation (without peroxide) and AOPs. Several studies have reported substantial reductions in effluent estrogenic activity in bioassay tests, along with significant removals of CECs after ozone-based oxidation (Huber et al., 2005; Snyder et al., 2006). However, Ozone-based oxidation of wastewater effluent can have the following problems: 1) formation of transformation byproducts that have potential aquatic toxicity (Stalter et al., 2010), 2) formation of byproducts that are suspected carcinogens such as bromate (von Gunten 2003; Marhaba et al., 2003) and NDMA (Andrzejewski et al., 2007), 3) inadequate treatment of compounds that are engineered to resist oxidation such as flame retardants (e.g., TCEP, TCPP, and TDCPP), 4) elevated levels of bioactivity in the effluent after oxidation (i.e. decrease in effluent biostability), and 5) need for effluent-specific pilot testing based on the influence of water quality parameters on ozone oxidation chemistry (e.g., TOC, pH, temperature, alkalinity, ammonia and nitrite)..

### 1.3.4 ADSORPTION

Small-scale laboratory tests have shown that granular activated carbon (GAC) is effective in removing CECs that have high hydrophobicity (Snyder et al., 2007). Performance of GAC units treating CECs present in wastewater on a continuous basis is still unclear.

### 1.3.5 OXIDATION-BIOADSORPTION

Biologically Active Carbon (BAC) is a biofilter that uses GAC as the support medium for microbial growth. The GAC provides an excellent medium on which to grow a complex stable microbial population capable of metabolizing as well as adsorbing many forms of contaminants. For BAC to work, a source of biodegradable organic carbon (BDOC) is needed to promote the necessary bioactivity. Filtered secondary effluent is a poor source of BDOC. However, oxidation of filtered secondary effluent by ozonation (without peroxide)or AOP increases filtered secondary effluent BDOC by oxidizing slowly biodegradable complex organic compounds (including many CECs) into simpler, more readily biodegradable organic compounds. BAC installed downstream of ozonation or AOP is known to reduce BDOC and eliminate taste and odor causing compounds (Juhna et al., 2006; Nerenberg et al., 2000). Other benefits of BAC are not well documented.

## 1.4 RENO-STEAD WRF DEMONSTRATION PROJECT

To facilitate various effluent reuse options that might potentially require CEC removal, the City of Reno and Stantec Consulting Services Inc. investigated the feasibility of treatment technologies based on the following principles:

- Refractory organics (EDCs, PPCPs, etc.) should be destroyed, not merely removed as a concentrate in need of specialized treatment and/or disposal, particularly in inland areas where ocean disposal is not an option.
- Because of RO's high cost and energy requirements, RO should be used only for salt removal, and only when needed. (Salt removal is not anticipated for Reno at this time for any reuse needs because the average effluent TDS is only 350 mg/L).
- Salinity and corrosivity of the water produced for reuse should be maintained at a safe level to prevent excessive leaching of subsurface constituents (e.g. arsenic) when the treated water is stored in the subsurface aquifers.
- The technology should be suitable for inland communities without access to ocean outfalls.

Based on these principles, a treatment train consisting of ozone biologically active carbon (BAC) was developed and demonstrated as a cost effective alternative to RO. The development and demonstration were accomplished over 2 years using a 10.7 gpm continuous flow, pilot scale, treatment process consisting of:

- Membrane Filtration (MF) to remove particulates from secondary treated effluent.
- Ozonation (O3) to oxidize most refractory organics into more readily biodegradable organic compounds. This treatment step included peroxide and/or ammonia addition to control formation of bromate (a well-known ozonation byproduct).
- BAC to remove the biodegradable organic byproducts of ozonation, and to remove some of the refractory organics resistant to oxidation (e.g., flame retardants).

The pilot-scale demonstration of the effectiveness of an MF-03-BAC post-secondary treatment process was conducted at the Reno-Stead Water Reclamation Facility (RSWRF), Reno, Nevada. RSWRF is a 2 Mgal/d extended aeration activated sludge process currently handling 1.5 Mgal/d of annual average flow from a largely residential area. Though RSWRF has effluent sand filters, the MF step was included in the pilot project to remove virtually all particulates prior to ozonation based on the literature results available in 2007. Pre-filter secondary effluent was diverted to the MF-03-BAC pilot project for this study. Membrane Filtration (MF) was selected as the filtration step to removal virtually all effluent particulates.

### 1.4.1 OZONATION BENEFITS AND ITS BYPRODUCTS

Ozonation was selected as the oxidation step to destroy the bulk of the CECs. The ozonation process is effective in improving various critical aspects of water quality including: 1) reducing CEC concentrations and overall estrogenic activity, 2) providing disinfection, 3) improving the UV transmittance (UVT) of the water, 4) increasing dissolved oxygen concentration in the water, and 5) eliminating colorants and odor causing compounds present in the water. Formation of ozonation byproducts is a critical concern. Bromate formation is of special concern (particularly

when its precursor bromide is present in concentrations in excess of 20 μg/L) because bromate has a drinking water Maximum Contaminant Level (MCL) of 10 μg/L. The optimal ozone dosage to balance the benefits of CEC oxidation with the drawbacks of bromate formation was determined under field conditions.

### 1.4.2 BAC AND ITS BENEFITS

BAC treatment, a type of biofiltration process, was selected to 1) create a stable biofilter capable of supporting a diverse microbial population within the micro-habitats expected to exist in GAC, 2) adsorb and/or metabolize a wide range of organics, including ozonation byproducts, and 3) thereby reduce the concentrations of CECs, organic ozone byproducts, and associated toxicity. The BAC process was allowed to mature naturally (i.e. without microbial seeding or other augmentations) to assure that the performance observed would be representative of indigenous, self-sustaining microbial populations present in effluent. BAC is an ideal polishing treatment process downstream of ozonation because it utilizes microorganisms and the biological metabolism to 1) metabolize BDOC resulting from ozone oxidation of CECs (using dissolved oxygen residuals from the ozonation process), and 2) renew the biofilter's adsorptive capacity (commonly referred to as bioregeneration) which increases the run time for the GAC medium before it needs to be replaced.

Section 2

# Scope of the Project

The primary objective of MF-O3-BAC testing was to develop and demonstrate the effectiveness of a treatment train that is:

1. Capable of removing a wide range of CECs and other constituents of concern without forming toxic byproducts;
2. Applicable to inland areas (i.e. does not create a concentrated waste stream needing either ocean discharge and/or specialized treatment and/or disposal); and
3. Effective in eliminating residual effluent toxicity and estrogenic activity.

Secondary objectives were to:

1. Perform detailed characterization of wastewater quality before and after MF-O3-BAC treatment;
2. Determine optimal ozone dosage for CEC removal and ozone byproduct formation control;
3. Develop an ozonation byproduct mitigation strategy, if required;
4 Determine the effectiveness of BAC in improving biological stability of ozonated effluent by removing biodegradable dissolved organic carbon (BDOC);
5 Determine the effect of MF-O3-BAC treatment on pathogen removal and UV transmittance (UVT) of the filtered wastewater;
6. Optimize critical process parameters and develop process design criteria for ozonation and BAC process design; and,
7. Develop a water quality database for future use in water reuse permitting.

Section 3

# Project Development

In this section, the pilot treatment process is described in terms of physical plant, how the treatment process was optimized (Phase 1), and how the treatment process was operated during the performance demonstration period (Phase 2).

## 3.1 DEMONSTRATION PROJECT SETUP

The pilot system was operated continuously over the course of 15 months at a flow rate of 10.7 gpm from startup through completion. The system received undisinfected secondary effluent from the RSWRF, Reno, NV. Solids Retention Time (SRT) of RSWRF's 2 Mgal/d extended aeration nitrification-denitrification secondary process varied from 17 days (2009) to 25 days (2008). Schematic of the pilot treatment train is shown in Figure 3-1.

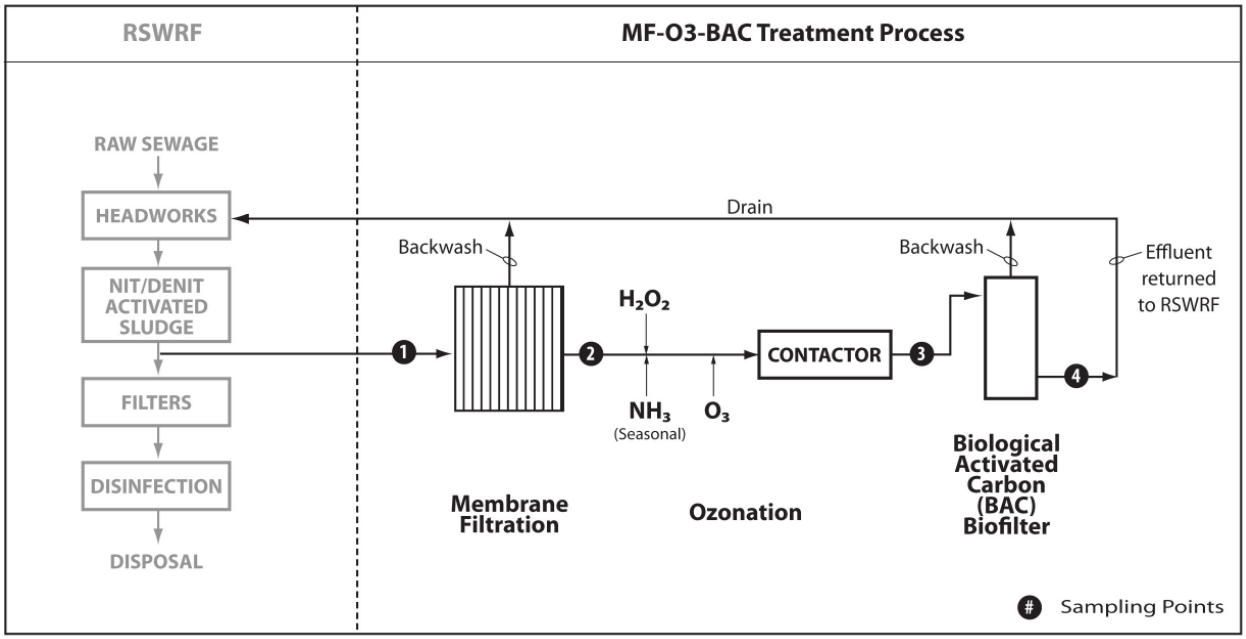


Figure 3-1
**Schematic of the MF-O3-BAC Pilot Treatment Process**

### 3.1.1 MEMBRANE FILTRATION

The membrane filtration pilot unit (AltaPac™, leased from WesTech Engineering Inc., Salt Lake City, UT, USA) used pressure-driven hollow fibers of polysulfone utilizing an outside-in flow configuration manufactured by Polymem. The nominal pore size of the membrane was 0.01 μm. The maximum pressure differential across the membrane was 30 psi. Prior to membrane filtration, the secondary effluent was passed through a 200 μm prefilter. Membrane maintenance

steps were per the manufacturer's recommendations and included periodic backwash with or without hypochlorite, Clean-in-Place (CIP) cleaning using caustic and hypochlorite, and membrane integrity testing. Critical membrane filtration parameters were monitored continuously and included pressure, flowrate, temperature, and turbidity.

### 3.1.2 OZONATION

The ozonation pilot unit (HiPOx$^{TM}$, leased from APTWater, Pleasant Hill, CA, USA) included a liquid oxygen-fed, solid-state, ozone generator capable of producing 4 lb/day of ozone at 10 percent concentration. The ozonation unit was operated in a direct gas injection mode both with and without peroxide addition, under a system pressure of 15 psi. Oxygen mass flow, and gaseous and dissolved ozone concentrations were monitored continuously.

### 3.1.3 BAC

The BAC pilot unit (leased from WesTech Engineering Inc., Salt Lake City, UT, USA) included a stainless steel pressure vessel designed to operate in the downflow mode. The 3.5 ft diameter vessel contained 1250 lbs of Filtrasorb F-400 (Calgon Carbon, Pittsburgh, PA, USA), resulting in a carbon media bed depth of about 4.5 ft and 30 minutes of empty bed contact time (EBCT). Headspace was more than 50% of the bed depth to allow for bed expansion during backwash without losing media. BAC column design and operational parameters are shown in Table 3-1. The BAC unit was constructed with sampling ports to allow the collection of carbon media samples at various depths from the media bed. Detailed discussions on ozone performance evaluation and optimization studies are presented in Appendix A.

Table 3-1
**Biologically Active Carbon Column Operational Details**

| Parameter | Average/Range |
|---|---|
| Average Flowrate, gpm | 10 |
| Mode | Downflow |
| Bed Depth, ft | 4.5 |
| Column Diameter, ft | 3.5 |
| Bed Volume, $ft^3$ | 43.3 |
| Empty Bed Contact Time (EBCT), min | 30 |
| Hydraulic Loading Rate, $gpm/ft^2$ | 1 - 1.1 |
| Depth-to-Diameter Ratio | 1.3 |
| Carbon Media Type | Calgon Filtrasorb 400 |
| Carbon Density, $lb/ft^3$ | 25 |
| Carbon Size, mm | 0.55 – 0.75 |
| Amount of Carbon, lbs | 1250 |
| Average Backwash Frequency | 14 days |
| Backwash Flowrate, gpm | 60 - 130 |

The first objective of the MF-O3-BAC pilot project (i.e., Phase 1) was to determine the optimal balance between the CEC removal benefits of ozonation and the bromate formation drawbacks of ozonation under field conditions. From the literature, it was expected that no more than 7 mg/L of transferred ozone dose would be needed to remove virtually all CECs subject to oxidation by ozone. It was also expected that ozonation of effluent naturally containing bromide could produce effluent bromate concentrations in excess of the 10 µg/L MCL for bromate (a suspected carcinogen). RSWRF's influent bromide concentration (~250 µg/L) is much higher than the threshold concentration of 20 µg/L reported by others to facilitate problematic bromate formation during ozonation (von Gunten 2003); therefore, bromate mitigation was expected to be necessary. Additionally from the literature, it was known that hydrogen peroxide ($H_2O_2$) and ammonia have the potential to reduce bromate formation. Results from the 5-month, Phase 1 ozonation optimization and bromate mitigation studies are presented in the following subsections.

## 3.2 PHASE 1: OZONE OPTIMIZATION AND BROMATE MITIGATION

### 3.2.1 OZONE DOSAGE OPTIMIZATION

The purpose of Phase 1 study to evaluate ozone's effectiveness on reducing CEC concentrations and estrogenic activity while mitigating byproducts formed such as bromate. Transferred ozone dosages of 3, 5, and 7 mg/L were tested on membrane effluent. Indicator CECs and estrogenic activity were monitored during the Phase 1 ozone evaluation study and their observed removal are summarized in Figure 3-2. Ozonation byproduct concentrations measured during the ozone evaluation study are shown in Figure 3-3.

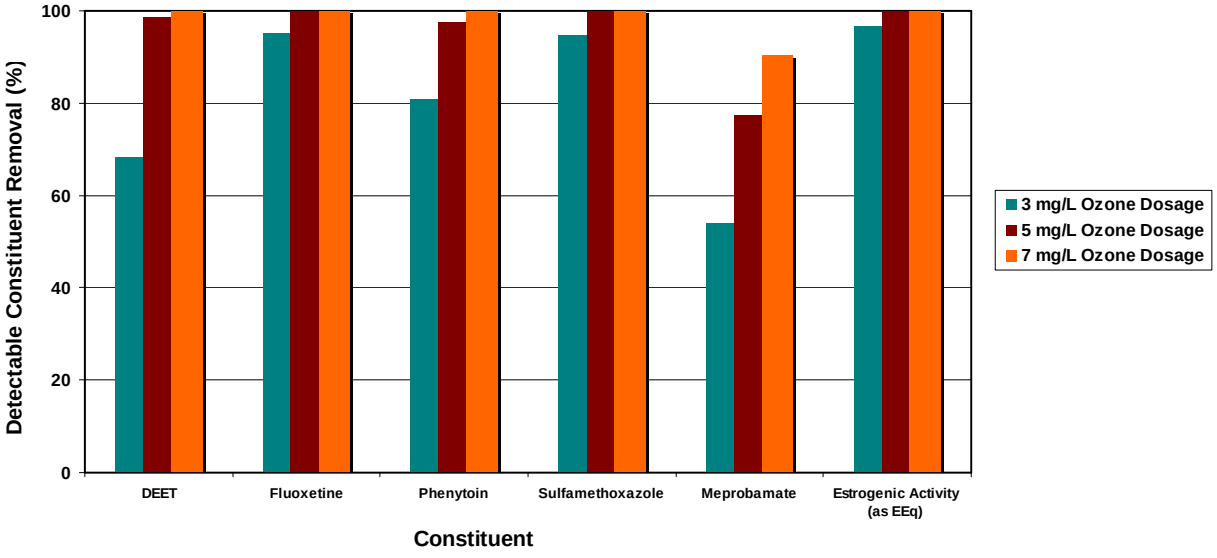


Figure 3-2
**CEC Removals by Ozone as a Function of Transferred Ozone Dose**

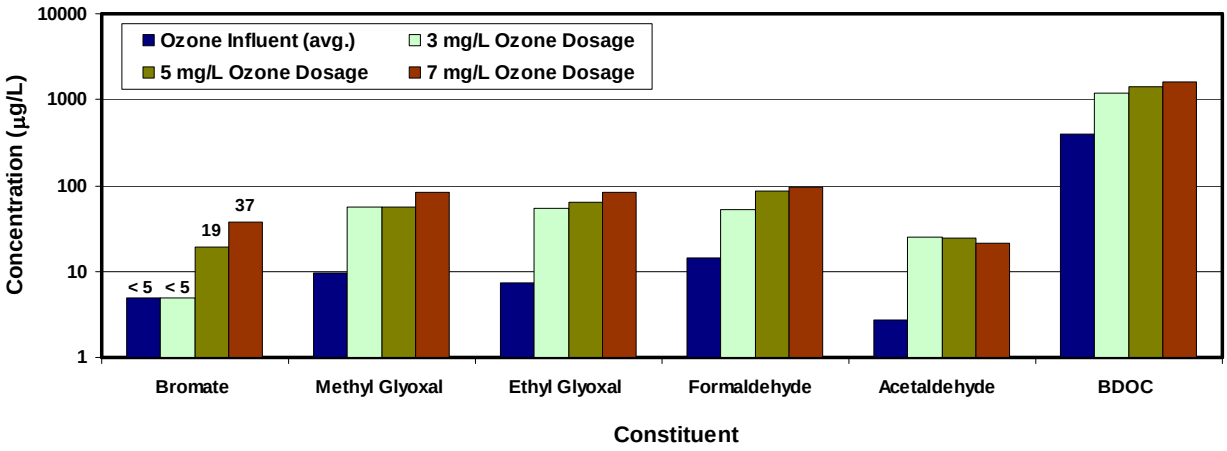


Figure 3-3
**Ozone Byproducts Observed During Phase 1 Ozone Performance Evaluation**

For RSWRF membrane filtered effluent, desired CEC and estrogenic activity removals were not achieved at an ozone dose of 3 mg/L. Ozonation at 5 mg/L or more completely removed estrogenic activity and presumably all CECs except for CECs with high resistance to ozonation. This corresponds to an ozone dose to average TOC concentration ratio of 0.86 (i.e., for an ozone dose of 5 mg/L), or more, for ozonation to be effective. Effective ozone doses of 5 µg/L and 7 µg/L resulted in effluent bromate concentrations of effluent bromate 19 µg/L and 37 µg/L, respectively. These bromate concentrations are in excess of the 10 µg/L MCL, and therefore needed to be reduced/controlled.

### 3.2.2 BROMATE MITIGATION

When using RSWRF secondary effluent, the ozonation treatment process generated effluent bromate concentrations exceeding the 10 µg/L MCL when ozone doses were 5 mg/L or more (See Figure 3-3). The literature reports several strategies for minimizing bromate formation during ozonation. These strategies include: 1) pH depression to as low as 6.8, 2) addition of ammonia, and 3) addition of peroxide (Marhaba et al., 2003). Because the average pH of RSWRF effluent was 6.9, further depression of pH would not be materially beneficial. Addition of ammonia reduces bromate generation by converting some bromine to bromamines rather than bromate, then, dissociate to non-toxic end products. Addition of peroxide reduces bromate formation by several pathways including peroxide competing with bromide for molecular ozone, and generating hydroxyl radicals that convert bromine to bromide (Amy, 1998; Marhaba et al., 2003).

For RSWRF secondary effluent, both peroxide and ammonia addition did not reduce bromate formation reliably to less than 10 µg/L when ozone doses were 7 mg/L (mgO3/mgTOC ratio of 1.2), see Appendix B. However, for the 5 mg/L ozone dose with peroxide addition, effluent bromate concentrations less than 10 µg/L appear to be possible except during summer months when secondary effluent ammonia concentrations were negligible. Highest bromate generation events coincided with significantly lower secondary effluent ammonia concentrations (see Figure 3-4). Therefore, seasonal pre-ozone ammonia addition is needed at RSWRF for MF-O3-BAC treatment each summer when warmer weather increases the efficiency of the

RSWRF nitrification process. Maintenance of ammonia concentrations greater than 1 mgN/L and year-round addition of peroxide were found to be an optimal bromate mitigation strategy for RSWRF.

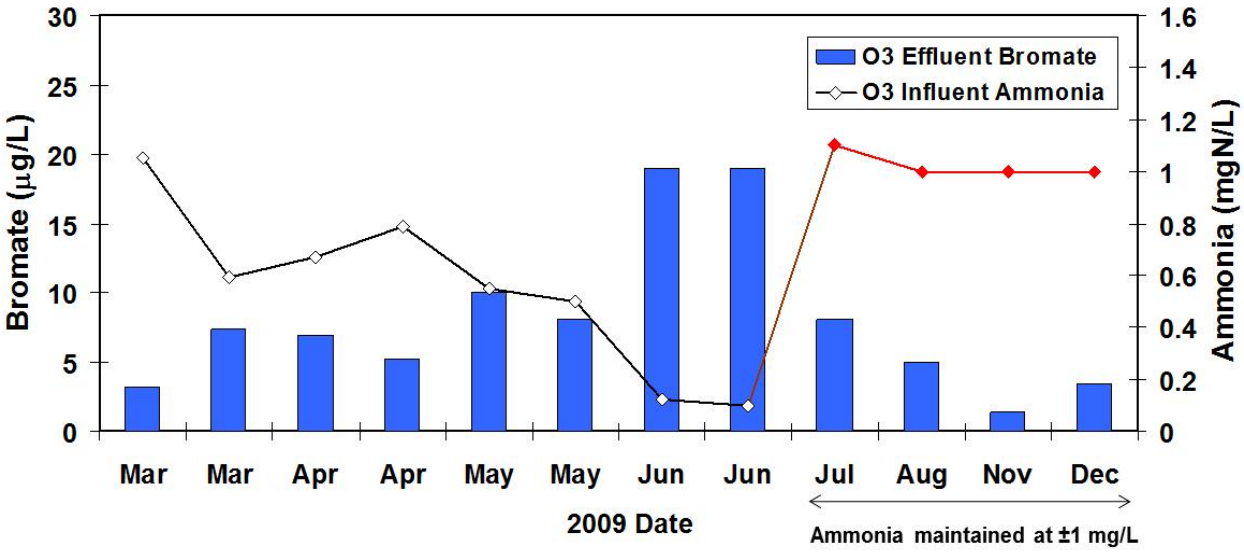


Figure 3-4
**Bromate and Ammonia Concentrations during Phase 2 Demonstration (5 mg/L Ozone and 1:1 Peroxide to Ozone Molar Ratio)**

## 3.3 PHASE 2: BAC MATURATION AND MF-O3-BAC DEMONSTRATION

After completing Phase 1, the 10-month Phase 2 demonstration of MF-O3-BAC treatment performance was conducted from February 2009 to December 2009. During Phase 2, the GAC medium of the BAC unit process was also "matured" into biologically active carbon. As will be discussed, this process took several months and had detectable effects on overall MF-O3-BAC performance. Operational conditions maintained during the Phase 2 demonstration are summarized in Table 3-2.

Table 3-2
**Phase 2 Operational Conditions**

| Parameter | Location | Units | Average/Range |
|---|---|---|---|
| Average ozone flowrate | Ozone Unit | gpm | 10.7 |
| Average BAC flowrate | BAC Unit | gpm | 10 |
| Temperature range | Secondary Effluent | °F | 74 – 55 |
| Median temperature | Secondary Effluent | °F | 66 |
| Alkalinity | Membrane Effluent | mg/L | 99 ± 13 [(a)] |
| pH | Membrane Effluent | - | 7.4 ± 0.2 [(a)] |
| Bromide | Membrane Effluent | μg/L | 260 ± 100 [(a)] |
| Gaseous ozone set point | Feed gas | % | 10 |
| Gaseous ozone | Off gas | % | 0.79 |
| Ozone dose set point | Ozone unit | mg/L | 5 |
| Peroxide:Ozone molar ratio | Ozone unit | - | 1 |
| Dissolved ozone | Ozone Effluent | μg/L | < 5 |
| Ozone contact time | Ozone unit | Min | 5 |
| BAC Empty Bed Contact Time | BAC unit | Min | 30 |
| Turbidity | BAC Effluent | NTU | 1.7 ± 1.7 [(a)] |

(a) average ± standard deviation

### 3.3.1 BAC MATURATION

Upon completion of Phase 1, the ozonated effluent (with supplemental $H_2O_2$) was plumbed to the GAC unit process to begin conversion to the BAC maturation process. To assure a natural, sustainable, endemic BAC microbial population, no supplemental carbon source or microorganisms were added to the BAC unit or ozonated effluent. The adsorption sites on the BAC were allowed to saturate naturally, and become populated with a complex population of microbes, mostly bacteria. Biological activity in the BAC was monitored by measuring PLFAs (phospholipids fatty acids) in the BAC media at various filter medium depths before each backwash (which occurred roughly every 14 days). The buildup of biomass in the upper six inches of the downflow BAC medium as a function of time based on PLFA results is shown in Figure 3-5. As shown, biomass concentrations increased from 104 cells/gram of carbon to 108 cells/gram of carbon over the course of 71 days. Thereafter, the biomass remained unchanged indicating an overall biomass maturation of BAC, though the microbial composition/population continued to evolve for months (see Figure 3-6).

The RSWRF BAC process developed a biomass and microbial community structure very comparable to those observed at the full-scale Fred Harvey Water Reclamation Plant (FHWRP) BAC unit in El Paso, Texas, even though the preceding wastewater treatment processes are substantially different. At FHWRP, the raw sewage passes through powdered activated carbon (PAC) activated sludge treatment, lime treatment, filtration, and ozonation prior to the BAC process. The current El Paso BAC medium is reportedly several years old, and is backwashed every 12 hours, not every 2 weeks as with the RSWRF BAC unit. Detailed discussions on BAC maturation and microbial characterization are presented in Appendix C.

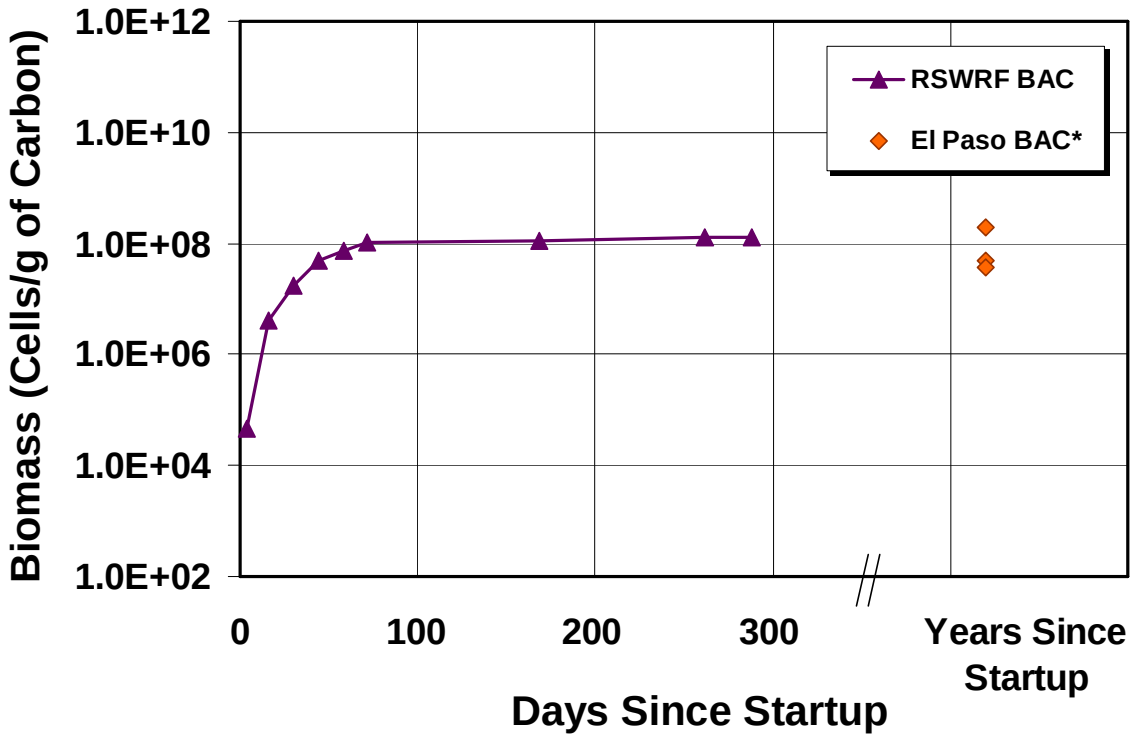


Figure 3-5
**Development of Biomass in the Upper 6 Inches of BAC Medium with Time**

*BAC located downstream of an ozonation system in Fred Harvey Water Reclamation Plant (FHWRP), El Paso, Texas.

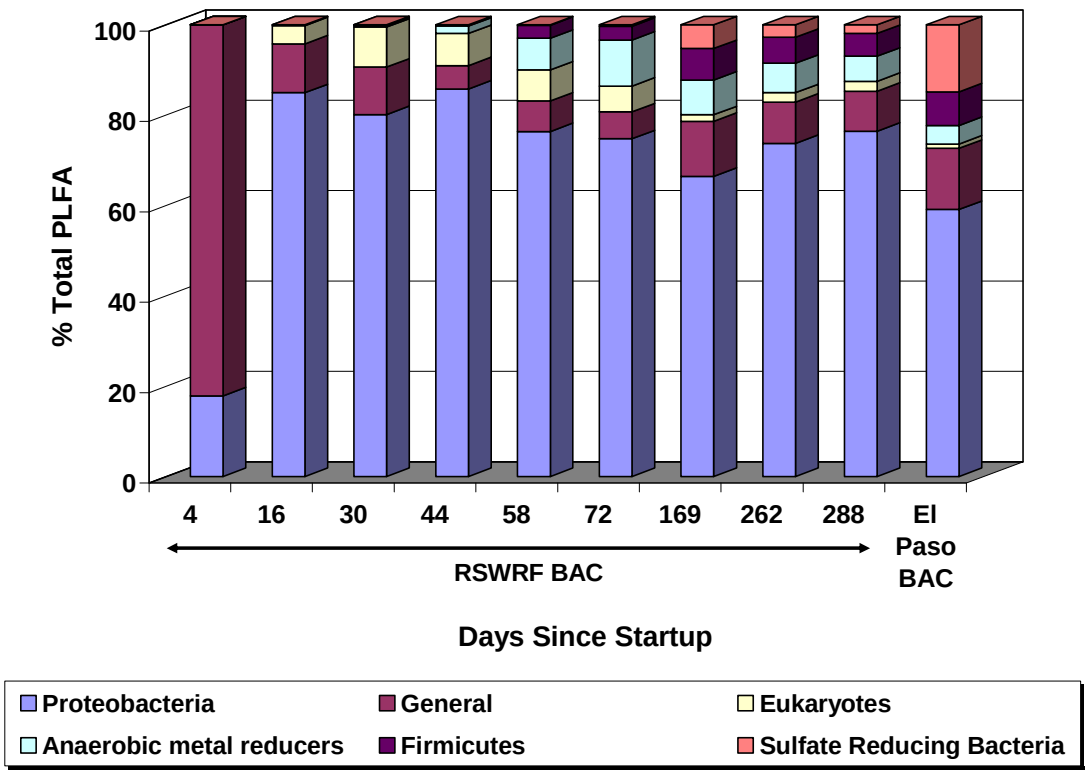


Figure 3-6
**Microbial Community Structure in the Upper 6 Inches of BAC Medium Over Time**

### 3.3.2 MF-O3-BAC PERFORMANCE DEMONSTRATION

Three sampling campaigns were conducted. Sample points included locations before and after each treatment process as shown in Figure 3-1. The first sampling campaign was conducted five months after BAC startup and after confirming the maturity of the BAC. Sampling campaign dates were selected to capture maximum effluent temperature variation from summer through winter. Secondary effluent temperature and pilot facility room temperatures measured during Phase 2 are shown in Figure 3-7.

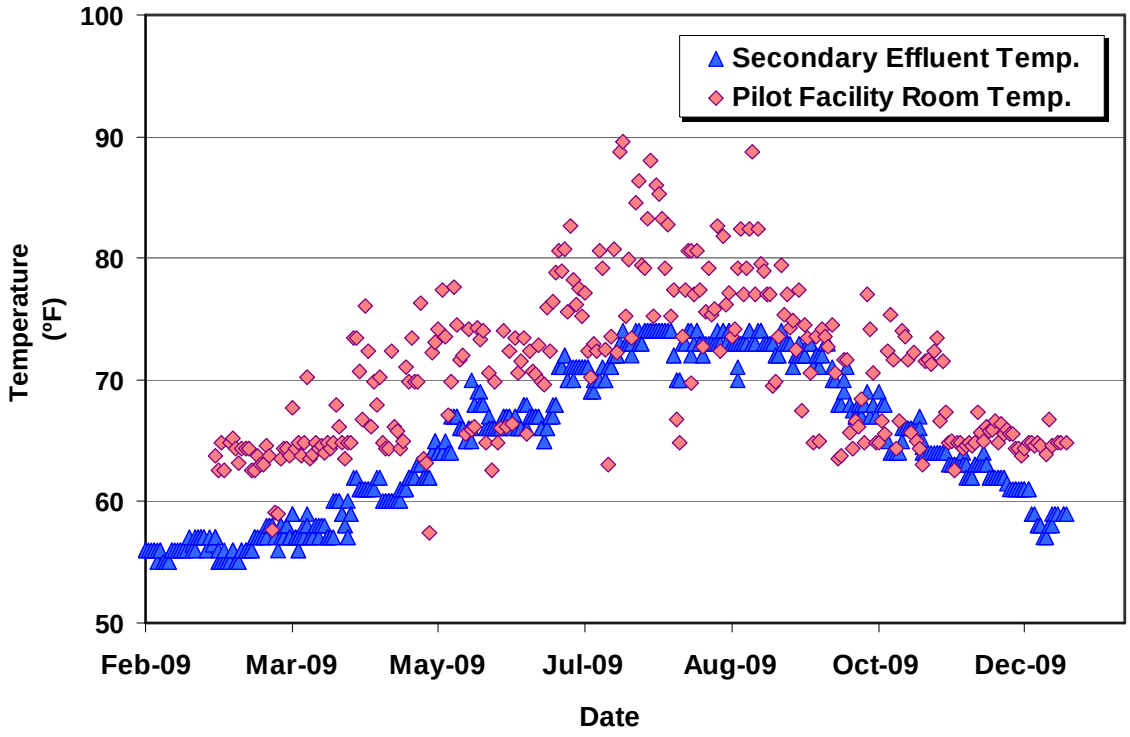


Figure 3-7
**Secondary Effluent Temperature and Pilot Facility Room Temperature Over Time**

During each sampling campaign, analyses for 490 constituents were conducted before and after each treatment step in the RSWRF demonstration project. The analytes included constituents in California's draft groundwater recharge regulations (CA recharge list; CDPH, 2008a), CECs, pathogens, drinking water contaminants, refractory organics, priority pollutants, and known and suspected byproducts. The analyte groups, together with the analytical methods employed in quantification of these constituents, are listed in Table 3-3. To our knowledge, Reno's demonstration project was the first and only non-RO project to monitor all of the contaminants specified in the CA recharge list.

This relative estrogenic activity of treated effluent expressed as Estradiol Equivalents (EEq) in ng/L was evaluated using the E-Screen and Yeast Estrogen Screen (YES) in vitro bioassays. The E-screen test uses a human breast cancer cell line (MCF-7) to determine the synergistic or additive estrogenic effects of various hormones and other CECs (Drewes et al., 2005).

To maximize the credibility and meaningfulness of the CEC results which were expected to be near to or less than best available analytical quantification limits, and therefore subject to some degree of uncertainty, field blanks and field duplicates were included in the sampling campaigns to supplement normal laboratory QA/QC checks (e.g., Lab Blank, MS/MSD). As a general check on pilot process performance and stability, aldehydes, $UVT_{254}$, TOC, BDOC, alkalinity, pH, and ammonia were monitored regularly throughout Phase 2 as well as during the three sampling campaigns. Data collected during membrane and ozone process monitoring and MF-O3-BAC effluent water quality monitoring are presented in Appendix D.

Table 3-3
**Analytical Methods Used in Quantification of Critical Constituents**

| Analyte Group | Method Name/Reference |
|---|---|
| CECs except akylphenols | EPA 1694 using ESI+, ESI- and APCI |
| Akylphenols | Lab-specific GC-MS SIM Method |
| PBDEs | EPA 1614M |
| Estrogenic Activity (E-Screen) | Drewes et al. 2005 |
| Biodegradable Dissolved Organic Carbon (BDOC) | Allgeier et al. 1996 |
| Total Organic Carbon | Standard Method 5310C |
| Trihalomethanes (THMs) | EPA 551 |
| Haloacetic Acids (HAAs) | Standard Method 6251B |
| Nitrosoamines (NDMA) | EPA 521 |
| Aldehydes | EPA 556 |
| Bromate | EPA 326 |
| Bromide | EPA 300.1 |
| VOCs | EPA 524.2 |
| SOCs | EPA 525.2. EPA 624, & EPA 625 |
| Pesticides and PCBs | EPA 505 & EPA 614 |
| Herbicides | EPA 515.4: |
| Carbamates | EPA 531.2: |
| Dioxins | EPA 1613: |
| Glyphosate | EPA 547 |
| Diquat | EPA 549.2 |
| Endothall | EPA 548 |
| Fumigants (EDB and DBCP) | EPA 540.1 |
| Tributyltin | Lab-specific GC-MS SIM Method |
| Glycols | EPA 8015B |
| Metals | EPA 200.7/200.8: |
| Total Mercury | EPA 1631 |
| Methyl Mercury | EPA 1630 |
| Hexavalent Chromium | EPA 218.6: |
| Free Cyanide | Standard Method 4500CN-F |
| Odor | Standard Method 2150B |
| Anions | EPA 300.0A, 300.B, & 317 |
| Radiological Parameters | EPA 900.0, 903.1, 904.0, 905.0, & 906.0 |
| Perchlorate | EPA 314 |
| Asbestos | EPA 100.2 |
| TDS, Corrosivity & EC | Standard Method 2450C, 2330C, & 2510B |
| Alkalinity | Standard Method 2320B |
| Anionic Surfactants as MBAS | Standard Method 5540C |

Section 4

# Results

Results from the 10-month Phase 2 demonstration of the performance of the optimized MF-O3-BAC treatment process under continuous flow field conditions are presented in tabular form in this section. The overall results have been divided into four categories to elucidate specific areas of interest:

- Overall MF-O3-BAC performance (Section 4.1)
- Effect of $H_2O_2$ addition on CEC removal (Section 4.2)
- Virus inactivation by ozone (Section 4.3)
- MF-O3-BAC performance in comparison to RO performance (Section 4.4)

## 4.1 MF-O3-BAC PERFORMANCE

Overall performance of the MF-O3-BAC pilot treatment process is presented in the following subsections:

- CECs (Section 4.1.1)
- Estrogenic activity (Section 4.1.2)
- 1,4 dioxane (Section 4.1.3)
- Ozonation byproducts (Section 4.1.4)
- TOC and BDOC (Section 4.1.5)
- UVT and turbidity (Section 4.1.6)
- Total and fecal coliform organisms (Section 4.1.7)
- Dioxins (Section 4.1.8)
- VOCs and SOCs (Section 4.1.9)
- Pesticides, herbicides, and PCBs (Section 4.1.10)
- THMFP and HAAs (Section 4.1.11)
- Other organics (Section 4.1.12)
- Inorganics (Section 4.1.13)
- General water quality parameters (Section 4.1.14)

In each subsection, constituent results are presented in one of the four following categories, based on the results:

Category A: All detectable concentrations removed by MF-O3-BAC, i.e., Category A constituents are detected at some point in the treatment process, but never in the BAC effluent.

Category B: All detectable concentrations not removed by MF-O3-BAC, i.e., Category B constituents are detected in at least one BAC effluent sample.

Category C: Concentrations not detected during the project, i.e., Category C constituents were never detected in any influent or effluent sample.

Category D: Constituents for which the results are inconsistent, i.e., Category D constituents have results that are so confounded that they cannot meaningfully be included in Categories A, B, or C.

Within each table, the result boxes are color coded:

- Grey means the constituent was not measured (NM).
- Green means the constituent was not detected
- Yellow means the result was detected.
- Orange means there is something odd about the result, e.g., :
  - There is a detectable concentration in a field blank (FB) or laboratory blank (LB).
  - A sample analytical result is detected at a concentration up to 110% of an FB or LB.
  - A field duplicate sample result is more than 50% different from the sample result.

### 4.1.1 CECs

Removals of CECs achieved by the MF-O3-BAC treatment during the 10-month Phase 2 demonstration period are summarized in Table 4-1.

Table 4-1
**CEC Removal Summary**

| Non-detects | 95 – 99% Removal* | > 99% Removal [(a)] |
|---|---|---|
| Acetaminophen | Meprobamate | Atenolol |
| Iopromide | TCEP | Amoxicillin |
| Caffeine | | Atorvastatin |
| PBDEs | | Atrazine |
| Bisphenol A | | Azithromycin |
| Ethylnylestradiol | | Benzophenone |
| Progesterone | | BHA |
| Tetstosterone | | Carbamzepine |
| | | Ciprofloxacin |
| | | Estradiol |
| | | Estrone |
| | | DEET |
| | | Diazepam |
| | | Diclofenac |
| | | Dilantin |
| | | Fluoxetine |
| | | Gemfibrozil |
| | | Ibuprofen |
| | | Naproxen |
| | | Methadone |
| | | Musk Ketone |
| | | Phenytoin |
| | | Primidone |
| | | Sulfamethoxazole |
| | | TCPP |
| | | TDCPP |
| | | Triclosan |
| | | Trimethoprin |

(a) Detectable Percent Removal

Results for all CECs monitored during Phase 2 are presented in Tables 4-2 (Categories A through D). As shown in Table 4-2 (Category A), some constituents were detected in a BAC effluent sample (e.g., estradiol), but the effluent value was not more than 10 percent greater than the corresponding field blank (FB) or laboratory blank (LB) which suggests that the sample result is questionable. Regarding Table 4-2 (Category A), it is noteworthy that the role of membrane filtration in removing CECs is minimal. CECs present in secondary effluent, in general, are not associated with particles such as would be removed by MF. A few unusual CEC removals were observed with membrane filtration in the last sampling campaign. However, ozonation was very effective in removing a wide range of CECs except for compounds that resist oxidation (e.g., flame retardants such as TCEP and TCPP). Table 4-2 (Category A & Category B) also shows that BAC is effective in removing those CECs that are resistant to oxidation.

Table 4-2 (Category A)
**CECs Removed to Detection Limits by MF-O3-BAC**

| Constituents | Unit | Sampling Campaign 1 (8/18/09) | | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | SD | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | FB | LB |
| **Hormones and EDCs** | | | | | | | | | | | | | | | | | | | | | | |
| Atrazine | ng/L | 1.5 | 1.8 | 2 | 0.5 | NM | < 0.25 | < 0.25 | < 0.25 | 0.83 | 1.1 | 0.39 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | 1.7 | 1.5 | 0.52 | < 0.25 | < 0.25 | < 0.25 |
| Benzophenone | ng/L | 320 | 330 | 250 | < 50 | NM | < 50 | < 50 | < 50 | 160 | 130 | < 50 | < 50 | < 50 | < 50 | < 50 | 130 | 140 | < 50 | < 50 | < 50 | < 50 |
| BHA | ng/L | 89 | 85 | 62 | < 1 | NM | < 1 | < 1 | < 1 | 69 | 30 | < 1 | < 1 | < 1 | < 1 | < 1 | 70 | 35 | < 1 | < 1 | < 1 | < 1 |
| Octylphenol | ng/L | 31 | 29 | < 25 | < 25 | NM | < 25 | < 25 | < 25 | < 26 | < 26 | < 25 | < 25 | < 25 | < 25 | < 25 | < 26 | < 26 | < 25 | < 25 | < 25 | < 25 |
| Estradiol | ng/L | 5.9 | 6.6 | 3.4 | 1.9 | NM | 1.8 | 2 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 |
| Estrone | ng/L | 110 | 120 | 23 | 0.52 | NM | 0.5 | 0.47 | < 0.2 | 52 | 4.5 | < 0.2 | < 0.2 | < 0.2 | < 0.2 | < 0.2 | 34 | 8.1 | < 0.2 | < 0.2 | < 0.2 | < 0.2 |
| **Pharmaceuticals** | | | | | | | | | | | | | | | | | | | | | | |
| Atenolol (Lab 2) | ng/L | 1200 | 1300 | 1100 | 15 | NM | < 100 | < 100 | < 1 | 860 | 790 | 9.2 | < 1 | < 1 | < 1 | < 1 | 800 | 780 | 7.5 | < 1 | < 1 | < 1 |
| Amoxicillin | ng/l | 580 | NM | 520 | 0.74 | 0.72 | < 10 | 0.70 | 0.765 | 920 | 640 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | 3400 | 1900 | < 2.0 | < 2.0 | < 2.0 | < 2.0 |
| Atorvastatin (Lab 1) | ng/l | 9.9 | NM | 8.1 | < 1.1 | < 1.1 | < 0.11 | < 0.11 | < 0.11 | 10 | 5.0 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | 23 | 3.5 | < 0.11 | < 0.11 | < 0.11 | < 0.11 |
| Atorvastatin (Lab 2) | ng/L | 18 | 18 | 17 | < 0.5 | NM | < 0.5 | < 0.5 | < 0.5 | 20 | 8.1 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | 22 | 7.3 | < 0.5 | < 0.5 | < 0.5 | < 0.5 |
| Azithromycin | ng/l | 250 | NM | 120 | < 22 | < 22 | < 2.2 | < 2.2 | < 2.2 | 250 | 84 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | 470 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 |
| Carbamazepine (Lab 2) | ng/L | 240 | 250 | 200 | 0.98 | NM | 0.88 | 0.82 | < 0.5 | 300 | 310 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | 230 | 230 | < 0.5 | < 0.5 | < 0.5 | < 0.5 |
| Ciprofloxacin | ng/l | 450 | NM | 290 | < 14 | 39 | < 1.4 | < 1.4 | < 1.4 | 200 | 160 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | 440 | 290 | < 1.4 | < 1.4 | < 1.4 | < 1.4 |
| Diazepam (Lab 1) | ng/l | 1.1 | NM | 1.1 | 0.18 | 0.23 | < 0.14 | 0.15 | < 0.14 | 1.2 | 0.96 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | 3.2 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 |
| Diazepam (Lab 2) | ng/L | 3.3 | 3.1 | 3.2 | < 0.25 | NM | < 0.25 | < 0.25 | < 0.25 | 3 | 3 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | 1.8 | 2.2 | < 0.25 | < 0.25 | < 0.25 | < 0.25 |
| Diclofenac | ng/L | 95 | 100 | 160 | < 0.5 | NM | < 0.5 | < 0.5 | < 0.5 | 98 | 79 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | 95 | 88 | < 0.5 | < 0.5 | < 0.5 | < 0.5 |
| Dilantin | ng/L | 260 | 280 | 140 | 3 | NM | < 10 | < 10 | < 10 | 310 | 110 | 3 | < 1 | < 1 | < 1 | < 1 | 190 | 200 | 3.3 | < 1 | < 1 | < 1 |
| Fluoxetine (Lab 1) | ng/l | 3.1 | NM | 1.7 | 2.0 | < 0.08 | < 0.08 | < 0.08 | < 0.08 | 3.5 | 2.9 | < 0.08 | < 0.08 | < 0.08 | < 0.08 | < 0.08 | 3.1 | 2.6 | < 0.08 | < 0.08 | < 0.08 | < 0.08 |
| Fluoxetine (Lab 2) | ng/L | 52 | 51 | 34 | < 0.5 | NM | < 0.5 | < 0.5 | < 0.5 | 72 | 46 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | 51 | 32 | < 0.5 | < 0.5 | < 0.5 | < 0.5 |
| Gemfibrozil (Lab 1) | ng/l | 49 | NM | 36 | < 0.08 | < 0.08 | < 0.08 | < 0.08 | < 0.08 | 36 | 27 | < 0.08 | < 0.08 | < 0.08 | < 0.08 | < 0.08 | 52 | 43 | 0.19 | 0.20 | < 0.08 | 0.251 |
| Gemfibrozil (Lab 2) | ng/L | 110 | 100 | 82 | < 0.25 | NM | < 0.25 | < 0.25 | < 0.25 | 65 | 50 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | 58 | 52 | < 0.25 | < 0.25 | < 0.25 | < 0.25 |
| Ibuprofen (Lab 1) | ng/l | 8.0 | NM | 7.4 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | 0.42 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | 4.8 | 5.3 | < 0.39 | < 0.39 | < 0.39 | < 0.39 |
| Ibuprofen (Lab 2) | ng/L | 7.7 | 8.2 | 8.6 | 2.1 | NM | 1.5 | 1.7 | 1.3 | < 1.1 | < 1.1 | < 1 | < 1 | < 1 | < 1 | < 1 | 9 | 7.6 | < 1 | < 1 | < 1 | < 1 |
| Naproxen (Lab 1) | ng/l | 26 | NM | 23 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | 7.6 | 6.8 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | 28 | 24 | < 0.25 | < 0.25 | < 0.25 | < 0.25 |
| Naproxen (Lab 2) | ng/L | 41 | 41 | 43 | < 0.5 | NM | < 0.5 | < 0.5 | < 0.5 | 13 | 12 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | 28 | 24 | < 0.5 | < 0.5 | < 0.5 | < 0.5 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate;
FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

Table 4-2 (Category A) - Continued
**CECs Removed to Detection Limits by MF-O3-BAC**

| Constituents | Unit | Sampling Campaign 1 (8/18/09) | | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | SD | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | FB | LB |
| **Pharmaceuticals *Continued*** | | | | | | | | | | | | | | | | | | | | | | |
| Methadone | ng/l | 36 | NM | 32 | 0.31 | 0.095 | 0.13 | < 0.04 | 0.134 | 60 | 29 | < 0.04 | < 0.04 | < 0.04 | < 0.04 | < 0.04 | 100 | 38 | < 0.04 | < 0.04 | < 0.04 | < 0.04 |
| Phenytoin | ng/l | 190 | NM | 150 | 4.2 | 2.6 | < 1.0 | < 1.0 | < 1.0 | 200 | 140 | 3.6 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 780 | 740 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Primidone (Lab 1) | ng/l | 170 | NM | 190 | 4.6 | 12 | < 0.60 | < 0.60 | < 0.60 | 90 | 68 | < 0.60 | < 0.60 | < 0.60 | < 0.60 | < 0.60 | 160 | 130 | < 0.60 | < 0.60 | < 0.60 | < 0.60 |
| Sulfamethoxazole (Lab 2) | ng/L | 1100 | 1100 | 880 | 9 | NM | < 0.25 | < 0.25 | < 0.25 | 1100 | 900 | 5.7 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | 590 | 720 | 3.4 | < 0.25 | < 0.25 | < 0.25 |
| Trimethoprim (Lab 1) | ng/l | 170 | NM | 130 | < 2.4 | 0.52 | < 0.24 | < 0.24 | < 0.24 | 210 | 130 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | 430 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 |
| Trimethoprim (Lab 2) | ng/L | 430 | 430 | 300 | < 0.25 | NM | < 0.25 | < 0.25 | < 0.25 | 460 | 240 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | 400 | 350 | < 0.25 | < 0.25 | < 0.25 | < 0.25 |
| **Personal Care Products** | | | | | | | | | | | | | | | | | | | | | | |
| Caffeine (Lab 1) | ug/l | 15 | NM | 12 | < 0.31 | < 3.1 | < 0.31 | < 0.31 | 0.477 | 14 | 9.6 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | 46 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 |
| DEET (Lab 1) | ng/l | 21 | NM | 24 | 0.68 | 0.64 | < 0.06 | < 0.06 | < 0.06 | 270 | 300 | 4.6 | < 0.06 | < 0.06 | < 0.06 | < 0.06 | 53 | 52 | 2.4 | < 0.06 | 1.2 | < 0.06 |
| DEET (Lab 2) | ng/L | 81 | 75 | 83 | 3 | NM | < 1 | < 1 | < 1 | 860 | 920 | 14 | < 1 | < 1 | < 1 | < 1 | 88 | 89 | 3.4 | < 1 | < 1 | < 1 |
| Musk Ketone | ng/L | 45 | 51 | 30 | < 25 | NM | < 25 | < 25 | < 25 | 50 | < 26 | < 25 | < 25 | < 25 | < 25 | < 25 | 45 | 46 | < 25 | < 25 | < 25 | < 25 |
| TCEP (Lab 2) | ng/L | 620 | 640 | 610 | 520 | NM | < 10 | < 10 | < 10 | 480 | 480 | 370 | < 10 | < 10 | < 10 | < 10 | 390 | 380 | 320 | < 10 | < 10 | < 10 |
| TCPP (Lab 2) | ng/L | 2100 | 2200 | 2400 | 1700 | NM | < 1000 | < 1000 | < 1000 | 2200 | 2400 | 1100 | < 100 | < 100 | < 100 | < 100 | 1300 | 1600 | 1600 | < 100 | < 100 | < 100 |
| Triclosan (Lab 1) | ng/l | 36 | NM | 2.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | 38 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | 90 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 |
| Triclosan (Lab 2) | ng/L | 62 | 59 | 1.4 | < 1 | NM | < 1 | < 1 | < 1 | 68 | 1.5 | < 1 | < 1 | < 1 | < 1 | < 1 | 68 | < 1.1 | < 1 | < 1 | < 1 | < 1 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate;
FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

Table 4-2 (Category B)
**CECs Detected At Least Once in MF-O3-BAC Effluent**

| Constituents | Unit | Sampling Campaign 1 (8/18/09) | | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | SD | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | FB | LB |
| **Pharmaceuticals** | | | | | | | | | | | | | | | | | | | | | | |
| Atenolol (Lab 1) | ng/l | 570 | NM | 700 | 5.4 | 15 | 0.37 | < 0.20 | < 0.20 | 200 | 240 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | 230 | 160 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |
| Cotinine | ng/l | 93 | NM | 17 | 21 | 11 | < 0.35 | < 0.35 | < 0.35 | 16 | 24 | 9.0 | 2.3 | 2.8 | 0.49 | 0.913 | <0.35 | <0.35 | 12 | < 0.35 | < 0.35 | < 0.35 |
| Carbamazepine (Lab 1) | ng/l | 120 | NM | 120 | < 0.8 | < 0.08 | 0.16 | < 0.08 | < 0.08 | 710 | 750 | < 0.08 | < 0.08 | < 0.08 | < 0.08 | < 0.08 | 230 | 220 | < 0.08 | < 0.08 | < 0.08 | < 0.08 |
| Primidone (Lab 2) | ng/L | 240 | 250 | 250 | 11 | NM | < 0.5 | < 0.5 | < 0.5 | 230 | 270 | 11 | 0.66 | < 0.5 | < 0.5 | < 0.5 | 170 | 190 | 7.2 | 0.62 | < 0.5 | < 0.5 |
| Sulfamethoxazole (Lab 1) | ng/l | 390 | NM | 380 | 2.2 | 2.9 | 0.26 | < 0.19 | < 0.19 | 320 | 340 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | 530 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 |
| Meprobamate (Lab 1) | ng/l | NM | | | | | | | | 290 | 290 | 36 | 3 | 3.2 | < 0.36 | < 0.36 | 480 | 430 | 51 | < 0.36 | < 0.36 | < 0.36 |
| Meprobamate (Lab 2) | ng/L | 710 | 700 | 700 | 130 | NM | 0.57 | 0.57 | < 0.25 | 830 | 840 | 97 | 8 | < 0.25 | < 0.25 | < 0.25 | 550 | 590 | 89 | 7.2 | < 0.25 | < 0.25 |
| **Personal Care Products** | | | | | | | | | | | | | | | | | | | | | | |
| TCEP (Lab 1) | ng/l | 400 | NM | 430 | 350 | 430 | < 0.34 | < 0.34 | < 0.34 | 98 | 75 | 220 | 2.0 | 1.8 | < 0.34 | < 0.34 | 360 | 360 | 290 | < 0.34 | < 0.34 | 0.951 |
| TCPP (Lab 1) | ng/l | 740 | NM | 640 | 700 | 720 | < 0.27 | 1.9 | < 0.27 | 500 | 550 | 450 | 2.1 | 1.5 | 0.61 | < 0.27 | 440 | 360 | 390 | 3.8 | 2.2 | 2.43 |
| TDCPP | ng/l | 690 | NM | 610 | 650 | 710 | 0.71 | 1.3 | 0.955 | 450 | 490 | 440 | 0.68 | 0.79 | 0.58 | < 0.47 | 760 | 770 | 790 | < 0.47 | 7.8 | < 0.47 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate;
FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

### Limited Occurrence of Some Commonly Reported Municipal Effluent CECs

Commonly reported municipal effluent CECs such as acetaminophen, bisphenol A (BPA), iopromide, ethynylestradiol, PBDEs, and estradiol were not found in RSWRF secondary effluent, presumably as a result of the long SRT and/or collection system pretreatment practices, see Table 4-2 (Category C). This observation is in agreement with reports by others (Clara et al., 2005).

Table 4-2 (Category C)
**CECs Not Detected in Any Sample**

| Constituents | Unit | Sampling Campaign 1 (8/18/09) | | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | SD | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | FB | LB |
| **Pharmaceuticals** | | | | | | | | | | | | | | | | | | | | | | |
| Acetaminophen | ng/l | < 1.4 | NM | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 |
| Iopromide (Lab 1) | ng/l | < 1.8 | NM | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 5.0 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 |
| Iopromide (Lab 2) | ng/L | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 11 | < 11 | < 10 | < 10 | < 10 | < 10 |
| **Personal Care Products** | | | | | | | | | | | | | | | | | | | | | | |
| Caffeine (Lab 2) | ng/L | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5.3 | < 5.3 | < 5 | < 5 | < 5 | < 5 |
| PBDE-100 | ug/l | < 12 | NM | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 | < 12 |
| PBDE-153 | ug/l | < 9 | NM | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 |
| PBDE-154 | ug/l | < 11 | NM | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 | < 11 |
| PBDE-47 | ug/l | < 7 | NM | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 | < 7 |
| PBDE-99 | ug/l | < 9 | NM | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 | < 9 |
| **Hormones and EDCs** | | | | | | | | | | | | | | | | | | | | | | |
| Bisphenol A (Lab 1) | ng/l | 18 | NM | 22 | < 0.27 | < 0.27 | < 0.27 | 2200 | 4.92 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | 0.292 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | 9.68 |
| Bisphenol A (Lab 2) | ng/L | < 5.3 | < 5.3 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5.3 | < 5.3 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5.3 | < 5.3 | < 5 | < 5 | < 5 | < 5 |
| Ethynylestradiol | ng/L | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 |
| Progesterone | ng/L | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 |
| Testosterone | ng/L | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 | < 0.5 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate;
FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

### QA/QC Checks as Related to Inconsistent CEC Results

From QA/QC checks, the unusual occurrence of two CECs (salicylic acid and bisphenol A) were explained. Salicylic acid was consistently detected in the lab water (i.e., the lab blank), see Table 4-2 (Category D). The 2200 ng/L concentration of Bisphenol A (BPA) in the campaign 1 field blank appears to have resulted from storing the bottled water for the blank in a plastic container for several days before use, see Table 4-2 (Category C). For campaigns 2 and 3, potable water treated with the RSWRF lab MilliQ water purification system was used as the field blank. Concentrations of BPA in field blanks of campaigns 2 and 3 were less than the detection limit, see Table 4-2 (Category C).

Table 4-2 (Category D)
**Inconsistent CEC Results**

| Constituents | Unit | Sampling Campaign 1 (8/18/09) | | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | SD | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | FB | LB |
| **Pharmaceuticals** | | | | | | | | | | | | | | | | | | | | | | |
| Salicylic Acid | ng/l | 19 | NM | 23 | 18 | 19 | 15 | 85 | 13.5 | 19 | 19 | 19 | 14 | 15 | 9.0 | 5.71 | 37 | 56 | 47 | 33 | 52 | 19.5 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate;
FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

### Removal of Flame Retardants

Mechanisms facilitating CEC removal (especially flame retardant removal) in BAC necessitate further discussion. Chlorinated organophosphates such as TCEP, TCPP and TDCPP are becoming widely used flame retardants in recent years as a replacement for recalcitrant, highly controversial, PBDEs (ASTOR, 2009). Flame retardants have high frequency of detection in wastewater effluent as they are not eliminated during conventional wastewater treatment. They are engineered to withstand fire (i.e. oxidation), and typically consist of a short chain of carbon atoms with a polar functional group. As a consequence, flame retardant removal during ozone-based oxidation is found to be marginal, as expected. Excellent removals (>99%) of flame retardants were observed during BAC treatment as noted in Table 4-2 (Category B) for TCEP and TCPP. Several physical, chemical, and/or biological mechanisms may be responsible for flame retardant removal during BAC treatment. This is still under investigation. Andersen, et al. (2006) has investigated flame retardant removal in GAC used in drinking water systems. They found that drinking water GAC with known biological activity removed greater amounts of flame retardants when compared to GACs without any known biological activity (Andersen et al., 2006). Bench-scale adsorption experiments in wastewater conducted by Snyder et al. (2007) showed effective removal of flame retardants by GAC. The data from the bench-scale studies using drinking water (TOC = 3 mg/L) spiked with average TCEP concentration of 178 ng/L showed 5 percent breakthrough of TCEP after treating 11,900 bed volumes (conventional GAC) to 37,100 bed volumes (tailored GAC). 20 percent breakthrough of TCEP occurred after 15,200 bed volumes (conventional GAC) to 43,600 bed volumes (tailored GAC). Significant breakthrough of TCEP was not observed in Reno BAC unit with conventional GAC treating ozone effluent (TOC = 5.8 mg/L) with an average TCEP concentration of 286 ng/L after 12,833 bed volumes of through flow during the Phase 2 demonstration (see Table 4-3). Lack of TCEP breakthrough with conventional GAC matured to BAC treating effluent with higher TCEP and TOC concentrations indicates that removal of flame retardants in BAC may be governed by more than GAC adsorption, as also suggested by the work of Andersen et al. (2006).

Table 4-3
**Flame Retardants Removal in BAC**

| | Sampling Campaign 1 | | Sampling Campaign 2 | | Sampling Campaign 3 | |
|---|---|---|---|---|---|---|
| Date | 8/18/09 | | 11/17/09 | | 12/9/09 | |
| Days Since Startup | 170 | | 261 | | 283 | |
| Bed Volumes Treated | 7,931 | | 11,910 | | 12,833 | |
| **Sample Location** | **O3 Effluent** | **BAC Effluent** | **O3 Effluent** | **BAC Effluent** | **O3 Effluent** | **BAC Effluent** |
| TCEP (ng/L) | 350 | <0.34 | 220 | 2 | 290 | <0.34 |
| TCPP (ng/L) | 700 | <0.27 | 450 | 2.1 | 390 | 3.8 |
| TDCPP (ng/L) | 650 | 0.71 | 440 | 0.68 | 790 | <0.47 |

### 4.1.2 ESTROGENIC ACTIVITY

Average estrogenic activities of secondary effluent, membrane effluent, ozone-based oxidation effluent and BAC effluent was measured by the E-screen and Yeast Estrogen Screen (YES) bioassays are shown in Figure 4-1. As shown, MF-O3-BAC (using a 5 mg/L ozone dose with peroxide) removed estrogenic activity to the level measured in the field blanks.

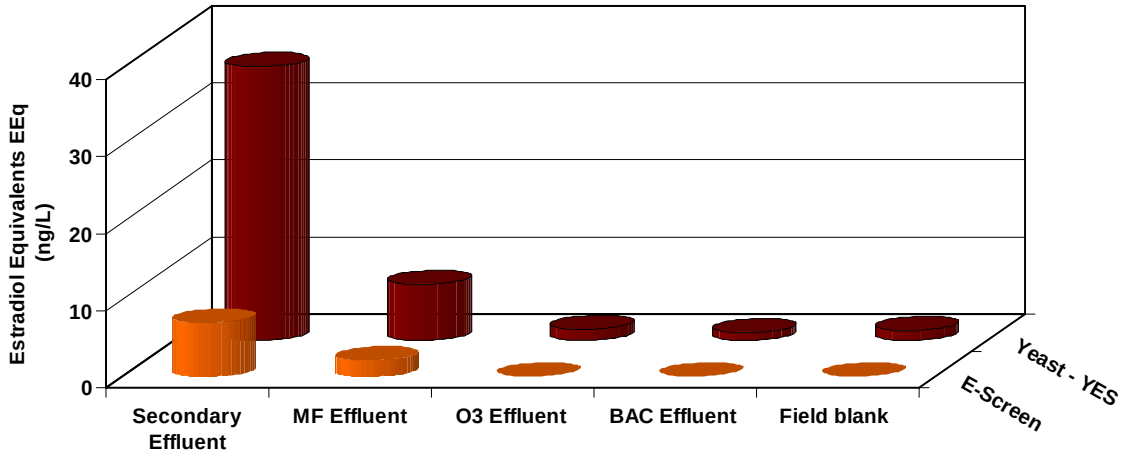


Figure 4-1
**E-Screen and Yeast Estrogen Screen (YES) Results**

### 4.1.3 1,4 DIOXANE

1,4 Dioxane is used primarily as a stabilizer for the widely used industrial solvent, 1,1,1 trichloroethane (TCA). 1,4 dioxane is a constituent of special concern because it is resistant to biodegradation, highly soluble in water, does not readily bind to solids, and readily leaches into groundwater. Exposure to high levels of 1,4 dioxane can result in liver and kidney damage. 1,4 dioxane results are presented in Table 4-4. Over 75% removal of 1,4 dioxane was observed during ozonation. BAC was ineffective at removing the residual 1,4 dioxane concentration.

Table 4-4 (Category B)
**1,4 Dioxane Detected At Least Once in MF-O3-BAC Effluent**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| 1,4-Dioxane | ug/l | | 1.7 | 1.6 | 0.38 | 0.38 | 0.43 | < 0.13 | < 0.13 | 1.3 | 1.3 | 0.31 | 0.31 | 0.30 | < 0.13 | < 0.13 | 1.7 | 1.7 | 0.35 | 0.35 | NM | < 0.13 | < 0.13 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate;
FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

### 4.1.4 OZONATION BYPRODUCTS: NDMA, BROMATE AND ALDEHYDES

Occurrence, formation, and removal of known ozonation byproducts are presented in Figures 4-2 and 4-3, and Tables 4-5. Secondary effluent and membrane effluent NDMA concentrations were close to the detection levels (See Figure 4-2). Ozone-based oxidation increased the NDMA by 6 to 11 ng/L confirming the findings of Andrzejewski et al. (2007). NDMA concentrations were consistently below the detection level of 0.28 ng/L after BAC. Anoxic and aerobic biodegradation of NDMA has been reported recently (Nalinakumari et al., 2010). Considering the findings of these reports and the occurrence of an aerobic environment in BAC following ozonation, NDMA removal during BAC treatment could be due to biodegradation.

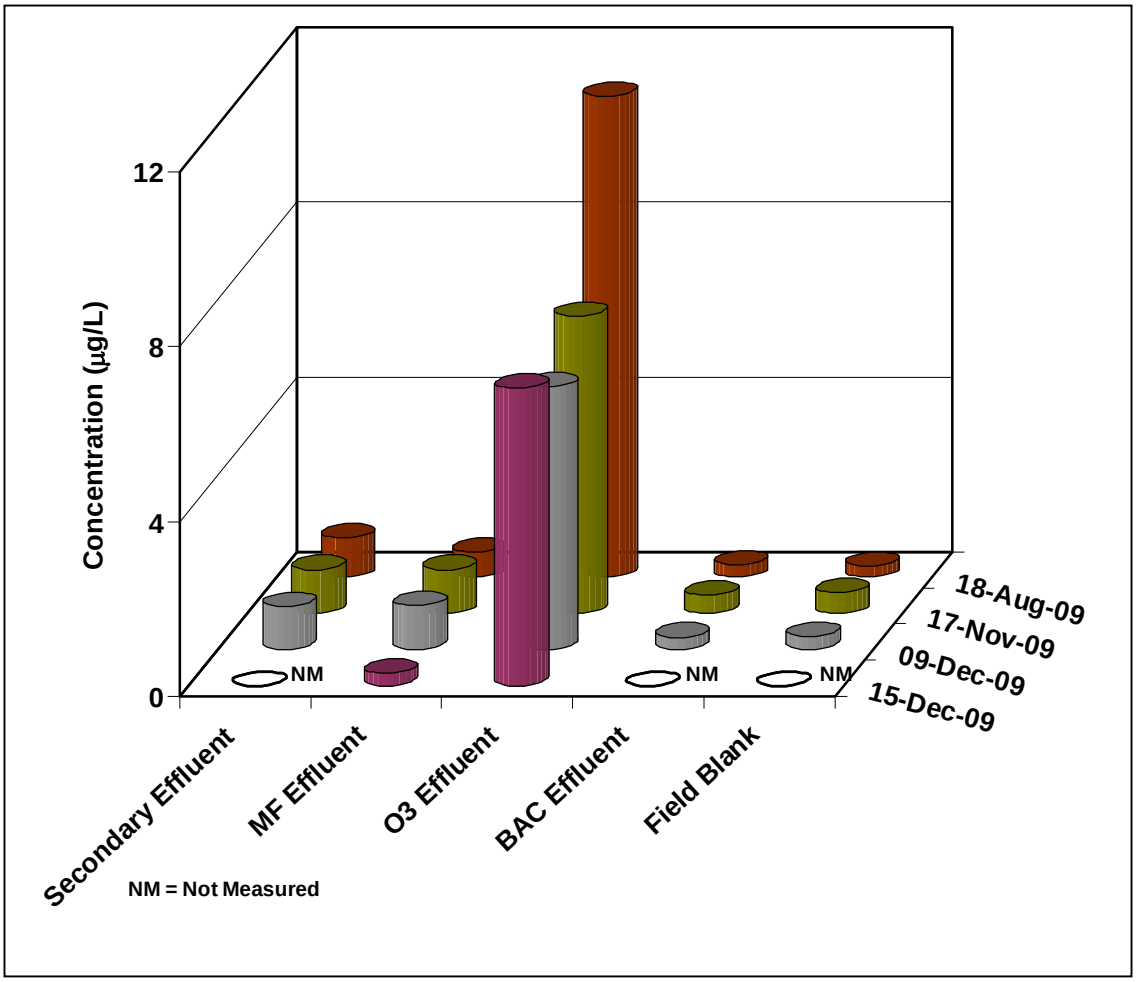


Figure 4-2
**NDMA: Occurrence, Formation, and Removal**

Concentrations of aldehydes and glyoxals (i.e. known ozonation byproducts), before and after ozonation and BAC treatment are shown in Figure 4-3. Glyoxal removal data shown in Figure 4-3 after 44 days of BAC maturation (mid-April 2009) suggest that biodegradation could be a dominant mechanism for this contaminant. Properties of glyoxal reported elsewhere support the findings of this study. Previous data show adsorption of glyoxal is highly unlikely due to its low octanol-water coefficient (OECD, 2004), and glyoxal is readily biodegradable (Kielhorn et al., 2004). In addition to glyoxal, BAC was effective in removing virtually all other byproducts that were monitored since the startup even though the concentrations of the byproducts showed variations (see Figure 4-3 and Table 4-5).

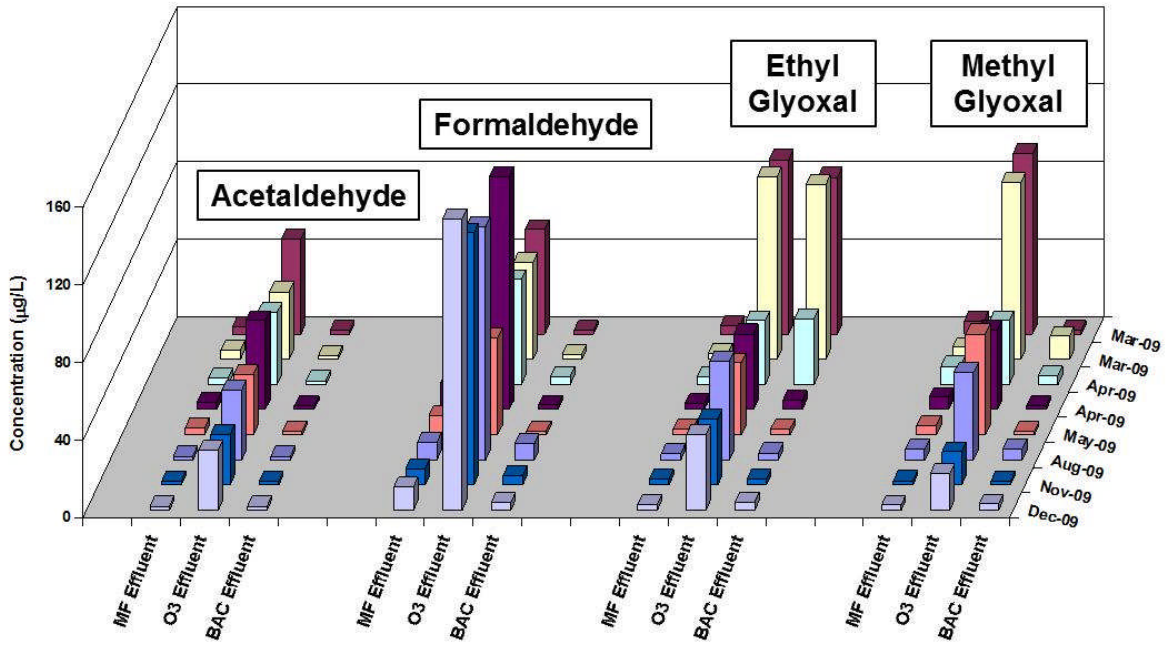


Figure 4-3
**Aldehydes and Glyoxals: Occurrence, Formation, and Removal**

## Table 4-5 (Category A)
## Ozonation Byproducts Removed to Detection Limits by MF-O3-BAC

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Aldehydes** | | | | | | | | | | | | | | | | | | | | | | | |
| Acetaldehyde | ug/l | | 3.5 | 2.0 | 36 | 36 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | 2.1 | 26 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | 31 | < 1.0 | < 1.0 | < 1.0 | < 1.0 |
| Propanal | ug/l | | < 0.70 | < 0.70 | 3.2 | 3.2 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | 4.4 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | 2.8 | < 0.70 | < 0.70 | < 0.70 | < 0.70 |
| **Nitrosamines** | | | | | | | | | | | | | | | | | | | | | | | |
| N-Nitrosodimethylamine (NDMA) | ng/l | | 0.89 | 0.57 | 11 | 11 | < 0.28 | < 0.28 | < 0.28 | 1.0 | 1.0 | 6.8 | 0.41 | 0.30 | 0.47 | 0.758 | 0.99 | 1.0 | 6.0 | < 0.28 | NM | 0.30 | < 0.28 |
| N-Nitrosodi-n-butylamine | ng/l | | 0.65 | 1.1 | < 0.59 | < 0.59 | < 0.59 | 0.75 | 0.648 | < 0.59 | < 0.59 | < 0.59 | < 0.59 | < 0.59 | < 0.59 | < 0.59 | < 0.59 | < 0.59 | < 0.59 | < 0.59 | NM | 0.68 | < 0.59 |
| N-Nitrosodiethylamine | ng/l | | 1.5 | 1.0 | 2.5 | 4.7 | < 0.72 | < 0.72 | < 0.72 | < 0.72 | < 0.72 | < 0.72 | < 0.72 | < 0.72 | < 0.72 | < 0.72 | < 0.72 | < 0.72 | < 0.72 | < 0.72 | NM | < 0.72 | < 0.72 |
| N-Nitrosodi-n-propylamine | ng/l | | 1.7 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.41 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.41 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | NM | < 0.35 | < 0.41 |
| N-Nitrosopiperidine | ng/l | | < 0.71 | < 0.71 | 1.8 | 1.2 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | NM | < 0.71 | < 0.71 |
| N-Nitrosopyrrolidine | ng/l | | < 0.66 | < 0.66 | 1.2 | 1.2 | < 0.66 | < 0.66 | < 0.66 | < 0.66 | < 0.66 | < 0.66 | < 0.66 | < 0.66 | < 0.66 | < 0.66 | < 0.66 | < 0.66 | < 0.66 | < 0.66 | NM | < 0.66 | < 0.66 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate; FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

## Table 4-5 (Category B)
## Ozonation Byproducts Detected At Least Once in MF-O3-BAC Effluent

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Aldehydes** | | | | | | | | | | | | | | | | | | | | | | | |
| Formaldehyde | ug/l | 100 | 9.2 | 9.0 | 120 | 120 | 8.4 | < 0.50 | < 0.50 | 8.9 | 8.4 | 130 | 4.9 | 5.7 | 2.4 | < 0.50 | 9.5 | 12 | 150 | 4.1 | 6.8 | < 0.50 | < 0.50 |
| Glyoxal | ug/l | | 3.3 | 3.2 | 51 | 54 | 3.6 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | 34 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | 2.9 | 39 | 4.2 | 2.6 | < 1.1 | < 1.1 |
| Methyl Glyoxal | ug/l | | 5.2 | 5.5 | 45 | 51 | 5.8 | < 0.50 | < 0.50 | 2.2 | 2.2 | 17 | 2.1 | 1.9 | < 0.50 | < 0.50 | 2.5 | 2.5 | 19 | 3.3 | < 0.50 | < 0.50 | < 0.50 |
| **Nitrosamines** | | | | | | | | | | | | | | | | | | | | | | | |
| N-Nitrosomethylethylamine | ng/l | | < 0.28 | < 0.28 | < 0.28 | < 0.28 | 1.5 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | NM | < 0.28 | < 0.28 |

Table 4-5 (Category C)
**Ozonation Byproducts Not Detected in Any Sample**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Aldehydes** | | | | | | | | | | | | | | | | | | | | | | | |
| Benzaldehyde | ug/l | | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |
| Butanal | ug/l | | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 |
| Crotonaldehyde | ug/l | | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 | < 0.80 |
| Cyclohexanone | ug/l | | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 |
| Decanal | ug/l | | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 |
| Heptanal | ug/l | | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |
| Hexanal | ug/l | | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 |
| Nonanal | ug/l | | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 |
| Pentanal | ug/l | | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate; FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

### 4.1.5 TOC AND BDOC

Membrane filtration removes TOC associated with particulates. Ozonation, though an oxidation process, is not expected to remove TOC at dosages utilized for refractory organics removal based on previous studies. This is because, in this case, ozone oxidation appears to cleave aromatic and long-chain aliphatic organic compounds into short-chain organic compounds, but not to mineralize organic carbon to inorganic carbon dioxide. However, the cleavages of these organic compounds transform slowly biodegradable organics to readily biodegradable organics, resulting in an increase in BDOC across the ozonation unit, as shown in Figure 4-5. The BAC unit removes the ozone-created BDOC to background concentrations, and in doing so reduces TOC and DOC. BAC effluent TOC increased over time to a stable concentration of about 3.5 mg/L, suggesting the loss of TOC adsorption by GAC over time. The chemical nature and significance of the TOC leaving BAC requires further investigation.

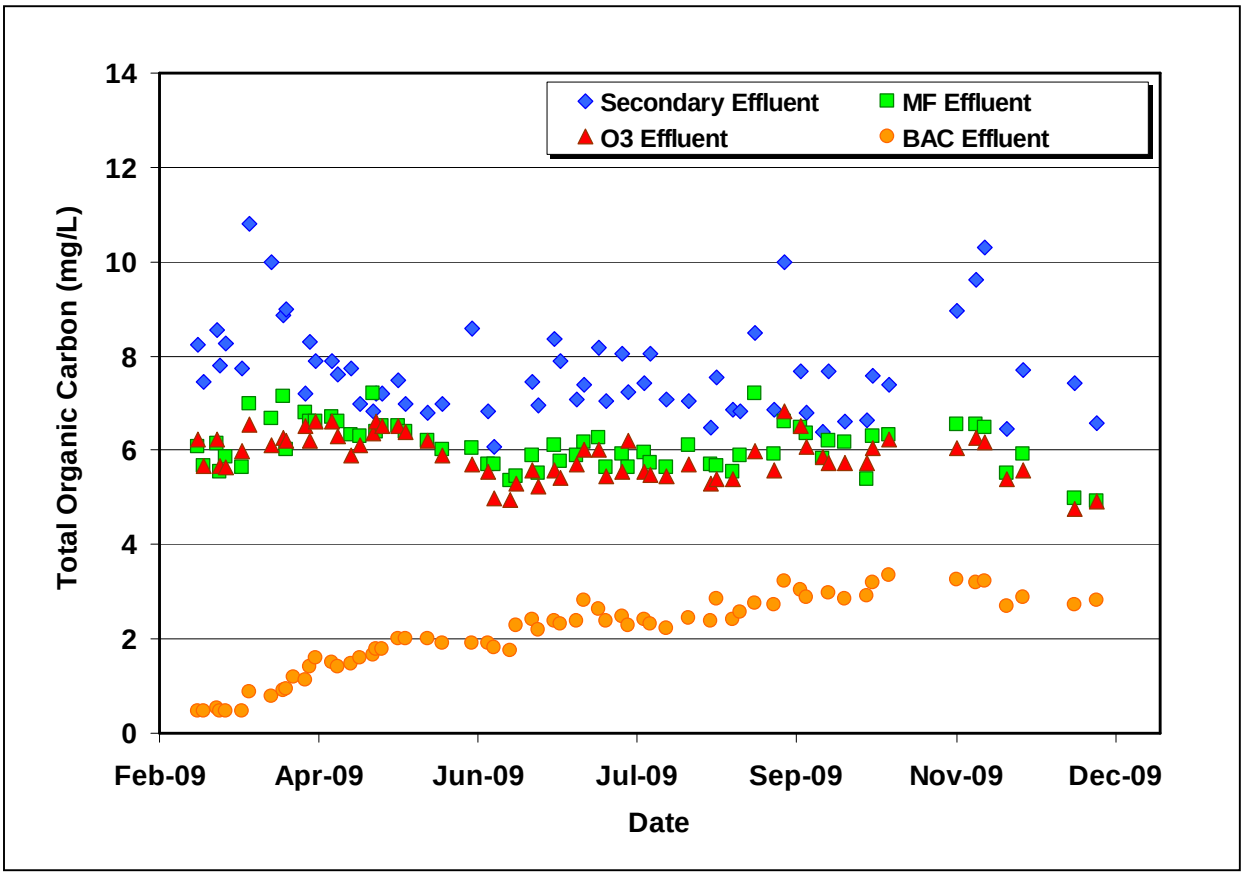


Figure 4-4
**TOC Measured During Phase 2**

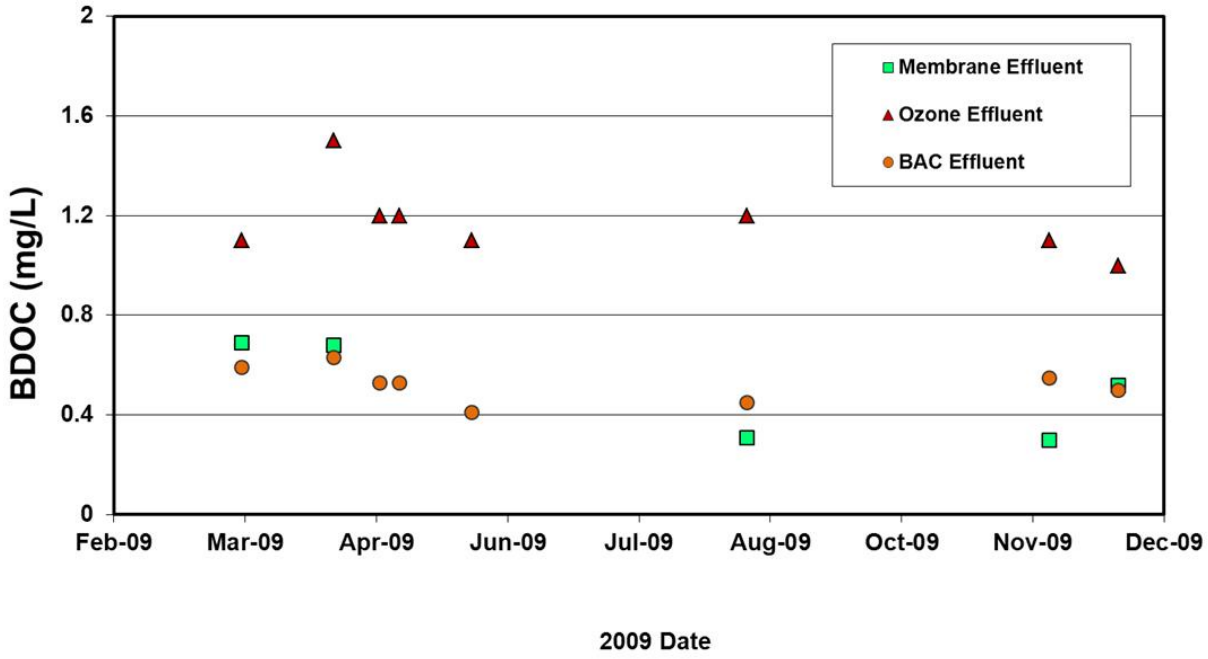


Figure 4-5
**BDOC Measured During Phase 2**

### 4.1.6 UVT AND TURBIDITY

Effluent $UVT_{254}$ improvement provided by membrane filtration is attributed to removal of particulates (see Figure 4-6). Ozone-based oxidation increased the $UVT_{254}$ to about 85%, which could be due to cleavage of aromatic organic compounds known to absorb UV light. The $UVT_{254}$ of BAC effluent was consistently above 90%, which is similar to the $UVT_{254}$ observed in RO effluent. $UVT_{254}$ improvement by BAC is possibly due to the removal of short-chain organics, including ozonation byproducts. BAC effluent turbidity measured during Phase 2 is shown in Figure 4-7.

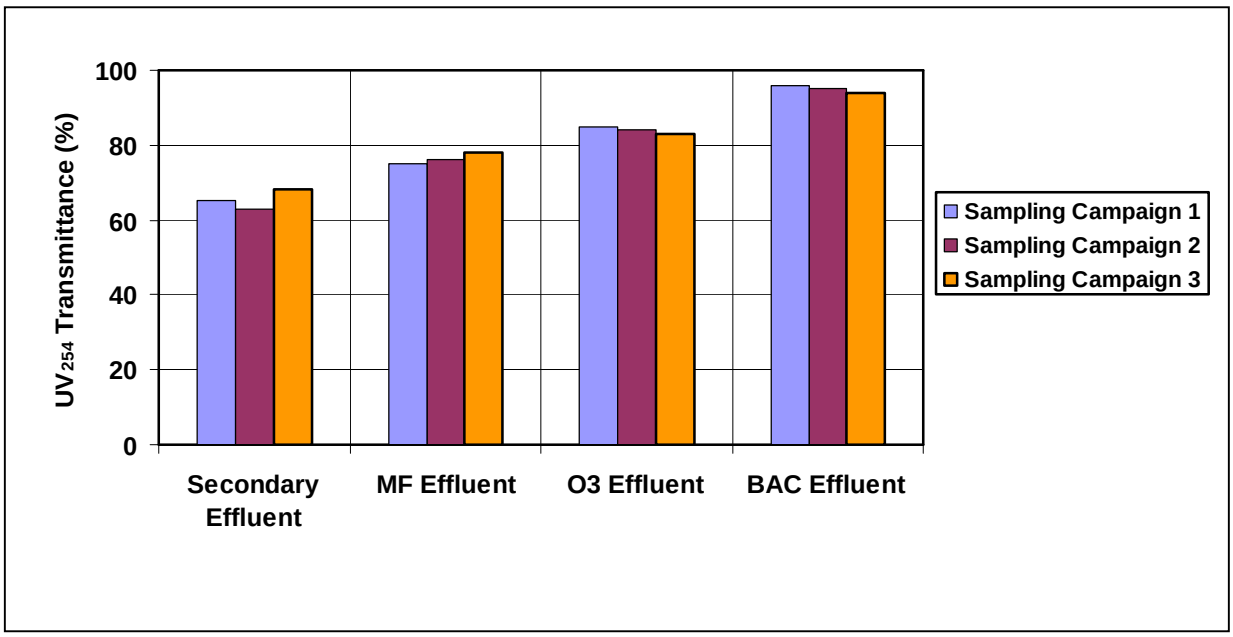


Figure 4-6
**$UVT_{254}$ Transmittance During Phase 2 Sampling Campaigns**

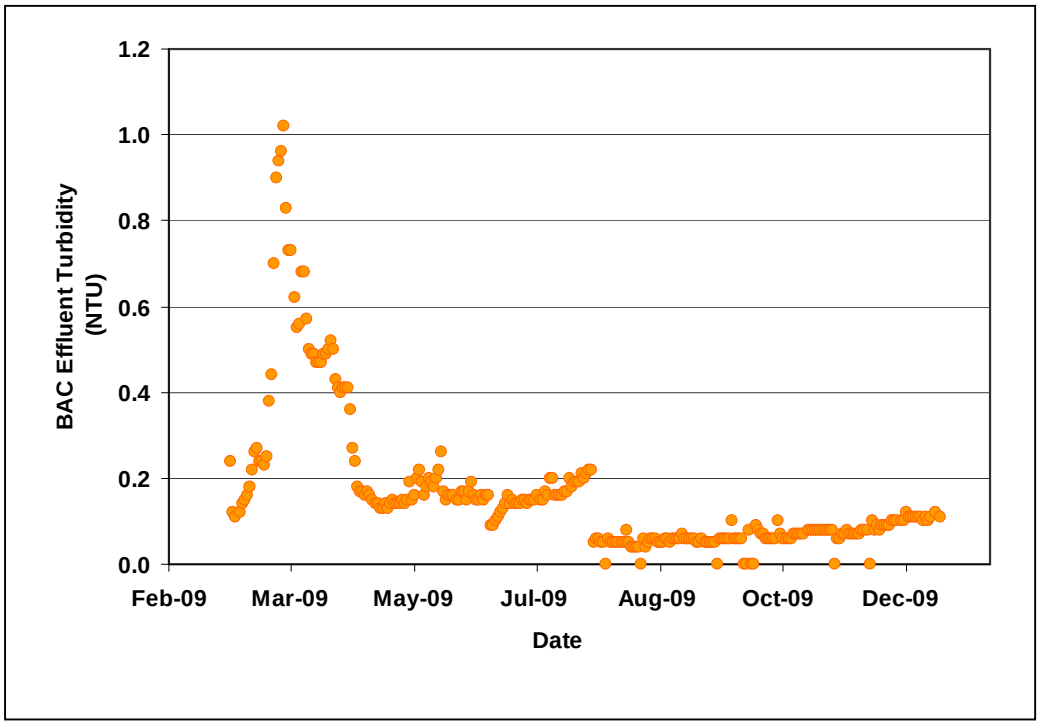


Figure 4-7
**BAC Effluent Turbidity during Phase 2**

### 4.1.7 TOTAL AND FECAL COLIFORM

Total and fecal coliform concentrations were monitored as a general indicator of the possibility of pathogenic organisms being present in the water at various stages of treatment. Fecal coliform are a more specific indicator of the presence of microbes (including pathogens) excreted by warm-blooded animals. Total coliforms are a much broader (and more conservative) indicator test covering excreted microbes as well as common soil microbes. Total and fecal coliform monitoring results are presented in Table 4-6. As shown, after membrane filtration, fecal coliform were never present in any sample, i.e., no evidence of fecal coliform regrowth in or release from the microbially active BAC unit. This is expected because the BAC microbial environment is extremely different from that of the intestine of a warm-blooded animal.

However, the more environmentally ubiquitous total coliform organisms were detected in some samples, particularly in a group of BAC effluent samples from Aug 26 (day 178) to Oct 14 (day 227), as shown in both Table 4-6. The cause of this shedding of total coliform (but not fecal coliform) bacteria from the BAC unit is not known. The most plausible explanation from available data is that the BAC unit developed a more substantial biomass over the entire depth of the BAC medium about this time during the overall BAC maturation process as shown in Figure 4-8.

To reduce the total biomass in the BAC medium, the backwash frequency was increased (see Figure 4-9). This appears to have helped, but a significant reduction in effluent total coliform did not occur immediately. Therefore, the filter backwash flowrate was increased from 60 gpm to around 130 gpm (concurrent with short backwash interval). This appeared to reduce effluent total coliform concentration significantly (as shown in Figure 4-10). Considering the length of time it took to build the biomass over the entire depth of the BAC medium, it was concluded that the increased hydraulic scour and medium agitation associated with a higher backwash rate was more important than backwash frequency in controlling biomass buildup in the medium. Consequently, for the remainder of the demonstration project, the backwash flowrate was maintained at 130 gpm while the backwash frequency was returned to the originally planned 2 week intervals. This operational protocol resulted in the BAC medium having a reduced biomass with increased depth (see Figure 4-8), and a return to BAC effluent total coliform concentrations of less than 1 MPN/100 ml (see Figure 4-9).

Because BAC is a microbially active treatment process, bacteria are expected to be in the BAC effluent, particularly immediately after backwash events. Thus, if effluent from a MF-O3-BAC treatment process is to be used in a manner needing an essentially microbe-free water quality, then post-BAC disinfection process should be employed.

Table 4-6
**Total and Fecal Coliform Concentrations**

| Date | Days since Startup | Total Coliform Concentration (MPN/100mL) | | | | Fecal Coliform Concentration (MPN/100ml) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Secondary Effluent | MF Effluent | O3 Effluent | BAC Effluent | Secondary Effluent | MF Effluent | O3 Effluent | BAC Effluent |
| 3/11/2009 | 10 | <2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 3/18/2009 | 17 | <2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 3/25/2009 | 24 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 4/1/2009 | 31 | <2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 4/8/2009 | 38 | <2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 4/15/2009 | 45 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 4/22/2009 | 52 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 4/29/2009 | 59 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 5/6/2009 | 66 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 5/13/2009 | 73 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 5/20/2009 | 80 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 5/27/2009 | 87 | >2420 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 6/10/2009 | 101 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 6/17/2009 | 108 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 6/24/2009 | 115 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 7/1/2009 | 122 | >2400 | 1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 7/8/2009 | 129 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 7/15/2009 | 136 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 7/22/2009 | 143 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 7/29/2009 | 150 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 8/5/2009 | 157 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 8/11/2009 | 163 | >2400 | 9 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 8/18/2009 | 170 | >2400 | 54 | 83 | <1 | >2400 | <1 | <1 | <1 |
| 8/26/2009 | 178 | >2400 | <1 | <1 | 11 | >2400 | <1 | <1 | <1 |
| 9/2/2009 | 185 | >2400 | <1 | <1 | 2000 | >2400 | <1 | <1 | <1 |
| 9/9/2009 | 192 | >2400 | <1 | <1 | 580 | >2400 | <1 | <1 | <1 |
| 9/16/2009 | 199 | >2400 | <1 | <1 | >2400 | >2400 | <1 | <1 | <1 |
| 9/23/2009 | 206 | >2400 | <1 | <1 | 2000 | >2400 | <1 | <1 | <1 |
| 9/30/2009 | 213 | >2400 | <1 | <1 | >2400 | >2400 | <1 | <1 | <1 |
| 10/7/2009 | 220 | >2400 | <1 | <1 | 460 | >2400 | <1 | <1 | <1 |
| 10/14/2009 | 227 | >2400 | <1 | <1 | 11 | >2400 | <1 | <1 | <1 |
| 11/4/2009 | 248 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 11/10/2009 | 254 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 11/24/2009 | 268 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 12/2/2009 | 276 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |
| 12/9/2009 | 283 | >2400 | <1 | <1 | <1 | >2400 | <1 | <1 | <1 |

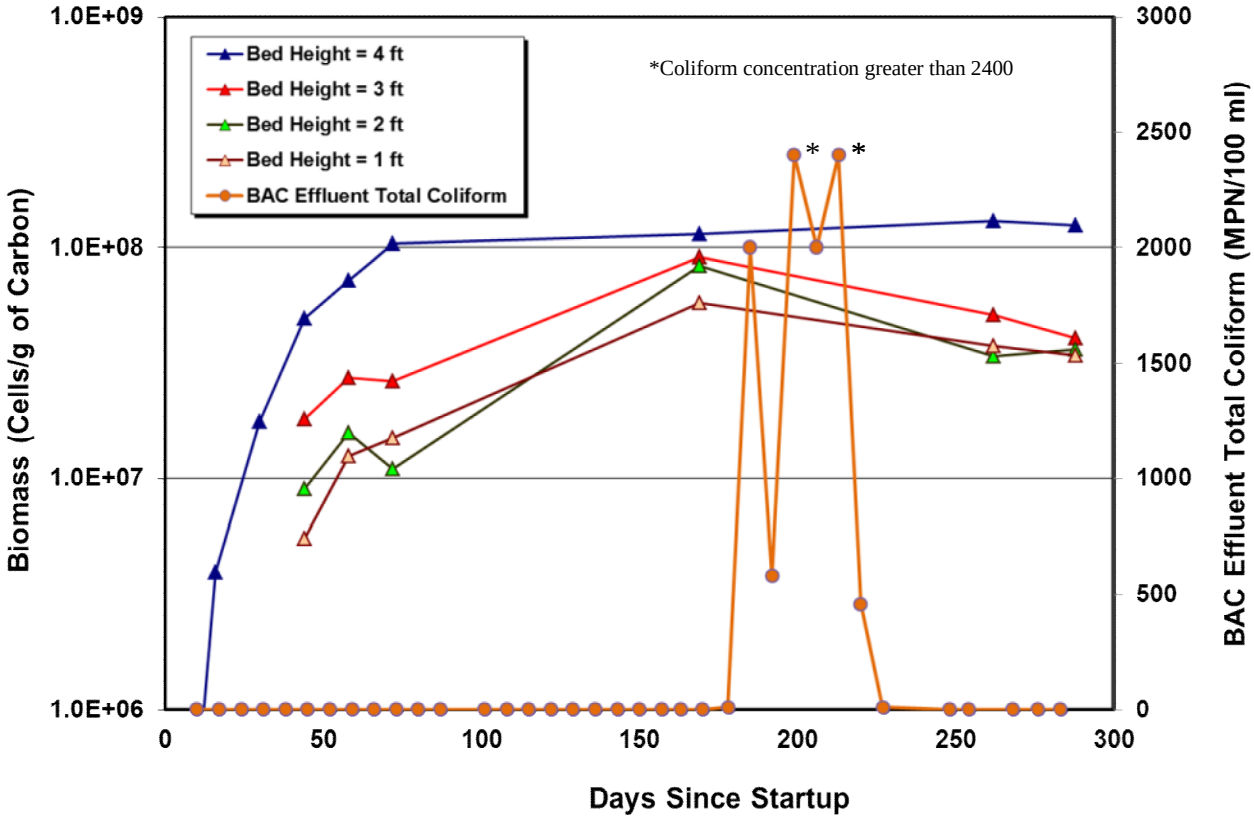


Figure 4-8
**Biomass in BAC Medium as a Function of Maturation Time and Location and BAC Effluent Total Coliform Concentrations**

(Bed heights referenced in Figure 4-9 are height up from the bottom of the BAC medium)

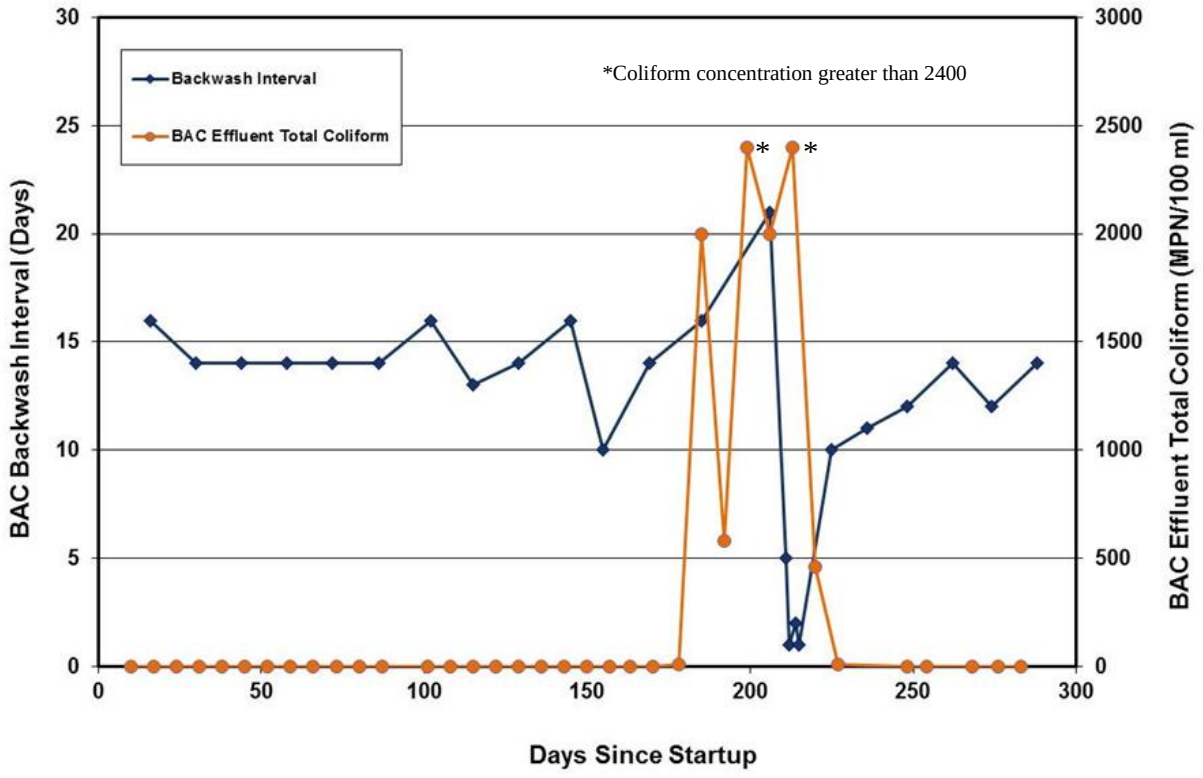


Figure 4-9
**BAC Effluent Total Coliform Concentrations and BAC Backwash Intervals**

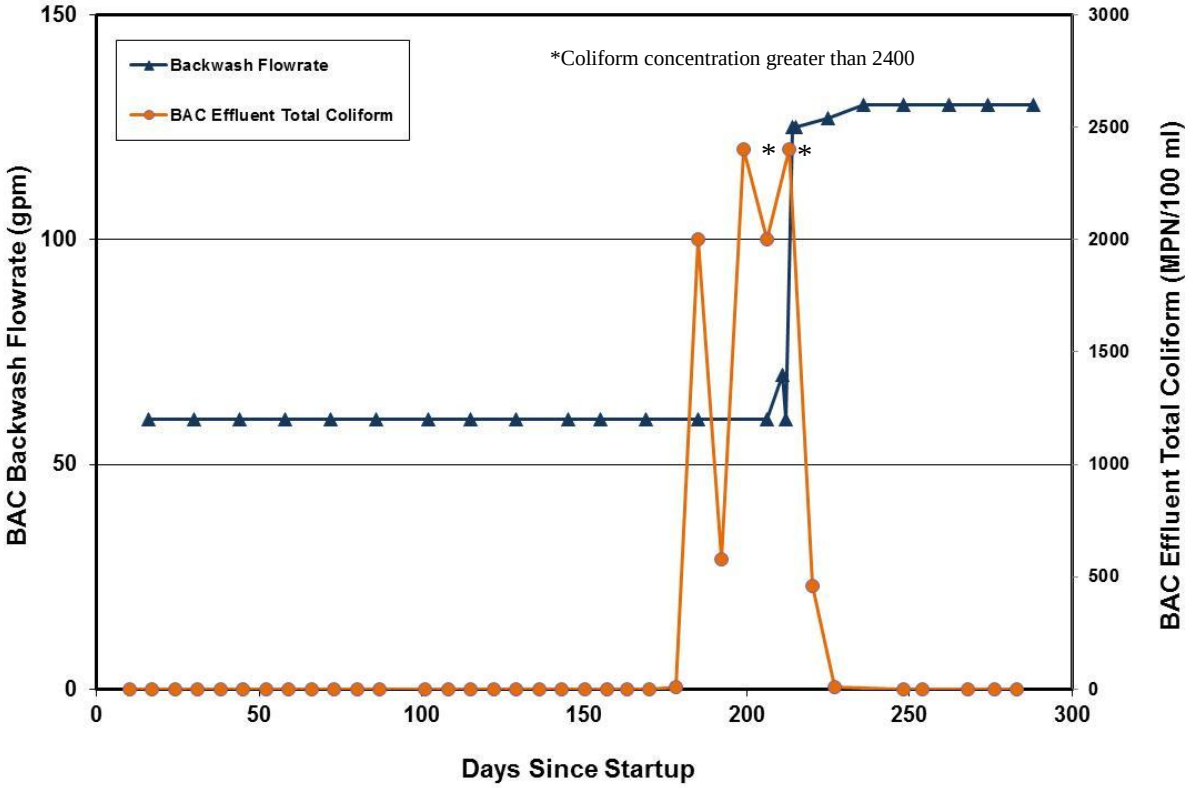


Figure 4-10
**BAC Effluent Total Coliform Concentrations and BAC Backwash Flowrates**

### 4.1.8 DIOXINS

Dixons results are presented in Table 4-7. As shown by the number of orange squares occurring for field blanks (FB) and laboratory blanks (LB) in these tables, the meaning of the majority of dioxin results measured at the pg/L level of accuracy is questionable/inconsistent (i.e., Category D results).

## Table 4-7 (Category C)
## Dioxins Not Detected in Any Sample

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Dioxins** | | | | | | | | | | | | | | | | | | | | | | | |
| 2,3,7,8-Tetra CDD | 30000 | pg/L | < 0.529 | < 0.587 | < 0.528 | < 0.576 | < 0.516 | < 0.603 | < 0.512 | < 0.515 | < 0.543 | < 0.552 | < 0.583 | < 0.55 | < 0.546 | < 0.545 | < 0.588 | < 0.578 | < 0.562 | < 0.593 | < 0.576 | < 0.551 | 1.22 |
| 1,2,3,7,8-Penta CDD | | pg/L | < 0.534 | < 0.556 | < 0.533 | < 0.724 | < 0.509 | < 0.555 | 0.806 | < 0.53 | < 0.561 | < 0.516 | < 0.565 | < 0.554 | < 0.531 | < 0.564 | < 0.568 | < 0.564 | < 0.595 | < 0.565 | < 0.575 | < 0.623 | 0.965 |
| 1,2,3,4,6,7,8-Hepta CDF | | pg/L | < 0.787 | < 0.814 | < 1.23 | < 2.04 | < 0.507 | < 0.812 | < 0.952 | < 0.53 | < 0.549 | < 1.24 | < 0.526 | < 0.561 | < 0.518 | < 0.691 | < 0.829 | < 0.52 | < 0.708 | < 8.75 | < 0.708 | < 0.811 | < 1.12 |
| 1,2,3,4,7,8,9-Hepta CDF | | pg/L | < 0.632 | < 0.528 | < 0.523 | < 0.529 | < 0.53 | < 0.588 | 1.25 | < 0.532 | < 0.551 | < 0.591 | < 0.528 | < 0.563 | < 0.521 | < 0.563 | < 0.73 | < 0.605 | < 0.58 | < 1.11 | < 0.642 | < 0.825 | < 1.2 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate; FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

## Table 4-7 (Category D)
## Inconsistent Dioxin Results

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Dioxins** | | | | | | | | | | | | | | | | | | | | | | | |
| 1,2,3,4,7,8-Hexa CDD | | pg/L | < 0.481 | < 0.514 | < 0.493 | 1.14 | < 0.487 | < 0.525 | 0.623 | < 0.532 | < 0.571 | < 0.541 | < 0.547 | < 0.559 | < 0.519 | < 0.527 | < 0.524 | < 0.561 | < 0.516 | < 0.538 | < 0.535 | < 0.532 | < 0.768 |
| 1,2,3,6,7,8-Hexa CDD | | pg/L | < 0.518 | < 0.553 | < 0.531 | 1.11 | < 0.524 | < 0.564 | 0.683 | < 0.572 | < 0.615 | < 0.582 | < 0.589 | < 0.601 | < 0.559 | < 0.567 | 0.583 | < 0.572 | < 0.526 | 1.32 | < 0.546 | < 0.543 | 0.889 |
| 1,2,3,7,8,9-Hexa CDD | | pg/L | 0.669 | < 0.542 | < 0.521 | 1.28 | < 0.514 | < 0.554 | 1.23 | < 0.561 | < 0.603 | < 0.571 | < 0.578 | < 0.59 | < 0.548 | < 0.567 | 1.01 | < 0.652 | < 0.6 | 0.667 | < 0.621 | < 0.618 | 1.05 |
| 1,2,3,4,6,7,8-Hepta CDD | | pg/L | 1.37 | 1.11 | 1.14 | 3.02 | 1.17 | 1.6 | 1.55 | 0.936 | 0.619 | 0.845 | < 0.569 | 3.36 | < 0.692 | < 0.671 | 1.68 | 0.973 | 1.32 | 32.3 | 1.53 | 1.63 | < 1.57 |
| Octa CDD | | pg/L | 4.02 | 3.77 | 3.31 | 17.2 | 3.23 | 6.08 | 3.58 | 3.58 | 2.25 | 3.35 | 2.2 | 25.5 | 3.36 | 2.54 | 5.03 | 2.93 | 4.12 | 157 | 6.61 | 4.17 | 3.86 |
| Total Tetra CDD | | pg/L | < 0.529 | < 0.587 | < 0.528 | < 0.576 | < 0.516 | < 0.603 | < 0.512 | < 0.515 | < 0.543 | < 0.552 | < 0.583 | < 0.55 | < 0.546 | < 0.545 | < 0.588 | < 0.578 | < 0.606 | 0.773 | < 0.576 | < 0.551 | < 0.561 |
| Total Penta CDD | | pg/L | < 0.534 | < 0.556 | < 0.533 | < 0.724 | < 0.509 | < 0.555 | 1.61 | < 0.53 | < 0.561 | < 0.516 | < 0.565 | < 0.554 | < 0.531 | < 0.564 | < 2.02 | < 1.56 | < 0.824 | < 0.873 | < 0.575 | < 1.13 | 0.965 |
| Total Hexa CDD | | pg/L | 0.669 | < 0.54 | < 0.519 | 3.53 | < 0.513 | < 0.552 | 2.54 | < 0.559 | < 0.901 | < 0.569 | < 0.576 | < 0.588 | < 0.546 | < 0.555 | 1.59 | < 0.601 | < 0.552 | 3.24 | < 0.572 | < 0.569 | 1.94 |
| Total Hepta CDD | | pg/L | 2.22 | 1.88 | < 0.538 | 5.09 | 1.17 | 1.6 | 2.54 | 0.936 | 0.619 | 0.845 | < 0.569 | 5.89 | < 0.692 | < 0.671 | 1.68 | 0.973 | 2.1 | 50.4 | 1.53 | 2.53 | < 1.57 |
| 2,3,7,8-Tetra CDF | | pg/L | < 0.535 | < 0.692 | 0.675 | 0.797 | 0.717 | 0.801 | < 0.586 | 0.865 | 0.911 | 0.738 | 0.815 | 0.779 | 0.965 | 0.708 | 1.43 | 1.37 | 1.31 | 1.75 | 1.15 | 1.48 | < 0.56 |
| 1,2,3,7,8-Penta CDF | | pg/L | < 0.514 | < 0.521 | < 0.528 | 0.649 | < 0.526 | < 0.54 | 0.722 | < 0.535 | < 0.55 | < 0.534 | < 0.524 | < 0.532 | < 0.542 | < 0.524 | 0.787 | < 0.606 | < 0.613 | < 0.572 | < 0.601 | < 0.595 | 1.06 |
| 2,3,4,7,8-Penta CDF | | pg/L | 0.568 | 0.526 | < 0.501 | 1.34 | 0.574 | 0.605 | 1.04 | 0.696 | 0.662 | 1.09 | 1.24 | 0.917 | 0.953 | 0.821 | 1.15 | < 1.15 | 1.3 | < 1.23 | 0.744 | < 1.08 | < 1.54 |
| 1,2,3,4,7,8-Hexa CDF | | pg/L | < 0.501 | < 0.487 | < 0.511 | 1.14 | < 0.501 | < 0.53 | 0.639 | < 0.529 | < 0.566 | < 0.508 | < 0.549 | < 0.515 | < 0.528 | < 0.533 | < 0.547 | < 0.54 | < 0.542 | < 0.566 | < 0.552 | < 0.584 | 1.03 |
| 1,2,3,6,7,8-Hexa CDF | | pg/L | < 0.523 | < 0.508 | < 0.533 | 1.02 | < 0.522 | < 0.552 | 0.681 | < 0.552 | < 0.59 | < 0.529 | < 0.573 | < 0.537 | < 0.551 | < 0.556 | < 0.582 | < 0.574 | < 0.577 | < 0.602 | < 0.588 | < 0.621 | 0.996 |
| 2,3,4,6,7,8-Hexa CDF | | pg/L | < 0.514 | < 0.499 | < 0.524 | 1.75 | < 0.513 | < 0.543 | 0.55 | < 0.542 | < 0.58 | < 0.52 | < 0.563 | < 0.528 | < 0.542 | < 0.546 | < 0.548 | < 0.541 | < 0.543 | < 0.567 | < 0.553 | < 0.585 | < 0.66 |
| 1,2,3,7,8,9-Hexa CDF | | pg/L | < 0.524 | < 0.509 | < 0.534 | 1.38 | < 0.523 | < 0.554 | 1.03 | < 0.553 | < 0.591 | < 0.531 | < 0.574 | < 0.538 | < 0.552 | < 0.557 | 0.817 | < 0.552 | < 0.554 | < 0.578 | < 0.564 | < 0.596 | 1.39 |
| Octa CDF | | pg/L | < 1.19 | < 1.04 | < 1.08 | 4.12 | < 1.04 | < 1.08 | 1.73 | < 1.14 | < 1.11 | < 1.05 | < 1.1 | < 1.02 | < 1.09 | < 1.04 | < 1.27 | < 1.16 | < 1.1 | 38.7 | < 1.91 | < 1.15 | 1.89 |
| Total Tetra CDF | | pg/L | < 0.535 | < 3.17 | 0.675 | 0.797 | 0.717 | 1.55 | < 2.78 | 0.865 | 1.57 | 2.57 | 1.52 | 1.93 | 2.62 | 1.29 | 3.55 | 2.32 | 2.98 | 7.31 | 1.15 | 4.04 | 2.17 |
| Total Penta CDF | | pg/L | 0.568 | 0.526 | < 0.514 | 1.99 | 0.574 | 0.605 | 2.26 | 0.696 | 0.662 | 1.95 | 1.24 | 0.917 | 0.953 | 0.821 | 1.94 | 0.786 | 1.3 | < 2.52 | 0.744 | < 1.12 | 1.06 |
| Total Hexa CDF | | pg/L | < 0.515 | < 0.501 | < 0.526 | 5.3 | < 0.515 | < 0.545 | 2.9 | < 0.544 | < 0.582 | < 0.522 | < 0.564 | < 0.529 | < 0.543 | < 0.548 | 0.817 | < 0.551 | < 0.554 | 5.44 | < 0.564 | < 0.596 | 3.42 |
| Total Hepta CDF | | pg/L | < 0.787 | < 0.814 | < 1.23 | < 2.04 | < 0.507 | < 0.812 | 1.25 | < 0.531 | < 0.55 | < 1.33 | < 0.527 | < 0.562 | < 0.519 | < 0.755 | < 1.02 | < 0.653 | < 0.882 | 39.7 | < 0.892 | < 0.818 | < 1.35 |

### 4.1.9 VOCs AND SOCs

Volatile organic compounds (VOCs) and non-volatile synthetic organic compounds (SOCs) results are presented in Table 4-8 and Table 4-9. The vast majority of VOCs and SOCs were not detected in any of the samples at concentrations greater than found in the QA/QC blanks as shown in Table 4-8 and 4-9, respectively. Toulene and acetone (an ozonation byproduct) were present in some samples, but not in the BAC effluent as shown in Table 4-8 (Category A). Two chlorination byproducts, bromodichloromethane and chloroform, were in all effluent samples, including the BAC effluent, see Table 4-8 (Category B). The origins of these constituents are unknown because the effluent used in the demonstration project was RSWRF secondary effluent prior to filtration and chlorine disinfection.

Table 4-8 (Category A)
**VOCs Removed to Detection Limits by MF-O3-BAC**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Volatile Organics by EPA Method 624** | | | | | | | | | | | | | | | | | | | | | | | |
| Toluene (Method 524.2) | ug/l | 150 | 0.34 | 0.49 | < 0.15 | < 0.15 | < 0.15 | 0.15 | < 0.15 | 0.22 | 0.22 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | 0.17 | 0.20 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 |
| Toluene (Method 624) | ug/l | 150 | 0.46 | 0.65 | < 0.45 | < 0.45 | < 0.45 | < 0.45 | < 0.15 | < 0.45 | < 0.45 | < 0.45 | < 0.45 | < 0.45 | < 0.45 | < 0.15 | < 0.45 | < 0.45 | < 0.45 | < 0.45 | < 0.45 | < 0.45 | < 0.15 |
| Acetone | ug/l | | < 1.7 | < 1.7 | 17 | 14 | < 1.7 | 2.7 | < 1.7 | < 1.7 | < 1.7 | 21 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | 22 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate;
FB - Field Blank; NM – Not Measured

Table 4-8 (Category B)
**VOCs Detected At Least Once in MF-O3-BAC Effluent**

| Constituents | MCL | Units | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Volatile Organics by EPA Method 624** | | | | | | | | | | | | | | | | | | | | | | | |
| Bromodichloromethane | ug/l | 80 (TTHM) | 0.39 | 0.37 | 0.37 | 0.37 | 0.14 | 0.52 | < 0.13 | 0.26 | 0.29 | 0.30 | 0.38 | 0.37 | < 0.13 | < 0.13 | 0.28 | 0.41 | 0.42 | 0.34 | 0.34 | < 0.13 | < 0.13 |
| Chloroform (Method 524.2) | ug/l | | 1.4 | 2.6 | 2.6 | 2.8 | 5.1 | 10 | < 0.17 | 1.5 | 3.4 | 3.0 | 6.0 | 5.9 | 0.29 | < 0.17 | 1.0 | 2.4 | 2.6 | 5.7 | 5.6 | < 0.17 | < 0.17 |
| Chloroform (Method 624) | ug/l | | 1.6 | 3.0 | 3.0 | 3.1 | 5.7 | 12 | < 0.17 | 1.8 | 4.7 | 4.1 | 7.6 | 7.6 | < 0.31 | < 0.17 | 1.1 | 2.4 | 2.5 | 6.2 | 6.5 | < 0.31 | < 0.17 |

Table 4-8 (Category C)
**VOCs Not Detected in Any Sample**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Volatile Organic Compounds by EPA Method 524.2** | | | | | | | | | | | | | | | | | | | | | | | |
| 1,1,1,2-Tetrachloroethane | ug/l | | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| 1,1,1-Trichloroethane | ug/l | 200 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 |
| 1,1,2,2-Tetrachloroethane | ug/l | 1 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 |
| 1,1,2-Trichloroethane | ug/l | 5 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | < 0.22 |
| 1,1-Dichloroethane | ug/l | | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 |
| 1,1-Dichloroethene | ug/l | 6 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 |
| 1,1-Dichloropropene | ug/l | | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 |
| 1,2,3-Trichlorobenzene | ug/l | | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 |
| 1,2,3-Trichloropropane | ug/l | | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.0012 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.0012 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.0012 |
| 1,2,4-Trichlorobenzene | ug/l | 5 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.26 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.26 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.26 |
| 1,2,4-Trimethylbenzene | ug/l | | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 |
| 1,2-Dichloroethane | ug/l | | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 |
| 1,2-Dichloropropane | ug/l | 5 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 |
| 1,3 Dichloropropene (Total) | ug/l | 0.5 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| 1,3,5-Trimethylbenzene | ug/l | | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 |
| 1,3-Dichloropropane | ug/l | | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 |
| 2,2-Dichloropropane | ug/l | | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 |
| 2-Butanone | ug/l | | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 |
| 2-Chloroethyl vinyl ether | ug/l | | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 |
| 2-Chlorotoluene | ug/l | | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 |
| 2-Hexanone | ug/l | | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 |
| 4-Chlorotoluene | ug/l | | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| 4-Methyl-2-pentanone | ug/l | | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 | < 1.5 |
| Acetonitrile | ug/l | | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 |
| Acrolein | ug/l | | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 |
| Acrylonitrile | ug/l | | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 |
| Allyl chloride | ug/l | | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| Benzene | ug/l | 1 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 |
| Bromobenzene | ug/l | | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 |
| Bromochloromethane | ug/l | | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |
| Bromoform | ug/l | | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| Bromomethane | ug/l | | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 |
| Carbon Disulfide | ug/l | 160 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 |
| Carbon tetrachloride | ug/l | 0.5 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 |
| Chlorobenzene | ug/l | 70 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 |
| Chloroethane | ug/l | | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 |
| Chloromethane | ug/l | | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |
| cis-1,2-Dichloroethene | ug/l | 6 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 |
| cis-1,3-Dichloropropene | ug/l | | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 |
| Dibromochloromethane | ug/l | | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 |
| Dibromomethane | ug/l | | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 |
| Dichlorodifluoromethane (Freon 12) | ug/l | | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 |
| Di-isopropyl ether | ug/l | | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 |
| Ethyl methacrylate | ug/l | | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 | < 0.51 |

Table 4-8 (Category C) -Continued
**VOCs Not Detected in Any Sample**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Volatile Organic Compounds by EPA Method 524.2 (Continued)** | | | | | | | | | | | | | | | | | | | | | | | |
| Ethyl tert-butyl ether | ug/l | | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 | < 1.3 |
| Ethylbenzene | ug/l | 300 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| Freon 113 | ug/l | | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 |
| Hexachlorobutadiene | ug/l | | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.41 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.41 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.41 |
| Iodomethane | ug/l | | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 |
| Isopropylbenzene | ug/l | | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| m,p-Xylene | ug/l | 1750 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 |
| m-Dichlorobenzene | ug/l | | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 |
| Methacrylonitrile | ug/l | | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| Methyl methacrylate | ug/l | | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 |
| Methyl tert-butyl ether (MTBE) | ug/l | 5 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 |
| Naphthalene | ug/l | | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.35 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.35 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.35 |
| n-Butylbenzene | ug/l | | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 |
| Nitrobenzene | ug/l | | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 0.37 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 0.37 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 0.37 |
| n-Propylbenzene | ug/l | | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 |
| o-Dichlorobenzene | ug/l | 600 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| o-Xylene | ug/l | 1750 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 |
| p-Dichlorobenzene | ug/l | 5 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| Pentachloroethane | ug/l | | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 | < 3.6 |
| p-Isopropyltoluene | ug/l | | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| sec-Butylbenzene | ug/l | | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 |
| Styrene | ug/l | 100 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 |
| Tert-amyl methyl ether | ug/l | | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 |
| tert-Butylbenzene | ug/l | | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | < 0.14 |
| Tetrachloroethene | ug/l | 5 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 |
| Tetrahydrofuran | ug/l | | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 |
| trans-1,2-Dichloroethene | ug/l | 10 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 |
| trans-1,3-Dichloropropene | ug/l | | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| trans-1,4-Dichloro-2-butene | ug/l | | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| Trichloroethene | ug/l | 5 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 |
| Trichlorofluoromethane | ug/l | 150 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |
| Vinyl acetate | ug/l | | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 |
| Vinyl chloride | ug/l | 0.5 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 |
| Xylenes, Total | ug/l | 1750 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 |
| **Volatile Organics by EPA Method 624** | | | | | | | | | | | | | | | | | | | | | | | |
| 1,1,1-Trichloroethane | ug/l | 200 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | < 0.15 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | < 0.15 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | < 0.15 |
| 1,1,2,2-Tetrachloroethane | ug/l | 1 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.18 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.18 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.18 |
| 1,1,2-Trichloroethane | ug/l | 5 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.22 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.22 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.22 |
| 1,1-Dichloroethane | ug/l | 5 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.15 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.15 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.15 |
| 1,1-Dichloroethene | ug/l | | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.21 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.21 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.21 |
| 1,2-Dichloroethane | ug/l | 0.5 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.14 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.14 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.14 |
| 1,2-Dichloropropane | ug/l | 5 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.15 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.15 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.15 |
| 2-Chloroethyl vinyl ether | ug/l | | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.35 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.35 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.35 |
| Acrolein | ug/l | | < 0.44 | < 0.44 | < 0.44 | < 0.44 | < 0.44 | < 0.44 | < 5.0 | < 0.44 | < 0.44 | < 0.44 | < 0.44 | < 0.44 | < 0.44 | < 5.0 | < 0.44 | < 0.44 | < 0.44 | < 0.44 | < 0.44 | < 0.44 | < 5.0 |

Table 4-8 (Category C) - Continued
**VOCs Not Detected in any Sample**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Volatile Organics by EPA Method 624** | | | | | | | | | | | | | | | | | | | | | | | |
| Acrylonitrile | ug/l | | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 1.1 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 1.1 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 1.1 |
| Benzene | ug/l | | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.15 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.15 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.15 |
| Bromoform | ug/l | | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.17 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.17 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.17 |
| Bromomethane | ug/l | | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.21 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.21 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.21 |
| Carbon tetrachloride | ug/l | | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.18 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.18 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.18 |
| Chlorobenzene | ug/l | 70 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.16 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.16 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.16 |
| Chloroethane | ug/l | | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.18 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.18 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.18 |
| Chloromethane | ug/l | | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.20 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.20 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.20 |
| cis-1,3-Dichloropropene | ug/l | | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.16 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.16 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.16 |
| Dibromochloromethane | ug/l | | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.19 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.19 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.19 |
| Ethylbenzene | ug/l | 300 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.17 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.17 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.17 |
| m-Dichlorobenzene | ug/l | | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.21 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.21 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.21 |
| o-Dichlorobenzene | ug/l | | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.17 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.17 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.17 |
| p-Dichlorobenzene | ug/l | | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.17 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.17 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.17 |
| Tetrachloroethene | ug/l | 5 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.26 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.26 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.26 |
| trans-1,2-Dichloroethene | ug/l | | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.18 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.18 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.18 |
| trans-1,3-Dichloropropene | ug/l | | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.17 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.17 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.17 |
| Trichloroethene | ug/l | 5 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.18 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.18 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.18 |
| Trichlorofluoromethane | ug/l | 150 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.20 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.20 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.20 |
| Vinyl chloride | ug/l | 0.5 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.18 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.18 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.18 |
| Methylene chloride | ug/l | | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | 0.56 | < 0.15 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.15 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | 81 | < 0.15 |
| Methylene chloride | ug/l | | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | 0.40 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | 65 | < 0.15 |
| Bromodichloromethane | ug/l | | 0.52 | 0.46 | 0.46 | 0.49 | < 0.32 | 0.67 | < 0.13 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.13 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.13 |

Table 4-9 (Category C)
**SOCs Not Detected in Any Sample**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Acid and Base/Neutral Extractables by EPA Method 625** | | | | | | | | | | | | | | | | | | | | | | | |
| 1,2,4-Trichlorobenzene | ug/l | 5 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 |
| 1,2-Dichlorobenzene | ug/l | | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 |
| 1,3-Dichlorobenzene | ug/l | | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 |
| 1,4-Dichlorobenzene | ug/l | | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 |
| 2,4,6-Trichlorophenol | ug/l | | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 | < 0.88 |
| 2,4-Dichlorophenol | ug/l | | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 | < 0.77 |
| 2,4-Dinitrophenol | ug/l | | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 | < 5.0 |
| 2,4-Dinitrotoluene | ug/l | | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 |
| 2,6-Dinitrotoluene | ug/l | | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 |
| 2-Chloronaphthalene | ug/l | | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 |
| 2-Chlorophenol | ug/l | | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 | < 0.71 |
| 2-Nitrophenol | ug/l | | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 | < 0.84 |
| 3,3´-Dichlorobenzidine | ug/l | | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 |
| 4,4´-DDD | ug/l | | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 | < 3.9 |
| 4,4´-DDE | ug/l | | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 | < 3.1 |
| 4,4´-DDT | ug/l | | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 | < 5.6 |
| 4,6-Dinitro-2-methylphenol | ug/l | | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Bromophenyl phenyl ether | ug/l | | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 |
| 4-Chloro-3-methylphenol | ug/l | | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 |
| 4-Chlorophenyl phenyl ether | ug/l | | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | < 0.24 |
| 4-Nitrophenol | ug/l | | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 | < 6.7 |
| Acenaphthene | ug/l | | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 |
| Acenaphthylene | ug/l | | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 |
| Aldrin | ug/l | | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 |
| alpha-BHC | ug/l | | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 |
| Anthracene | ug/l | | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 |
| Benzo (a) anthracene | ug/l | | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 |
| Benzo (a) pyrene | ug/l | 0.2 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |
| Benzo (b) fluoranthene | ug/l | | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 |
| Benzo (g,h,i) perylene | ug/l | | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | < 0.31 |
| Benzo (k) fluoranthene | ug/l | | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 |
| beta-BHC | ug/l | | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 |
| Bis(2-chloroethoxy)methane | ug/l | | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 |
| Bis(2-chloroethyl)ether | ug/l | | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 | < 0.46 |
| Bis(2-chloroisopropyl)ether | ug/l | | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 | < 0.48 |
| Butyl benzyl phthalate | ug/l | | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 |
| Chrysene | ug/l | | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 |
| Dibenzo (a,h) anthracene | ug/l | | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 |
| Dieldrin | ug/l | | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 | < 3.0 |
| Diethyl phthalate | ug/l | | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 |
| Dimethyl phthalate | ug/l | | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 |
| Di-n-butyl phthalate | ug/l | | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 | < 0.53 |
| Di-n-octyl phthalate | ug/l | | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate; FB - Field Blank; NM – Not Measured

Table 4-9 (Category C) - Continued
**SOCs Not Detected in Any Sample**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Acid and Base/Neutral Extractables by EPA Method 625 (Continued)** | | | | | | | | | | | | | | | | | | | | | | | |
| Endrin aldehyde | ug/l | | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 | < 6.8 |
| Fluoranthene | ug/l | | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 |
| Fluorene | ug/l | | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 |
| Heptachlor | ug/l | | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 | < 2.1 |
| Heptachlor epoxide | ug/l | | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 | < 1.9 |
| Hexachlorobenzene | ug/l | | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 | < 0.15 |
| Hexachlorobutadiene | ug/l | | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 |
| Hexachloroethane | ug/l | | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 |
| Indeno (1,2,3-cd) pyrene | ug/l | | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 |
| Isophorone | ug/l | | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Naphthalene | ug/l | | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 | < 0.35 |
| Nitrobenzene | ug/l | | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 | < 0.37 |
| N-Nitrosodi-n-propylamine | ng/l | | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | < 0.41 |
| Pentachlorophenol | ug/l | 1 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 |
| Phenanthrene | ug/l | | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 |
| Phenol | ug/l | | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 |
| Pyrene | ug/l | | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 |
| **Non-volatile Synthetic Organic Compounds by GC/MS** | | | | | | | | | | | | | | | | | | | | | | | |
| 2,4-Dinitrotoluene | ug/l | | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 | < 0.58 |
| 2,6-Dinitrotoluene | ug/l | | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | < 0.25 |
| 4,4´-DDD | ug/l | | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 |
| 4,4´-DDE | ug/l | | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 |
| 4,4´-DDT | ug/l | | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 | < 0.089 |
| Acenaphthene | ug/l | | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |
| Acenaphthylene | ug/l | | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 |
| Acetochlor | ug/l | | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 | < 0.29 |
| Alachlor | ug/l | 2 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 |
| Aldrin | ug/l | | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 | < 0.087 |
| alpha-BHC | ug/l | | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 |
| alpha-Chlordane | ug/l | 0.1 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 |
| Anthracene | ug/l | | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 |
| Atrazine | ug/l | 1 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 | < 0.047 |
| Benzo (g,h,i) perylene | ug/l | | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 | < 0.18 |
| Benzo (k) fluoranthene | ug/l | | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 |
| beta-BHC | ug/l | | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 |
| Bis(2-ethylhexyl)adipate | ug/l | 400 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 |
| Bis(2-ethylhexyl)phthalate | ug/l | 4 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 | < 1.1 |
| Bromacil | ug/l | | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 |
| Butachlor | ug/l | | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 |
| Butyl benzyl phthalate | ug/l | | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 | < 0.56 |
| Caffeine | ug/l | | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | < 0.042 | 0.140 |
| Captan | ug/l | | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 | < 0.86 |
| Chloropropham | ug/l | | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 |
| Cyanazine | ug/l | | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 |
| delta-BHC | ug/l | | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 | < 0.085 |
| Diazinon | | ug/l | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 |

Table 4-9 (Category C) - Continued
**SOCs Not Detected in Any Sample**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Non-volatile Synthetic Organic Compounds by GC/MS** | | | | | | | | | | | | | | | | | | | | | | | |
| Dibenzo (a,h) anthracene | ug/l | | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 |
| Dieldrin | ug/l | | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 |
| Dimethoate | ug/l | | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 |
| Dimethyl phthalate | ug/l | | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 |
| Di-n-butyl phthalate | ug/l | | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 | < 0.87 |
| Di-n-octyl phthalate | ug/l | | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 | < 0.30 |
| Diethyl phthalate | ug/l | | < 0.035 | < 0.035 | < 0.035 | < 0.035 | < 0.035 | < 0.035 | < 0.035 | < 0.035 | < 0.035 | < 0.035 | < 0.035 | < 0.035 | < 0.035 | < 0.035 | < 0.035 | < 0.035 | < 0.035 | 0.050 | < 0.035 | 0.14 | < 0.035 |
| Diphenamid | ug/l | | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 |
| Disulfoton | ug/l | | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 | < 0.030 |
| Endosulfan I | ug/l | | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 |
| Endosulfan II | ug/l | | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 |
| Endosulfan sulfate | ug/l | | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |
| Endrin | ug/l | 2 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | < 0.19 |
| Endrin aldehyde | ug/l | | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 |
| Endrin ketone | ug/l | | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 |
| EPTC | ug/l | | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 |
| Ethion | ug/l | | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 |
| Fluoranthene | ug/l | | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 | < 0.50 |
| gamma-BHC (Lindane) | ug/l | 0.2 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 | < 0.094 |
| gamma-Chlordane | ug/l | 0.1 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 |
| Heptachlor | ug/l | | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 |
| Heptachlor epoxide | ug/l | | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 | < 0.086 |
| Hexachlorobenzene | ug/l | 1 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 |
| Hexachlorocyclopentadiene | ug/l | 50 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 |
| Indeno (1,2,3-cd) pyrene | ug/l | | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 | < 0.17 |
| Methoxychlor | ug/l | | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 |
| Metolachlor | ug/l | | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 | < 0.056 |
| Metribuzin | ug/l | | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 |
| Molinate | ug/l | 20 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 | < 0.051 |
| Naphthalene | ug/l | | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 | < 0.20 |
| PCNB | ug/l | | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 |
| Pentachlorophenol | ug/l | 1 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 |
| Prometon | ug/l | | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 | < 0.16 |
| Prometryn | ug/l | | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 | < 0.074 |
| Propachlor | ug/l | | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 |
| Simazine | ug/l | 4 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 | < 0.083 |
| Terbacil | ug/l | | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 | < 0.55 |
| Thiobencarb | ug/l | 1 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | < 0.11 |
| Trifluralin | ug/l | | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 | < 0.10 |
| Trithion | ug/l | | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 | < 0.010 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate;
FB - Field Blank; NM – Not Measured

Table 4-9 (Category D)
**Inconsistent SOC Results**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Acid and Base/Neutral Extractables by EPA Method 625** | | | | | | | | | | | | | | | | | | | | | | | |
| Bis(2-ethylhexyl)phthalate | ug/l | 4 | 82 | 5.4 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | < 2.6 | 110 | < 2.6 | < 2.6 | < 2.6 | 29 | < 2.6 | < 2.6 |
| 2-Fluorobiphenyl | ug/l | | 40.8 | 38.3 | 42.6 | 38.9 | 45.1 | 35.9 | 41.7 | 37.7 | 42.1 | 45.9 | 39.6 | 41.5 | 42.1 | 44.2 | 38.6 | 39.7 | 41.9 | 46.8 | 42.4 | 43.8 | 43.7 |
| **Non-volatile Synthetic Organic Compounds by GC/MS** | | | | | | | | | | | | | | | | | | | | | | | |
| Benzo (a) anthracene | ug/l | | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | 0.17 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 |
| Benzo (a) pyrene | ug/l | 0.2 | < 0.073 | < 0.073 | < 0.073 | < 0.073 | < 0.073 | < 0.073 | < 0.073 | < 0.073 | < 0.073 | < 0.073 | 0.12 | < 0.073 | < 0.073 | < 0.073 | < 0.073 | < 0.073 | < 0.073 | < 0.073 | < 0.073 | < 0.073 | < 0.073 |
| Benzo (b) fluoranthene | ug/l | | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | 0.20 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 |
| Chrysene | ug/l | | < 0.076 | < 0.076 | < 0.076 | < 0.076 | < 0.076 | < 0.076 | < 0.076 | < 0.076 | < 0.076 | < 0.076 | 0.080 | < 0.076 | < 0.076 | < 0.076 | < 0.076 | < 0.076 | < 0.076 | < 0.076 | < 0.076 | < 0.076 | < 0.076 |
| Fluorene | ug/l | | < 0.072 | < 0.072 | < 0.072 | < 0.072 | < 0.072 | < 0.072 | < 0.072 | < 0.072 | < 0.072 | < 0.072 | 0.090 | < 0.072 | < 0.072 | < 0.072 | < 0.072 | < 0.072 | < 0.072 | < 0.072 | < 0.072 | < 0.072 | < 0.072 |
| Phenanthrene | ug/l | | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | 0.11 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 |
| Pyrene | ug/l | | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate; FB - Field Blank; NM – Not Measured

### 4.1.10 PESTICIDES, HERBICIDES AND PCBS

Pesticide, herbicide and PCB were not detected in any samples during the project as shown in Table 4-10.

Table 4-10 (Category C)

## Pesticides, Herbicides, and PCBs Not Detected in Any Sample

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Carbamates and Urea Pesticides (EPA 531.1)** | | | | | | | | | | | | | | | | | | | | | | | |
| 3-Hydroxycarbofuran | ug/l | | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 |
| Aldicarb | ug/l | | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 | < 0.70 |
| Aldicarb sulfone | ug/l | | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 | < 0.36 |
| Aldicarb sulfoxide | ug/l | | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Carbaryl | ug/l | | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 | < 0.97 |
| Carbofuran | ug/l | 18 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 |
| Methiocarb | ug/l | | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | < 1.4 |
| Methomyl | ug/l | | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 |
| Oxamyl | ug/l | 50 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 | < 0.57 |
| Propoxur (Baygon) | ug/l | | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 | < 0.43 |
| **Chlorinated Pesticides and/or PCBs (EPA 508)** | | | | | | | | | | | | | | | | | | | | | | | |
| Alachlor | ug/l | 2 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 | < 0.0090 |
| Aldrin | ug/l | | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 | < 0.0037 |
| alpha-Chlordane | ug/l | 0.1 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 | < 0.0043 |
| Chlordane (tech) | ug/l | 0.1 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 | < 0.045 |
| cis-Nonachlor | ug/l | | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 |
| Dieldrin | ug/l | | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 | < 0.0044 |
| Endrin | ug/l | 2 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 |
| gamma-BHC (Lindane) | ug/l | 0.2 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 | < 0.0050 |
| gamma-Chlordane | ug/l | 0.1 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 | < 0.0040 |
| Heptachlor | ug/l | 0.01 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 | < 0.0052 |
| Heptachlor epoxide | ug/l | 0.01 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 | < 0.0058 |
| Hexachlorobenzene | ug/l | 1 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 | < 0.0020 |
| Hexachlorocyclopentadiene | ug/l | 50 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 | < 0.016 |
| Methoxychlor | ug/l | 30 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 | < 0.0064 |
| PCB-1016 | ug/l | | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 | < 0.097 |
| PCB-1221 | ug/l | | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 | < 0.084 |
| PCB-1232 | ug/l | | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 |
| PCB-1242 | ug/l | | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 | < 0.070 |
| PCB-1248 | ug/l | | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 |
| PCB-1254 | ug/l | | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 |
| PCB-1260 | ug/l | | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 | < 0.069 |
| PCBs, Total | ug/l | 0.5 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 |
| Toxaphene | ug/l | 3 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 | < 0.031 |
| trans-Nonachlor | ug/l | | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 |
| **Chlorinated Herbicides (EPA 515.3)** | | | | | | | | | | | | | | | | | | | | | | | |
| 2,4,5-T | ug/l | | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 |
| 2,4,5-TP (Silvex) | ug/l | 50 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 |
| 2,4-DB | ug/l | | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 | < 0.42 |
| 3,5-Dichlorobenzoic acid | ug/l | | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 |
| Acifluorfen | ug/l | | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate; FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

Table 4-10 (Category C) -Continued
**Pesticides, Herbicides, and PCBs Not Detected in Any Sample**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Chlorinated Herbicides EPA 515.3 ( Continued)** | | | | | | | | | | | | | | | | | | | | | | | |
| Bentazon | ug/l | 18 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 | < 0.23 |
| Chloramben | ug/l | | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | < 1.0 |
| Dalapon | ug/l | 200 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 | < 0.040 |
| DCPA | ug/l | | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 |
| Dicamba | ug/l | | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 | < 0.080 |
| Dichloroprop | ug/l | | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 | < 0.060 |
| Dinoseb | ug/l | 7 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 | < 0.050 |
| Pentachlorophenol | ug/l | 1 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 |
| Picloram | ug/l | 500 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 | < 0.34 |
| **Glyphosate (EPA 547)** | | | | | | | | | | | | | | | | | | | | | | | |
| Glyphosate | ug/l | 700 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 | < 1.8 |
| **Organophosphorus Pesticides (EPA 8141A)** | | | | | | | | | | | | | | | | | | | | | | | |
| Azinphos methyl (Guthion) | ug/l | | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 | < 0.12 |
| Chlorpyrifos | ug/l | | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 | < 0.041 |
| Coumaphos | ug/l | | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 | < 0.068 |
| Demeton-o | ug/l | | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 | < 0.049 |
| Demeton-s | ug/l | | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 | < 0.063 |
| Diazinon | ug/l | | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 | < 0.058 |
| Disulfoton | ug/l | | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 | < 0.064 |
| Methyl parathion | ug/l | | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 | < 0.057 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate; FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

### 4.1.11 THMFP AND HAAS

Haloacetic acids (HAAs) and THM formation potential (THMFP) results are presented in Table 4-11. Some HAAs were in the RSWRF, and others may have been formed during ozonation. Overall, BAC appears to be effective in removing HAAs, regardless of their origins. THMFP was monitored and detected only in the BAC effluent. Change in THMFP during MF-O3-BAC is unknown.

Table 4-11 (Category A)
**HAAs Removed to Detection Limits by MF-O3-BAC**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| Bromochloroacetic acid (bcaa) | ug/l | | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | < 0.28 | 0.52 | 0.71 | < 0.28 | < 0.28 | < 0.28 | < 0.28 |
| Monochloroacetic acid (mcaa) | ug/l | | < 0.32 | < 0.32 | 1.8 | 1.7 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | 2.0 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | < 0.32 | 2.7 | < 0.32 | < 0.32 | < 0.32 | < 0.32 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate; FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

Table 4-11 (Category B)
**THM Formation Potential Detected At Least Once in MF-O3-BAC Effluent**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| THM Formation Potential | ug/l | | NM | NM | NM | NM | 120 | NM | NM | NM | NM | NM | 140 | NM | NM | NM | NM | NM | NM | 150 | NM | NM | NM |

Table 4-11 (Category C)
**HAAs Not Detected in Any Sample**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| Dibromoacetic acid (dbaa) | ug/l | | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | < 0.13 | 0.24 | 0.25 | 0.28 | 0.28 | 0.26 | 0.26 | < 0.13 |
| Monobromoacetic acid (mbaa) | ug/l | | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 | < 0.21 |

Table 4-11 (Category D)
**Inconsistent HAA Results**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| HAAs | | | | | | | | | | | | | | | | | | | | | | | |
| Dichloroacetic acid (dcaa) | ug/l | | 0.64 | 1.4 | 2.5 | 2.5 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | 1.1 | 2.4 | < 0.41 | < 0.41 | < 0.41 | < 0.41 | 0.91 | 1.9 | 4.3 | 0.52 | 3.4 | 1.1 | < 0.41 |
| HAA5, Total | ug/l | 60 | 5.1 | 7.3 | 8.4 | 7.6 | < 1.0 | < 1.0 | < 1.0 | 3.4 | 5.0 | 8.2 | < 1.0 | < 1.0 | < 1.0 | < 1.0 | 2.7 | 5.8 | 12 | < 1.0 | 5.5 | 2.1 | < 1.0 |
| Trichloroacetic acid (tcaa) | ug/l | | 5.1 | 5.9 | 5.9 | 5.1 | < 0.22 | < 0.22 | < 0.22 | 3.4 | 3.9 | 3.8 | < 0.22 | < 0.22 | < 0.22 | < 0.22 | 2.7 | 3.9 | 4.6 | < 0.22 | 2.1 | 1.0 | < 0.22 |
| Chlorite | ug/l | | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 4.6 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 |

### 4.1.12 OTHER ORGANICS

A range of other organic compounds not falling into any of the aforementioned categories were monitored, with results being presented in Table 4-12 and 4-13. These other organics include alcohols, glycols, diquat, endothall and fumigants. As shown none of these other organics were detected in any samples.

Table 4-12 (Category C)
**Alcohols and Glycols Not Detected in Any Sample**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Alcohols (EPA 8015B)** | | | | | | | | | | | | | | | | | | | | | | | |
| 1-Butanol | mg/l | | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | < 2.2 |
| 1-Propanol | mg/l | | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 | < 10 |
| Ethanol | mg/l | | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 | < 0.92 |
| Isopropyl alcohol | mg/l | | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 |
| Methanol | mg/l | | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 | < 0.63 |
| **Glycols (EPA 8015B)** | | | | | | | | | | | | | | | | | | | | | | | |
| Ethylene glycol | mg/l | 14 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 | < 3.2 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate;
FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

Table 4-13 (Category C)
**Diquat, Endothall and Fumigants Not Detected in Any Sample**

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Diquat and Paraquat (EPA 549.2)** | | | | | | | | | | | | | | | | | | | | | | | |
| Diquat | ug/l | 20 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 | < 0.90 |
| **Endothall (EPA 548.1)** | | | | | | | | | | | | | | | | | | | | | | | |
| Endothall | ug/l | 100 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 | < 3.5 |
| **Fumigants (EPA 504.1)** | | | | | | | | | | | | | | | | | | | | | | | |
| 1,2-Dibromo-3-chloropropane | ug/l | | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 | < 0.0030 |
| 1,2-Dibromoethane (EDB) | ug/l | 0.05 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 | < 0.0049 |

### 4.1.13 INORGANICS

Though MF-O3-BAC was developed primarily as a process to remove refractory organics, inorganic constituents are also of overall water quality concern, and therefore were monitored with the results being presented in Table 4-14. Inorganic constituents include metals, ions, asbestos, and radiological parameters. MF-O3-BAC treatment is not expected to remove inorganics, except incidentally via MF removal of particulates and possibly via adsorption in the BAC unit.

Table 4-14 (Category B)

## Inorganics Detected At Least Once in MF-O3-BAC Effluent

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Metals by EPA 200 Series Methods** | | | | | | | | | | | | | | | | | | | | | | | |
| Aluminum, Total | ug/l | 200 | 36 | 14 | 15 | 16 | 12 | 2.2 | 0.988 | 43 | 19 | 24 | 16 | 17 | 6.4 | 0.590 | 37 | 17 | 18 | 18 | 13 | 2.5 | 0.650 |
| Antimony, Total | ug/l | 6 | 0.39 | 0.35 | 0.33 | 0.33 | 0.35 | 0.037 | 0.0366 | 0.40 | 0.35 | 0.33 | 0.32 | 0.33 | 0.050 | 0.0400 | 0.39 | 0.34 | 0.34 | 0.31 | 0.32 | 0.020 | 0.110 |
| Arsenic, Total | ug/l | 10 | 2.3 | 2.4 | 2.3 | 2.3 | 2.4 | < 0.014 | < 0.014 | 2.1 | 2.1 | 2.0 | 2.0 | 2.0 | 0.18 | 0.0700 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 0.070 | 0.0200 |
| Barium, Total | ug/l | 1000 | 8.7 | 9.0 | 8.8 | 8.8 | 11 | 0.058 | < 0.024 | 17 | 16 | 16 | 16 | 16 | 0.35 | < 0.024 | 20 | 19 | 19 | 18 | 18 | < 0.024 | < 0.024 |
| Calcium, Total | ug/l | | NM | NM | NM | NM | NM | NM | 0.0191 | 25 | 25 | 25 | 23 | 24 | 0.23 | < 0.016 | 28 | 28 | 28 | 28 | 27 | < 0.016 | < 0.016 |
| Cadmium, Total | ug/l | 5 | 0.017 | 0.014 | 0.017 | 0.019 | 0.015 | < 0.013 | < 0.013 | 0.030 | 0.030 | 0.030 | 0.030 | 0.030 | < 0.013 | < 0.013 | < 0.013 | < 0.013 | < 0.013 | 0.020 | 0.020 | < 0.013 | < 0.013 |
| Chromium, Total | ug/l | 50 | 0.39 | 0.33 | 0.39 | 0.41 | 0.42 | 0.015 | 0.0129 | 0.43 | 0.41 | 0.48 | 0.45 | 0.49 | 0.21 | 0.0500 | 0.33 | 0.35 | 0.32 | 0.32 | 0.33 | 0.050 | 0.0500 |
| Chromium, Hexavalent | mg/L | | < 0.006 | < 0.006 | 0.18 | 0.19 | 0.13 | < 0.006 | < 0.006 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.05 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 |
| Copper, Total | ug/l | 50 | 2.1 | 1.3 | 1.5 | 1.7 | 0.32 | < 0.022 | < 0.022 | 1.8 | 1.2 | 1.2 | 0.27 | 0.26 | 0.15 | 0.0900 | 1.6 | 1.1 | 1.1 | 0.36 | 0.28 | 0.043 | 0.0338 |
| Cobalt, Total | ug/l | | 0.18 | 0.17 | 0.17 | 0.17 | 0.10 | < 0.0050 | < 0.0050 | 0.21 | 0.20 | 0.19 | 0.12 | 0.13 | < 0.0050 | < 0.0050 | 0.17 | 0.16 | 0.16 | 0.11 | 0.11 | < 0.0050 | < 0.0050 |
| Lead, Total | ug/l | 5 | 0.21 | 0.19 | 0.18 | 0.18 | 0.019 | < 0.017 | < 0.017 | 0.53 | 0.46 | 0.45 | 0.060 | 0.080 | 0.11 | 0.0300 | 0.33 | 0.32 | 0.30 | 0.080 | 0.090 | 0.020 | < 0.017 |
| Manganese, Total | ug/l | 50 | 10 | 10 | 9.6 | 9.7 | 0.48 | < 0.019 | < 0.019 | 12 | 12 | 11 | 0.79 | 1.2 | 0.64 | < 0.019 | 12 | 12 | 12 | 1.9 | 1.9 | < 0.019 | < 0.019 |
| Molybdenum, Total | ug/l | | 4.1 | 4.1 | 4.5 | 4.6 | 4.7 | 0.01 | 0.0136 | 2.4 | 2.3 | 2.4 | 2.4 | 2.4 | 0.03 | 0.0200 | 2.4 | 2.4 | 2.5 | 2.5 | 2.4 | < 0.009 | 0.0600 |
| Nickel, Total | ug/l | 100 | 1.5 | 1.3 | 1.5 | 1.5 | 1.5 | < 0.011 | < 0.011 | 0.72 | 0.70 | 0.67 | 0.76 | 0.82 | 0.020 | < 0.011 | 0.42 | 0.35 | 0.35 | 0.38 | 0.39 | < 0.011 | < 0.011 |
| Selenium, Total | ug/l | 50 | 0.44 | 0.30 | 0.48 | 0.29 | 0.42 | < 0.017 | < 0.017 | 0.39 | 0.35 | 0.35 | 0.37 | 0.37 | 0.020 | 0.0200 | 0.37 | 0.38 | 0.40 | 0.39 | 0.37 | < 0.017 | < 0.017 |
| Thorium, Total | ug/l | | 0.12 | 0.083 | 0.065 | 0.12 | 0.15 | 0.054 | 0.0554 | 0.22 | 0.12 | 0.090 | 0.090 | 0.080 | < 0.038 | < 0.038 | 0.040 | < 0.038 | < 0.038 | 0.040 | < 0.038 | < 0.038 | < 0.038 |
| Vanadium, Total | ug/l | 50 (CA) | 2.8 | 2.7 | 2.7 | 2.6 | 4.3 | < 0.0090 | < 0.0090 | 2.7 | 2.7 | 2.7 | 3.0 | 3.1 | 0.52 | 0.250 | 2.3 | 2.3 | 2.3 | 2.2 | 2.2 | < 0.0090 | < 0.0090 |
| Zinc, Total | ug/l | 5000 | 53 | 51 | 51 | 51 | 48 | 0.46 | 0.492 | 59 | 58 | 58 | 56 | 55 | 0.36 | 0.330 | 49 | 48 | 50 | 50 | 51 | < 0.30 | < 0.30 |
| Uranium, Total | ug/l | 30 | 0.25 | 0.09 | 0.09 | 0.10 | < 0.008 | < 0.008 | < 0.008 | 0.17 | 0.08 | 0.07 | 0.01 | 0.01 | < 0.008 | < 0.008 | 0.26 | 0.14 | 0.13 | 0.01 | 0.01 | < 0.008 | < 0.008 |
| **Anions by EPA Method 300.0/300.1/326** | | | | | | | | | | | | | | | | | | | | | | | |
| Bromate (EPA 300.1) | ug/l | 10 | < 1.6 | < 1.6 | 5.8 | 7.9 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 3.2 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | < 1.6 | 6.5 | 1.8 | 3.0 | < 1.6 | < 1.6 |
| Bromate (EPA 326.0) | ug/l | 10 | 0.32 | < 0.25 | 5.0 | 4.6 | 5.9 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | 1.4 | 1.6 | 1.9 | < 0.25 | < 0.25 | < 0.50 | < 0.50 | 3.4 | 3.5 | 3.2 | 0.81 | < 0.25 |
| Chloride, Total | mg/l | 250 | 52 | 53 | 53 | 53 | 53 | 0.11 | 0.22 | 56 | 56 | 55 | 57 | 57 | 0.70 | 0.0960 | 59 | 55 | 62 | 61 | 62 | < 0.079 | 0.0960 |
| Sulfate as SO4 | mg/l | 250 | 35 | 36 | 40 | 40 | 40 | 4.6 | < 0.038 | 46 | 47 | 51 | 49 | 50 | < 0.038 | < 0.038 | 49 | 45 | 54 | 53 | 53 | < 0.038 | < 0.038 |
| Bromide | mg/l | | 110 | 110 | 120 | 120 | 120 | < 4.1 | < 4.1 | 57 | 60 | 68 | 66 | 69 | < 4.1 | < 4.1 | 83 | 81 | 84 | 90 | 88 | < 4.1 | < 4.1 |
| Fluoride, Total | mg/l | 2 | 0.10 | 0.10 | 0.085 | 0.081 | 0.11 | < 0.013 | < 0.013 | 0.11 | 0.12 | 0.071 | 0.10 | 0.098 | < 0.013 | < 0.013 | 0.080 | 0.073 | 0.078 | 0.071 | 0.079 | < 0.013 | < 0.013 |
| Nitrate as N | ug/l | 45000 | 3800 | 3800 | 4200 | 4400 | 5600 | < 14 | < 14 | 3300 | 3400 | 3800 | 5000 | 5000 | < 14 | < 14 | 3400 | 3100 | 3900 | 4900 | 4900 | < 14 | < 14 |

## Table 4-14 (Category C)
## Inorganics Not Detected in Any Sample

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Metals by EPA 200 Series Methods** | | | | | | | | | | | | | | | | | | | | | | | |
| Beryllium, Total | ug/l | 4 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 | < 0.022 |
| Thallium, Total | ug/l | 2 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 | < 0.020 |
| **Methyl Mercury** | | | | | | | | | | | | | | | | | | | | | | | |
| Methyl Mercury | ng/L | | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 |
| **Anions by EPA Method 300.0/300.1/326** | | | | | | | | | | | | | | | | | | | | | | | |
| Chlorite | ug/l | 1000 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 4.6 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 | < 2.3 |
| **Asbestos** | | | | | | | | | | | | | | | | | | | | | | | |
| Asbestos | MFL | 7 | < 0.200 | < 0.200 | < 0.200 | < 0.200 | < 0.200 | < 0.200 | NM | < 0.500 | < 0.500 | < 0.200 | < 0.200 | < 0.200 | < 0.200 | NM | < 0.400 | < 0.200 | < 0.200 | < 0.200 | < 0.200 | < 0.200 | NM |

## Table 4-14 (Category D)
## Inconsistent Inorganics Results

| Constituents | Units | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Radiological Parameters by APHA/EPA Methods** | | | | | | | | | | | | | | | | | | | | | | | |
| Gross Alpha | pCi/L | 15 | 0.04 | 0.49 | 0 | 0 | 0.82 | 4.8 | 0.32 | 0.00 | 5.9 | 0.00 | 0.00 | 0.252 | 0 | 0.0 | 5.78 | 5.63 | 6.5 | 4.62 | 0.637 | 0.5 | 0.0 |
| Gross Beta | pCi/L | 50 | 12 | 9.8 | 9.2 | 15 | 12 | 0.94 | 0.40 | 9.4 | 13 | 9.7 | 9.1 | 11 | 0.084 | 0.0 | 14 | 1.9 | 14 | 6.4 | 2.5 | 0.73 | 0.0 |
| Radium 226 | pCi/L | 5 | 0.0620 | 0.0620 | 0.0920 | 0.122 | 0.0310 | 0.0270 | NM | 0.103 | 0.0260 | 0.154 | 0.00 | 0.132 | 0.0560 | NM | 0.00 | 0.0680 | 0.00 | 0.00 | 0.00 | 0.00 | NM |
| Strontium 90 | pCi/L | 8 | 0 | 0 | 0 | 0.181 | 0 | 0 | NM | 0.00 | 0.00 | 0.00 | 0.00 | 0.291 | 0.233 | NM | 0.0230 | 0.234 | 0.0700 | 0.187 | 0.234 | 0.187 | NM |
| Tritium | pCi/L | 20000 | 0 | 0 | 0 | 31.0 | 68.8 | 0 | NM | 0.00 | 61.9 | 193 | 103 | 0.00 | 0.00 | NM | 0.00 | 58.5 | 107 | 261 | 120 | 213 | NM |
| Mercury, Total (Lab 1) | ug/l | 2 | 0.020 | < 0.015 | < 0.015 | < 0.015 | < 0.015 | < 0.015 | < 0.015 | 0.020 | 0.020 | < 0.015 | < 0.015 | < 0.015 | < 0.015 | 0.0200 | < 0.015 | < 0.015 | < 0.015 | < 0.015 | < 0.015 | < 0.015 | < 0.015 |
| Silver, Total | ug/l | 100 | 0.032 | 0.017 | 0.0093 | < 0.0080 | 0.0086 | < 0.0080 | 0.0400 | 0.20 | 0.12 | 0.10 | 0.090 | 0.090 | 0.080 | 0.160 | 0.080 | 0.030 | 0.020 | 0.010 | 0.010 | < 0.0080 | 0.0900 |
| Mercury, Total (Lab 3) | ng/L | 2000 | 2.6 | 1.4 | 1.4 | 1.2 | < 1 | < 1 | < 1 | 3.4 | < 1 | 1.1 | < 1 | < 1 | < 1 | < 1 | < 0.4 | <0.4 | <0.4 | < 0.4 | < 0.4 | < 0.4 | < 0.4 |
| **Anions by EPA Method 300.0/300.1/326** | | | | | | | | | | | | | | | | | | | | | | | |
| Nitrite as N | ug/l | | < 15 | < 15 | < 15 | < 15 | < 15 | < 15 | < 15 | < 15 | < 15 | < 15 | < 15 | < 15 | < 15 | < 15 | < 15 | 110 | < 15 | < 15 | < 15 | < 15 | < 15 |
| **Perchlorate by EPA 314.0** | | | | | | | | | | | | | | | | | | | | | | | |
| Perchlorate | ug/l | 6 | 0.93 | 1.2 | < 0.82 | < 0.82 | < 0.82 | < 0.82 | < 0.82 | < 4.1 | < 4.1 | < 1.6 | < 1.6 | < 1.6 | 1.3 | < 0.82 | < 0.82 | < 0.82 | < 0.82 | < 0.82 | < 0.82 | < 0.82 | < 0.82 |
| **Cyanide, weak acid dissociable** | | | | | | | | | | | | | | | | | | | | | | | |
| Cyanide | ug/L | 150 | < 2.00 | < 2.00 | 5.35 | < 2.00 | < 2.00 | < 2.00 | < 2.00 | < 2.00 | < 2.00 | < 2.00 | 4.12 | < 2.00 | < 2.00 | < 2.00 | < 2.00 | < 2.00 | < 2.00 | < 2.00 | < 2.00 | < 2.00 | < 2.00 |

### 4.1.14 GENERAL WATER QUALITY PARAMETERS

The effect of MF-O3-BAC on general water quality is also of interest; and results from general water quality monitoring are presented in Table 4-15. More significant results include:

- BAC removed residual ammonia concentrations (from secondary treatment or bromate mitigation) to very low levels (< 0.1 mgN/L).
- Total effluent nitrogen concentrations will increase somewhat when ammonia is added to control bromate formation.
- The odor potential of effluent is reduced by MF-O3-BAC.

Table 4-15 (Category A)

## General Water Quality Parameter Removed to Detection Limits by MF-O3-BAC

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Nitrogen & Phosphorus** | | | | | | | | | | | | | | | | | | | | | | | |
| Biological Oxygen Demand (BOD) | mg/L | | < 2 | < 2 | 2 | NM | < 2 | NM | NM | 2 | < 2 | 2 | < 2 | NM | NM | NM | 3 | < 2 | < 2 | < 2 | NM | NM | NM |
| Nitrite-N | mg/L | 1 | NM | NM | NM | NM | NM | NM | NM | 0.04 | 0.04 | < 0.005 | < 0.005 | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM |
| MBAS | mg/L | 0.5 | 0.064 | 0.070 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | 0.059 | 0.053 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | 0.051 | 0.041 | < 0.019 | < 0.019 | < 0.019 | < 0.019 | < 0.019 |

Note: S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate;
FB - Field Blank; LB – Laboratory Blank; NM – Not Measured.

Table 4-15 (Category B)

## General Water Quality Parameter Detected At Least Once in MF-O3-BAC Effluent

| Constituents | Unit | MCL | Sampling Campaign 1 (8/18/09) | | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | | Sampling Campaign 3 (12/9/09) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | MF | O3 | O3D | BAC | FB | LB | S | MF | O3 | BAC | BACD | FB | LB | S | MF | O3 | BAC | BACD | FB | LB |
| **Nitrogen & Phosphorus** | | | | | | | | | | | | | | | | | | | | | | | |
| Ammonia as N | mg/L | | 0.06 | 0.05 | 0.92 | NM | 0.05 | NM | NM | 0.02 | < 0.02 | 0.72 | < 0.02 | NM | NM | NM | 0.07 | 0.05 | 0.93 | 0.02 | NM | NM | NM |
| ammonia as N, filtered | mg/L | | 0.06 | 0.09 | 0.92 | NM | 0.07 | NM | NM | < 0.02 | < 0.02 | 0.75 | < 0.02 | NM | NM | NM | 0.06 | 0.07 | 0.94 | 0.03 | NM | NM | NM |
| Dissolved Inorganic Nitrogen (DIN) | mg/L | | 4 | 4 | 5.3 | NM | 5.8 | NM | NM | 3.5 | 3.5 | 4.8 | 5 | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM |
| Dissolved Organic Nitrogen (DON) | mg/L | | 0.7 | 0.5 | 0.5 | NM | 0.2 | NM | NM | 1 | 0.7 | 0.5 | 0.5 | NM | NM | NM | 1 | 0.8 | 0.6 | 0.6 | NM | NM | NM |
| Nitrate-N | mg/L | 45 | NM | NM | NM | NM | NM | NM | NM | 3.5 | 3.4 | 4.1 | 5.1 | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM |
| Nitrate-Nitrite as N | mg/L | 10 | 4 | 3.9 | 4.4 | NM | 5.8 | NM | NM | 3.6 | 3.5 | 4.1 | 5.1 | NM | NM | NM | 3.3 | 3.5 | 4 | 4.8 | NM | NM | NM |
| Nitrate-Nitrite as N, Filtered | mg/L | 10 | 4 | 3.9 | 4.4 | NM | 5.8 | NM | NM | 3.5 | 3.5 | 4.1 | 5 | NM | NM | NM | 3.6 | 3.5 | 4 | 4.8 | NM | NM | NM |
| Total Organic Nitrogen | mg/L | | 0.9 | 0.6 | 0.5 | NM | 0.3 | NM | NM | 1.1 | 0.8 | 0.5 | 0.4 | NM | NM | NM | 1.6 | 0.08 | 0.6 | 0.06 | NM | NM | NM |
| Total Inorganic Nitrogen | mg/L | | 4 | 3.9 | 5.4 | NM | 5.8 | NM | NM | 3.6 | 3.5 | 4.8 | 5.1 | NM | NM | NM | 3.3 | 3.5 | 4.9 | 4.9 | NM | NM | NM |
| Total Nitrogen | mg/L | | 1.9 | 4.5 | 5.8 | NM | 6.1 | NM | NM | 4.7 | 4.2 | 5.4 | 5.6 | NM | NM | NM | 4.9 | 4.3 | 5.5 | 5.5 | NM | NM | NM |
| Total Nitrogen, filtered | mg/L | | 4.8 | 4.5 | 5.8 | NM | 6 | NM | NM | 4.5 | 4.2 | 5.3 | 5.5 | NM | NM | NM | 4.6 | 4.4 | 5.5 | 5.5 | NM | NM | NM |
| Ortho-phosphate as P | mg/L | | 1.8 | 1.9 | 1.9 | NM | 2 | NM | NM | 1.9 | 1.9 | 2 | 2 | NM | NM | NM | 1.3 | 1.3 | 1.3 | 1.3 | NM | NM | NM |
| Phosphorus, Total as P | mg/L | | 2 | 2 | 2 | NM | 2 | NM | NM | 2 | 1.9 | 2 | 2 | NM | NM | NM | 1.5 | 1.3 | 1.3 | 1.3 | NM | NM | NM |
| o-Phosphate as P | mg/l | | 0.0046 | 2.3 | 2.4 | 2.2 | 2.1 | 2.1 | < 0.00083 | 1.8 | 2.2 | 2.1 | 2.3 | 2.3 | < 0.00083 | < 0.00083 | 1.3 | 1.2 | 1.3 | 1.3 | 1.3 | < 0.00083 | < 0.00083 |
| TOC | mg/L | | 6.1 | 5.6 | 5.4 | 5.4 | 2.3 | 0.099 | 0.0573 | 6.2 | 5.7 | 5.6 | 2.8 | 3.0 | 0.17 | 0.0570 | 5.3 | 5.1 | 5.0 | 2.8 | 2.7 | 0.099 | 0.0355 |
| Alkalinity as CaCO3 | mg/l | | 100 | 110 | 100 | 100 | 96 | 10 | < 2.0 | 120 | 120 | 110 | 110 | 110 | 17 | 6.04 | 130 | 130 | 120 | 120 | 120 | 8.1 | 5.03 |
| Langelier Index @ 20 C | N/A | | -0.737 | -0.636 | -0.604 | -0.577 | -0.848 | -4.23 | NM | -0.970 | -0.837 | -0.822 | -0.951 | -0.926 | -4.96 | NM | -0.912 | -0.876 | -0.796 | -0.839 | -0.895 | -6.79 | NM |
| Langelier Index @ 60 C | N/A | | -0.217 | -0.116 | -0.085 | -0.058 | -0.328 | -3.70 | NM | -0.451 | -0.318 | -0.303 | -0.432 | -0.406 | -4.43 | NM | -0.393 | -0.357 | -0.277 | -0.320 | -0.376 | -6.25 | NM |
| pH | N/A | | NM | NM | NM | NM | NM | NM | NM | 6.99 | 7.12 | 7.17 | 7.08 | 7.09 | 5.71 | NM | 6.97 | 7.00 | 7.12 | 7.08 | 7.04 | 5.98 | NM |
| Threshold Odor Number | T.O.N. | 3 | 25 | 12 | NM | 17 | 1.0 | 1.0 | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM | NM |
| Specific Conductance (EC) | umhos/cm | 900 | 490 | 490 | 500 | 500 | 500 | 27 | 0.440 | 530 | 530 | 540 | 530 | 530 | 5.0 | 0.430 | 580 | 580 | 590 | 590 | 590 | 6.0 | 0.470 |
| Total Dissolved Solids | mg/l | 500 | 300 | 300 | 290 | 300 | 310 | 14 | < 4.0 | 330 | 320 | 310 | 320 | 330 | 9.0 | < 4.0 | 350 | 330 | 350 | 360 | 360 | < 4.0 | < 4.0 |

Because total nitrogen can be a critical water quality parameter when biostimulation is an issue, the nitrogen data warrant further discussion. Total nitrogen concentrations measured during Phase 2 are presented in Figure 4-11. Seasonal addition of ammonia for bromate mitigation resulted in increasing the total nitrogen concentration in ozone and BAC effluents during summer months. The consistently higher values of total nitrogen measured in BAC effluent compared to ozone effluent might be a result of change in nitrogen speciation during BAC treatment. The Skalar method for total nitrogen analysis employed in this study includes a catalytic oxidation step converting chemically bound nitrogen to nitric oxide. BAC has been found to be effective in converting ammonia to nitrate (i.e. nitrification). Therefore, it appears that nitrogen in the form of ammonia is prone to more analytical interference and/or incomplete oxidation when compared to nitrogen in other forms, such as nitrate.

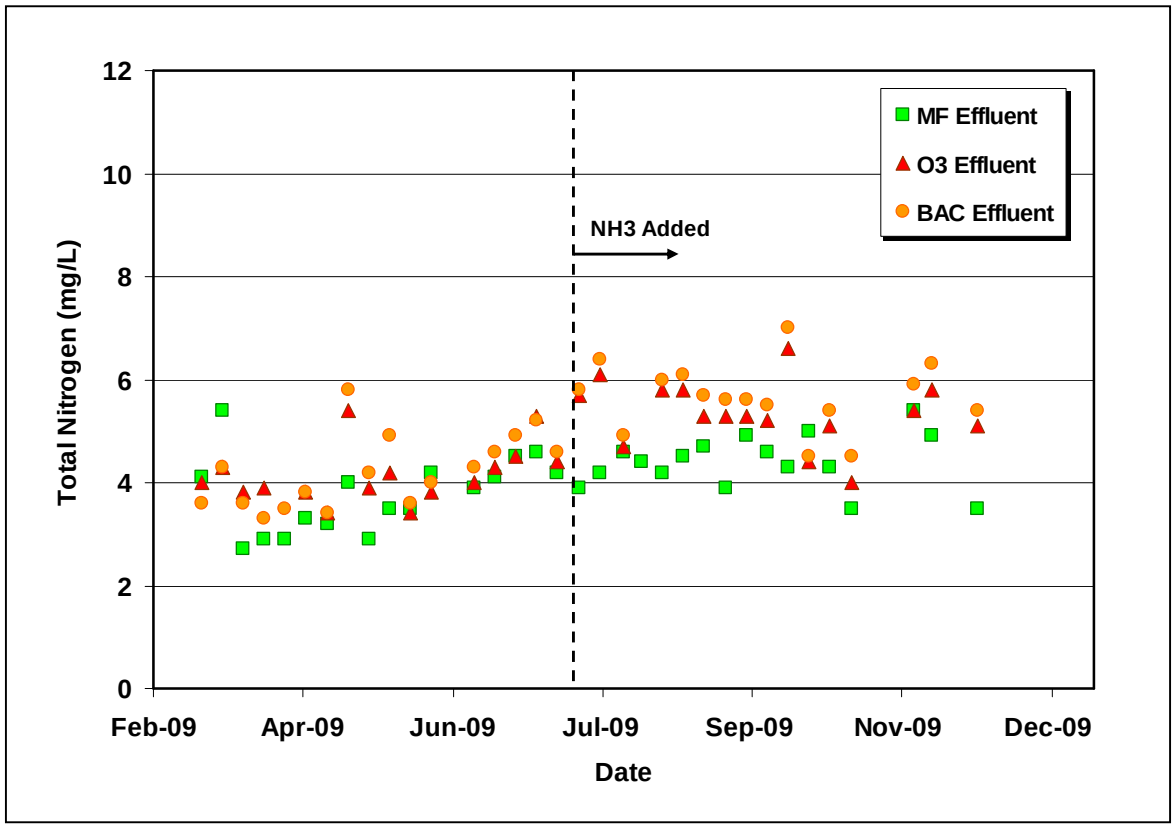


Figure 4-11
**Total Nitrogen during Phase 2**

## 4.2 EFFECT OF PEROXIDE ON CEC REMOVAL

The RSWRF pilot study confirmed findings by others that addition of peroxide to ozonation does not affect materially the extent of CEC removal achieved by a given ozone dose (Acero et al., 2001), as shown in Table 4-16. However, addition of peroxide reduces the time needed to attain CEC removal and mitigates bromate formation.

Table 4-16
**Effect of Peroxide on CEC Removal Achieved with 5 mg/L Ozone Dose**

| | Without Peroxide | | With Peroxide | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Sampling Campaign 1 | | Sampling Campaign 2 | | Sampling Campaign 3 | |
| | MF Influent | O3 Effluent | MF Influent | O3 Effluent | MF Influent | O3 Effluent | MF Influent | O3 Effluent |
| Constituent | ng/L | ng/L | ng/L | ng/L | ng/L | ng/L | ng/L | ng/L |
| DEET | 40 | 5.5 | 24 | 0.68 | 300 | 4.6 | 52 | 2.4 |
| Fluoxetine | 33 | < 1 | 1.7 | 2.0 | 2.9 | < 0.080 | 2.6 | < 0.080 |
| Phenytoin | 390 | 14 | 150 | 4.2 | 140 | 3.6 | 740 | < 0.33 |
| Sulfamethoxazole | 410 | < 1 | 380 | 2.2 | 340 | < 0.19 | < 0.19 | < 0.19 |
| Meprobamate | 870 | 200 | 700 | 130 | 840 | 97 | 590 | 89 |
| Estrone | 10 | < 1 | 23 | 0.52 | 4.5 | < 0.2 | 8.1 | < 0.2 |
| Carbamazepine | 250 | < 1 | 120 | < 0.80 | 750 | < 0.080 | 220 | < 0.080 |
| Diclofenac | 59 | < 2 | 160 | < 0.5 | 79 | < 0.5 | 88 | < 0.5 |
| Gemfibrozil | 120 | < 1 | 36 | < 0.080 | 27 | < 0.080 | 43 | 0.19 |
| Methadone | 67 | < 5 | 32 | 0.31 | 29 | < 0.040 | 38 | < 0.040 |
| Naproxen | 7.9 | < 1 | 23 | < 0.25 | 6.8 | < 0.25 | 24 | < 0.25 |
| Trimethoprim | 83 | < 5 | 130 | < 2.4 | 130 | < 0.24 | < 0.24 | < 0.24 |
| Bisphenol A | 20 | 15 | 22 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 |
| Atrazine | 2.8 | < 1 | 2 | 0.5 | 1.1 | 0.39 | 1.5 | 0.52 |
| Diazepam | 1 | < 1 | 1.1 | 0.18 | 0.96 | < 0.14 | < 0.14 | < 0.14 |
| E-Screen Estradiol Equivalents (EEq) | 1.7 | < 0.027 | 2.1 | < 0.027 | 1.1 | < 0.027 | 1.7 | < 0.027 |

## 4.3 VIRUS INACTIVATION BY OZONE

### 4.3.1 OZONE (NO PEROXIDE) MS2 INACTIVATION

The effectiveness of ozonation in inactivating MS2 bacteriophage to levels required in California Title 22 regulations was evaluated. MS2 has lesser resistance to ozonation than poliovirus; therefore, at least 6.5-Log removal of MS2 was targeted as being equivalent to demonstrate 5-Log removal of poliovirus (CDPH, 2008b). Raw data and statistical summaries are provided in Table 4-17 with results plotted in Figure 4-12. Figure 4-13 presents the foregoing data in a CT format showing that 6.5 Log removal of MS2 can be achieved within an ozonation CT of 0.1 mg•min/L when applied to a membrane filtered effluent.

Table 4-17
**Virus Testing: MF-O3 (No Peroxide, No BAC)**

| Contact Time (min.) | Sample 1 | Sample 2 | Sample 3 | Average | Std. Dev. | Log Removal |
|---|---|---|---|---|---|---|
| 0 | 1.8E+08 | 1.4E+08 | 1.8E+08 | 1.7E+08 | 2.3E+07 | |
| 0.00417 | 6.0E+02 | 3.3E+02 | 1.0E+02 | 3.4E+02 | 2.5E+02 | 5.7 |
| 0.02 | 1.0E+01 | 1.0E+00 | 1.0E+01 | 7.0E+00 | 5.2E+00 | 7.4 |
| 0.04 | 1.0E+00 | 1.0E+00 | 1.0E+00 | 1.0E+00 | 0.0E+00 | 8.2 |
| 0.06 | 1.0E+00 | 1.0E+00 | 4.0E+00 | 2.0E+00 | 1.7E+00 | 7.9 |
| 0.08 | 2.0E+00 | 2.0E+00 | 1.0E+00 | 1.7E+00 | 5.8E-01 | 8.0 |
| 0.13 | 1.0E+00 | 7.0E+00 | 1.0E+00 | 3.0E+00 | 3.5E+00 | 7.7 |
| 0.56 | 1.0E+00 | 1.0E+00 | 1.0E+00 | 1.0E+00 | 0.0E+00 | 8.2 |

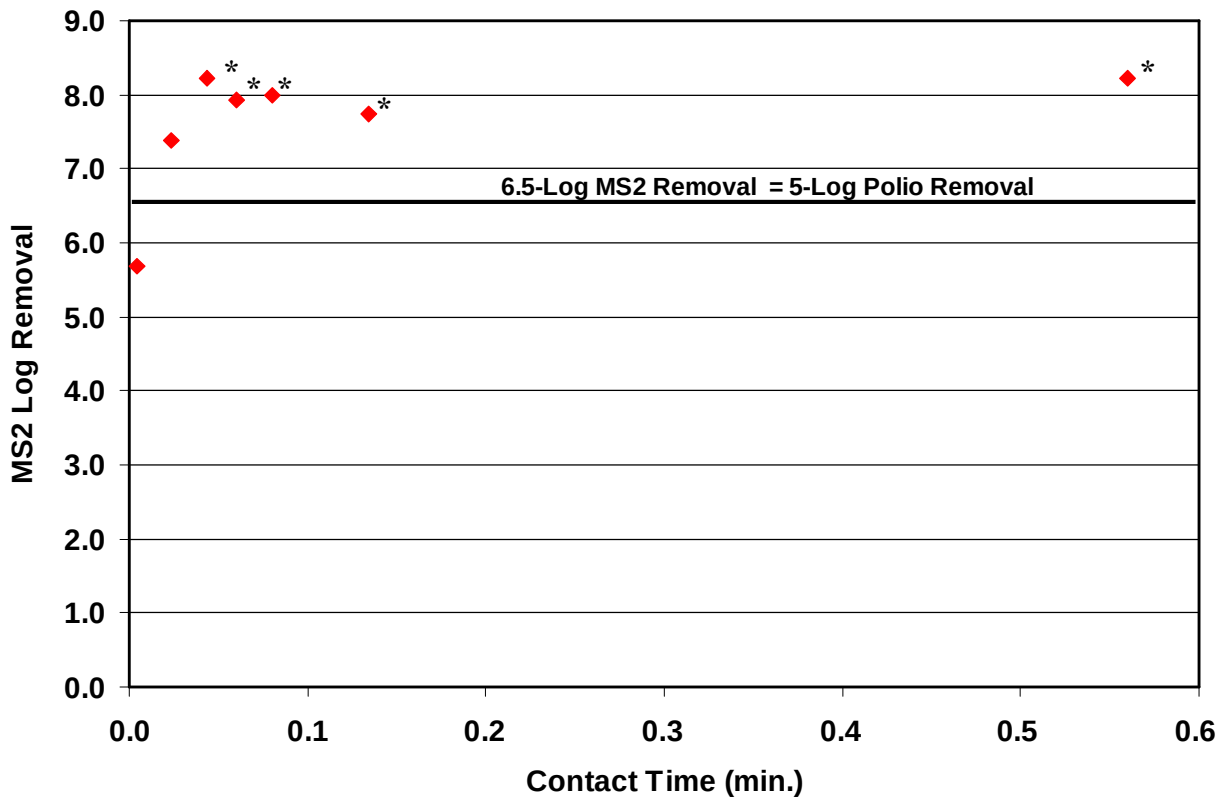


Figure 4-12
**Virus Inactivation using Ozone (No Peroxide, No BAC) as a Function of Contact Time**

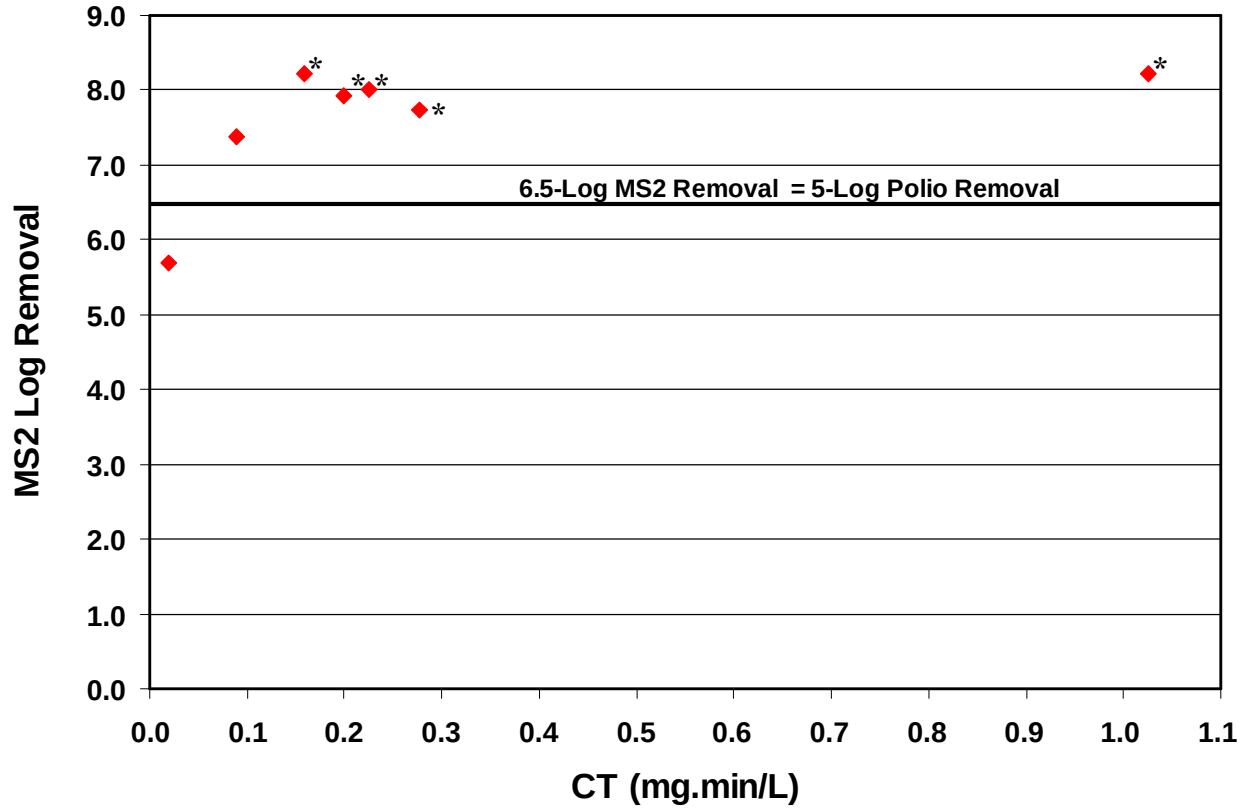


Figure 4-13
**Virus Inactivation using Ozone (No Peroxide, No BAC) as a Function of CT**

### 4.3.2 TOC INTERFERENCE IN VIRUS TESTING

The TOC concentration of some MS2 virus seed solutions can substantially affect virus inactivation test conditions. As shown in Figure 4-14, the Lab 2 virus seed solution had a high TOC residual from the MS2 reproduction process. This seed solution TOC increased the TOC of ozone test solution from 5.5 mg/L to 21.5 mg/L. These added organics express an ozone demand that complicates the interpretation of the viral inactivation results in terms of CT. TOC interference was addressed by switching to a different virus seed (Lab 1) with a relatively low TOC concentration. As shown in Figure 4-14, the ozone residual curves with high (~21.5 mg/L) TOC interference is substantially different from the ozone residual curves without major TOC interference.

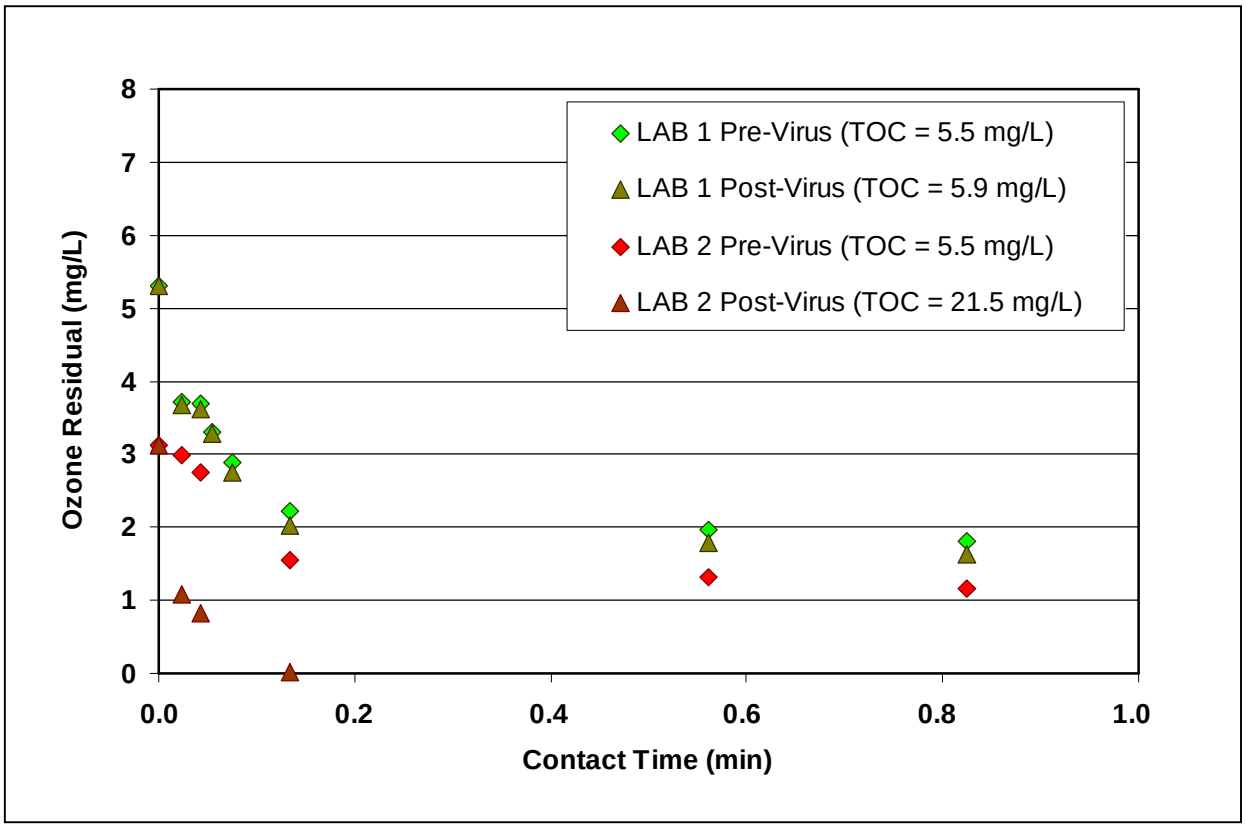


Figure 4-14
**Impact of Background TOC on Ozone Demand**

### 4.3.3 THE EFFECT OF PEROXIDE ADDITION ON OZONE INACTIVATION OF MS2

The effect of peroxide addition to mitigate bromate formation on ozone inactivation of MS2 bacteriophage to levels required in California Title 22 regulations was evaluated. Results presented in Table 4-18 and Figure 4-15 show that 6.5 Log removal of MS2 can be achieved within an ozonation CT of 0.1 mg•min /L. Unfortunately, detectable concentrations of virus were found in subsequent samples, probably denoting the analytical uncertainty (see Outliers in Table 4-18).

Table 4-18
**Virus Testing: MF-O3 (With Peroxide, No BAC)**

| Contact Time (min.) | Sample 1 | Sample 2 | Sample 3 | Average | Std. Dev. | Log Removal |
|---|---|---|---|---|---|---|
| 0 | 1.2E+08 | 1.0E+08 | 1.1E+08 | 1.1E+08 | 1.0E+07 | |
| 0.00417 | 8.0 | 1.0 | 2.0 | 3.7 | 3.8 | 7.5 |
| 0.02 | 120* | 3.0 | 2.0 | 2.5 | 0.71 | 7.6 |
| 0.04 | 1.0 | 1.0 | 11 | 4.3 | 5.8 | 7.4 |
| 0.06 | 2.0 | 4.0 | 240* | 3.0 | 1.4 | 7.6 |
| 0.08 | 1.0 | 1.0 | 97* | 1.0 | 0 | 8.0 |
| 0.13 | 1.0 | 3.0 | 1.0 | 1.7 | 1.2 | 7.8 |
| 0.56 | 1.0 | 1.0 | 6.0 | 2.7 | 2.9 | 7.6 |
| 0.83 | 7800* | 3.0 | 1.0 | 2.0 | 1.4 | 7.7 |

* Outliers; not included in the data analysis.

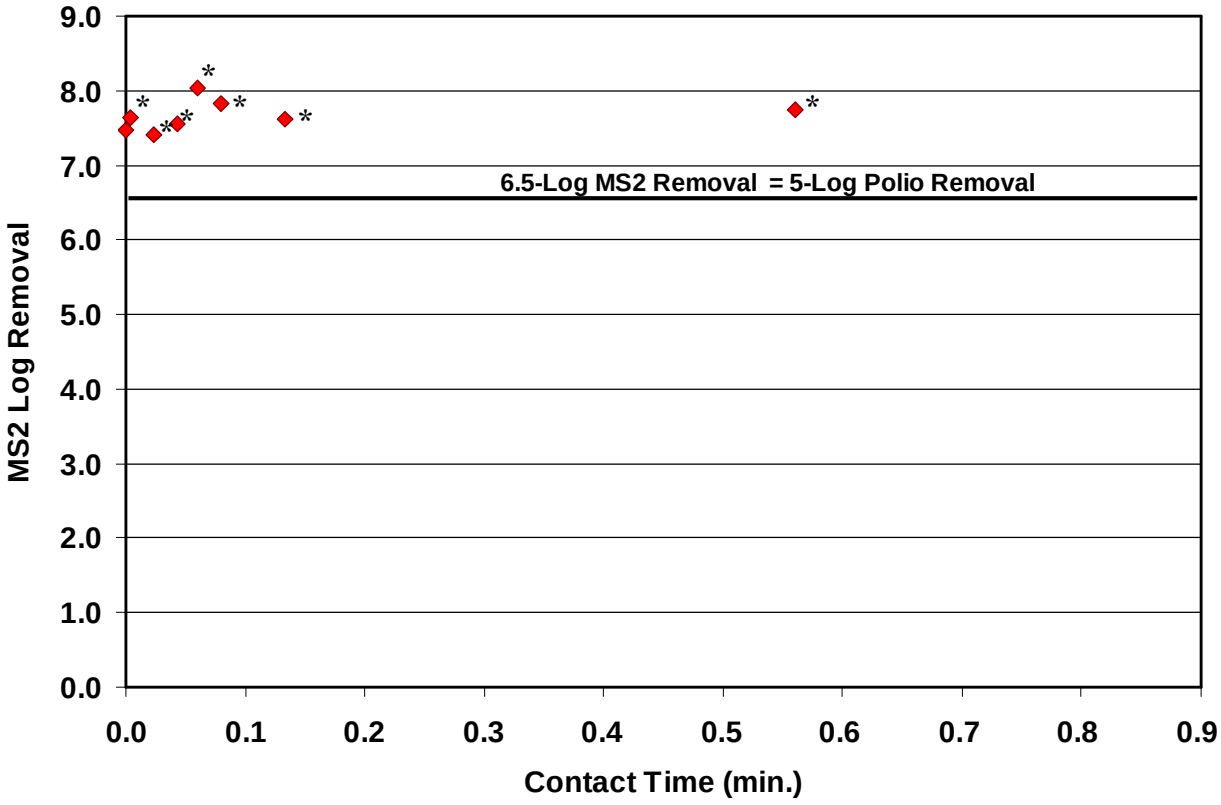


Figure 4-15
**Virus Inactivation Using Ozone (With Peroxide, No BAC) as a Function of Contact Time**

## 4.4 MF-O3-BAC VERSUS RO

The primary objective of this project was to determine if there was a means comparable to RO treatment to effectively and reliably remove CECs from wastewater effluents without the brine waste associated with RO treatment (comparative energy demands for treatment process trains consisting of O3-BAC and RO are presented in Appendix E). To achieve this objective, the MF-O3-BAC treatment process was developed, optimized and demonstrated over the course of 3 years with the results being presented, herein. In this subsection, those results are compared to published results of RO wastewater treatment projects to determine the similarities and differences between these two treatment technologies in the key areas including:

- CEC Removal
- Byproducts (e.g., bromate and NDMA)
- Effluent Salinity and Corrosivity
- TOC

### CEC Removal

Key CEC parameters include EDCs (hormones) and PPCPs (e.g., cleaning compounds, insect repellents, flame retardants, etc.). Based on the Reno results and results published in the literature, critical contaminants in each category are:

- EDCs including specifically total hormone concentrations, and overall (i.e. synergistic) estrogenic activity as measured by E-screen bioassay.
- Pharmaceuticals such as meprobamate, which appears to be a pharmaceutical most difficult to remove.
- Personal care products such as TCEP (a flame retardant) which appears to be most difficult to remove.

Comparative effluent quality results for these key CEC parameters for MF-O3-BAC and RO are presented in Figure 4-16. As shown, MF-O3-BAC appears to be comparable to RO in the removal of these most critical indicator CECs.

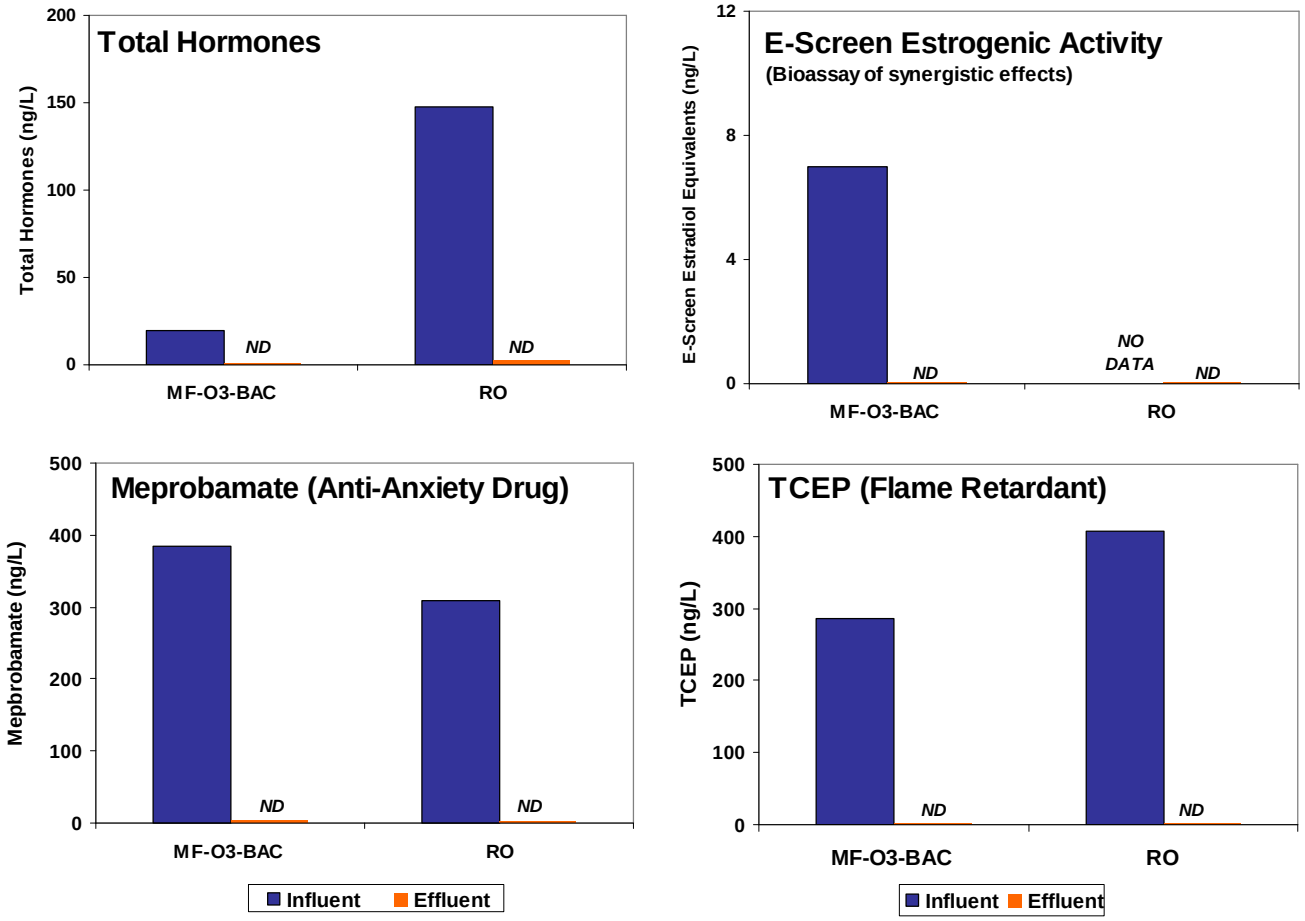


Figure 4-16
**Removal of Critical Indicator CECs by MF-O3-BAC and RO**

## Byproducts

### *NDMA*

NDMA (N-Nitrosodimethylamine) is a carcinogen which can form when strong oxidizing agents (such as chlorine or ozone) are utilized. The target water quality objective in California for NDMA is 10 ng/L to control risk of cancer. NDMA results for MF-O3-BAC and RO are presented in Table 4-19. As shown, even with peroxide and high-energy UV (HUV) post-treatment, RO effluent typically contains detectable amounts of NDMA, whereas MF-O3-BAC does not. The source of NDMA in RO effluent appears to be the chloramination pre-treatment step used to control membrane biofouling.

Table 4-19
**NDMA Formation and Mitigation**

| MF-O3-BAC | | RO-H2O2-HUV (Sedlak et al, 2006) | |
|---|---|---|---|
| **Location** | **NDMA (ng/L)** | **Location** | **NDMA (ng/L)** |
| Secondary Effluent (Chloramination is not required) | 1 | Secondary Effluent (after Chloramination) | 52-640 |
| Membrane Effluent | 0.9 | Before RO | 50-100 |
| Ozone Effluent | 6-11 | After RO | 13-50 |
| BAC Effluent | <0.28 | After H2O2-HUV | 2-28 |

### *Bromate*

Bromate is a suspected carcinogen with a MCL of 10 μg/L. Bromate formation is not a concern during RO treatment. If bromate is present, the RO membrane is very effective in rejecting bromate ions to the concentrate stream. The presence of excessive amounts of peroxide significantly reduces bromate formation during the RO post-treatment process of H2O2-HUV used to mitigate NDMA in RO effluent.

During ozonation, ozone dosage, presence of ammonia, and effluent bromide levels are major determinants of bromate formation. Bromate formation generally is not problematic when effluent bromide concentrations are less than 20 μg/L. If ozonation causes bromate concentrations of concern, results from this study show addition of peroxide (year-round) and ammonia (seasonally) is effective in reducing the levels of bromate to well below the MCL.

## Effluent Salinity and Corrosivity

RO can reduce salinity (measured as TDS, total dissolved solids) to relatively low levels (see Figure 4-16) whereas MF-O3-BAC does not. Thus, when some removal of salinity is necessary, some use of RO (possibly on only a portion of the total wastewater flow) is necessary. However, it is important to note that salinity removal is not necessary or appropriate in all cases. Extensive removal of TDS has an unwanted side effect: elevated effluent corrosivity (commonly expressed as Langelier Saturation Index, LSI). Water with an LSI less than -0.5 is considered to be aggressively corrosive. In water reuse projects involving groundwater recharge, increasing the corrosivity of effluent injected into the groundwater increases the probability that naturally occurring metals in subsurface soils, such as arsenic, will leach into the injected effluent, and therefore into the groundwater resource. A recent evaluation of RO effluent stabilization showed

that chemical addition of about 20 mg/L of calcium chloride and 10 mg/L of caustic is required to control corrosivity (Ghosh, 2008). As shown in Figure 4-17, MF-O3-BAC has no effect on LSI.

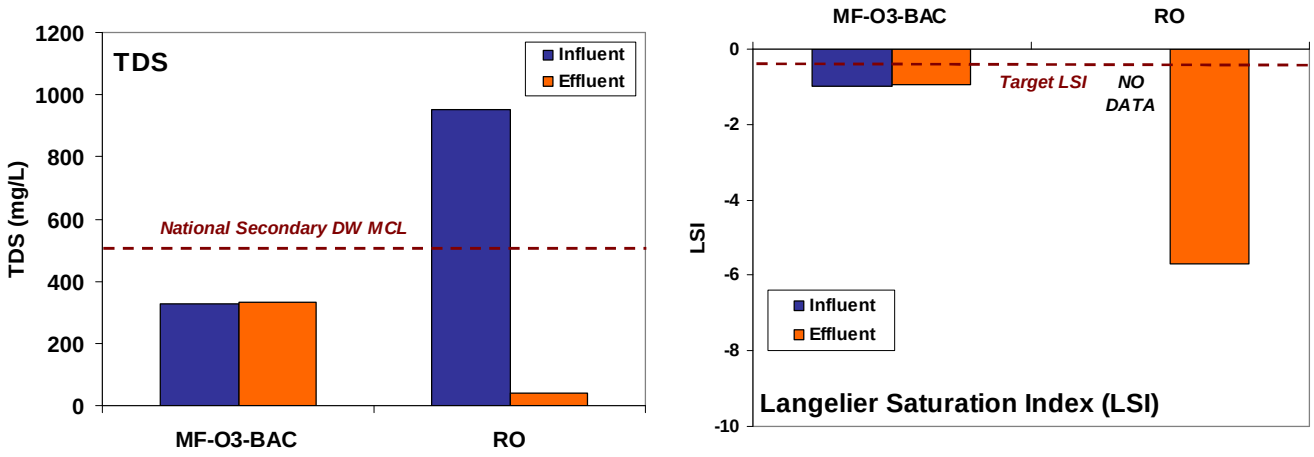


Figure 4-17
**MF-O3-BAC versus RO: Salinity and Effluent Corrosivity**

## TOC

RO-H2O2-HUV is more effective than MF-O3-BAC in reducing effluent Total Organic Carbon (TOC) as shown in Figure 4-18. The technical significance of this difference, currently, is unknown, though TOC is of regulatory significance as an indicator for the possible presence of CECs. Because MF-O3-BAC was shown to be effective at fully removing a wide range of CECs in the Reno study, TOC as an indicator of the presence of CECs does not appear to be valid. The issue and significance of TOC in the context of MF-O3-BAC effluent for various types of water reuse projects require further investigation.

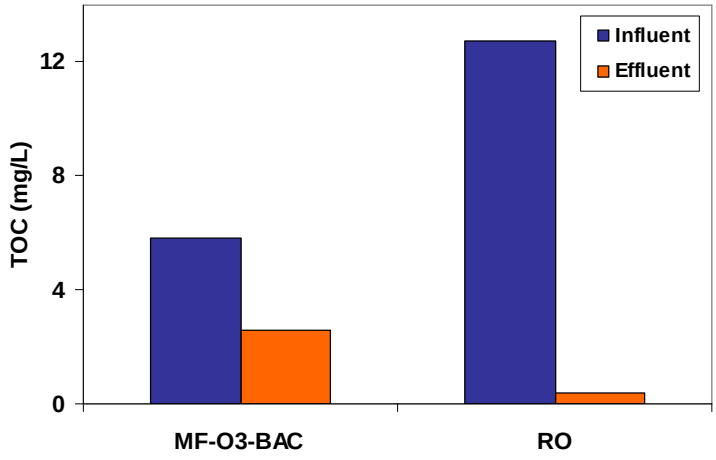


Figure 4-18
**MF-O3-BAC versus RO: Total Organic Carbon (TOC)**

Section 5

# Project Conclusions

MF-O3-BAC is effective for removing a broad spectrum of contaminants of emerging concern (CECs) under sustained, continuous flow, field conditions. MF-O3-BAC has the following advantages over the commonly used reverse osmosis alternative:

- The majority of the CECs are degraded with MF-O3-BAC, not concentrated in a brine stream in need of specialized treatment or disposal as with RO.
- With MF-O3-BAC, there is no continuous reject stream resulting in loss of water resource. With RO, roughly 20% of the water resource is lost via the brine stream.
- Pretreatment and post-treatment requirements for MF-O3-BAC are typically less than required for RO. As an example, MF-O3-BAC does not require separate, energy intensive, NDMA post-treatment control steps.
- MF-O3-BAC effluent has greater ionic stability than RO effluent unless the RO effluent is stabilized via lime addition.

In comparison to RO, MF-O3-BAC does not remove salts (i.e., TDS) and inorganics (e.g., metals). Metals issues can be addressed by source control and alternative treatment processes, if needed. In Reno's case, TDS reduction is not required at this time as the current levels of effluent TDS are considerably lower than the published effluent TDS limitations. In other inland locations where TDS reduction is needed, installation of a small downstream RO unit treating a portion of MF-O3-BAC can be considered.

RO produces lower effluent TOC concentration than MF-O3-BAC. TOC is an indicator parameter used by some regulatory agencies in certain water reuse situations. The actual significance of TOC as an indicator is unknown at this time.

Benefits of some of the specific components of the MF-O3-BAC process are discussed in the following sections.

**MF (membrane filtration)** is very effective at removing almost all particulates, including microbes/pathogens, prior to ozonation. MF is the only pretreatment process that was investigated as a part of this demonstration project. The effectiveness of other alternative filtration steps (e.g., sand filtration) as pretreatment for O3-BAC is still unknown and therefore warrants further investigation.

**O3 (ozone),** as an oxidant and disinfectant, provides several benefits. The following conclusions are made from this demonstration project:

- Ozone dosed at 5 mg/L (or 0.85 $mgO_3$/mgTOC) is effective in removing the majority of CECs present in membrane effluent except for those constituents engineered to be highly resistive to any type of oxidation (e.g., flame retardants).
- Ozone with or without peroxide is effective in providing the level of virus inactivation specified in the California Title 22 requirements for unrestricted reuse of reclaimed water.
- Ozone doses needed to remove CECs may generate bromate at concentrations higher than 10 μg/L (i.e., the current MCL) when high concentrations of bromide are present in the influent (≥ 250 μg/L). Year-round addition of peroxide (1:1 peroxide: ozone molar ratio) and seasonal addition of ammonia (~1-1.5 mg/L) were found to be an effective bromate mitigation strategy.

**BAC (biologically active filtration)** plays a synergistic role with O3 in stabilizing biodegradable organics created by ozone's oxidative cleavage of refractory organics. The following conclusions are made from this demonstration project:

- The microbial biomass maturation time for BAC is about 60 to 70 days.
- BAC consistently improves the biological stability of the ozonated effluent by removing readily biodegradable organic byproducts of ozonation.
- BAC provided NDMA and short-chain organics mitigation by reducing their concentrations to below detection levels.
- BAC is effective in consistently removing many CECs residual in ozonated effluent, such as flame retardants. Mechanisms causing CEC removal in BAC require further investigation.

Section 6

# Next Steps

With the successful completion of this MF-O3-BAC treatment performance demonstration project, next steps towards the full-scale implementation of this technology can be subdivided into two general categories:

- Additional studies of specific technical and regulatory issues.
- Extended operation of a small-scale, purified effluent groundwater replenishment demonstration project, specifically an Aquifer Storage and Recovery (ASR) project.

## 6.1 ADDITIONAL STUDIES OF SPECIFIC TECHNICAL AND REGULATORY ISSUES

The performance results presented herein are substantial evidence that MF-O3-BAC technology is as effective as RO-based treatment technologies in the removal of refractory organics from RSWRF effluent, in general. However, additional studies are needed to more fully optimize the technology, and to demonstrate its effectiveness under a wide range of conditions. These additional studies are of two types: technical and regulatory:

- Recommended technical studies:
  - Evaluate the impact of changing from MF to sand filtration (SF) as pretreatment process.
  - Further optimize design and operational parameters.
- Recommended regulatory studies:
  - Evaluate treatment robustness by testing different secondary effluent sources.
  - Assess the significance of final effluent TOC.

### 6.1.1 EVALUATE THE IMPACT OF SAND FILTRATION

Refractory organic removal performance data presented herein are based on membrane filtered secondary effluent. MF is relatively more costly and labor intensive. Sand filtered (SF) secondary effluent is much more common. Determining the impact on treatment process design, performance, operation, and maintenance resulting from changing from MF to SF as pretreatment to the O3-BAC processes is of great potential value. The City was able to develop some very preliminary data on SF-O3-BAC from Dec 2009 to May 2010 during the decommissioning phase of the pilot project. Limited results collected during SF testing phase are promising, but more extensive testing and monitoring are necessary prior to drawing conclusions, particularly with regard to BAC performance and maintenance.

### 6.1.2 FURTHER PROCESS OPTIMIZATION

Though critical process design variables such as ozone dosage and bromate mitigation strategy were optimized during this study, other design variables could not be investigated within the available time.

#### BAC EBCT

Empty bed contact time (EBCT) is a key BAC process design parameter. An EBCT of 30 min (at a hydraulic loading rate of around 1 gpm/ft$^2$) was maintained during Phase 2 MF-O3-BAC testing. This design value was used based on an extensive literature survey of BAC design practices in somewhat similar water treatment situations. If EBCT could be reduced without loss of effectiveness, then the cost of BAC treatment could also be reduced. However, the effect of decreased EBCT on BAC performance needs to be investigated. Testing BAC performance at EBCTs less than 30 minutes under a wide range of water temperature and TOC/BDOC loading rates is recommended.

#### BAC Removal Mechanisms

BAC can remove several CECs (e.g., flame retardants). The removal mechanisms involved may include adsorption and biodegradation. Investigations evaluating CEC removal mechanisms in the BAC are recommended.

### 6.1.3 ROBUSTNESS EVALUATION

This demonstration project was conducted on one effluent from a specific treatment process and a specific community. It is recommended that the next stage of testing and demonstration be conducted at a different WWTP. This approach provides an opportunity to evaluate the robustness of the treatment train employing a different secondary effluent and a different operational team. The RSWRF pilot study used secondary effluent from a treatment process operated under fairly high SRTs (~17-25 days). High SRT extended aeration treatment processes are known to reduce effluent CEC concentrations via biometabolism or adsorption onto the activated sludge. Consequently, a few CECs common to many municipal WWTP effluents were not detected in RSWRF secondary effluent, and therefore could not be demonstrated to be removed by MF-O3-BAC treatment. If future testing is conducted at a WWTP with long SRT conditions, targeted CECs could be spiked into the secondary effluent to verify removals, if permitted by regulatory authorities. Based on results presented herein and results available in the literature, spiking effluent with at least caffeine and iopromide is recommended for the future robustness evaluation.

### 6.1.4 ASSESS THE SIGNIFICANCE OF FINAL EFFLUENT TOC

Total organic carbon (TOC) is an overall measure of organics present in effluent. The TOC test does not differentiate dioxin from sugar water, and thus provides no information as to whether the organics present in the water are of concern. However, TOC is often regulated as a "catch all" surrogate for the possibility of refractory organics of concern being present in the water. Results from this demonstration project show excellent removal of organic compounds of concern with the effluent TOC of 3.5 mg/L. By way of comparison, natural groundwaters have TOCs of around 0 to 1.5 mg/L, and surface waters have TOCs of around 0.5 to 4.5 mg/L. The significance, if any, of TOC in BAC effluent needs to be determined. Part of that determination

is whether it is removed readily by soil aquifer treatment (SAT), and whether it has significant trihalomethane formation potential (THMFP).

It is recommended that the composition of TOC present in BAC effluent be studied and compared with natural waters to determine its significance. The following consortium of analytical techniques should be considered to assay the samples:

- Fluorescence Excitation Emission Matrices (EEMs): EEMs are used in the identification and comparison of protein-like and humic-like fractions of organics in water samples. EEMs for RSWRF MF-O3-BAC treatment process samples collected on 8/18/09 are shown in Figure 6-1. Clean natural waters also have considerably low fluorescence intensities as shown for the O3-BAC effluent.

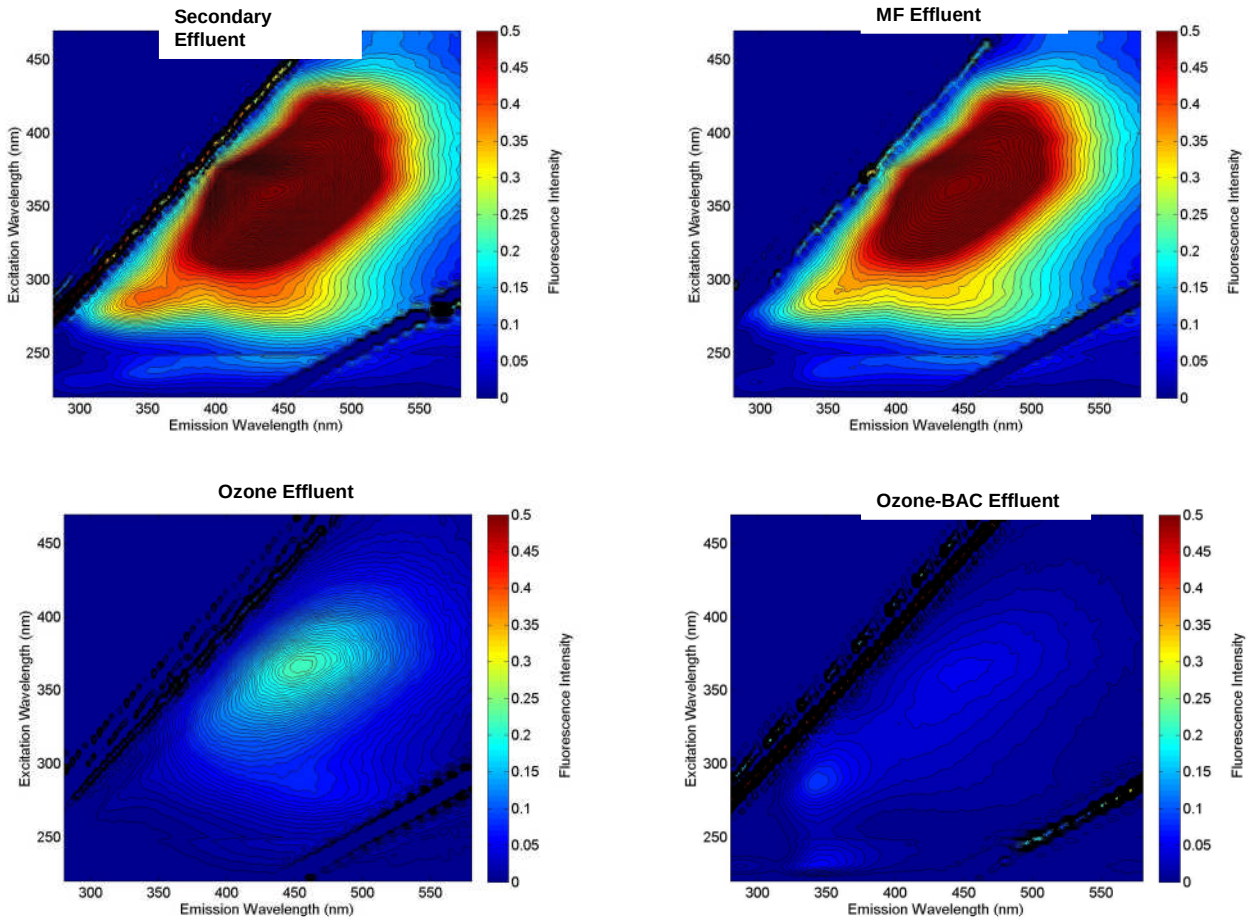


Figure 6-1
**Emission Excitation Matrices for RSWRF Pilot Treatment Process (Courtesy of Southern Nevada Water Authority)**

- Size exclusion chromatography (SEC) is used to determine molecular weight distribution and concentrations of DOC fractions such as proteins and polysaccharides, humic substances, and low-molecular weight acids.

- $^{13}$C-nuclear magnetic resonance spectroscopy ($^{13}$C-NMR) is used to determine shifts between chemical structures (e.g., alkyl, aromatic groups)
- Infrared spectrometry can be used to fractionate bulk DOC into hydrophobic and hydrophilic groups.

## 6.2 EXTENDED OPERATION OF A SMALL-SCALE EFFLUENT ASR PROJECT

The most important "next step" in the development and implementation of MF-O3-BAC and/or SF-O3-BAC for use in IPR projects is to build and operate for an extended period of time a small, continuous flow, ASR project. Similar to other effluent ASR projects, disinfected MF-O3-BAC effluent will be injected into the groundwater aquifer and recovered at a later date. This demonstration project will provide information on long-term changes to effluent quality during aquifer storage as a function of aquifer lithology. It will also provide information on the natural attenuation of TOC during aquifer storage and on effluent injection rates into the aquifer over time. Of special interest is quantifying any desorption (i.e., release) of naturally occurring aquifer constituents (e.g., arsenic, iron, manganese, etc.). As presently conceived, an ASR demonstration project would remove the injected reclaimed water after a relatively short period of time and without the benefits of flowing through the aquifer and co-mingling with the natural groundwater. Therefore, an extended period of water quality results from a MF-O3-BAC based ASR demonstration project would be a conservative estimate of water quality resulting from a MF-O3-BAC based IPR project. This extended period of results would be an important step towards determining whether a MF-O3-BAC based groundwater replenishment project would be acceptable to regulators and the general public.

The ideal MF-O3-BAC based ASR demonstration project includes:

- A water and wastewater agency willing to investigate these new ideas.
- An area with near-term or long-term effluent reuse plans such that the small ASR project could naturally evolve into a larger project satisfying water needs.
- Either a short SRT treatment process or approval to add CECs to the effluent from a long SRT process.
- Required filtration pretreatment processes.
- Aquifer strata with potentially leachable constituents of concern.
- A large effluent reclamation area to utilize the ASR project water. For this demonstration ASR project, the objective would be to remove each irrigation season, all effluent injected into the aquifer during the preceding non-irrigation season. In other words, essentially no reclaimed water is left in the aquifer on an annual basis.
- An underlying aquifer that is relatively homogeneous and has low horizontal flowrates.
- Facilities and staff to perform the additional studies identified in Section 6.1.

### 6.2.1 ASR DEMONSTRATION

Prior to initiating an ASR demonstration project, an injection permit must be obtained from the Nevada Division of Environmental Protection, Bureau of Water Pollution Control, Underground Injection Control. The background water quality and effluent quality; the location, design, and injection rate of the ASR well; and the design of any required monitoring wells, must be described in the application.

Specific elements of a recommended ASR demonstration project include:

- Monitor groundwater elevations in monitoring wells to determine the pre-injection groundwater flow direction in the vicinity of the site.
- Monitor groundwater elevations during the injection tests and recovery activities to evaluate the long-term injection potential of the aquifer under possible future full-scale project conditions. This work would include predicting changes in the groundwater flow direction and the effluent dispersion.
- Monitor the chemical quality of groundwater and effluent prior to, and after each recharge operation in both the ASR well and selected monitoring wells.

Tools used during the groundwater monitoring effort may include:

- Reclaimed water injection rates and pressures.
- Data loggers equipped with pressure transducers to monitor groundwater levels in the monitoring wells.
- Groundwater samples would be collected regularly from both the ASR and monitoring wells and analyzed for a select list of organic, inorganic, geochemical, and microbial constituents.

Possible water quality parameters of interest are summarized in Table 6-1.

Table 6-1
**Process Constituents**

| General Water Quality Parameters | Inorganic Parameters | Organic Parameters |
|---|---|---|
| Oxidation-Reduction Potential (ORP) | Metals (Dissolved and Total) | Total Organic Carbon (TOC) |
| Temperature | Minerals and Anions | Dissolved Organic Carbon (DOC) |
| pH | Total Dissolved Fixed Solids (TDFS) | Organic Nitrogen (Dissolved and Total) |
| Turbidity | Alkalinity | CECs: EDCs and PPCPs |
| Total Suspended Solids (TSS) | Nitrogen Species | NDMA |
| UV Transmittance (UVT) | Phosphorous Species | TCA |
| Dissolved Oxygen | Bromide | 1,4 Dioxane |
| Phospholipid Fatty Acids (PLFA) | Bromate | DBPs: TTHMs and HAAs |
| Coliforms (Fecal and Total) | | VOCs and SVOCs |
| Conductivity, Total Dissolved Solids (TDS) and Total Ionic Strength | | |

Section 7

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Appendix A

# Ozone Performance Evaluation and Optimization

Appendix A

# Ozone Performance Evaluation and Optimization



## TABLES



## FIGURES

Appendix A

# Ozone Performance Evaluation and Optimization

Ozone performance evaluation and optimization consisted of two steps: 1) contact time testing, and 2) ozone dosage optimization study.

## A.1 CONTACT TIME TESTING

For each ozone dose tested, ozone residuals were measured as a function of contact time. Specifically, the location along the pipe contact chamber whereby the measured ozone residual was less than 50 μg/L was determined. Determining the contact time necessary to reduce ozone concentrations to less than 50 μg/L was because it varies with water quality and establishes the needed contact time for full-scale design to fully utilize the oxidizing potential of ozone prior to BAC treatment where any residual ozone could affect BAC biology adversely.

Operational conditions maintained during contact time testing are summarized in Table A-1. Ozone transfer efficiencies calculated based on feed gas flowrate, feed gas and off-gas concentrations are summarized in Table A-2. Dissolved ozone residuals measured at various sampling ports are summarized in Tables A-3, A-4 and A-5. Side-by-side comparisons of dissolved ozone residuals measured using online monitoring and bench-top ampul methods are presented in Tables A-4 and A-5. Ozone decay rates monitored over time using various ozone doses are shown in Figure A-1.

Table A-1
**Operation Conditions during Contact Time Testing**

| Ozone Dose | Units | 3 mg/L | 5 mg/L | 7 mg/L |
|---|---|---|---|---|
| **Test Date** | **-** | 11/6/08 | 11/10/08 | 11/10/08 |
| **Liquid Flowrate** | **gpm** | 10.7 | 10.7 | 10.7 |
| **Ozone Feedgas Flowrate** | **slpm** | 0.93 | 1.59 | 2.31 |
| **Ozone Feedgas Concentration** | **%** | 10 | 10 | 10.1 |
| **Ozone Offgas Concentration** | **%** | 0.496 | 0.83 | 1.2 |
| **Generator Power Setting** | **%** | 9.8 | 13.1 | 17.1 |
| **Ozone System Pressure** | **psi** | 14 | 14.5 | 15 |

Table A-2
**Ozone Transfer Efficiencies during Contact Time Testing**

| Ozone Transferred, mg/L | Ozone Injected, mg/L | Transfer Efficiency, % |
|---|---|---|
| 3 | 3.1 | 95.9 |
| 5 | 5.4 | 92.6 |
| 7 | 7.9 | 88.9 |

Table A-3
**Contact Time Test Results for 3 mg/L Ozone Dose**

| Sample Port (SP) Along the Length of the Contact Chamber | Contact Time (min) | Ozone Residual (mg/L) | |
|---|---|---|---|
| | | Online Monitor | Ampul |
| SP-4 | 0.004 | 1.15 | Not Tested |
| SP-5 | 0.024 | 2.5 | |
| SP-6 | 0.043 | 2.25 | |
| SP-7 | 0.134 | 1.13 | |
| SP-8 | 0.561 | 0.92 | |
| SP-9 | 0.825 | 0.795 | |
| SP-10 | 1.082 | 0.53 | |
| SP-11 | 1.550 | 0.44 | |
| SP-12 | 1.808 | 0.38 | |
| SP-13 | 2.071 | 0.225 | |
| SP-14 | 2.575 | 0.16 | |
| SP-15 | 3.102 | 0.0825 | |

Table A-4
**Contact Time Test Results for 5 mg/L Ozone Dose**

| Sample Port (SP) Along the Length of the Contact Chamber | Contact Time (min) | Ozone Residual (mg/L) | |
|---|---|---|---|
| | | Online Monitor | Ampul |
| SP-4 | 0.004 | 1.965 | 1.52 |
| SP-5 | 0.024 | 4.535 | > 1.65 |
| SP-6 | 0.043 | 4.14 | > 1.65 |
| SP-7 | 0.134 | 2.75 | > 1.65 |
| SP-8 | 0.561 | 2.45 | 1.5 |
| SP-9 | 0.825 | 2.165 | 1.44 |
| SP-10 | 1.082 | 1.825 | 1.33 |
| SP-11 | 1.550 | 1.64 | 1.25 |
| SP-12 | 1.808 | 1.475 | 1.09 |
| SP-13 | 2.071 | 1.23 | 1 |
| SP-14 | 2.575 | 1.04 | 0.867 |
| SP-15 | 3.102 | 0.89 | 0.7 |
| SP-16 | 3.570 | 0.73 | 0.53 |
| SP-17 | 4.097 | 0.55 | 0.45 |
| SP-18 | 4.600 | 0.495 | 0.35 |
| SP-21 | 4.700 | 0.4 | 0.355 |
| SP-22 | 5.432 | 0.225 | 0.2 |
| SP-23 | 6.552 | 0.065 | 0.03 |

Table A-5
**Contact Time Test Results for 7 mg/L Ozone Dose**

| Sample Port (SP) Along the Length of the Contact Chamber | Contact Time (min) | Ozone Residual (mg/L) | |
|---|---|---|---|
| | | Online Monitor | Ampul |
| SP-4 | 0.004 | 3.135 | > 1.6 |
| SP-5 | 0.024 | 7.575 | > 1.6 |
| SP-6 | 0.043 | 6.725 | > 1.6 |
| SP-7 | 0.134 | 5.135 | > 1.6 |
| SP-8 | 0.561 | 4.765 | > 1.6 |
| SP-9 | 0.825 | 4.16 | > 1.6 |
| SP-10 | 1.082 | 3.825 | > 1.6 |
| SP-11 | 1.550 | 3.62 | > 1.6 |
| SP-12 | 1.808 | 3.43 | > 1.6 |
| SP-13 | 2.071 | 2.97 | > 1.6 |
| SP-14 | 2.575 | 2.695 | > 1.6 |
| SP-15 | 3.102 | 2.345 | > 1.6 |
| SP-16 | 3.5699 | 2.13 | 1.3 |
| SP-17 | 4.0967 | 1.845 | 1.46 |
| SP-18 | 4.6001 | 1.71 | 1.3 |
| SP-21 | 4.7001 | 1.51 | 1.19 |
| SP-22 | 5.4317 | 1.13 | 0.96 |
| SP-23 | 6.5517 | 0.79 | 0.72 |
| SP-24 | 7.6737 | 0.57 | 0.48 |
| SP-25 | 8.7957 | 0.39 | 0.28 |
| SP-26 | 9.9177 | 0.235 | 0.2 |
| SP-27 | 11.0397 | 0.145 | 0.1 |
| SP-28 | 12.1617 | 0.09 | 0.09 |
| SP-29 | 13.2837 | 0.035 | 0.02 |
| SP-30 | 13.4789 | 0.07 | 0.05 |

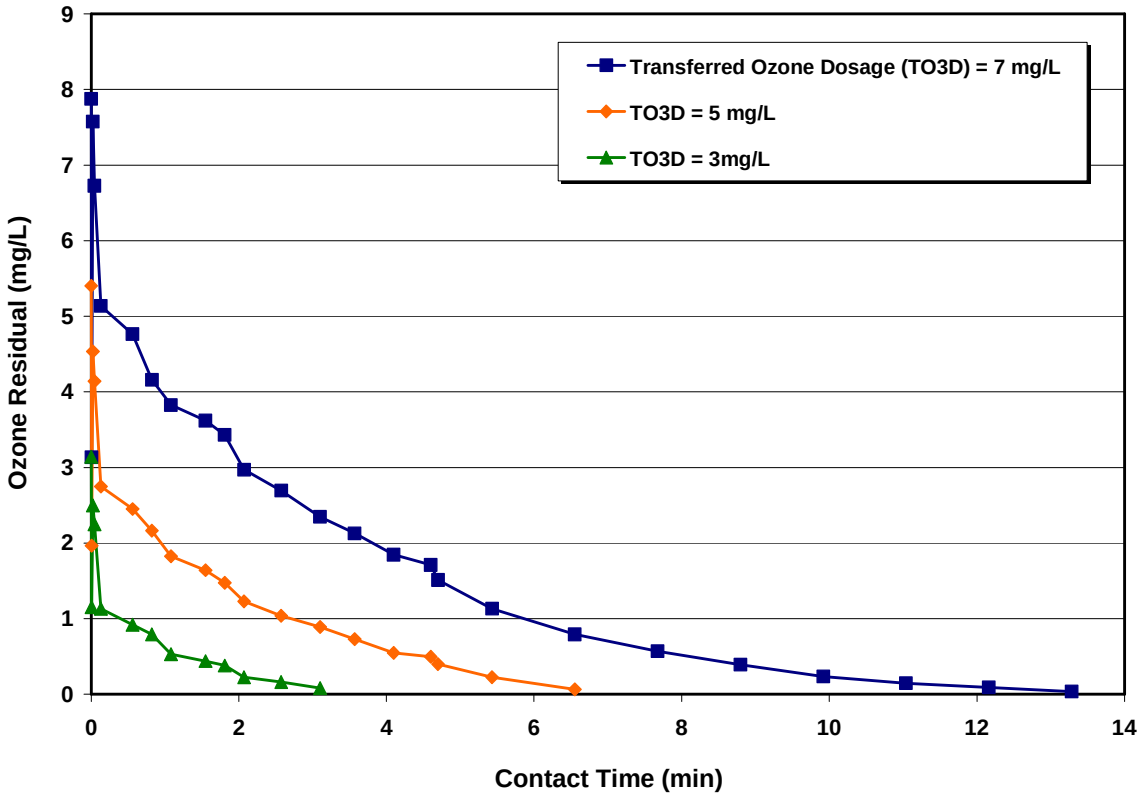



Figure A-1
**Ozone Decay over Time at Various Doses**

## A.2 OZONE PERFORMANCE OPTIMIZATION

Ozone dosage is a critical process parameter that was optimized during the initial stage of the pilot study by testing the effect of three transferred ozone dosages (3, 5, and 7 mg/L) on the water quality of membrane-filtered effluent. Reactions of ozone and the instantaneous demand for ozone-based oxidants in wastewater are dependent on various site-specific parameters such as TOC, suspended solids, alkalinity, nitrite, and temperature. During Phase 1 studies, membrane effluent water quality averaged: pH of 6.7, temperature of 66 °F, and alkalinity of 92 mg/L. Membrane effluent nitrite concentrations were negligible (< 60 μg/L). The effect of ozonation on effluent quality was measured in the ozone contact pipe/chamber where the measured ozone residual was negligible (~ 50 μg/L), thus ensuring complete utilization of ozone-based oxidants. Operational conditions maintained during ozone performance optimization are summarized in Table A-6.

Table A-6
**Ozone Performance Optimization Testing Operation Conditions**

| **Ozone Dose** | **Units** | 3 mg/L | 5 mg/L | 7 mg/L |
|---|---|---|---|---|
| **Test Date** | **-** | 11/17/08 | 11/13/08 | 11/13/08 |
| **Secondary Treatment SRT** | **days** | 25 | 25 | 25 |
| **Liquid Flowrate** | **gpm** | 10.7 | 10.8 | 10.8 |
| **Ozone Feedgas Flowrate** | **slpm** | 0.93 | 1.57 | 2.31 |
| **Ozone Feedgas Concentration** | **%** | NM[a] | 10.1 | 10.1 |
| **Ozone Offgas Concentration** | **%** | 0.44 | 0.8 | 1.2 |
| **Generator Power Setting** | **%** | 9.61 | 13.1 | 17.1 |
| **Ozone System Pressure** | **psi** | 15 | 14.5 | 14.5 |
| **Ozone Effluent Sample Port** | **-** | SP-16 | SP-24 | SP-30 |
| **Residual in Ozone Effluent** | **mg/L** | 0.003 | 0.015 | 0.03 |
| **Contact Time [(a)]** | **min** | 3.6 | 7.7 | 13.5 |

(a) Not Measured

### A.2.1 CEC REMOVAL

Removal of detected contaminants of emerging concern (CECs) observed during the ozone performance optimization testing is summarized in Table A-7. Monitoring occurred for more CECs, but was not at detectable concentrations in any samples.

Table A-7
**CEC Results During Phase 1 Ozone Performance Optimization**

| Constituent | 3 mg/L Transferred Ozone Dosage | | | 5 mg/L Transferred Ozone Dosage | | | 7 mg/L Transferred Ozone Dosage | | |
|---|---|---|---|---|---|---|---|---|---|
| | MF Effluent, ng/L | O3 Effluent, ng/L | DPR [(a)] % | MF Effluent ng/L | O3 Effluent, ng/L | DPR % | MF Effluent, ng/L | O3 Effluent, ng/L | DPR % |
| DEET | 170 | 57 | 68 | 40 | 5.5 | 99 | 33 | < 5 | 100 |
| Fluoxetine | 34 | 2.6 | 95 | 33 | < 1 | 100 | 36 | < 1 | 100 |
| Phenytoin | 310 | 63 | 81 | 390 | 14 | 98 | 350 | < 5 | 100 |
| Sulfamethoxazole | 670 | 35 | 95 | 410 | < 1 | 100 | 440 | < 1 | 100 |
| Meprobamate | 800 | 370 | 54 | 870 | 200 | 77 | 850 | 86 | 90 |
| Oxybenzone | 8.7 | 2 | 100 | 5.9 | < 2 | 100 | 5.1 | < 2 | 100 |
| Estrone | 10 | < 1 | 100 | 10 | < 1 | 100 | 8.8 | < 1 | 100 |
| Carbamazepine | 210 | < 1 | 100 | 250 | < 1 | 100 | 250 | < 1 | 100 |
| Diclofenac | 44 | < 2 | 100 | 59 | < 2 | 100 | 62 | < 2 | 100 |
| Gemfibrozil | 230 | < 1 | 100 | 120 | < 1 | 100 | 99 | < 1 | 100 |
| Hydrocodone | 83 | < 1 | 100 | 110 | < 1 | 100 | 70 | < 1 | 100 |
| Methadone | 71 | < 5 | 100 | 67 | < 5 | 100 | 64 | < 5 | 100 |
| Naproxen | 13 | < 1 | 100 | 7.9 | < 1 | 100 | 7.2 | < 1 | 100 |
| Trimethoprim | 130 | < 5 | 100 | 83 | < 5 | 100 | 76 | < 5 | 100 |
| 4-Nonylphenol monoethoxylates | 62.3 | < 3.92 | 100 | 31.1 | < 5.52 | 100 | 35.3 | < 6.44 | 100 |
| 4-Nonylphenol diethoxylates | 73.6 | < 17.6 | 100 | 72.3 | < 12.7 | 100 | 73.3 | < 13.3 | 100 |
| Octylphenol | 1.83 | < 1.03 | 100 | 1.5 | < 1 | 100 | 1.46 | < 1.29 | 100 |
| Atrazine | 2.8 | 1.4 | 78 | 2.8 | < 1 | 100 | 1 | 1 | NA |
| Diazepam | 1.8 | < 1 | 100 | < 1 | < 1 | NA | 1.2 | < 1 | 100 |
| E-Screen Estradiol Equivalents (EEQ) | 2.3 | 0.1 | 97 | 1.7 | < 0.027 | 100 | 1.6 | < 0.027 | 100 |

(a) Detectable Percent Removal

### A.2.2 UV TRANSMITTANCE ($UVT_{254}$)

Ozonation improves the Ultraviolet Transmittance ($UVT_{254}$) of effluent, which is measured at a wavelength of 254 nm. Major constituents that influence UVT254 are: (1) inorganic compounds (e.g., copper, iron, etc.), (2) aromatic organic compounds, and (3) suspended solids. $UVT_{254}$ is the critical process parameter utilized in sizing Ultraviolet Disinfection Systems. $UVT_{254}$ values measured before and after ozonation are summarized in Table A-8.

Table A-8
**$UVT_{254}$ Results During Phase 1 Ozone Optimization**

| Ozone Dose | Effluent Sample | $UVT_{254}$ (%) |
|---|---|---|
| 3 mg/L | Secondary Effluent | 72.4 |
| | MF Effluent | 74 |
| | O3 Effluent | 84.6 |
| 5 mg/L | Secondary Effluent | 71.1 |
| | MF Effluent | 74.8 |
| | O3 Effluent | 87.1 |
| 7 mg/L | Secondary Effluent | NM |
| | MF Effluent | 74.5 |
| | O3 Effluent | 89.9 |

### A.2.3 GENERAL WATER QUALITY PARAMETERS

Concentrations of general water quality parameters measured during the ozone performance optimization testing are presented in Table A-9.

Table A-9
**General Water Quality Parameters Results during Phase 1 Ozone Optimization**

| | 3 mg/L Ozone Testing | | | 5 mg/L Ozone Testing | | | 7 mg/L Ozone Testing | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sample Name** | **Secondary Effluent** | **MF Effluent** | **O3 Effluent** | **Secondary Effluent** | **MF Effluent** | **O3 Effluent** | **Secondary Effluent** | **MF Effluent** | **O3 Effluent** |
| Ammonia-N (mg/L) | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Nitrite-N (mg/L) | 0.06 | 0.05 | <0.025 | 0.1 | 0.07 | <0.025 | 0.05 | 0.07 | <0.025 |
| Nitrate-N (mg/L) | 5.4 | 5.5 | 4.7 | 4.6 | 5.4 | 5.5 | 5.1 | 4.9 | 5 |
| TKN (mg/L) | 1.6 | 1.1 | 1.1 | 1.6 | 1.3 | 0.7 | 1.2 | 1.1 | 0.6 |
| TN (mg/L) | 7 | 6.6 | 5.8 | 6.3 | 6.7 | 6.2 | 6.4 | 6 | 5.6 |
| TSS (mg/L) | 2 | <2 | <2 | 4 | <2 | <2 | <2 | <2 | <2 |
| Fecal Coliforms (MPN/100ml) | 17000 | <2 | <2 | 14000 | <2 | <2 | 8700 | <2 | <2 |
| Total Coliforms (MPN/100ml) | >24000 | 19 | <2 | >24000 | >2400 | 33 | >24000 | 13 | <2 |
| cBOD (mg/L) | <2 | <2 | <2 | <2 | <2 | <2 | <10 | <2 | <2 |
| TOC (mg/L) | 5.91 | 5.38 | 5.51 | 6.32 | 5.4 | 5.28 | 6.06 | 5.21 | 5.01 |
| DOC (mg/L) | 6.64 | 5.42 | 5.48 | 6.45 | 5.48 | 5.32 | 5.76 | 5.51 | 5.02 |
| DON (mg/L) | 1.1 | 1 | 0.8 | 1.2 | 1.1 | 0.8 | 1.1 | 1 | 1 |
| TP (mg/L) | 2.5 | 2.5 | 2.4 | 2.9 | 2.8 | 2.8 | 3 | 2.8 | 2.9 |
| Ortho-P (mg/L) | 2.5 | 2.5 | 2.4 | 2.7 | 2.8 | 2.8 | 2.9 | 2.7 | 2.7 |
| TDS (mg/L) | 312 | 313 | 312 | 304 | 312 | 311 | 306 | 304 | 304 |
| Bromide (ug/L) | NM | 190 | 220 | NM | 200 | 260 | NM | 200 | 270 |

Appendix B

# Evaluation of Bromate Mitigation Strategies

Appendix B

# Evaluation of Bromate Mitigation Strategies



## TABLES



## FIGURES

Appendix B

# Evaluation of Bromate Mitigation Strategies

## B.1 BROMATE FORMATION DURING OZONE OPTIMIZATION STUDY

Bromate is a suspected carcinogen with a drinking water MCL of 10 μg/L. RSWRF's influent bromide concentration (~250 μg/L) is much higher than the threshold concentration of 20 μg/L reported by others to facilitate problematic bromate formation during ozonation (von Gunten, 2003). For RSWRF effluent, bromate mitigation was needed when 5 mg/L or more of ozone was used for CEC control (see Table B-1).

Table B-1
**Bromate Formation during Ozone Optimization Study**

| O3 Dose, mg/L | Effluent NH3, mg/NL | Bromate | |
|---|---|---|---|
| | | Before Ozonation, μg/L | After Ozonation, μg/L |
| 3 | 0.6 | <5 | <5 |
| | 1.1 | <1 | 2 |
| 5 | 0.6 | <5 | 19 |
| | 1.1 | <1 | 9 |
| 7 | 0.6 | <5 | 37 |
| | 1.1 | <1 | 14 |

## B.2 BROMATE MITIGATION STRATEGIES

The literature reports several strategies for minimizing bromate formation during ozonation. The strategies include: 1) pH depression to as low as 6.8, 2) addition of ammonia, 3) addition of peroxide, and 4) addition of alkalinity (EPA, 1999; Rakness, 2005). Since the average pH of RSWRF effluent was 6.9, further depression of pH would not be considered materially beneficial. Adding alkalinity would negatively impact effluent quality by increasing dissolved solids concentrations. Therefore, addition of alkalinity was not considered to be a suitable bromate mitigation measure. Peroxide addition was the implemented ozone mitigation measure. Ammonia addition was held in reserve as an additional mitigation measure, if needed, because it does add nitrogen to the effluent.

Previous studies have indicated that the addition of peroxide can minimize bromate formation by several pathways such as peroxide competing with bromide for molecular ozone, and/or generating hydroxyl radicals that convert bromine to bromide (Amy, 1998). However, these studies have also shown that bromate mitigation by peroxide can depend on pH (Amy, 1998). To

reduce uncertainty related to effluent specific water quality parameters, the effect of peroxide on bromate mitigation was investigated comprehensively in this study.

## B.3 TESTING PLAN

The ozone-peroxide system design parameters tested during the study are summarized in Table B-2. Bromate mitigation study results are summarized in Table B-3.

Table B-2
**Bromate Mitigation Study Testing Plan [(a)]**

| Factors | Range of Studied Design Variables | | | | | |
|---|---|---|---|---|---|---|
| $O_3$ Dose (mg/L) | 3 | **5** | 7 | | | |
| $H_2O_2$-$O_3$ Molar Ratio | 0 | 0.25 | 0.5 | 0.7 | **1** | 1.5 |
| $O_3$ Injection Points | 1 | 3 | | | | |
| Injection sequence | **$H_2O_2$ First** | $H_2O_2$ Last | | | | |

(a) Shaded and bold cells indicate levels that have been selected for further analysis.

Table B-3
## Bromate Mitigation Summary

| Run ID | Date | O3 Dose | Peroxide to Ozone Molar Ratio | H2O2 Injection Point* | Ozone Injection Location(s) | Temp | O3 System Pressure | O2 Flow | Generator Power | O3 Feed gas | O3 Offgas | Sample Port (SP) # | O3 Residual at SP | UV Absorbance | | Average Bromide | | Effluent Bromate | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | MF Effluent | Ozone Effluent | O3 Influent | O3 Effluent | Sample A | Sample B | Sample C | Average |
| | | mg/L | | | | °F | PSI | Std L/min | % | % | % | | mg/L | m-1 | m-1 | mg/L | mg/L | µg/L | µg/L | µg/L | µg/L |
| 1 | 1/23/2009 | 3 | 0 | NA | MXR1 | 56 | 15 | 0.93 | 9.60 | 10.18 | 0.363 | 14 | 0.02 | | | 0.23 | 0.253333 | 1.6 | 1.7 | 2.3 | 1.87 |
| 2 | 1/23/2009 | 3 | 0.7 | MXR3 | MXR1 | 57 | 15 | 0.93 | 9.60 | 10.18 | 0.372 | 10 | 0.005 | | | | 0.24 | 1.2 | | | 0.40 |
| 4 | 1/23/2009 | 5 | 0 | NA | MXR1 | 57 | 15 | 0.93 | 9.60 | 10.18 | 0.682 | 25 | 0.06 | | | | 0.263333 | 9.2 | 8.7 | 8.7 | 8.87 |
| 5 | 1/23/2009 | 5 | 0.25 | SS | MXR1 | 57 | 15 | 1.59 | 13.10 | 9.81 | 0.665 | 17 | 0.035 | 11.7 | 6.3 | 0.23 | 0.25 | 7.3 | | | 2.43 |
| 6 | 1/23/2009 | 5 | 0.25 | SS | MXR1,2,3 | 57 | 15 | 1.59 | 13.10 | 9.81 | 1.160 | 17 | 0.01 | 11.7 | 6.2 | | 0.26 | 6.4 | | | 2.13 |
| 7 | 1/23/2009 | 5 | 0.25 | MXR3 | MXR1 | 57 | 15 | 1.59 | 13.10 | 9.81 | 0.691 | 17 | 0.015 | 11.7 | 6.1 | | 0.25 | 6.9 | | | 2.30 |
| 8 | 1/22/2009 | 5 | 0.5 | SS | MXR1,2,3 | 57 | 15 | 1.59 | 13.10 | 9.81 | 1.140 | 13 | 0.035 | 11.6 | 6.7 | | 0.223333 | 5.5 | 5.8 | 5.6 | 5.63 |
| 9 | 1/22/2009 | 5 | 0.5 | MXR3 | MXR1 | 57 | 15 | 1.59 | 13.10 | 9.81 | 0.667 | 13 | 0.01 | 11.6 | 6.5 | 0.2 | 0.22 | 5.8 | 5.7 | 5.3 | 5.60 |
| 10 | 1/22/2009 | 5 | 0.7 | SS | MXR1 | 56 | 15 | 1.59 | 13.10 | 9.81 | 0.643 | 13 | 0.01 | 11.5 | 6.4 | | 0.2 | 5.7 | | | 1.90 |
| 11 | 1/22/2009 | 5 | 0.7 | SS | MXR1,2,3 | 56 | 15 | 1.59 | 13.10 | 9.81 | 1.366 | 13 | 0.025 | 11.5 | 6.5 | | 0.21 | 4.8 | | | 1.60 |
| 12 | 1/22/2009 | 5 | 0.7 | MXR3 | MXR1 | 56 | 15 | 1.59 | 13.10 | 9.81 | 0.674 | 13 | 0.025 | 11.5 | 6.4 | 0.2 | 0.2 | 6.4 | 6.1 | 5.9 | 6.13 |
| 13 | 1/22/2009 | 5 | 1 | SS | MXR1,2,3 | 57 | 15 | 1.59 | 13.10 | 9.81 | 1.331 | 12 | 0.015 | 11.5 | 6.7 | | 0.19 | 4.2 | 4.2 | | 2.80 |
| 14 | 1/22/2009 | 5 | 1 | MXR3 | MXR1 | 57 | 15 | 1.59 | 13.10 | 9.81 | 0.654 | 12 | 0.015 | 11.5 | 6.5 | 0.2 | 0.21 | 5 | 5.5 | | 3.50 |
| 15 | 1/20/2009 | 7 | 0 | NA | MXR1 | 55 | 15 | 2.31 | 17.10 | 9.85 | 0.996 | 30 | 0.04 | 12.4 | 5.7 | 0.17 | 0.22 | 14 | | | 4.67 |
| 16 | 1/20/2009 | 7 | 0.25 | SS | MXR1 | 56 | 15 | 2.31 | 17.10 | 9.85 | 0.959 | 18 | 0.035 | 12.2 | 6.1 | 0.19 | 0.21 | 12 | | | 4.00 |
| 17 | 1/20/2009 | 7 | 0.25 | SS | MXR1,2,3 | 57 | 15 | 2.31 | 17.10 | 9.85 | 1.524 | 17 | 0.025 | | | 0.19 | 0.22 | 12 | | | 4.00 |
| 18 | 1/20/2009 | 7 | 0.25 | MXR3 | MXR1 | 57 | 15 | 2.31 | 17.10 | 9.85 | 1.011 | 18 | 0.02 | 12.2 | 5.9 | 0.21 | 0.22 | 12 | | | 4.00 |
| 19 | 1/22/2009 | 7 | 0.5 | SS | MXR1,2,3 | 57 | 15 | 2.31 | 17.10 | 9.85 | 1.621 | 15 | 0.01 | 11.4 | 5.4 | | 0.246667 | 17 | 16 | 16 | 16.33 |
| 20 | 1/22/2009 | 7 | 0.5 | MXR3 | MXR1 | 56 | 15 | 2.31 | 17.10 | 9.85 | 0.963 | 15 | 0.015 | 11.4 | 5.3 | 0.24 | 0.246667 | 17 | 18 | 18 | 17.67 |
| 21 | 1/22/2009 | 7 | 0.7 | SS | MXR1 | 56 | 14.5 | 2.31 | 17.10 | 9.85 | 0.905 | 13 | 0.025 | 11.4 | 5.5 | | 0.25 | 16 | | | 5.33 |
| 22 | 1/22/2009 | 7 | 0.7 | SS | MXR1,2,3 | 56 | 14.5 | 2.31 | 17.10 | 9.85 | 1.584 | 13 | 0.01 | 11.5 | 5.7 | | 0.243333 | 14 | 14 | 15 | 14.33 |
| 23 | 1/22/2009 | 7 | 0.7 | MXR3 | MXR1 | 57 | 15 | 2.31 | 17.10 | 9.85 | 0.980 | 13 | 0.02 | | | 0.22 | 0.233333 | 18 | 17 | 17 | 17.33 |
| 24 | 1/20/2009 | 7 | 1 | SS | MXR1,2,3 | 58 | 15 | 2.31 | 17.10 | 9.85 | 1.476 | 10 | 0.015 | 12.2 | 7.2 | 0.2 | 0.23 | 5.4 | | | 1.80 |
| 25 | 1/20/2009 | 7 | 1 | MXR3 | MXR1 | 58 | 15 | 2.31 | 17.10 | 9.85 | 0.938 | 10 | 0.015 | 12.2 | 6.9 | 0.21 | 0.22 | 6.6 | | | 2.20 |
| 26 | 1/22/2009 | 7 | 1.5 | SS | MXR1 | 57 | 15 | 2.31 | 17.10 | 9.85 | 0.856 | 10 | 0.025 | 11.4 | 5.9 | 0.23 | 0.22 | 11 | | | 3.67 |
| 27 | 1/22/2009 | 7 | 1.5 | SS | MXR1,2,3 | 57 | 15 | 2.31 | 17.10 | 9.85 | 1.570 | 10 | 0.025 | 11.4 | 6.0 | | 0.223333 | 10 | 10 | 9.8 | 9.93 |
| 28 | 1/22/2009 | 7 | 1.5 | MXR3 | MXR1 | 57 | 15 | 2.31 | 17.10 | 9.85 | 0.924 | 10 | 0.02 | 11.5 | 6.0 | 0.2 | 0.213333 | 11 | 11 | 11 | 11.00 |

*MXR3 indicates peroxide being injected after ozone (i.e., peroxide last). Whereas, SS indicates peroxide was injected before ozone (i.e., peroxide first).

Table B-4
## Bromate Mitigation Study: Dissolved Ozone Residual Data

| Run ID | Date | O3 Dose | Peroxide to Ozone Molar Ratio | H2O2 Injection Point* | Ozone Injection Location(s) | Sample Port (SP) # | O3 Residual at Various Sampling Ports (Contact Time, min) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 7 (0.13) | 8 (0.56) | 9 (0.83) | 10 (1.1) | 11 (1.6) | 12 (1.8) | 13 (2.1) | 14 (2.6) | 15 (3.1) | 17 (4.1) | 21 (4.7) | 25 (8.8) | 30 (13.5) |
| | | mg/L | | | | | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| 1 | 1/23/2009 | 3 | 0 | NA | MXR1 | 14 | 0.062 | 0.47 | 0.37 | 0.215 | 0.175 | 0.135 | 0.045 | 0.015 | | | | | |
| 2 | 1/23/2009 | 3 | 0.7 | MXR3 | MXR1 | 10 | 0.34 | 0.01 | 0.08 | 0.007 | | | | | | | | | |
| 4 | 1/23/2009 | 5 | 0 | NA | MXR1 | 25 | 2.28 | 2.045 | | 1.575 | | 1.325 | | 1.06 | | | 0.525 | 0.175 | 0.06 |
| 5 | 1/23/2009 | 5 | 0.25 | SS | MXR1 | 17 | 1.78 | | 1.25 | | 0.765 | | 0.415 | | 0.175 | 0.035 | | | |
| 6 | 1/23/2009 | 5 | 0.25 | SS | MXR1,2,3 | 17 | 1.65 | 1.38 | | 0.78 | | 0.57 | | 0.24 | | 0.01 | | | |
| 7 | 1/23/2009 | 5 | 0.25 | MXR3 | MXR1 | 17 | 1.76 | | 1.25 | | | | 0.395 | | 0.085 | 0.015 | | | |
| 8 | 1/22/2009 | 5 | 0.5 | SS | MXR1,2,3 | 13 | 1.33 | 1.01 | 0.805 | 0.425 | 0.325 | 0.225 | 0.035 | | | | | | |
| 9 | 1/22/2009 | 5 | 0.5 | MXR3 | MXR1 | 13 | 1.155 | 0.745 | 0.5 | 0.185 | 0.105 | 0.055 | 0.01 | | | | | | |
| 10 | 1/22/2009 | 5 | 0.7 | SS | MXR1 | 13 | 1.28 | 0.955 | 0.67 | 0.305 | 0.215 | 0.135 | 0.01 | | | | | | |
| 11 | 1/22/2009 | 5 | 0.7 | SS | MXR1,2,3 | 13 | 1.2 | 0.85 | 0.65 | 0.315 | 0.28 | 0.135 | 0.025 | | | | | | |
| 12 | 1/22/2009 | 5 | 0.7 | MXR3 | MXR1 | 13 | 1.35 | 1.04 | 0.74 | 0.355 | 0.245 | 0.16 | 0.025 | | | | | | |
| 13 | 1/22/2009 | 5 | 1 | SS | MXR1,2,3 | 12 | 1.01 | 0.61 | 0.38 | 0.105 | 0.04 | 0.015 | | | | | | | |
| 14 | 1/22/2009 | 5 | 1 | MXR3 | MXR1 | 12 | 1.09 | 0.72 | 0.45 | 0.135 | 0.065 | 0.015 | | | | | | | |
| 15 | 1/20/2009 | 7 | 0 | NA | MXR1 | 30 | 3.96 | 3.58 | | 2.96 | | 2.65 | | | | | 1.32 | | 0.04 |
| 16 | 1/20/2009 | 7 | 0.25 | SS | MXR1 | 18 | 2.97 | 2.46 | 2.07 | 1.45 | 1.23 | 1.03 | 0.67 | 0.485 | 0.27 | 0.08 | | | |
| 17 | 1/20/2009 | 7 | 0.25 | SS | MXR1,2,3 | 17 | 2.71 | 2.12 | 1.78 | 1.235 | 1.03 | 0.86 | 0.52 | 0.34 | 0.185 | 0.015 | | | |
| 18 | 1/20/2009 | 7 | 0.25 | MXR3 | MXR1 | 18 | 2.97 | 2.515 | 2.07 | 1.42 | 1.22 | 1.015 | 0.635 | 0.455 | 0.26 | 0.07 | | | |
| 19 | 1/22/2009 | 7 | 0.5 | SS | MXR1,2,3 | 15 | 2.38 | 1.72 | 1.28 | 0.84 | 0.65 | 0.4 | 0.15 | 0.06 | 0.01 | | | | |
| 20 | 1/22/2009 | 7 | 0.5 | MXR3 | MXR1 | 15 | 2.46 | 1.9 | 1.46 | 0.91 | 0.68 | 0.55 | | 0.08 | 0.015 | | | | |
| 21 | 1/22/2009 | 7 | 0.7 | SS | MXR1 | 13 | 2 | 1.35 | 0.97 | 0.4 | 0.32 | 0.2 | 0.025 | | | | | | |
| 22 | 1/22/2009 | 7 | 0.7 | SS | MXR1,2,3 | 13 | 1.95 | 1.28 | 0.95 | 0.36 | 0.25 | 0.135 | 0.01 | | | | | | |
| 23 | 1/22/2009 | 7 | 0.7 | MXR3 | MXR1 | 13 | 2.05 | 1.37 | 0.95 | 0.33 | 0.3 | 0.2 | 0.015 | | | | | | |
| 24 | 1/20/2009 | 7 | 1 | SS | MXR1,2,3 | 10 | 0.89 | 0.35 | 0.01 | 0.008 | | | | | | | | | |
| 25 | 1/20/2009 | 7 | 1 | MXR3 | MXR1 | 10 | 0.86 | 0.35 | 0.13 | 0.008 | | | | | | | | | |
| 26 | 1/22/2009 | 7 | 1.5 | SS | MXR1 | 10 | 1.19 | 0.58 | 0.26 | 0.025 | | | | | | | | | |
| 27 | 1/22/2009 | 7 | 1.5 | SS | MXR1,2,3 | 10 | 1.17 | 0.53 | 0.28 | 0.025 | | | | | | | | | |
| 28 | 1/22/2009 | 7 | 1.5 | MXR3 | MXR1 | 10 | 1.13 | 0.58 | 0.3 | 0.02 | | | | | | | | | |

*MXR3 indicates peroxide being injected after ozone (i.e., peroxide last). Whereas, SS indicates peroxide was injected before ozone (i.e., peroxide first).

## B.4 RESULTS

Substantial findings from the bromate mitigation study are illustrated in Figures B-1, B-2, B-3, and B-4. Any addition of peroxide reduced bromate formation at all ozone dosages as shown in Figures B-1 through B-4 (results obtained from 3 mg/L ozone dosages are not shown for clarity). The extent of bromate formation was found to be mainly a function of ozone dose and peroxide concentration. In the case of 7 mg/L ozone dosage, the concentration of bromate was close to 10 µg/L even after adding peroxide at the maximum 1.5 molar ratio investigated in this study (see Figure B-2). Previous studies have shown that peroxide molar ratios higher than 2 can diminish the oxidation efficiency (Beltran, 2004). Adding the specified ozone by means of multiple injection points reduced bromate further; however, the incremental benefits were minimal (see Figure B-3). Results also showed that bromate formation was not dependent on the injection sequence of peroxide and ozone injection (see Figure B-4).

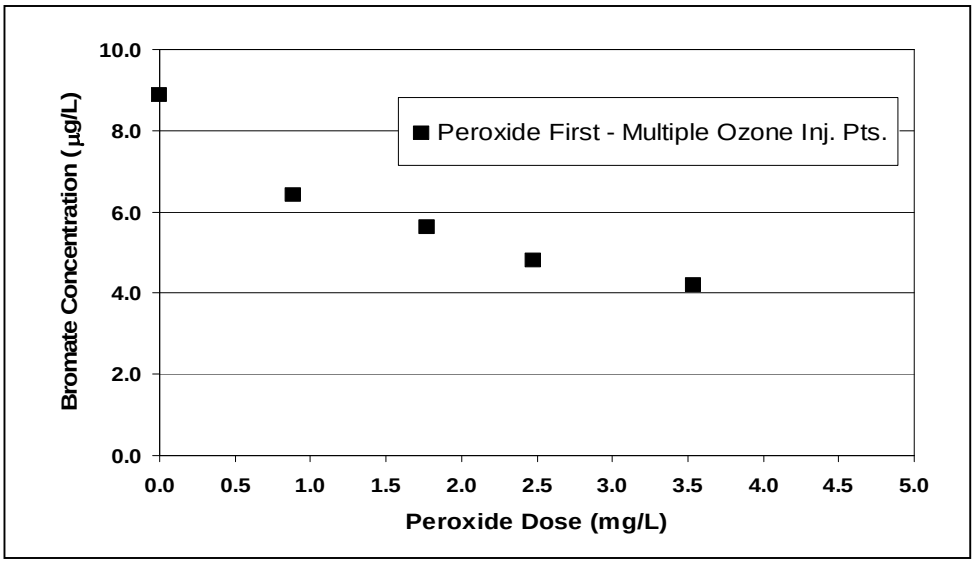



Figure B-1
**Effect of Peroxide Dose with 5 mg/L Ozone and 1.1 mg/L Ammonia (as N)**

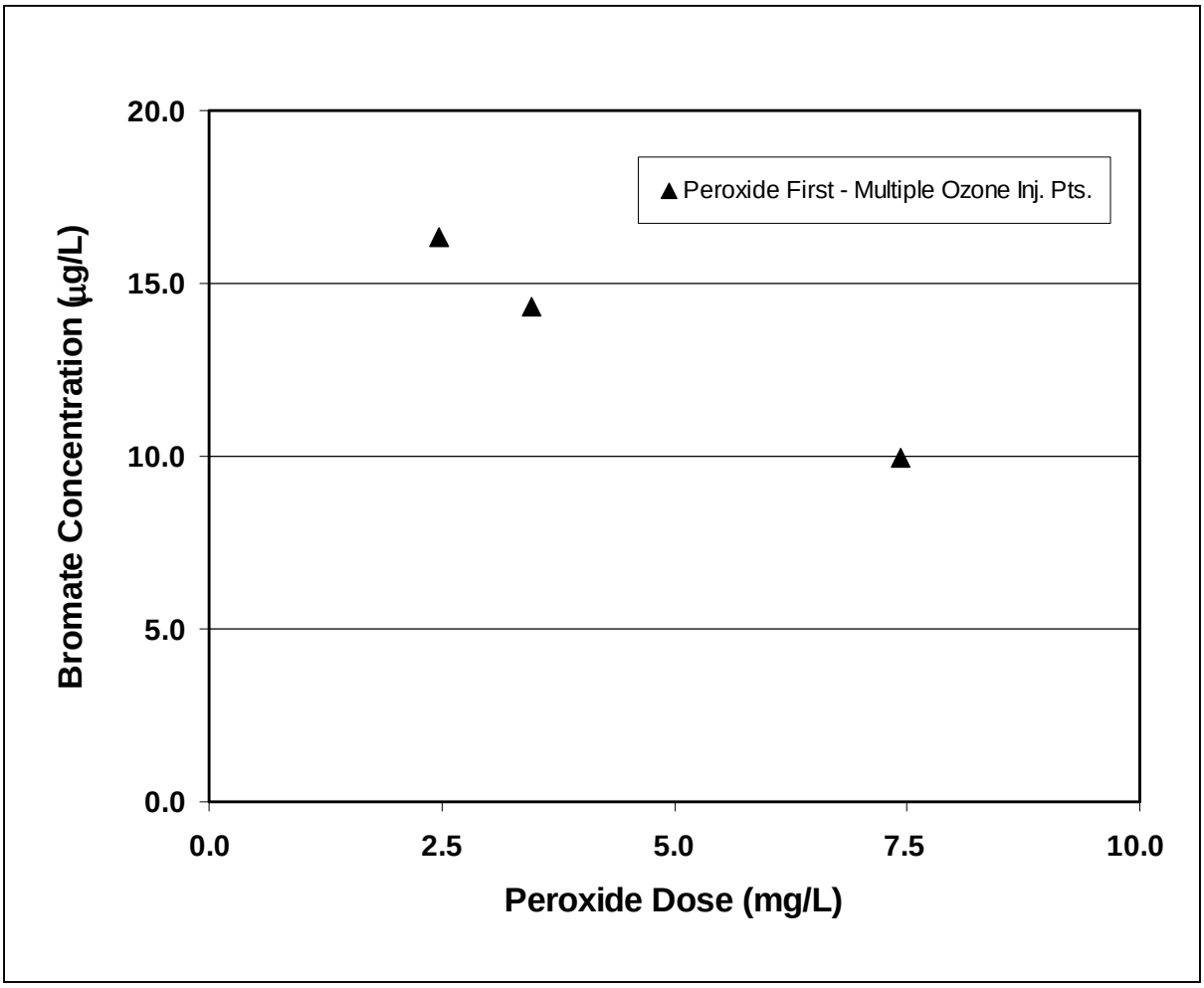



Figure B-2
**Effect of Peroxide Dose with 7 mg/L Ozone and 1.1 mg/L Ammonia (as N)**

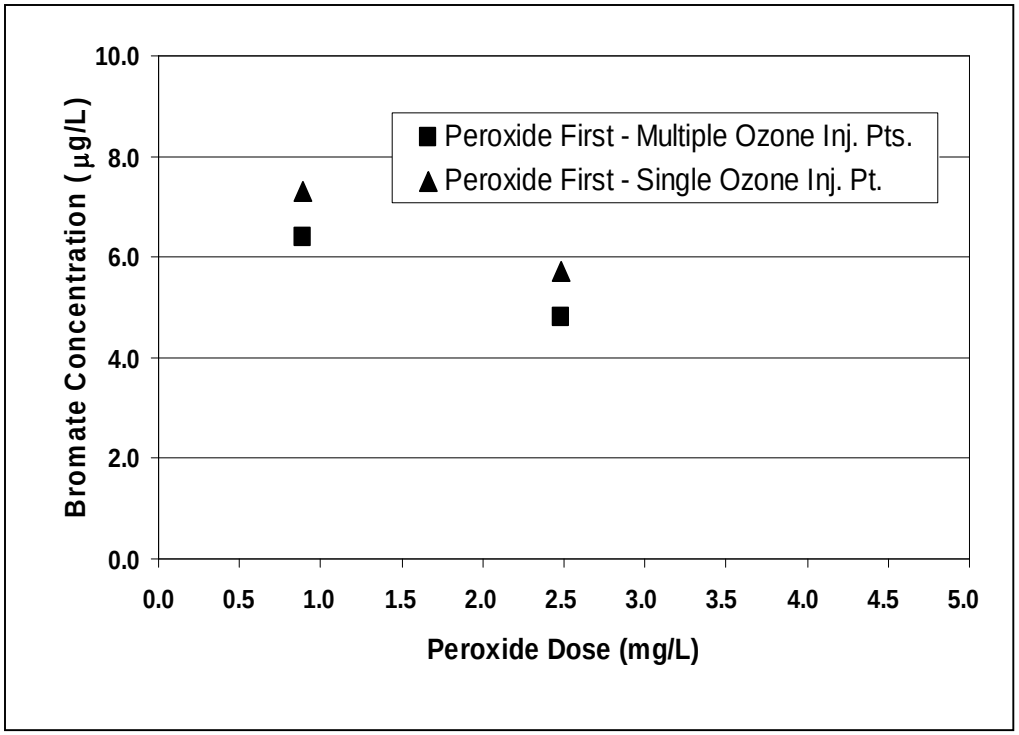



Figure B-3
**Effect of Ozone Injection Strategy with 5 mg/L Ozone and 1.1 mg/L Ammonia (as N)**

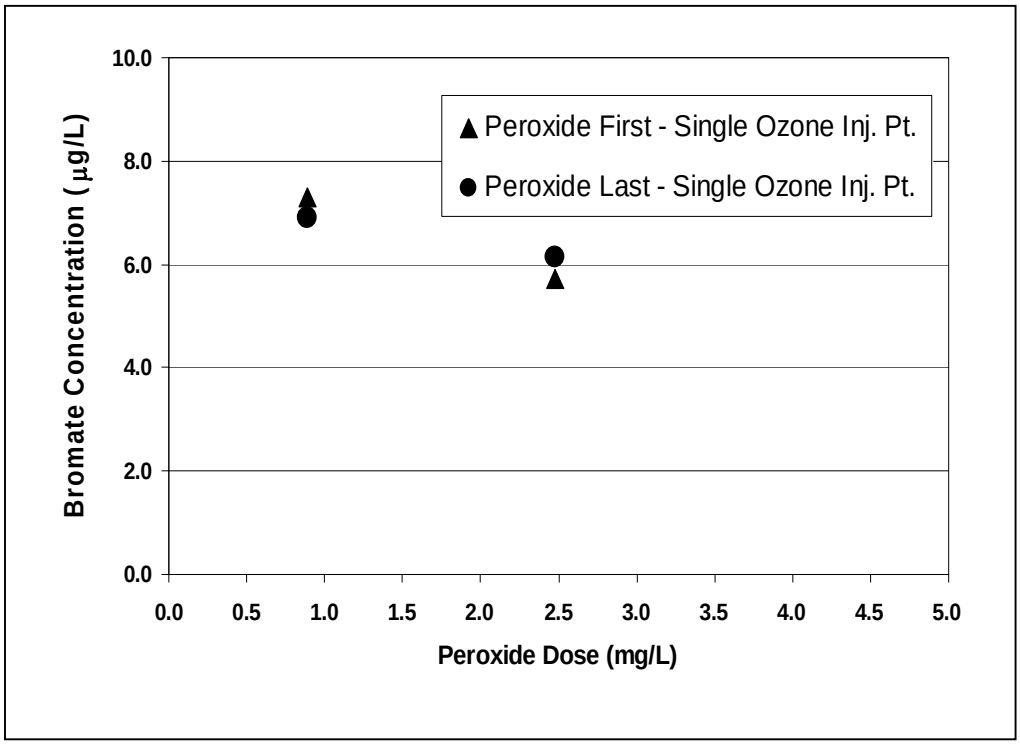



Figure B-4
**Effect of Ozone Peroxide Injection Sequence with 5 mg/L Ozone and 1.1 mg/L Ammonia (as N)**

Based on the results obtained from ozone optimization and bromate mitigation studies, an ozone dose of 5 mg/L injected at one location, with peroxide added at 1 molar ratio prior to ozonation was selected for steady state operation. An ozone dose of 7 mg/L was not selected due to the higher peroxide concentration requirement to mitigate bromate. Additionally, the higher peroxide requirement could reduce ozone oxidation efficiency, or require a more complex ozone reactor configuration. A single point ozone injection design was selected for analysis because the benefits of a multiple ozone injection strategy were minimal for this specific effluent.

## B.5 PERFORMANCE DURING STEADY-STATE OPERATION

Even with peroxide addition, ozonated effluent bromate concentrations exceeded 10 μg/L when effluent ammonia concentrations decreased (See Figure B-5). At RSWRF, this decrease was caused by seasonal warming of the wastewater which increases the ammonia removal efficiency of the treatment process. Ammonia plays a beneficial role in bromate control by combining with bromide to form bromamines (Marhaba et al., 2000). This seasonal effect was addressed by injecting ammonia into membrane effluent, as needed, so as to maintain ammonia concentrations during ozonation at levels around 1 to 1.5 mg/L. This addition appears to have reduced bromate concentrations to less than 10 μg/L as shown in Figure B-5. Addition of peroxide and seasonal addition of ammonia were found to be a suitable strategy for controlling bromate formation resulting from a ozone dose of 5 mg/L (see Figure B-5).

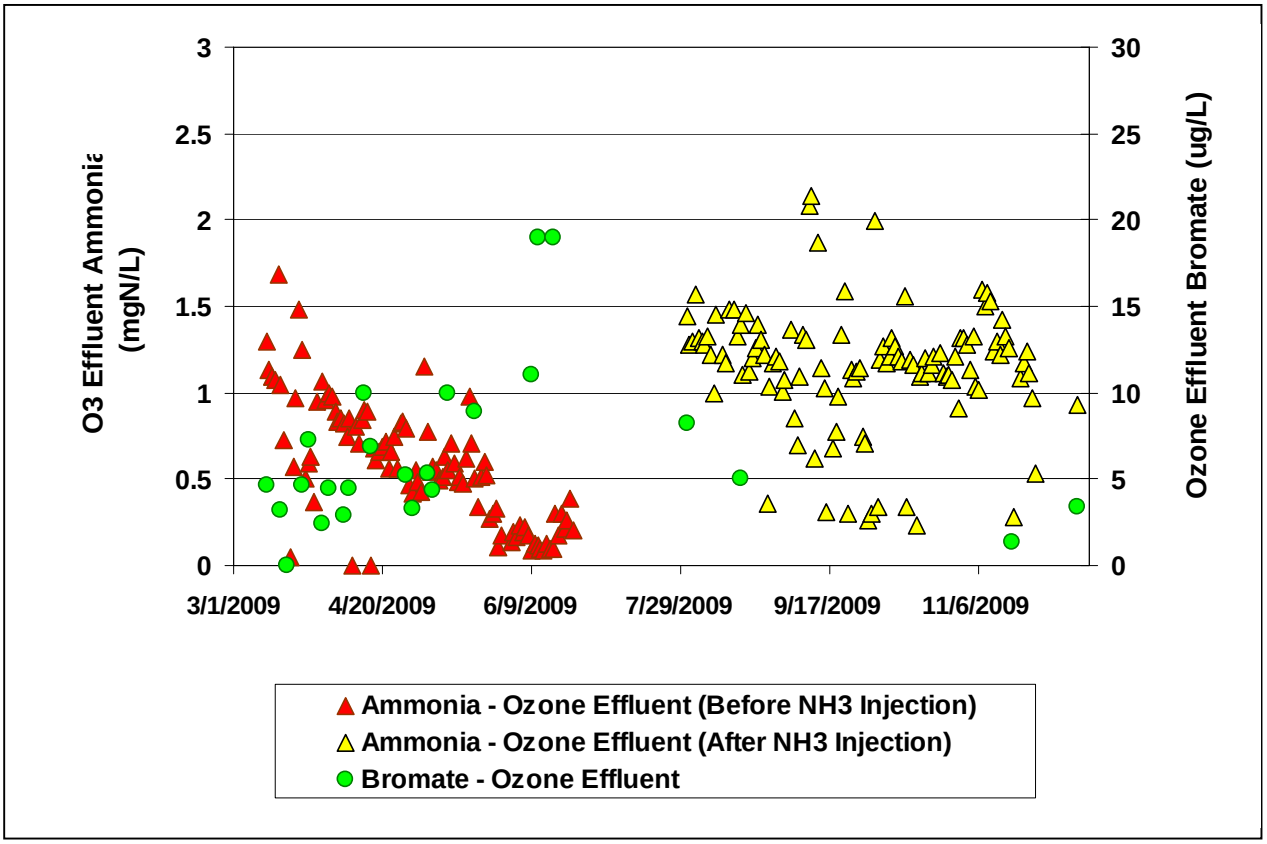



Figure B-5
**Bromate and Ammonia Concentration during Phase 2 Demonstration (5 mg/L Ozone; 1:1 Peroxide to Ozone Molar Ratio)**

***Ammonia Addition***

A few sources of ammonia including 1) aqua ammonia, 2) aqua ammonia and sulfuric acid, and 3) ammonia sulfate were evaluated to increase the ammonia concentration close to 1 mg/L in the membrane effluent during summer months. Ammonia sulfate (99% ACS Grade) was found to be cost-effective, maintenance-free and reliable source of ammonia for this testing. Feed solution was prepared by adding 493 g of the salt and 20 liters of DI water.

## B.6 REFERENCES

Amy, G. and M. S. Siddiqui. Strategies to Control Bromate and Bromide, AWWRF, 1998.

EPA, Alternative Disinfectants and Oxidants, EPA Guidance Manual, 1999.

Marhaba, T.F.; Bengraïne, K. (2003) Review of strategies for minimizing bromate formation resulting from drinking water ozonation. *Clean Techn. Environ. Policy*, **5**, 101-112.

Rakness, K. L., Ozone in drinking water treatment: Process design, operation, and optimization, AWWA, 2005.

Von Gunten, U, (2003) Ozonation of drinking water: Part II. Disinfection and by-product formation in presence of bromide, iodide or chlorine. *Water Res.*, **37**, 1469-1487.

Appendix C

# BAC Process Development and Evaluation

Appendix C

# BAC Process Development and Evaluation



## TABLES



## FIGURES

Appendix C

# BAC Process Development and Evaluation

## C.1 BAC UNIT PROCESS DEVELOPMENT

Protracted steady state operation of the pilot process was needed to provide the time necessary to endemically convert the GAC (Granular Activated Carbon) to a BAC (Biological Activated Carbon) treatment process. The GAC was "conditioned" into a BAC biofilter process by passing membrane-filtered and ozonated effluent produced by the pilot process through the bed of GAC on a continuous basis for two months at a flow rate of 10.7 gpm. During the conditioning period, the optimized ozone and peroxide dosages were maintained; and the BAC unit was backwashed every two weeks. Biological activity in the BAC was monitored by 1) measuring concentrations of various forms of organic carbon monitored before and after the BAC unit and 2) measuring PLFAs (Phospholipids Fatty Acids) in the BAC media at various bed depths before each backwash.

## C.2 BIOMASS GROWTH

PLFA analysis is a reliable and accurate way to determine viable microbial biomass in GAC conditioned into BAC. Phospholipids break down rapidly upon cell death; therefore, biomass calculations based on PLFA content do not contain lipids from dead cells. Figure C-1 shows biomass concentrations as a function of time based on PLFA results. Figure C-2 shows biomass concentrations as a function of location (i.e., depth) in the BAC biofilter bed. To understand these figures the depth of the BAC biofilter medium is 4.5 feet; and the "bed height" values reported in the figures are measured up from the bottom (effluent side) of the biofilter. In other words a bed height of 4 feet is equivalent to a bed depth (from the top/influent side of the medium) of 0.5 feet.

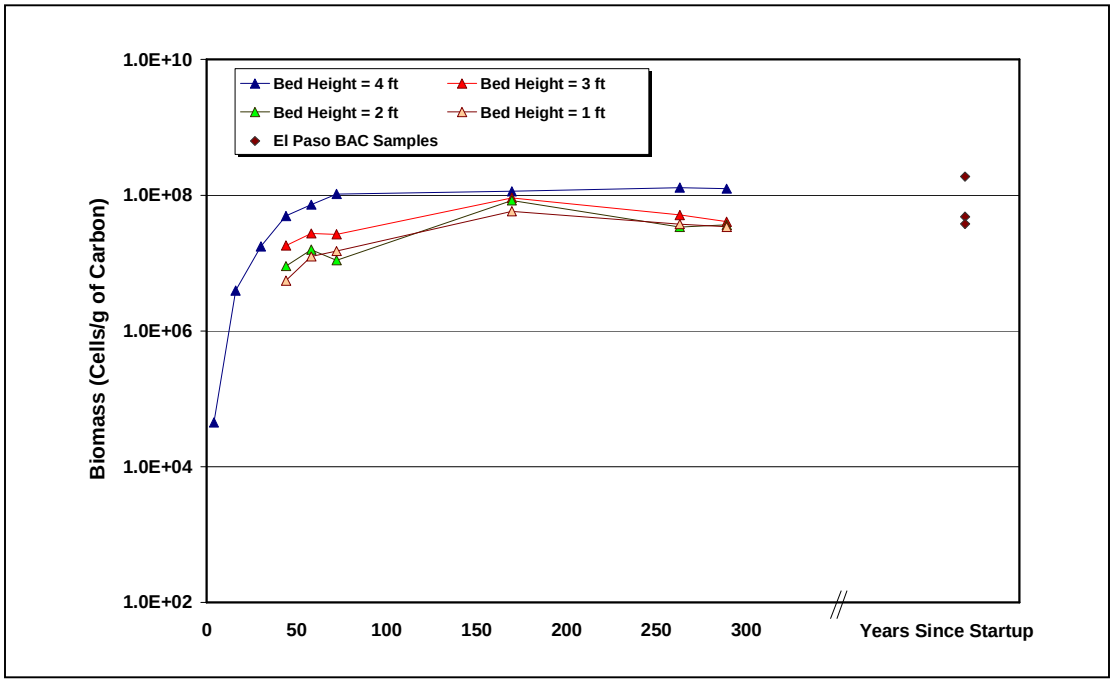



Figure C-1
**Biomass Growth with Time**

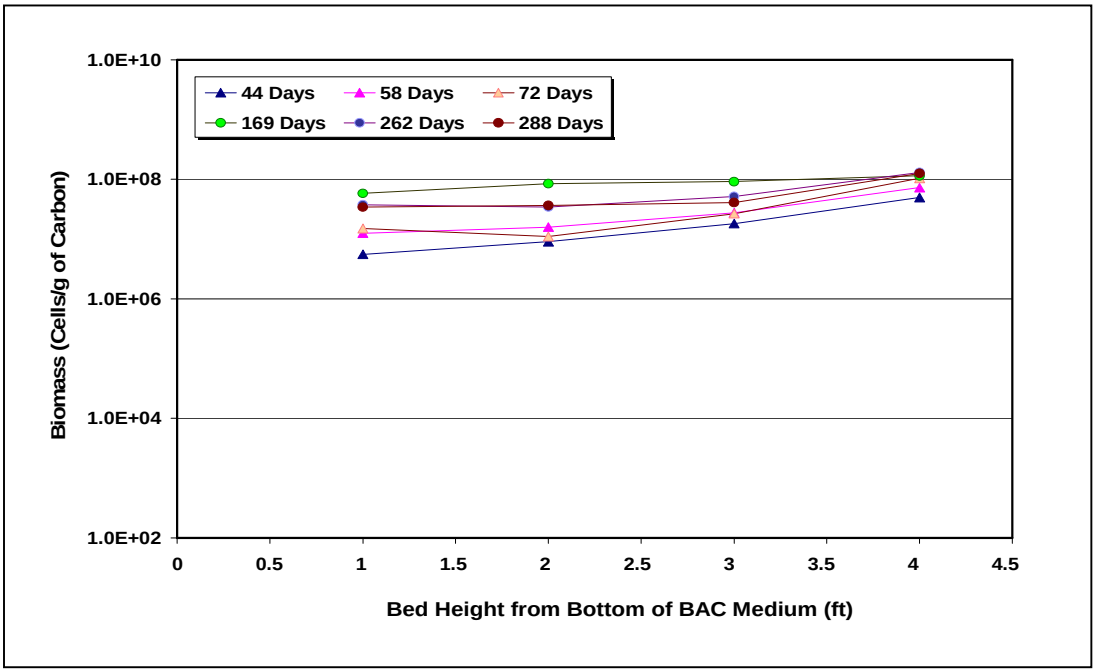



Figure C-2
**Biomass Growth with Bed Depth**

## C.3 MICROBIAL CHARACTERIZATION

Changes in the PLFA profile (i.e., microbial community structure) over time were measured at various bed depths, as shown in Figure C-3. The initial microbial community during startup was limited in biomass and microbial diversity. Opportunistic microbes (categorized as the Normal Saturated Group or "Nsats") were the dominant microbial population, initially. The microbial community increased in biomass and diversity over time. Fast growing, hydrocarbon utilizing proteobacteria (the Monoenoic Group or "Monos") became dominant. Anaerobic metal reducing bacteria (Branched Monoenoic Group or "Brmonos"), Nsats, and eukaryotes such as fungi (Polyenoic Group or "Polys") were also present. The microbial community structure throughout the conditioned BAC bed was fairly uniform. However, there was comparatively less biomass towards the bottom the bed, where a scarcity of food source is expected to have occurred.

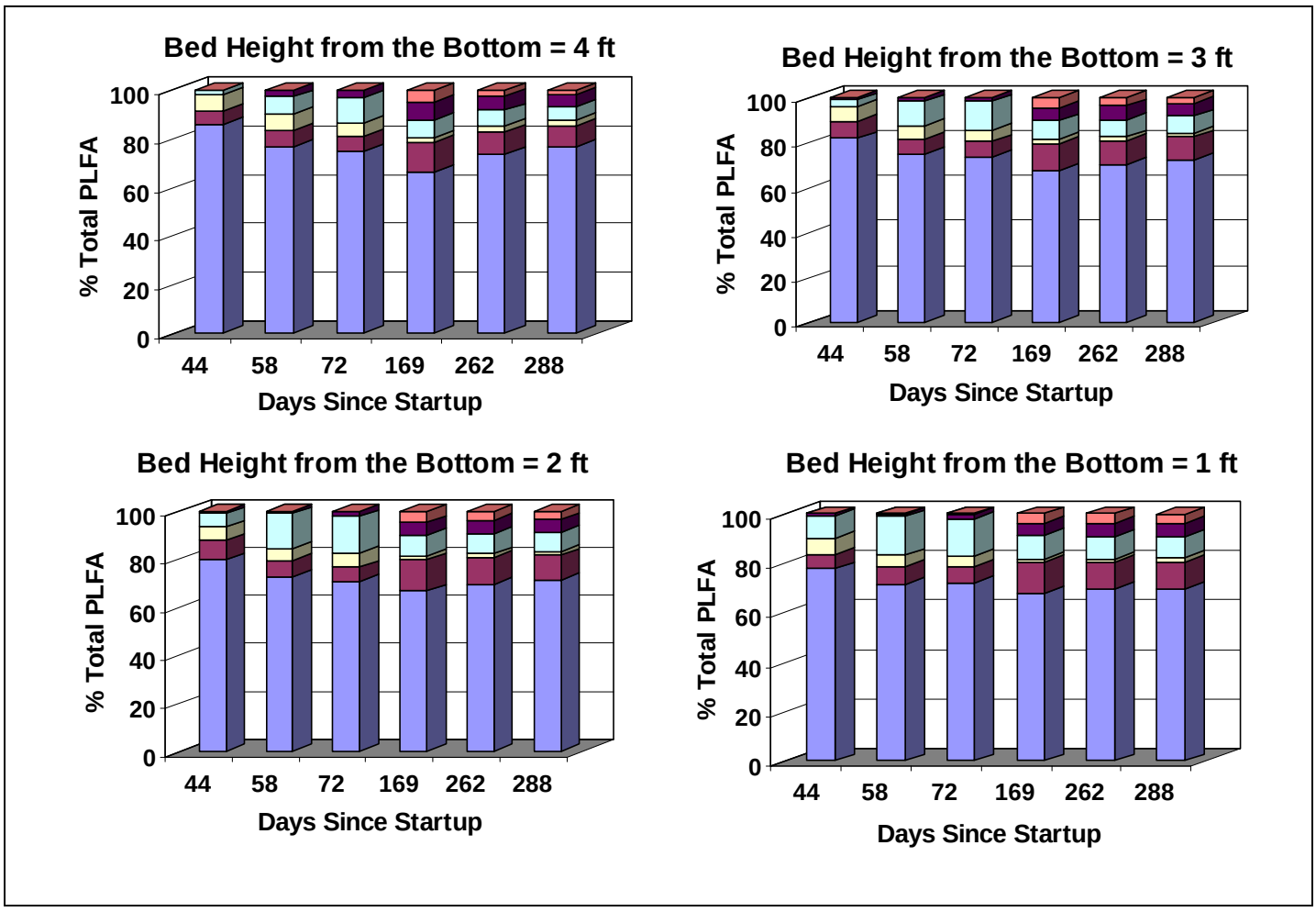



Figure C-3
**Microbial Community Structure with Time**

Table C-1
Description of PLFA Types and Bacterial Groups

| PLFA Type | Bacterial Group | Potential Relevance to Bioremediation |
|---|---|---|
| Monoenoic (Monos) | Abundant in Proteobacteria which includes a wide variety of aerobes and anaerobes | Many hydrocarbon utilizing bacteria are classified within Proteobacteria |
| Terminally Branched Saturated (TerBrSats) | Characteristic of Firmicutes and *Bacteroides* | Firmicutes include anaerobic fermenting bacteria which produce the $H_2$ necessary for reductive dechlorination |
| Branched Monoenoic (BrMonos) | Anaerobes and micro-aerophiles such as sulfate- or iron-reducing bacteria | High proportions are often associated with anaerobic sulfate and iron reducing bacteria |
| Mid-Chain Branched Saturated (MidBrSats) | Common in sulfate reducing bacteria and also *Actinomycetes* | High proportions are often associated with anaerobic sulfate and iron reducing bacteria |
| Normal Saturated (Nsats) | Found in all organisms | High proportions often indicate less diverse populations |
| Polyenoic (Polys) | Found in eukaryotes (fungi, algae, protozoa, plants and animals) | Eukaryotic scavengers often prey on contaminant utilizing bacteria |

Source: Microbial Insights Inc.

## C.4 BAC HYDRAULICS

BAC flowrate over the course of the demonstration project is presented in Figure C-4. The cumulative volume of effluent treated by the BAC biofilter (in the units of treated bed volumes) over time is presented in Figure C-5. A "bed volume" for the 4.5' deep, 3.5' diameter bed of BAC biofilter medium is 324 gallons.

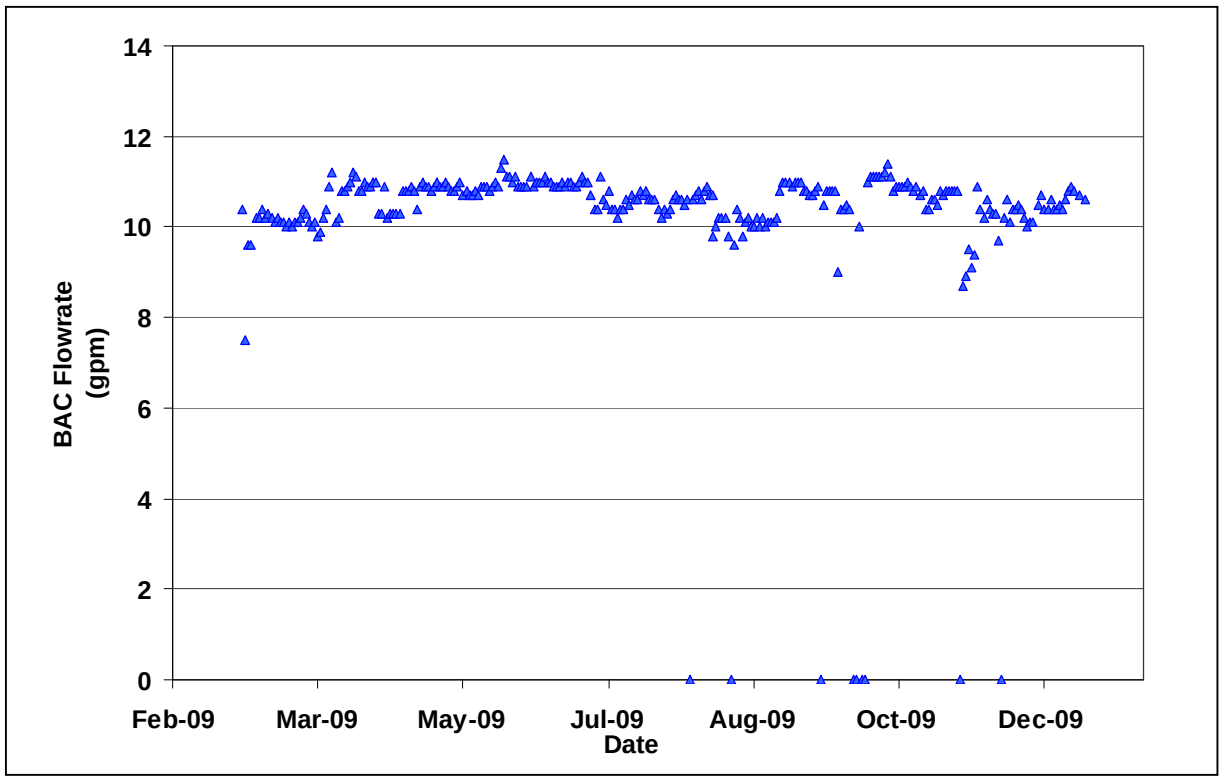



Figure C-4
**BAC Flowrate with Time**

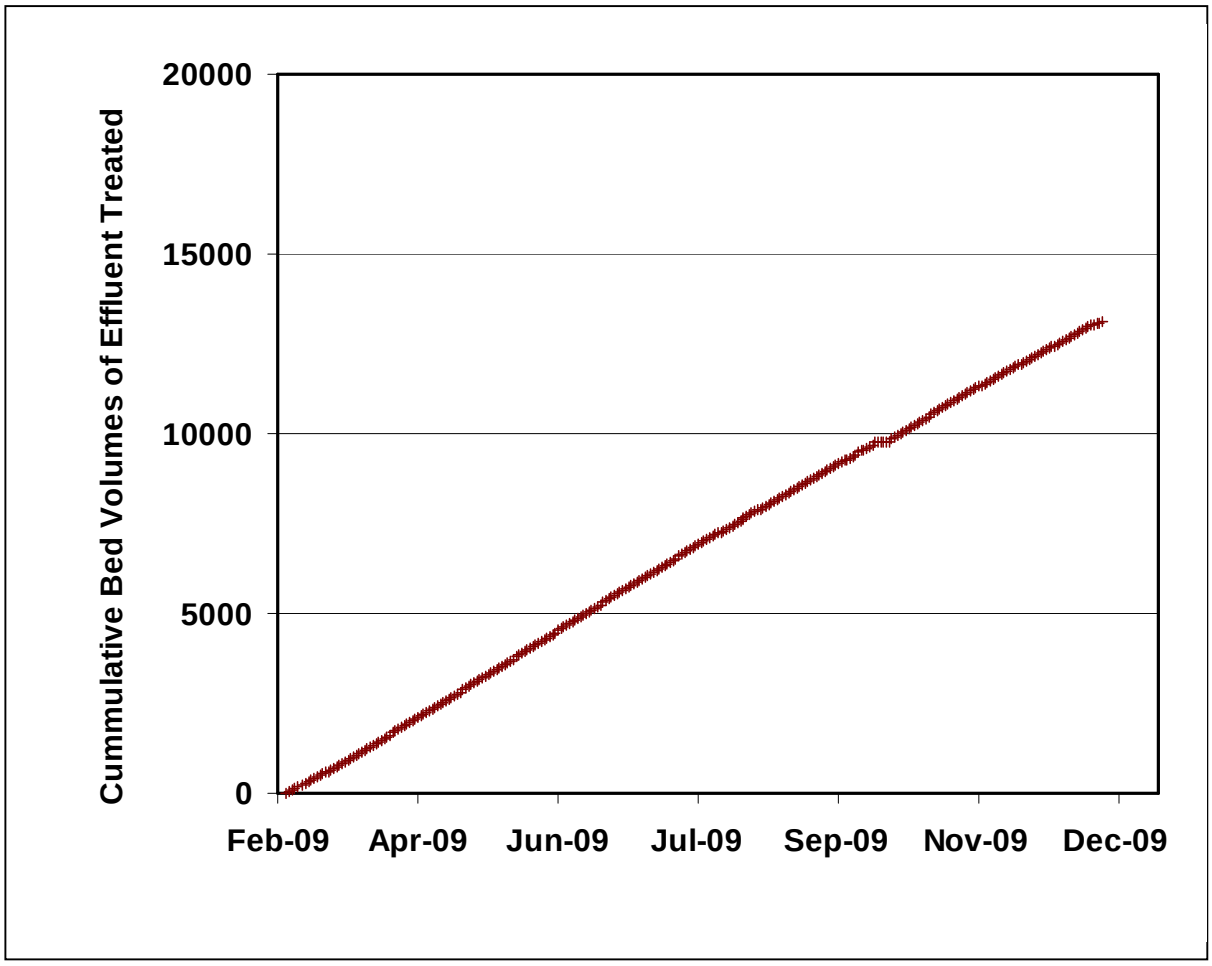



Figure C-5
**BAC Treated Bed Volumes with Time**

## C.5 BAC BACKWASH OPTIMIZATION

Pressure differential across the BAC biofilter during Phase 2 is shown in Figure C-6.

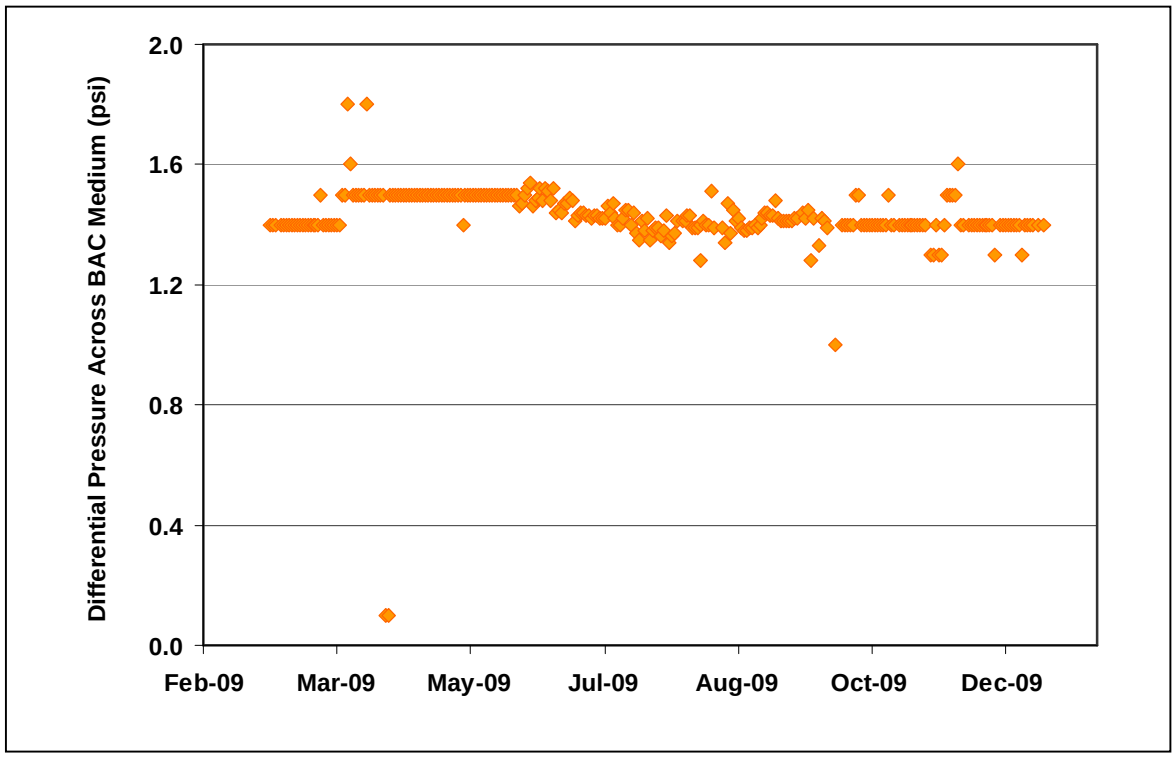



Figure C-6
**BAC Pressure Drop with Time**

BAC backwash flowrate and its impact on backwash interval are shown in Figure C-7.

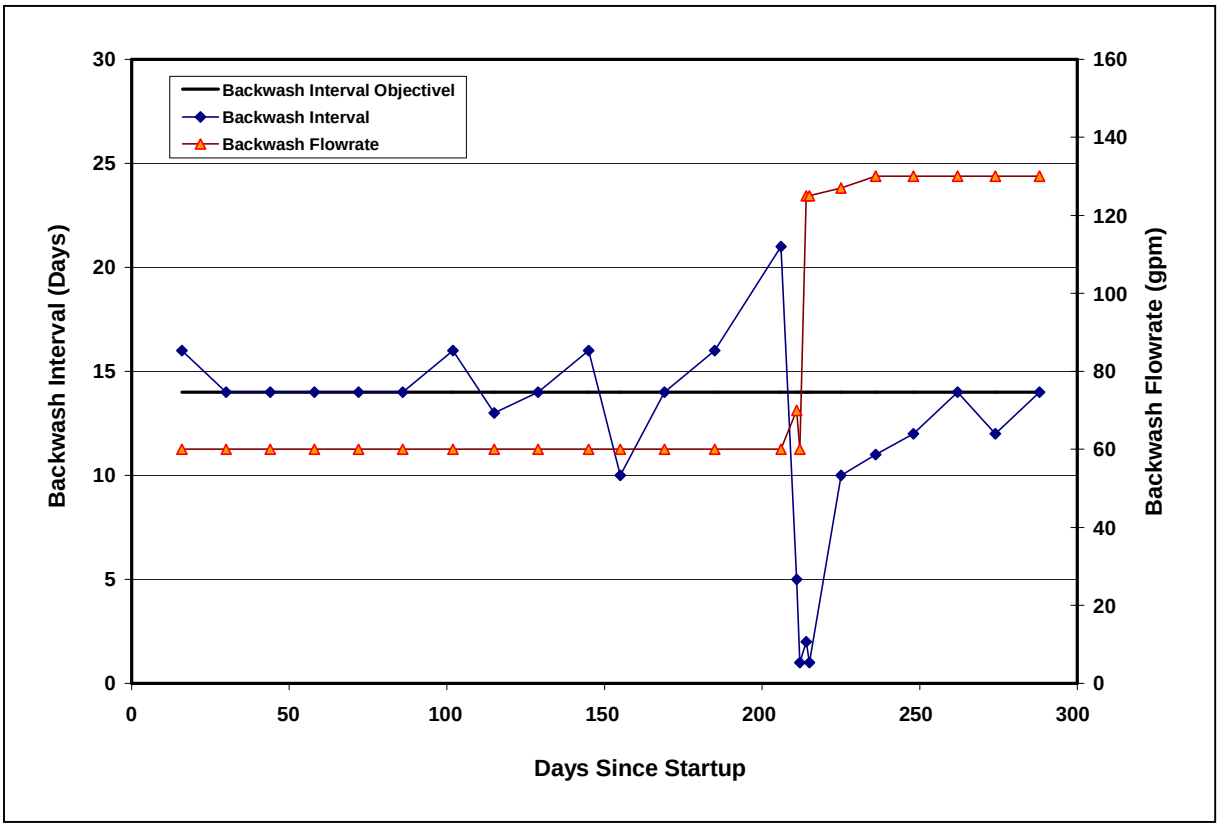



Figure C-7
**BAC Backwash Interval and Backwash Flowrate over Time**

## C.6 REMOVAL OF AMMONIA

After start-up, concentration of ammonia in BAC effluent was not detectable. Ammonia removal could be attributed to biological nitrification of effluent by microbes living on the BAC medium using molecular oxygen in the effluent that is residual from the ozonation process. Changes in ammonia concentration over time are shown in Figure C-8.

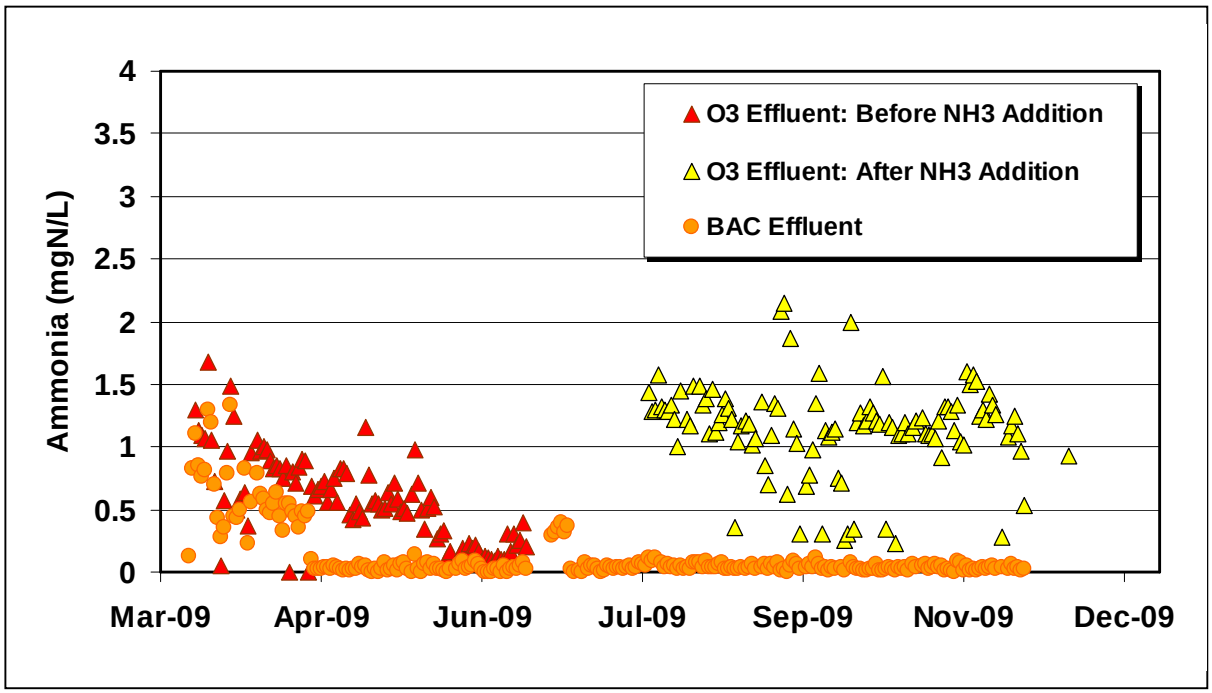



Figure C-8
**Changes in Ammonia Concentration over Time**

## C.7 TOTAL ORGANIC CARBON (TOC)

Changes in TOC concentration over time are shown in Figure C-9. Samples from intermediate BAC bed depths were utilized for TOC analysis. BAC-1 and BAC-2 represents samples taken from intermediate sample ports at heights of 3 feet and 1 foot, respectively, above the bottom (i.e., effluent side) of the BAC bed. BAC-3 represents BAC effluent samples.

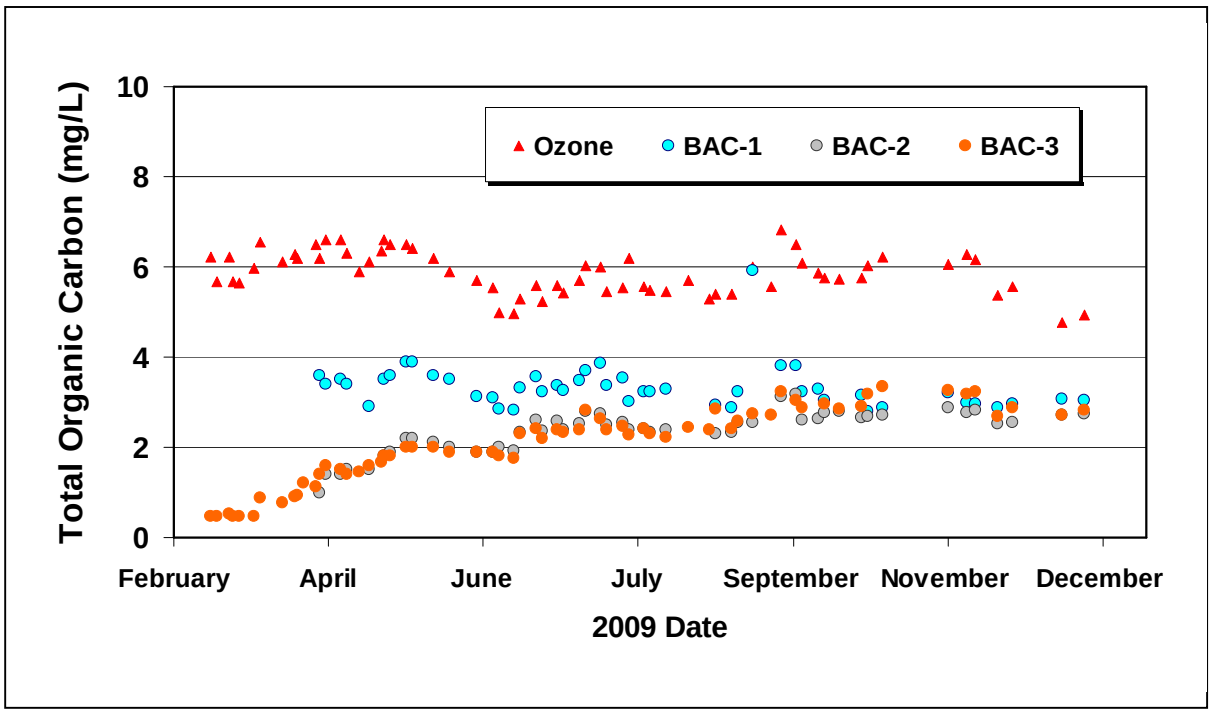



Figure C-9
**Changes in TOC Concentration over Time through the BAC Bed**

# C.8 CHARACTERIZATION OF BAC BACKWASH FLOW

Results from the characterization of BAC backwash flow are presented in Tables C-1 and C-2. The average volume of BAC backwash water is approximately 0.9 percent of the inflow volume.

Table C-2
**Ozonation Byproducts in BAC Backwash Water**

| Analyte | Result (µg/L) |
|---|---|
| Acetaldehyde | < 1.0 |
| Benzaldehyde | < 0.20 |
| Butanal | < 0.50 |
| Crotonaldehyde | < 0.80 |
| Cyclohexanone | < 0.30 |
| Decanal | < 0.90 |
| Formaldehyde | 3.3 |
| Glyoxal | < 1.1 |
| Heptanal | < 0.20 |
| Hexanal | < 1.0 |
| Methyl Glyoxal | < 0.50 |
| Nonanal | < 1.4 |
| Pentanal | < 0.20 |
| Propanal | < 0.70 |
| N-Nitrosodiethylamine | < 0.72 |
| N-Nitrosodimethylamine | 0.34 |
| N-Nitrosodi-n-butylamine | < 0.59 |
| N-Nitrosodi-n-propylamine | < 0.35 |
| N-Nitrosomethylethylamine | < 0.28 |
| N-Nitrosopiperidine | < 0.71 |
| N-Nitrosopyrrolidine | < 0.66 |

Table C-3
**CECs in BAC Backwash Water**

| Analyte | Result (ng/L) |
|---|---|
| 4-tert-Octylphenol | < 0.080 |
| Nonylpheno | < 0.30 |
| Nonylphenol diethoxylate | < 2.1 |
| Nonylpheno monoethoxylate | < 0.87 |
| 17a-Ethynylstradiol | < 0.56 |
| Estadiol | < 0.31 |
| Estrone | < 0.20 |
| Progesterone | < 0.17 |
| Testosterone | < 0.14 |
| Bispheno A | < 0.27 |
| Gemfibrozil | 0.16 |
| Ibuprofen | < 0.39 |
| Iopromide | < 1.8 |
| Naproxen | < 0.25 |
| Salicylic Acid | 49 |
| Triclosan | < 1.2 |
| Acetaminophen | < 1.4 |
| Amoxicillin | < 2.0 |
| Atenolol | < 0.20 |
| Atorvastatain | < 0.11 |
| Azithromycin | < 2.2 |
| Caffeine | < 0.31 |
| Carbamazepine | < 0.080 |
| Ciprofloxacin | 12 |
| Cotinine | < 0.35 |
| DEET | < 0.060 |
| Diazepam | < 0.14 |
| Fluoxetine | < 0.080 |
| Meprobamate | 16 |
| Methadone | < 0.040 |
| Phentytoin | < 0.33 |
| Primidone | < 0.60 |
| Sulfamethoxazole | < 0.19 |
| TCEP | 30 |
| TCPP | 38 |
| TDCPP | 57 |
| Trimethoprim | < 0.24 |

## C.9 EL PASO FRED HARVEY WRP TOC RESULTS

TOC results from the samples collected at El Paso Fred Harvey WRP (FHWRP) are shown in Figure C-10.

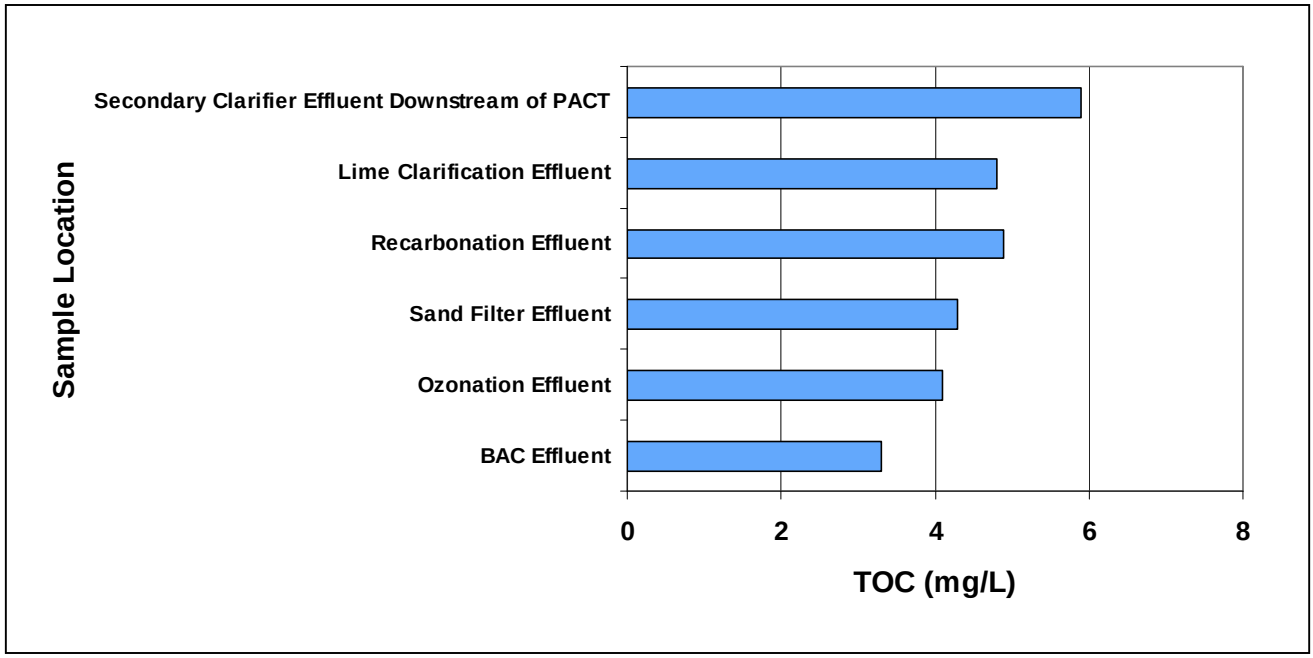



Figure C-10
**El Paso FHWRP TOC Profile**

Appendix D

# MF-O3-BAC Steady State Operation

Appendix D

# MF-O3-BAC Steady State Operation



## FIGURES

Appendix D

# MF-O3-BAC Steady State Operation

Data presented in this appendix include: 1) membrane process monitoring, 2) membrane cleaning protocol, 3) ozone process monitoring and 4) MF-O3-BAC effluent water quality monitoring conducted during the steady state operation of the pilot units.

## D.1 STEADY STATE OPERATION

Steady state operation of the pilot process provided the time necessary for 1) evaluation of membrane and ozone process performance, 2) development of microbial colonies converting GAC biofilter media endemically into a BAC biofilter, 3) evaluation of MF-O3-BAC reliability under the full range of seasonal conditions, and 4) providing hands-on experience for the treatment plant operators.

To facilitate overall process monitoring and control, the City installed various online sensors that were connected to the RSWRF SCADA system. Benefits of this decision included 1) reduced daily monitoring requirements, 2) generation of a comprehensive dataset that captured system performance and variability during seasonal and diurnal variations, and 3) hands-on experience for the RSWRF plant staff in dealing with cutting edge instruments and advanced treatment technologies.

## D.2 MEMBRANE FILTRATION (MF) PROCESS MONITORING

Changes in transmembrane pressure (TMP) over time across the MF unit are presented in Figure D-1 along with changes in membrane production flowrate. Temperature corrected (normalized) membrane flux calculated based on secondary effluent (i.e., membrane feed) temperature, membrane surface area, and production flowrate is presented in Figure D-2.

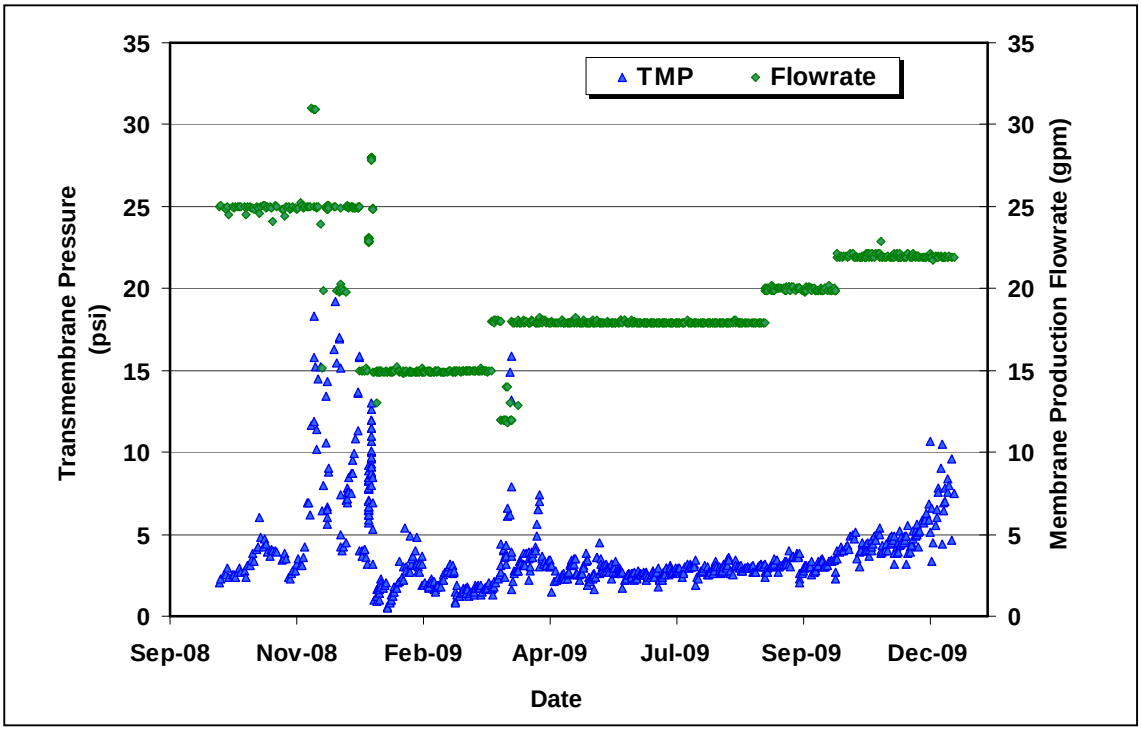



Figure D-1
**Membrane Process Monitoring: Transmembrane Pressure (TMP) and Production Flowrate over Time**

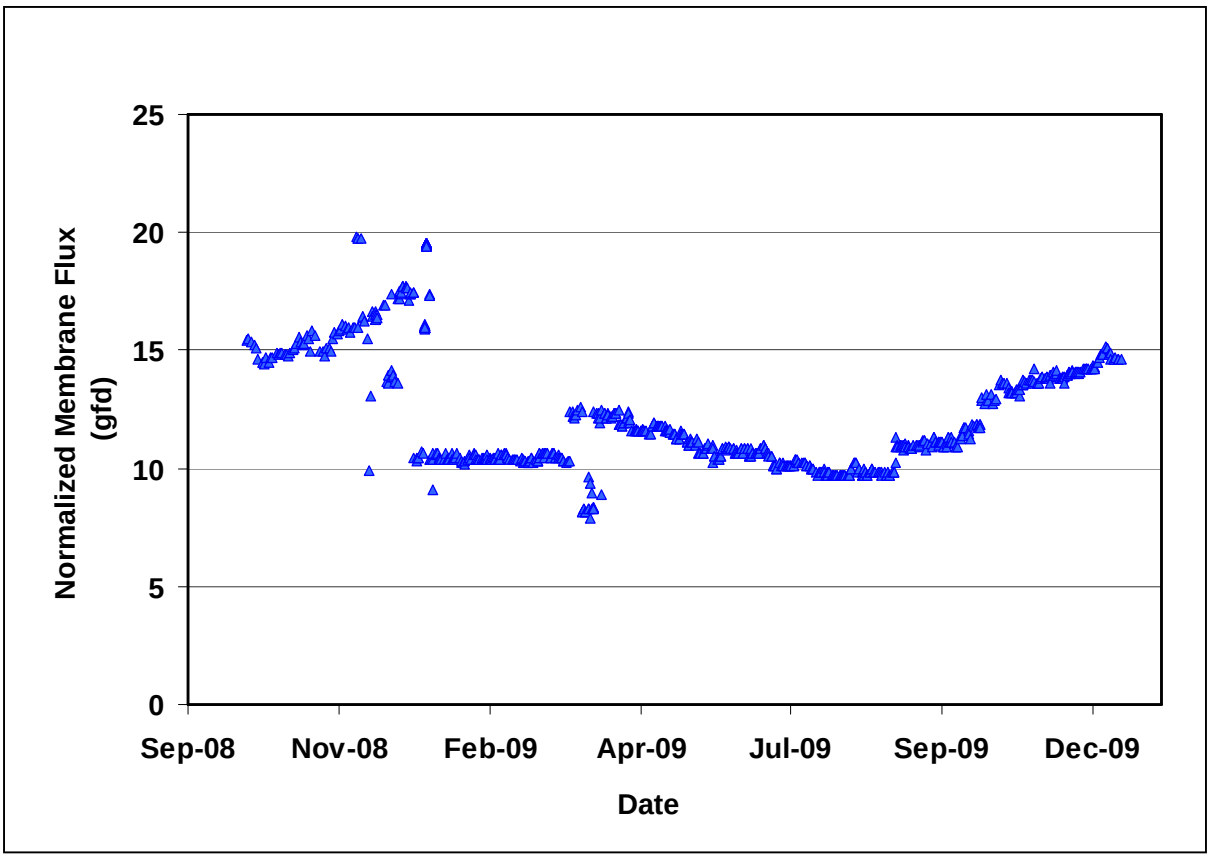



Figure D-2
**Membrane Process Monitoring: Temperature Corrected Flux over Time**

Changes in membrane permeability (flux divided by the TMP) and production flowrate are presented in Figure D-3.

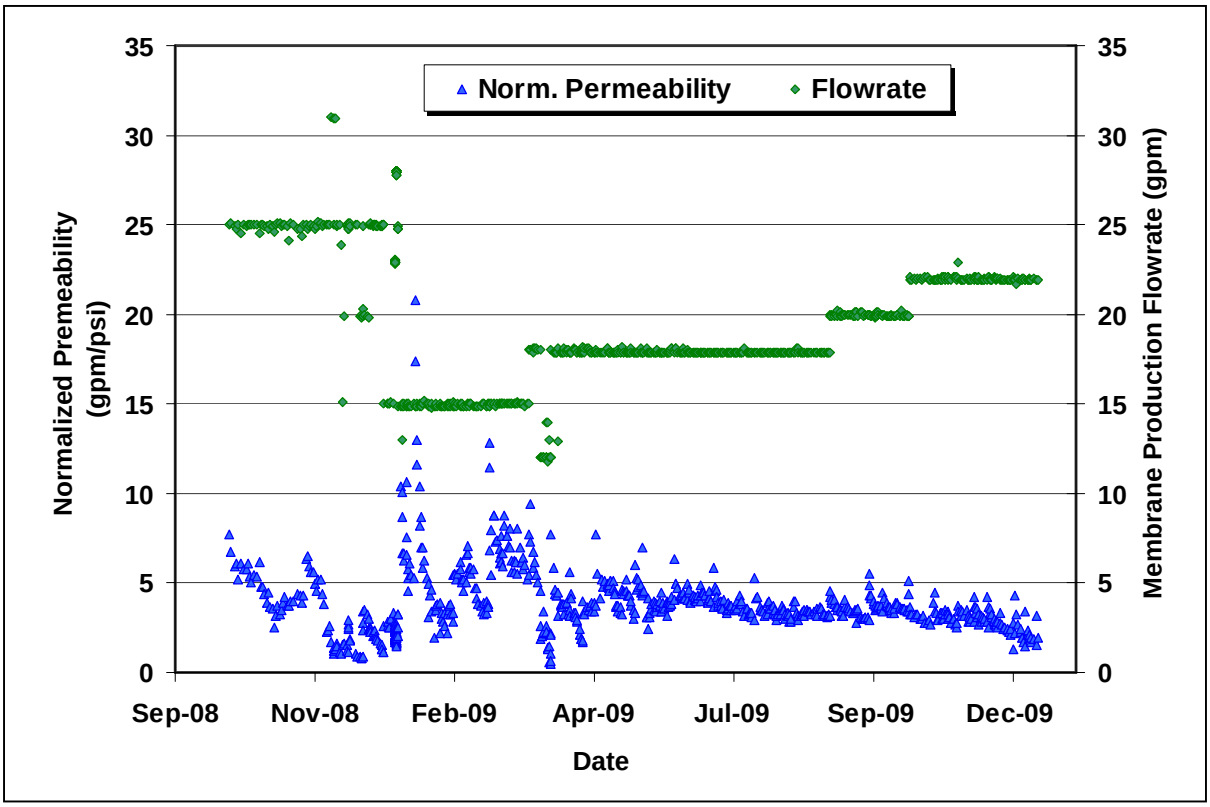



Figure D-3
**Membrane Process Monitoring: Normalized Permeability and Production Flowrate over Time**

### D.2.1 MEMBRANE MAINTENANCE

Membrane maintenance steps include: 1) backwash, 2) monitoring of membrane integrity using pressure decay test, 3) CIP and 4) mini clean-in-place (mini-CIP).

**Membrane Backwash:** Membrane filters were backwashed every 35 minutes at a flowrate of 80-100 gpm using a chemical solution containing sodium hypochlorite and caustic. Caustic was added per the manufacturer's recommendation to retain membrane integrity. Each backwash cycle lasted approximately 4.5 minutes, and consisted of air scour, pause, chemical soak, and rinse steps.

**Pressure Decay Test (PDT):** Membrane integrity was monitored by conducting PDT once a day. Membrane modules were pressurized to 15 psi and held at that level for 3 minutes. Membrane modules are considered to have an integrity failure if the pressure decay is over 0.72 psi/min.

**CIP and Mini-CIP**: CIP was conducted once every 3 weeks. Mini-CIP was conducted each week between CIPs. Each mini-CIP cycle included five steps: air scour, chemical soak, chemical recirculation, pause, and rinse. The CIP procedure included acetic acid, sodium hypochlorite, and caustic chemical additions. The mini-CIP procedure does not include acetic acid. The duration of a CIP cycle was longer than a mini-CIP cycle even though the four steps were identical.

### D.2.2 PREFILTER MAINTENANCE

The MF prefilter was backwashed routinely using the MF backwash flow. The prefilter was also cleaned manually once every 10-14 days.

## D.3 OZONE PROCESS MONITORING

Ozone flowrate is presented in Figure D-4. Changes in ozone off-gas over time are presented in Figure D-5.

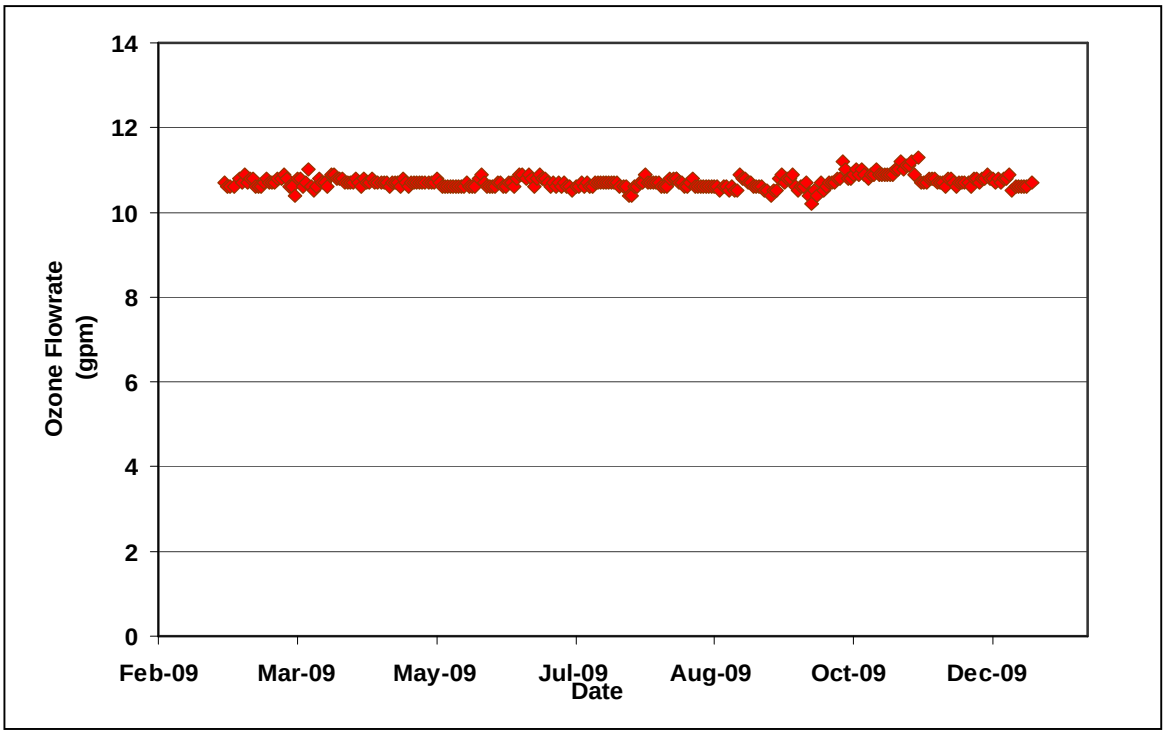



Figure D-4
**Ozone Process Monitoring: Ozone Flowrate with Time**

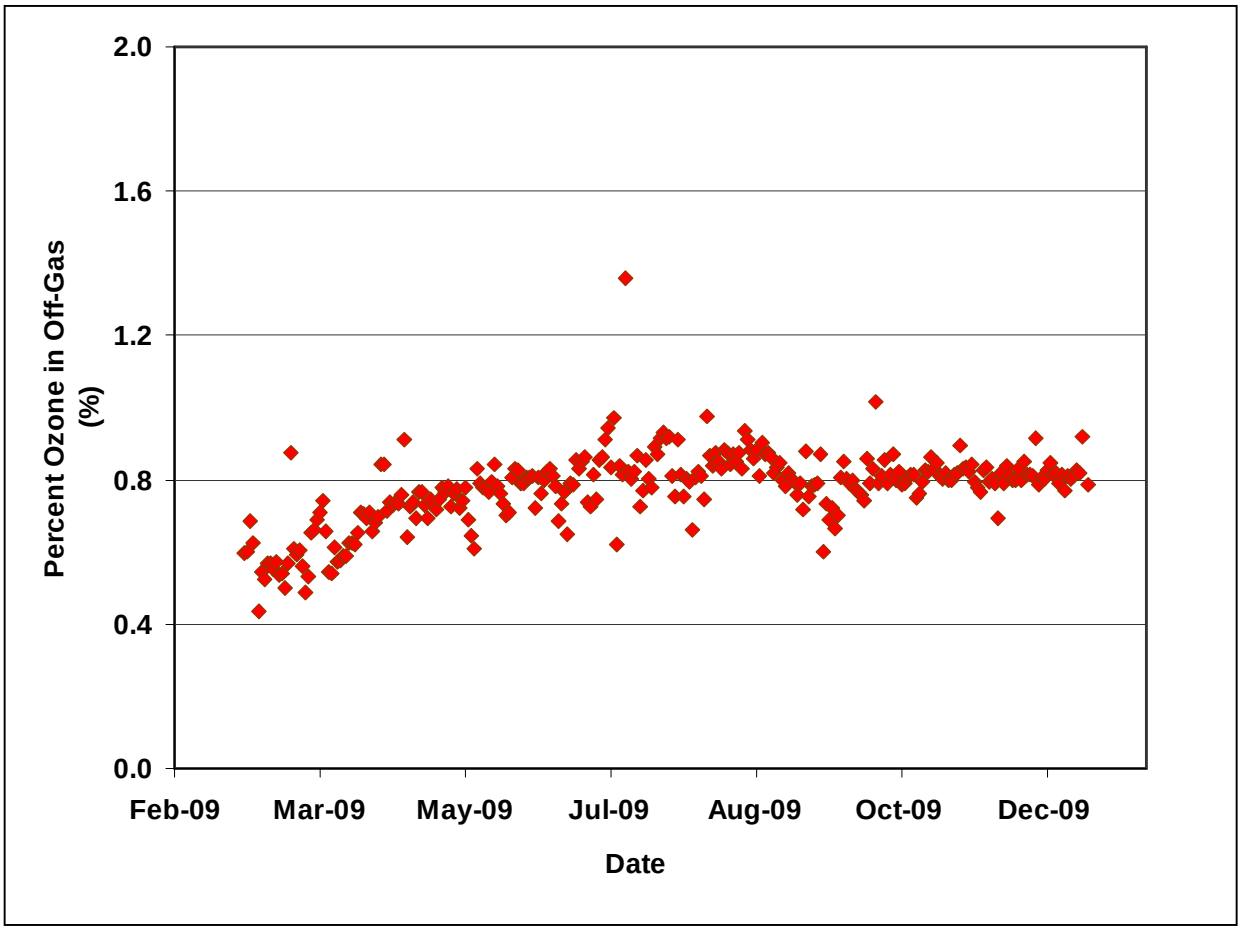



Figure D-5
**Ozone Process Monitoring: Ozone Off-Gas with Time**

## D.4 BAC PROCESS MONITORING

BAC process monitoring data including flowrate and differential pressure can be found in Appendix C –BAC Process Development and Evaluation.

## D.5 WATER QUALITY PARAMETERS

A number of water quality parameters were monitored over time during steady state operations. An index to the where data for various parameters can be found is presented below.

| Parameter | Effluent Sampling Points | Figure in Which Data are Presented |
|---|---|---|
| pH | Secondary, Membrane, Ozone and BAC | D-6 |
| Alkalinity | Membrane and Ozone | D-7 |
| Ortho-Phosphate | Membrane, Ozone, and BAC | D-8 |
| Total Phosphate | Membrane, Ozone, and BAC | D-9 |
| Total Nitrogen | Membrane, Ozone, and BAC | D-10 |
| Ammonia | Membrane, Ozone, and BAC | D-11 |
| Nitrite + Nitrate | Membrane, Ozone, and BAC | D-12 |
| Dissolved Organic Nitrogen (DON) | Membrane, Ozone, and BAC | D-13 |
| Total Organic Nitrogen (TON) | Membrane, Ozone, and BAC | D-14 |
| Dissolved Inorganic Nitrogen (DIN) | Membrane, Ozone, and BAC | D-15 |
| Total Inorganic Nitrogen (TIN) | Membrane, Ozone, and BAC | D-16 |
| Dissolved Oxygen (DO) | Ozone, BAC | D-17 |
| Bromide | Secondary, Membrane, Ozone, and BAC | D-18 |
| Bromate | Secondary, Membrane, Ozone, and BAC | D-19 |
| Chemical Oxygen Demand (COD) | Secondary, Membrane, Ozone and BAC | D-20 |

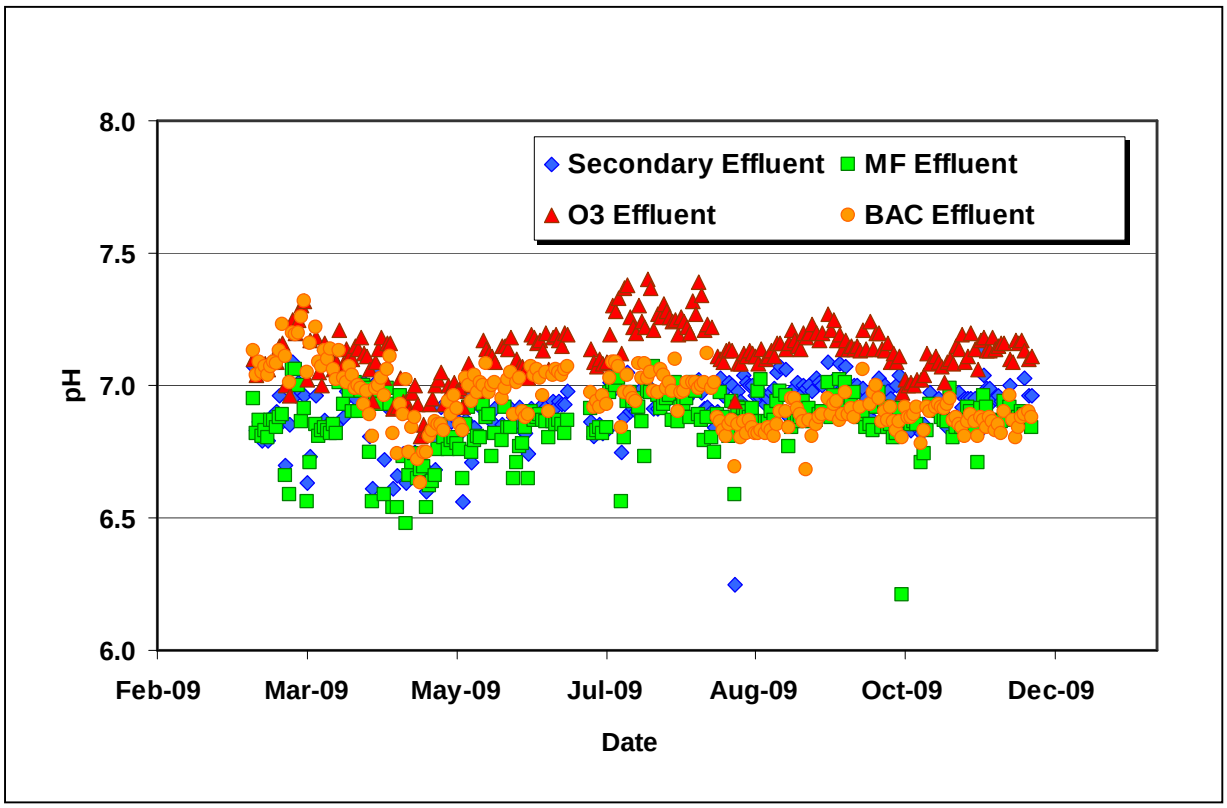



Figure D-6
**MF-O3-BAC Effluent Water Quality Monitoring: pH over Time**

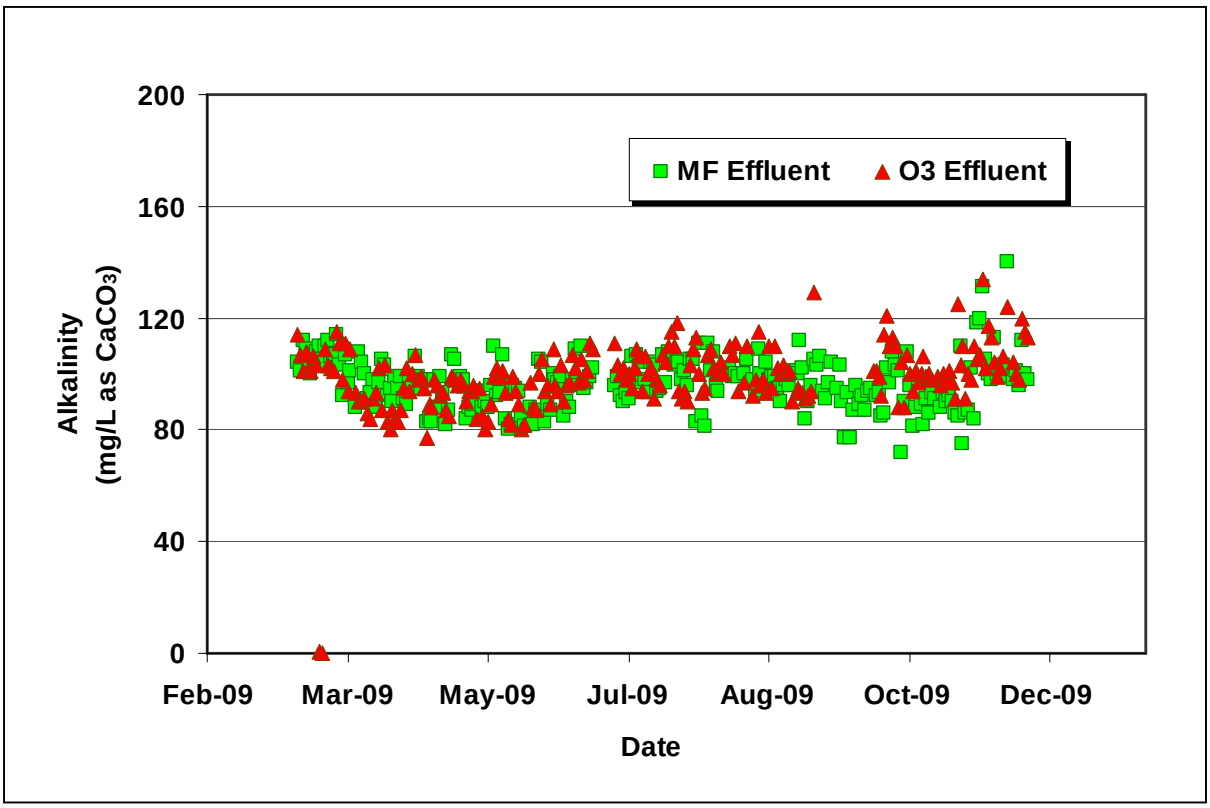



Figure D-7
**MF-O3-BAC Effluent Water Quality Monitoring: Alkalinity over Time**

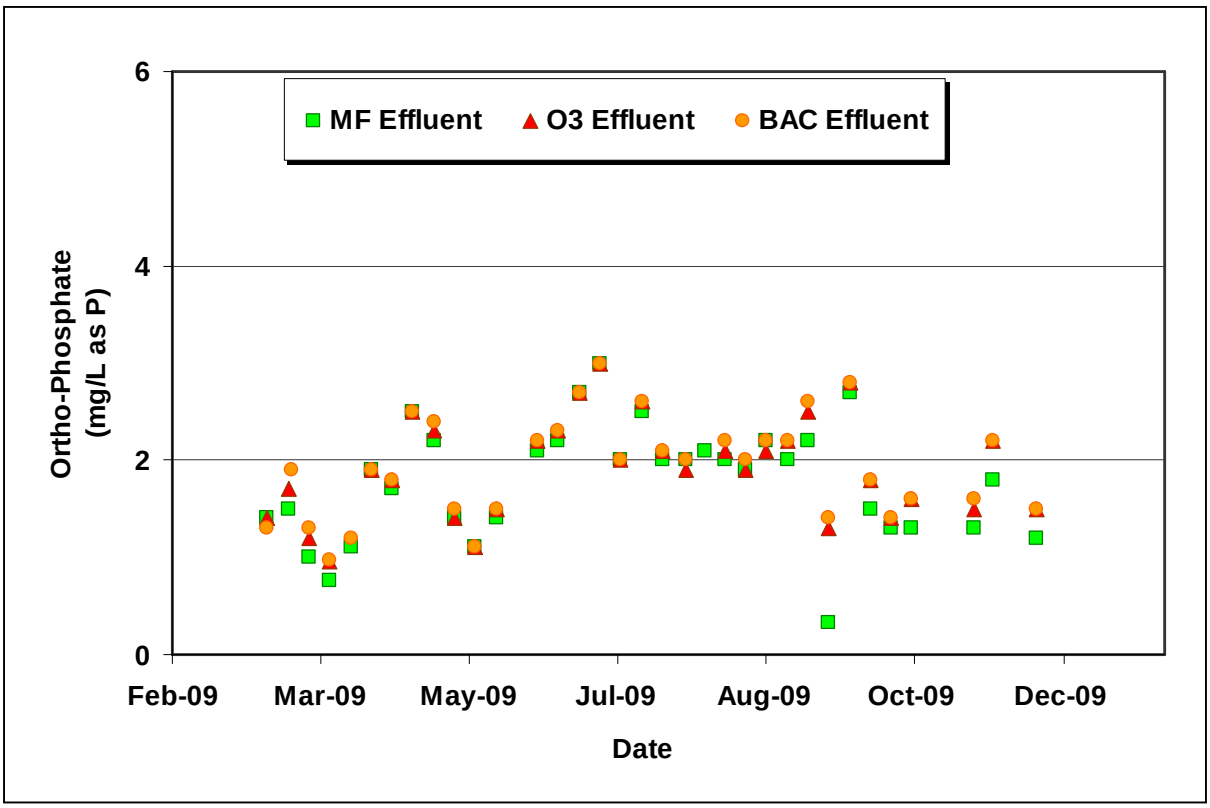



Figure D-8
**MF-O3-BAC Effluent Water Quality Monitoring: Ortho-Phosphate over Time**

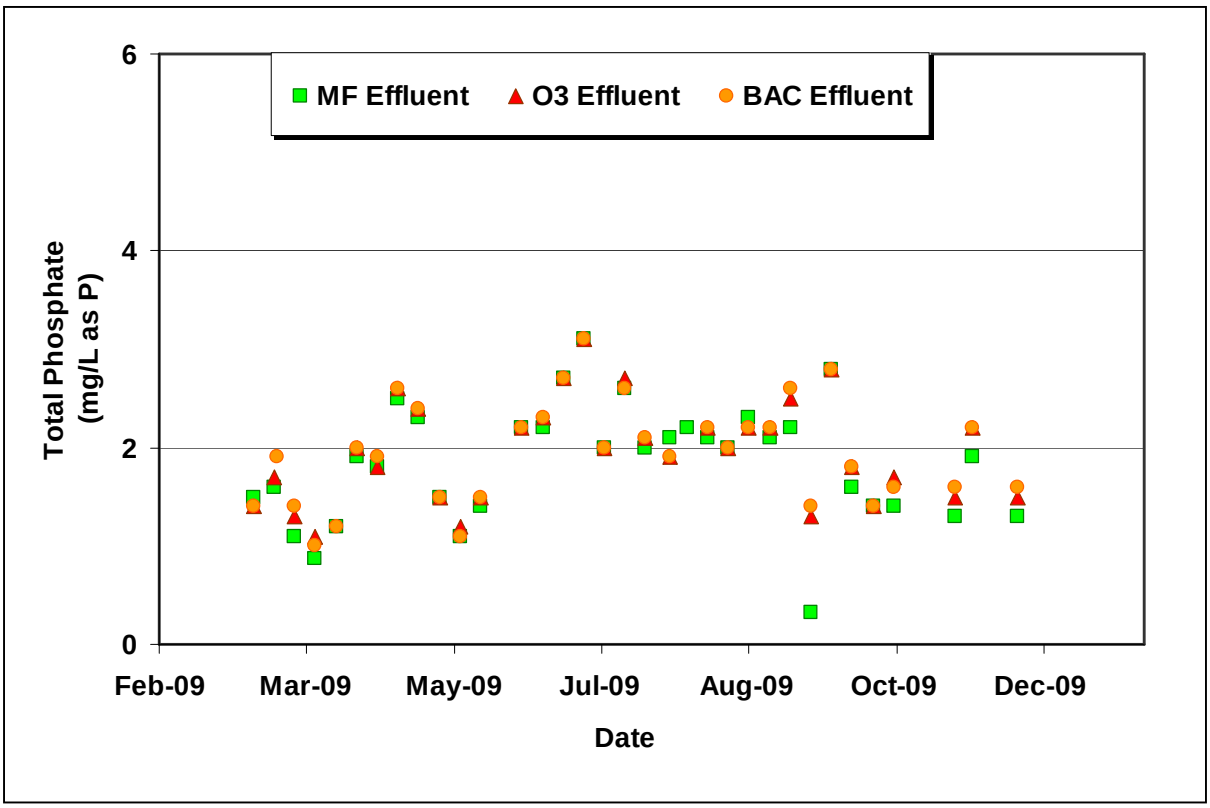
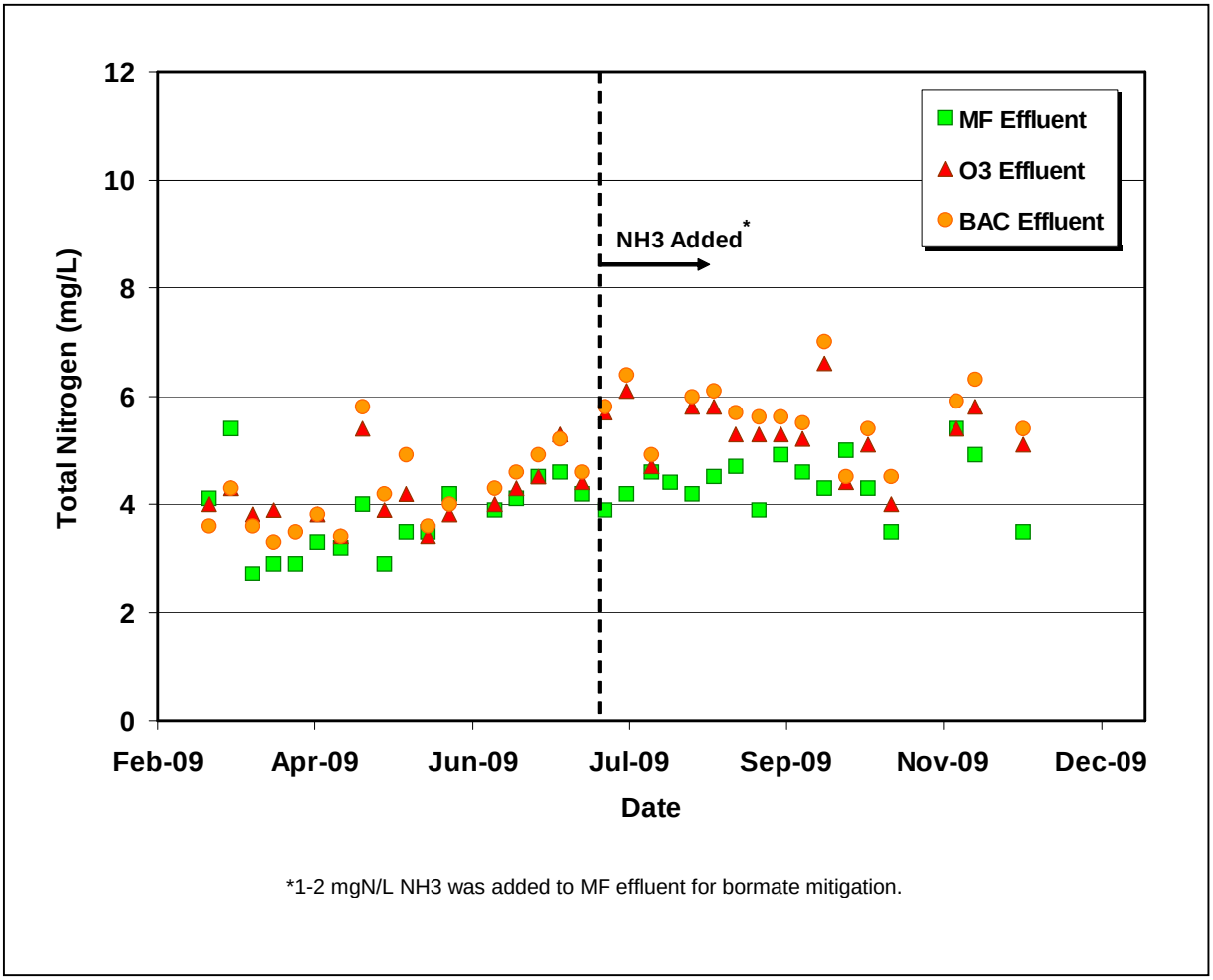
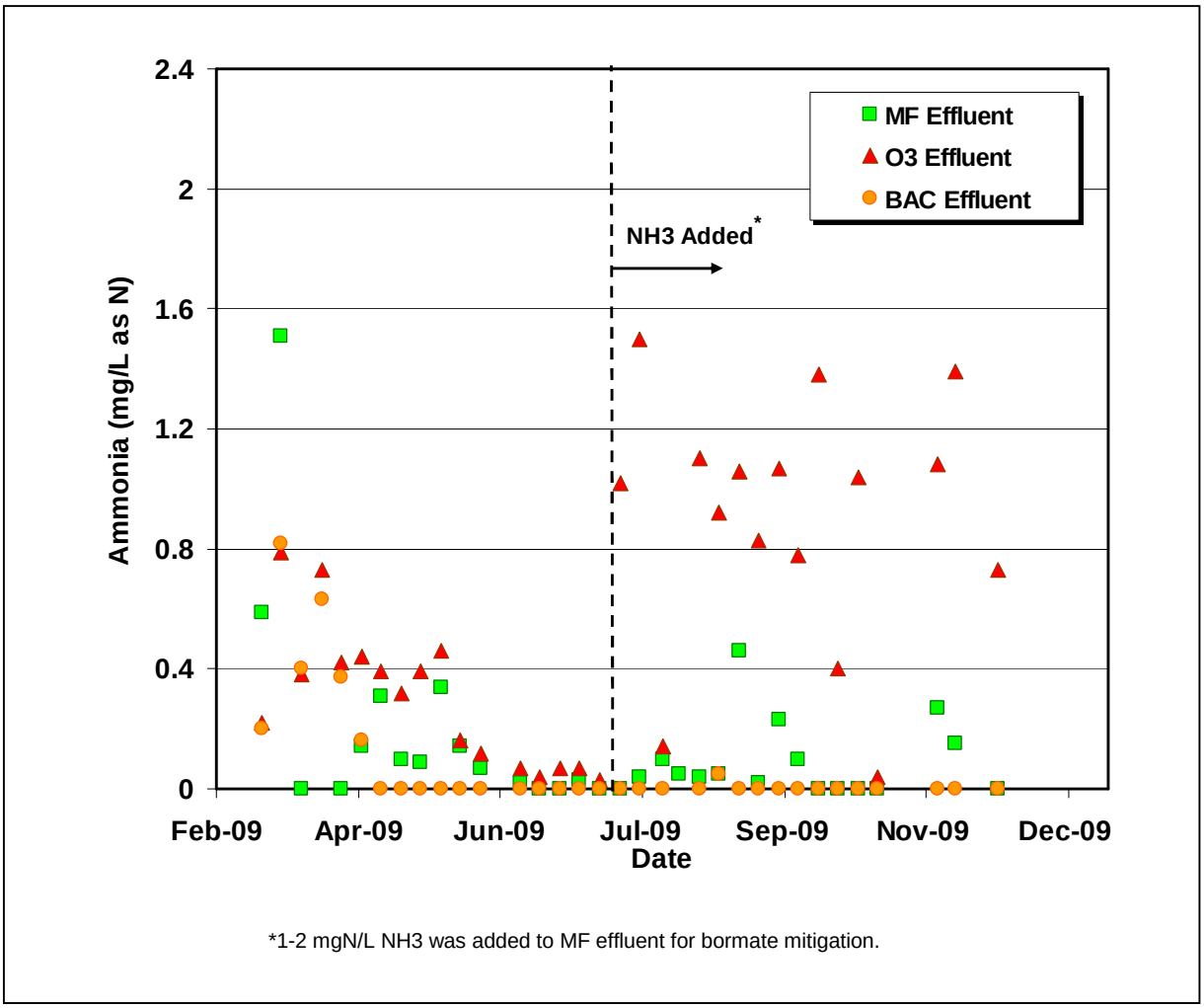



Figure D-9
**MF-O3-BAC Effluent Water Quality Monitoring: Total Phosphate over Time**




*1-2 mgN/L NH3 was added to MF effluent for bormate mitigation.

Figure D-10
**MF-O3-BAC Effluent Water Quality Monitoring: Total Nitrogen over Time**




*1-2 mgN/L NH3 was added to MF effluent for bormate mitigation.

Figure D-11
**MF-O3-BAC Effluent Water Quality Monitoring: Ammonia over Time**

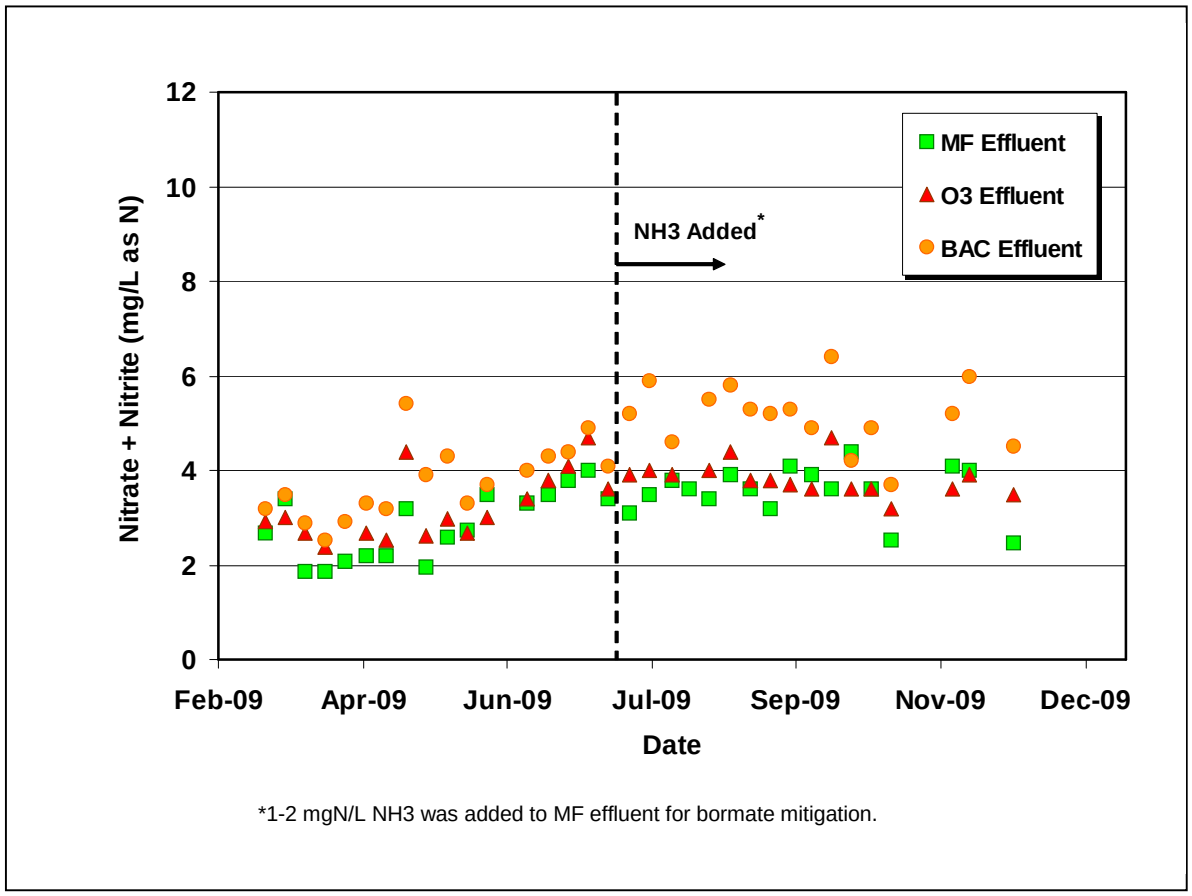



Figure D-12
**MF-O3-BAC Effluent Water Quality Monitoring: Nitrate and Nitrite over Time**

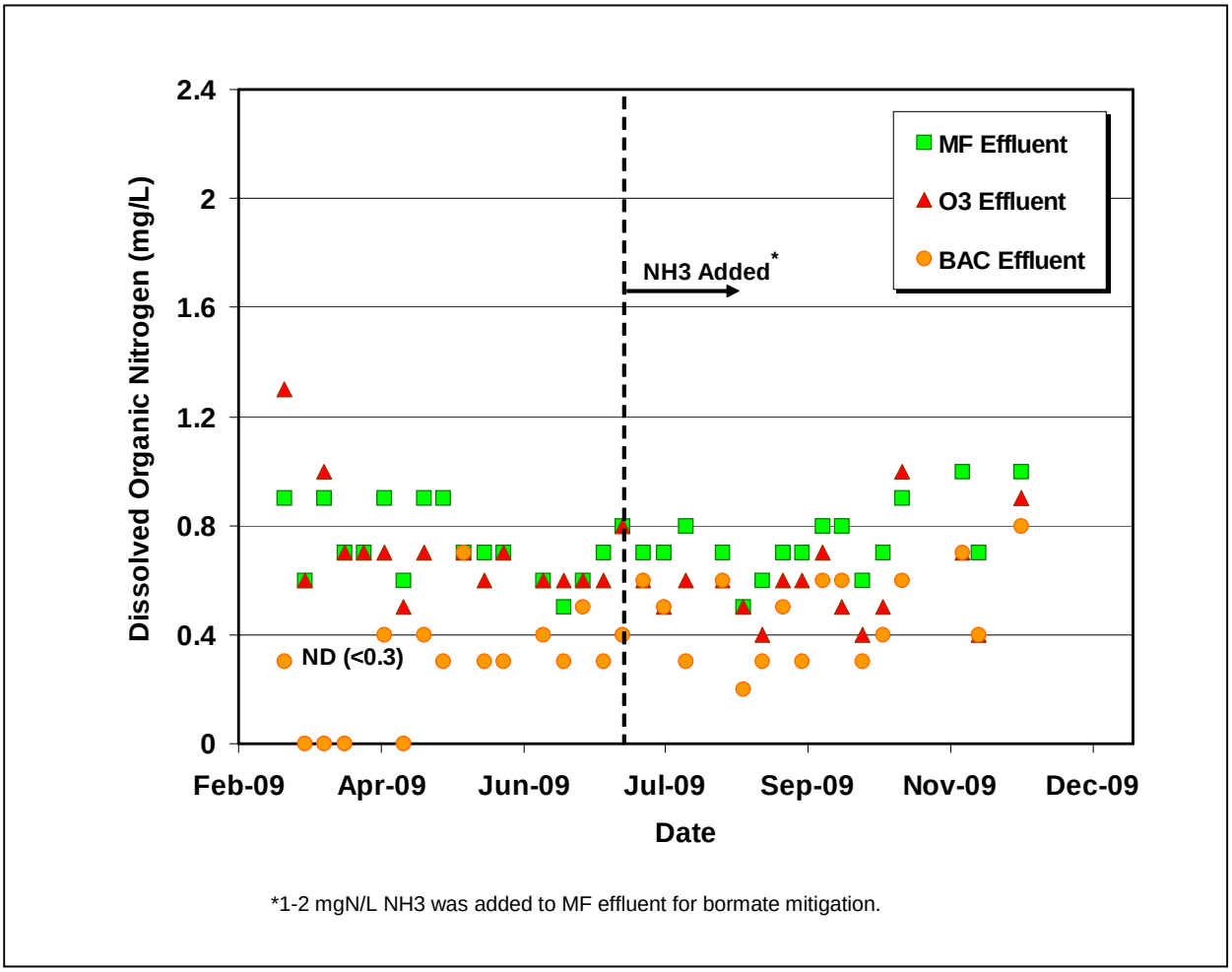



Figure D-13
**MF-O3-BAC Effluent Water Quality Monitoring: Dissolved Organic Nitrogen (DON) over Time**

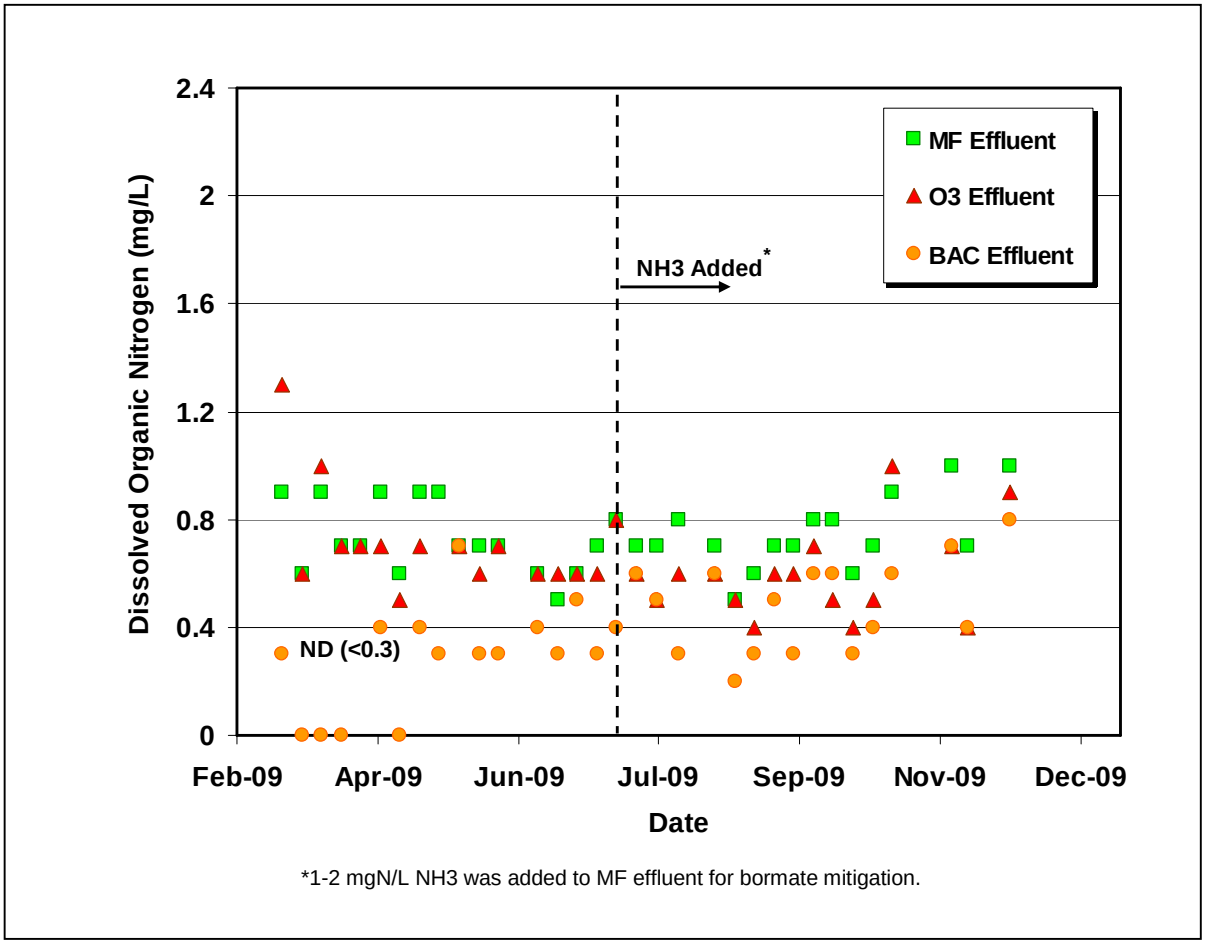



Figure D-14
**MF-O3-BAC Effluent Water Quality Monitoring: Total Organic Nitrogen (TON) over Time**

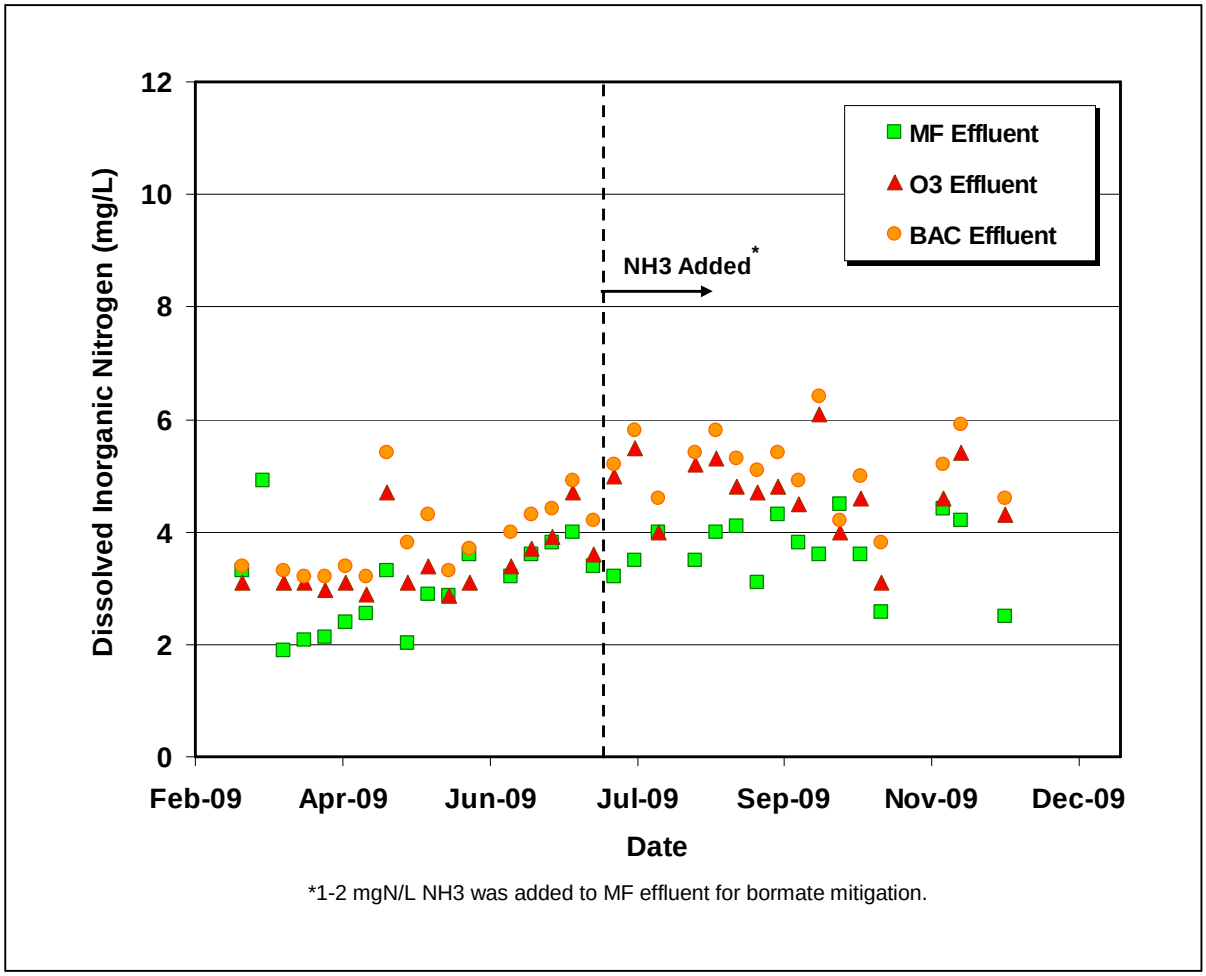



Figure D-15
**MF-O3-BAC Effluent Water Quality Monitoring: Dissolved Inorganic Nitrogen (DIN) over Time**

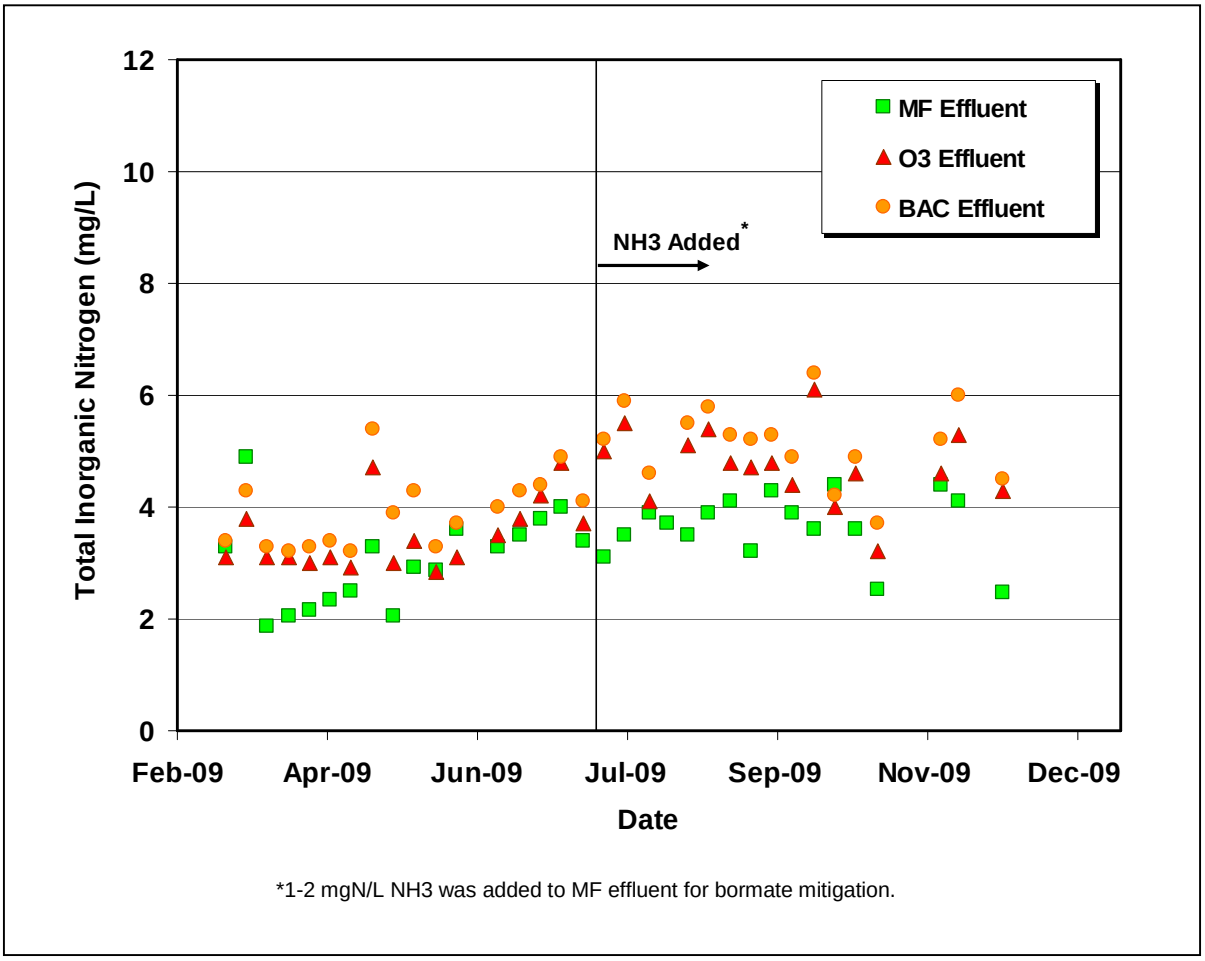



Figure D-16
**MF-O3-BAC Effluent Water Quality Monitoring: Total Inorganic Nitrogen (TIN) over Time**

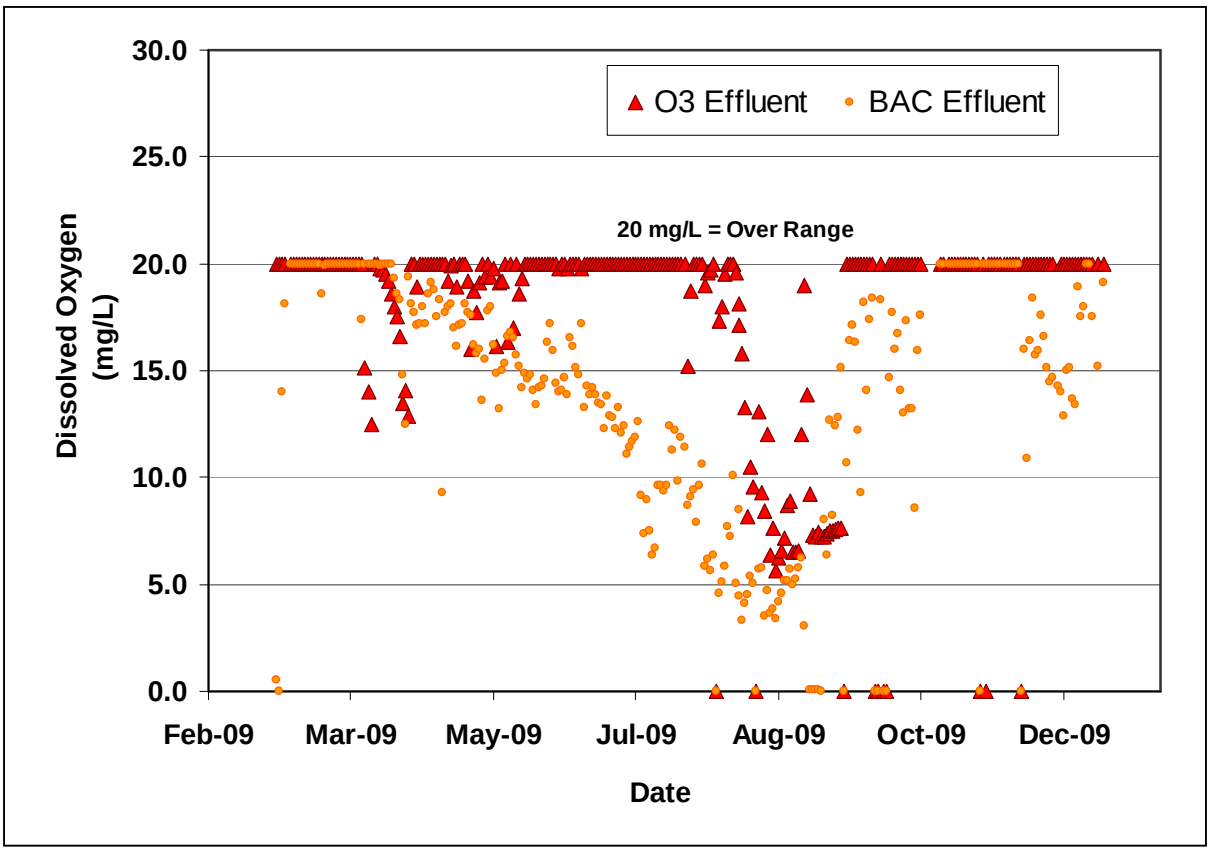



Figure D-17
**O3-BAC Effluent Water Quality Monitoring: Dissolved Oxygen over Time**

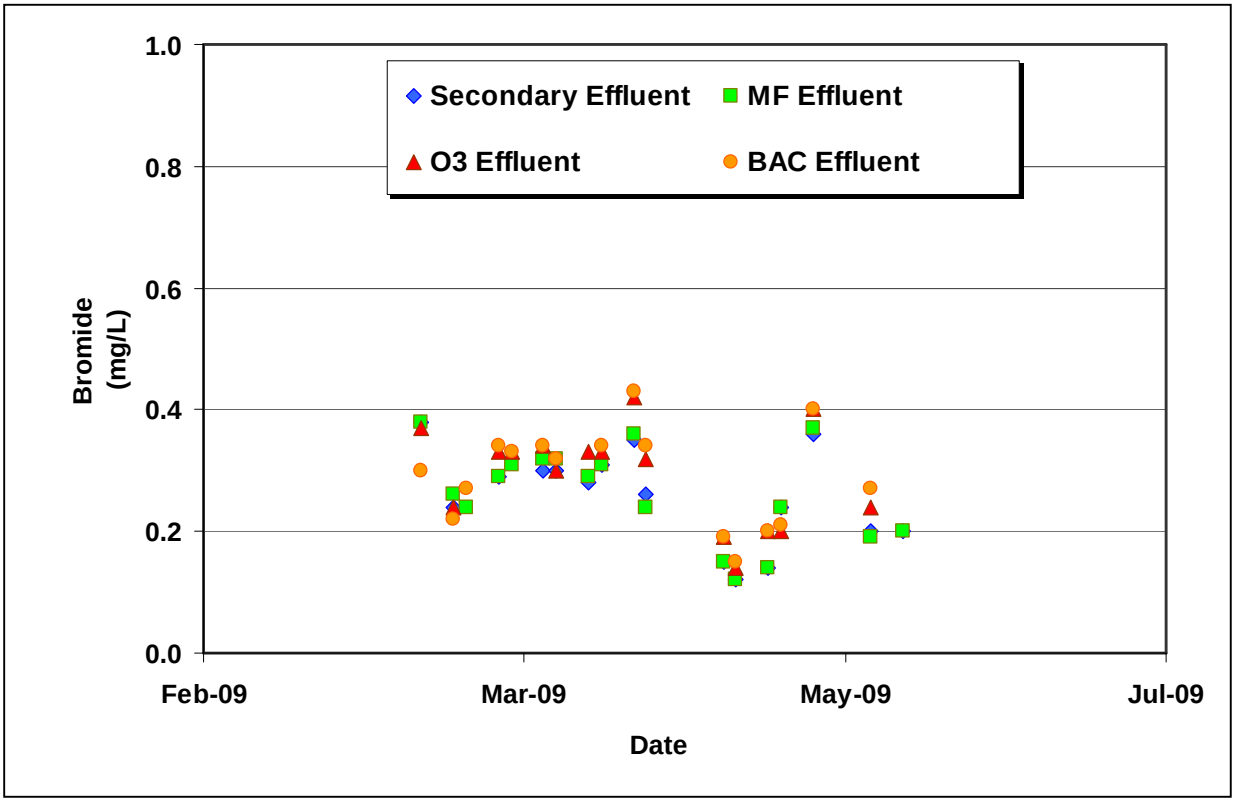



Figure D-18
**MF-O3-BAC Effluent Water Quality Monitoring: Bromide over Time**

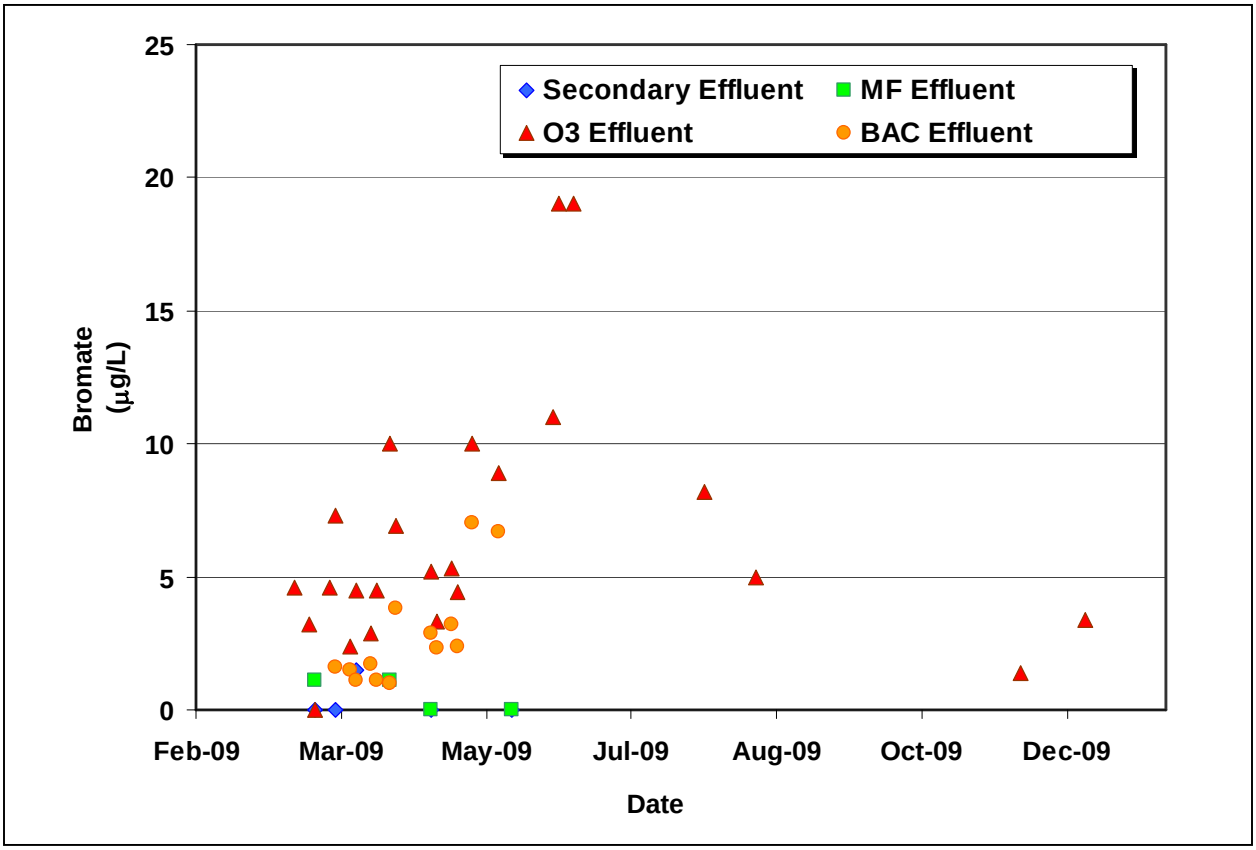



Figure D-19
**MF-O3-BAC Effluent Water Quality Monitoring: Bromate over Time**

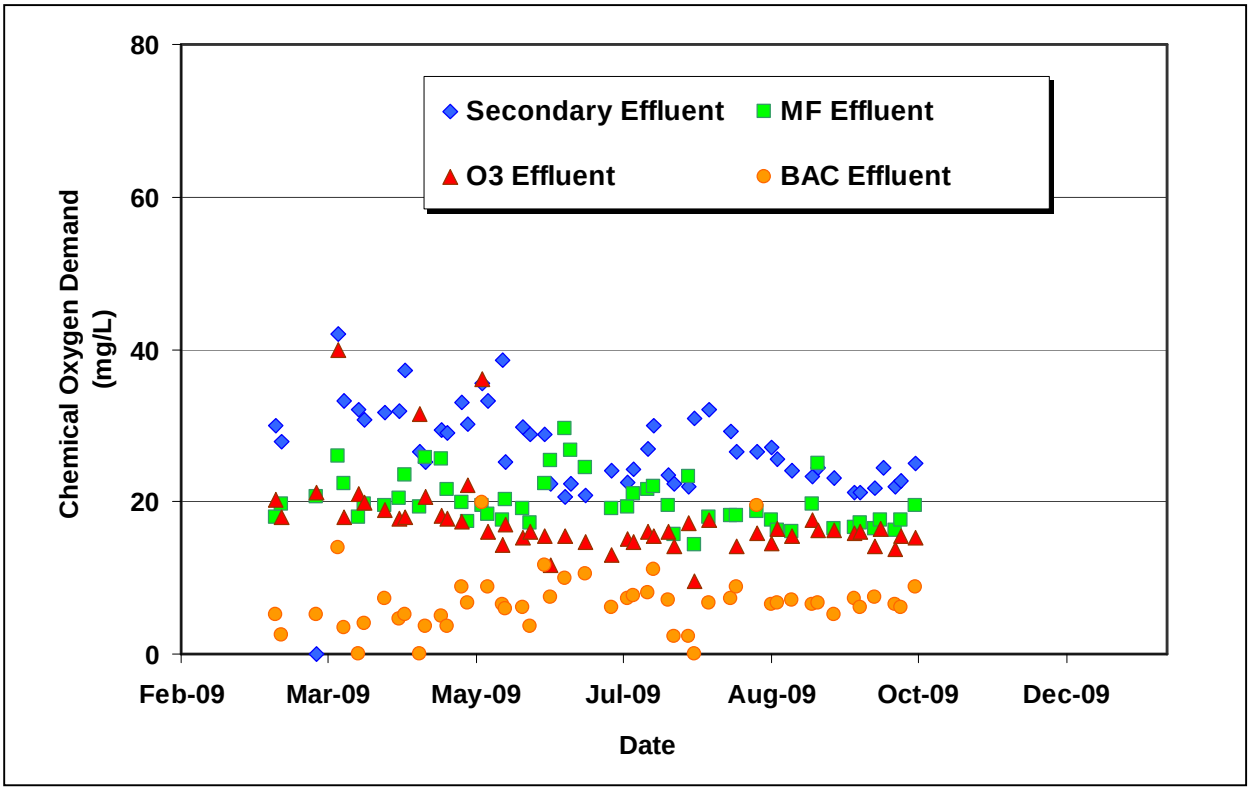



Figure D-20
**MF-O3-BAC Effluent Water Quality Monitoring: COD over Time**

Appendix E

# Energy Utilization Analysis

Appendix E

# Energy Utilization Analysis



## TABLES



## FIGURES



## FOREWORD

This appendix includes a hypothetical energy utilization analysis intended to establish relative energy demands between the five scenarios discussed herein using RO and O3-BAC treatment processes, not quantitative reliable energy demands.

Appendix E

# Energy Utilization Analysis

## E.1 ABSTRACT

Treated municipal wastewater effluents contain numerous constituents threatening public health and aquatic life. Chronic water shortages in areas of the United States necessitate identification of new potable and aquatic habitat water supplies. Treated municipal wastewater has the potential water supply to significantly offset this demand. Prior to implementing an indirect or direct potable reuse project or aquatic habitat restoration project, concerns pertaining to microconstituents (particularly, endocrine disrupting compounds [EDCs] and pharmaceuticals and personal care products [PPCPs]) and salinity must be addressed. Reverse osmosis (RO) treatment is a commonly used technology for removing microconstituents and/or salinity. Current RO application methods require multiple pre- and post- treatment steps. Capital and operation and maintenance (O&M) costs may be prohibitive in many cases. Byproducts of RO based treatment also pose some threat to the environment. Incorporating an Ozone-BAC treatment process train into projects requiring removal of microconstituents and salinity when needed, can lower cost, energy utilization, and environmental impacts. Power usage for Ozone-BAC treatment for removal of microconstituents, with and without partial-stream RO treatment for removal of salinity, are presented and compared to full-stream RO treatment.

## E.2 BACKGROUND

Affordable clean water is essential to the United States' economy. All demographic analyses forecast that our population will continue to increase significantly. Two important elements necessary for continued growth and a high quality of life are adequate reliable sources of freshwater and power which are indelibly linked. About 0.47 gal of freshwater is evaporated per kWh of end use electricity generated by thermoelectric power plants, which supply 89% of our nation-wide power needs (NREL, 2003). Many western states rely heavily on transporting large volumes of water over long distances and/or providing advanced treatment of substandard water to meet municipal water needs. California water and wastewater utilities spend more than $500 million each year on energy alone (California Energy Commission, 2009). Based on numerous forecasting studies on power and water use trends, available freshwater resources will be dwindling at the same time that greenhouse gas emissions and climate change concerns are increasing. Water shortages can be addressed in the immediate future by more efficient management of available freshwater resources, recycling water resources, and producing new freshwater resources from under-utilized sources (seawater or municipal wastewater effluent), where applied. The latter typically is achieved following extensive treatment using reverse osmosis (RO) technology. Problems with widespread use of RO treatment include high costs, high energy usage, and a brine waste stream that requires specialized treatment and/or disposal.

In many inland areas, the major under-utilized water resource is municipal wastewater. Recycling municipal wastewater for indirect potable reuse (IPR) has public perception, and health and safety concerns. Even use of effluent for aquatic habitat restoration must not result in direct adverse effects or gradual buildup of contaminants. To overcome these concerns, virtually all microconstituents or contaminants of emerging concern (CECs) such as endocrine disrupting chemicals (EDCs), pharmaceuticals and personal care products (PPCPs) must be effectively removed from the effluent prior to reuse. Removal of some effluent salinity is also necessary at some point in time to prevent build-up of salinity in the overall freshwater resource environment.

Soil Aquifer Treatment (SAT) can remove microconstituents very cost effectively under some soil and groundwater conditions. However, this does not address the long-term build-up of salinity in the inland water environment. With these limitations on SAT, the general IPR project, heretofore, has utilized RO treatment to remove virtually all contaminants from the process stream, and concentrate those residuals roughly 5-fold in the brine waste stream that leaves the RO process. The finish water leaving the RO process has a very low concentration of salinity and CECs, and has been shown to satisfy general public concerns about reuse of municipal wastewater. However, the cost is high and there are remaining concerns about RO byproducts in the finish water (NDMA [N-nitrosodimethylamine]), and what is to be done with the brine if it cannot be discharged directly to a marine environment.

To address these RO byproduct problems, particularly in inland areas, ECO:LOGIC investigated for the City of Reno an alternative approach consisting of ozonation (O3) followed by biological activated carbon (BAC) treatment of wastewater effluent as a means to destroy CECs, without creating NDMA or a brine waste stream. Currently, the Reno effluent salinity is about 350 mg/L, which is low relative to other alternative supplies. Therefore, the need for salinity reduction as a necessary step in the process is not expected to be required for many years. From the outset, it was recognized that O3-BAC would not initially address the long-term buildup of salinity in the freshwater resource environment, but that the salinity problem could be addressed after many years by employing RO treatment on only that portion of the effluent needed to achieve a desired effluent salinity threshold. This partial use of RO would reduce RO-related costs and byproduct concerns for the City of Reno. The critical objective for IPR of municipal wastewater to occur in the near term is that: virtually 100 percent removal of CECs is necessary from the outset, removal of salinity can often be postponed for years, and even then, only a portion of the effluent salinity may need to be removed.

The Reno investigation, therefore, targeted whether O3-BAC could achieve virtually 100 percent removal of CECs under real-world field conditions. To address this issue, ECO:LOGIC and the City of Reno built a 10.7 gpm continuous flow O3-BAC advanced treatment process and operated it for two years at the Reno-Stead Water Reclamation Facility, which provides secondary treatment of municipal wastewater with a capacity of 2 Mgal/d. The purpose of this article is to present results from that research, and to compare energy utilization of Ozone-BAC-partial RO treatment, and conventional full RO treatment.

# E.3 ENERGY UTILIZATION FOR CEC AND SALT REMOVAL: O3-BAC VERSUS RO

A key factor in the application potential of O3-BAC in lieu of RO is relative power use between the two. Energy utilizations presented herein are based specifically on the Reno-Stead pilot study circumstances, and therefore, may not be applicable to any actual project. There are many project-specific factors involved in determining actual energy usage for a particular project. As with the capital costs assessment, there are three categories of IPR projects under consideration:

- Projects needing virtually complete removal of CECs only.
- Projects needing virtually complete removal of CECs and partial removal of salinity.
- Projects needing virtually complete removal of CECs and salinity.

RO brine can be handled by OD (or equal) or ZLD, depending on the project-specific factors. Annual energy costs per Mgal/d of feed are estimated for these three categories of IPR projects in Figure 1 based on the assumptions presented in Table 2 and summarized below:

1. Influent to the advanced treatment process would be filtered secondary effluent meeting California Recycled Water Criteria as specified in Title 22, Division 4, Chapter 3, Section 60301.320 of the California Code of Regulations.
2. Influent to the RO membrane would receive microfiltration or ultrafiltration pretreatment.
3. As a mitigation measure for NDMA, RO Permeate would be treated by high energy UV (HUV) and hydrogen peroxide (H2O2).
4. As a pathogen control, BAC effluent would be disinfected utilizing low energy UV (LUV).
5. The Zero Liquid Discharge (ZLD) process train would include (in the order of use): concentrate treatment process, brine concentrator, and crystallizer.
6. Energy consumption for periodic RO membrane replacement and BAC carbon replacement are not included.
7. For scenarios consisting of O3-BAC and side-stream RO, the BAC effluent will be split into two streams. Part of the BAC effluent would be further treated by RO for salinity reduction. Final effluent would be a blend between RO permeate and BAC effluent.
8. For scenarios consisting of side-stream RO for salinity reduction, assumed reduction of the secondary effluent is 50 percent, from 1000 mg/L to 500 mg/L.
9. When the side-stream RO is installed downstream of Ozone-BAC treatment, the power requirement of RO will decrease by 15% and concentrate management will be decrease by 10% because of the higher quality of RO feed water in these scenarios.

Table E-1
**Summary of Criteria for Comparative Analysis**

| Parameter | Unit | Value |
|---|---|---|
| Flow | Mgal/d | 1 |
| Power Cost | $/kWh | 0.14 |
| RO Recovery | % | 85 |
| RO TDS Removal Efficiency | % | 95 |
| Concentrate Treatment Recovery | % | 85 |
| Brine Concentrator | % | 95 |
| Ozone Dose | mg/L | 5 |
| BAC Empty Bed Contact Time | min | 30 |

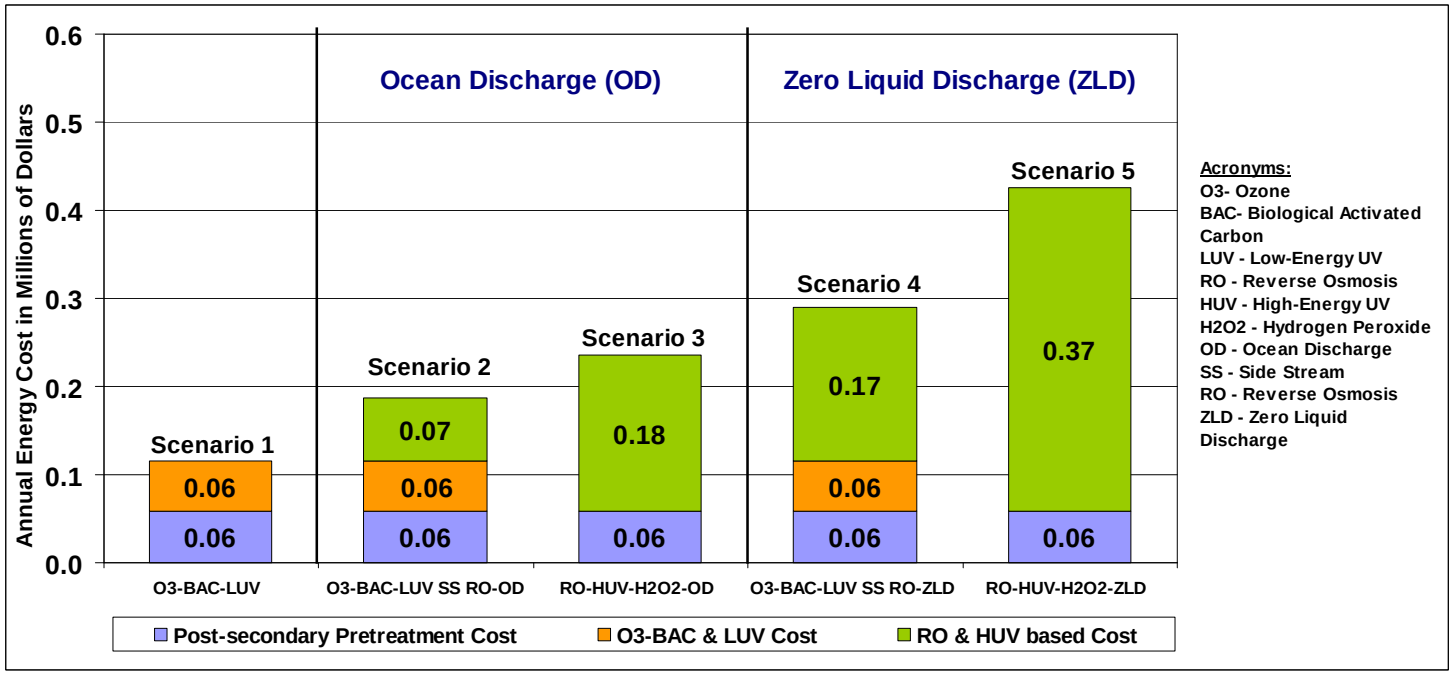



Figure E-1
**Annual Energy Cost Per MGD (Unit Power Cost = $0.14/kWh)**

## E.4 SUMMARY AND CONCLUSIONS

For IPR projects needing only CEC removal, Scenarios 1 through 5 would all be adequate. Scenario 1 has lowest energy requirements. For IPR projects needing CEC removal and a 50 percent reduction in effluent salinity with ocean discharge of brine being possible, Scenario 2 has lower energy requirements than Scenario 3. For this same IPR project but with ZLD brine disposal, Scenario 4 has lower energy requirements than Scenario 5. When complete CEC and salinity removal are required, conventional RO treatment (Scenario 3 and 5) appears to be appropriate. Even with this extreme form of IPR, O3-BAC may have a place in treating the brine stream under OD brine disposal if concentrated CECs in this waste are of concern (Benner, 2008).

For cases in which secondary effluent salinity is below 500 mg/L, the goal of most IPR projects is CEC removal, not salt reduction. Utilities can achieve significant energy savings by implementing the O3-BAC process in these IPR situations.

For IPR projects where significant but not complete salt removal is necessary in addition to CEC removal, O3-BAC followed by side-stream RO reduces power consumption, and waste stream production, when compared to full-stream RO.

## E.5 REFERENCES

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Appendix F

# RSWRF Pilot Testing Conference Proceedings

Appendix F

# RSWRF Pilot Testing Conference Proceedings



## FOREWORD

This appendix includes two of the conference proceedings that resulted from this pilot project. These specific papers are included in the report because:

- The first paper is an easy to read abbreviated form of this entire report.
- The second paper deals with an important peripheral issue to this report: energy necessary to perform the described treatment.

# Field Evaluation of MF-Ozone-BAC Process Train for the Removal of Microconstituents from Wastewater Effluent

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*Stanley E. Shumaker, P.E., City of Reno Public Works Department, Reno, NV*
**Corresponding Author: emerick@ecologic-eng.com*

## Abstract

Removing microconstituents from wastewater for subsequent reuse is gaining in importance. Water quality concerns include potential human and aquatic life impacts resulting from exposure to Endocrine Disrupting Chemicals (EDCs), Pharmaceuticals, Personal Care Products (PPCPs), and other wastewater-derived organics, and long-term salinity built-up. At present, microconstituents are most typically removed by advanced treatment facilities utilizing Membrane Filtration (MF), Reverse Osmosis (RO), and an oxidation step consisting of high-energy ultraviolet radiation (UV) coupled with hydrogen peroxide (Peroxide). The MF-RO-UV-Peroxide process is expensive, energy intensive, potentially increases effluent corrosivity, and generates a relatively large reject stream containing concentrated salts and microconstituents that require further treatment and/or disposal. An alternative multi-barrier treatment train to reduce overall costs and energy usage was developed and pilot tested on secondary effluent at the Reno-Stead Water Reclamation Facility (RSWRF). The pilot process train consists of (in the order of use): Membrane Filtration (MF), Ozone, and Biological Activated Carbon (BAC) treatment. MF-Ozone-BAC treatment consumes less power, is more sustainable, does not generate a reject stream, and does not increase effluent corrosivity.

This comprehensive study presents the wastewater community and water resource community with in-depth knowledge about an advanced process train which: 1) does not generate a reject stream; 2) does not cause disturbance to the ionic stability of the effluent; 3) reduces post-treatment biofilm growth potential; and 4) is sustainable, consumes less energy, and requires lesser O&M effort than other alternatives.

## Introduction

The City of Reno (City) is expanding the wastewater treatment and disposal capacity of its Reno-Stead Water Reclamation Facility (RSWRF) to serve continuing community growth. Because water resources in the Reno area are limited, reuse of treated wastewater is an important part of City planning. Two effluent storage options are 1) storage in conventional open-topped reservoirs and 2) storage in a local aquifer (i.e. subsurface storage in the natural groundwater reservoir). Of the two, subsurface storage is believed to be superior because 1) effluent water quality in open-topped reservoirs deteriorates because of algae growth and wildlife use, 2) water is lost from open-topped reservoirs by evaporation thereby increasing effluent salinity, and 3) costs associated with open-topped reservoirs are dependent on land topography and availability. This pilot testing was conducted to demonstrate that an advanced multi-barrier wastewater treatment system can reliably produce an effluent suitable for subsurface storage from an environmental and public health protection perspective, and still be affordable.

At present, advanced Water Reclamation Facilities (WRFs) are either utilizing 1) Membrane Filtration (MF) followed by Reverse Osmosis (RO) and an oxidation step consisting of high-energy ultraviolet radiation (UV) and hydrogen peroxide (Peroxide), or 2) Ozonation coupled with Biological Activated Carbon (Ozone-BAC) (Asano, 2006; Sheng, 2005). MF-RO-UV-Peroxide treatment train has high-energy demands and produces a waste stream of concentrated contaminants needing additional treatment and/or disposal.

***Best Apparent Process Alternative***

MF-Ozone-BAC was selected over MF-RO-UV-Peroxide for the RSWRF application because 1) MF-Ozone-BAC has expected lower cost and power consumption, 2) MF-Ozone-BAC does not produce a waste stream needing specialized treatment and/or disposal, and 3) a reduction in effluent salinity prior to subsurface storage is neither necessary nor desired in the RSWRF situation. A side-by-side comparison of these two advanced treatment process trains is provided in Table 1 with highlights being discussed below:

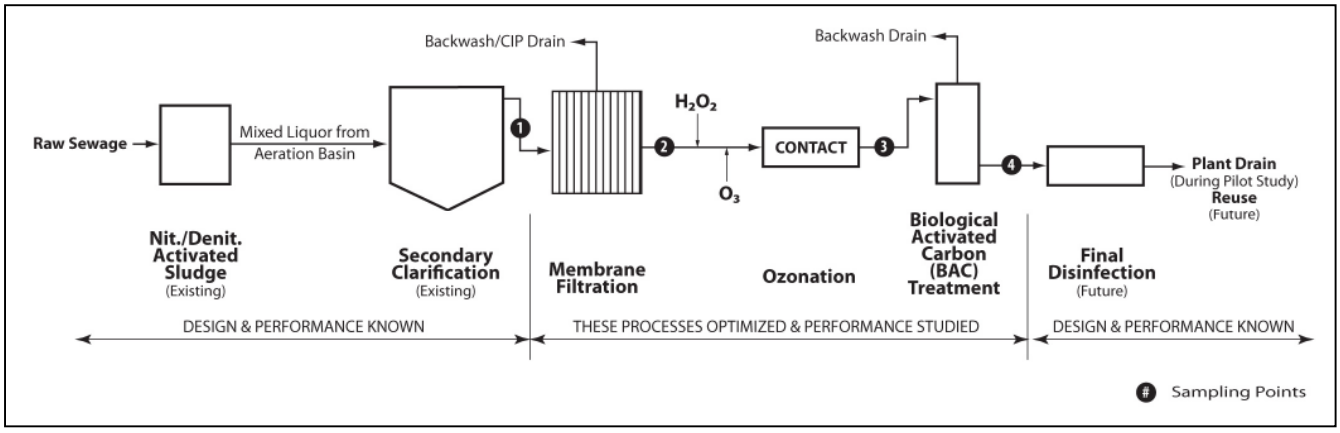
- *Microconstituents Removal*: In both the ozonation and BAC processes, microconstituents are effectively destroyed rather than concentrated in a reject stream (as with RO) or transferred to another substrate (as with Granular Activated Carbon [GAC] treatment) requiring further treatment and/or disposal.
- *Energy and Sustainability:* MF-Ozone-BAC is a more sustainable process than MF-RO-UV-peroxide because MF-Ozone-BAC requires less energy, fewer replacement parts, and minimal maintenance. In addition to the energy required to operate RO, the energy required by high-energy UV lamps for hydroxyl radical generation is seven to eight times greater than the energy consumed by conventional UV lamps commonly used for wastewater disinfection.
- *Reject/Side Streams:* The RO component of a MF-RO-UV-Peroxide advanced treatment train produces a reject stream (often roughly 20% of the effluent volume) needing complex disposal strategies in inland facilities such as RSWRF where ocean disposal is not possible.
- *Salinity:* The main water quality difference between MF-RO-UV-Peroxide and MF-Ozone-BAC is that MF-RO-UV-Peroxide treatment removes salts and organics present in the effluent, whereas MF-Ozone-BAC treatment mainly removes organics. The salt concentration of RSWRF effluent is below 500 mg/L, therefore salt reduction does not appear to be needed at this time, which makes the costly RO step unnecessary. Ultimately, a salinity control or reduction element will have to be added to the City's overall water resource plan to control salt built-up in the groundwater resource over time.
- *Corrosivity:* In cases such as RSWRF where effluent salt concentrations are already low, a further reduction in effluent salinity by use of the MF-RO-UV-Peroxide process increases the corrosivity of the treated effluent. Increasing the corrosivity of effluent injected into groundwater increases the probability that naturally occurring metals in subsurface soils, such as arsenic in the Reno area, will leach into the injected effluent and groundwater resource.

**Table 1: Side-by-Side Comparison of Advanced Treatment Process Trains**

| Category | MF-Ozone-BAC | MF-RO-UV-Peroxide |
|---|---|---|
| Microconstituents | Degraded | Concentrated (in a side stream) |
| Energy | Substantially less usage | |
| Sustainability | Lower materials and labor needs | |
| Reject/Side Streams | Minor (periodic backwash water) | Major (± 20% of flow) |
| Salinity | Unchanged | Decreased Substantially |
| Corrosivity | Unchanged | Increased |

The effectiveness of MF-Ozone-BAC at removing microconstituents from secondary effluent under field conditions with continuous flow from an operating wastewater treatment plant was investigated. This level of investigation has not been undertaken in previous studies. The secondary effluent to be studied is from the existing RSWRF nitrification/denitrification activated sludge process operated at a mean cell residence time (MCRT) of approximately 25 days. Effluents from shorter MCRT process are expected to have different microconstituent characteristics (Clara, 2005). A few of the critical MF-Ozone-BAC process design variables studied include: (1) the optimum ozone dosage to remove selected wastewater indicator microconstituents, (2) an effective strategy for bromate mitigation; and (3) the sustainability of a GAC column functioning as a BAC biofilter when receiving membrane-filtered and ozonated effluent without any supplemental carbon source or microorganisms. The overall treatment process schematic for RSWRF with inclusion of the MF-Ozone-BAC train is shown in Figure 1.

**Figure 1: RSWRF Pilot Process Schematic**




## Project Description

The first component of the MF-Ozone-BAC pilot is the MF step to remove turbidity, total suspended solids (and associated heavy metals and contaminants), and pathogens such as Giardia Lamblia and Cryptosporidium that are commonly present in the secondary effluent. The second component, ozonation, with or without peroxide, 1) reduces microconstituent concentrations and estrogenic activity, 2) provides some disinfection (Zhou, 2002); 3) reduces Trihalomethane

Formation Potential (Zhou, 2002); 4) increases the dissolved oxygen concentration of the effluent; and 5) eliminates colorants and odor causing compounds present in the effluent. However, the performance of ozonation in removing microconstituents is heavily influenced by the quality of the effluent being treated, and the addition of peroxide. The effect of various ozone dosages in removing Selected Organic Wastewater Indicator microconstituents, and effect of peroxide in minimizing bromate formation were studied.

It has been reported that ozonation will increase the Biodegradable Dissolved Organic Carbon (BDOC) concentration, and therefore biologically mediated well clogging (Juhna, 2006; Page, 2006). BAC (the third component of the pilot) has been demonstrated to reduce BDOC present in ozonated effluent (Juhna, 2006). However, the benefits of integrating BAC into an advanced wastewater treatment process train for microconstituent removal has not been reported in the literature. Because, Filtrasorb F-400 (Calgon Carbon) GAC medium has been used successfully in numerous BAC water and wastewater treatment investigations (Levine, 2000; Nishijima, 2004), this medium was selected for use in this project.

## Methods

The MF-Ozone-BAC pilot treatment train system was operated on a continuous basis from September 2008, with performance data being available for this paper through May 2009. The effluent flow rate through the train was 10.7 gal/min. The effluent source was undisinfected secondary effluent from the RSWRF. After passing through membrane filtration, the RSWRF effluent was stored in a 10,300 gallon "day tank" to assure 1) operation of ozonation and BAC units was not interrupted during the periodic cleaning of membrane, and 2) influent to the ozone unit was independent of any temporary, atypical, upset of the RSWRF process.

### *Membrane Filtration*

WesTech supplied a packaged membrane filtration skid. The membrane filters were pressure-driven hollow fibers of Polysulfone utilizing an outside-in flow configuration manufactured by Polymem. The nominal pore size of the membrane was 0.01 μm. The maximum pressure differential across the membrane filters was 30 psi. Membrane periodic maintenance steps included backwash with or without hypochlorite, Clean-in-Place (CIP) cleaning using caustic and hypochlorite, and membrane integrity testing.

### *Ozonation*

Applied Process Technology supplied a skid-mounted ozonation unit based on their HiPOx$^{TM}$ technology. The skid included a liquid oxygen-fed, solid-state, ozone generator capable of producing 4 lb/day of ozone at 10 percent concentration. The ozonation skid was operated in a direct gas injection mode both with and without peroxide addition, under a system pressure of 15 psi.

### *Biological Activated Carbon (BAC)*

WesTech manufactured the skid-mounted BAC unit, specifically for this project. The unit included a stainless steel, vertical pressure vessel designed to operate in the downflow mode. The 3.5 ft diameter vessel contained 1250 lbs of Filtrasorb F-400 (Calgon Carbon), resulting in a carbon media bed depth of about 4.5 ft. Headspace was more than 50% of the bed depth to allow for bed expansion during backwash without losing media. The BAC unit also had provisions for

obtaining carbon media samples at various depths from the media bed. Previous studies on BAC have found that the performance of BAC is heavily dependent on the Empty Bed Contact Time (EBCT) (Juhna, 2006; Page, 2006). EBCTs ranging from 20 to 30 minutes have been utilized for full-scale BAC treatment processes (Asano, 2006; Page, 2006). An EBCT of 30 minutes was selected for this pilot study to provide reliability and mitigate temperature effects on bacterial activity in this biofilter. RSWRF effluent temperature can be as low as 46 ºF in winter. The BAC biofilter was backwashed every two weeks to remove the build-up of particles and decaying microorganisms.

The GAC column was converted to a BAC biofilter without any supplemental carbon source or microorganisms over a two-month period by continuous application of membrane-filtered and ozonated secondary effluent. During the conversion process, the optimized ozone and peroxide dosages were maintained and the biological activity of the carbon column was monitored regularly by measuring Phospholipid Fatty Acids (PLFAs). The result was a pilot-scale BAC biofilter with biomass amounts varying with depth in the media bed, as occurs in full-scale BAC units (Juhna, 2006).

***Process Monitoring***

- *Selected Organic Indicator Microconstituents:* Microconstituents monitored during the ozone optimization phase of this study included compounds with characteristic of the microconstituents listed in California draft groundwater recharge regulations (CDPH, 2008). Microconstituents are quantified using EPA Method 1694 for PPCPs, USGS Method 4 for wastewater indicators, and a lab-specific method developed by AXYS Analytical Services for alkyl phenols. The majority of microconstituents monitored in this study are typically found in municipal wastewater treatment plant effluent (Lietz, 2004).
- *Estrogenic Activity (E-Screen):* The E-screen test is an in vitro bioassay used to determine the relative estrogenic activity (Estradiol Equivalents; EEQ) of a sample. E-screen uses a breast cancer cell line (MCF-7) that responds to estrogens by proliferating. In this assay, a sample of effluent is applied to a plate of breast cancer cells, and after five days, the increase in the numbers of cells is determined. Tests are run concurrently with standard water samples of known estrogen concentrations. Cell proliferation in the effluent is compared to the cell proliferation in the standard samples. The result of the comparison is reported as the effluent EEQ in ng/L.
- *Phospholipid Fatty Acids (PLFAs):* PLFAs occur in viable cell membranes and provide a quantitative tool for assessing microbial populations, and their responses to their environment (Page, 2006). PLFA analyses conducted by Microbial Insights provided broad-based information about the entire microbial community in the BAC biofilter: viable biomass concentrations, community composition, and metabolic status.
- *Ozonation Byproducts:* Bromide and bromate were monitored since they are critical constituents that play a vital role in the design and operation of an ozonation process. Bromate and bromide were quantified using Methods 317, and 300.1, respectively. Organic ozonation byproducts are quantified using EPA Method 556.
- *Organic Carbon Fractions:* Total Organic Carbon (TOC) is an overall indicator of organics present in the effluent, which are removed by several processes in the pilot's multi-barrier process train. Dissolved Organic Carbon (DOC) was analyzed to provide insight on the dissolved organics fraction that passes through the membranes. TOC and DOC were

quantified using EPA Method 5310C. The MWH Laboratories conducted BDOC analyses in order to evaluate the effectiveness of BAC.

- *Gaseous and Dissolved Ozone:* Gaseous and dissolved ozone were monitored using online ozone monitors (Teledyne API Models 460H and 460M). Dissolved ozone residuals at various sampling ports were measured using an online ozone analyzer (HACH Ultra Analytics) and a sample sequencer (Sentry Equipment). Ambient atmospheric ozone concentrations were monitored in the pilot testing area to ensure ozone concentrations were below OSHA standards.

## Results and Discussion

The MF-Ozone-BAC pilot testing at RSWRF consisted of several critical steps including ozone dosage optimization, bromate mitigation, and conversion of GAC to BAC as discussed below.

***Ozone Dosage Optimization***

Ozone dosage is a critical process parameter that was optimized during the initial stage of the pilot study by testing the effect of three transferred ozone dosages (3, 5, and 7 mg/L) on membrane-filtered effluent. Reactions of ozone and instantaneous demand for ozone-based oxidants in the wastewater are dependent on various site-specific parameters such as TOC, suspended solids, alkalinity, nitrite, and temperature. In the case of RSWRF, influent to the ozonation using from the MF unit had an average TOC of 6.4 mg/L; and an alkalinity of 92 mg/L. Nitrite concentrations remained negligible (< 60 μg/L) throughout the study. Effluent temperature varied from 62 to 64 °F. The effect of ozonation on effluent quality was measured at specific locations in the ozone contact pipe at which the measured ozone residual was negligible (< 50 μg/L), thus ensuring complete utilization of ozone-based oxidants. Estimated contact times at which ozone residuals were negligible were 3.6, 7.7, and 13.5 minutes for 3, 5, and 7 mg/L transferred ozone dosages, respectively.

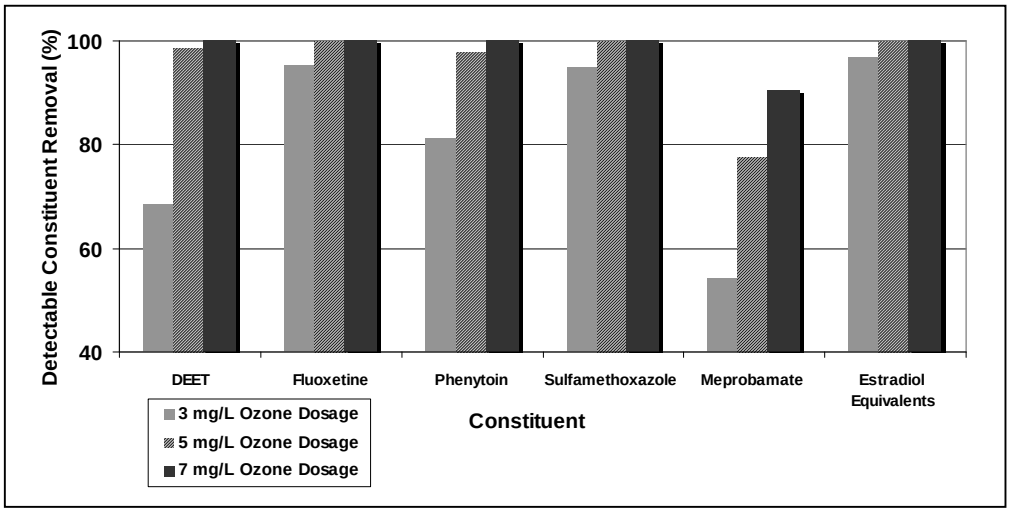
Microconstituent occurrences and removals obtained from the ozone optimization study are presented in Table 3. About one-third of the microconstituents were not detected consistently in the MF unit effluent. This could be a result of the long MCRT (±25 days) that was maintained at RSWRF and/or of removal of these microconstituents by MF. Another third of the indicator microconstituents were removed to a level below the detection limits by an ozone dose of 3 mg/L or more. These compounds have high reactivities with ozone-based oxidants (Snyder, 2007). Microconstituents with Quality Control (QC) parameters outside acceptable limits of the analytical methods used were grouped under “Inconsistent Results”. The presence of several microconstituents in the “Inconsistent Results” grouping emphasizes the importance of including field blanks, field duplicates, and other lab QC steps during sampling and analysis. Figure 2 shows removal of some microconstituents, and EEQs as a function of ozone dosage. EEQs were below detection limits when the ozone dosage was more than 3 mg/L. Meprobamate was found to be the most recalcitrant microconstituent to oxidation by ozone.

## Table 3: Microconstituents Results[1]

| Removal by Ozone at 3 mg/L Dose or More | | | | |
|---|---|---|---|---|
| **99% or More Removal** | **99% – 50% Removal (See Figure 2)** | | **Occurrence: Non-Detects[2]** | **Inconsistent Results: Failed QC** |
| Oxybenzone (2 ng/L) | DEET (5 ng/L) | | Acetaminophen (10 ng/L) | Phenol (50 ng/L) |
| Estrone (1 ng/L) | Fluoxetine (1 ng/L) | | Ibuprofen (10 ng/L) | TDCPP (50 ng/L) |
| Carbamazepine (1 ng/L) | Phenytoin (5 ng/L) | | Caffeine (50 ng/L) | TCEP (50 ng/L) |
| Diclofenac (2 ng/L) | Meprobamate (5 ng/L) | | Estradiol (2 ng/L) | Bisphenol A (10 ng/L) |
| Gemfibrozil (1 ng/L) | Estradiol Equivalents (0.027 ng/L) | | Diethylstilbestrol (2 ng/L) | Salicylic Acid (10 ng/L) |
| Hydrocodone (1 ng/L) | Sulfamethoxazole (1 ng/L) | | Ethinyl Estradiol (2 ng/L) | Triphenylphosphate (25 ng/L) |
| Methadone (5 ng/L) | | | Iopromide (100 ng/L) | Atrazine (1 ng/L) |
| Naproxen (1 ng/L) | | | Pentoxifyline (1 ng/L) | Diazepam (1 ng/L) |
| Trimethoprim (5 ng/L) | | | Progesterone (10 ng/L) | 4-Methylphenol (25 ng/L) |
| Octylphenol (1.1 ng/L) | | | Testosterone (10 ng/L) | |
| 4-Nonylphenol diethoxylates (14.5 ng/L) | | | Estriol (1 ng/L) | |
| 4- Nonylphenol monoethoxylates (5 ng/L) | | | alpha-Estradiol (1 ng/L) | |
| | | | Androstendione (10 ng/L) | |

[1]*Detection limits shown in parentheses.*
[2]*Microconstituents not detected in influent to the ozonation unit from the MF unit.*

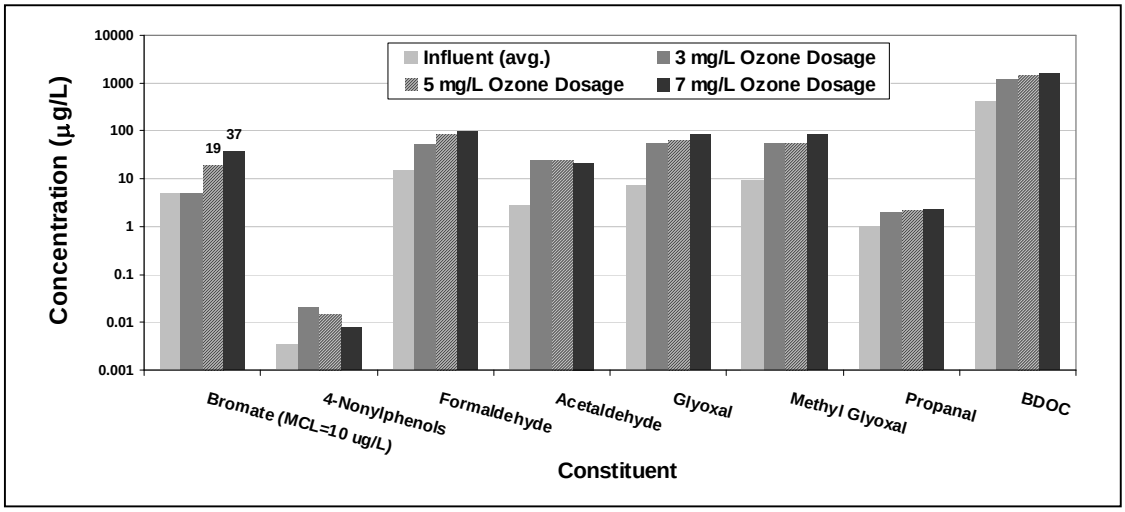
**Figure 2: Microconstituent Removals by Ozone as a Function of Ozone Dose**




***Ozonation Byproduct Formation***

Formation of byproducts is a critical concern with effluent ozonation process. Ozonation byproduct concentrations monitored during the ozone optimization study are shown in Figure 3. Bromate is a byproduct of special concern because it has a drinking water Maximum Contaminant Level (MCL) of 10 μg/L, which may be lowered to 5 μg/L. Ozone dosage, presence of ammonia, and background bromide levels are major determinants of bromate formation. Influent bromate concentrations and 3 mg/L ozone dosed effluent bromate concentrations were below the detection limit (<5 μg/L). Effluent bromate concentrations were 19 μg/L for 5 mg/L ozone doses, and 37 μg/L for 7 mg/L ozone doses. Figure 3 also shows ozone forming 4-Nonylphenols (4-NP), various aldehydes, and other short chain organic compounds as a result of oxidation of more complex organic compounds. With 4-NP, increasing the ozone dose from 3 mg/L to 5 mg/L and 7 mg/L resulted a decreases in 4-NP concentrations as a result of further oxidation of this ozonation byproduct at higher ozone doses. BDOC was also monitored as an indicator of whether refractory organics were being oxidized by ozone to more biodegradable compounds. Figure 3 confirms the observations presented elsewhere that BDOC increases with increases in ozone dosage.

**Figure 3: Ozonation Byproduct Formation**




***Bromate Mitigation***

The literature reports several strategies for minimizing bromate formation during ozonation. The strategies include: 1) pH depression to as low as 6.8, 2) addition of ammonia, 3) addition of peroxide, and 4) addition of alkalinity (EPA, 1999; Rakness, 2005). Since the average pH of RSWRF effluent was 6.9, further depression of pH would not be considered materially beneficial. Adding ammonia and alkalinity would negatively impact effluent quality by increasing total nitrogen, and dissolved solids concentrations. Therefore, addition of ammonia and alkalinity were not suitable bromate mitigation measures. Adding peroxide with ozone generates more potent hydroxyl radicals, reduces the required contact time, and does not negatively impact water quality as it decomposes to oxygen and water. Peroxide addition was the implemented ozone mitigation measure.

Previous studies have indicated that the addition of peroxide can minimize bromate formation by several pathways such as peroxide competing with bromide for molecular ozone, and/or generating hydroxyl radicals that convert bromine to bromide (Amy, 1998). Results from previous investigations also showed mixed performance from peroxide depending on pH (Amy, 1998). Therefore, the effect of peroxide on bromate mitigation was investigated comprehensively in this study. The ozone-peroxide system design parameters tested during the study are summarized in Table 4.

**Table 4: Bromate Mitigation Study[1]**

| Factors | Range of Studied Design Variables | | | | | |
|---|---|---|---|---|---|---|
| $O_3$ Dose (mg/L) | 3 | 5 | 7 | | | |
| $H_2O_2$-$O_3$ Molar Ratio | 0 | 0.25 | 0.5 | 0.7 | 1 | 1.5 |
| $O_3$ Injection Points | 1 | 3 | | | | |
| Injection sequence | $H_2O_2$ First | $H_2O_2$ Last | | | | |

*1 – Shaded cells indicate levels that have been selected for further analysis.*

Some results from the bromate mitigation study are shown in Figures 4, 5, and 6. Any addition of peroxide reduced bromate formation at all ozone dosages as shown in Figure 4 (results obtained from 3 mg/L and 7 mg/L ozone dosages are not shown for clarity). The extent of bromate formation was found to be mainly a function of ozone dose and peroxide concentration. In the case of 7 mg/L ozone dosage, the concentration of bromate was close to 10 µg/L even after adding peroxide at the maximum 1.5 molar ratio investigated in this study. Previous studies have shown that peroxide molar ratios higher than 2 can diminish the oxidation efficiency (Beltran, 2004). Adding the specified ozone by means of multiple injection points reduced bromate further; however, the incremental benefits were minimal (see Figure 5). Results also showed that bromate formation was not dependent on the injection sequence of peroxide and ozone injection (see Figure 6).

**Figure 4: Effect of Peroxide Dose -5 mg/L Ozone; 1.1 mg/L Ammonia;**

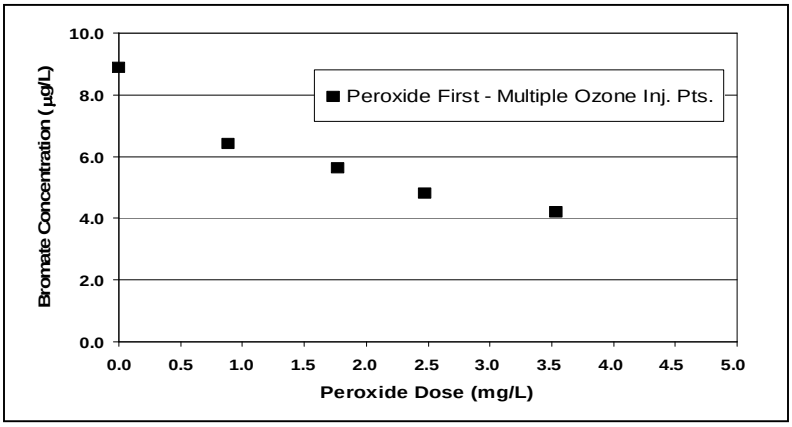


**Figure 5: Effect of Ozone Injection Strategy - 5 mg/L Ozone, 1.1 mg/L Ammonia**

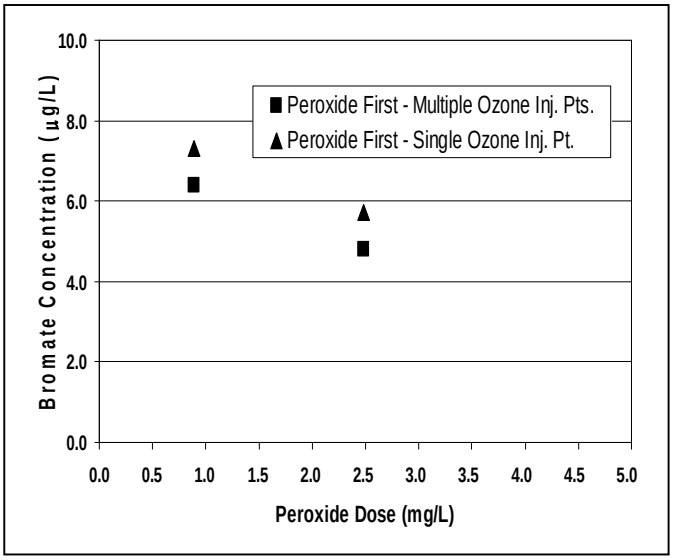
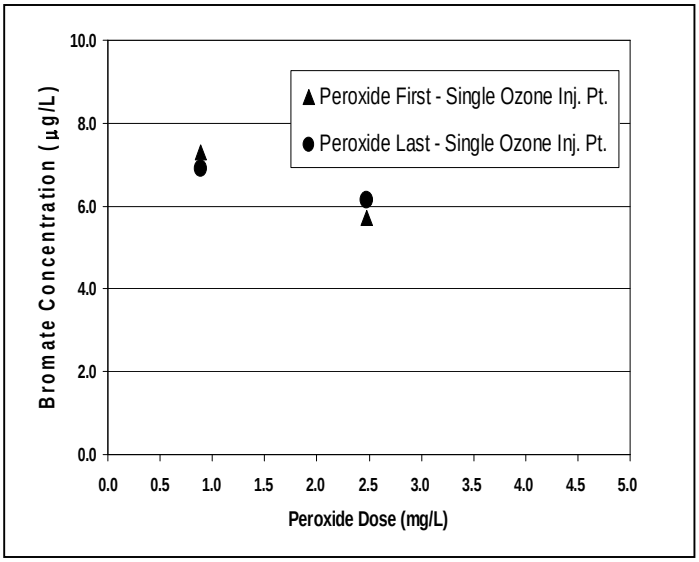


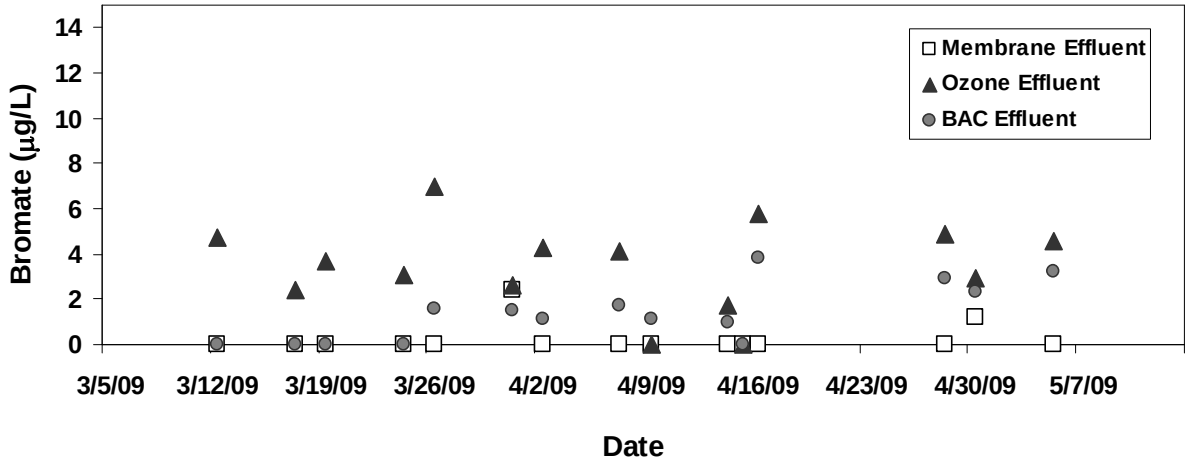

**Figure 6: Effect of Ozone Peroxide Injection Sequence - 5 mg/L Ozone; 1.1 mg/L Ammonia**




Based on the results obtained from ozone optimization and bromate mitigation studies, an ozone dosage of 5 mg/L injected at one location, with peroxide added at 1 molar ratio prior to ozonation was selected for further analysis, and steady state testing and sampling. An ozone dose of 7 mg/L was not selected due to the higher peroxide concentration requirement to mitigate bromate. Additionally, the higher peroxide requirement could reduce the oxidation efficiency, or require a more complex ozone reactor configuration. A single point ozone injection design was selected for analysis because the benefits of a multiple ozone injection strategy were minimal for this specific effluent.

Effluent bromate concentrations after implementing the bromate mitigation strategy are shown in Figure 7. Results from composite sample monitoring of ozonation unit influent and effluent bromate concentrations indicate successful control of bromate formation during this study. It is significant to note from Figure 7 that effluent bromate concentrations appear to be reduced further by BAC treatment. This phenomenon will be investigated further in this study.

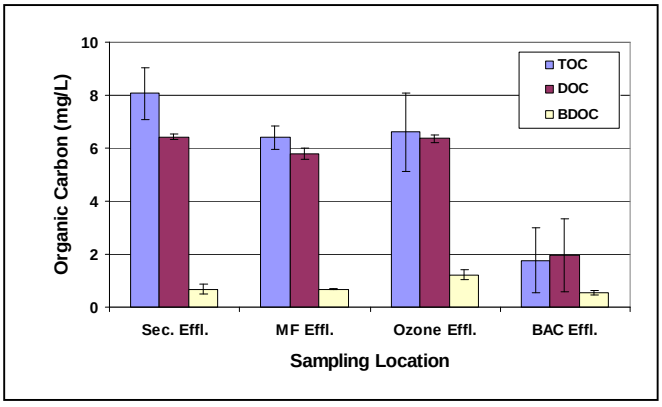
**Figure 7: Effluent Bromate Concentrations Under Steady-State Pilot Operation**




***BAC Unit Process Development***

Steady state operation of the pilot process provided the time necessary for development of microbial colonies converting GAC biofilter media into a BAC biofilter. The GAC was "conditioned" into a BAC biofilter process by passing membrane-filtered and ozonated effluent produced by the pilot process through the bed of GAC on a continuous basis for two months at a flow rate of 10.7 gpm. During the conditioning period, the optimized ozone and peroxide dosages were maintained; and the BAC unit was backwashed every two weeks. Biological activity in the BAC was monitored by 1) measuring concentrations of various forms of organic carbon monitored before and after the BAC unit (see Figure 8) and 2) measuring PLFAs in the BAC media at various bed depths before each backwash (see Figures 9,10, and 11).

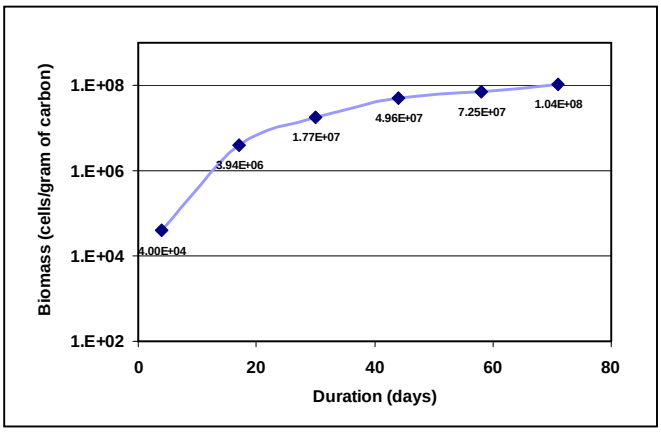
**Figure 8: Organic Carbon Profile Across Pilot Treatment Process**




When considering the Figure 8 data, membranes removed TOC associated with particulates. TOC remained unchanged by ozonation because ozone-based oxidants are cleaving the aromatic and long-chain aliphatic compounds, but not mineralizing organic carbon to inorganic carbon-di-oxide. However, these cleavages transform slowly biodegradable DOC to readily biodegradable DOC, resulting in an increase in BDOC across the ozonation unit, though the TOC remains unchanged. The BAC unit reduces ozone-created BDOC to background concentrations, and in doing so reduces TOC and DOC. These reductions improve effluent biostability, and decrease the effluent's biofilm growth potential.

PLFA analysis is a reliable and accurate way to determine viable microbial biomass in GAC conditioned into BAC. Phospholipids break down rapidly upon cell death; therefore, biomass calculations based on PLFA content do no contain lipids from dead cells. Figure 9 shows biomass concentrations in the upper six inches of the BAC medium as a function of time based on PLFA results. Biomass values increased from low levels ($\leq 4x10^4$ cells/gram of carbon) to high levels ($1x10^8$ cells/gram of carbon) over the course of 71 days since startup. The flattening of the biomass concentration curve signifies that the GAC has been conditioned and converted to BAC.

**Figure 9: Biomass Growth with Time at Bed Depth of 0.5 ft**




Changes in the PLFA profile (or microbial community structure) during the conditioning period was monitored (see Figure 10). The initial microbial community during the startup was limited in biomass and diversity. Opportunistic microbes (categorized as the Normal Saturated Group or "Nsats") were the dominant microbial population. The microbial community increased in biomass and diversity over time. Fast growing, hydrocarbon utilizing proteobacteria (the Monoenoic Group or "Monos") became dominant. Anaerobic metal reducing bacteria (Branched Monoenoic Group or "Brmonos"), Nsats, and eukaryotes such as fungi (Polyenoic Group or "Polys") were also present.

The change in PLFA profile or microbial community structure with increasing depth in the BAC bed is shown in Figure 11. The microbial community structure throughout the conditioned BAC bed was fairly uniform, with there being comparatively less biomass towards the bottom the bed, where a scarcity of food source is expected.

**Figure 10: PLFA Profile (and Biomass Concentrations) with Time at Bed Depth of 0.5 ft**

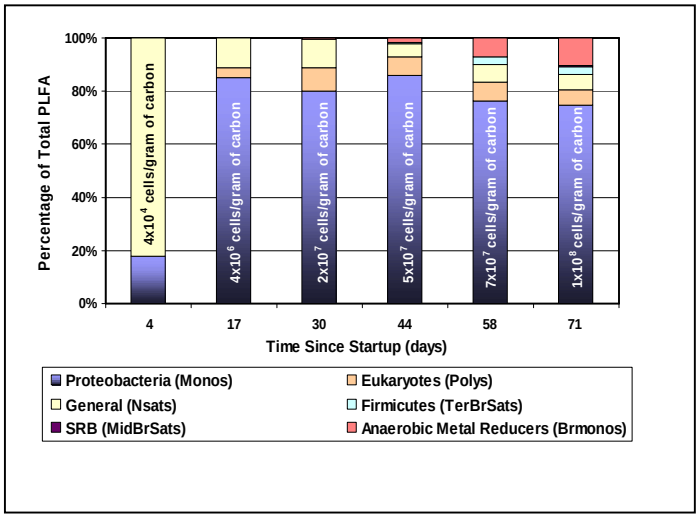
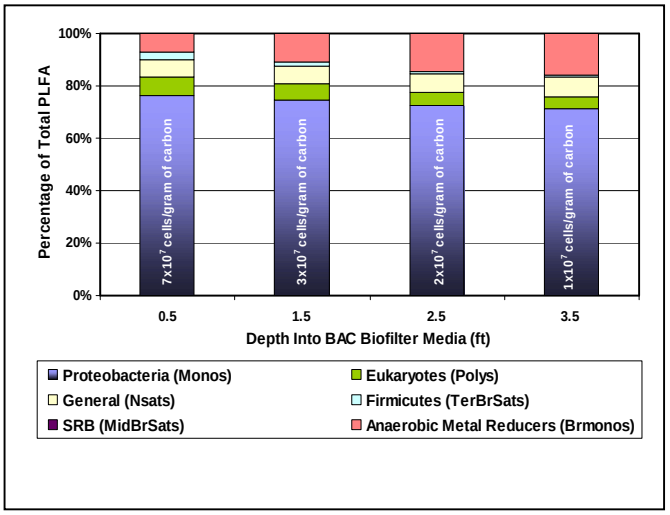



**Figure 11: PLFA Profile (and Biomass Concentrations) with Bed Depth on the 58th Day**




## Conclusions

Results from this pilot study show that ozonation is effective in substantially reducing the concentrations of many microconstituents of treated wastewater. For RSWRF effluent after membrane filtration, a transferred ozone dose of 5 mg/L is recommended for microconstituents removal. Addition of peroxide is found to be an effective bromate mitigation strategy. Injecting ozone at multiple points along with peroxide provides minimal benefits in reducing bromate concentration. The injection sequence between ozone and peroxide is not significant with respect to reducing bromate concentration.

PLFA analysis is an effective tool for assessing and monitoring the microbial population in a BAC biofilter. Based on PLFA analyses, converting GAC to BAC for treatment of MF-Ozone effluent requires about two months. This was unknown prior to this study. BAC removes almost all BDOC generated by ozonation. BAC removes substantial amounts of TOC, and some bromate. These two parameters will be monitored regularly during the rest of the pilot testing. Extensive testing of around 300 effluent contaminants, mostly microconstituents, is planned. The RSWRF MF-Ozone-BAC pilot process is being operated continuously at the time of this paper.

## Acknowledgement

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# Energy Efficient Advanced Treatment Process for Microconstituents Removal

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## ABSTRACT

The objective of this study was to demonstrate the effectiveness of an advanced treatment process not utilizing reverse osmosis (RO) for removal of hormones, pharmaceuticals, and flame retardants (collectively termed microconstituents or chemicals of emerging concern [CECs]) from municipal effluent. The advanced treatment process consisted of (in the order of use): membrane filtration (MF), ozonation (O3), and biological activated carbon (BAC). The 15-month, continuous flow, 10.7 gpm, MF-O3-BAC demonstration study was conducted in two phases at the Reno-Stead Water Reclamation Facility (RSWRF): Phase 1 focused on ozone process optimization and bromate mitigation; Phase 2 was a 10-month steady-state demonstration of process performance. For RSWRF effluent, an ozone dosage of at least 5 mg/L was needed for desired CEC removals. Peroxide (year-round) and ammonia (seasonal) were added to mitigate bromate formation during ozonation. BAC removed flame retardants, and ozonation byproducts including NDMA (N-Nitrosodimethylamine), aldehydes, and biodegradable organic carbon. Findings of this study imply that MF-O3-BAC treatment is equally effective as RO-based treatment for CEC removals, but with substantially less energy utilization.

**KEYWORDS:** Ozone, AOP, BAC, CECs, Emerging Contaminants, Hormones, Pharmaceuticals, Flame Retardants, Ozonation Byproducts, NDMA, Bromate

## INTRODUCTION

Industrialization and advancement in human lifestyle have resulted in increased presence of man-made, predominantly refractory, organic compounds in the environment. Of these, the chemicals of emerging concern (CECs) include endocrine disrupting chemicals (EDCs) and pharmaceuticals and personal care products (PPCPs). Most of CECs are life improving drugs and useful household products (e.g., anti-bacterial agents and flame retardants) which makes complete source control infeasible until less refractory substitutes are developed. A recent study has reported annual consumption of an estimated 622,000 metric tons of flame retardants in the US in 2007 (ATSDR, 2009). Production of TCEP, a common flame retardant used in polyurethane foams increased from 2000 pounds in 1975 to nearly a million pounds in 2006 (ATSDR, 2009). Many CECs are present in wastewater and are released to the environment through this medium because conventional wastewater treatment processes are not completely effective in removing refractory organics, such as CECs. Occurrences of CECs in effluent-dominated streams are well documented and reported elsewhere (Goodbred et al., 2007; Vajda et al., 2008; Jenkins et al., 2009). Releases of CECs to the environment 1) have affected aquatic organisms living in the receiving water, and 2) may affect people ingesting water containing CECs.

Aquatic impacts of CECs have been reported in various studies performed worldwide. This is of concern to stakeholders involved in projects discharging treated municipal effluents to water bodies, particularly water bodies providing limited dilution of the effluent. Increases in intersex fish, female-

biased sex ratios, and elevated levels of vitellogenin (Vtg) were found in white sucker fish populations living immediately downstream from an effluent discharge to Boulder Creek in Colorado (Vajda et al., 2008). Vtg is an egg yolk protein expressed mainly by the female species. Male white suckers living in the WWTP effluent site had approximately 25 times more Vtg in spring (effluent more diluted) and 500 times more Vtg in fall (effluent less diluted, plus elevated temperature) than upstream males used as reference. Recently, investigators found selective uptake of anti-depressants in the brain cells of native white suckers living in Boulder Creek downstream of WWTP discharge (Schultz et al., 2010). U.S. Geological Survey (USGS) studies found elevated levels of Vtg, reduced sperm motility and distribution, and consistently lower gonadosomatic index in male common carp living in Las Vegas Bay of Lake Mead that receives treated municipal effluent (Goodberd et al., 2007). Reproductive and endocrine biomarkers in western mosquitofish at various Santa Ana River sites showed significant evidence of endocrine disruption as a function of proximity to WWTP effluent discharges (Jenkins et al., 2009). Though there have been detectable effects of CECs on specific, localized fish populations, Mills et al. (2005) concluded that the information linking these effects with an ecologically relevant impact on an overall fish population in a water resource is missing.

Direct evidence of harmful impacts on human impacts from exposure to and ingestion of CECs in water resources is not known to exist. However, the impacts on aquatic life are ample evidence of the bioactivity of CECs at very low concentrations. This bioactivity is of concern to agencies and regulators involved in reuse of municipal effluents for creating alternative water supplies, and irrigating landscapes. Even though the levels of individual CECs detected in drinking water supplies, thus far, are far below their known threshold effect levels, synergistic effects of numerous CECs on the human body over a lifetime exposure in addition to medicines taken by an individual are still unclear. Accordingly, the 2010 President's Cancer Panel recommended that pregnant women and children should minimize their exposure to CECs (Reuben, 2010). A California advisory panel recommended monitoring a few key indicator CECs in groundwater recharge applications (CSWRCB, 2010). This panel excluded CEC monitoring requirements for irrigation projects due to the lesser chance of people ingesting irrigation water.

Treatment for removing CECs from wastewater has been mainly based on four mechanisms: biological metabolism, membrane separation, chemical oxidation, and adsorption. Previous studies have shown significant removals of hydrophobic CECs during secondary treatment by biological metabolism and adsorption to sludge (Clara et al., 2005). Hydrophilic and recalcitrant CECs including organophosphate flame retardants (e.g., TCEP) and iodinated contrast media (i.e. iopromide) are not removed during secondary treatment (Snyder et al., 2007).

Researchers have focused their investigations on evaluating treatment technologies for removing CECs remaining in secondary effluent. Microfiltration and ultrafiltration are marginally effective in controlling CECs (Snyder et al., 2007). Reverse osmosis (RO) is successful in removing virtually all CECs by concentrating them in the RO membrane reject stream. However, RO effluent may still contain NDMA (Plumlee et al., 2008), TCEP, and iopromide (Snyder et al., 2007). In many cases, NDMA is generated during the chloramination step to prevent RO membrane biofouling (Sedlak et al, 2006). To remove these residual CECs from RO effluent, the effluent can receive advanced oxidation treatment consisting of high-energy ultraviolet light and hydrogen peroxide. With RO treatment, the bulk of the removed CECs are concentrated in the reject stream. This reject stream poses a threat to aquatic life, and therefore may need special treatment and/or disposal. To our knowledge at this time, RO with its associated treatment process is the most effective method for removing a broad range of CECs, but it involves high capital costs, high power utilization, and it creates a substantial and potentially harmful waste stream.

Less costly and less power intensive CEC removal methods have included oxidation by ozonation (without peroxide), hydroxyl radical-based advanced oxidation processes (i.e. AOPs such as ozone-peroxide, high-energy UV-peroxide), chlorination, and chloramination. However, all have been less effective than RO to varying degrees. Chlorination is fairly effective in removing CECs but creates carcinogenic byproducts. Chloramination is not effective in removing CECs. The most effective oxidation processes, thus far, are ozonation (without peroxide) and AOPs. Several studies have reported substantial reduction in effluent estrogenic activity along with significant removal of CECs after ozone-based oxidation (Huber et al., 2005; Snyder et al., 2006). However, ozone-based oxidation of wastewater effluent can have the following drawbacks: 1) formation of transformation byproducts that have potential toxicity (Stalter et al., 2010), 2) formation of byproducts that are suspected carcinogens such as bromate (von Gunten 2003; Marhaba et al., 2003) and NDMA (Andrzejewski et al., 2007), 3) inadequate treatment of compounds that are engineered to resist oxidation such as flame retardants (e.g., TCEP, TCPP, and TDCPP), 4) elevated levels of bioactivity in the effluent after oxidation (i.e. decrease in effluent biostability), and 5) need for effluent-specific pilot testing based on the impact of water quality parameters such as TOC, pH, temperature, alkalinity, and nitrite on ozone oxidation chemistry. Studies addressing the drawbacks of ozone oxidation of CECs in effluent are sparse.

Small-scale laboratory tests showed that Granular Activated Carbon (GAC) is effective in removing CECs that have high hydrophobicity (Snyder et al., 2007). Performance of GAC units treating CECs present in wastewater on a continuous basis is still unclear. Biological Activated Carbon (BAC) is a biofilter that uses GAC as the support medium for microbial growth. BAC needs a source of biodegradable organic carbon (BDOC) to promote the necessary bioactivity, but tertiary effluent is a poor source of BDOC. Both ozonation (without peroxide) and AOP increase tertiary effluent BDOC by oxidizing slowly biodegradable complex organic compounds into simpler, more readily biodegradable organic compounds. BAC installed downstream of ozonation or AOP is known to reduce BDOC and eliminate taste and odor causing compounds (Juhna et al., 2006; Nerenberg et al., 2000). Other benefits of BAC are not documented.

The objective of this study was to develop and demonstrate the effectiveness of a treatment train that is 1) capable of removing a wide range of CECs without forming toxic byproducts, 2) affordable, 3) applicable to inland areas (i.e. where an ocean does not exist to receive concentrated RO brine waste), and 4) effective in eliminating residual effluent toxicity. The pilot demonstration study was conducted at the Reno-Stead Water Reclamation Facility (RSWRF), Reno, Nevada, a 2 Mgal/d extended aeration activated sludge process currently handling 1.5 Mgal/d of annual average flow from a largely residential area. Membrane Filtration (MF) was selected as the filtration step to removal virtually all effluent particulates. Ozonation was selected as the oxidation step to destroy the bulk of the CECs. The optimal ozone dosage to balance the benefits of CEC oxidation with the drawbacks of bromate formation was determined under actual field conditions. Peroxide addition was needed to mitigate bromate formation during ozonation dosages necessary to achieve desired CEC removal. The BAC process was selected to 1) create a stable biofilter capable of supporting diverse microbial population within the micro-habitats expected to exist in GAC, 2) adsorb and/or metabolize a wide range of organics, including ozonation byproducts, and 3) thereby reduce the concentrations of CECs, organic ozone byproducts, and associated toxicity. The BAC process was allowed to nature naturally (i.e. without microbial seeding or other augmentations) to assure that the performance observed would be representative of indigenous, self-sustaining microbial populations present in effluent.

Biological activity in the BAC was monitored by 1) measuring Phospholipid Fatty Acids (PLFAs) in the BAC media at various bed depths over time so as to determine live cell biomass and microbial population, and 2) measuring concentrations of BDOC and TOC. MF-O3-BAC treatment performance was monitored over a 10-month period spanning hot to cold climatic conditions. The sampling and monitoring plan included 1) a wide range of CECs (belonging to various categories such as EDCs, and PPCPs), 2) estrogenic activity, 3) ozonation byproducts, and 4) general water quality parameters.

## METHODOLOGY

### Pilot Testing Setup

The MF pilot unit (AltaPac™, leased from WesTech Engineering Inc., Salt Lake City, UT, USA) used pressure-driven hollow fibers of polysulfone utilizing an outside-in flow configuration manufactured by Polymem. The nominal pore size of the membrane was 0.01 µm. The maximum pressure differential across the membrane was 30 psi. Prior to membrane filtration, the secondary effluent was passed through a 200 µm prefilter. Membrane maintenance steps were per the manufacturers recommendations and included periodic backwash with or without hypochlorite, Clean-in-Place (CIP) cleaning using caustic and hypochlorite, and membrane integrity testing. Critical membrane filtration parameters were monitored continuously and included pressure, flowrate, temperature and turbidity.

The O3 pilot unit (HiPOx™, leased from APTWater, Pleasant Hill, CA, USA) included a liquid oxygen-fed, solid-state, ozone generator capable of producing 4 lb/day of ozone at 10 percent concentration. The ozonation unit was operated in a direct gas injection mode both with and without peroxide addition, under a system pressure of 15 psi. Oxygen mass flow, and gaseous and dissolved ozone concentrations were monitored continuously.

The BAC pilot unit (leased from WesTech Engineering Inc., Salt Lake City, UT, USA) included a stainless steel, pressure vessel designed to operate in the downflow mode. The 3.5 ft diameter vessel contained 1250 lbs of Filtrasorb F-400 (Calgon Carbon, Pittsburgh, PA, USA), resulting in a carbon media bed depth of about 4.5 ft and 30 minutes of empty bed contact time (EBCT) at a flow of 10.7 gpm. Headspace was more than 50% of the bed depth to allow for bed expansion during backwash without losing media. The BAC unit was constructed with sampling ports to allow the collection of carbon media samples at various depths from the media bed.

**Quantification of CEC and Other Constituents**

Analytical methods utilized by ELAP certified commercial laboratories employed for this project are summarized in Table 1. CECs, including those listed in draft California groundwater recharge regulations (CDPH, 2008), were quantified using EPA Method 1694 using positive and negative electrospray ionization (ESI+ and ESI-) and atmospheric pressure chemical ionization (APCI).

**Table 1. Analytical Methods.**

| Analyte Group | Method Name/Reference |
|---|---|
| Aldehydes | EPA 556 |
| Bromate | EPA 326 |
| Bromide | EPA 300.1 |
| Nitrosoamines (NDMA) | EPA 521 |
| Total Organic Carbon | Standard Method 5310C |
| Alkalinity | Standard Method 2320B |
| CECs[a] except akylphenols | EPA 1694 using ESI+, ESI- and APCI |
| Akylphenols | Lab-specific method based on GC-MS Selective Ion Monitoring |
| E-Screen | Drewes et al. 2005 |
| Biodegradable Dissolved Organic Carbon (BDOC) | Allgeier et al. 1996 |
| Phospholipids Fatty Acids (PLFAs) | White et al., 1997 |

[a] CECs include hormones, pharmaceuticals, and flame retardants.

The E-screen test was used to evaluate relative estrogenic activity of treated effluent expressed as Estradiol Equivalents (EEQ) in ng/L. The E-screen test is an in vitro bioassay that uses a human breast cancer cell line (MCF-7) to determine the synergistic or additive effects of various hormones and other CECs (Drewes et al., 2005). PLFA analysis provided broad-based information about the entire microbial community in the BAC biofilter. BDOC was measured using a simplified and rapid method developed by Allgeier et al. (1996). BDOC analysis is critical in determining 1) the extent to which the refractory organics were being oxidized by ozone-based oxidants to more biodegradable compounds, and 2) the effectiveness of BAC in utilizing those biodegradable ozonation byproducts. Dissolved oxygen concentrations in the ozonated effluent and BAC effluent were monitored continuously. UV transmittance at 254 nm (UVT254) was measured using online and bench-top UV spectrophotometers. UVT254 is found to be influenced primarily by 1) presence of suspended particles, 2) organic compounds with aromatic ring structures, and 3) other constituents with higher affinity towards UV irradiation. Therefore, UVT254 is considered to be valuable in assessing overall water quality, and could be utilized in the comparison of effluent and the receiving water qualities. Known ozonation byproducts such as bromate, aldehydes, glyoxals and NDMA (N-Nitrosodimethylamine) were analyzed. NDMA was included based on a recent study reporting

formation of NDMA during ozonation process (Andrzejewski et al., 2007), and NDMA having a California Notification Level of 10 ng/L. Bromate is a byproduct of special concern because it has a drinking water Maximum Contaminant Level (MCL) of 10 μg/L. Critical water quality parameters such as alkalinity, pH, ammonia, bromide and TOC were measured throughout this study.

**Pilot Operation**

The pilot system was operated continuously for 15 months at a flow rate of 10.7 gpm from startup through completion. The system received undisinfected secondary effluent from the RSWRF. The solids retention time (SRT) of RSWRF's 1.5 Mgal/d (i.e. annual average flow during the testing) extended aeration nitrification-denitrification secondary process varied from 25 days (2008) to 17 days (2009). A schematic of the pilot treatment train is shown in Figure 1. The 10.7 gpm return flow from the pilot process had no material impact on the quality of 1040 gpm average daily flow through RSWRF, or influent to the pilot process. The pilot system was operated in two phases: Phase 1. Ozone Evaluation and Bromate Mitigation Studies, and Phase 2. MF-O3-BAC Demonstration.

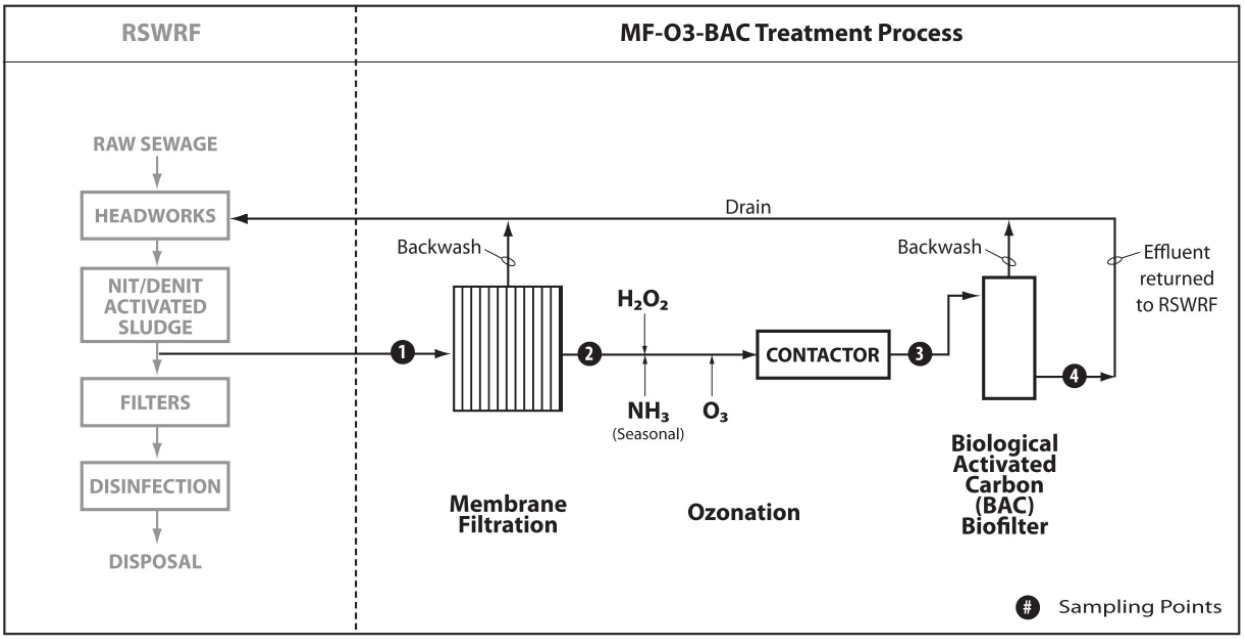



**Figure 1: Schematic of the MF-O3-BAC Pilot Treatment Process.**

**Phase 1. Ozone Evaluation and Bromate Mitigation Studies**

Phase 1 spanned 5 months. To evaluate ozone removal of CECs, reduction in estrogenic activity, and formation of byproducts, transferred ozone dosages of 3, 5, and 7 mg/L were applied to MF effluent. During Phase 1 studies, MF effluent water quality averaged: TOC of 5.3 mg/L, bromide of 197 μg/L, ammonia of less than 0.1 mg-N/L, pH of 6.7, temperature of 66 °F and alkalinity of 92 mg/L. MF effluent nitrite concentrations were negligible (< 60 μg-N/L). The activated sludge process SRT was approximately 25 days. The effect of ozonation on effluent quality was measured in the ozone contact pipe where the measured ozone residual was negligible (< 50 μg/L), thus ensuring complete utilization of ozone-based oxidants. Estimated contact times causing negligible ozone residuals from ozone transferred dosages of 3, 5, and 7 mg/L were 3.6, 7.7, and 13.5 minutes, respectively. Desired CEC and estrogenic activity removals were not achieved at an ozone dose of 3 mg/L. The extent of bromate formation was found to be mainly a function of ozone dose, peroxide dose, and ammonia concentration. Bromate concentrations higher than the MCL (10 μg/L) were created at ozone doses

of 5 mg/L or more. To determine an optimal bromate mitigation strategy, effluent bromate concentrations were monitored for various ozone and peroxide injector configurations at ozone doses of 5 and 7 mg/L. Ammonia and bromide concentrations during bromate mitigation testing were approximately 1 mg-N/L and 250 μg/L, respectively. Results from Phase 1 became the operational parameters for Phase 2.

**Phase 2. 10-month MF-O3-BAC Demonstration**

After completing Phase 1, the 10-month MF-O3-BAC demonstration was conducted from February 2009 to December 2009. Operational conditions maintained during the Phase 2 demonstration are summarized in Table 2. During Phase 2, the GAC was "conditioned" into a BAC process by passing membrane-filtered and ozonated effluent through the biofilter on a continuous basis without any supplemental carbon source or microorganisms. Biological activity in the BAC was monitored by measuring PLFAs in the BAC media at various bed depths before each backwash (which occurred roughly every 14 days). RSWRF BAC was compared to full scale effluent BAC located in the Fred Harvey Water Reclamation Plant (FHWRP) BAC unit in El Paso, Texas. At FHWRP, the raw sewage passes through powdered activated carbon (PAC) treatment, lime treatment, filtration and ozonation processes before it reaches BAC process. FHWRP BAC is backwashed every 12 hours.

**Table 2. Phase 2 Operational Conditions.**

| Parameter | Location | Units | Value |
|---|---|---|---|
| Temperature range | Secondary effluent | °F | 55 – 74 |
| Median temperature | Secondary effluent | °F | 66 |
| Alkalinity | MF Effluent | mg/L | 99 ± 13 |
| pH | Mf Effluent | - | 7.4 ± 0.2 |
| Bromide | Mf Effluent | μg/L | 260 ± 100 |
| Nitrite | MF effluent | μg-N/L | < 60 |
| Gaseous ozone | Feed gas | % | 10 |
| Average ozone dose (calculated) | - | mg/L | 5 |
| Peroxide:ozone molar ratio | - | - | 1 |
| Dissolved ozone | O3 effluent | μg/L | < 5 |
| Average ammonia concentration | O3 effluent | mg-N/L | 1-1.5 |
| Ozone contact time | - | Min | 5 |
| Turbidity | BAC effluent | NTU | 1.7 ± 1.7 |

Three sampling campaigns were conducted during Phase 2. Sample points included locations before and after each treatment process. The first sampling campaign was conducted five months after BAC startup and after confirming the maturity of the BAC. Sampling campaigns dates were selected to capture maximum effluent temperature variation from summer through winter. To maximize the credibility and meaningfulness of the CEC results at low concentrations near the analytical limits of current methods, field blanks and field duplicates were included in the sampling campaigns to supplement normal laboratory QA/QC checks (e.g., lab blank, MS/MSD). All constituents presented herein, including CECs and estrogenic activities, are quantified during each sampling campaign. Aldehydes, UVT254, TOC, BDOC, alkalinity, pH, and ammonia were monitored regularly during Phase 2.

## RESULTS

CEC and estrogenic activity removals observed during the Phase 1 ozone evaluation study are presented in Table 3. Ozonation byproduct concentrations measured during the ozone evaluation study are shown in Figure 2. Bromate concentrations in the O3 unit influent and 3 mg/L ozone dosed effluent were below the detection limit (<5 μg/L). Effluent bromate concentrations were 19 μg/L for 5 mg/L ozone doses, and 37 μg/L for 7 mg/L ozone doses. Peroxide addition at a 1:1 peroxide to ozone molar ratio was identified as the most suitable bromate mitigation strategy for ozone doses of 5 mg/L (data not presented). Bromate concentrations in ozonation effluent measured during the Phase 2 demonstration are shown in Figure 3. Even with peroxide addition, bromate concentrations exceeded 10 μg/L when effluent ammonia concentrations decreased to less than about 0.6 mg-N/L. This phenomenon has been observed by others (Marhaba et al., 2003). This seasonal effect was addressed by injecting ammonia into membrane effluent, as needed, so as to maintain ammonia concentrations during ozonation at levels around 1 to 1.5 mg-N/L. This addition appears to have reduced bromate concentrations to less than 10 μg/L as shown in Figure 3.

Table 3. CEC Results during Phase 1 Ozone Performance Optimization.

| | 3 mg/L Transferred Ozone Dosage | | | 5 mg/L Transferred Ozone Dosage | | | 7 mg/L Transferred Ozone Dosage | | |
|---|---|---|---|---|---|---|---|---|---|
| **Constituent** | **MF, ng/L** | **O3, ng/L** | **Detectable Percent Removal** | **MF, ng/L** | **O3, ng/L** | **Detectable Percent Removal** | **MF, ng/L** | **O3, ng/L** | **Detectable Percent Removal** |
| DEET | 170 | 57 | 68 | 40 | 5.5 | 99 | 33 | < 5 | 100 |
| Fluoxetine | 34 | 2.6 | 95 | 33 | < 1 | 100 | 36 | < 1 | 100 |
| Phenytoin | 310 | 63 | 81 | 390 | 14 | 98 | 350 | < 5 | 100 |
| Sulfamethoxazole | 670 | 35 | 95 | 410 | < 1 | 100 | 440 | < 1 | 100 |
| Meprobamate | 800 | 370 | 54 | 870 | 200 | 77 | 850 | 86 | 90 |
| Oxybenzone | 8.7 | 2 | 100 | 5.9 | < 2 | 100 | 5.1 | < 2 | 100 |
| Estrone | 10 | < 1 | 100 | 10 | < 1 | 100 | 8.8 | < 1 | 100 |
| Carbamazepine | 210 | < 1 | 100 | 250 | < 1 | 100 | 250 | < 1 | 100 |
| Diclofenac | 44 | < 2 | 100 | 59 | < 2 | 100 | 62 | < 2 | 100 |
| Gemfibrozil | 230 | < 1 | 100 | 120 | < 1 | 100 | 99 | < 1 | 100 |
| Hydrocodone | 83 | < 1 | 100 | 110 | < 1 | 100 | 70 | < 1 | 100 |
| Methadone | 71 | < 5 | 100 | 67 | < 5 | 100 | 64 | < 5 | 100 |
| Naproxen | 13 | < 1 | 100 | 7.9 | < 1 | 100 | 7.2 | < 1 | 100 |
| Trimethoprim | 130 | < 5 | 100 | 83 | < 5 | 100 | 76 | < 5 | 100 |
| 4-Nonylphenol monoethoxylates | 62.3 | < 3.92 | 100 | 31.1 | < 5.52 | 100 | 35.3 | < 6.44 | 100 |
| 4-Nonylphenol diethoxylates | 73.6 | < 17.6 | 100 | 72.3 | < 12.7 | 100 | 73.3 | < 13.3 | 100 |
| Octylphenol | 1.83 | < 1.03 | 100 | 1.5 | < 1 | 100 | 1.46 | < 1.29 | 100 |
| Atrazine | 2.8 | 1.4 | 78 | 2.8 | < 1 | 100 | 1 | 1 | NA |
| Diazepam | 1.8 | < 1 | 100 | < 1 | < 1 | NA | 1.2 | < 1 | 100 |
| E-Screen Estradiol Equivalents (EEQ) | 2.3 | 0.1 | 97 | 1.7 | < 0.027 | 100 | 1.6 | < 0.027 | 100 |

MF – Membrane Filter Effluent; O3 - Ozonation Effluent

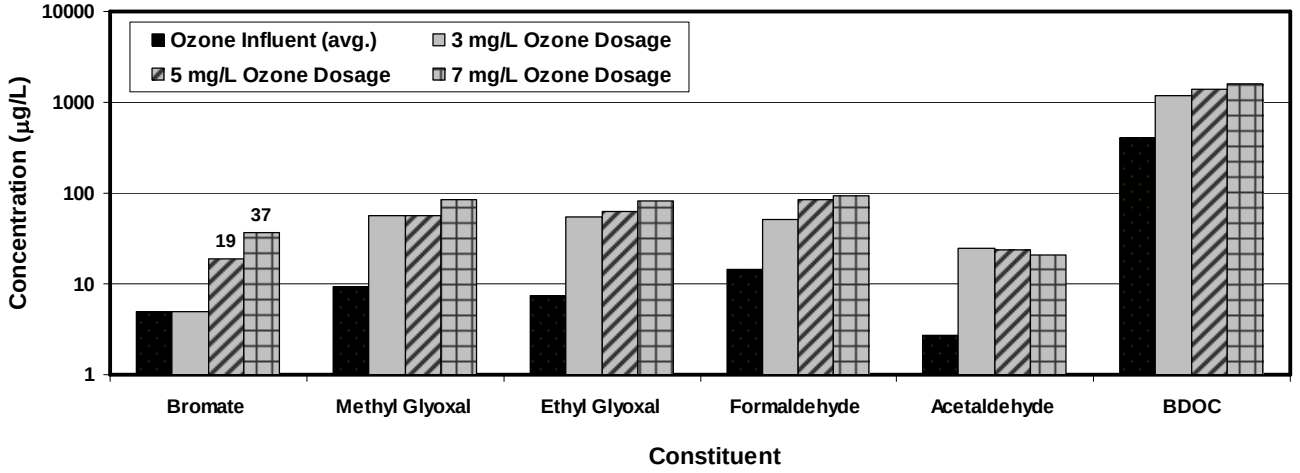



**Figure 2. Ozone Byproducts Observed during Phase 1 Ozone Performance Evaluation.**

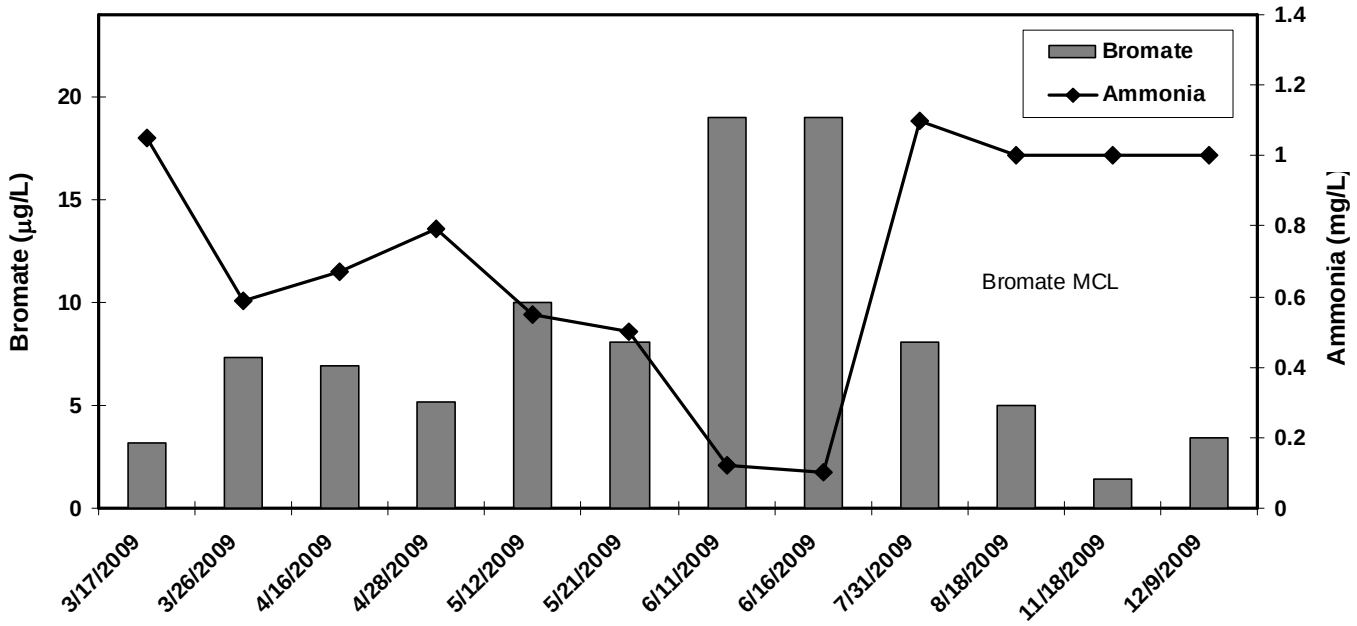
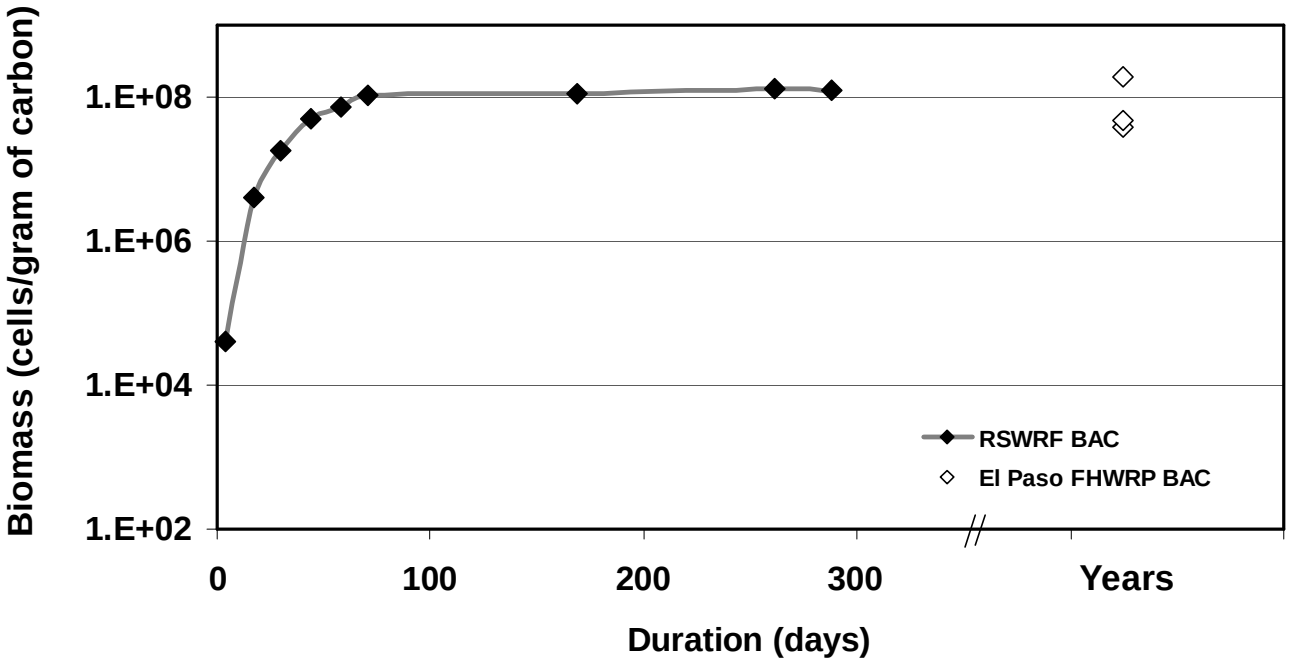



**Figure 3. O3 Effluent Bromate and O3 Influent Ammonia Concentrations during Phase 2 Demonstration (5 mg/L Ozone and 1:1 Peroxide to Ozone Molar Ratio).**

**BAC process development**

Biomass concentrations in the upper six inches of the BAC medium as a function of time (based on PLFA results) are shown in Figure 4. Biomass values increased from low levels ($\leq 4x10^4$ cells/gram of carbon) to high levels ($1x10^8$ cells/gram of carbon) over the course of 71 days since startup. Thereafter, the biomass density remained unchanged indicating maturation of BAC though the microbial makeup of the biomass continued to evolve for months. Post-maturation biomass levels measured in the pilot RSWRF BAC were found to be comparable to the biomass levels measured in the full-scale FHWRP BAC, as shown in Figure 4.




The performances of MF-O3-BAC in removing a wide range of CECs monitored during sampling campaigns 1,2, and 3 are shown in Table 4. Average estrogenic activities of secondary effluent, MF effluent, O3 effluent and BAC effluent observed are shown in Table 4. Occurrence, formation and removal of NDMA are also included in Table 4. Concentrations of ozonation byproducts, aldehydes and glyoxals, before and after ozonation and BAC treatment are shown in Figure 5. UVT254, TOC and BDOC measured before and after each treatment process are shown in Table 4, Figure 6, and Figure 7, respectively.

## Table 4. CEC Results during Phase 2 demonstration.

| Constituents | Unit | Sampling Campaign 1 (8/18/09) | | | | | | Sampling Campaign 2 (11/17/09) | | | | | | Sampling Campaign 3 (12/9/09) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | MF | O3 | O3D | BAC | FB | S | MF | O3 | BAC | BACD | FB | S | MF | O3 | BAC | FB |
| Gemfibrozil | ng/l | 49 | 36 | < 0.08 | < 0.08 | < 0.08 | < 0.08 | 36 | 27 | < 0.08 | < 0.08 | < 0.08 | < 0.08 | 52 | 43 | 0.19 | 0.20 | < 0.08 |
| Ibuprofen | ng/l | 8.0 | 7.4 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | 0.42 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | < 0.39 | 4.8 | 5.3 | < 0.39 | < 0.39 | < 0.39 |
| Naproxen | ng/l | 26 | 23 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | 7.6 | 6.8 | < 0.25 | < 0.25 | < 0.25 | < 0.25 | 28 | 24 | < 0.25 | < 0.25 | < 0.25 |
| Triclosan | ng/l | 36 | 2.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | 38 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | < 1.2 | 90 | < 1.2 | < 1.2 | < 1.2 | < 1.2 |
| Diazepam | ng/l | 1.1 | 1.1 | 0.18 | 0.23 | < 0.14 | 0.15 | 1.2 | 0.96 | < 0.14 | < 0.14 | < 0.14 | < 0.14 | 3.2 | < 0.14 | < 0.14 | < 0.14 | < 0.14 |
| Fluoxetine | ng/l | 3.1 | 1.7 | 2.0 | < 0.08 | < 0.08 | < 0.08 | 3.5 | 2.9 | < 0.08 | < 0.08 | < 0.08 | < 0.08 | 3.1 | 2.6 | < 0.08 | < 0.08 | < 0.08 |
| Primidone | ng/l | 170 | 190 | 4.6 | 12 | < 0.6 | < 0.6 | 90 | 68 | < 0.6 | < 0.6 | < 0.6 | < 0.6 | 160 | 130 | < 0.6 | < 0.6 | < 0.6 |
| Trimethoprim | ng/l | 170 | 130 | < 0.24 | 0.52 | < 0.24 | < 0.24 | 210 | 130 | < 0.24 | < 0.24 | < 0.24 | < 0.24 | 430 | < 0.24 | < 0.24 | < 0.24 | < 0.24 |
| Atorvastatin | ng/l | 9.9 | 8.1 | < 1.1 | < 1.1 | < 0.11 | < 0.11 | 10 | 5 | < 0.11 | < 0.11 | < 0.11 | < 0.11 | 23 | 3.5 | < 0.11 | < 0.11 | < 0.11 |
| Azithromycin | ng/l | 250 | 120 | < 22 | < 22 | < 2.2 | < 2.2 | 250 | 84 | < 2.2 | < 2.2 | < 2.2 | < 2.2 | 470 | < 2.2 | < 2.2 | < 2.2 | < 2.2 |
| Caffeine | ng/L | 15 | 12 | < 0.31 | < 3.1 | < 0.31 | < 0.31 | 14 | 9.6 | < 0.31 | < 0.31 | < 0.31 | < 0.31 | 46 | < 0.31 | < 0.31 | < 0.31 | < 0.31 |
| Ciprofloxacin | ng/l | 450 | 290 | < 14 | 39 | < 1.4 | < 1.4 | 200 | 160 | < 1.4 | < 1.4 | < 1.4 | < 1.4 | 440 | 290 | < 1.4 | < 1.4 | < 1.4 |
| Cotinine | ng/l | 93 | 17 | 21 | 11 | < 0.35 | < 0.35 | 16 | 24 | 9.0 | 2.3 | 2.8 | 0.49 | < 0.35 | < 0.35 | 12 | < 0.35 | < 0.35 |
| Sulfamethoxazole | ng/l | 390 | 380 | 2.2 | 2.9 | 0.26 | < 0.19 | 320 | 340 | < 0.19 | < 0.19 | < 0.19 | < 0.19 | 530 | < 0.19 | < 0.19 | < 0.19 | < 0.19 |
| Meprobamate | ng/L | NM | NM | NM | NM | NM | NM | 290 | 290 | 36 | 3 | 3.2 | < 0.36 | 480 | 430 | 51 | < 0.36 | < 0.36 |
| Methadone | ng/l | 36 | 32 | 0.31 | 0.095 | 0.13 | < 0.04 | 60 | 29 | < 0.04 | < 0.04 | < 0.04 | < 0.04 | 100 | 38 | < 0.04 | < 0.04 | < 0.04 |
| Atenolol | ng/l | 570 | 700 | 5.4 | 15 | 0.37 | < 0.2 | 200 | 240 | < 0.2 | < 0.2 | < 0.2 | < 0.2 | 230 | 160 | < 0.2 | < 0.2 | < 0.2 |
| Carbamazepine | ng/l | 120 | 120 | < 0.8 | < 0.08 | 0.16 | < 0.08 | 710 | 750 | < 0.08 | < 0.08 | < 0.08 | < 0.08 | 230 | 220 | < 0.08 | < 0.08 | < 0.08 |
| Amoxicillin | ng/l | 580 | 520 | 0.74 | 0.72 | < 10 | 0.70 | 920 | 640 | < 2 | < 2 | < 2 | < 2 | 3400 | 1900 | < 2 | < 2 | < 2 |
| Phenytoin | ng/l | 190 | 150 | 4.2 | 2.6 | < 1.0 | < 1.0 | 200 | 140 | 3.6 | < 0.33 | < 0.33 | < 0.33 | 780 | 740 | < 0.33 | < 0.33 | < 0.33 |
| Salicylic Acid | ng/l | 19 | 23 | 18 | 19 | 15 | 85 | 19 | 19 | 19 | 14 | 15 | 9.0 | 37 | 56 | 47 | 33 | 52 |
| TCEP | ng/l | 400 | 430 | 350 | 430 | < 0.34 | < 0.34 | 98 | 75 | 220 | 2 | 1.8 | < 0.34 | 360 | 360 | 290 | < 0.34 | < 0.34 |
| TCPP | ng/l | 740 | 640 | 700 | 720 | < 0.27 | 1.9 | 500 | 550 | 450 | 2.1 | 1.5 | 0.61 | 440 | 360 | 390 | 3.8 | 2.2 |
| TDCPP | ng/l | 690 | 610 | 650 | 710 | 0.71 | 1.3 | 450 | 490 | 440 | 0.68 | 0.79 | 0.58 | 760 | 770 | 790 | < .47 | 7.8 |
| Bisphenol A | ng/l | 18 | 22 | < 0.27 | < 0.27 | < 0.27 | 2200 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 | < 0.27 |
| DEET | ng/l | 21 | 24 | 0.68 | 0.64 | < 0.06 | < 0.06 | 270 | 300 | 4.6 | < 0.06 | < 0.06 | < 0.06 | 53 | 52 | 2.4 | < 0.06 | 1.2 |
| 1,4-Dioxane | µg/l | 1.7 | 1.6 | 0.38 | 0.38 | 0.43 | < 0.13 | 1.3 | 1.3 | 0.31 | 0.31 | 0.3 | < 0.13 | 1.7 | 1.7 | 0.35 | 0.35 | < 0.13 |
| NDMA | ng/l | 0.89 | 0.57 | 11 | 11 | < 0.28 | < 0.28 | 1.0 | 1.0 | 6.8 | < 0.28 | 0.3 | 0.47 | 0.99 | 1.0 | 6.0 | < 0.28 | 0.30 |
| E-screen Estradiol Equivalents (EEQ) | ng/L | 7 | 2.1 | < 0.03 | < 0.03 | < 0.03 | < 0.03 | 2 | 1.1 | < 0.03 | < 0.03 | < 0.03 | < 0.03 | 1.7 | 0.71 | < 0.03 | < 0.03 | < 0.03 |
| UVT | % | 65 | 75 | 85 | 96 | | | 63 | 76 | 84 | 95 | | | 68 | 78 | 83 | 94 | |

S - Secondary Effluent; MF - Membrane Effluent; O3 - Ozone-based Oxidation Effluent; O3D - Ozone-based Oxidation Effluent Duplicate; BAC - BAC effluent; BACD - BAC Effluent Duplicate; FB - Field Blank; NM – Not Measured

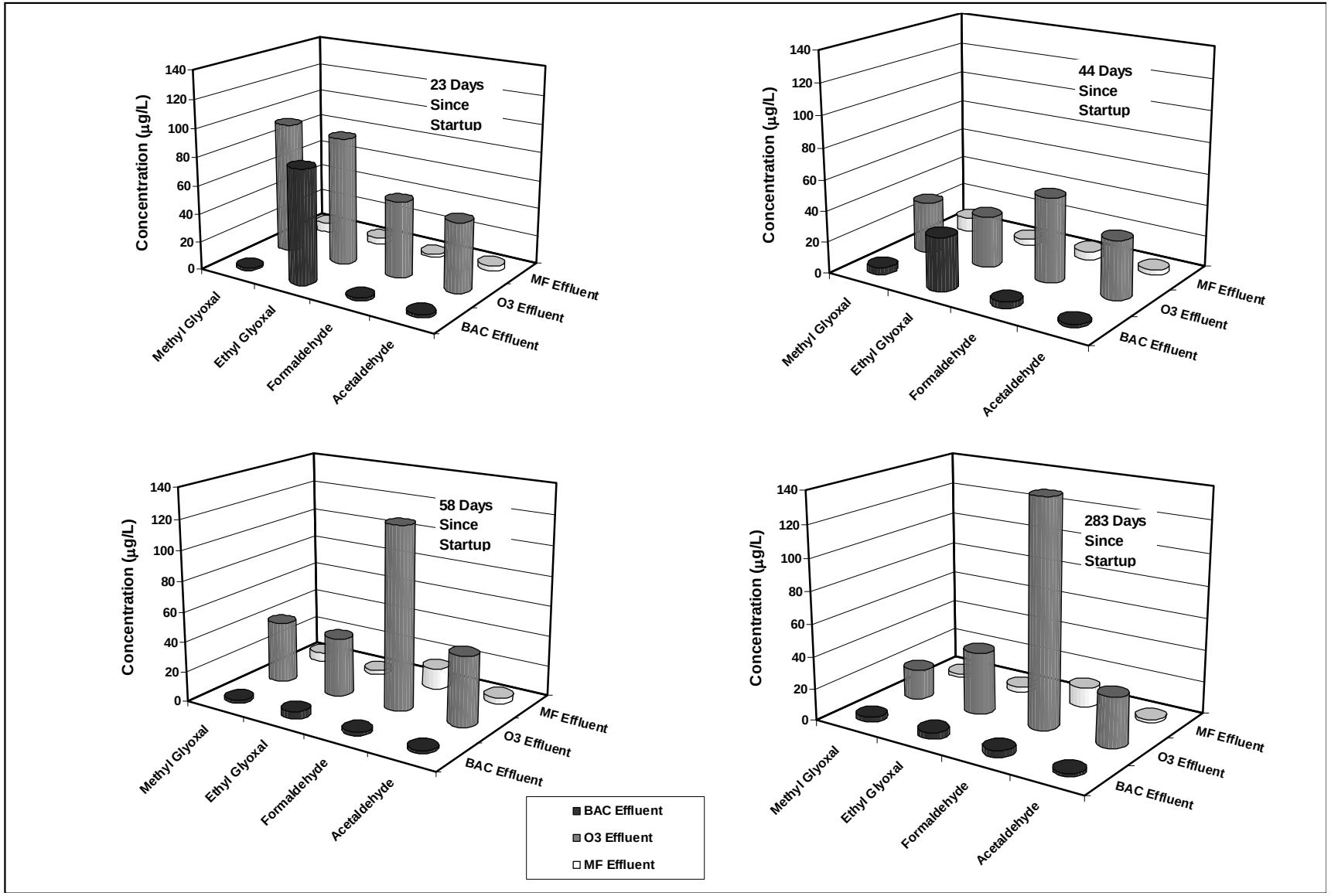



**Figure 5. Phase 2 Aldehydes and Glyoxals Concentrations with Time.**

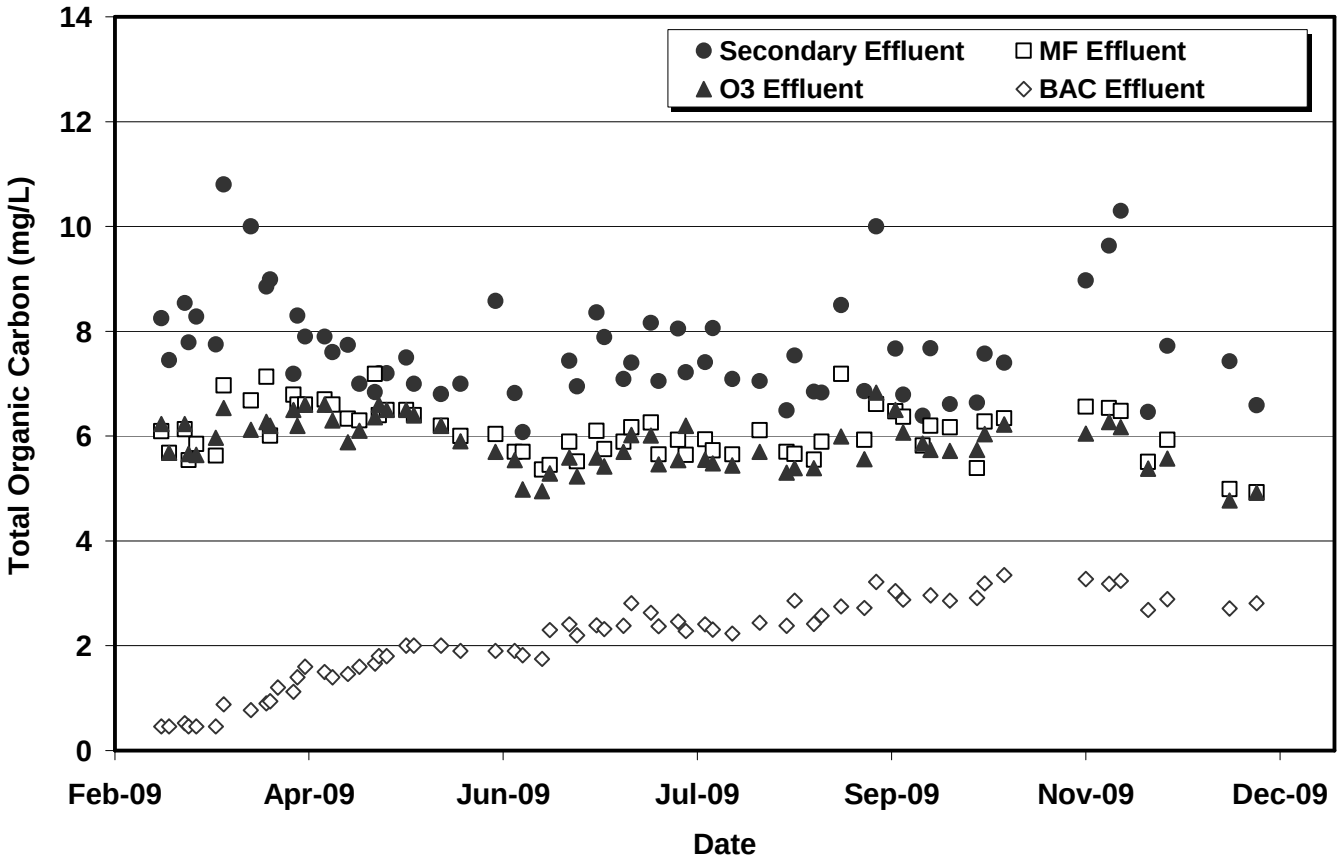
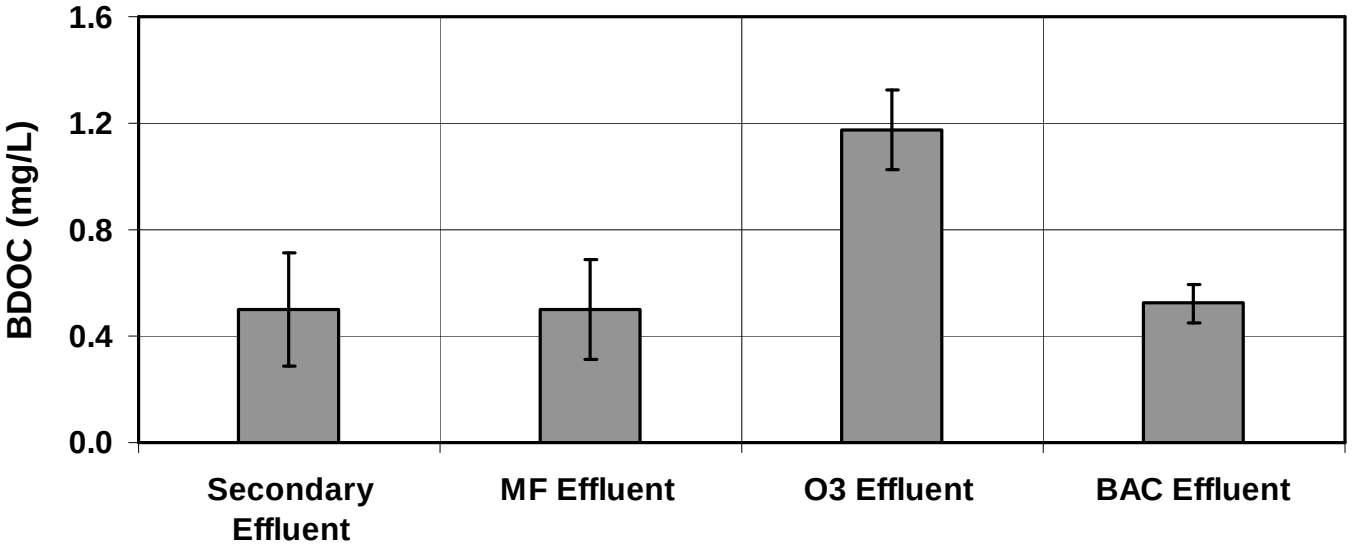



**Figure 6. TOC during Phase 2 Demonstration.**

**Figure 7. BDOC during Phase 2 Demonstration**




## DISCUSSION

Ozonation effects on municipal effluents were evaluated at RSWRF to quantify site-specific CEC removal benefits reported by others (Snyder et al., 2006; Huber et al., 2005), and adverse ozonation byproduct effects reported by others (von Gunmen 2003; Andrzejewski et al., 2007; Stalter et al., 2010). Ozonation at dosages of 3 mg/L or more removed most estrogenic activity, and most CECs with low resistance to ozonation (see Table 3). Ozonation at 5 mg/L or more completely removed estrogenic activity and presumably all CECs except for CECs with high resistance to oxidation. Meprobamate was found to be the most recalcitrant CEC to oxidation by ozone. Ozone performance results presented herein confirm the findings of previous bench-scale and pilot-scale studies (Snyder et al., 2006). Ozonation kinetics involved in oxidation of CECs has been documented elsewhere and therefore is not discussed in this article (Huber et al., 2005). For RSWRF membrane filtered effluent, an ozone dose to average TOC concentration ratio of 0.86 or more was found to be effective. RSWRF's influent bromide concentration (~250 μg/L) is much higher than the threshold concentration of 20□ μg/L reported by others to facilitate problematic bromate formation during ozonation (von Gunten 2003). For RSWRF effluent, bromate mitigation was needed when 5 mg/L or more of ozone was used for CEC control (see Figure 2). In the case of 7 mg/L ozone dosage, the bromate concentration was close to 10 μg/L even after adding peroxide at the maximum 1.5 molar ratio in the presence of 1 mg-N/L of influent ammonia (data not shown). Maintaining ozone dose at 5 mg/L with year-round addition of peroxide and seasonal addition of ammonia was found to be a suitable strategy for controlling bromate (see Figure 3). Mechanisms involved in bromate mitigation using peroxide are water-specific. Hence, peroxide addition for bromate control has resulted in mixed outcomes in other studies. More detailed discussion of pathways responsible for observed bromate formation control is beyond the scope of this article. Ammonia plays a beneficial role in bromate control by combining with bromide to form bromamines (Marhaba et al., 2000). Maintaining an

ammonia concentration in excess of 1.0 mg-N/L resulted in a net reduction in bromate formation in this demonstration project. Formation of various aldehydes and other short chain organic compounds as a result of oxidation of more complex organic compounds are shown in Figure 2. The toxicological significance of aldehydes and other short chain organic compounds are under investigation. Though there is no clear correlation between the concentrations of individual organic compounds and ozone doses, BDOC always increased with increased ozone dosage within the dosage range studied.

Quantitative data about maturation of a wastewater BAC biofiltration unit located downstream of an ozonation process were not available. Both membrane filtration and ozonation are known to remove microbes essential for converting a GAC to a BAC biofilter. Figure 4 shows the progress of key parameters as GAC converts to BAC using natural, sustainable processes without introduction of foreign microbes or nutrients causing ill-defined transient effects. Even though the backwash interval and pretreatment processes of FHWRP BAC are different from the BAC pilot unit investigated in this study, both BAC units had comparable levels of biomass based on PLFA analyzes. It appears that the microbial biomass maturation time for BAC is about 60 to 70 days. Use of BAC in the United States for wastewater treatment was been hindered by lack of performance data and limited information about BAC startup, monitoring, and control protocols. Findings presented herein may cover some of the gap in BAC performance, startup, and operation knowledge.

The role of membrane filtration in removing CECs is minimal because CECs present in secondary effluent, in general, are not particle associated. A few unusual CEC removals were observed with membrane filtration in the last sampling campaign. The ozonation step is very effective in removing a wide range of CECs except for compounds that resist oxidation (e.g., flame retardants). BAC is effective in consistently removing: 1) CECs that escaped ozonation, and 2) biodegradable organic byproducts of ozonation. Based on results shown in Table 4, CEC removals by MF-O3-BAC and RO-based processes are comparable. E-screen results, as shown in Table 4, confirmed complete removal of estrogenic activity when 5 mg/L of ozone were added with peroxide and ammonia.

From QA/QC checks, the unusual occurrence of two CECs (salicylic acid and bisphenol A) was explained. Salicylic acid was consistently detected in the lab water (i.e., the lab blank). The 2200 ng/L concentration of bisphenol A (BPA) in the campaign 1 field blank appears to have resulted from storing the bottled water for the blank in a plastic container for several days before use. For campaigns 2 and 3, potable water treated with the RSWRF lab MilliQ water purification system was used as the field blank. Concentrations of BPA in field blanks of campaigns 2 and 3 were less than the detection limit.

Mechanisms facilitating CEC removal (especially flame retardant removal) in BAC necessitate further discussion. Chlorinated organophosphates such as TCEP, TCPP and TDCPP are becoming widely used flame retardants in recent years as a replacement for recalcitrant, highly controversial, PBDEs (ASTOR, 2009). Flame retardants have high frequency of detection in wastewater effluent as they are not eliminated during conventional wastewater treatment. They are engineered to withstand fire (i.e. oxidation), and typically consist of a short chain of carbon atoms with a polar functional group. As a consequence, flame retardant removal during ozone-based oxidation is found to be marginal, as expected. Excellent removals (>99%) of flame retardants were observed during BAC treatment. Concentrations of flame retardants in BAC effluent were consistently close to detection limits. Several physical, chemical, and/or biological mechanisms may be responsible for flame retardant removal during BAC treatment. This is still under investigation. Andersen, et al. (2006) has

investigated flame retardant removal in GAC used in drinking water systems. They found that drinking water GAC with known biological activity removed greater amounts of flame retardants when compared to GACs without any known biological activity (Andersen et al., 2006). Bench-scale adsorption experiments in wastewater conducted by Snyder et al. (2007) showed effective removal of flame retardants by GAC. The data from the bench-scale studies using drinking water (TOC = 3 mg/L) spiked with average TCEP concentration of 178 ng/L showed 5 percent breakthrough of TCEP after treating 11,900 bed volumes (conventional GAC) to 37,100 bed volumes (tailored GAC). 20 percent breakthrough of TCEP occurred after 15,200 bed volumes (conventional GAC) to 43,600 bed volumes (tailored GAC). Significant breakthrough of TCEP was not observed in RSWRF BAC unit with conventional GAC treating ozone effluent (TOC = 5.8 mg/L) with an average TCEP concentration of 286 ng/L after 13,800 bed volumes of through flow during the Phase 2 demonstration. Lack of TCEP breakthrough with conventional BAC treating effluent with higher TCEP and TOC concentrations indicates that the removal of flame retardants in BAC maybe governed by more than one removal mechanism, as also suggested by the work of Andersen et al. (2006).

Glyoxal removal data shown in Figure 5 after 44 days of BAC maturation suggest that biodegradation could be a dominant mechanism for this contaminant. Properties of glyoxal reported elsewhere support the findings of this study. Previous data show adsorption of glyoxal is highly unlikely due to low octanol-water coefficient (OECD, 2004) and glyoxal is readily biodegradable (Kielhorn et al., 2004). In addition to glyoxal, BAC was effective in removing all other byproducts that were monitored since the startup even though the concentrations of the byproducts showed variations (see Figure 5). Secondary effluent and membrane effluent NDMA concentrations were close to the detection levels (See Table 4). Ozone-based oxidation increased the NDMA by 6 to 11 ng/L confirming the findings of Andrzejewski et al. (2007). NDMA concentrations were consistently below the detection level of 0.28 ng/L after BAC. Anoxic and aerobic biodegradation of NDMA has been reported recently (Nalinakumari et al., 2010). Considering the findings of these reports and the generally aerobic environment in the BAC, NDMA removal during BAC treatment could be due to biodegradation.

Effluent UVT254 improvement provided by membrane filtration could be attributed to removal of particulates (see Table 4). Ozone-based oxidation increased the UVT254 to 85%, which could be due to removal of aromatic organic compounds. The UVT254 of BAC effluent was consistently above 90%, which is similar to the UVT254 observed in RO effluent. UVT254 improvement by BAC are possibly due to the removal of short-chain organics and other ozonation byproducts.

With respect to TOC, as shown in Figure 6, membrane filtration removed the TOC fraction associated with particulates. TOC remained unchanged during oxidation, because the ozone-based oxidants are cleaving aromatic and long-chain aliphatic organic compounds into short-chain organic compounds, but not mineralizing organic carbon to inorganic carbon dioxide. However, these cleavages transformed slowly biodegradable DOC to readily biodegradable DOC, resulting in an increase in BDOC across the ozonation unit, as shown in Figure 7. The BAC unit, then, reduced the ozone-created BDOC to background concentrations, and in doing so reduced TOC and DOC. BAC effluent TOC varied from 2.5 mg/L to 3.5 mg/L during the last 3 months of operation, suggesting the loss of GAC adsorption effects over time. The chemical nature and significance of TOC leaving BAC is under investigation. This study shows that BAC acts as a treatment barrier when installed downstream of ozonation by 1) treating oxidation byproducts, thereby eliminating associated toxicity, 2) mitigating NDMA, 3) reducing concentrations of flame retardants that escaped ozone-

based oxidation., and 4) reducing wastewater derived bioactivity to background levels, which decreases the effluent's biofilm growth potential. Investigations evaluating 1) the performance of BAC over the course of its life, 2) the fate of spent carbon when BAC requires media replacement, and 3) the fate of CECs removed by BAC are required prior to full-scale implementation of BAC in wastewater treatment applications.

Discussion of two supplementary topics is presented below. Commonly reported municipal effluent CECs such as acetaminophen, iopromide, PBDEs, and estradiol were not found in RSWRF secondary effluent, presumably as a result of the long SRT. This observation is in agreement with reports by others (Clara et al., 2005). At RSWRF, changing SRT from 25 days to 17 days did not impact the occurrence of CECs in the membrane effluent as shown in Tables 2 and 4. The RSWRF pilot study (see Tables 2 and 4) also confirmed findings by others that addition of peroxide to ozonation does not affect the extent of contaminant removal materially (Acero et al., 2001). However, addition of peroxide reduces the time needed to attain CEC removal and mitigates bromate formation.

**Energy Utilization for CEC Removal: O3-BAC versus RO**

Energy utilizations presented, herein, should only be used for comparative evaluation purposes and should not be applied to any actual project, because there are many project-specific factors involved in determining actual energy usage for a particular project. There are three scenarios of CEC removal projects under consideration:

- MF-Ozone-BAC
- MF-RO-HUV with ocean discharge of reject stream
- MF-RO-HUV with zero liquid discharge (i.e. without ocean discharge)

RO brine can be handled by ocean discharge (or equal) or zero liquid discharge, depending on the project-specific factors. Annual energy costs per Mgal/d of feed are estimated for these three scenarios in Figure 8 based on the assumptions presented in Table 5 and summarized below:

1. Influent to both O3-BAC and RO would receive microfiltration or ultrafiltration pretreatment.
2. As a mitigation measure for NDMA, RO Permeate would be treated by high energy UV (HUV) and hydrogen peroxide (H2O2).
3. The Zero Liquid Discharge (ZLD) process train would include (in the order of use): concentrate treatment process, brine concentrator, and crystallizer.
4. Energy uses related to RO membrane replacement and BAC carbon replacement are not included.

**Table 5: Summary of Critical Variables**

| Parameter | Unit | Value |
|---|---|---|
| Flow | Mgal/d | 1 |
| Power Cost | $/kWh | 0.14 |
| RO Recovery | % | 85 |
| RO TDS Removal Efficiency | | 95 |
| Concentrate Treatment Recovery | | 85 |
| Brine Concentrator | | 95 |
| Ozone Dose | mg/L | 5 |
| BAC Empty Bed Contact Time | min | 30 |

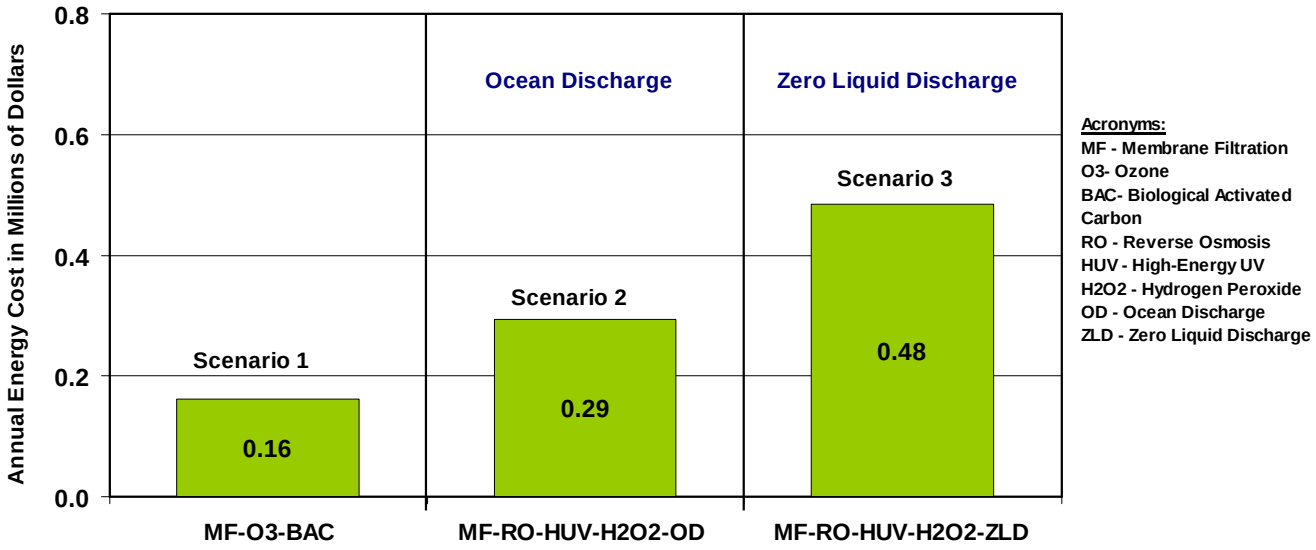



**Figure 8: Annual Energy Cost Per MGD (Unit Power Cost = $0.14/kWh)**

For CEC removal projects, Scenarios 1 through 3 would all be adequate. Scenario 1 has lowest energy requirements. Energy analyses presented herein show that using O3-BAC rather RO for CEC removal can reduce power consumption by 45 to 65%.

## CONCLUSIONS

Adverse effects of CECs on aquatic life are well documented. The case for CEC impacts on public health is less clear. Thus far, RO is considered to be the only option to remove a broad spectrum of CECs reliably under a wide-range of site-specific conditions. This study demonstrates under

sustained, continuous flow, field conditions the effectiveness of MF-O3-BAC treatment in removing a broad spectrum of CECs. This removal is achieved at lower costs and power utilizations than RO, and without generating a reject stream.

With MF-O3-BAC, the primary CEC removal process is ozonation, which may produce many undesirable byproducts, including bromate, NDMA and short-chain organics. When bromate is of concern, addition of peroxide (year-round) and ammonia (seasonally) is found to be effective in reducing bromate levels to well below the MCL of 10 μg/L. This study confirmed formation of NDMA during ozonation to a relatively minor extent. BAC provided NDMA and short-chain organics mitigation by reducing their concentration to below detection levels. MF-O3-BAC increased $UVT_{254}$ to values similar to RO effluent; indicating MF-O3-BAC treatment is effective in removing a wide range of organics and other UV absorbing agents present in the effluent. The synergistic role of BAC in treating ozonation residuals and improving stability of the ozonated effluent is clearly demonstrated. Protocols for startup and monitoring of BAC have not been reported in the literature before this investigation.

Findings from this study indicate that reliable CEC removal is more affordable than previously thought. By inspection, MF-O3-BAC treatment has lower capital cost than RO treatment including 1) pretreatment, 2) high energy UV and peroxide post treatment processes, and 3) handling of RO reject stream. Energy utilization of MF-O3-BAC is 45-65% lower than RO based treatment trains. Though some process components are still under investigation, MF-O3-BAC appears to be more cost effective for CEC removal than RO.

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Appendix G

# Chronology of Pilot Testing Operations and Protocols

Appendix G

# Chronology of Pilot Testing Operations and Protocols



## FOREWORD

This appendix includes a chronology of significant events that occurred during the pilot project. Events that are believed to have had some impact on pilot project results have been discussed in the report in the appropriate section.

This appendix also includes the Emergency Standard Operating Procedures used throughout the pilot project to assure minimum interference in project results from outside factors. This same level of control from outside factors will be provided in full-scale installations by standby power, redundant equipment, and alternative effluent storage/disposal methods.

The final part of this appendix is the procedure used to collect and ship the samples to the appropriate analytical laboratories.

## Chronology of Pilot Operation

| Date | MF-O3-BAC Days since Startup | Event |
|---|---|---|
| 10/08/2008 | NA | Membrane skid went online |
| 10/08/2008 | NA | Ozone skid went online |
| 11/06/2008 | NA | 3 mg/L ozone only contact time testing |
| 11/07/2008 | NA | 3, 5, & 7 mg/L ozone only contact time testing |
| 11/13/2008 | NA | 5 & 7 mg/L ozone only ozone optimization testing |
| 11/17/2008 | NA | 3 mg/L ozone only ozone optimization testing |
| 01/14/2009 | NA | MS2 Testing (no peroxide) |
| 01/23/2009 | NA | Evaluation of bromate mitigation strategies |
| 02/06/2009 | NA | SRT dropped from 30 days to 18 days over the next two weeks |
| 02/23/2009 | NA | SRT = 18 days |
| 03/02/2009 | 5 | BAC unit went online. |
| 03/16/2009 | 15 | DO setpoint in aeration basins was changed from 1.75 to 2.0 mg/L (to address sludge bulking) |
| 03/30/2009 | 29 | One of the two membrane modules was replaced. Membrane flow changed from 12 to 18 gpm. SRT dropped from 18 days to 15 days (to address scum and foaming issues) |
| 06/17/2009 | 108 | Peroxide pump was recalibrated from 6.3 ml/min to 4.7 ml/min |
| 07/08/2009 | 129 | Ammonia (1 mgNH3-N/L) injection initiated. |
| 07/31/2009 | 152 | Ammonia (1 mgNH3-N/L) injection was fine tuned (via pH depression). This was followed by ammonia injection via ammonium sulfate. |
| 08/18/2009 | 170 | Final Sampling Event No. 1 (FS-1) |
| 09/27/2009 | 210 | Increase in headloss through BAC resulted in flow of water through air release valve at the top. |
| 09/28/2009 | 211 | BAC backwash flowrate was increased from 60 gpm to 100 gpm to address BAC headloss issues. |
| 11/17/2009 | 261 | Final Sampling Event No. 2 (FS-2) |
| 12/09/2009 | 283 | Final Sampling Event No. 3 (FS-3) |
| 12/15/2009 | 289 | MF-Peroxide-Ozone Virus Testing (with peroxide) |
| 12/17/2009 | 291 | Switched to Sand Filter (Membrane unit was taken offline) |

***Date : 03/12/09***
***Version: 1***

# RSWRF MF-OZONE-BAC PILOT TESTING
# Emergency Standard Operating Procedures (ESOPs)

| Event | Action Steps |
|---|---|
| **Plant Wide Power Failure** | 1. Check that the emergency backup generator is providing power to the pilot system. |
| | 2. Check that all treatment systems and equipment are correctly running in their steady state conditions. |
| | 3. After power is restored, again check that all treatment systems and equipment are correctly running in their steady state conditions. |
| **Loss of Pilot Influent Feed Pump** | 1. Switch to the standby pump |
| **Loss of Membrane Feed Pump** | 2. Replace damaged pump with on shelf back-up pump. |
| | 3. Continue to feed ozone and BAC systems from the membrane effluent storage tank. |
| **Membrane System Short Term Failure (< 26 hours)** | 1. Reduce the flow rate to the Ozone and BAC systems to 5 gpm. |
| | 2. Continue to feed ozone and BAC systems from the membrane effluent storage tank. |
| **Membrane System Long Term Failure (>26 hours)** | 1. Move pilot influent feed pump from the sand filter inlet channel to the sand filter effluent channel and feed sand filtered effluent to the ozone system. |
| | 2. Decrease flow rate to ozone system to 5 gpm. |
| | 3. Increase the ozone dose from 5 ppm to 7 ppm |
| **Peroxide System Failure** | 1. Reduce ozone generator power from the 13.25% set point to a 10% set point to reduce the ozone dose. |
| **Ozone System Failure (less than 8 hours)** | 1. Isolate the BAC column by closing the outlet valves. Make sure the media is hydrated. |
| **Ozone System Failure (8-24 hours)** | 1. Recirculate BAC effluent from the backwash tank<br>2. Reduce the flow rate to the BAC system to 5 gpm. |

<table>
<tr><th>Event</th><th colspan="2">Action Steps</th></tr>
<tr><td>Ozone System Failure (more than 24 hours)</td><td colspan="2">1. Recirculate BAC effluent from the backwash tank<br>2. Reduce the flow rate to the BAC system to 5 gpm.<br>3. Every 24 hours, feed membrane effluent for one hour at 5 gpm</td></tr>
<tr><td rowspan="2">BAC Feed Pump Failure</td><td colspan="2">1. Replace damaged pump with on shelf back-up pump.</td></tr>
<tr><td colspan="2">2. If back-up pump is not available, increase the ozone system backpressure to 25 psi to feed the BAC system.</td></tr>
<tr><td rowspan="6">BAC – Higher Headloss</td><td colspan="2">1. Monitor and record water level in the BAC unit daily.<br>2. Whenever a backwash is performed, record time, date, liquid flowrate, and air flowrate (if applicable).<br>3. Monitor backwash drain flow for carbon media loss.<br>4. Backwash time will be based on working volume of the backwash tank.</td></tr>
<tr><td>Scenario 1: If BAC water level rises slowly and the level is far below the air release valve after 10 days following a backwash.</td><td>Perform a liquid only backwash at a flowrate of 125 gpm on the tenth day.</td></tr>
<tr><td>Scenario 2: If BAC water level rises at a faster rate and the level is close to air release valve after 6 days following a backwash.</td><td>Perform a liquid only backwash at a flowrate of 125 gpm.</td></tr>
<tr><td>Scenario 3: If BAC water level rises at a very fast rate and the level is close to air release valve within 6 days following a backwash</td><td>Perform a liquid only backwash at a flowrate of 125 gpm and call Vijay Sundaram at ECO:LOGIC (916-773-8100)</td></tr>
<tr><td colspan="2">Whenever air scour is required, perform air scour after draindown but before liquid backwash. Perform air scouring for 2 minutes at approximately flowrate of 19.3 scfm (i.e. 2 scfm/ft2).</td></tr>
<tr><td colspan="2">For operations related questions please call Vijay Sundaram at ECO:LOGIC (916-773-8100)</td></tr>
<tr><td colspan="2">For equipment related questions please call Bryce Myers at WesTech (801-290-1516)</td></tr>
</table>

| Event | Action Steps |
|---|---|
| **General Notes** | 1. BAC vessel manual bottom drain is to always remain closed. |
| | 2. BAC backwash tank is to remain full at all times except during drawdown from backwash. |
| | 3. Potable water is not an acceptable water source for the BAC pilot operation due to the presence of free chlorine residual. |
| **Emergency Contacts** | ECO:LOGIC Office (916) 773-8100 |
| | Vijay Sundaram Cell Phone: (916) 303-6608 |
| | Bob Emerick Cell Phone: (916) 826-6990 |
| | Mike Harrison Cell Phone: (916) 826-3230 |

## Emerging Contaminants Sampling Protocol

| | |
|---|---|
| TO: | Field Sampling Team |
| OBJECTIVE: | To conduct successful field sampling by 1) avoiding external contamination, 2) minimizing human errors, 3) maintaining steady-state process conditions, and 4) meeting time restrictions. |
| GENERAL INFORMATION: | **External Contamination:** Most contaminants that are targeted in this sampling event are commonly present in the environment. Care must be taken to avoid potential contamination (i.e., resulting in false positives).<br>**Human Errors:** This is one of the most comprehensive sampling events to be implemented in this pilot program. About 500 sample containers will be used within this event. Therefore, multiple checks and other quality assurance steps are necessary.<br>**Steady-State Process Conditions:** Operation of Nit. / Denit., Membrane, Ozone/Peroxide, and BAC processes should be as smooth as possible without any major disturbances.<br>**Time Restrictions:** Packing and delivery of several ice chests requires considerable time and effort. All of the ice chests will be dropped off at the FedEx location during the same evening. |

**PROCEDURES:**

**1. Before the Sampling Day:**

- Make sure you have received all the empty sample containers and required amount of blue ice packs are present in the refrigerator.
- Chain of Custody (COC) forms must be completed except for the time, date and sampler's signature.
- FedEx Address Labels has to be completed and placed or tagged onto the ice chests.
- Create ample amount of desktop and floor space for sample collection and organization.

**2. Process Control:**

- Make sure required amount of LOX, peroxide, ammonia, and membrane cleaning chemicals (hypo) are available in the feed tank/cylinder and peroxide and ammonia feed pumps are calibrated.
- Make sure intermediate ozone feed tank is full and operational and membrane CIP or mini-CIP is not scheduled on the sampling day.
- Make sure all of pilot SCADA controls and data collection devices are operational.
- A dedicated team member should be monitoring all three pilot processes for major changes or disturbances, and recording operating conditions during sampling.

**3. Ultra-clean Sampling Preparation:**

- Wear gloves, coat, goggles and at all times, during sampling and avoid touching or even breathing on the samples. (Note: We are measuring compounds at ng/L levels, so the potential for contamination of samples is great).
- Avoid smoking, drinking caffeinated or alcoholic beverages, or taking medications during sampling.
- Avoid wearing perfumes, or other fragrances, and using sunscreen on the day of sampling.

**4. During Sampling:**

- Verify (QA/QC check) sample label located on the empty container against actual sample location before sampling.
- Do not rinse or overfill container, leave approximately 1-inch headspace.
- Do not contaminate the container cap.
- Use sampling tap that is free of aerators, strainers, or hose attachments.
- Flush for 3-5 minutes to obtain a representative sample (preferably using a tap that is constantly flowing).
- For travel blank, please transfer water provided into travel blank sample bottle.

**5. Packing and Delivery:**

- Place sample in 1-4°C refrigerator or ice chest to cool sample prior to shipping (min. 2 hours).
- When ready to ship, place sample bottles into ice chest, include ice packs and Sample Information Sheet/COC in a sealed plastic bag.
- Verify (QA/QC check) sample names, COCs and address labels present in each ice chest before sealing the container.

**6. General:**

- Report any unusual incidents that occurred during the sampling event.

Appendix H

# Glossary of Abbreviations and List of Acronyms

Appendix H

# Glossary of Abbreviations and List of Acronyms

The following is a Glossary of Abbreviations and a List of Acronyms that has been used throughout this report.

| Glossary of Abbreviations and List of Acronyms | |
|---|---|
| **Abbreviation/Acronym** | **Description** |
| AOP | Advanced Oxidation Process |
| ASR | Aquifer Storage and Recovery |
| BAC | Biologically Active Carbon Filtration |
| BDOC | Biodegradable Dissolved Organic Carbon |
| BHA | Butylated Hydroxyanisole (food preservative) |
| BOM | Soluble Biodegradable Organic Matter |
| BPA | Bisphenol-A (plastic ingredient) |
| CDPH | California Department of Public Health |
| CFR | Code of Federal Regulations |
| CIP | Clean-In-Place |
| CT | CT = disinfectant concentration x contact time = C mg/L x T minutes |
| DEET | N,N-diethyl-3-methylbenzamide (insect repellant) |
| DOC | Dissolved Organic Carbon |
| EBCT | Empty Bed Contact Time |
| EC | Electrical Conductivity |
| EDR | Electrodialysis Reversal |
| EEQ | Estradiol Equivalent quotient |
| E-Screen | Estrogenic Activity Screening |
| FB | Field Blank |
| FHWRP | Fred Harvey Water Reclamation Plant, El Paso, TX |
| GAC | Granular Activated Carbon |
| $H_2O_2$ | Hydrogen Peroxide or Peroxide |
| HAAs | Haloacetic Acids (disinfection byproducts) |
| HUV | High-Energy Ultraviolet Radiation |
| IPR | Indirect Potable Reuse |
| LB | Lab Blank |
| LSI | Langelier Saturation Index |

| Glossary of Abbreviations and List of Acronyms | |
|---|---|
| **Abbreviation/Acronym** | **Description** |
| LUV | Low-Energy Ultraviolet Radiation |
| MCL | Maximum Contaminant Level |
| MF | Membrane Filtration (e.g., microfiltration, ultrafiltration) |
| MS/MSD | Matrix Spike/Matrix Spike Duplicate |
| MS2 | MS2 Bacteriophage, a surrogate virus organism |
| ND | Not detected |
| NDMA | N-nitrosodimethylamine (rocket propellant, disinfection byproduct) |
| NM | Not Measured |
| NMR, C-NMR | Nuclear Magnetic Resonance Spectroscopy |
| NP | 4-Nonylphenol (surfactant) |
| O3 or $O_3$ | Ozonation |
| OP | n-Octylphenol (surfactant) |
| ORP | Oxidation-Reduction Potential |
| PAC | Powdered Activated Carbon |
| PAH | Polycyclic aromatic hydrocarbons (product of carbon combustion) |
| PBDEs | Polybrominated diphenyl ethers (flame Retardants) |
| PCBs | Polychlorinated Biphenyls (coolant used in transformers) |
| PLFA | Phospholipids Fatty Acids |
| QA/QC | Quality Assurance/Quality Control |
| RO | Reverse Osmosis |
| RSWRF | Reno-Stead Water Reclamation Facility, Reno, NV |
| SAT | Soil-Aquifer Treatment |
| SEC | Size Exclusion Chromatography |
| SF | Sand Filtration |
| SOCs | Synthetic Organic Compounds |
| SRT | Solids Retention Time |
| TCA | Trichloroethane (industrial solvent) |
| TCEP | Tris(2-chloroethyl) Phosphate (flame retardant) |
| TCPP | Tris(chloroisopropy) Phosphate (flame retardant) |
| TDCPP | Tris(1,3-dichloro-2-propyl) Phosphate (flame retardant) |
| TDFS | Total Dissolved Fixed Solids |
| TDS | Total Dissolved Solids |
| THMFP | Trihalomethane Formation Potential |
| THMs | Trihalomethane Potential (disinfection byproducts) |
| TOC | Total Organic Carbon |

| Glossary of Abbreviations and List of Acronyms | |
|---|---|
| **Abbreviation/Acronym** | **Description** |
| UV | Ultraviolet Radiation |
| UVT or $UVT_{254}$ | Ultraviolet Transmittance measured at 254 nm |
| VOCs | Volatile Organic Compounds |
| WWTP | Wastewater Treatment Plant |
| YES | Yeast Estrogen Screen |

Appendix I

# Field Test Reports
# (see additional files on CD)

Appendix J

# Laboratory Reports
# (see additional files on CD)