

**Efficiency Evaluation of an Advanced Oxidation Processes (AOP)
Package Plant for MTBE Removal from Natural Waters**

by

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Abstract

To provide safe drinking water to small communities in Puerto Rico, this project evaluates the performance and reliability of a small-scale, advanced oxidation processes (AOP) package plant for water treatment. Specifically, this project investigates the performance of ozone and UV combination technologies in the destruction of the gasoline additive Methyl Tert-Butyl Ether (MTBE). The project uses groundwater collected from a rural community in Añasco, PR and transported to the laboratory, where it was used for the plant evaluation. This project involved water quality characterization, and a physical and chemical evaluation of the AOP unit performance. From the physical evaluation (operation and maintenance) it was shown that, the plant is not a viable and reliable technology to being used on small communities in PR, even though the chemical evaluation (efficiency to remove contaminants from water) consents it as an alternative.

Resumen

Con el propósito de proveer agua potable segura a las comunidades pequeñas en Puerto Rico, esta investigación evalúa el funcionamiento y la confiabilidad de una planta paquete de tratamiento de oxidación avanzada (TOA) para el tratamiento de aguas. Específicamente, esta investigación investiga el funcionamiento de la combinación de tecnologías de ozono con ultravioleta para la destrucción del aditivo de gasolina éter metilo tert-butílico (MTBE). El proyecto utiliza agua subterránea colectada de una comunidad rural en Añasco, PR y transportada al laboratorio, en donde fue utilizada para la evaluación de la planta. Este proyecto implicó la caracterización del agua, y una evaluación física y química del funcionamiento de la unidad de TOA. De la evaluación física (operación y mantenimiento), fue demostrado que la planta no es una tecnología viable y confiable a ser utilizada en las comunidades pequeñas en PR, aunque la evaluación química (eficiencia para la remoción de contaminantes del agua) lo acepta como alternativa.

Dedication

To God, because he made me, without him I will not be here and be the person that I am now.

To my family, which are my inspiration to do what I do, and always encourage me to continue with perseverance reaching my objectives in live: my mom Carmen, my father Carmelo, my sisters Camille and Claribel, my nephew Exor Alexander, my two nieces Nicole Alanis and Kynaisha Mar, and my grandmother Antonia.

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1. Introduction

The work presented herein is an effort to address some of the problem of water treatments present in small communities in Puerto Rico and other rural areas. It evaluates the potential for using an advanced oxidation processes package plant (AOP) to treat and provide drinking water to those communities. The AOP water treatment is one of a variety range of treatments available for this purpose.

1.1. Statements of the problem

The amendments of 1996 of the Safe Drinking Water Act (SDWA) require that all conventional drinking water treatment satisfy the Maximum Contamination Level (MCL). In addition, drinking water systems must comply with the Disinfection/Disinfection By-Product Rule, Surface Water Treatment Rule and Ground Water Disinfection Rule. These regulations require the removal and/or disinfection of chemical and bacteriological contaminants from drinking water. In Puerto Rico, that regulation applies to the Puerto Rico Aqueduct Sewer Authority (PRASA) and small communities not served by PRASA (non-PRASA communities). Studies performed by the U.S. Environmental Protection Agency (USEPA) and the Puerto Rico Department of Health (PRDOH) showed that non-PRASA communities fail the SDWA mostly in the MCL of coliforms (USEPA, 1998a). The extent of contamination by other water quality parameters is, however, unknown because of the lack of water quality analysis performed on the non-PRASA communities' water sources.

Small non-PRASA communities obtain their water from streams, springs, or groundwater wells and are responsible for managing their water supply system. These communities are limited economically and most of them do not have the resources to pay costly treatment technologies to solve their water quality problems. Furthermore, these communities often lack of skilled personnel to operate necessary water treatments systems. Consequently, these communities need a simple water treatment

processes that involve low construction, operational and maintenance costs and that meet all stipulated regulations.

With the purpose of providing simple and cost effective water treatment alternatives for these communities, the EPA has been evaluating some techniques that small communities can adopt. These include rapid sand filtration, ultrafiltration, bag filtration system and Advanced Oxidation Processes (AOP) packed plants. The AOP package plants include UV/ozone, UV/hydrogen peroxide/iron (photo-Fenton) and UV/titanium dioxide. Those evaluations have recently been performed at the Test and Evaluation (T&E) facility in Cincinnati, Ohio (USEPA and IT Corporation, 2001a & 2001b). Advanced oxidation is attractive because its potential to remove contaminant from drinking water, low apparent maintenance requirements, and efficient removal of contaminant.

1.2. Justification for this work

The Environmental Protection Agency (EPA) on the T&E Facility built an AOP package plant with UV/Ozone treatment components in 2001 to serve as a potential solution for treating contaminated drinking water used by small communities. Experiments performed on the AOP plant evaluated its potential to remove Methyl Tert-Butyl Ether (MTBE). MTBE is a gasoline additive, which was used to replace lead since 1979 and is included in the Drinking Water Contaminant Candidate List (CCL). Different types of water (surface and groundwater) and quality of water (specifically the amount of turbidity) were processed by the package plant. The experiments demonstrated that MTBE could be removed significantly from the matrix of water for specific conditions.

EPA wanted to evaluate the performance of the AOP package plant in terms of its implementation at the community level to determine if the AOP unit represents a real solution to water treatment issues faced by rural communities. Evaluation parameters for the implementation include easiness for mobility, installation, maintenance, energy

consumption, and community perception. The work presented here address implementation parameters. It mainly focuses on the implementation performance in the point of the community, not only on the advantages of this unit for MTBE removal.

1.3. Objectives

The principal objective of this project is to do a performance evaluation of the advanced oxidation processes (AOP) package plant built by the EPA (IT Corporation, 2001). The evaluation concentrates on a possible implementation of this AOP package plant unit in a non-PRASA community for the removal of chemicals such as MTBE.

The performance is evaluated in terms of the physical implementation, as well as efficiency of chemical removal under the conditions tested. The physical evaluation focuses on the operation, and maintenance of the AOP plant. The chemical evaluation focuses on the efficiency, and cost to remove contaminants from water using advanced oxidation process (AOP) treatment. The objective was accomplished using questionnaires from the community, data obtained from EPA, and some experiments performed in the Environmental Engineering Laboratory (EEL) at the University of Puerto Rico at Mayagüez.

Another objective of this project is to determine the effect of water quality characteristics on the AOP removal efficiency of contaminants, and production of treatment by-products. This was accomplished by performing experiments with a different water quality characteristic than those used at the T&E Facility. The T&E Facility data includes both surface water and ground water (IT Corporation, 2002).

On the experiments done at EEL, a non-PRASA community using groundwater was chosen to evaluate the removal effectiveness of MTBE as contaminant. Groundwater was chosen because: (1) there is a greater percent of non-PRASA communities in groundwater than surface water; (2) groundwater is more likely to show MTBE contamination; and (3) groundwater has less sediments and less turbidity than surface water, which are known to interfere with UV/O₃ AOP treatment.

2. Literature Review

Water quality parameters for drinking water must comply with the Surface Water Treatment Rule, Disinfection/Disinfection By-Product Rule, and pending Enhanced Surface Water Treatment Rule and Ground Water Disinfection Rule (USEPA, 1998b; USEPA and IT Corporation, 2001c). These regulations require the removal and/or disinfection of chemical and bacteriological contaminants from the matrix of drinking water producing harmless compounds than the original contaminant.

2.1. Special Communities Information

In Puerto Rico, 97 % of the population use water provided by the Puerto Rico Aqueduct and Sewer Authority (PRASA) (Minning and Ramirez-Toro, 2001). The remaining is largely served by small private systems ranging in size from 2 to approximate 500 homes and most are in rural areas. Many of the non-PRASA systems qualify as community water supply and are required to meet most of the same Safe Drinking Water Act regulations as the PRASA system (Minning and Ramirez-Toro, 2001). Non-PRASA communities are increasing: 231 non-PRASA communities existed in 2002 (PRDOH, 2002), and 297 for 2004 (PRDOH, 2004). PRASA does not have the necessary capacity to supply the water demand for those communities, although some of them are connected to both systems. The consensus of these communities is that the Non-PRASA source of water is of higher quality than PRASA water. In addition, these communities show a lack of trust on the ability of PRASA to fulfill their water needs. Consequently, they rather use their water source, even if the water is of poor quality (Minning and Ramirez-Toro, 2001).

Water sources are classified according to their source as surface water (107 communities in 2002) or groundwater sources (124 communities in 2002). Surface water sources are those where water is intercepted from unprotected springs, rivers or streams. Groundwater sources are those where the water is obtained from wells.

The Caribbean Environmental Protection Agency (USEPA Caribbean) and the Puerto Rico Department of Health (PRDOH) are responsible for compliance of water quality regulations of Non-PRASA communities. EPA and PRDOH make and verify the fulfillment of administrative orders on surface water and groundwater systems. PRDOH is responsible for examining the non-PRASA community water quality by inspecting, sampling, and conducting sanitary surveys of the systems. They have identified a number of factors contributing to non-compliance from the non-PRASA systems. Some of these factors include topography, lack of trained personnel, resources at the system-level, and a lack of coordination with pertinent agencies (USEPA, 2001b).

Many non-PRASA water supply systems of non-PRASA must comply with the same regulations as the PRASA systems. A large number of those communities, however, fail the standard water quality of the SDWA, mostly in the maximum contamination level of coliforms (USEPA, 1997a; PRDOH, 2004). Other violations of the water quality parameters are unknown because of the lack of analysis performed on those non-PRASA communities' water sources. U.S. EPA and PRDOH, in conjunction with the Partnership for Pure Water (PPW), rehabilitated 77 drinking water systems with the use of chlorination (USEPA, 1998a), but 125 systems continued to fail and required installation of filtration units (USEPA, 2001a).

Usually the method of water treatment used by non-PRASA communities depends on the water source. For surface water, sediments must be removed with a slow sand filter followed by disinfection is the requirement. However, if the community has technical and economical constraints they can use small package plants that offer the same conventional treatment as pre-oxidation, coagulation, rapid mixing, flocculation, rapid sand filtration and disinfection. For groundwater systems, only disinfection is necessary because it is assumed that groundwater has better quality than surface water.

2.2. *Methyl Tert-Butyl Ether (MTBE)*

The Clean Air Act Amendments of 1990 requires that states with a high concentration of ozone or carbon monoxide, add oxygenates to their gasoline to decrease the carbon monoxide. MTBE is an oxygenated, volatile organic compound, which has been used as a replacement for lead to boost octane since 1979 (Squillace et al., 1995). It's low-cost, readily simple production makes MTBE very attractive over other compounds like ethanol (Squillace et al., 1995; Jacobs et al., 2000). The fraction of MTBE found in gasoline depends on the concentration of ozone and carbon monoxide found in the atmosphere. Areas having high carbon monoxide concentration must contain 2.7 % oxygen by weight, which would require 15 % of MTBE. Areas with high tropospheric ozone must contain 2 % of oxygen by weight, which is equivalent to 11 % of MTBE (Moran et al., 2000).

2.3. *Source of MTBE*

Contamination of water resources occurs through point and non-points sources. Point sources contamination includes spills from underground storage tanks, pipelines, and gasoline spills; and potential non-point sources include precipitation, urban and industrial runoff, and motor-water craft (Squillace et al., 1996b; Jacobs et al., 2000).

2.4. *Contamination Problems*

MTBE is widely used for two purposes, as oxygenated fuel to reduce the carbon monoxide and ozone in the atmosphere, and to increase the efficiency of combustion in vehicles. Due to its dual use, MTBE is broadly used as a gasoline additive. Its widespread use translates to greater contamination of surface and groundwater. The U.S. Geological Survey (USGS) conducted two national surveys from 1999 to 2001 to obtain water quality data from different types of community water systems (CWS) (Grady, 2003). The results of those surveys confirmed the contamination of MTBE

nationally. MTBE was found in 36 states, with concentration from 0.1 to 17,800 micrograms per liter ($\mu\text{g/L}$), but in general, the concentration of the samples was less than 20 $\mu\text{g/L}$ (Grady, 2003; Delzer and Ivahnenko, 2003). The surveys were used to assess the risk factors for MTBE occurrence. Population density and the use of reformulated gasoline were found to be significant factors. Type of well, water supply and proximity to gasoline storage tanks were not associated with high risk factors. A higher MTBE occurrence was observed in surface waters (14 %) than in groundwater (5.4 %).

In the specific case of Puerto Rico, the USGS survey included samples from 14 CWS: 10 surface water systems and 4 groundwater systems. No occurrence of MTBE was detected above the laboratory minimum reporting level (MRL) of 0.078 $\mu\text{g/L}$. Since, the CWS sampled were located in areas of low MTBE use, and monitoring of MTBE is not required in PR, the findings of the survey did not discard an existence of a possible CWS contamination with MTBE.

MTBE contamination has, in fact, been reported at some gasoline refineries located in PR. The Chevron Phillips Chemical PR Core, Inc. located in Guayama, PR had detected MTBE in groundwater, with maximum concentration of 64 $\mu\text{g/L}$ in the shallow aquifer and 7.2 $\mu\text{g/L}$ in the deep aquifer (on and off-site). Natural attenuation is in use as MTBE treatment (USEPA, 2004a). Another refinery with MTBE is the Caribbean Petroleum Refinery located in the Luchetti Industrial Park, in Bayamón, PR, which measure a MTBE concentration of 652 $\mu\text{g/L}$ (USEPA, 2004b). In addition to these problems with MTBE contamination, PR confirmed 1,022 cases of underground storage tanks (UST) releases as by September 2005. Only 440 have been cleaned (USEPA, 2005).

In Puerto Rico, MTBE has also been detected in air. Two sites in PR have been annually studied; one is in Barceloneta and the other in San Juan (USEPA, 2004c). The main difference between these sites is the type of land-use category where they are located. The Barceloneta site is located mainly in an urban area. The San Juan

site is a commercial area. Lower MTBE air concentration ($0.58 \mu\text{g}/\text{m}^3$) was observed in Barceloneta, and a higher concentration ($1.15 \mu\text{g}/\text{m}^3$) in San Juan, PR.

2.5. MTBE Properties

MTBE is an oxygenated, volatile organic compound (VOC) derived from methanol (Squillace et al., 1995). As an oxygenate, MTBE has characteristic of ethers, making difficult and challenging its removal from water. Some of the physical and chemicals properties of MTBE are included on Table 2-1.

Table 2-1: Physical and Chemical Properties of MTBE

<i>Properties</i>	<i>Value</i>
CAS Registry Number*	1634-04-4
Molecular Structure	$\begin{array}{c} \text{CH}_3 \\ \\ \text{H}_3\text{C}-\text{O}-\text{C}-\text{CH}_3 \\ \\ \text{CH}_3 \end{array}$
Synonyms*	Tertiary-butyl methyl ether, t-butyl methyl ether, methyl t-butyl ether, 2-methoxy 2 methyl propane, 2-methyl-2 methoxypropane, methyl-1, 1-dimethylethyl ether, MTBE
Molecular Mass** (g/mole)	88.15
Boiling Point* (°C)	55 to 56
Melting Point** (°C)	-109
Flashpoint Temperature* (°C)	-2
Auto ignition Temperature* (°C)	373
Density* (g/mL)	0.740
Water Solubility** (mg/L) at 25 °C	23,200 to 54,000
Henry's Law Constant* at 25 °C	$0.026 (\text{cm}^3\text{w}/\text{cm}^3\text{g})$
Vapor Pressure*	27.6 kPa (4.05 psi) at 20 °C

* - Jacobs et al. (2000); ** - MSDS (Aldrich Chemical Co.)

2.5.1. Solubility

MTBE is a volatile organic carbon (VOC) which is less dense than water, and is highly soluble in water. Pure MTBE solubility is about 50,000 mg/L (milligrams per

liter) in water, but it can range from 23,200 to 54,000 mg/L. In comparison with others VOC at 20 °C, MTBE is more water soluble than others gasoline compounds (BTEX) like benzene (1,800 mg/L), toluene (530 mg/L), ethylbenzene (150 mg/L); and xylene, which is mostly insoluble in water (Parsons et al., 1999).

2.5.2. *Volatility*

Volatility is measured with the Henry's law constant, which describes tendency of a constituent to partition between aqueous and vapor phases. MTBE has a low volatility and low Henry's law constant, and consequently, MTBE has more affinity to stay in the aqueous phase. Compared with benzene, MTBE is 10 times less volatile from aqueous phase (Parsons et al., 1999).

2.5.3. *Adsorption (K_d)*

Absorption is the relative tendency of dissolved constituent to partition between the sorbed and aqueous phases; and it depends on fraction of organic carbon in soil (f_{oc}) and chemical organic-carbon partition coefficient (K_{oc}). MTBE will have more sorption to solids with high content of organic carbon, than to solids that presents none or minor organic content. Its sorption is, however, limited due to its high solubility in water (Jacobs et al., 2000). Because of the low sorption capacity of MTBE, it travels much faster than other gasoline components, like benzene, which has a K_{oc} approximately 7 times greater than MTBE (80 mg/L for benzene and 11 mg/L for MTBE; Parsons et al., 1999, Squillace et al., 1996a; Kinner, 2001).

2.5.4. *Taste and Odor*

MTBE has a distinctive unpleasant taste with a turpentine-like odor. With these characteristics, humans taste and odor can occur at lower concentrations, from 5 to 20

µg/L. The advisory level for MTBE is 20 µg/L, which coincides with this range of detection of this compound in drinking water (USEPA, 1997b).

2.5.5. Toxicological Properties

The toxicological property of a compound is classified according to the exposure. The routes of exposure of a substance are by breathing, eating, or drinking the substance or by skin contact. Exposure is determined from factors such as dose, duration, and type of exposure, as well as to age, sex, diet, lifestyle, state of health, personal trails and habits, and whether other chemicals are present.

The exposure of MTBE occur through skin contact, breathing contaminated air while pumping gasoline, breathing exhaust fumes while driving a car, breathing air near highways or in cities; drinking, swimming, or showering in water that has been contaminated with MTBE; and by receiving MTBE treatment for gallstones.

The MTBE that enters the body thru breathing is changed into other chemicals such as butyl alcohol, methyl alcohol, formaldehyde, formic acid, and carbon dioxide. These by-products leave the body by breathe out or in the urine (ASTDR, 1996). If the MTBE enters the body by other mechanisms, it transforms to acetone, tert butyl alcohol (TBA), methyl alcohol, formaldehyde and carbon dioxide (Jacobs et al., 2000). MTBE and its by-products leave the body in 1 or 2 days.

The effects of the toxicological properties of MTBE are widely known on animals, such as rats, mice, and rabbits (ASTDR, 1996). The most common effect of MTBE is on their nervous systems. Effects from inhaling high doses of MTBE includes becoming less active and staggered, losing balance, falling down, not being able to get up, and having partially close eyelids. Drinking high doses of MTBE resulted on some animals having diarrhea and irritation in their stomachs and intestines. The exposure of MTBE by skin contact irritated the skin of some animals. Rats and mice studies show a possible gastrointestinal irritation, liver, and kidney damage, and nervous system effects.

The effects of the toxicological properties of MTBE on humans are uncertain (USEPA, 1997b). Exposure of small amounts of MTBE through breathing for short periods may cause nose and throat irritation, headaches, nausea, dizziness, and mental confusion. There are no studies of the exposure of drinking MTBE contaminated water, but there are patients that have been treated for gallstone, and have shown MTBE-related toxicological symptoms. These patients are evidence that MTBE may cause minor liver damage, lower amounts of white blood cells, nausea, vomiting, sleepiness, dizziness, and confusion.

MTBE was found to cause cancer in animals. The exposure of high levels of MTBE by breathing for long periods may cause kidney cancer in rats, and liver cancer in mice (ASTDR, 1996; USEPA, 1997b). However, MTBE has at least 55 times less carcinogen toxicity than benzene, or another component of gasoline (Jacobs et al., 2000).

Although MTBE has been shown to cause cancer in animals, there are no studies on its potential to cause cancer on humans. Therefore, MTBE is classified as a possible carcinogen to humans. (USEPA, 1997b; ASTDR, 1996) The USEPA recommends that drinking water levels of MTBE do not exceed 4 milligrams per liter of water for an exposure of 1-10 days, and 3 mg/L for longer-term exposures. Moreover, in air, the American Conference of Governmental Industrial Hygienist (ACGIH) recommends do not exceed a concentration of 40 mg/L for an 8-hour workday, 40-hour workweek.

2.5.6. MTBE Degradation in the Environment

Degradation is the process in which a contaminant is reduced in concentration over time. Degradation of MTBE may occur naturally in the environment or may be man-induced. MTBE is introduced in the environment through leaking storage tanks, spills, emissions from industry and vehicles (Figure 2-1); when conditions are favorable for cloud formation MTBE is washed off the atmosphere to the surface by

precipitation. Otherwise, MTBE would remain in the atmosphere with a lifetime of approximately 4 days. The degradation of MTBE in the atmosphere can occur by the reaction with hydroxyl radicals (OH^\bullet) and by photolysis. Photolysis is the degradation due to the UV light and is limited because depends on the penetration of UV light from the sun. The degradation by hydroxyl radicals depends on the concentration of OH^\bullet . Because there is lesser amount of OH^\bullet in metropolitan areas there is less degradation by this means. If MTBE degradation occurs by OH^\bullet , it leads to formation of tert butyl formate (TBF), methyl acetate, acetone, TBA, and formaldehyde; moreover, if MTBE is degraded by photolysis leads to carbon dioxide and water. (Kinner, 2001; Jacobs et al., 2000)

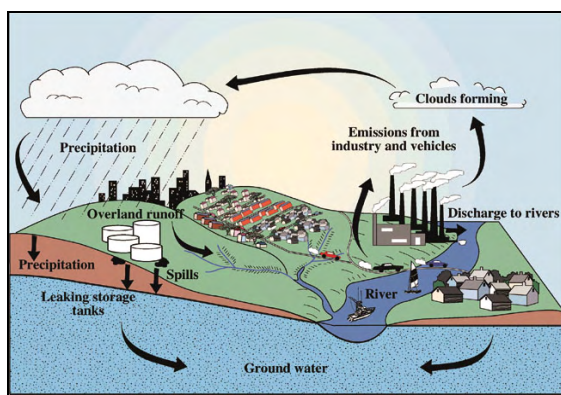


Figure 2-1: MTBE pathways in the environment

Source: <http://www.nwrc.usgs.gov/world/content/water1.html>

In addition to the MTBE contamination from storage tanks and spills, MTBE washed off the atmosphere by precipitation can reach the ground surface and subsurface resulting in a contamination of groundwater and surface water. Once in the land surface water, MTBE half-life is approximately 9 hours, but depending on the water velocity, water depth and temperature, it can also range from 4 weeks to 6 months. In the subsurface, MTBE can be degraded biotically, and by abiotic chemical reactions, which occur from non-biological processes. Abiotic degradation may occur through hydrolysis, photolysis, or photooxidation.

2.6. *Available Treatments for MTBE*

Different treatments options are currently available for the remediation of MTBE from water and subsurface (soil), including in-situ and ex-situ treatments. Remediation of MTBE from contaminated sites includes pump and treat, air sparging, phytoremediation, biodegradation, chemical oxidation, soil vapor extraction and adsorption system (Sutherland et al., 2004).

Optimal treatment of MTBE-contaminated groundwater depends on the MTBE concentration, and subsurface properties, such as permeability of the aquifer, and its alkalinity. Remediation of MTBE is expensive due to its distinctive characteristic of low volatility, high solubility and mobility, and resistance to biodegradation (Kinner, 2001; Jacobs et al., 2000).

2.6.1. *Natural Attenuation*

Natural attenuation occurs when the contaminant decreases the concentration in time without the application of any chemical treatment. This natural chemical treatment is dependable of the geology and soil characteristics of the site, and can be attributed to other mechanisms like adsorption, dilution, dispersion or biodegradation (USEPA, 2000).

Natural attenuation is a primary choice for MTBE treatment, specifically in some releases sites when is the most economical treatment available (Reisinger and Reid, 2001). Some researches (Reisinger and Reid, 2001; Schirmer et al., 2003; and Hristova et al. 2003) found that MTBE resist natural biological degradation when other fuel components (BTEX) are present inhibiting the degradation of MTBE. Therefore, dispersion is the primary attenuation mechanism for MTBE, followed by biodegradation (once BTEX are not present). Another important fact is that when natural attenuation occurs, it tends to be slow, limited by the slow growth of bacteria and long lag times needed before a removal of MTBE can be observed (Kinner, 2001).

2.6.1.1. Biodegradation

MTBE bioremediation involves the mineralization (converting it to carbon dioxide) by acclimatized bacteria. In addition, by cometabolism, this occurs when the microorganism uses MTBE as a sole carbon energy source, a degradation of MTBE can be observed (Kinner, 2001).

Reisinger and Reid (2001), Schirmer et al. (2003), and Hristova et al. (2003) found that MTBE competes with BTEX; they observed MTBE biodegradation when no other sources of carbon were present including BTEX. Reisinger and Reid (2001) suggest this as a reason for MTBE plumes to travel farther than other BTEX plumes.

Schirmer et al. (2003) investigated MTBE biodegradation in the Borden Aquifer in Canada after eight years from a slug injection of groundwater with dissolved oxygenate containing gasoline below the water Table. They found that aerobic toluene metabolism does not support MTBE removal. In addition, TBA, which is a by-product of MTBE under aerobic conditions, degraded faster than MTBE.

Hristova et al. (2003) documented a bacteria obtained from a biofilter effluent (PM1), which uses MTBE as a sole source of carbon and occurs naturally in MTBE contaminated ground waters. The MTBE biodegradation was observed approximately a year after MTBE was detected in the biofilter effluent. Moreover, the density of bacteria was related with the amount of oxygen and MTBE concentration in the sample. Hass II and Trego (2001) observed biodegradation of MTBE using a Hydrogen-Releasing Compound (HRCTM), a form of polylactate ester, which slowly releases biodegradation-stimulating constituent and increases the methanogenic conditions. Those findings confirmed findings by USEPA (2000) of MTBE biodegradation under methanogenic conditions (bacteria that produce methane) on a site contaminated by MTBE in North Carolina. Removal of MTBE at this site occurred after all BTEX compounds were removed. Therefore, the degradation of MTBE was observed after 490 days.

In summary, MTBE biodegradation is not favorable due to the very slow growing of bacteria as documented in all biodegradation cases. Additionally, biodegradation can only be used when the MTBE plume is stable and the remediation is not critical. Moreover, tert-butyl alcohol (TBA) was found to be the MTBE by-product using biodegradation treatment.

2.6.2. Pump and Treat

Pump and treat is used for removal of large quantities of MTBE by pumping water from the aquifer and treating it above ground. MTBE does not sorb in soil, leaving the larger amount of MTBE in water, consequently, pump and treat is an effective groundwater remediation scheme (USEPA, 1998c).

2.6.3. Air Stripping

Air stripping, which involves removing the contaminant by stripping it from water with an inert gas, is not economically feasible, because MTBE prefers to stay in the aqueous phase rather than the air phase. In situ air sparging involves injecting air into the ground to volatilize the compound and/or induces degradation. Air sparging effectiveness depends on the soil (i.e. homogenous sands) and is not economically feasible because of the low volatility of MTBE (USEPA, 1998c). Keller et al., (1999) reported that air stripping could be more effective in the removal of MTBE if the water to be treated is heated, and/or a reduction of the overall pressure of the air stripping system is made; these two situations cause an increase of the vapor pressure of MTBE, and not the solubility, increasing the Henry's constant.

The main problem of air stripping is that it's a transfer of MTBE contamination of one phase (liquid) to another (gas), as a result, two or more treatments are required to remove MTBE; one for water and another for the air discharged by the air stripping system.

2.6.4. Absorption

As air stripping, adsorption on activated carbon (AC) and/or in resins is a non-destructive process, which transfers the contaminants from one phase to another (Georgi and Kopinke, 2005). After saturation with MTBE occurs on the activated carbon, or in the resins, it needs to be regenerated by one of the treatments used for MTBE removal from water. In addition, the discharge air that exits the GAC column needs to be treated as well (Kinner, 2001).

Keller et al. (1999) pointed out several advantages of hollow fiber membranes over air stripping. Those advantages are related to the application of the treatment and the use of its waste materials. Some of these advantages are that the water and airflow rates can be controlled independently; therefore, a more efficient treatment of MTBE in the gas phase can be achieved. In addition, using lower airflow rates, smaller vapor-phase treatment units can be used. A removal efficiency of 90 % was achieved with only one pass through the system of hollow membranes. Davis and Powers (2000) studied the adsorption of MTBE to carbonaceous resins. The study attributes the polar oxygen molecule in MTBE to be the responsible to be hydrophilic than other hydrocarbons in gasoline. Carbonaceous resins (Ambersorb 563 and 572) were suggested as a feasible treatment for MTBE removal showing six times the sorption capacity of AC.

Anderson (2000) studied the use of zeolites, which are minerals that have a porous structure, to remove MTBE from water. The study focused on three different zeolites, with variants in their pore sized and $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios. Zeolites were chosen for their desired properties that make them attractive for MTBE removal; such as, the stability over a wide range of conditions. In addition, the zeolites can be generated with removal/destruction of MTBE by heating.

Georgi and Kopinke (2005) combined absorption with catalytic reactions for MTBE removal. The study concentrated in three variations of the modes of operation for sorption with AC and destruction with H_2O_2 , to take advantage of both treatment

processes. The differences of the three modes were in the order of application of the method (sorption and/or destruction). One of these modes was cycle two times for absorption of the contaminant followed by regeneration, the second one, was a simultaneous mode of sorption/destruction, and the third one was obtained using a quasi-simultaneous mode. Achievement of more than 50 % removal of the initial MTBE concentration for all cases was reported.

In general, the granular activated carbon (GAC) and/or resins treatment is good, but not economically feasible (USEPA, 1998c).

2.6.5. Chemical Oxidation

MTBE oxidation includes chlorine, ultraviolet radiation (UV), hydrogen peroxide (H_2O_2), ozone (O_3), and their combinations, like UV/ H_2O_2 , UV/ O_3 and Fenton's reagent (H_2O_2 and Fe (II)) (IT Corporation, 1997). The combinations are classified as advanced oxidation processes. Oxidation of MTBE using UV, UV/ H_2O_2 , and UV/ O_3 yields tert butyl formate (TBF) as major degradation by-product, but efficiently removes MTBE (<10 mg/L). Chlorine does not affect MTBE. Fenton's reagent is the most effective oxidation treatment yielding low concentrations of TBA and acetone, as degradation by-products. Fenton's reagent is affected by pH, alkalinity and permeability of the aquifer (more efficiency for pH between 2 and 4 and low alkalinity; Jacobs et al., 2000).

Another type of chemical oxidation is using potassium permanganate. Damm et al. (2002) studied the oxidation of MTBE by potassium permanganate and found that it takes place using different reaction paths, such as, electron exchange, hydrogen atom abstraction and direct donation of oxygen. Generally, this reaction is influenced by pH, temperature, solubility of target compound and the concentration of the compound. However, the mentioned study by Damm et al. (2002) did not notice any pH effect on the oxidation of MTBE by potassium permanganate, achieving MTBE

degradation in aqueous media up to 99 % between 356 to 3649 hours of treatment, which depends on MTBE initial concentration.

Lien and Zhang (2002) studied another oxidation treatment called bifunctional aluminum, which was obtained by sulfating aluminum metal with sulfuric acid. Using this bifunctional aluminum as the reductant, and dioxygen as the oxidant, a degradation of gasoline oxygenated was observed with a fast degradation of MTBE. MTBE by-products obtained from this treatment were TBF, TBA, methyl acetate, and acetone.

2.6.6. Advanced Oxidation Process

Advanced Oxidation Process (AOP) is based on the production of a powerful oxidant (hydroxyl radicals) that can remove the organic and inorganic contaminants from drinking water with the production of less harmful by-products than the original water matrix. Some of the AOP technologies use a combination of different technologies such as ultraviolet radiation (UV), ozone (O_3), hydrogen peroxide (H_2O_2), photo-Fenton (Fe^{2+}), and titanium dioxide (TiO_2). Combinations like UV/ O_3 , UV/ H_2O_2 , O_3/H_2O_2 , UV/ TiO_2 , and Fe^{2+}/H_2O_2 are currently evaluated for different drinking water treatments (USEPA, 1999; IT Corporation, 1997).

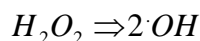
AOP systems have several advantages including the potential for treatment of inorganic and organic chemicals and the lack of formation of disinfection by-products. In addition, additional space for chemical storage is not required because the reaction species are generated on site. A disadvantage of AOP systems is that other disinfectants must be used to produce a residual disinfection due to the short life of AOP disinfectant reactive. Another disadvantage of the AOP system is the potential for interferences on the formation of hydroxyl radical by scavengers on the water matrix such as calcium, iron, manganese, and other organic/inorganic compounds (USEPA, 1999).

Degradation by-products of MTBE are the major problem on AOP water treatment. The degradation of MTBE by different advanced oxidation process generates many by-products that are not degradable by the same process. Generally, the by-products found in AOP include TBF, TBA, acetone, methanol, and formaldehyde (Chang and Young, 2000).

The most common reactions used in AOP systems are briefly described below.

2.6.6.1. *Hydrogen Peroxide (H_2O_2 ; Photo-Fenton (UV/H_2O_2))*

Hydrogen peroxide is used commonly in AOP systems studied because it yields the direct formation of hydroxyl radical as illustrated on the following formula (IT Corporation, 1997):



Zang and Fammod (2005) found that a combination of UV and H_2O_2 could degrade MTBE but not them alone. In addition, it was found that an excessive concentration of hydrogen peroxide, instead of degrading MTBE, it would act as the hydroxyl radical scavenger. Therefore, the degradation of MTBE depends on the right combination of UV and H_2O_2 .

In photo-Fenton technologies, the hydroxyl radicals are formed by two methods: the photolysis of $Fe(OH)_2^+$ and the reaction of Fe(II) with H_2O_2 . Recent investigations have shown that more hydroxyl radicals are formed in the presence of photo-Fenton than when hydrogen peroxide is used (IT Corporation, 1997). The main disadvantage of using Fenton reagent for MTBE removal is the requirement to lower the pH by acidification, which contaminates the sample with dissolved iron (Georgi and Kopinke, 2005). This situation does not occur with H_2O_2 in combination with O_3 or UV. Jacobs et al. (2000) specifies that the pH is a challenge in the application of Fenton's reagent; it is because the pH must be less than 5 for no occurrence of dissolved iron precipitates. However, there are reports that documented the

degradation of MTBE, with or without acidification; the difference was in the production of MTBE by-products, which leads to residual MTBE and some by-products for the sample without acidification.

Burbano et al. (2005) indicated as main advantage of H_2O_2 (Fenton) treatment the environmental friendly property, because it decomposes into oxygen and water, without producing any toxicity compound. In addition, it was found that the generation of MTBE by-products, iron oxidation, the production of hydroxyl radicals, and the degradation of the by-products generated by the treatment are related to the pH value of the sample. As an example, on pH 3, TBF and acetone were found as MTBE by-products; but, at pH 7, TBA and acetone, followed by TBF were found in order of abundance, as MTBE by-products. In another study, Burbano et al. (2002), found MTBE by-products, in order of abundance, to be TBF, acetone, TBA, and methyl acetate. From the same study, it was found the pathways of generation of MTBE by-products: TBA forms from the degradation of TBF; acetone is produced by hydroxyl radical attacks in MTBE, TBF and TBA. Besides, methyl acetate has a low reaction with hydroxyl radicals and is generated first and then degraded and TBA is generated after TBF.

2.6.6.2. *Ultrasound – Sonolysis, Photolysis, Catalysis and combinations*

Ultrasound (US) treatment works by ultrasonic waves, which forms cavitation bubbles in the liquid solution by compression and refraction cycles. After several cycles, the cavitation bubbles collapse producing an adiabatical reaction. From this reaction, in the interface of bubble/water, a contaminant experience thermal decomposition (Neppolian et al. 2002). As other treatments, the rate of degradation of MTBE depends on the initial concentration, and produced TBF and acetone as MTBE by-products. The combination of US and Fe/H_2O_2 leads to a higher removal of by-products, than using US alone. In addition, a complete degradation of MTBE occurs

after 3 hours of US and Fenton, but nearly half of the degradation for the treatment by themselves.

Kang and Hoffmann (1998) obtained better MTBE degradation using the combination of O_2 with US. This is due to the direct reaction of ozone and MTBE at the cavitation bubbles interfaces, where a high temperature relative to the ambient temperature exists and the reaction of ozone with MTBE is more effective. However, the reaction rates are limited by diffusion of OH or by the reaction of OH and MTBE. The O_3 -US treatment produces TBF, TBA, methyl acetate, and acetone as MTBE by-products.

Another study made by Bertelli and Selli (2004), utilized different combinations of photocatalysis (UV+ TiO_2), and sonolysis (US) to compare MTBE removal. The faster MTBE degradation was obtained using H_2O_2 + TiO_2 treatment producing TBF, TBA and acetone, as MTBE by-products. With US alone, TBF was not detected. Barreto et al. (1995) also found TBA and acetone as by-products of the photocatalytic degradation of MTBE in TiO_2 slurries. In addition, Sahle-Demessie et al. (2002), found TBF, tert butyl hydroperoxide, acetone, formaldehyde, acetic acid and formic acid. The main problem of photocatalytic is the requirement of a pre-treatment of the feed water and/or use air stripping to treat them in the gas phase. This pre-treatment is required in the presence of BTEX, or dissolved metals, and involves filtration, and pH adjustment to increase the effectiveness of the treatment (Sahle-Demessie et al., 2002).

2.6.6.3. *Irradiation*

Irradiation refers to the application of radiation and is used to ionizing the sample. These kinds of treatments that include gamma rays, electron beams or X-rays do not induce a state of radioactivity. The treatment consists of photons that penetrate the solid matter until a scatter of electrons from molecules occurs, and then the electrons destroy the pathogen DNA, or improves the material characteristics (USEPA, 1999)

2.6.6.3.1. *Radiolysis*

Radiolysis involves the application of radiation to dissociate molecules on the sample which can modify the solubility of the compound by locally modify redox conditions. The use of radiolysis by alpha radiation in water leads to the breakdown of water into hydrogen peroxide, hydrogen radicals, and oxygen compounds like ozone. Hsieh et al. (2004) and Wu et al. (2002) studied the remediation of MTBE using radiolysis. From those studies, TBF, TBA, acetone, and methyl acetate were found as MTBE by-products.

O'Shea et al. (2002) studied the gamma radiolysis of MTBE with N_2O/O_2 , in the presence of BTEX compounds, and found that MTBE degradation is slower, requiring much time to degrade than BTEX. Over time, the degradation of MTBE decreases because the hydroxyl radicals tend to degrade the reaction by-products first.

2.6.6.3.2. *Ultrasound Irradiation*

Water decomposes to hydrogen atoms and hydroxyl radicals under irradiation and with oxygen present in the sample, the hydrogen atoms react with oxygen to form hydroperoxyl radicals. Kim et al. (2002) applied ultrasound irradiation to remove MTBE yielding acetone, TBA, TBF, methyl acetate, formaldehyde, acetic acid, and formic acid as MTBE byproducts. However, by using ultrasonic irradiation and ozone, the MTBE byproducts were TBF, TBA, acetone, and methyl acetate; and with a saturation of oxygen in the sample, the byproducts observed were formaldehyde, acetone, TBF, TBA, methyl acetate, formic acid, acetic acid, and isobutylene. In only 21-25 minutes, MTBE can be degraded by ultrasonic irradiation under oxygen saturation conditions.

2.6.6.3.3. *Ultraviolet radiation*

Ultraviolet radiation (UV) works against viruses, bacteria, and pathogens by producing a photochemical reaction that damages irreparability nucleic acid of the cell (USEPA, 1999). It is necessary, however, to maintain darkness after the UV treatment because some bacteria regenerate with the sunlight (USEPA, 1999). The best germ inactivation occurs with a 254 nm (nanometers) lamp. UV is widely used in combination with others AOP, such as O_3 , because helps generating the hydroxyl radicals more quickly producing a better efficiency.

Several factors may cause UV treatment interferences and inefficient treatment ability. Most of the time, these factors are associated with particles that interfere with the lamp irradiation, either by covering the organism from the light or by covering the lamp. These interferences include suspended solids, turbidity, and chemicals that may form complex forms and precipitates such as calcium, magnesium, manganese and iron. Waters that contain high concentrations of iron, hardness, hydrogen sulfide, and organics compounds generally cause low efficiencies in UV disinfection (USEPA, 1999).

2.6.6.4. *Ozone*

Ozone (O_3) is a very powerful oxidant, which is a gas at ambient temperature. In water and wastewater treatment, O_3 has been used for disinfection, taste and odor control, iron and manganese removal, and turbidity and algal control. It also has the capacity to oxidize many organics and inorganic compounds in water, such as iron, nitrite, sulfide and cyanide ions to produce easily filtered materials (Rice, 1991). Some operational problems, however, may occur when the water matrix has carbonate and bicarbonate because they can precipitate affecting the removing capacity of organic matter (Langlais et al., 1991; Rice, 1991; Savoye et al., 2001).

Ozone is generated by different methods, including the Corona Discharge and electrolytic processes. The most widely used is the Corona Discharge (Langlais et al.,

1991; USEPA, 1999). The corona discharge method consists of passing an oxygen-containing gas through two electrodes separated by a dielectric and a discharge gap (USEPA, 1999). The electrodes provide sufficient energy to separate the electrons of the oxygen molecular and form the ozone (USEPA, 1999). The reaction of ozone with water produces hydrogen peroxide, which further reacts to form hydroxyl radicals. The necessary components to produce ozone are a gas feed system, an ozone generator, an ozone contractor and an off gas destruction system.

Ozone is unstable and has short life duration. Consequently, ozone cannot be used alone without other disinfectant because it does not meet the minimum residual level requirement for drinking water. An advantage of ozone, however, is that it requires less space than other water treatments systems because it is generate on site, thus avoiding additional storage space.

Ozone reacts as molecular ozone in pH less than 7 and as hydroxyl radical at pH greater than 8. Water with high levels of alkalinity, at neutral pH, bicarbonate ions scavenged hydroxyl radicals as they form, thus only remain molecular ozone. The same occurs with water with a pH 10.3, where the bicarbonate ions converts into carbonate ion, thus resulted in no oxidative effect no matter the concentration of ozone (Rice, 1991; Savoye et al., 2001). The oxidation of iron and manganese by ozone makes it necessary to do a filtration of insoluble materials. In addition, the oxidation of organic materials and aromatic compounds leads to aldehydes, ketones and acids. If amino acids are not oxidized by ozone, and then the water is chlorinated it could produce acetonitrile or chloroacetonitriles, acetaldehyde.

The removal of MTBE by ozone yields TBF, TBA, acetone, and formaldehyde as MTBE byproducts (Acero et al, 2001). Degradation of MTBE and its byproducts by molecular ozone is too slow to be used as drinking water treatment. Faster degradation occurs thru hydroxyl radicals, which are formed during the decay of ozone. A decrease in MTBE concentration is observed at pH 9 with addition of ozone in high doses, and in presence of alkaline waters, where ozone decomposes faster. Therefore, the water quality will influence the ozone concentration. The concentration

of HCO_3^- resulted in high alkaline waters; however, a high dissolved organic carbon in groundwater does not affect the concentration of ozone. The disadvantage of using ozone is the formation of bromate in water, which contains bromide. The production of bromate occurs as a function of ozone exposure, which is less affected by higher pH values (Acero et al., 2001; Baus et al., 2005).

2.6.6.5. *Ozone/H₂O₂ (peroxone)*

There are different studies using ozone and H_2O_2 for MTBE removal. The addition of hydrogen peroxide to ozone accelerates the formation of hydroxyl radicals by decomposing ozone that leads to a better degradation of MTBE (Baus et al., 2005; Rice, 1991). However, if H_2O_2 is added in excess, the H_2O_2 in excess scavenged the hydroxyl radicals, which cannot be able to degrade MTBE. Only a visible reduction of MTBE is observed at high initial concentration of ozone and H_2O_2 . In addition, using this treatment, Acero et al. (2001), and Burbano et al. (2005), found that the degradation of MTBE could not proceed completely without exceeding the standard for bromate.

2.6.6.6. *UV/Ozone*

The combination of UV/Ozone produces more hydroxyl free radicals than ozone alone because the UV enhances the oxidation of the ozone molecule. This is due to the high absorbency of radiation by the ozone at 254 nm that leads to a quick production of hydroxyl radicals from hydrogen peroxide generation (USEPA, 1999). Using UV/Ozone treatment, Graham et al. (2002) found that MTBE degraded into TBF, methyl acetate, acetone, butene, and acetaldehyde. An AOP package plant consisting of UV and ozone was used for this project.

2.7. Interferences on the UV/Ozone AOP Water Treatment

Table 2 lists interferences and potential by-products formed by UV and Ozone AOP. As previously mentioned, for the UV interferences, these potential interferences may result from the formation of precipitates that cover the lamp and prevent it from irradiating (USEPA, 1999). In addition, some interferences scavenge the hydroxyl radicals and may prevent oxidation of target compounds. Consequently, UV cannot oxidize the ozone molecule and the system will work as if ozone treatment was being used alone. If the water matrix contains organic matter, UV may cause the formation of formaldehyde and ozonation may form aldehydes and acids (USEPA, 1999). Additionally, if bromide ions are present, it will scavenge hydroxyl radicals and form the bromate ion, which is a regulated water quality parameter (USEPA, 1999).

Table 2-2: Treatment Interferences and By-Products Formation for UV/O₃

<i>Treatment</i>	<i>Interferences</i>	<i>By – Products</i>
UV	Calcium, Magnesium High concentrations of organics, Iron > 0.1 mg/L; hardness > 140 mg/L; hydrogen sulfide > 0.2 mg/L Turbidity, color Humic acids, phenolic compounds Chromium, cobalt, copper and nickel Suspended solids, sulfites, nitrites Iron and manganese precipitation	Trace of formaldehyde

Table 2-2: Continued

<i>Treatment</i>	<i>Interferences</i>	<i>By – Products</i>
Ozone	Iron and manganese precipitation Bromide ion Organic matter	Aldehydes: Formaldehyde, acetaldehyde, glyoxal, methyl glyoxal, oxalic acid, Acids: succinic acid, formic acid, acetic acid If water contains bromide: bromate ion, bromoform, brominated acetic acids, bromopicrin, brominated acetonitriles Hydrogen peroxide

Adapted from USEPA (1999)

2.7.1. *Water Quality Characteristics Dependence on Water Sources*

Water sources for non-PRASA communities include surface waters and groundwater. These two sources generally have different water quality characteristics (Table 2-3). Although it is generally thought that groundwater has better water quality than surface water, it has a high concentration of some components like dissolved solids, calcium, magnesium, iron, manganese, sulfate and chloride (Reynolds and Richards, 1996). These compounds may interfere with the AOP treatment.

This project evaluates the effectiveness of MTBE removal from groundwater. Groundwater was chosen because: (1) there is a greater percent of non-PRASA communities in groundwater than surface water; (2) groundwater is more likely to show MTBE contamination; and (3) groundwater has less sediments and less turbidity than surface water, which are known to interfere with UV/O₃ AOP treatment.

Table 2-3: Typical Water Quality Characteristics of Surface and Groundwater Water Sources

<i>Parameter</i>	<i>Groundwater</i>	<i>Surface Water</i>
Coliform counts	Low	Moderate to high
Total bacterial counts	Low	High
Turbidity	Low	Moderate to high
Color	Low	Variable
Taste	Pleasant	Variable
Odor	Low	Variable
Dissolved Solids	Moderate to high	Low to moderate
Radioactivity	Low	Variable
Dissolved Oxygen	Low	Variable
Carbon dioxide	Moderate to high	Variable

Modified from: Reynolds and Richards (1996)

2.8. *Costs*

The cost to remove MTBE varies depending on the treatment and site. Major treatments for MTBE are discussed in section 2.6. In summary, MTBE can be treated by using air stripping, GAC, biodegradation, and by AOP. Air stripping is not economically feasible due to the MTBE low volatility and Henry's constant, and the need to increase the cost of the treatment because an off gas treatment must also be employed (Sutherland et al., 2004; Sahle-Demessie et al., 2002). Air stripping and granular activated carbon are not destructive technologies, but only transfer MTBE from water media to another phase, which needs to be cleaned. In addition, this treatment is costly, because MTBE has a low affinity for carbon with high water solubility. As an example, to treat small concentrations of MTBE it requires large amounts of GAC (Jacobs et al., 2000; USEPA, 1998c).

Treatments of MTBE in the air include carbon adsorption, thermal and catalytic oxidation, biological treatment, and gas phase chemical oxidation (Sahle-Demessie et al., 2002), and the cost depends of the volume of air to treat. The GAC is the most

cost-effective off-gas treatment technology for concentrations less than 200 ppbv, and oxidation for higher concentrations. AOP has been used to treat MTBE-contaminated water (IT Corporation, 2002, Safarzadeh-Amiri, 2001). The treatment is influenced by the concentration of MTBE, dissolved organics, solution pH and alkalinity, suspended solids, and others. Because each AOP treatment is site specific, an evaluation decides, what treatment is more economical.

Safarzadeh-Amiri (2001) compared two AOP treatments, UV/H₂O₂ and O₃/H₂O₂ for different types of water, and concluded that O₃/H₂O₂ was the most economical by a factor of 4. The study found that the operating cost to treat 3785 L (1000 gal) of water increase more than doubled for the case of tap water and groundwater.

Sutherland et al. (2004) evaluated the removal of MTBE by air stripping, carbon absorption, and advanced oxidation using five groundwater sources that varies in water quality. The approximate treatment cost, without considering water flow, for four out of the five sources studied range between \$0.10 and \$1.20 per 1000 L for air stripping; from \$0.80 to \$4.60 per 1000 L for GAC; from \$0.20 to \$2.80 per 1000 L for UV/H₂O₂; and between \$0.30 to \$2.90 per 1000 L for O₃/H₂O₂. The results suggest that air stripping has the lowest treatment cost for high water flows, and AOP such as hydrogen peroxide, ozone, UV or combinations of them for low water flows (Jacobs et al., 2000; Sutherland et al., 2004).

3. Experimental Procedure

This project evaluates the operation, performance, and viability to implement an AOP package plant system in a non-PRASA community. It also evaluates the AOP efficiency and cost effectiveness for the removal of MTBE from drinking water sources of small, non-PRASA communities.

The objectives were accomplished through data collection and analysis at the community, field, and laboratory levels. At the community level, several non-PRASA communities were visited, interviewed, and surveyed. At the field level, groundwater sources from a selected community were sampled, collected, and stored for use in AOP evaluation. At the laboratory level, a system was designed and implemented to deliver the non-PRASA community groundwater to the AOP unit in the lab, measure MTBE removal efficiency for the unit, and evaluate the overall performance of the AOP package plant.

Data analysis was performed on two (2) sets of data: one is the data obtained by USEPA (IT Corporation, 2002) in Cincinnati, Ohio, and the other set of data was obtained from the laboratory experiments conducted in the Environmental Engineering Laboratory (EEL) at the Civil Engineering Department, University of Puerto Rico at Mayagüez.

The tasks involved in this project included field site selection, field sampling and water collection, laboratory and equipment design and work, data analysis, and system evaluation. Their description follows.

3.1. *Field Site Selection*

The field-site selection involved choosing non-PRASA communities using groundwater as a water source from a list of non-PRASA communities obtained from the PRDOH (Appendix 1). The selection of the non-PRASA community was based on location and proximity to the University of Puerto Rico at Mayagüez (UPRM), population served, and water treatment used if any. Thirteen (13) sites were visited

and evaluated (Appendix 2), based on potential for contamination, amount of water available, accessibility to point of use, and community approval. A questionnaire was prepared (Appendix 3) to collect information about the well dimensions and conditions, site accessibility, access to sampling and water collection at the point of entry of the system, amount of water available, and presence of contaminants or potential for contamination. The answers to the questionnaire are included in Appendix 4.

A non-PRASA community well was chosen in the Añasco town (Figure 3-1). The “Hatillo Community” (Figure 3-2) well was selected for the project AOP performance evaluation. This well is located on the 4401 Rd, Km. 1.0. From our evaluation, this well appears to have a large potential for the presence of contaminants (e.g. from septic systems) and treatment interference chemicals. The well was relatively close to Mayagüez, and served more than 200 people.

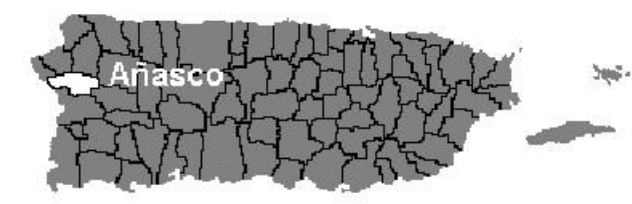


Figure 3-1: Location of Añasco Town, Puerto Rico



Figure 3-2: Communities in the Añasco Town

3.2. Field Sampling and Water Collection

The field water was analyzed on-site for temperature, dissolved oxygen, conductivity, oxidation/reduction potential, pH, total dissolved solids, chloride, ammonia and nitrate concentration measured with an HYDROLAB®. Field water sampling was done to characterize the major water quality components of the water used and verify that water quality characteristics remain the same while in storage. Field water samples were analyzed for the parameters given in Table 3-1. Field sampling involves collecting a given amount of sample in given containers and preserving them with appropriate chemicals. Table 3-2 lists the containers and preservation method used for given parameters.

Table 3-1: Analytical Methods

	<i>Method</i>
<u>Physical Properties</u>	
Turbidity	EPA 180.1
Acidity	EPA 305.1
Alkalinity	EPA 310.1
Hardness	EPA 130.2
Conductivity	EPA 120.1
Solids	
Total Dissolved Solids	EPA 160.1
Total Suspended Solids	EPA 160.2
Total Solids	EPA 160.3
Fixed and Volatile Solids	EPA 160.4
Temperature	EPA 170.1
Particle Counting and Size Distribution	Standard Method 2560
Oxidation Reduction Potential	Standard Method 2580B
<u>Metals</u>	
Cadmium, Calcium, Cooper, Iron, Lead	EPA 215.1, EPA 200.7
Magnesium, Manganese, Potassium, Sodium	
<u>Inorganic Nonmetallic Constituents</u>	
Bromide	Ion Selective Electrode
Carbon Dioxide	Standard Method 4500-CO ₂ D
Chloride	Standard Method 4500-Cl ⁻ D

Table 3-1: Continued

	<i>Method</i>
<u>Inorganic Nonmetallic Constituents</u>	
Chlorine (Free Residual)	HACH 10069
PH value	EPA 150.1
Nitrogen	
Nitrogen – Ammonia	Standard Method 4500-NH ₃ C
Nitrogen – Nitrite	HACH 8507/8153
Nitrogen – Nitrate	Standard Method 4500-NO ₃ ⁻ B
Oxygen (Dissolved)	EPA 360.1
Ozone (Residual)	HACH 8311
Sulfide	EPA 376.1
Sulfite	EPA 377.1
Sulfate	EPA 375.4
<u>Aggregate Organic Constituents</u>	
Total Organic Carbon	EPA 415.1
Dissolved Organic Carbon	EPA 415.1

Table 3-2: Field Sample Containers and Preservation Method for Given Water Quality Parameters

<i>Parameter</i>	<i>Containers</i>	<i>Preservatives</i>	<i>Maximum Holding Time</i>
<u>Physical Properties</u>			
Turbidity	G	None	Analyze Immediately
Acidity	P, G	Cool, 4 °C	14 days
Alkalinity	P, G	Cool, 4 °C	14 days
Hardness	P, G	Add HNO ₃ to ph < 2	6 months
Conductivity	P, G	Cool, 4 °C	28 days
Solids			
Total Dissolved Solids	P, G	Cool, 4 °C	7 days
Total Suspended Solids	P, G	Cool, 4 °C	7 days
Total Solids	P, G	Cool, 4 °C	7 days
Fixed and Volatile Solids	P, G	Cool, 4 °C	7 days
Temperature	P, G	None	Analyze Immediately
Particle Counting and Size Distribution	P, G	None	Analyze Immediately
Oxidation Reduction Potential	P, G	None	Analyze Immediately

Table 3-2: Continued

<i>Parameter</i>	<i>Containers</i>	<i>Preservatives</i>	<i>Maximum Holding Time</i>
<u>Metals</u>			
Total	P	Add HNO ₃ to pH < 2	6 months
<u>Inorganic Nonmetallic Constituents</u>			
Bromide	P, G	None	28 days
Carbon Dioxide	P, G	None	Analyze Immediately
Chloride	P, G	None	28 days
Chlorine (Free Residual)	P, G	None	Analyze Immediately
pH value	P, G	None	Analyze Immediately
Nitrogen			
Nitrogen - Ammonia	G	Cool, 4 °C, add H ₂ SO ₄ to pH < 2	28 days
Nitrogen – Nitrite	G	Cool, 4 °C	48 hours
Nitrogen – Nitrate	G	Cool, 4 °C	48 hours
Oxygen (Dissolved)	P, G	None	Analyze Immediately
Ozone (Residual)	G	None	Analyze Immediately
Sulfide	P, G	Cool, 4 °C, add 2 ml zinc acetate plus NaOH to pH > 9	7 days
Sulfite	P, G	None	Analyze Immediately
Sulfate	P, G	Cool, 4 °C	28 days
<u>Aggregate Organic Constituents</u>			
Total Organic Carbon	G	Cool, 4 °C, add H ₂ SO ₄ to pH < 2	28 days
Dissolved Organic Carbon	G	Filter on side, cool at 4 °C, add H ₂ SO ₄ to pH < 2	28 days

P = plastic, G = glass

Groundwater sampling requires purging the well for one to three well volumes before taken the water sample. The “Hatillo Community” well is 0.25 m (10 inch) in diameter and 45.72 m (150 ft) deep, yielding an estimated volume of 2.32 m³ (612 gallons). Because the “Hatillo Community” well is pumped every day from 2 pm and 7 am, and samples are to be taken shortly after, only one well volume was purged before sampling. This is because the purged water is pumped to the community storage tank and adding to much water may cause tank overflow and resource misutilization. After the well was purged, the water was collected using a 15.24 m (50

ft) hose of 0.012 m ($\frac{1}{2}$ inch) diameter in a 2.27 m³ (600 gallons) polyethylene tank. Once the tank was half-full, the water sampling was performed using sampling containers, preservatives, and the holding times given in Table 3-2.

After sampling, the 2.27 m³ (600 gallons) tank was filled and transported to the Environmental Engineering Laboratory at the Civil Engineering Department, University of Puerto Rico at Mayagüez. On the arrival of the 2.27 m³ (600 gallons) tank to the Civil Engineering Department the water was drained with three 7.62 m (25 ft) hoses (0.2 m ($\frac{3}{4}$ inch) diameter), placed into the tank and connected to three pumps (two pumps to Jabsco, model 12290-0001 and one to Jabsco, model 8050-7002). The water was pumped to a 3.78 m³ (1000 gallons) fiberglass tank outside of the Environmental Engineering Laboratory. This tank was lined with reflective and insulation material to minimize water temperature fluctuations and algae growth inside tank. Once the 2.27 m³ (600 gallons) was emptied, another water collection trip was done to bring more water, following the same procedure as described before. Water collection trips were repeated until all storage tanks in the Environmental Engineering Laboratory were full. These include a 0.76 m³ (200 gallon) polypropylene tank located inside the Environmental Engineering Laboratory, the 3.78 m³ (1000 gallons) fiberglass tank located outside of the laboratory, and a 2.27 m³ (600 gallons) polyethylene tank, also outside of the laboratory.

The 0.76 m³ (200 gallons) tank was connected to the 3.78 m³ (1000 gallons) tank through a series of pipes and tubes (described in the laboratory and equipment setup section). The water from the 2.27 m³ (600 gallons) tank was transferred to the 3.78 m³ (1000 gallons) tank as required. A total of 6.81 m³ (1800 gallons) were collected within a period of three days. A monthly water collection frequency was used to yield enough water for the experiments.

3.3. *Laboratory and Equipment Setup*

The facility setup for the Advanced Oxidation Process (AOP) plant in the Environmental Laboratory involved the design and construction of a water delivery system. This system starts with the 3.78 m³ (1000 gallons) tank located outside of the Environmental Engineering Laboratory. This tank was connected to a 0.76 m³ (200 gallons) tank inside the Environmental Engineering Laboratory through a series of PVC pipe (0.2 m [¾ inch]) section, unions, elbows, and shut-off valves (Figure 3-3 and Figure 3-4). A relay pump, (Jabsco, model 12290-0001), was used to enhance water delivery to the 0.76 m³ (200 gallons) tank, which was directly connected to the AOP plant (Figure 3-5). The purpose of this 0.76 m³ (200 gallons) tank was to acclimatize the water to the laboratory temperatures and avoid the reactions that could occur at the AOP plant due to temperature changes. The 0.76 m³ (200 gallons) tank was connected to the AOP plant through a (0.025 m [1 inch] OD) plumbing system consisting of check valves, shut-off valves and tees. The 1st tee is connected through a shut-off valve to two 0.21 m³ (55 gallons) tanks filled with dechlorinated tap water (carbon-filtered). This water was used to clean the AOP plant in between runs. After the 1st tee, there was another relay pump that delivers the well or dechlorinated water to the AOP plant. Contaminants are introduced, into the well water stream through a 2nd tee downstream of the relay pump. They were delivered through a mixing system consisting of a metering pump (Cole-Parmer® U-07104-72), a check valve and a 40 liters Teflon bag (Figure 3-5). Those contaminants were mixed with the non-PRASA community well water using an inline mixer of six elements (Cole-Parmer® 04669-14) prior to the inlet of the AOP plant. The schematic drawings of the water delivery system constructed are included in Appendix 5.



Figure 3-3: Plumbing System outside the Environmental Engineering Laboratory

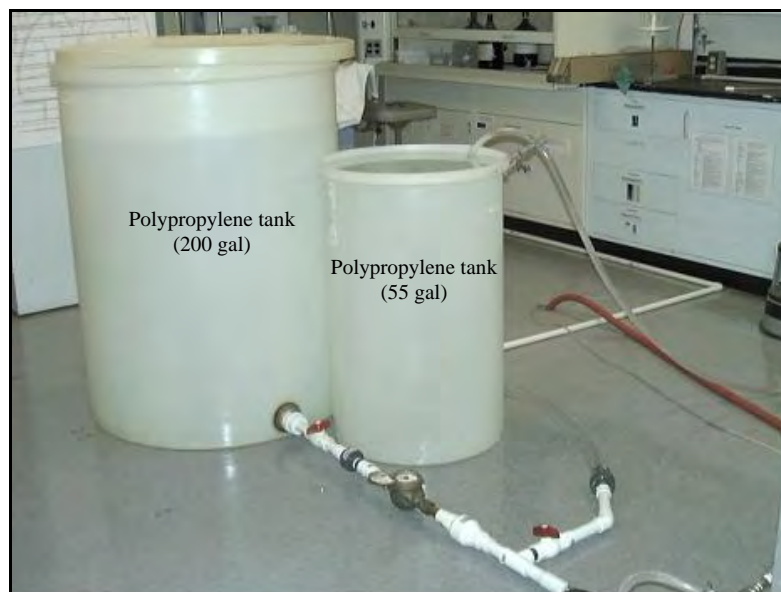


Figure 3-4: Plumbing System inside the Environmental Engineering Laboratory

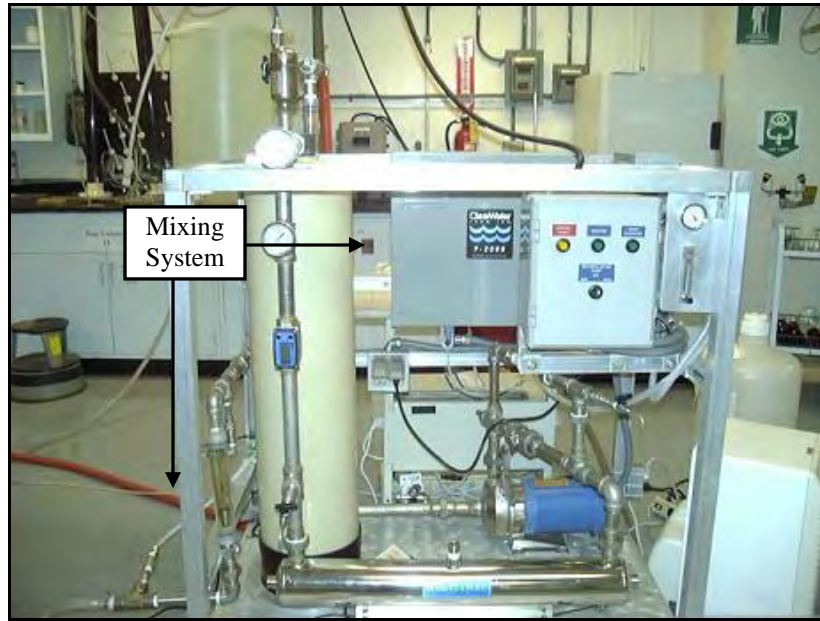


Figure 3-5: Plumbing System to the AOP plant and mixing system

3.4. *Experimental Evaluation*

The experimental evaluation on this project included a physical and chemical evaluation of the AOP plant. Different experimental and analytical methods were used to perform this evaluation and there are described on the following sections. A detailed description of the AOP plant operation is provided first, followed by the experimental methods used to evaluate it. Two AOP package plants are described. The “field unit” is the plant tested at UPRM. The “T&E unit” was used by the USEPA (IT Corporation, 2002). Data generated by the USEPA using both units was used in conjunction with experimental data obtained at UPRM to evaluate the AOP performance.

3.4.1. Advanced Oxidation Process Package Plant

The experimental work used an Advanced Oxidation Process package plant fabricated by the EPA Test and Evaluation (T&E) Facility in Cincinnati, OH. This AOP plant (Figure 3-6) was transferred from the T&E Facility to the Environmental Engineering Laboratory at University of Puerto Rico at Mayagüez on April 2002. The AOP plant uses ozone (O_3) and ultraviolet (UV) treatments, and a combination of both.



Figure 3-6: Field Unit UV/Ozone Treatment System Package Plant

3.4.1.1. AOP Plant Components and Operation

The AOP plant has different modes of operation: ozone, UV, and combined UV/Ozone. The plant is comprised of three principal system components: the ozone generation system, the UV system, and the water delivery system (Figure 3-7). The standard operation procedures of the AOP field unit plant used in the EEL are included in Appendix 6; those procedures were modified from IT Corporation (2001).

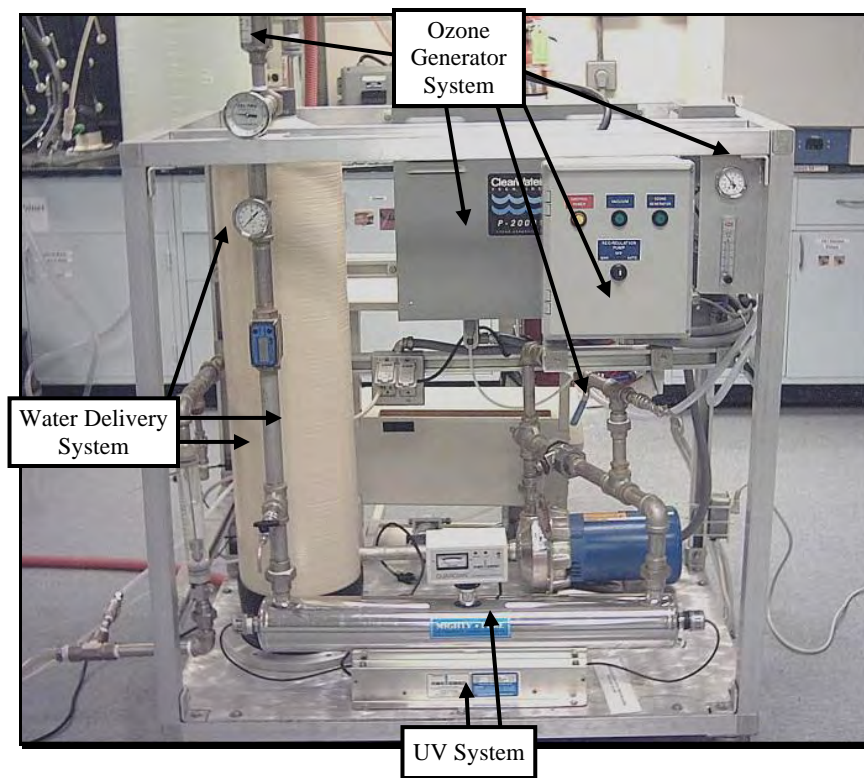


Figure 3-7: Field Unit AOP Package Plant Components

3.4.1.1.1. Ozone Generation System

The ozone generation system was used when the AOP plant was operated in ozone or UV/Ozone treatments. The AOP field unit plant includes the following components: an air dryer (model AD40); a ClearWater Tech P2000 Corona Discharge ozone generator; a Mazzei kynar venturi ozone injector; a 0.049 m^3 (13 gallons) contact chamber; an Armstrong Air Vent (model 11 AV), and an off-gas destruction system.

The air dryer has a flow capacity of $0.85 \text{ m}^3/\text{hr}$ [30 SCFH - standard cubic feet per hour], and is capable of lowering the dew point of the feed gas to $-51 \text{ }^\circ\text{C}$ ($-60 \text{ }^\circ\text{F}$) to provide clean, dry and contaminant-free air to the ozone generation. The principal function of the air dryer is to lower the dew point to less than $-55 \text{ }^\circ\text{C}$ because the

ability of the ozone generator to produce ozone is reduced above this temperature (IT Corporation, 2001). If the air dryer fails to lower the dew point, the amount of ozone produced will be a minimum and a moist feed air will cause nitric acid to form inside the generator.

The ozone generator has a specified maximum production of 5.6 grams O_3 /hr. The venturi injector injected ozone under vacuum conditions to transfer O_3 efficiently to the flowing water. The venturi injector works in conjunction with a check valve, injection valve, solenoid valve (Figure 3-8), and the air dryer. Any issues with these parts affect the operation and performance of the venturi injector. If the venturi fails it will create several problems to the AOP plant, some of them will have relation with ozone generator, air dryer and recirculation pump. The amount of ozone in the water stream will be reduced and an input of air will be introduced to the AOP plant. This air can damage the recirculation pump because it will operate with water and air at the same time. The air vent (Figure 3-9) transferred ozone and related gases to the off-gas destruction system (Figure 3-10), where ozone is collected, transformed to oxygen, and release to the atmosphere. The contact chamber provided a required contact time to achieve efficient treatment.

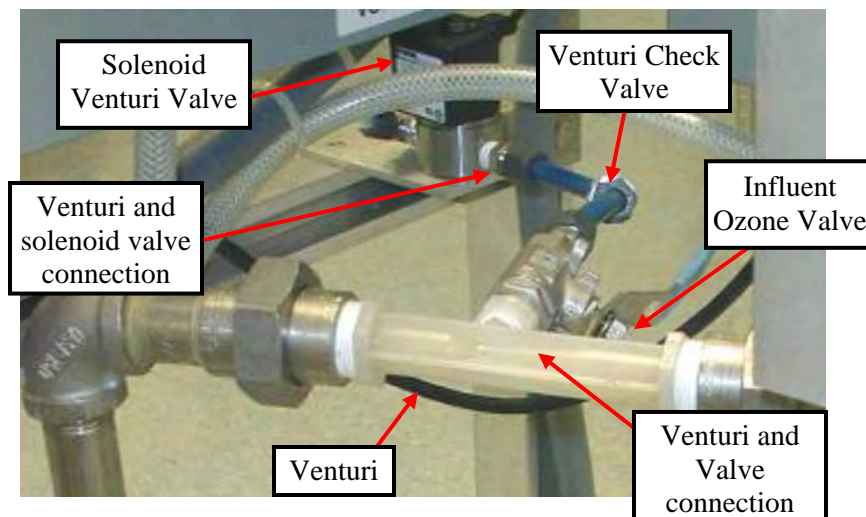


Figure 3-8: Ozone Generation System Components

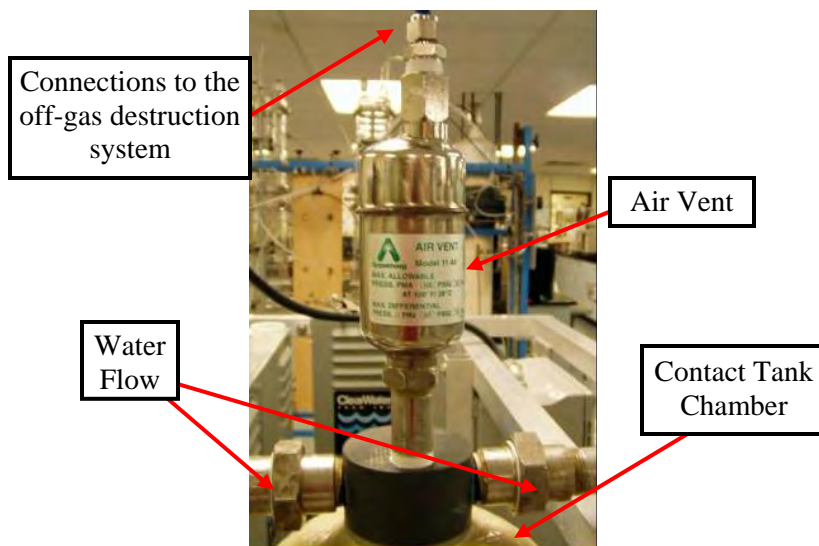


Figure 3-9: Air Vent in the AOP Field Unit Plant

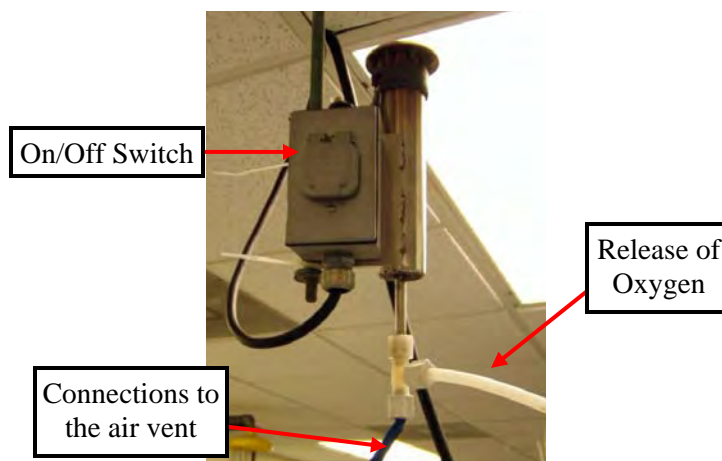


Figure 3-10: Off-gas Destruction System

The AOP T&E unit has all the above components for ozone generation, but has a different ozone generator. It has a Clearwater Tech model CD AD/15 Corona Discharge ozone generator with a maximum production of 4.5 grams O_3 /hr. The ozone generator differences includes the available amount of ozone to be delivered to the system, (4.5 vs. 5.6 grams O_3 /hr), in addition that the P2000 has a dual reaction chamber vs. a single reaction chamber of the CD15.

3.4.1.1.2. UV System

The UV system in the field unit AOP plant consists of an Atlantic Ultraviolet UV lamp (model MP36B) with a $0.045 \text{ m}^3/\text{min}$ (12 gal/min) capacity and a UV intensity monitor (Figure 3-11). In the T&E unit, the UV system is composed of a Trojan Aqua UV Advantage water sterilizer, with the same capacity of $0.045 \text{ m}^3/\text{min}$ (12 gal/min).

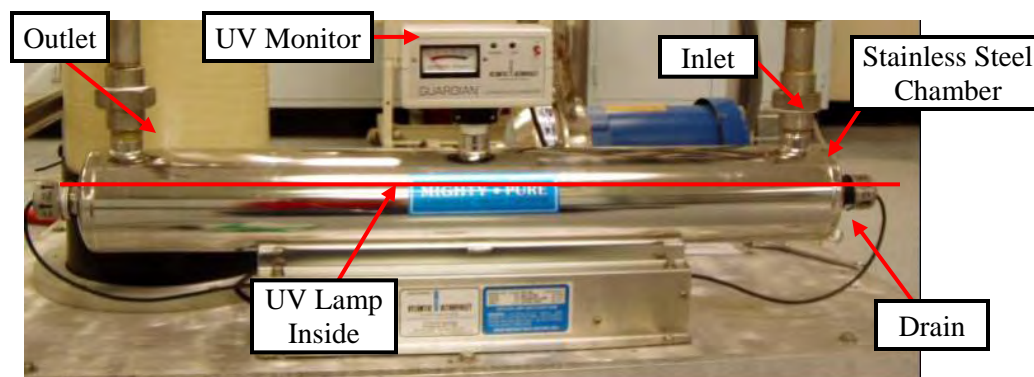


Figure 3-11: Field Unit AOP Package plant UV System

This UV is a cylindrical low-pressure 254-nm reactor. To provide the darkness and the contact time necessary to achieve a better disinfection treatment, the UV system and ozone system share the 0.049 m^3 (13 gallons) contact chamber. The UV system was used when the AOP plant was operated in UV and UV/Ozone treatments.

3.4.1.1.3. Water Delivery System

The water delivery system on the AOP plant includes the delivery of water to and from the AOP plant. This system begins with an inlet to the AOP plant of 0.020 m ($\frac{3}{4}$ in.) and continues with a loop of 7.92 m (26 ft) long and 0.025 m (1 in.) diameter 316 Schedule 40 stainless steel plumbing. The loop (Figures 3-12 to 3-14) has many check valves, a bypass valve, two regulating valves (influent and effluent), and a

recirculation pump (Franklin Electric feed pump of 372.85 W (½ HP) - model 1113007478). To monitor the water thru the system, a series of liquid flowmeters (influent, recirculation, and effluent from 0 to 0.08 m³/min [0 to 20 gal/min]), temperature gauges (°C), pressure gauges (psi), and vacuum gauges (inches Hg) are included in the unit. Improper operation of water delivery system may cause problems with recirculation pump, which affects other components.

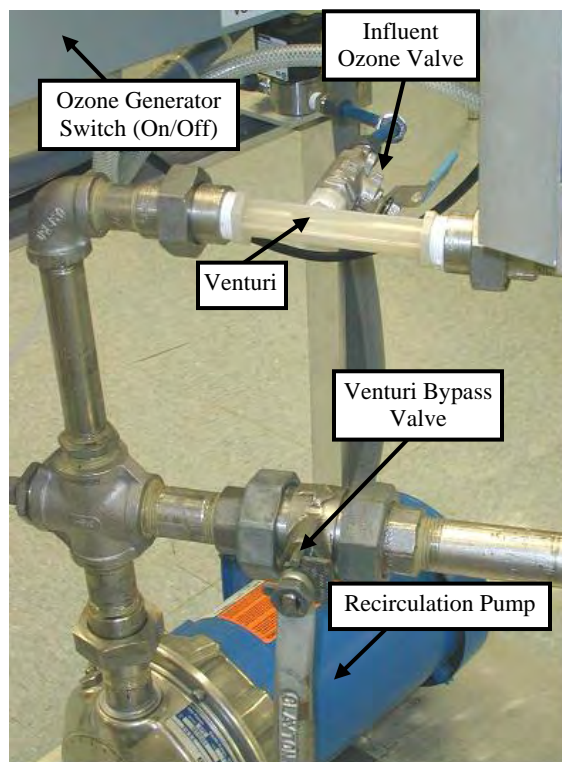


Figure 3-12: Field Unit AOP Package Plant Recirculation Loop

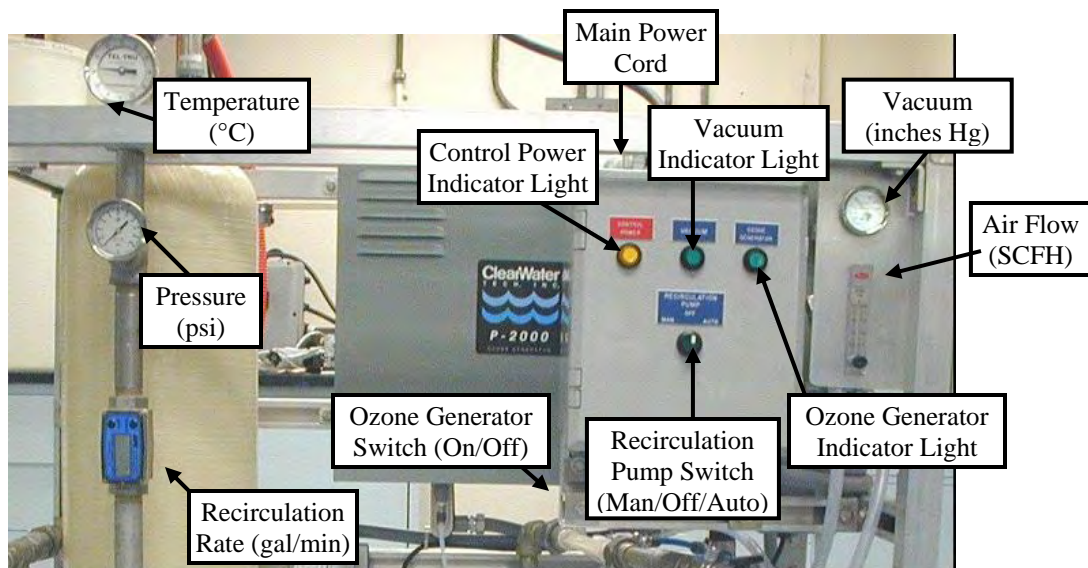


Figure 3-13: Field Unit AOP Package Plant Controls and Gauges

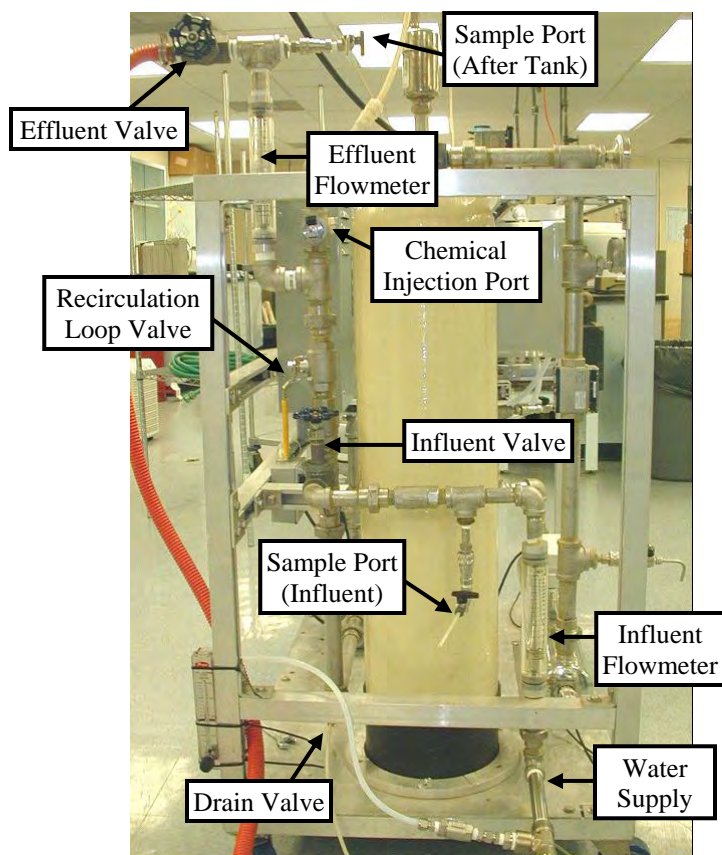


Figure 3-14: Field Unit AOP Package Plant Controls and Gauges

3.4.1.1.4. Electronics

The AOP plant includes an electrical interlock box that controls all the electrical operation of the AOP plant. If the electrical interlock box has a problem, all the system experiences it. The interlock box is named control panel and controls the ozone generator, recirculation pump and vacuum generation; it also controls parts of the air preparation system (air dryer) (Figure 3-15). Figure 3-16 shows the details of the electrical interlock box.

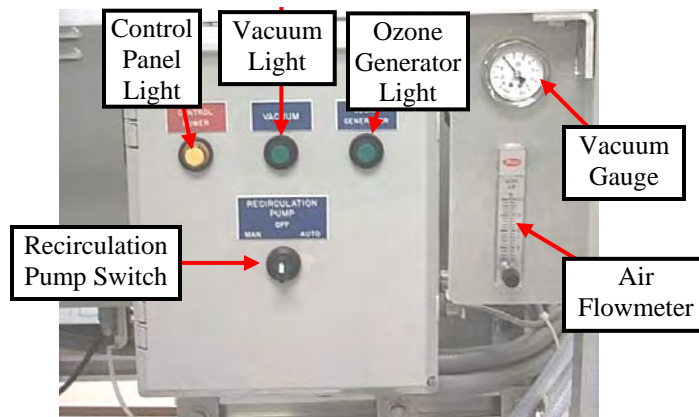


Figure 3-15: AOP Plant Electrical Interlock Box

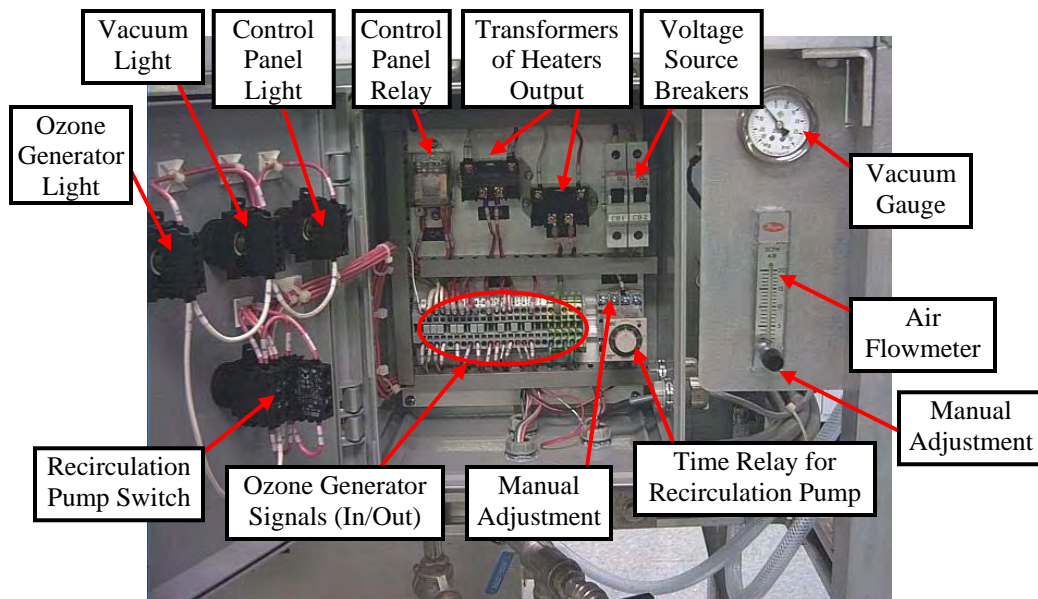


Figure 3-16: Details of the electrical interlock box

3.4.1.2. AOP Operation

The AOP plant has three different types of operation (treatments), including: closed loop (batch), single pass with partial recirculation (continuous flow), and single pass (continuous flow). Treatments types are produced with a combination of open/closed valves. For closed loop treatment, the influent and effluent valves are closed with the recirculation valve open. Single pass with partial recirculation has influent, recirculation, and effluent valves open. And, single pass has influent and effluent valves open with the recirculation valve closed. For this project, only the first two cases were considered (IT Corporation 2002).

3.4.1.3. AOP Plant Evaluation

As a principal objective of this project, a general and detailed evaluation of the AOP plant was done. This evaluation includes from the time when the plant arrives to UPRM to the time when finally was operated. The performance of the AOP plant was evaluated in terms of its physical implementation, as well as efficiency of chemical removal under the conditions tested.

To evaluate the physical performance of the plant, the parameters considered were the mobility of the system, proper operation, cost of operation, performance, and maintenance. For the chemical evaluation, the parameters considered were contaminant removal, and water quality treated. Several runs of the AOP plant were done specifically for the physical evaluation rather than for chemical evaluation in the EEL.

3.5. Experimental Methods

Different experiments were used to evaluate the AOP package plant. Those experiments were conducted by delivering the stored groundwater to the AOP plant, introducing MTBE to the system, and measuring the MTBE and related by-products

removal efficiency. These experiments were performed under different operational conditions, MTBE concentration, and treatment time. In addition, the AOP unit was operated in different modes, including no-treatment, ozone treatment, UV treatment, and UV/ozone treatment. The amount of data collected for the chemical efficiency evaluation is limited due to issues with the AOP system performance (discussed later at physical evaluation of the AOP plant). Consequently, the chemical evaluation removal efficiency used two sets of experimental data: one called at UPRM; and the other was obtained from a study performed by USEPA (IT Corporation, 2002) in Cincinnati, Ohio.

Different types of water were used for the experimental evaluation of the AOP plants. The experimental work conducted at the T&E Facility (IT Corporation, 2002) used different types of water: dechlorinated (city of Cincinnati) tap water, Mill Creek wastewater, East Fork Lake water, and C.M. Bolton well water. The main purpose of the water variability was to see the behavior of the AOP plant under different turbidities: <0.5 , 1, 2, and > 15 NTU (IT Corporation, 2002). In the case of the EEL data, the main purpose was to evaluate the AOP plant for non-PRASA communities using groundwater sources, which represent less than 0.5 NTU of turbidity.

Initially, the experimental runs in EEL were done using similar procedures of the experiments performed by the USEPA on the T&E Facility, in Cincinnati (as reported by IT Corporation, 1997). Later, those experiments were modified to the existing conditions at the EEL. These modifications included higher MTBE concentrations, lower sampling frequency, and the addition of metals analysis. In general, those experiments included the spike of MTBE at different concentration. For closed loop experiments, 40, 140, and, 200 μl spikes of MTBE were injected into a 57-liter water loop to produce concentrations of 500, 1800, and 2600 $\mu\text{g/L}$, respectively. Single pass with partial recirculation treatments were used only to evaluate the operation of the AOP plant without the injection of MTBE.

T&E experimental runs were done with MTBE concentration of 100, 300, 1200 and 3000 µg/L, for closed loop experiments; and with concentrations of 50, 100, and 1000 µg/L, for single pass with partial recirculation treatment.

Samples were taken at different intervals, depending on the treatment. The sampling volume and frequency for the experiments performed at the EEL are listed in Table 3-3, and only are for closed loop treatments. Table 3-4 lists the parameters for the T&E experiments, which includes closed loop and single pass with partial recirculation treatments.

Table 3-3: Sampling Volumes and Frequency in EEL data

<i>Parameter</i>	<i>Units</i>	<i>Sample Volume (milliliters)</i>	<i>Sample Frequency Closed- Loop</i>
PH	S.U.*		1,6,11,21,31,61
Turbidity	NTU**	1 x 50	1, 6,11,21,31,61
Contact Tank Ozone Concentration	mg/L O ₃	1 x 50	1,6,11,21,31,61
Venturi Injector Ozone Concentration	mg/L O ₃	1 x 50	1,6,11,21,31,61
MTBE and Degradation Byproducts	µg/L (ppb)	2 x 40	1,6,11,21,31,61
Total Organic Carbon	µg/L (ppb)		Raw 0, 61
Dissolved Organic Carbon	µg/L (ppb)	1 x 250	Raw 0, 61
Alkalinity	mg/L CaCO ₃	1 x 125	Raw 0, 61
Total Hardness	mg/L CaCO ₃	1 x 125	Raw 0, 61
Metals (calcium and iron)	mg/L	1 x 60	Raw 0, 61
Recirculation Rate	gpm	On-Line Meter	1,6,11,21,31,61
Air Flow into Ozone Generator	SCFH***	On-Line Meter	1, 6,11,21,31,61
Temperature	°C	On-Line Gauge	1, 6,11,21,31,61
Water Pressure	psi	On-Line Gauge	1, 6,11,21,31,61
Vacuum at the Venturi Injector	in. Hg	On-Line Gauge	1, 6,11,21,31,61

* - S.U. (Standard Units)

** - NTU (nephelometric turbidity unit)

*** - SCFH (standard cubic feet per hour)

Table 3-4: Sampling Volumes and Frequency used in T&E data

<i>Parameter</i>	<i>Units</i>	<i>Sample Volume (milliliters)</i>	<i>Sample Frequency</i>	
			<i>Closed- Loop</i>	<i>Single Pass with Partial Recirculation</i>
PH	S.U.*	1 x 50	1,2,3,4,5,6,11,21,31,61	Raw0, 5,10,15,20,25,Raw30
Turbidity	NTU**			
Contact Tank Ozone Concentration	mg/L O ₃	1 x 50	1, 6, 11, 21, 31, 61	Raw0, 5,10,15,20,25,Raw30
Venturi Injector Ozone Concentration	mg/L O ₃	1 x 50	1, 6, 11, 21, 31, 61	Raw0,5,10,15,20,25,Raw30
MTBE and Degradation Byproducts	µg/L	2 x 40	1,2,3,4,5,6,11,21,31,61	Raw0,5,10,15,20,25,Raw30
Total Organic Carbon	µg/L	1 x 40	Raw 0, 61	Raw 0, 15
Dissolved Organic Carbon	µg/L	1 x 40	Raw 0, 61	Raw 0, 15
Alkalinity	mg/L CaCO ₃	1 x 40	Raw 0, 61	Raw 0, 15
Total Hardness	mg/L CaCO ₃	1 x 40	Raw 0, 61	Raw 0, 15
Recirculation Rate	gpm	On-Line Meter	1,2,3,4,5,6,11,21,31,61	Raw0, 5,10,15,20,25,Raw30
Air Flow into Ozone Generator	SCFH***		1,2,3,4,5,6,11,21,31,61	Raw0, 5,10,15,20,25,Raw30
Temperature	°C	On-Line Gauge	1,2,3,4,5,6,11,21,31,61	Raw0, 5,10,15,20,25,Raw30
Water Pressure	psi		1,2,3,4,5,6,11,21,31,61	Raw0, 5,10,15,20,25,Raw30
Vacuum at the Venturi Injector	in. Hg	On-Line Gauge	1,2,3,4,5,6,11,21,31,61	Raw0, 5,10,15,20,25,Raw30

* - S.U. (Standard Units)

** - NTU (nephelometric turbidity unit)

*** - SCFH (standard cubic feet per hour)

Samples were taken at the contact tank sample port and the venturi injector sample port (Figure 3-17). The samples were analyzed for total organic carbon (TOC), dissolved organic carbon (DOC), alkalinity, turbidity, pH, MTBE, MTBE by-products, calcium, iron and others. Table 3-5 includes the sample containers and preservatives for the parameters that were analyzed. These analyses were done using the same methods listed in Table 3-1 and briefly discussed before.

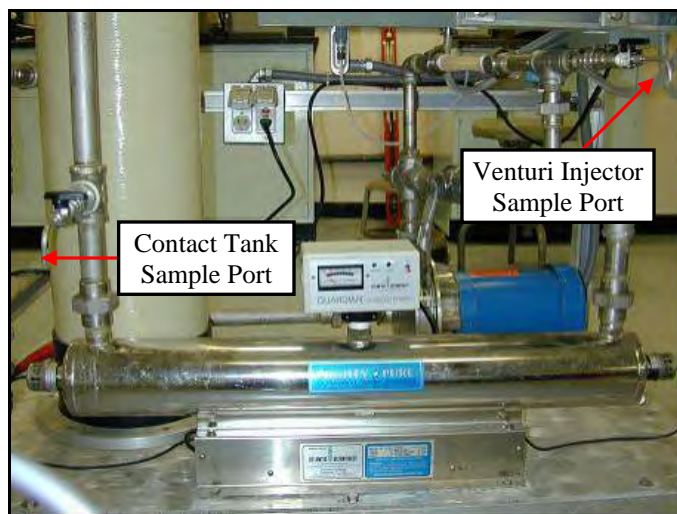


Figure 3-17: Sampling Ports on the Field Unit UV/Ozone Treatment System

Table 3-5: Experimental Sample Container and Preservation

<i>Parameter</i>	<i>Sample Container</i>	<i>Preservatives</i>
Turbidity	50 ml – glass beaker	No preservatives - analyze immediately
pH value	50 ml – glass beaker	No preservatives - analyze immediately
Total Hardness	125 ml – plastic bottle	No preservatives - analyze immediately
Alkalinity	125 ml – plastic bottle	No preservatives - analyze immediately
Total Organic Carbon	40 ml amber VOA* vial	2 drops of sulfuric acid and storage at 4°C
Dissolved Organic Carbon	40 ml amber VOA* vial	Filter, add 2 drops of sulfuric acid and storage at 4°C
Ozone (Residual)	50 ml – glass beaker	No preservatives - analyze immediately
Calcium, Iron	60 ml – plastic bottle	No preservatives - analyze immediately
Particle Count	125 ml – glass bottle	No preservatives - analyze immediately
MTBE	40 ml amber VOA* vial	25 mg of ascorbic acid and storage at 4°C

* - VOA (Volatile Organic Analysis)

3.6. Analytical Methods

The water characterization was done using the methods listed in Table 3-1. Briefly, samples that require filtration were placed in a cooler at 4°C until analyzed. They were filtered and acidified with HNO₃ before analysis. Acidity, alkalinity,

hardness, sulfite and sulfide concentration were measured using titrimetric analysis as described in USEPA (1983), Clesceri et al. (1998), and HACH (1998). Sulfate and turbidity were measured with a HACH Turbidimeter 2100 A. Bromide, ammonia, and chloride were measured with their respective ion selective electrode using a Corning – pH/ion analyzer 455, and a Thermo Orion pH/ion analyzer 720A. Metals were analyzed using an atomic absorption spectrometer (SOLAAR 32 – UNICAM 969) with direct aspiration as flame type and using an Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES Leeman Labs DRE). Nitrate concentrations were analyzed using a HACH 2100 Spectrometer. Total, and dissolve organic carbon were measured using a UV–Persulfate TOC Analyzer (Dohrmann’s Phoenix 8000). Particle counting and size distribution was done using a Liquid Particle Counting System (HIAC Royco – Model 9703 of Pacific Scientific) for the results from EEL, and for the T&E a Met1 particle size analyzer was employed. Volatiles organic compound concentrations were measured using a Gas Chromatograph (GC) equipped with a Flame Ionization Detector (GC/FID – Perkin Elmer Autosystem) in the case of EEL; for T&E results, a Gas Chromatograph (GC) equipped with a Flame Ionization Detector (GC/FID) with purge and trap extraction.

3.6.1. Analysis of Volatile Organic Carbon

Approved methods for the determination of MTBE are EPA 502.2 or EPA 524.2. These methods consist of purge and trap with gas chromatograph (GC) equipped with a photoionization and or mass spectra detectors respectively. Other methods such as EPA 8260, EPA 8020A/8021B and a modified version of the American Standard for Testing and Materials (ASTM) D4815 are also used but have not been validated (Jacobs et al., 2000). Modifications on the extraction procedure including direct aqueous injection (DAI) and Solid Phase Microextraction (SPME) have also been used (Church et al, 1997; Piazza et al.; 2001 and Cassada et al., 2000). The DAI method requires the injection of 10 μ L of water directly into the GC injector (Church et al.,

1997). SPME is a solvent-free method that incorporates the sampling, extraction, concentration, and sample introduction in a simple step (Zhang et al., 1994). SPME removes the sample components by absorption to a fibers resulting in equilibrium with the sample and a better proportionality (Supelco Inc., 2001). With the DAI method, the minimum detection limit (MDL) for MTBE has been reported to be 0.1 µg/L (micrograms per liter) using a GC/FID (Church et al., 1997). For SPME, a MDL of 14 µg/L is accomplished by sampling the headspace (Piazza et al., 2001), whereas, MDL of 0.008 µg/L was found for aqueous sampling (Cassada et al., 2000) using both GC/MS.

MTBE and by-products were analyzed using the Solid Phase Micro-Extraction (SPME) technique in aqueous solution and a Gas Chromatograph (GC) equipped with a Flame Ionization Detector (GC/FID – Perkin Elmer Autosystem). The detailed method employed is explained in the following sections.

3.6.1.1. Analysis of MTBE and MTBE by-products at EEL

The AOP plant was previously evaluated on the EPA Test and Evaluation (T&E) Facility in Cincinnati, OH from February 2000 to June 2001 (Graham et al. 2004). From that evaluation, the major MTBE degradation by-products found were tert-butyl formate (TBF), methyl acetate, acetone, butene, and acetaldehyde. Using the same approach, those MTBE by-products were analyzed in the EEL with the exception of butene. A combination of the methods used by Cassada et al. (2000) and Graham et al. (2004) was followed, and it is explained in the analysis procedure section.

3.6.1.1.1. Materials

The MTBE and related by-products analysis performed at the Environmental Engineering Laboratory included acetaldehyde, methyl acetate, TBF and acetone. Acetaldehyde (99.5 % GC), methyl acetate, anhydrous (99.5 %), TBF (99.5 %) and MTBE (99.8 % HPLC grade) was obtained from Aldrich Chemicals (Milwaukee, WI).

Acetone (HPLC grade) was obtained from Fisher Scientific. Sodium chloride (certified A.C.S. grade) was purchased from Fisher Scientific and heating overnight at 105 °C. Purified water was obtained by passing distilled water through a Barnstead 4-Module Nanopure cartridge system. Vials and septas were obtained from Alltech®. A Zebron DB-624 column (6 % Cyanopropylphenyl – 94 % methylpolysiloxane) of 0.53 mm x 3.0 µm x 60 m was obtained from phenomenex® and installed in the GC/FID Perkin Elmer Autosample. A SPME liner injector of 0.75 mm was purchased from Supelco® to fit the GC. The 50/30-mm DVB Carboxen PDMS SPME fibers and manual holder was purchased from Supelco®.

3.6.1.1.2. Analysis Procedure

The analysis protocol used on this project was a combination of Cassada et al. (2000) and Graham et al. (2002), adapted to the conditions and equipments available at the Environmental Engineering Laboratory.

The analysis of the samples was conducted using VOA vials. The average volume for the 40 ml VOA vial was estimated as 43.1 ml with a standard deviation of 0.09 ml. From the total volume of 43.1 ml, 30 ml of this volume was used for the aqueous sample and 13.1 ml for headspace volume.

A stock standard was prepared for each organic compound analyzed. This stock was obtained by placing 30 ml of deionized (DI) water by pipette (class A) into a 40 ml VOA vial and adding with a syringe approximately 5 µl of the organic compound of interest (for i.e. acetone, MTBE, TBF, and methyl acetate). Due to the high volatility of acetaldehyde and lower boiling point (21 °C) it was difficult to obtain 5 µl of pure acetaldehyde by syringe and a different procedure to prepare the stock standard was followed. Acetaldehyde stock standard was obtained by adding a drop of pure acetaldehyde into the 30 ml DI water using a disposable FisherBrand Pasteur pipette. For all organic compounds, the stock concentration was obtained by difference in weight and total mass concept (equations 1 to 5), assuming partition in

water and air. The properties of the organic compound utilized to prepare the standards are summarized in Table 3-6.

$$M_{\text{Total}} = M_{\text{air}} + M_{\text{water}} \quad (1)$$

$$M_{\text{Total}} = C_{\text{air}} V_{\text{air}} + C_{\text{water}} V_{\text{water}} \quad (2)$$

$$M_{\text{Total}} = K_H C_{\text{water}} V_{\text{air}} + C_{\text{water}} V_{\text{water}} \quad (3)$$

$$C_{\text{water}} = \frac{M_{\text{total}}}{K_H V_{\text{air}} + V_{\text{water}}} \quad (4)$$

where:

M = mass; C = concentration; V = volume; K_H = Henry's Constant

$$K_H = \frac{C_{\text{air}}}{C_{\text{water}}} \quad (5)$$

Table 3-6: Properties of the analyzed organic compounds

<i>Organic Compound</i>	<i>CAS No.</i>	<i>Formula</i>	<i>Molecular Weight</i>	<i>Vapor Pressure (atm)</i>	<i>Henry's Constant</i>
Acetone	67-64-1	C ₃ H ₆ O	58.08	0.2434	0.0017
Acetaldehyde	75-07-0	C ₂ H ₄ O	44.05	0.9737	0.0027
Methyl Acetate	79-20-9	C ₃ H ₆ O ₂	74.08	0.2237	0.0028
MTBE	1634-04-4	C ₅ H ₁₂ O	88.15	0.3289	0.0260
TBF	762-754	C ₅ H ₁₀ O ₂	102.1	0.1066	0.0111

*Data obtained from the MSDS of the organic compound

The calibration standards were prepared by adding a specific amount of the stock standard to a 40-mL-VOA vial. First, the total mass required to obtain the desired water concentration was calculated using equation 3. Then, this value was substituted on equation 6 to obtain the volume of stock standard to be added to the vial. A Microsoft Excel[®] Spreadsheet was used to make the stock concentration and standards (explained on Appendix 7).

$$\mu\text{l of stock} = \frac{\text{Total Mass } [\mu\text{g}]}{\text{Stock Concentration } [\text{mg/l}]} \times 1,000 \quad (6)$$

A standard calibration vial was prepared by adding 7.5 grams of sodium chloride (about 80 % of saturation or 25 % w/w), 30 ml of DI water using a volumetric pipette and a miniature magnetic stirrer. The water was left acclimatizing in the vial (~30 minutes), the vial was weighted, the known volume of stock standard was added, and the vial was placed in a magnetic plate until all the sodium chloride was dissolved in the solution. Once the solution was completely homogeneous, the vial was retired from the magnetic plate and left to reach equilibrium in the air and water phase (approximately 30 minutes). Then, the vial was weighted again and the difference in weight gives the real concentration (equation 4) of the standard calibration.

The extraction of MTBE and MTBE by-products was using a SPME fibers 50/30-mm DVB Carboxen PDMS (Supelco®) on the aqueous phase, and desorbing the compounds from the SPME fiber in the GC injector. The GC/FID program involves splitless injection as done by Cassada et al. (2000). The SPME fiber was conditioned at 240 °C for fifteen (15) minutes in an idle GC (GC/FID/TCD - Buck Scientific – Model 910) inlet, and allowed cooling for one minute before inserting on the sample. An extraction time of 60 minutes was used as suggested by Graham et al. (2002) with desorption time of three minutes at 240 °C. The GC program consist in holding the oven temperature at 40 °C for 4 minutes, increasing it to 240 °C at a rate of 10 °C/min, and holding it for 10 minutes, for a total time of 34 minutes.

3.6.1.1.3. Method Calibration

A routine calibration protocol of the organics compounds analyzed in the Environmental Engineering Laboratory was developed, as described on Appendix 7. The organic compounds analyzed were acetaldehyde, acetone, methyl acetate, tert-butyl formate and MTBE. This analysis was done using two different manual holders

with their respective SPME fibers. A calibration curve was prepared for each fiber and organic compound. The calibration curve for MTBE by-products consisted of four points with a linear regression and forced origin. For acetone, methyl acetate and acetaldehyde the concentration range used were between 0 $\mu\text{g/L}$ and 100 $\mu\text{g/L}$. TBF calibration curve enclosed the range between 0 $\mu\text{g/L}$ and 500 $\mu\text{g/L}$. MTBE calibration curve consisted of five points of linear regression with forced origin and depended on the target concentration in the AOP plant, as specified in Table 3-7.

Table 3-7: MTBE calibration curve depending of AOP plant target concentration

<i>AOP Operation Mode</i>	<i>MTBE Target Concentration ($\mu\text{g/L}$)</i>	<i>Calibration Curve Concentration ($\mu\text{g/L MTBE}$)</i>
Closed Loop	500	0, 50, 100, 300, 500, 600
	1800	0, 100, 500, 1000, 1500, 2000
	2600	0, 1000, 1500, 2000, 2500, 3000

3.6.1.2. Analysis of MTBE and MTBE by-products at T&E Facility

As mentioned before, the AOP plant was previously evaluated on the EPA Test and Evaluation (T&E) Facility in Cincinnati, OH from February 2000 to June 2001 (Graham et al. 2000). Tert-butyl formate (TBF), methyl acetate, acetone, butene, and acetaldehyde were found as the major MTBE degradation by-products.

The T&E Facility used two different methods for MTBE and by-products analyzes. One of the analysis protocol used is the one explained in Graham et al. (2002), which was modified to use in the EEL. The other one is using the EPA Method 502.2, “Volatile Organic Compounds-Water/Purge and Trap” (USEPA, 1995), as explained in IT Corporation (2002).

4. Results and Discussion

As described in Chapter 3, the experimental evaluation on this project included a physical and chemical evaluation of the AOP plant. This chapter addresses the evaluation of the AOP plant. First, a description of the field site in terms of location and water quality is introduced. Then, a physical evaluation, which includes maintenance, performance, and operation by plant component, is discussed. Chemical evaluation focuses on the removal efficiency of MTBE. In addition, others parameters like the cost effectiveness of removing MTBE from drinking water sources of small, non-PRASA communities, difficulties in operate the AOP plant, and viability to implementing this AOP plant system in a non-PRASA community are presented. The data analysis to evaluate those parameters was achieved by comparing it under different scenarios.

4.1. Field Site Description and Water Characterization

The selection of the Hatillo's Community as field site for the AOP evaluation was done in July 2002. The "Hatillo Community" well was selected because of the proximity to Mayaguez, number of population served (>200), potential for contamination (e.g. from septic system and nearby gas stations), and accessibility to site. The well located on Rd 4401, Km 11.0, is easily accessible by truck, yields enough water for collection, and had sampling ports. The well is located in a zone of volcaniclastic rocks (blue color - Figure 4-1).

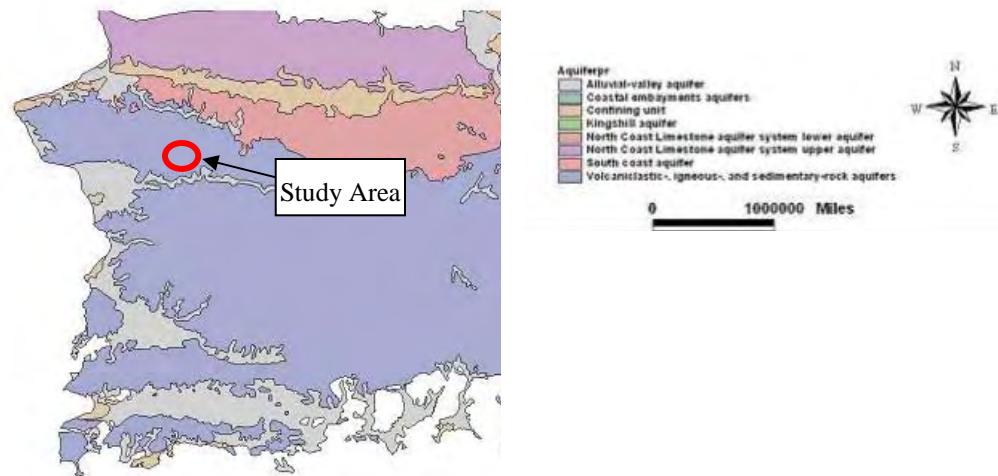


Figure 4-1: Description of Aquifers on the western Puerto Rico
 Data source: http://water.usgs.gov/GIS/metadata/usgswrd/XML/aquifers_pr.xml

4.1.1. Water characterization in field

The field water was analyzed on-site for temperature, dissolved oxygen (DO), specific conductivity (SpC), oxidation/reduction potential (ORP), pH, total dissolved solids (TDS), chloride (Cl^-), ammonia (NH_4) and nitrate (NO_3^-) concentration measured with an HYDROLAB[®]. At different dates, the Hatillo well water was collected and the parameters mentioned before were measured (Table 4-1). Generally, the water had a low DO content, showed a fairly neutral pH, and relatively low TDS. Nitrate concentration was however fairly high. This was potentially due to contamination from nearby septic tanks. Appendix 8 has these parameters for others visited non-PRASA communities.

Table 4-1: Hatillo well water field characteristics using an HYDROLAB®

<i>Date</i>	<i>TEMP</i> °C	<i>DO</i> mg/L	<i>NH4</i> <i>TOTAL</i> mg/L - N	<i>CL-</i> mg/L	<i>PH</i> s.u.	<i>NO3-</i> mg/L - N	<i>SAL</i> ppt	<i>ORP</i> mV	<i>SpC</i> mS/cm	<i>TDS</i> g/L
May 8, 2003	26.49	3.09	0.42	55.26	7.12	10.52	0.33	----	0.6356	0.4068
Oct 15, 2003	26.63	4.04	0.54	32.04	7.07	3.15	0.33	429	0.6507	0.4165
Dec 15, 2003	26.54	4.30	0.51	51.07	7.24	28.48	0.35	370	0.6778	0.4337
Dec 18, 2003	26.64	3.5	0.42	20.77	7.15	26.36	0.35	362	0.6765	0.4329
Average	26.58	3.73	0.47	39.79	7.15	17.13	0.34	387	0.6602	0.4225

4.1.2. Water characterization in laboratory

Field water sampling was done to characterize the major water quality components of the water used and verify that water quality characteristics remain the same while in storage. Field water samples were analyzed for the parameter given in chapter 3, and are summarized in Table 4-2.

Table 4-2: Water Characterization

	<i>Result</i>
<i>Physical Properties</i>	
Turbidity	0.00 NTU
Alkalinity	288.33 mg/L as CaCO ₃
Hardness	290 mg/L as CaCO ₃
Conductivity	0.6285 µs/cm
Total Dissolved Solids	368 mg/L
Total Suspended Solids	28.5 mg/L
Total Solids	396.5 mg/L
Fixed and Volatile Solids	0 mg/L
Temperature	27 °C
Oxidation Reduction Potential	536 mV

Table 4-2: Continued

	<i>Result</i>
<i>Metals</i>	
Cadmium	0.06 mg/L
Calcium	217 mg/L
Copper	0.00 mg/L
Iron	0.00 mg/L
Lead	0.00 mg/L
Magnesium	11.40 mg/L
Manganese	0.06 mg/L
Potassium	0.65 mg/L
Sodium	20 mg/L
<i>Inorganic Nonmetallic Constituents</i>	
Bromide	0.36 mg/L
Carbon Dioxide	260.7 mg/L
Chloride	23.55 mg/L
Chlorine (Free Residual)	0 mg/L
Ph value	7.07
Nitrogen – Ammonia	0.43 mg/L-N
Nitrogen – Nitrite	1.00 mg/L-N
Nitrogen – Nitrate	2.53 mg/L-N
Oxygen (Dissolved)	3.38 mg/L
Total Organic Carbon	0.52 mg/L-C

The overall analysis indicates that the well water is high in calcium and CO₂. It supports the field data on pH, DO, and to some degree NO₃⁻. The presence of relatively high Ca⁺⁺ and CO₂ concentrations was reflected in the water collected at the well and stored in several tanks at the EEL. Water in storage tanks developed a fine film on water and tank surfaces. In the 0.76 m³ (200 gal) tank, the film was distributed uniformly on the entire water surface of the tank (Figure 4-2a), but in the 3.78 m³ (1000 gal) tank it has a much-defined structure with high cohesion to remain in that form (Figure 4-2b). The film reflects adhere to a plastic test tube, but not to a glass

beaker. It dissolved when the sample was heated on a hot plate, also it reacts with sulfuric acid producing instant reactions with high turbidity sample and then the precipitation of the film. With this precipitate more tests were made. The precipitate did not dissolve neither in methanol nor in TKA, suggesting that it was not of organic origin. The precipitate was observed in the microscope at the Biology Department to eliminate the possibility that it could be bacteria or fungi, but crystals were observed in the sample. The precipitate was analyzed using an X-Ray Diffraction (XRD) instrument located in the Department of Geology at UPRM.



Figure 4-2: Film observed (a) on the 0.76-m³ tank (b) and in the 3.78 m³ tank

The XRD results (Figure 4-3) indicated the presence of calcite (CaCO_3) and gypsum (CaSO_4). The gypsum was caused by the addition of sulfuric acid to precipitate the film.

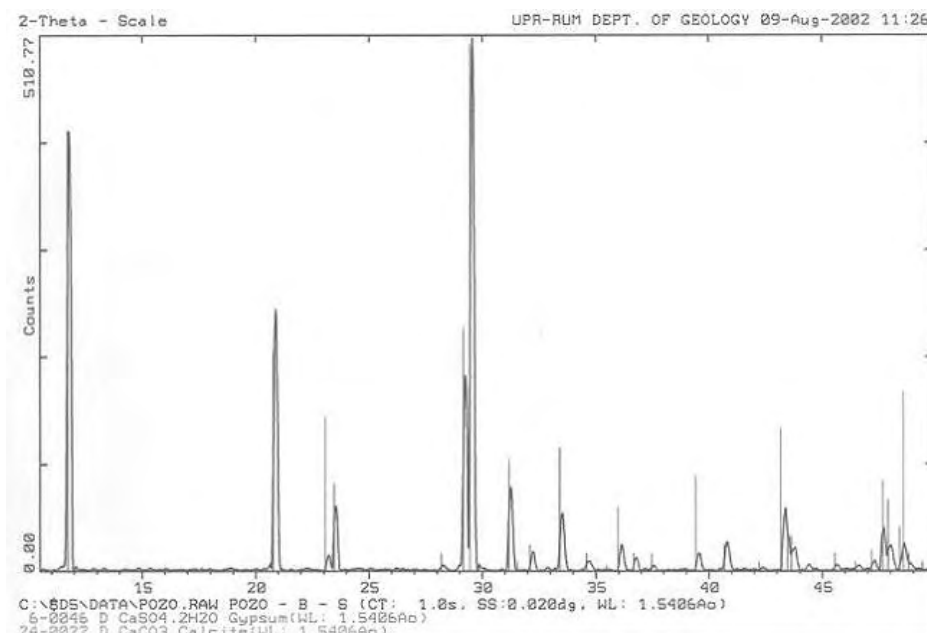


Figure 4-3: Output obtained from the XRD test

The presence of these crystals was confirmed by a microscopy. The formation of calcite crystals is common for conditions of high temperature fluctuations and high carbon dioxide (CO_2) concentrations. These conditions were consistent with those found on the 3.78 m³ (1000 gal) tank (outside of the Environmental Laboratory), which was exposed to high temperature variations, relative to the 0.76 m³ (200 gal) tank (inside of the Environmental Engineering Laboratory).

The finding of the presence of calcite in the Hatillo Community water is an advantage to this project. This is because the AOP plant would be evaluated in one of the worst-case scenarios since calcite is a known interference in the AOP technologies (USEPA, 1999). Two problems were encountered; one is the increase in water temperature during the treatment due to the energy generated on the UV lamp (resulting in the production of more precipitate), and the other problem is that the precipitate can remain in the UV lamp, reducing its capacity. Nevertheless, the presence of calcite is an advantage because the objective of this project is to evaluate the performance of the AOP plant with the addition of interferences to the water

treatments (UV and ozone) and fortunately, calcite is one of the interference in both processes.

Volatile organic compound was not detected on the analysis done to the Hatillo well water sample. For the particle counting and size distribution analysis, Figure 4-4 shows the cumulative particle counts as a function of particle size. It reflects particles generally smaller than 10 μm .

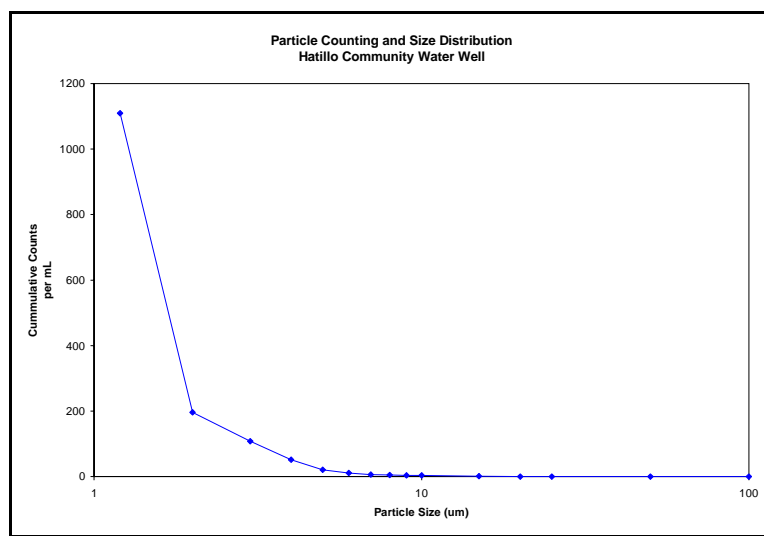


Figure 4-4: Cumulative particle counts per mL as a function of particle size

4.2. *Physical Evaluation of the AOP Field Unit Package Plant*

This section discusses the physical evaluation of the AOP plant (field unit) based on the performance of the different components of the plant. The AOP plant was built and tested by the USEPA (IT Corporation, 2001; IT Corporation, 2002). It was transferred to UPRM on April 2002 for evaluation. The performance of the AOP plant was evaluated in terms of its physical implementation, as well as efficiency of chemical removal under the conditions tested.

The evaluation on the plants physical implementation commences from the day it is assembled. Table 4-3 lists chronological events describing the operation of the plant.

Table 4-3: List of chronological events describing the operation of the AOP plant (field unit)

<i>Description</i>	<i>Operation / Maintenance</i>	<i>Comments / Actions</i>	<i>Operation Run Code*</i>
Shipment <ul style="list-style-type: none"> - shipment in April 2002 via Yellow Freight in a crate 1.22 m long x 0.91 m width x 1.52 m height - shipped partially dissemble 		Dissembled parts: <ul style="list-style-type: none"> - water flowmeters - ozone destruction system - air vent - sampling ports 	0
Installation of AOP unit at UPRM <ul style="list-style-type: none"> - IT Corporation personnel (Mr. Craig Patterson) supervised and assisted on AOP installation, checked functionality, and provided training on the AOP plant operation. Graduate students, lab technicians and faculty were “trained” on the basic operation of the plant 	During initial operation, the AOP plant: <ul style="list-style-type: none"> - leaked water at most pipe junctions - failed to vent the ozone and associated gases, causing pressure built up on the system - did not read pressure at gauge meters 	Air vent was clogged with shipping foam. Vent was unclogged and reassembled	0
Training and Initial Run	The AOP plant was ran in both modes (closed loop and single pass with partial recirculation loop) and in UV/Ozone treatment		1

Table 4-3: Continued

<i>Description</i>	<i>Operation / Maintenance</i>	<i>Comments / Actions</i>	<i>Operation Run Code*</i>
<p>Run 1. First scheduled experiment</p> <ul style="list-style-type: none"> - Run to evaluate chemical efficiency on removal of MTBE 	<ul style="list-style-type: none"> - The amount of ozone measured in the after venturi sample port, just after the ozone injection, was lower than the level of operation of 1 mg/L-O_3 as indicated on the UV/Ozone User's Manual (IT Corporation, 2001). - The dry airflow rate rose to 0.57 m³/hr (20 SCFH) and dropped - The vacuum pressure had the same behavior; it reached -127 mmHg (-5 inHg) of vacuum and decayed - The water rose to the ozone destructor, and vapor began to leave from it - The AOP plant shut down after 15 secs of operation when it cannot maintain a -127 mmHg or less of vacuum due to safety protection that activate an electrical interlock relay. This relay is located on the circuit control electric box and serves to protect the plant, specifically the ozone generator. <p>As suggested by IT Corporation</p> <ul style="list-style-type: none"> - Recirculation flow was maintained at a range between 30.28-37.87 L/min - Confirmed that the influent and effluent valves are either open (continuous flow) or both closed (closed-loop) 	<ul style="list-style-type: none"> - Problem continued hard to diagnosed because of the short time of operation (15 secs) of the plant - Troubleshooting guides were provided for each component of plant (not integrated) and each troubleshooting had different solution to same behavior. - Brownish film developed on flowmeters (Figure 4-5) - Flowmeters were cleaned with soap and water. 	0

Table 4-3: Continued

<i>Description</i>	<i>Operation / Maintenance</i>	<i>Comments / Actions</i>	<i>Operation Run Code*</i>
Troubleshoot 1: Approach to determine the cause of AOP operation failure (from most basic to most complicated)	As indicated by the different components manuals: - Disassembled, cleaned, and tightened the venturi injector - Change indicating desiccant material to CaSO ₄ (drierite)	Indicating color indicated good condition but changed anyway	0 1
Run 2: First chemical efficiency experimental run	- Worked		1
Run 3: Second chemical efficiency experimental run	- Worked		1
Run 4: Third chemical efficiency experimental run	- Low UV intensity (<0.80) - Clean with mild soap - Producing less ozone than usual - AOP shut down	- Precipitates residue were formed on lamp, chamber, and quartz sleeve (Figure 4-6) - UV developed optimal intensity - ClearWater Tech (the ozone generator company) suggested that the venturi had a leak which cause a reduction of the vacuum and, therefore, ozone	0
Troubleshoot 2:	- check venturi - changed dessicant material - check solenoid and check vales associated with venturi - change venturi-related check valve	- the venturi was operational - solenoid valve operational but check valve was leaking water to solenoid valve - solve problem	0 1

Table 4-3: Continued

<i>Description</i>	<i>Operation / Maintenance</i>	<i>Comments / Actions</i>	<i>Operation Run Code*</i>
Run 5: Fourth chemical efficiency experimental run	<ul style="list-style-type: none"> - clean the AOP plant system with dechlorinated tap water - presented same operational problems as for Run 4, except that the ozone generator shut down after 3 minutes (instead of 15 secs) - air dryer producing 0.17 m³/hr of airflow at vacuum of -127 mmHg - unstable airflow 	<ul style="list-style-type: none"> - AOP does not work efficiently if water is chlorinated - Potential problem with the air dryer - According to UV/Ozone, system manual optimum airflow rate for optimum ozone concentration is 0.57 m³/hr. To obtain more ozone production is required having a higher airflow rate with lower vacuum. For the P-2000 ozone generator, ClearWater Tech correct airflow rate is 0.40 m³/hr 	0
Troubleshoot 3:	<ul style="list-style-type: none"> - changed flowmeter - operated at airflow rate lower than 0.14 m³/hr <ul style="list-style-type: none"> • created slight ozone smell in laboratory • ozone concentrations were lower than 0.3 mg/L O₃ for the UV/Ozone treatment 	<ul style="list-style-type: none"> - no improvement - not operated at safety zone - according to ClearWater Tech these problems may be caused by: <ul style="list-style-type: none"> ▪ faulty venturi ▪ vacuum leak ▪ failure of desiccants in the drier chamber 	0

Table 4-3: Continued

<i>Description</i>	<i>Operation / Maintenance</i>	<i>Comments / Actions</i>	<i>Operation Run Code*</i>
Troubleshoot 3: Air Dryer Maintenance	<p>With all the problems that the AOP plant was presenting and no common solution, it was decided to perform maintenance of the entire plant, taking in consideration the schedule maintenance of all the parts together. A maintenance table was prepared to execute this task. Table 4-4 summarizes all the parts that the AOP plant has with their proper maintenance schedule. Detailed maintenance tasks are presented for each component in Appendix 9.</p> <ul style="list-style-type: none"> - changed indicating desiccant (ClearWater Tech part no. DES12) - disassemble and inspected air dryer - tighten electric connection - tested solenoid valve and fuse - change non-indicating dessicant 	<p>Maintenance conducted under the direction of ClearWater Tech technicians (Marc DeBrum – sales engineer/service manager, Joe Sigala (service department) and Chad Relis (service supervisor)</p> <ul style="list-style-type: none"> - corrosion was observed inside the steel dryer chamber (Figure 4-7a) - non-indicating dessicant yellow in color and cracked - inlet to indicating dessicant cartridge (Figure A9-14) was clogged with a silicon particle, thus limiting the amount of air entering the dryer - loosen electric connection - operational 	1
Troubleshoot 3: Venturi Maintenance	<ul style="list-style-type: none"> - inspect venturi injector - clean injector with mild soap and replaced into unit - leak at venturi injector: water was being sucked in - replace venturi 	<ul style="list-style-type: none"> - injector in the AOP plant was a modified version of original part - the injector showed a brownish film inside - can hear air leaks - the sealant at the venturi connection was damage (Figure 4-8 and 4-9) - did not solve the problem, leak continued and seal was damage again 	0 0

Table 4-3: Continued

<i>Description</i>	<i>Operation / Maintenance</i>	<i>Comments / Actions</i>	<i>Operation Run Code*</i>
Troubleshoot 3: Ozone Generator	<ul style="list-style-type: none"> - disassembled and inspected the ozone generator - changed particulate filter (Figure 4-10) - inspected check valves and electrical fuse - inspected reaction and dielectric tubes 	<ul style="list-style-type: none"> - all in working conditions - the chambers was free of debris and dielectric was in perfect conditions - problems continues 	0
Troubleshoot 3: Air Vent	<ul style="list-style-type: none"> - Inspected 	<ul style="list-style-type: none"> - no problem found 	0
Troubleshoot 3: Ozone destructor	<ul style="list-style-type: none"> - Inspected 	<ul style="list-style-type: none"> - show vapor and water being released from the destructor, when low ozone concentration were observed 	0
Troubleshoot 3: UV System	<ul style="list-style-type: none"> - Inspected - Cleaned all components - Replaced lamp 	<ul style="list-style-type: none"> - found residues on lamp, quartz sleeves and lamp chamber - increased UV intensity for the period of operation 	0
Troubleshoot 3: Water Delivery System	<ul style="list-style-type: none"> - clean flowmeters, stainless-steel plumbing with soap and water - inspect all gauges, ports, and recirculation pump 	<ul style="list-style-type: none"> - brownish film on influent flowmeter (Figure 4-5) continue to develop through all experiments. Black film observed on effluent flowmeter connections (Figure 4-11) - clogged effluent flowmeter with shipping foam (Figure 4-11; possible preserve of shipping foams in contact chamber) - Leaking gauges (oil leak), pump (water), ports (water), corrosion and particulates observed in port connections (Figure 4-12) 	0

Table 4-3: Continued

<i>Description</i>	<i>Operation / Maintenance</i>	<i>Comments / Actions</i>	<i>Operation Run Code*</i>
Troubleshoot 3: Electronics	<ul style="list-style-type: none"> - checked electronic control panel by Mr. Ivan Santiago, electronic mechanic at the Civil Eng. Dept. at UPRM - a problem was observed with the electrical signals measured at the control panel <ul style="list-style-type: none"> ▪ the control panel was not receiving the necessary signals to turn on and off the ozone generator, and the interface (done by an F-5100 series subminiature pressure switch of Air Logic Company) from pressure to electrical control circuit was incorrectly calibrated. ▪ All connections, bulbs, relays, and switches were tested ▪ System was calibrated and synchronized as described on Appendix 10 	<ul style="list-style-type: none"> - electronics controlling airflow valves and meters and the air dryer required calibration and synchronization. The pressure switch and gauges (Figure 4-13) sensed different pressures for the same airflow, causing unstable regulation. 	1

* - 0 = not operational; 1 = operational

Table 4-4: Summary of maintenance schedule for the AOP Plant

<i>Service</i>	<i>AOP plant part</i>	<i>Maintenance</i>
Daily	Air dryer	<ul style="list-style-type: none"> - Check to see that the air dryer is warm - Regenerate the desiccant in the external indicating chamber on the air dryer if they are clear to white in appearance, or the desiccant beads is less than 25 % blue in color
	Check valve	<ul style="list-style-type: none"> - Inspect the ozone delivery line check valves daily for water seepage
Monthly	Check valve at venturi	<ul style="list-style-type: none"> - Inspect and replace if necessary
	Ozone generator	<ul style="list-style-type: none"> - Clean the air filters
	Flowmeters	<ul style="list-style-type: none"> - Inspect and cleaned if is dirty or with deposits
Yearly	Ozone generator	<ul style="list-style-type: none"> - Replace the cooling fan filters - Replace the air inlet particulate filter - Replace the check valve - Remove and clean the glass dielectric in reaction chamber - Rebuild the solenoid valve on the electrical interlock box - Replace the flange gasket and clean the diffuser in the contact column
	Check valve	<ul style="list-style-type: none"> - Replace ozone delivery line check valves
Every three years	Ozone generator	<ul style="list-style-type: none"> - Replace the cooling fans - Disassemble and hone corona discharge reaction chambers, clean glass dielectric and replace O-rings.
Every five years	Ozone generator	<ul style="list-style-type: none"> - Replace the glass dielectrics in the reaction chambers and replace O-rings
	Air dryer	<ul style="list-style-type: none"> - Replace the desiccant in the AD-40



Figure 4-5: AOP plant influent flowmeter



Figure 4-6: Quartz sleeve inside UV system

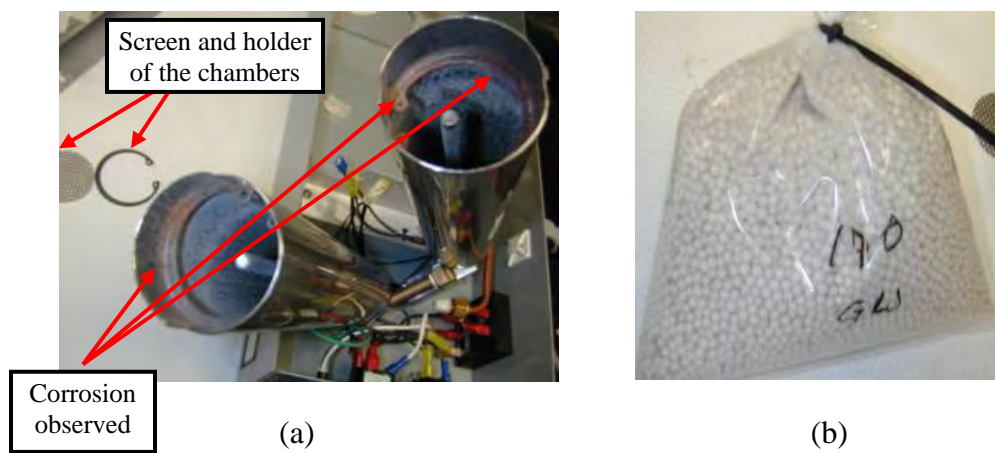


Figure 4-7: Inside the steel drier chambers (a); non-indicating desiccant beads (b)

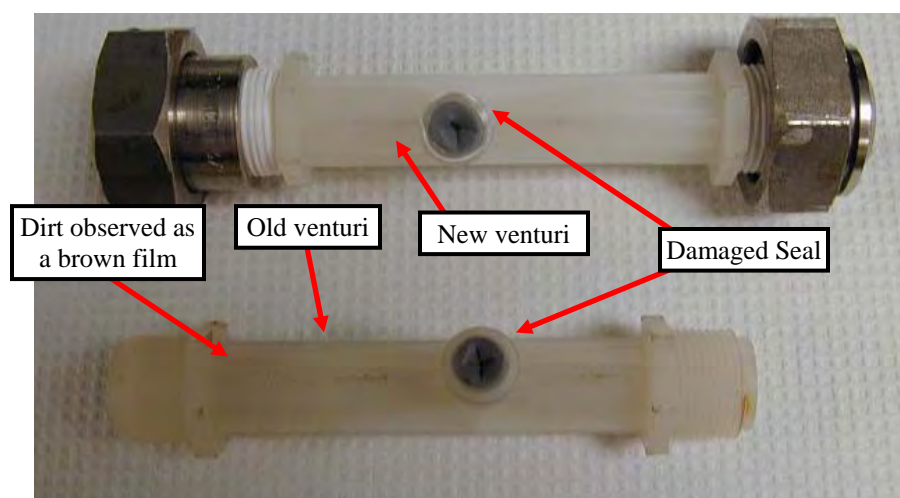


Figure 4-8: Both venturis with the seal damaged

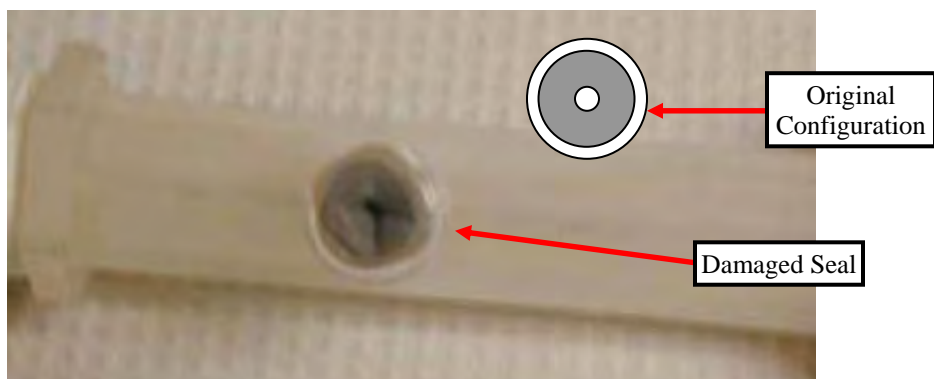


Figure 4-9: Pattern observed in the venturi seal



Figure 4-10: Particulate filter inside the ozone generator

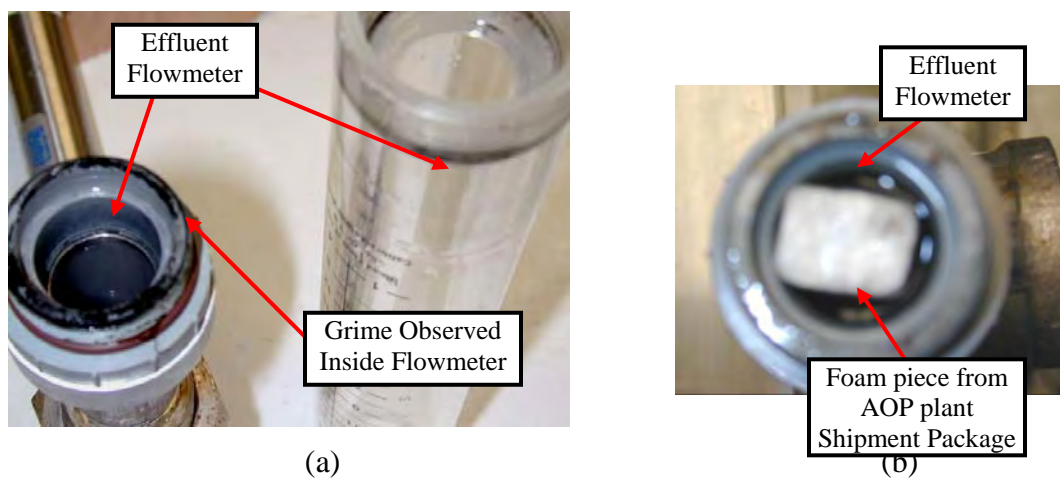


Figure 4-11: AOP plant effluent flowmeter

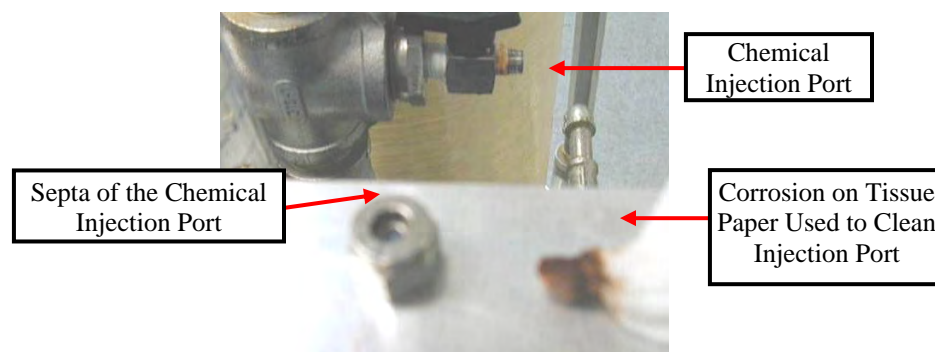


Figure 4-12: AOP plant effluent flowmeter

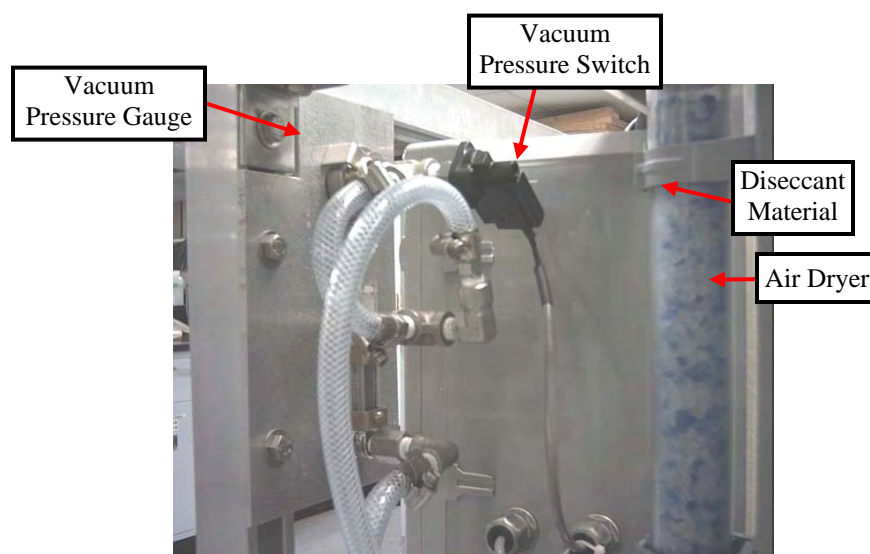


Figure 4-13: AOP plant vacuum gauge system

In summary, the AOP plant presented several panoramas of different problems. Whenever a problem was solved, another one appeared. It is difficult to mention a particular solution to a problem; it is more convenient to mention the group of solutions used to solve a problem because it can be a combination of problems, instead of one alone.

4.3. *Chemical Evaluation of the AOP Plant*

For the chemical evaluation of the AOP plant, the parameters considered were contaminant removal, and water quality treated. As discussed earlier, this evaluation used two datasets: one is the data obtained for closed loop treatment at UPRM-EEL; and the second one is using experimental data collected at the USEPA laboratory in Cincinnati, OH (IT Corporation, 2001), herein mentioned as USEPA dataset. The USEPA is used because it was not possible to run the AOP plant in a continuous basis at the EEL, as discussed in the physical evaluation. Using only the data obtained in the EEL may cause misinterpretation of the capabilities of the AOP technology to destruct MTBE and MTBE by-products.

IT Corporation (2001) and Graham et al. (2004) addressed the degradation of MTBE and MTBE by-products generation through the AOP package plant. Their analyses were based on the data from T&E Facility treatments. Most of the results presented herein use the same data but focuses on the chemical performance of the plant at a physical level (i.e., if plant does not perform optimally physically, cannot perform well chemically).

The following sections discuss the T&E and EEL data. The subsections are divided by closed loop and single pass with partial recirculation, then by treatment or parameter.

4.3.1. *Hydraulic Residence Time*

The hydraulic residence time (HRT) represents the mean amount of time that a molecule stays or resides in a system. This time was calculated in the T&E Facility for both AOP plants. The HRT for the AOP plants (both field and T&E units) is 20 minutes.

4.3.2. *Closed Loop*

Closed loop treatments are batch treatments where the influent and effluent valves are closed with the recirculation valve open. For those tests, a total treatment time of 61 minutes was chosen. An advantage of this type of treatment is the monitoring of the MTBE degradation over time. MTBE removal can be observed more drastically in closed loop treatment than with single pass with recirculation treatment.

For closed-loop test, the treatments applied were no-treatment (control), ozone, UV, and the UV/ozone combination. As mentioned before, two data sets were used to evaluate the AOP performance. One is the data obtained at the EEL (Appendix 11), which has eight tests, with initial target MTBE concentration of 500, 1800, and 2600 µg/L. The other one is the USEPA dataset (Appendix 12), which has 12 tests for the each AOP plant (field unit and T&E unit) for 24 tests in total, and initial target MTBE concentration of 100, 300, 1200, and 3000 µg/L. All tests were performed using 37.85 L/min (10 gal/min) recirculation rates.

4.3.2.1. *No treatment*

No-treatments or control runs, in closed loop, were carry out with dechlorinated tap water for the case of USEPA datasets, and with Hatillo well water for UPRM-EEL runs. All these runs were with turbidities of less than 0.5 NTU. USEPA control runs include one test for the field unit and three tests for the T&E unit. While, EEL control runs include 10 runs with the field AOP package plant unit.

USEPA runs, resulted in average removal efficiency of 10 percent, and a small amount of TBF as MTBE by-product. Once the TBF was formed, it was not degraded in the entire run, which lasted for one hour. In the case of EEL, Figure 4-14 shows one of the control runs with initial target MTBE concentration of 500 µg/L. For this run, and mainly all the control runs, the MTBE remains constant with average removal efficiency of 11 %, and as USEPA with a small production of TBF. TBF was found to

have an average concentration ratio of 0.44 over MTBE concentration. The amount of TBF was not degraded at the end of the run. In addition, no occurrence of methyl acetate, and acetone were observed.

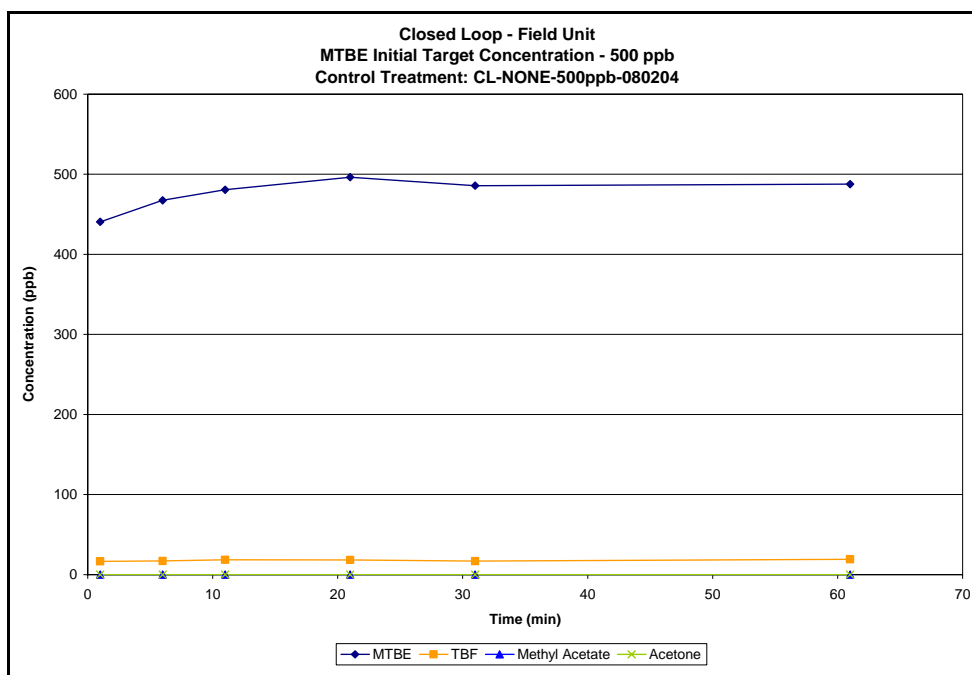


Figure 4-14: No-treatment AOP Plant Run at EEL – MTBE: 500 µg/L

4.3.2.2. *Ozone*

For ozone treatments runs, USEPA had five tests with the field unit and three runs with the T&E unit. The type of water used on those runs was dechlorinated tap water, surface, and ground waters, with turbidities between 0.3 to 16 NTU. The average MTBE removal efficiency observed for all test was 73 %, with TBF as MTBE by-product, which does not degrade in the entire treatment.

Figure 4-15 shows a graph of MTBE and TBF concentration for ozone treatment at different turbidities using the field AOP plant unit, these runs performed by USEPA. At a higher amount of turbidity (16 NTU), the removal efficiency of MTBE was 2.75 times the removal at lower turbidities (0.5 NTU), with removal efficiency of 90.8 %

and 33 %, respectively. In addition, the production of TBF is proportional to the removal of MTBE; larger amount of TBF concentration at the same time as more MTBE is removed. The highest concentration of TBF occurs at 31 minutes after the run started. Degradation of TBF is observed for the water with higher turbidity after 66 % of the MTBE was removed. In the lower turbidities case, the amount of TBF increases over time due to the small amount of MTBE removal. TBF formation rates decrease with time, but removal of TBF does not take place for this water.

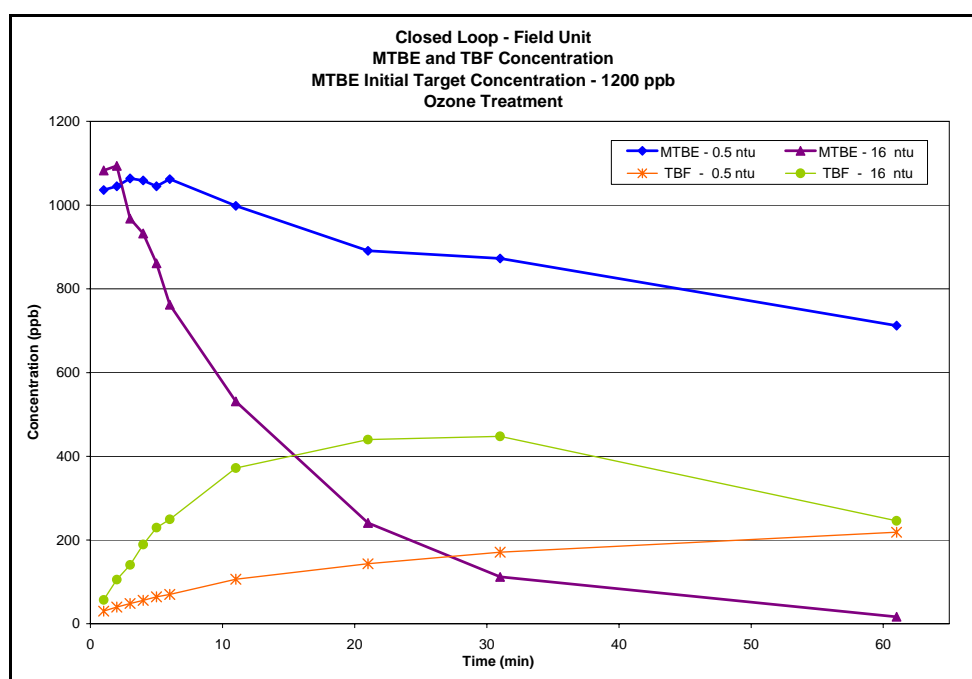


Figure 4-15: Ozone treatment AOP Plant Run at T&E – MTBE: 1200 µg/L (IT Corporation, 2001)

The data suggest that the higher removal efficiency of MTBE is observed at 16 NTU, than at <0.5 NTU. This behavior is the result of the ozone concentration applied in the treatment, which is a function of the air dryer and ozone generator performance. The parameters related to ozone concentration are airflow and vacuum, where high airflow and low vacuum are the desired optimum parameters. Also, the temperature of the water should be taken into account, which can change the Henry's

law constant of MTBE. Figure 4-16 shows the ozone concentration (after venturi sample port) as a function of time and turbidity. The left plot illustrates the ozone concentration for the <0.5 NTU run, which was done using -355.6 mmHg (-14 inHg) of vacuum, 0.30 m³/hr (10.5 SCFH) of air, and with a water temperature range of 10 to 18°C. The right plot shows the run for 16 NTU, using -152.4 mmHg (-6 inHg) of vacuum, 0.48 m³/hr (17 SCFH) of air, and with water temperature range of 24 to 28°C. More optimized conditions were therefore applied to the water with higher turbidity.

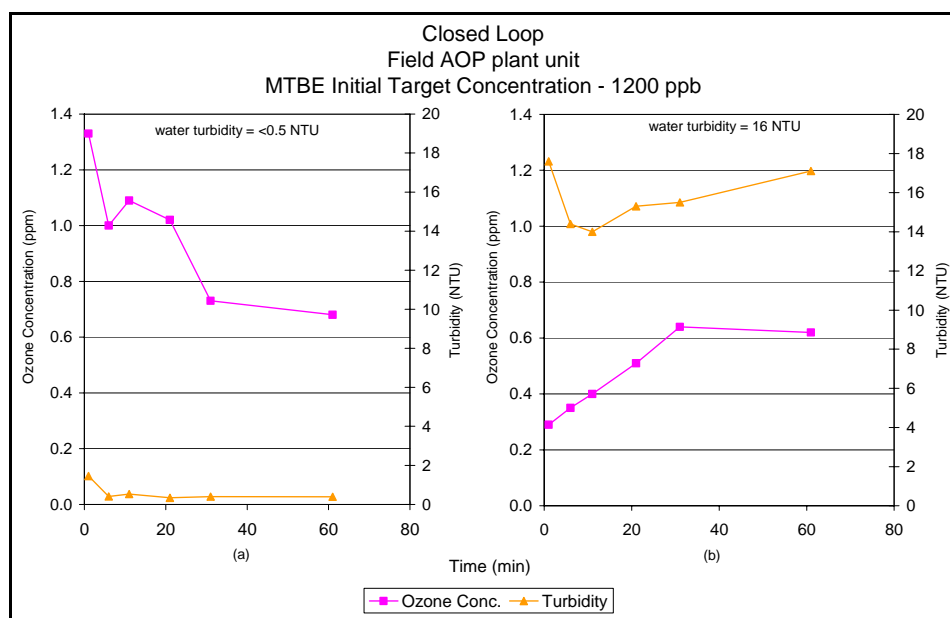


Figure 4-16: Ozone concentration as a function of time and turbidity for water with (a) <0.5 NTU and (b) 16 NTU (IT Corporation, 2001)

Figure 4-16 shows higher ozone concentrations for the runs with lower turbidity, even though the ozone generation parameters were less optimized. The higher the removal efficiency but lower O_3 concentrations for the higher NTU-water, however, suggests chemical oxidation is enhanced at the more optimum parameters. Consequently, more O_3 is used for oxidation, resulting in lower O_3 concentrations in water.

For the T&E unit, the panorama was different as observed on Figure 4-17. The removal efficiency of MTBE for this run was 68 %, more than the 33 % observed for the AOP field unit for the same turbidity (<0.5 NTU; Figure 4-15). This result can be attributed to a small range of water temperature (18 to 22 °C), and more vacuum in the treatment (-304.8 mmHg [-12 inHg]) with 0.28 m³/hr (10 SCFH) of airflow. As observed for the field unit, the T&E unit produced a small amount of TBF, directly related to the amount of MTBE removed from the matrix of water, and this amount of TBF is not removed in the entire duration of the run.

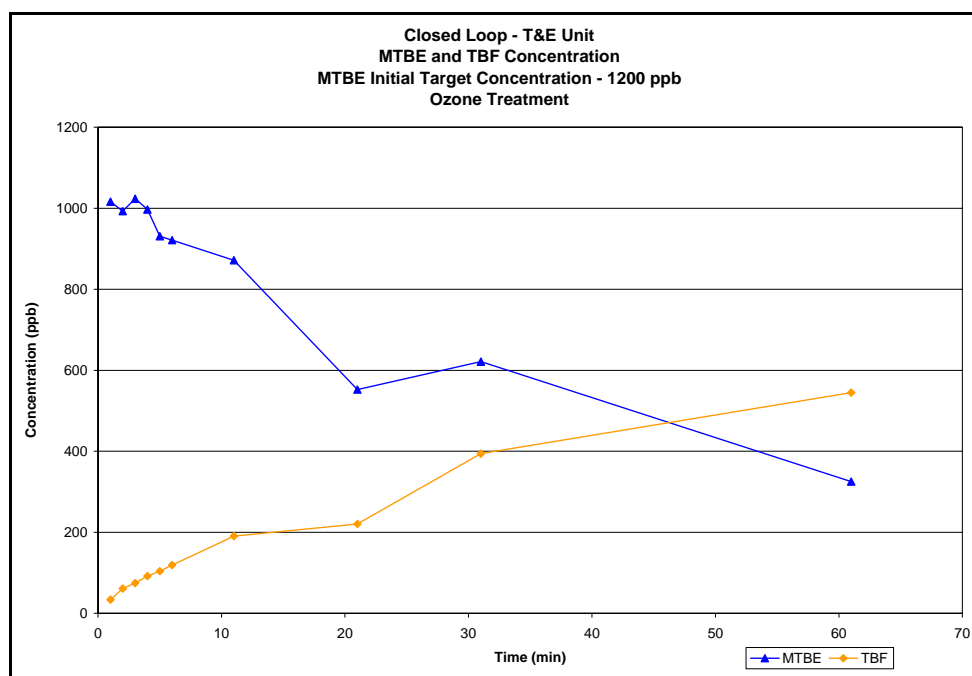


Figure 4-17: Ozone treatment AOP Plant Run at T&E – MTBE: 1200 µg/L

In the case of EEL ozone test run using the field AOP plant unit, and the Hatillo community well water, which had an average turbidity of 0.06 NTU, the removal efficiency of MTBE obtained was 89 %, which was more than the removal observed for both AOP plants in turbidities less than 0.5 NTU. This result, as stated before, can be attributed to an elevated water temperature (29 to 31°C). The vacuum applied to the system were similar to the 16 NTU run (-127 mmHg [-5 inHg]), which achieved

more MTBE removal, with more airflow (0.34 m³/hr [12 SCFH]) than at the T&E Facility run. Also, it is important to note that the initial concentration of MTBE for the run conducted at the EEL was 500 µg/L, which was lower than the USEPA run (1200 µg/L). However, the observed amount of TBF produced in the EEL run was higher than USEPA runs for both AOP plant units. TBF concentration increases over the first 30 minutes of the run, and then started to degrade, as more than half of the MTBE initial concentration was removed (Figure 4-18). Ozone treatment did not achieve a complete removal of MTBE and TBF concentration, and showed no evidence of methyl acetate and acetone on the samples. It is believed that the higher efficiency attained at the EEL run was due to lower MTBE initial concentration and better optimized parameters for ozone generation.

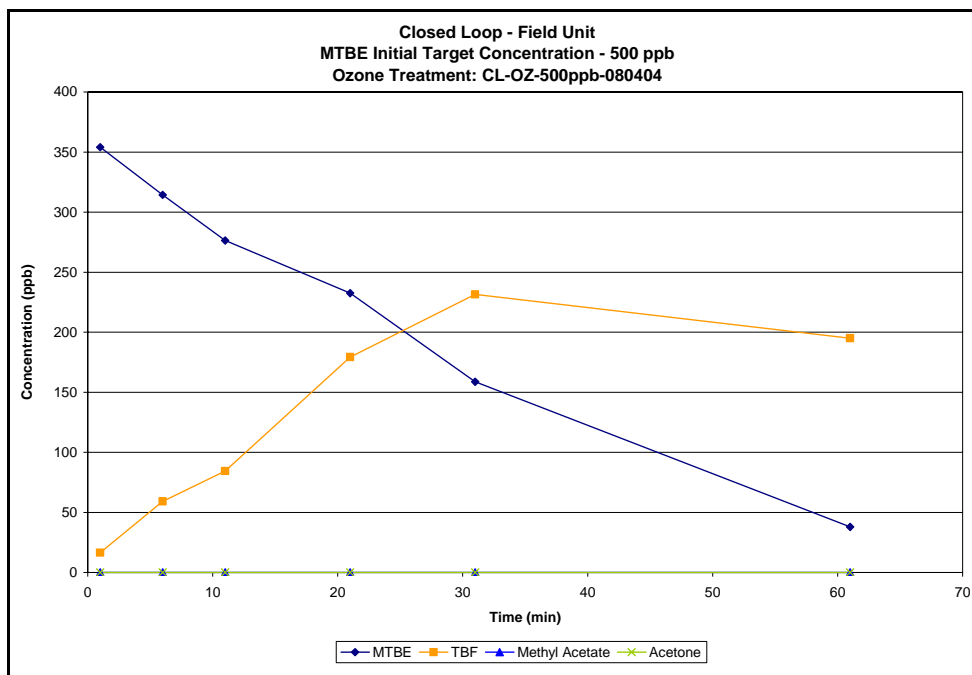


Figure 4-18: Ozone treatment AOP Plant Run at EEL – MTBE: 500 µg/L

4.3.2.3. UV

Using UV treatment, USEPA (IT Corporation, 2002) made one test with the field AOP plant unit and three runs or tests with the T&E unit to address the removal of MTBE. All runs were conducted with waters with turbidities of 0.5 NTU or less. The average MTBE removal efficiency observed for all the tests was 9 percent. Only a little amount of TBF was reported as MTBE by-products, which was not destroyed in the entire run.

Figure 4-19 shows a graph of MTBE and TBF concentration for UV treatment for a run performed by USEPA (IT Corporation, 2002) using the field AOP unit. For this run, the removal efficiency of MTBE was 14 % with initial target MTBE concentration of 1200 µg/L. As observed in the previous section, the production of TBF is proportional to the removal of MTBE, which started 10 minutes after the run begun. No degradation of TBF was observed, resulting in a higher concentration over time due to its production from the MTBE degradation.

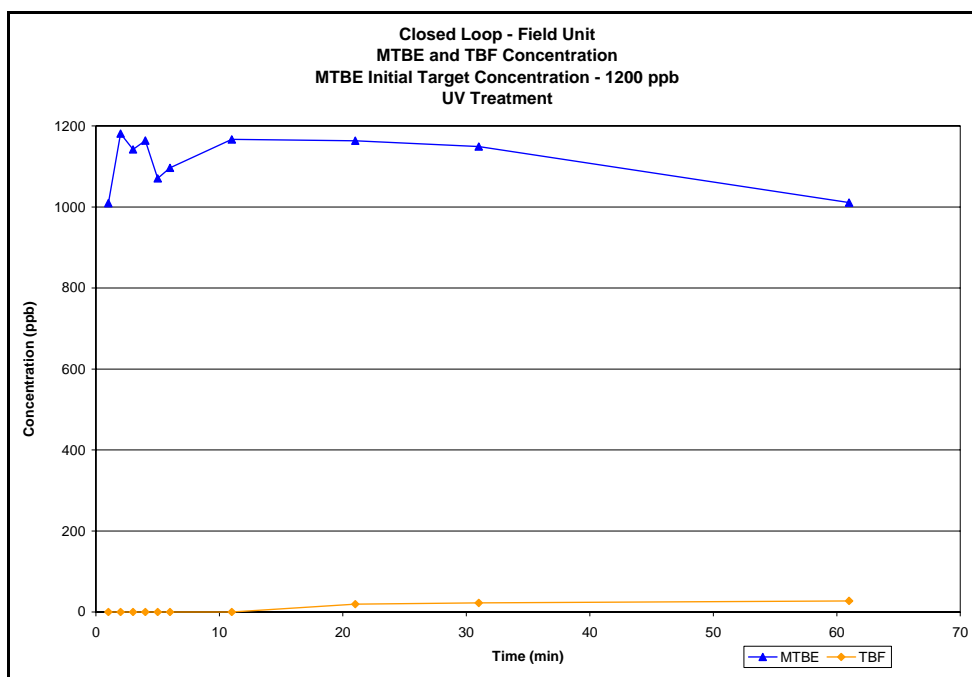


Figure 4-19: UV treatment AOP Plant Run at T&E – MTBE: 1200 µg/L

For the T&E unit, again, the response was different as shown on Figure 4-20. The removal efficiency of MTBE for this run was 4 %, less than the 14 % achieved for the AOP field unit (Figure 4-19). The low MTBE concentration value (at one minute) was due to the limited time between the addition of MTBE and sample extraction for this run (IT Corporation, 2001). TBF is observed after 2 minutes of the application of UV, as opposed to the field unit, where TBF appeared after 10 minutes from the start of the run. Interesting, the TBF concentration does not follow the same pattern of production by removal of MTBE. This result can be attributed to the water temperature during the UV run. For the field unit, the water temperature range was from 10 to 18 °C, while for the T&E unit the range was from 13 to 18 °C. In both runs, a production of TBF is observed when the water reaches 13 °C or a warmer water temperature on the treatment. In addition, the UV treatment itself produces an increase in water temperature, which may affect waters with high carbonate content that can produce some precipitate on the UV lamp.

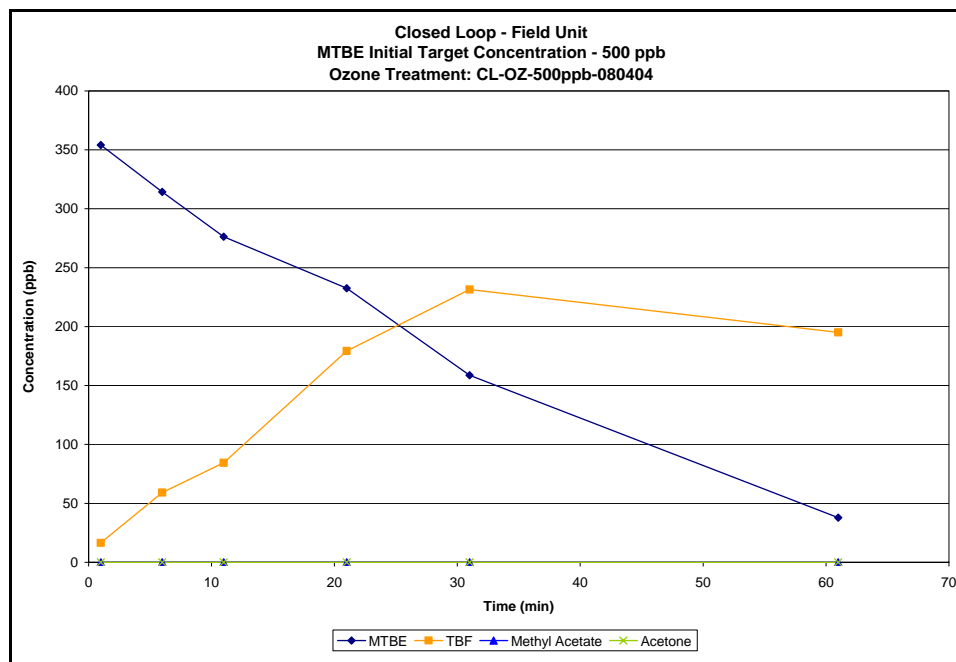


Figure 4-20: UV treatment AOP Plant Run at T&E – MTBE: 1200 µg/L

In the case of EEL, Figure 4-21 shows one of the UV treatment runs with initial target MTBE concentration of 500 µg/L. For this run, a removal efficiency of 73 % was achieved, and as USEPA results, TBF was found as MTBE by-product. The amount of TBF produced by UV treatment was not degraded at the end of the run, and no occurrence of methyl acetate, and acetone were observed.

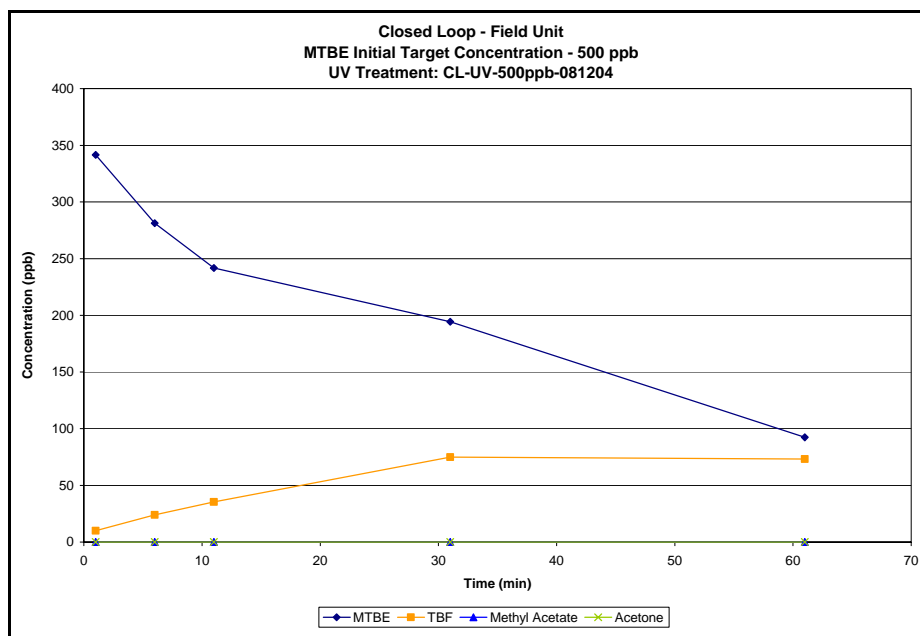


Figure 4-21: UV treatment AOP Plant Run at EEL – MTBE: 500 µg/L

In the EEL UV run, the removal efficiency was greater than for USEPA, which obtained 4 % for the same AOP field unit and 14 % for the T&E unit. This is attributed to the lower initial concentration of MTBE in the EEL UV run, which was 500 µg/L (vs. 1200 µg/L for USEPA) since both runs had the same treatment time (61 minutes).

4.3.2.4. UV / Ozone

For UV/Ozone treatment, USEPA made five tests with the field AOP plant unit and three runs or tests with the T&E unit to address the removal of MTBE. The

waters included on those runs were dechlorinated tap water, surface, and ground waters, with turbidities between 0.3 to 16 NTU. The average MTBE removal efficiency achieved for all the test runs was 99 %. Figures 4-22 and Figure 4-23 show some of the UV/ozone runs done at different turbidities for 1200 $\mu\text{g/L}$ as initial target MTBE concentration. Figure 4-22 shows that the time to reach less than half of the initial target MTBE concentration is 6 minutes for the 16 NTU water, and 4 minutes for the 2 NTU water. On both runs, maximum TBF concentrations occur at approximately 11 minutes, and then decreases until it disappears at the end of the run (61 minutes). It is therefore concluded that at lower turbidities, the AOP plant is capable of removing MTBE and TBF concentrations more quickly than at higher turbidities. Complete removal of both species is achieved for an initial target MTBE concentration of 1200 $\mu\text{g/L}$ at the end of the run, independently of the water turbidity amount.

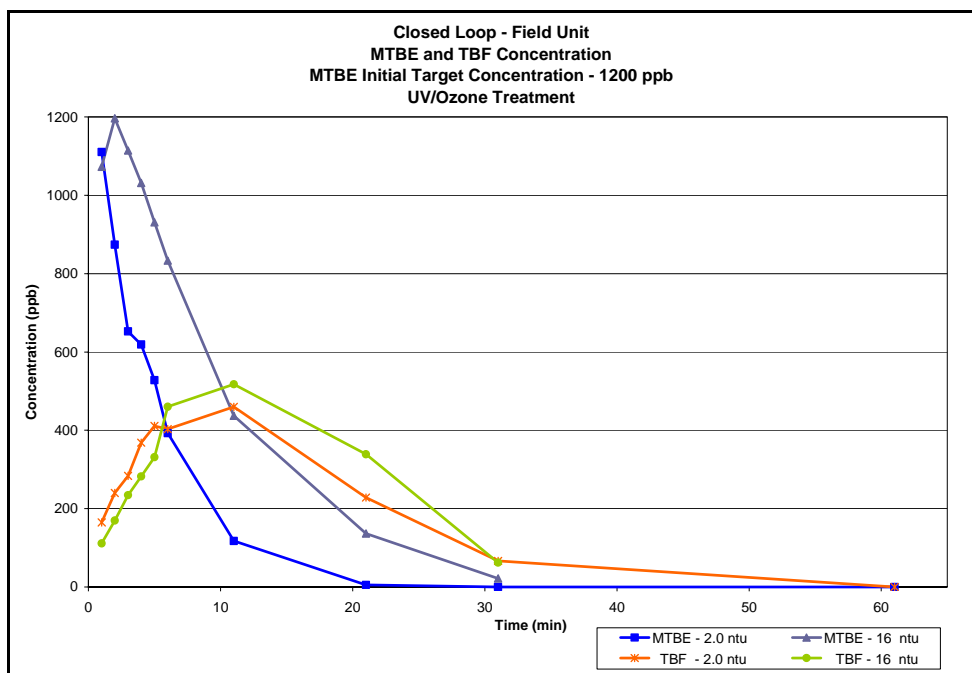


Figure 4-22: UV/Ozone treatment AOP Plant Run at T&E – MTBE: 1200 $\mu\text{g/L}$

Figure 4-24 shows the results for a UV/Ozone run for 0.5 NTU and MTBE target concentration of 1200 µg/L. Note that the real initial MTBE concentration was around 600 µg/L. The TBF reaches a maximum concentration of nearly the same amount as the initial MTBE concentration (~600 µg/L) at 21 minutes. Note that at lower MTBE concentration, the TBF production is higher than at higher MTBE concentrations. Consequently, a complete removal of TBF is not achieved at lower MTBE concentrations, but it is achieved for the cases with higher initial target MTBE concentrations and higher turbidity (Figure 4-22).

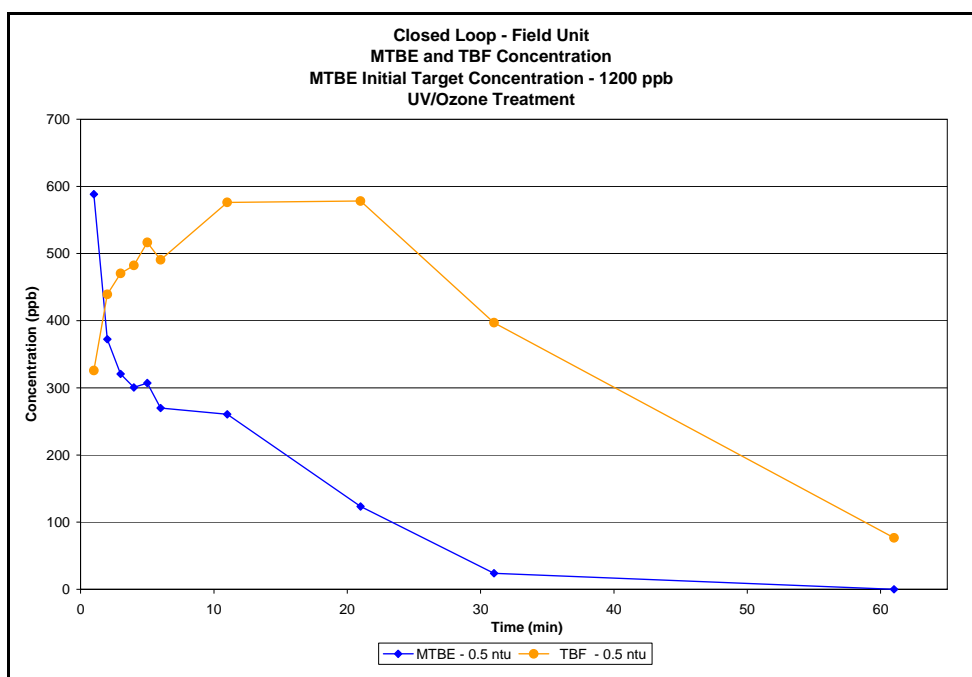


Figure 4-23: UV/Ozone treatment AOP Plant Run at T&E – MTBE: 1200 µg/L

From previous discussion, it is expected that the AOP plant T&E unit performs better than the field unit does. Figure 4-24 confirms this statement, showing a complete MTBE removal after 30 minutes, and a lower concentration of TBF at the end of the run, for a MTBE target concentration of 1200 µg/L. In addition, as observed in Figure 4-24, the concentration of TBF reaches a maximum concentration

of nearly the initial MTBE concentration at 5 minutes of the run, approximately 20 % more quickly than the AOP plant field unit.

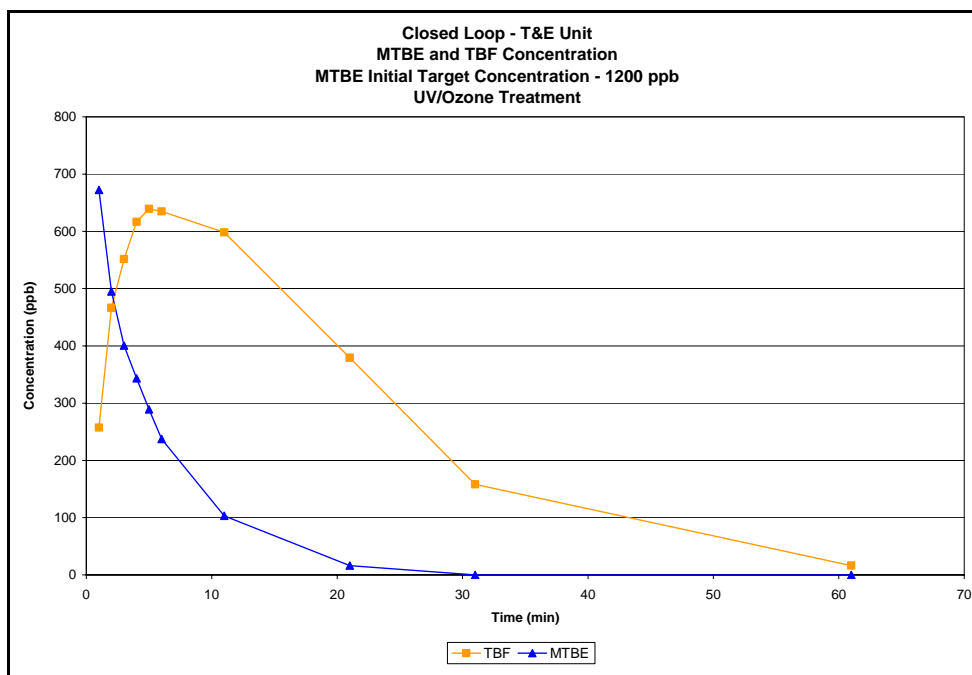


Figure 4-24: UV/Ozone treatment AOP Plant Run at T&E – MTBE: 1200 µg/L

Figures 4-25 to 4-27 show the runs performed in the EEL using UV/Ozone treatment with initial target MTBE concentration of 500, 1800, and 2600 µg/L. Figure 4-25 addresses the removal of MTBE at 500 µg/L initial concentration. For these runs, a complete removal of MTBE was observed 30 minutes after the start of the run. In addition, the peak of TBF concentration was observed at 11 minutes for both runs, and a minimal concentration of TBF remained at the end of the second run, while in the first run TBF was completely eliminated. For both runs, no occurrence of acetone was observed, however a minimal concentration of methyl acetate was detected, which remained at the end of the second run (Figure 4-26), but not in at the end of the first one.

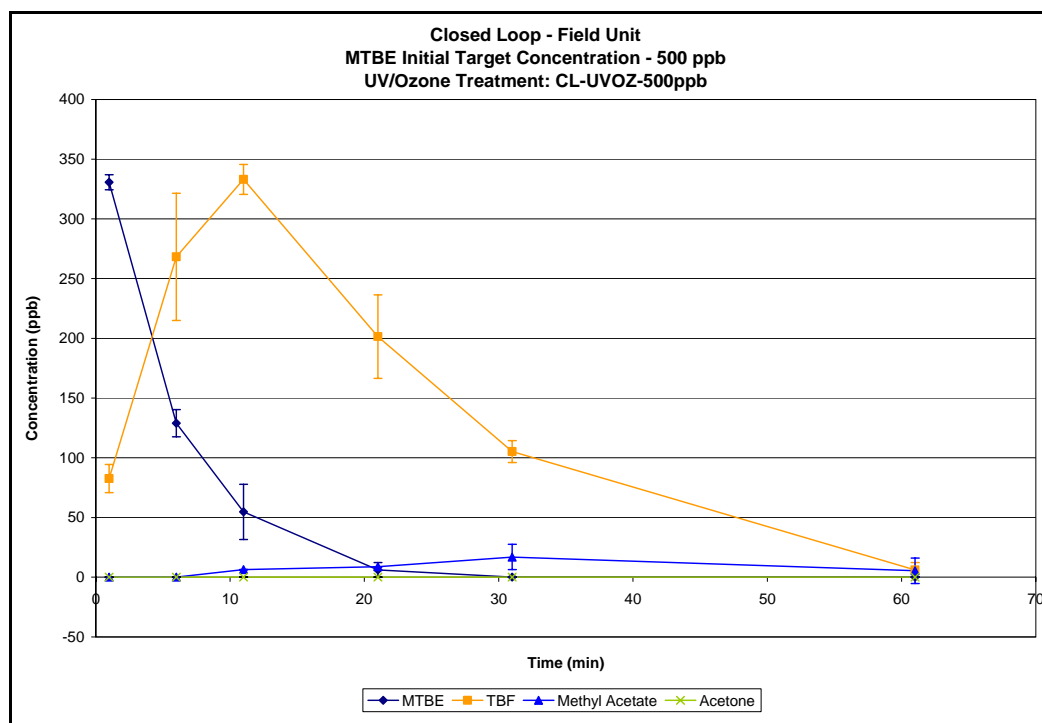


Figure 4-25: UV/Ozone treatment AOP Plant Run at EEL – MTBE: 500 $\mu\text{g/L}$

For initial target MTBE concentration of 1800 $\mu\text{g/L}$, (Figure 4-26) the AOP plant had the same behavior as for initial target MTBE concentration of 500 $\mu\text{g/L}$. A complete removal of MTBE was observed at 31 minutes of the UV/Ozone treatment, and the peak of TBF concentration occurred at 21 minutes. However, in this run, a concentration of acetone was observed, and it increased over time as TBF and MTBE was removed. A minimal concentration of methyl acetate was also observed.

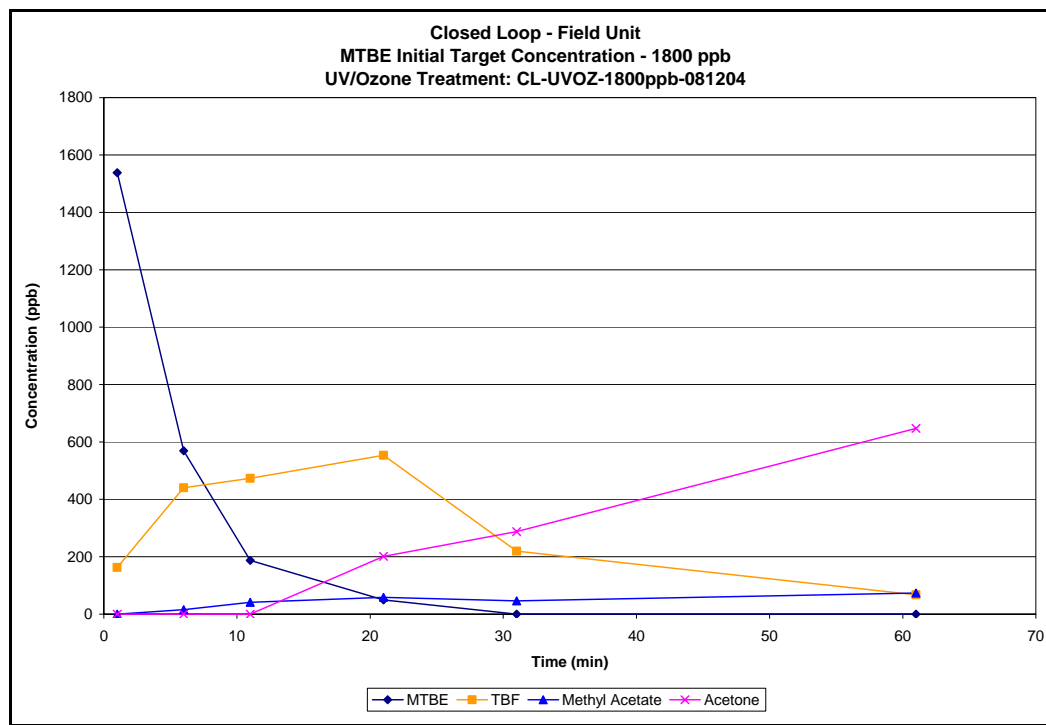


Figure 4-26: UV/Ozone treatment AOP Plant Run at EEL – MTBE: 1800 $\mu\text{g/L}$

Similar behavior was observed for initial target MTBE concentration of 2600 $\mu\text{g/L}$ (Figure 4-27), with the difference that all were shifted in time. A complete removal of MTBE was observed at the end of the run (61 minutes), and the peak of TBF concentration occurred at 31 minutes. As observed on the 1800 $\mu\text{g/L}$ graph, a concentration of acetone was observed, and increases over time as TBF and MTBE was removed from the matrix of water. A minimal concentration of methyl acetate was also observed. At the end of the run, there remained methyl acetate, acetone and TBF concentration in the water.

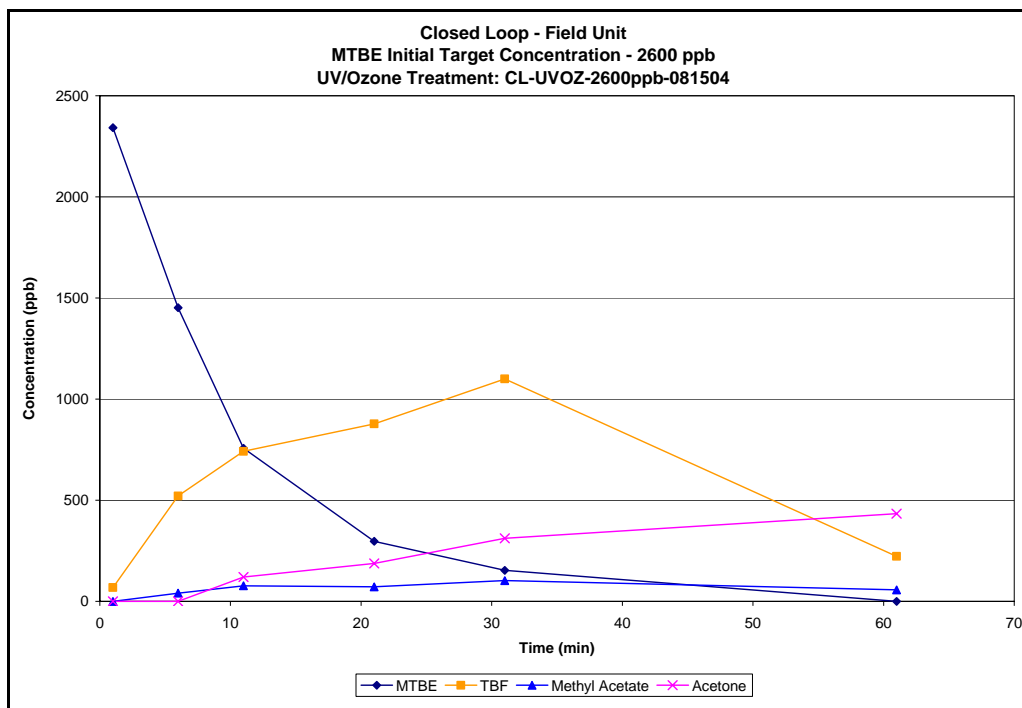


Figure 4-27: UV/Ozone treatment AOP Plant Run at EEL – MTBE: 2600 $\mu\text{g/L}$

4.3.2.5. Summary of Closed Loop Runs

In the preceding subsections, a discussion of closed loop runs for no-treatment, UV, ozone and the combination UV/ozone treatment was presented. The summary of these results are listed in Table 4-5, and shown in Figures 4-28 to 4-31. From Table 4-5, it can be noticed that for initial target MTBE concentrations of less than 1200 $\mu\text{g/L}$, a complete removal of MTBE is achieved using UV/Ozone treatment. In addition, UV/Ozone was the best treatments for all the runs, followed by ozone, and then by UV. The T&E AOP plant unit achieved better MTBE removal efficiency compared to the field unit on almost all treatments, except for UV, in which the field unit achieved about three times the MTBE removal efficiency of the T&E unit.

Table 4-5: Removal Efficiency of MTBE by Treatment and AOP plant unit

<i>AOP plant</i>	<i>Field Unit</i>		<i>T&E Unit</i>	
<i>MTBE initial conc.</i>	<i>500 µg/L (EEL)</i>	<i>1200 µg/L (USEPA)</i>	<i>1200 µg/L (USEPA)</i>	<i>3000 µg/L (USEPA)</i>
<i>Treatment</i>				
Control	11 %	2 %	10 %	12.9 %
UV	73 %	14 %	4 %	12.5 %
Ozone	89 %	33 %	68 %	32.7 %
UV/Ozone	100 %	100 %	100 %	93.2 %

Figure 4-28 and 4-29, illustrates the removal of MTBE over time for the different treatments of the AOP plants for 1200 µg/L and 3000 µg/L, respectively. In both graphs, UV/Ozone removes more MTBE than the other treatments, and UV performs similar to the no-treatment (control) run for the T&E unit. However, the UV treatment shows higher removal for the field unit tested at EEL, as shown on Figure 4-30.

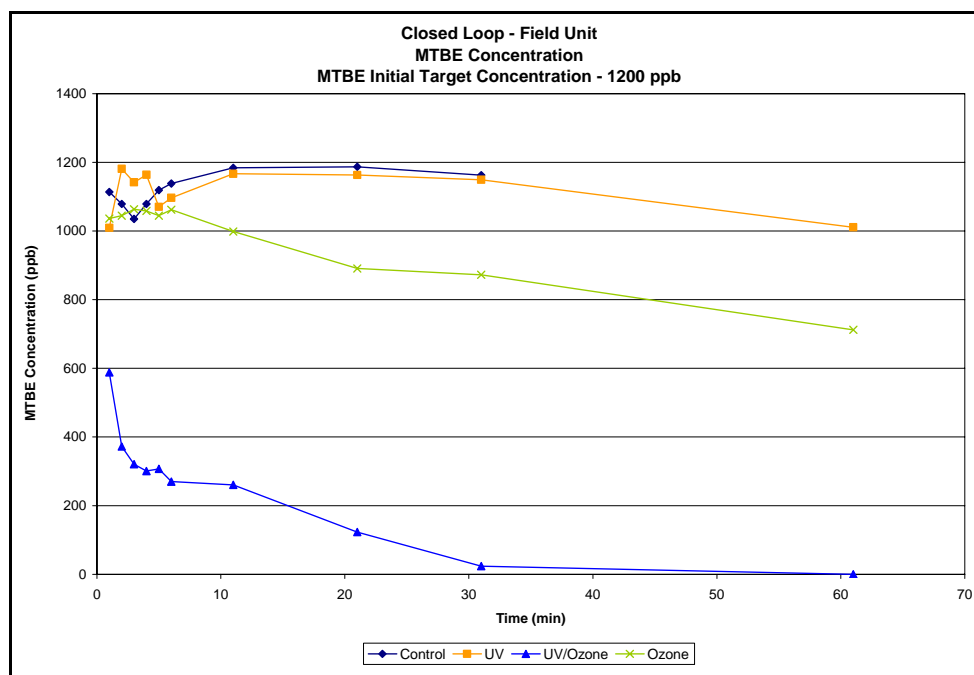


Figure 4-28: Treatment comparison for AOP Plant Run at T&E – MTBE: 1200 µg/L

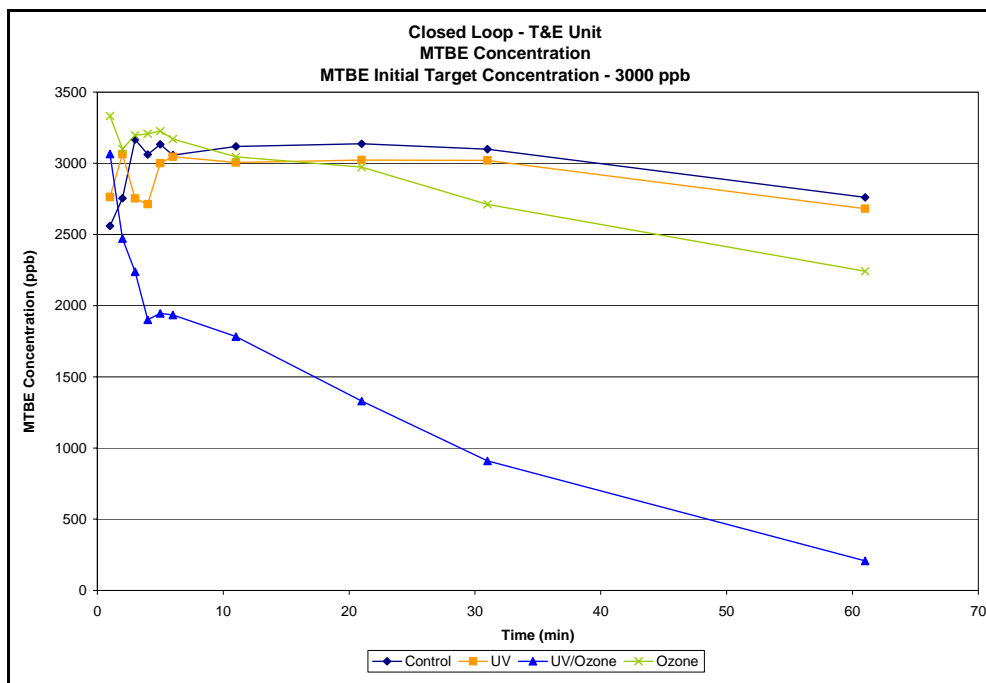


Figure 4-29: Treatment comparison for AOP plant run at T&E – MTBE: 3000 $\mu\text{g/L}$

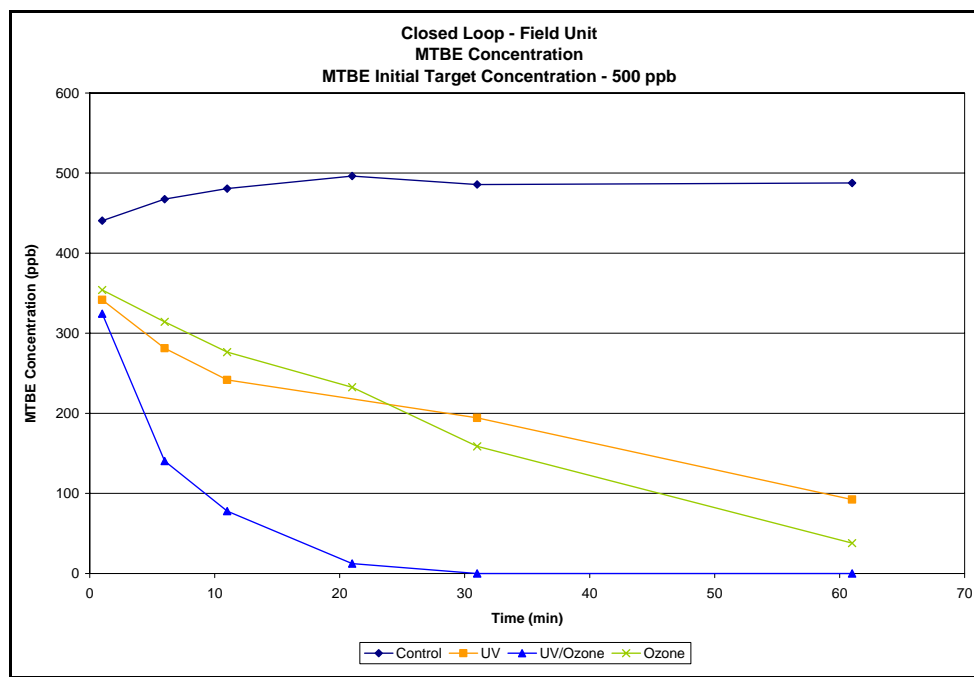


Figure 4-30: Treatment comparison for AOP plant run at EEL – MTBE: 500 $\mu\text{g/L}$

Table 4-6 shows the first order kinetics for the removal of MTBE for different treatments and AOP plant units. The individual first-order reaction rates were obtained from an exponential regression with correlation coefficients between 0.9683 and 0.9959. Control runs are not in consideration because the removal of MTBE is due to dilution and extraction of MTBE from the system while sampling takes place (IT Corporation, 2001).

Table 4-6: First Order Kinetics for MTBE Removal by Treatment and AOP plant unit

<i>AOP plant</i>	<i>Field Unit</i>				<i>T&E Unit</i>	
	<i>EEL</i>		<i>USEPA</i>		<i>USEPA</i>	
<i>k value (min⁻¹)</i> <i>Treatment</i>	<i>Average k</i>	<i>Std. Dev.</i>	<i>Average k</i>	<i>Std. Dev.</i>	<i>Average k</i>	<i>Std. Dev.</i>
UV	0.0203	*	--	--	--	--
Ozone	0.0370	*	0.0461	0.030	0.0023	0.0078
UV/Ozone	0.1656	0.059	0.1702	0.078	0.1743	0.1312

* only one run performed / it was the only first-order reaction

From Table 4-6, UV/Ozone reaction rates are higher than other treatments, achieving more MTBE removal in the same amount of time (61 min of run duration), as observed previously. In addition, the field AOP plant unit performed better on ozone treatments than the T&E unit achieving a faster reaction rate. The half-life for MTBE was calculated as: $t_{1/2} = \ln 2/k$, where k is the reaction rate. The average half-life of MTBE was of 34, 24, and 4 minutes for UV, Ozone, and UV/Ozone treatments, respectively.

As mentioned earlier, the UV treatment depends on the amount of UV light that can penetrate and act in the matrix of water. For the field AOP plant unit, the UV intensity used on the UV/ozone treatment remains constant for approximately the first 30 minutes the run (Figure 4-31), and then decreases to the end of the run. Consequently, UV or UV/ozone treatments are not feasible for longer runs, due to the loss of effectiveness over time.

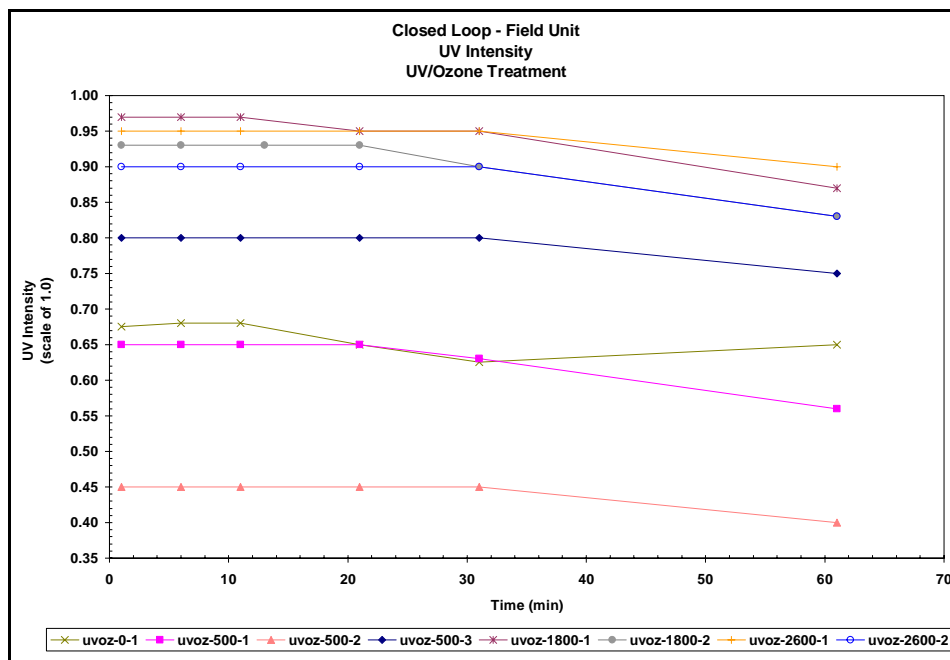


Figure 4-31: UV Intensity for UV/Ozone Treatment – AOP Plant Field Unit

Another factor to consider is the temperature of the treatment. The AOP plant increases the water temperature in the loop by approximately 6 °C for control, UV and UV/ozone treatments, while ozone only increases it by 3.5 °C. Also, from Tables 4-7, 4-8 and 4-9, a pattern is observed for turbidity and pH values, and for alkalinity and total hardness. For a decrease in pH value, an increase in turbidity is observed, and vice versa. When the turbidity remains constant during the test, the pH decrease, and when the pH remains constant, the turbidity increases. In the case of alkalinity and total hardness, the pattern is associated with the carbonate content in the water, as shown that the Hatillo well water has a high calcite concentration. In UV/ozone treatment runs, both, alkalinity and total hardness decreases. For UV, the pattern is that when one increases, the other decreases, and for control, and ozone treatment a strong relationship cannot be determined but the total hardness is less affected than the alkalinity. Another parameter to notice is the amount of calcium, which decreases in all the tests that was measured, indicating that remains in the AOP plant, which can explain why the UV lamp was coated with calcium film.

Table 4-7: pH and turbidity values for selected AOP plant runs

<i>Run</i>	<i>Date</i>	<i>pH</i> (<i>s.u.</i>)				<i>Turbidity</i> (<i>NTU</i>)			
		<i>1 min</i>	<i>61 min</i>	<i>Diff</i>	<i>Ave</i>	<i>1 min</i>	<i>61 min</i>	<i>Diff</i>	<i>Ave</i>
CL-UV-500ppb-1	8/4/2004	8.43	8.39	-0.04	8.41	0.08	0.08	0.00	0.08
CL-UV-500ppb-2	8/12/2004	8.40	8.38	-0.02	8.39	0.07	0.10	0.03	0.09
CL-OZ-500ppb-1	8/4/2004	8.38	8.35	-0.03	8.38	0.06	0.09	0.03	0.07
CL-OZ-500ppb-2	8/5/2004	8.36	8.07	-0.29	8.27	0.06	0.50	0.44	0.15
CL-UVOZ-500ppb-1	4/16/2003	8.10	8.18	0.09	8.09	0.20	0.15	-0.05	0.18
CL-UVOZ-2600ppb	2/19/2004	8.36	8.36	-0.01	8.40	0.15	3.50	3.35	1.02
CL-UVOZ-500ppb-1	8/5/2004	8.16	8.09	-0.07	8.10	0.10	0.50	0.40	0.28
CL-UVOZ-500ppb-2	8/11/2004	8.36	8.35	-0.01	8.33	0.16	2.00	1.84	0.64
CL-UVOZ-1800ppb-1	8/15/2004	8.24	8.21	-0.03	8.17	0.08	0.12	0.04	0.09
CL-UVOZ-1800ppb-2	8/15/2004	8.32	8.24	-0.08	8.20	0.08	0.10	0.02	0.08
CL-UVOZ-2600ppb-1	8/15/2004	8.13	8.10	-0.03	8.03	0.08	0.08	0.00	0.07
CL-UVOZ-2600ppb-2	8/15/2004	8.02	8.54	0.52	8.13	0.08	0.23	0.15	0.15

Table 4-8: Alkalinity, Total Hardness and TOC for selected AOP plant runs

<i>Run</i>	<i>Date</i>	<i>Alkalinity</i> (<i>mg/L as CaCO₃</i>)			<i>Total Hardness</i> (<i>mg/L as CaCO₃</i>)			<i>TOC</i> (<i>mg/L C</i>)		
		<i>1 min</i>	<i>61 min</i>	<i>Diff</i>	<i>1 min</i>	<i>61 min</i>	<i>Diff</i>	<i>1 min</i>	<i>61 min</i>	<i>Diff</i>
CL-none-0ppb-1	6/7/2004	207	210	3	172	156	-16	0.74	0.75	0.02
CL-none-0ppb-2	6/7/2004	213	204	-9	156	152	-4	0.74	1.09	0.35
CL-none-0ppb-1	7/23/2004	118	112	-6	128	128	0	0.43	0.55	0.12
CL-none-500ppb-1	6/24/2004	210	197	-13	144	144	0	0.94	1.01	0.06
CL-none-500ppb-1	6/30/2004	189	192	3	160	146	-14	---	---	---
CL-none-500ppb-1	8/2/2004	126	112	-14	128	128	0	0.43	0.55	0.12
CL-UV-0ppb-1	6/11/2004	198	201	3	160	156	-4	0.80	0.78	-0.02
CL-UV-0ppb-2	6/11/2004	204	201	-3	164	168	4	0.92	0.77	-0.14
CL-UV-0ppb-1	7/23/2004	114	114	0	130	132	2	0.55	0.51	-0.04
CL-UV-500ppb-1	8/4/2004	111	112	1	128	130	2	0.51	0.68	0.17
CL-UV-500ppb-2	8/12/2004	218	208	-10	194	200	6	---	---	---

Table 4-9: Alkalinity, Total Hardness and Calcium conc. for selected AOP plant runs

Run	Date	Alkalinity (mg/L as CaCO ₃)			Total Hardness (mg/L as CaCO ₃)			Calcium (mg/L)		
		1 min	61 min	Diff	1 min	61 min	Diff	1 min	61 min	Diff
CL-OZ-0ppb-1	7/23/2004	114	100	-14	128	130	2	---	---	---
CL-OZ-500ppb-2	8/5/2004	235	166	-69	268	202	-66	130	94	-36
CL-UVOZ-0ppb-1	7/23/2004	110	76	-34	128	130	2	---	---	---
CL-UVOZ-500ppb-1	8/5/2004	239	132	-107	266	162	-104	140	67	-73
CL-UVOZ-500ppb-2	8/11/2004	231	121	-110	216	144	-72	82	49	-33
CL-UVOZ-1800ppb-2	8/15/2004	208	128	-80	220	154	-66	104	58	-46
CL-UVOZ-2600ppb-1	8/15/2004	182	140	-42	240	176	-64	118	70	-48
CL-UVOZ-2600ppb-2	8/15/2004	224	130	-94	260	164	-96	107	56	-51

Particle counts test are an indirect measure of the treatment effectiveness. This indirect relation is used to determine the treatment efficiency for microorganisms, such as *Cryptosporidium* and *Giardia* microorganisms, which have a particulate size between 4 μm and 7 μm . A removal percent of the particulates that can be detected using a particle counter can be assumed to have the same magnitude of removal percent for those particulates that cannot be detected by the particle counter (Broadwell, 2000). Therefore, for drinking water, it is desirable to remove as much particulate matter, to achieve a successful treatment.

The amount of particle counts in the water treated by the AOP plant was measured before MTBE addition and after the end of the runs (61 minutes). Percent differences (which are the same as percent removal) were calculated for each run. A negative percent difference indicates a reduction on particles, whereas a positive percent difference indicates a gain (increase in numbers of particles in that range). Figure 4-32 compares the particle counts differences for different treatments and a MTBE initial concentration of 500 $\mu\text{g/L}$. In terms of particle counts differences, the control treatment reduces (negative differences) all particle concentration at the end of the run, with more reduction observed on sizes of more than 12.5 μm . In addition, UV reduces the particle concentration for almost all sizes, but tends to aggregate the particle

concentration in the 7.5 μm , and reduce the particles concentration for channels of less than 5.5 μm . UV/ozone treatment only removes particulate on channels of more than 12.5 μm , but increases the particulate counts (positive difference) considerably on channels between 2.5 to 6.5 μm .

UV/ozone is the desired treatment of the AOP plant because of its higher MTBE percent removal, and, therefore, a detailed analysis of particle counts differences for UV/ozone treatment is presented on Figure 4-33. The same pattern is observed on all UV/ozone treatment, only a removal of particles that belongs to channels of more than 12.5 μm is observed for 500 and 1800 $\mu\text{g/L}$, while for 2600 $\mu\text{g/L}$ of MTBE the removal is observed on channels beyond 37.5 μm . In addition, for all MTBE concentrations there is a considerable increase on channels between 2.5 to 6.5 μm .

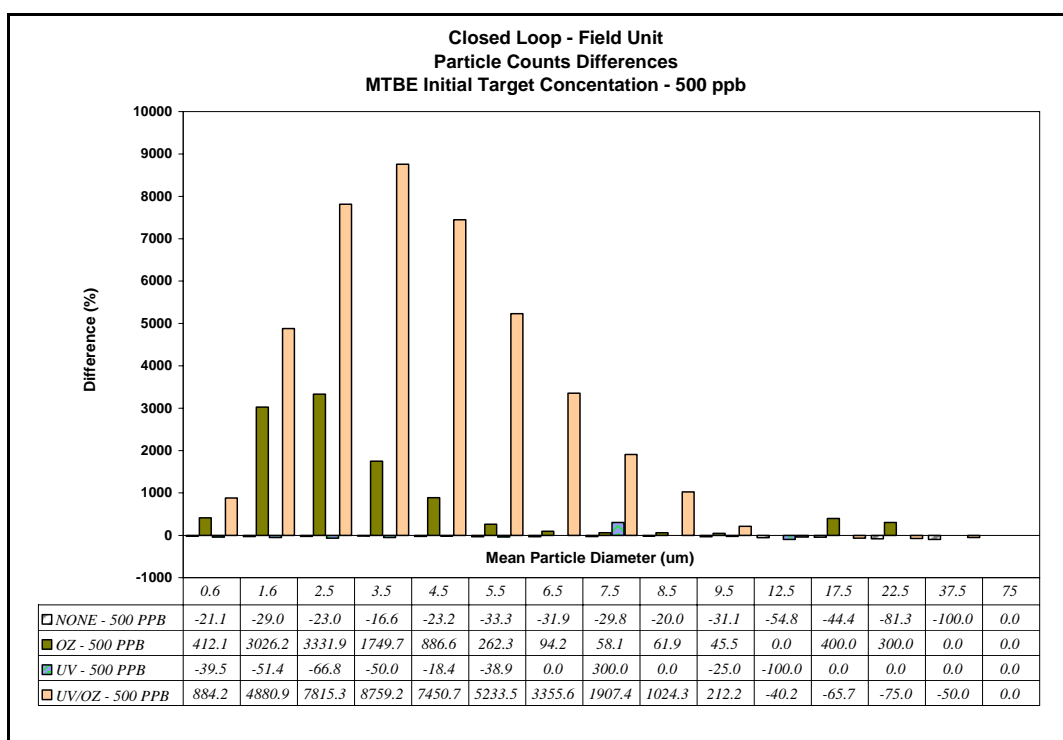


Figure 4-32: Particle Counts Differences for all treatments with a starting MTBE target concentration of 500 $\mu\text{g/L}$

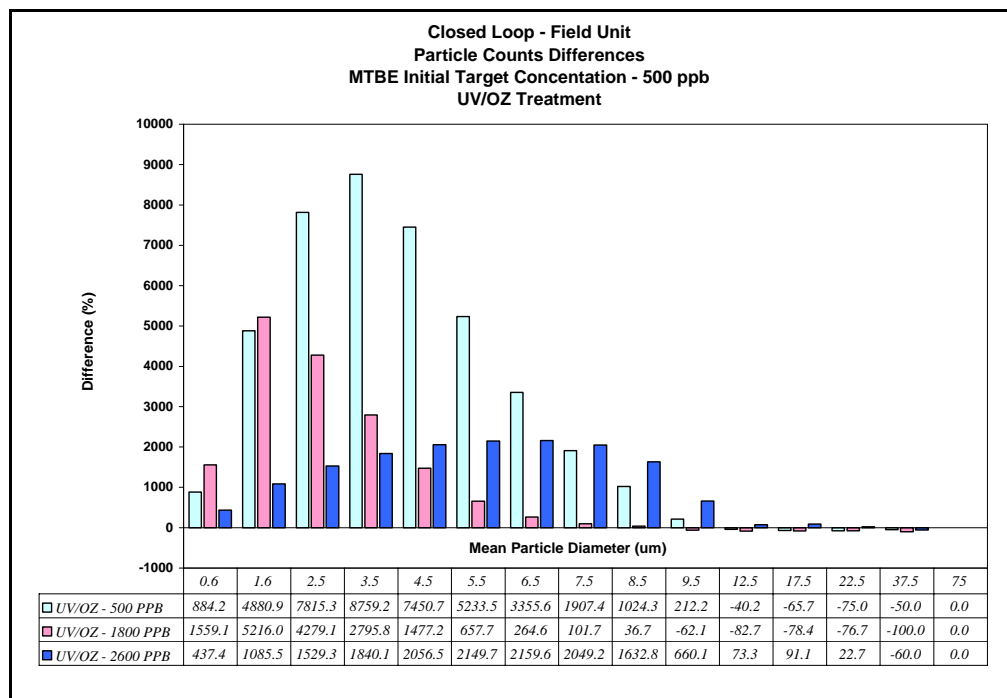


Figure 4-33: Particle Counts Differences for UV/Ozone treatment at different MTBE initial target concentrations

Most of the runs were performed with the same batch of water, because it was when the AOP plant worked fine. An analysis of particle counts differences without MTBE concentration is presented on Figure 4-34. It can be seen that in the absence of MTBE, all treatments (except for UV/Ozone) yield a negative percent difference, indicating a reduction in the particle size. Even though UV/Ozone yields a positive difference for several particle size ranges, it is much smaller than in the presence of MTBE (Figure 4-35). The positive difference for the UV/Ozone may result from the formation of precipitates. This indicates that, in the presence of MTBE, treatment is increasing the number of particles in the 0-9.5 μm range.

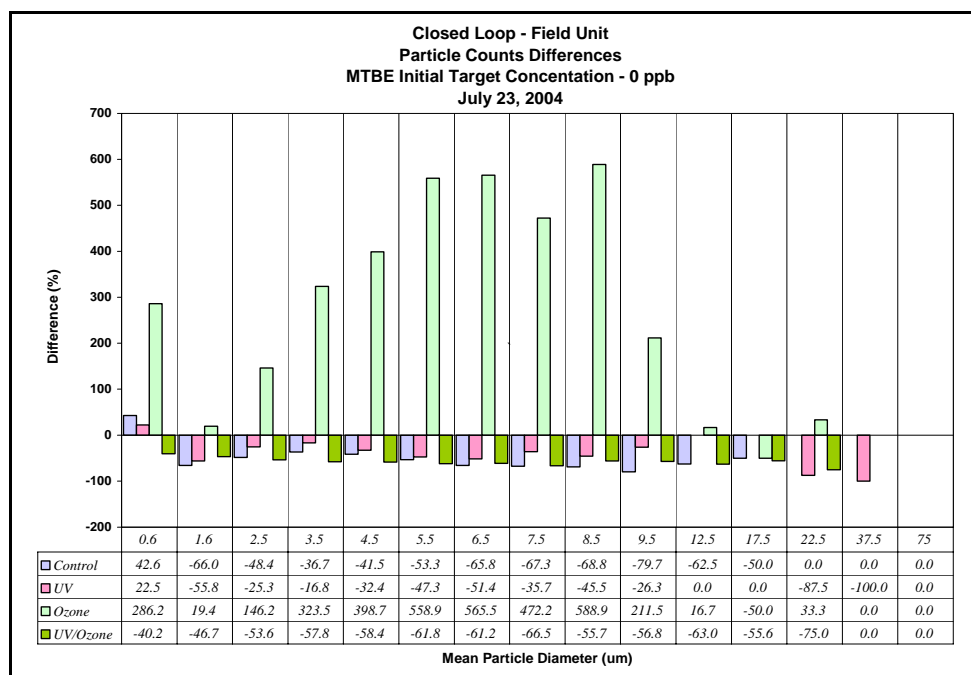


Figure 4-34: Particle Counts Differences – Initial target MTBE concentration: 0 µg/L

4.3.3. Single Pass with Partial Recirculation

Single pass with partial recirculation (SP) treatments test has influent, recirculation, and effluent valves open. For those tests, a total treatment time of 21 or 31 minutes were chosen. Contrary to closed-loop test, SP runs only take care of the removal of MTBE and by-products during the time that the water is in the recirculation loop. The advantage is that the treatment is continuous.

All the equipments for SP tests were setup at the EEL, but due to the continuous problems with this AOP plant, it was decided that SP would not be evaluated at the EEL. Therefore, for SP test, only the dataset of USEPA (IT Corporation, 2001) is used to evaluate the performance of the AOP plant. Fourteen tests were done at the T&E Facility using the field AOP plant unit for no-treatment or control (five runs), and UV/ozone (nine runs) for initial target MTBE concentration of 50, and 1000 µg/L. Since the SP only treats water during the recirculation loop time (approximately 15

minutes), the removal efficiency of MTBE will depend on the water flowrates for influent, effluent, and recirculation. For that reason, these tests vary on the influent/effluent rates of 9.46, 15.14, and 18.93 L/min (2.5, 4, and 5 gal/min); recirculation rates of 18.93, 30.28, and 37.85 L/min (5, 8, and 10 gal/min), respectively; and in the turbidities of the water treated.

A flow rate of 15.14 L/min (4 gal/min) with recirculation rate of 37.85 L/min (10 gal/min) was found to be the optimal conditions for the AOP plant related to the MTBE removal efficiency.

4.3.3.1. No treatment

No-treatments or control runs, in single pass with partial recirculation, were carried out with dechlorinated tap water (0.5 NTU), surface water (2 NTU), and its combination to obtain a water with 1 NTU of turbidity. A MTBE average removal efficiency of 16 % was found for all control run tests performed at the T&E Facility.

Figure 4-35 shows some no-treatment runs for an influent/effluent rate of 9.46 L/min (2.5 gal/min). In those tests, the MTBE water sample is from the influent port at 0 and 30 minutes and from the effluent port at other times. MTBE concentration at 0 minutes is the initial concentration at the influent sampling port, represents the constant inlet concentration. The target MTBE inlet concentration was 50 µg/L, but they ranged from 24 to 48 µg/L. To compare the results, the measured concentration was normalized with initial concentration (i.e. concentration divided by initial concentration; Figure 4-36). Since the hydraulic residence time of the plant is 20 minutes, the general increase in MTBE effluent concentration after 5 minutes indicates that there is incomplete mixing in the system. Relative effluent concentration during the run higher than 70 % does not exist between turbidity and MTBE effluent concentrations for the control runs in the SP tests. Higher effluent relative concentrations are observed for the 1 NTU water. No tert-butyl formate was found as MTBE by-product in the control run, as occurred with the close loop runs.

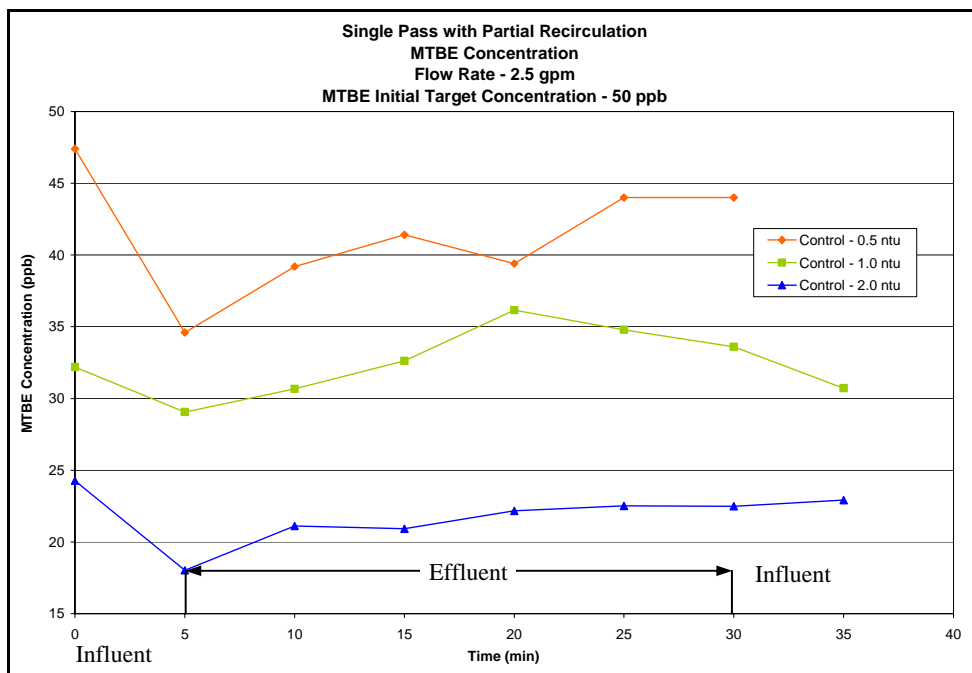


Figure 4-35: No-treatment AOP Plant Run at T&E – MTBE: 50 $\mu\text{g/L}$

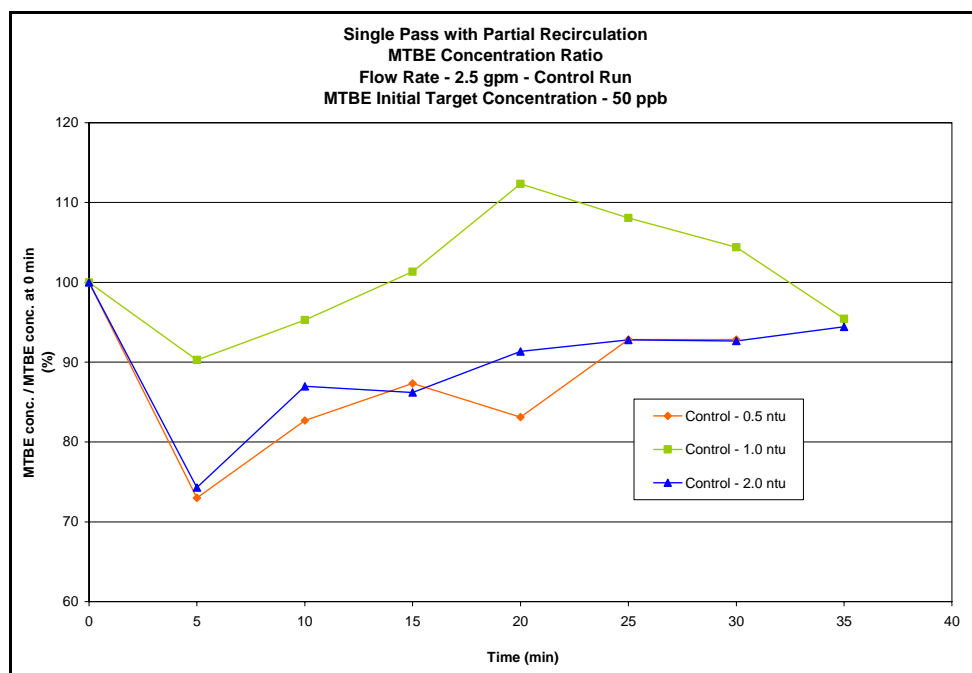


Figure 4-36: Normalized MTBE concentrations – No-treatment Run

4.3.3.2. UV / Ozone

UV/ozone treatments runs in single pass with partial recirculation, were carried out with dechlorinated tap water (<0.5 NTU), Mill Creek wastewater (1-2 NTU), and East Fork Lake water (2.7 and 18.7 NTU). A MTBE average removal efficiency of 42 % was found for all UV/Ozone SP tests performed at the T&E Facility.

Figure 4-37 shows some of the UV/ozone treatment runs for an influent/effluent rate of 9.46 L/min (2.5 gal/min), and an initial target MTBE concentration of 50 µg/L. Similarly to the control runs, the MTBE water sample is from the influent port at 0 and 30 minutes and from the effluent port at other times. Relative effluent concentrations (Figure 4-37) decreased significantly more than for the control runs at 5 minutes of operation (lower than 70 %), indicating MTBE removal from the water. MTBE removal was higher for the lower turbidity water (Figure 4-38). Although some removal is observed initially, no net removal was observed for the 2 NTU water at the end of the run (i.e., the effluent concentration equals the inlet concentration).

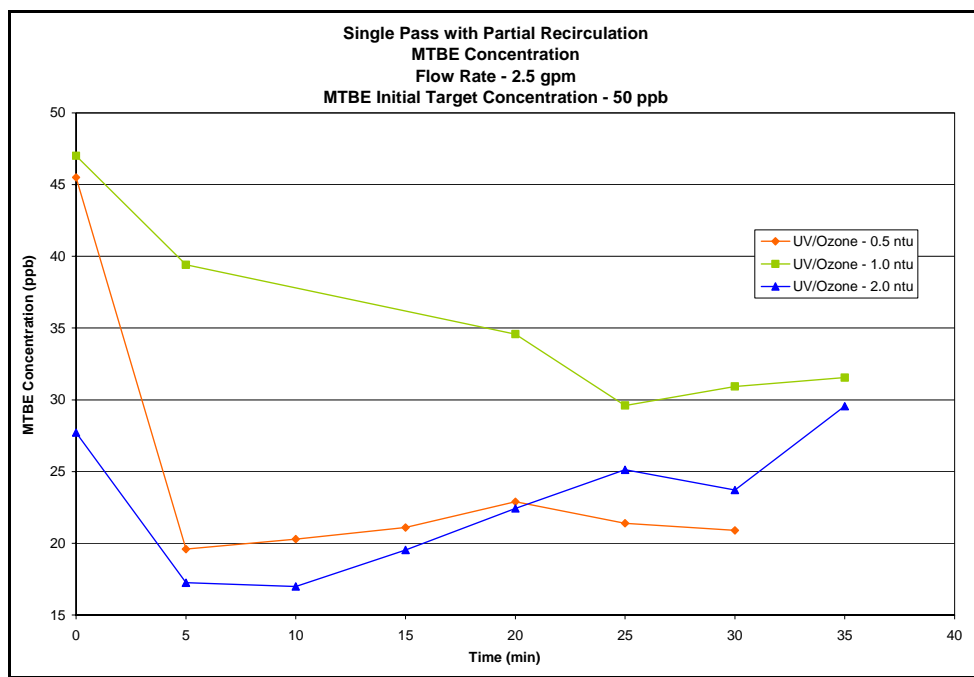


Figure 4-37: UV/Ozone treatment AOP Plant Run at T&E – MTBE: 50 µg/L

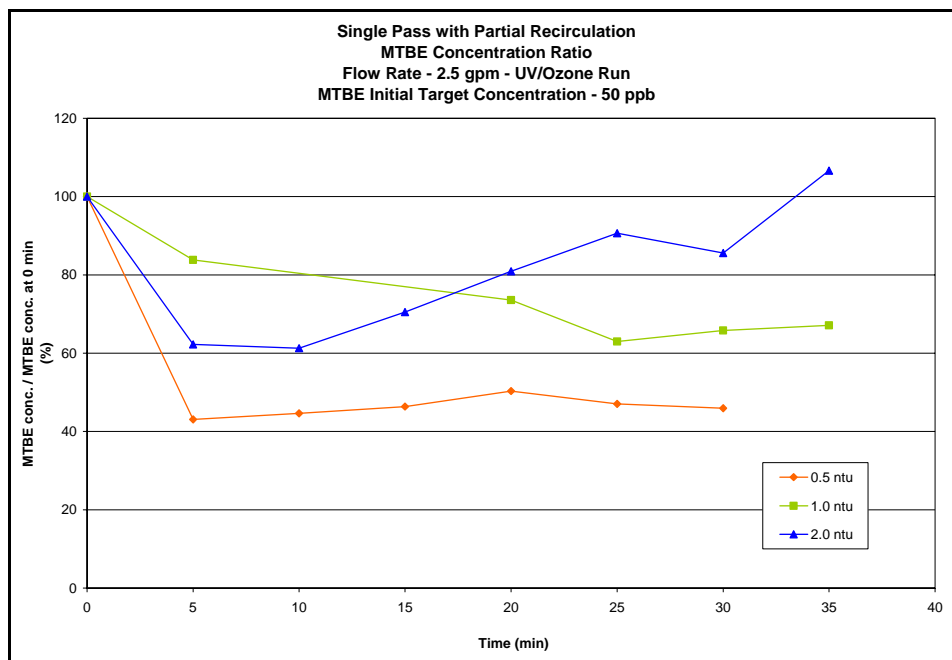


Figure 4-38: Relative removal of MTBE water concentration for UV/Ozone treatment AOP Plant Run at T&E – MTBE: 50 $\mu\text{g/L}$

A production of TBF is observed for all UV/Ozone runs (Figure 4-39), which does not occur in control runs. Because the initial MTBE concentration was not the same for all the runs, Figure 4-40 provides a normalization that can be used to compare those runs. However, in this occasion, the normalization was done using the TBF concentration over the initial measured MTBE concentration (0 min). As it happens with closed loop test, the production of TBF is proportional to the MTBE concentration removed from the matrix of water.

TBF relative effluent concentrations (Figure 4-40) remain nearly constant at 0.5 NTU, whereas increases slightly for the 1.0 NTU water. Products of TBF for the 2.0 NTU water decreases in time from a 0.25 % at five minutes to 0 after 25 minutes. TBF behavior, for the 2 NTU correlates with the MTBE removal behavior (i.e. slight initial removal).

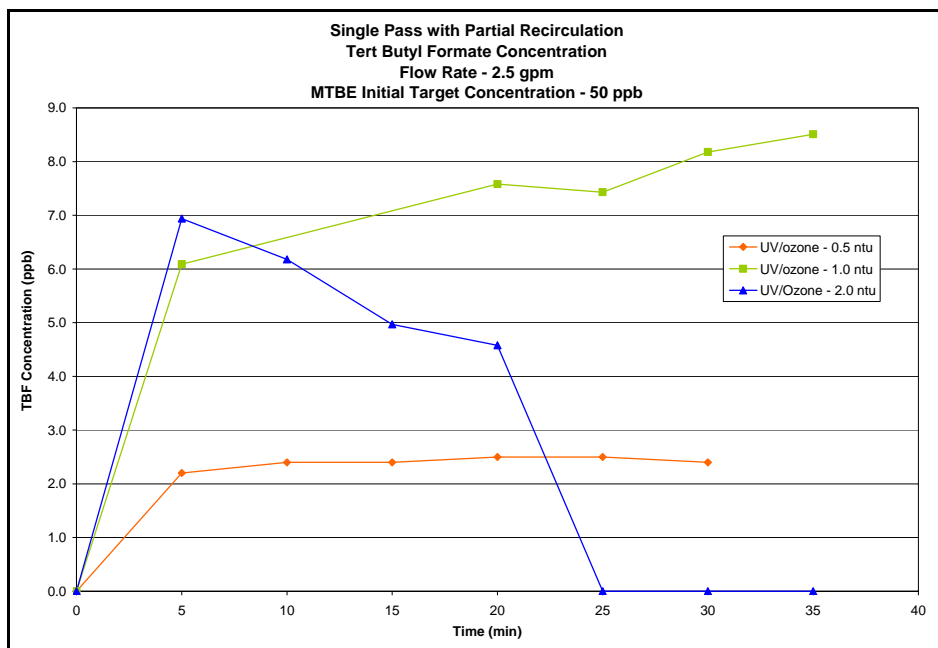


Figure 4-39: TBF concentrations - UV/Ozone treatment AOP Plant Run at T&E –
MTBE: 50 $\mu\text{g/L}$

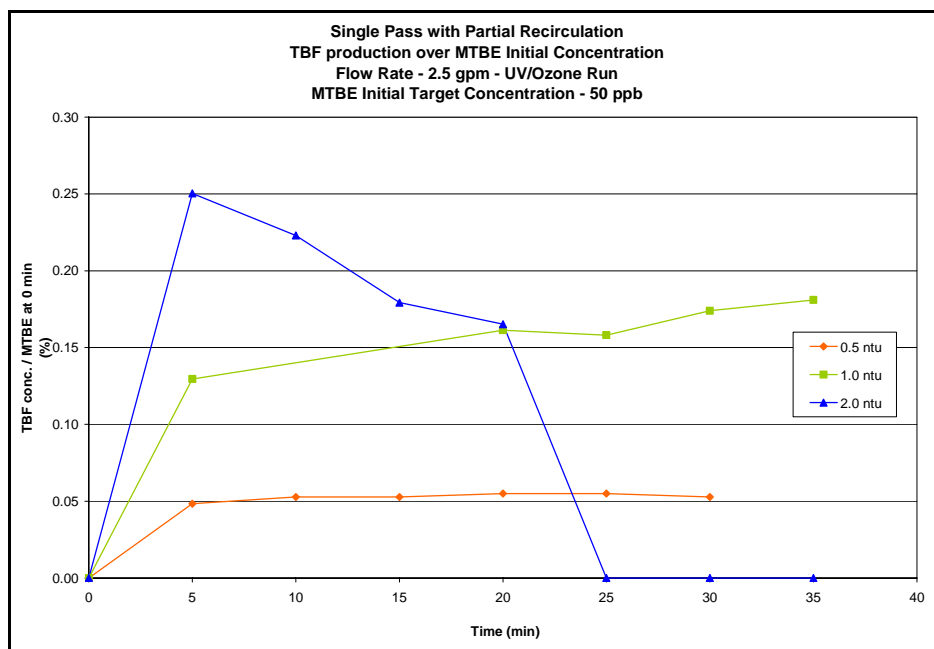


Figure 4-40: Relative TBF concentration - UV/Ozone treatment AOP Plant Run at
T&E – MTBE: 50 $\mu\text{g/L}$

4.4. Cost Evaluation

Cost evaluation includes the cost to remove the contaminant and by-products formed during the treatment and all cost that involves the acquisition and operation of the AOP plant. To account for all of this, and to give a more detailed description of the cost, this section is divided by performance and maintenance costs, and by contaminant removal. Performance and maintenance costs will address all the cost that was incurred upon the arrival of the AOP plant to the EEL, and the contaminant removal will include the costs calculated by EPA (IT Corporation, 2001), with little information on the test performed in the EEL.

4.4.1. Performance and Maintenance

This section addresses most of the cost incurred to operate the AOP plant at the EEL. Higher maintenance and replacement cost is expected when the unit is at the field because of the variable and harsh conditions it would be exposed to. Parts replaced at the EEL are included in Table 4-10. These include parts obtained as part of the maintenance schedule and parts replaced during the troubleshooting of the AOP plant (Table 4-3). The cost of a technician should also be included since troubleshooting is not straight forward.

Table 4-10: Replaced AOP plant parts at the EEL

Item No.	UV/Ozone Component	Cost	Model
1	Air Flowmeter	29.25	RMA-6-SSV
2	Atlantic UV Ozone Producing Lamp	58.00	G36T6VH
3	Check Valve (1/4" Compression)	49.40	4Z-C4L-1/3-SS
4	Indicating Desiccant for Air Dryer	62.00	DES 12
5	Inlet Particulate Filter	27.20	FLT34
6	Mazzei Kynar Venturi	64.00	684 Kynar
7	Mazzei Kynar Venturi	64.00	685 Kynar
8	Non-Indicating Desiccant for Air Dryer	44.46	DES 16

* Shipping and handling not included

4.4.2. Contaminant Removal

The AOP plant has a high consumption of electricity due to its high voltage requirement for the treatment of UV and ozone. Therefore, this section addresses the cost of the AOP plant operation in terms of the chemical removal. The consumption by each AOP plant treatment was calculated, and shown on Table 4-11.

Table 4-11: KWH used per Instrument or Treatment in the AOP plant

<i>Instrument or Treatment</i>	<i>Average Time per Watt-Hour (seconds)</i>	<i>KWH for a 61 minutes closed loop test</i>
Air dryer	42.5	0.086
UV	5.57	0.657
Ozone	4.26	0.859
UV/Ozone	3.85	0.951

The cost of MTBE removal is based on the runs that achieved concentration levels below the advisory level of 20 µg/L (Table 4-12). In addition, Table 4-12 provides the required treatment time to reach this concentration in that run, and the hours required to treat 3.78-m³ (1000-gal) at this concentration, all tests included used the field AOP plant unit.

Table 4-12: Time to reduce MTBE concentration to less than 20 µg/L

Type of Run	Treatment	Date	Initial MTBE conc. (µg/L)	Average Turbidity (NTU)	Time to Reduce MTBE conc. to <20 µg/L (min)	Adjusted Flow Rate to Treat 3.78-m ³ (gal/min)	Hours to Treat 3.78-m ³ to < 20 µg/L	Electrical Cost to Treat 3.78-m ³ to <20 µg/L
CL	UV/Ozone	1/29/2001	1200	<0.5	61	0.25	67.78	\$10.17
CL	UV/Ozone	5/22/2001	1200	2	21	0.71	23.33	\$3.50
CL	UV/Ozone	5/30/2001	1200	15	61	0.25	67.78	\$10.17
CL	Ozone	5/30/2001	1200	16	61	0.25	67.78	\$10.17
SP	UV/Ozone	4/3/2001	50	0.5	5	2.50	6.67	\$1.00
SP	UV/Ozone	4/23/2001	50	2	15	2.50	6.67	\$1.00
CL	UV/Ozone	8/5/2004	500	<0.5	61	0.25	67.78	\$10.17
CL	UV/Ozone	8/11/2004	500	<0.5	21	0.71	23.33	\$3.50
CL	UV/Ozone	8/15/2004	1800	<0.5	31	0.48	34.44	\$5.17
CL	UV/Ozone	8/15/2004	2600	<0.5	61	0.25	67.78	\$10.17

The cost of electricity is determined by the AOP plant treatment (Table 4-11), in conjunction with the cost of the KWH. For the specific case, that this AOP plant would be operated in a small community in Puerto Rico (non-PRASA), the cost that will pay the community is considered. Assuming that the community pays for a residential rate, the cost per KWH is approximately 15 cents, which traduces to an electrical cost range of \$1.00 to \$10.17 (Table 4-11).

4.4.3. Cost Summary

The operation and maintenance of the AOP plant is expensive and some of the Non-PRASA community could not afford its costs. The acquisition cost of the field AOP plant unit is between \$5000 and \$10,000 (IT Corporation, 2001), and its routine maintenance range between \$300 and \$400. This approximate maintenance cost is without taking in consideration the wage of the person in charge of the maintenance, and without further problem of the AOP plant on the field. In addition, the cost of electricity of the AOP plant, which range between \$1.00 and \$10.67 per 3.78-m³ (1000-gal) of contaminated water treated, must be considered.

The cost of AOP plant operation and maintenance is undeterminable due to the uncertainties that the package plant presented at the EEL. For a remote site, the cost of operation and maintenance could be higher. The AOP plant was tested on controlled operational conditions at T&E Facility and at the EEL, but in a remote site, the conditions are not controlled, such as climate, exposition to substances, and point of operation is undetermined.

5. Conclusions and Recommendations

The principal objective of this project was to evaluate a physical and chemical feasibility of the AOP package plant for a possible future implementation in a non-PRASA community. In addition, a consideration in the mobility and installation of the AOP plant in the field should be taken account as well. Some of the non-PRASA community wells, visited during the site evaluation, are located in the area hard to reach. The first problem will be how to transport the package plant to the site location due to its heavy weight, and then its installation, both procedures are expensive.

In terms of maintenance, the AOP plant required constant maintenance in the flowmeters, pipes, and, in the air dryer and ozone generator units when it was operated at the EEL. For example, for a controlled humidity conditions and temperature (laboratory conditions), the indicating beads of the air dryer were regenerated on a daily basis, therefore, on the field, this unit could not operate in a full mode. The flowmeters presented algae on them most of the time, the venturi was changed twice, and the UV lamp coated with calcite film, losing its capacity of operation, every other run. In addition, because the AOP plant was designed to be small, it is very uncomfortable to perform maintenance; due to the difficulty that presents to disassemble it. Furthermore, a constant supervision of the AOP plant operation is required, which makes it not desirable for remote sites, as is the case of non-PRASA communities in PR.

From the physical evaluation of the AOP package plant, it was illustrated that the implementation of this package plant in a non-PRASA community cannot provide them with a reliable technology in which they can trust. The AOP plant operation is halted continuously by faulty equipment, which, like a domino effect, affects multiple components. If this plant unit is used in a non-PRASA community, instead of solving a problem, it will be a problem itself, generating more problems to the community.

On the other hand, the AOP plant demonstrated to performs quite well in the chemical evaluation (when it worked). It achieved a complete removal of MTBE using the combination of UV and ozone treatments for MTBE initial concentration of less than 1200 $\mu\text{g/L}$. To determine the effect of water quality characteristics on the AOP plant MTBE removal efficiency, as an objective of this project, the T&E Facility dataset was used. As well, this dataset was used to complement the data obtained at the EEL, because the AOP plant was not always operational as explained before. The water characteristics studied were turbidity (USEPA dataset), temperature, and calcium concentration (EEL dataset). Turbidity and calcium concentration demonstrated to affect negatively the performance of the UV/Ozone treatment of the AOP plant unit for MTBE removal.

Another point to consider is the flow of the AOP plant. The visited non-PRASA communities used an average of 168- m^3/day (44,000 gal/day) with a well pumping rate between 0.09 to 0.47 m^3/min (25 to 125 gal/min). The AOP plant is not capable to producing this amount of water on a daily basis; if it is operated 24 hours, it will only produce 21.8- m^3/day (5,760-gal/day) based on its maximum inflow rate of 0.01 m^3/min (4 gal/min).

The cost of the AOP plant operation and maintenance is high, but much higher cost is expected at the field than the lab due to maintenance, troubleshooting and faulty operation issues. The cost of acquisition and operation, if the AOP plant operates free of problems, is excessively high for non-PRASA communities. Even if the AOP plant operates, free of problem.

In summary, the AOP plant is an excellent technology for small communities in terms of chemical removal, but is not feasible when cost, maintenance and operation are considered. Therefore, the AOP plant is not recommended to be an alternative for non-PRASA communities. From conversations with some visited communities, they prefer use waters without treatments than to not have water. As a result, a technology for those communities should be reliable, trustable, and economical.

In the case of MTBE removal, a trustable, reliable and economical solution can be the use of carbon absorption and/or absorption by resins. This technology shows to be an alternative for MTBE removal for high volume flows. A disadvantage of carbon absorption is the transfer of MTBE from one phase (water) to another (air), but it is the best solution available than to close the well.

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Appendices

**Appendix 1: List of Non-PRASA Communities Using Groundwater Wells
(PRDOH, 2002)**

Region: North				
Pws ID	Name of the System	Town	# Wells	Population
PR0207002	Campamento Penal Sabana	Arecibo	1	400
PR0207042	Arrozal – Los Muertos	Arecibo	1	350
PR0220042	Cumbre Arriba	Ciales	1	340
PR0242012	Lucas Lugo	Lares	1	40
PR0242052	Acueducto Comunidad Magueyes	Lares	1	140
PR0242062	Vega Acevedo	Lares	1	396
PR0242122	Com. Las Cuarenta	Lares	1	212
PR0242142	Alejandrina Orjales	Lares	1	28
PR0272032	Finca William Lugo	Utua	1	45
PR0272282	Finca Carbonell	Utua	1	240
PR0302013	Cerro Gordo	Aguada	1	740
PR0302023	Jagüey Chiquito	Aguada	1	680
PR0302033	Quebrada Larga	Aguada	1	408
PR0302043	Cerro Gordo Arriba II	Aguada	1	304
PR0302053	Com. Aislada en Desarrollo	Aguada	1	440
PR0302063	Com. Cerro Gordo Sec. El Parque	Aguada	1	304
PR0302073	Escuela Atalaya	Aguada	1	270
PR0351023	Sonador II	San Sebastián	1	340
PR0367013	Acueducto Rural Guacio	San Sebastián	1	304
PR0724027	Mana I	Corozal	1	320
PR0724077	Comunidad Palmarito Centro	Corozal	1	744
PR0724097	Mana III	Corozal	1	132
PR0754057	Comunidad Anones Maya	Naranjito	1	1,260
PR0754067	Anones Centro I	Naranjito	1	1,200
PR0754077	Feijo	Naranjito	1	460
PR0754087	Lolo Padilla	Naranjito	1	400
PR0754097	Las Cruces	Naranjito	1	1,200
PR0754107	Comunidad Nieves Sánchez	Naranjito	1	740
PR0754117	Acued. El Llano de Los Padilla	Naranjito	1	60
Region: Metro				
Pws ID	Name of the System	Town	# Wells	Population
PR0770037	Base Naval Sabana Seca	Toa Baja	1	1,100

Appendix 1: Continued

Region: South-West				
Pws ID	Name of the System	Town	# Wells	Population
PR0306013	Piñales Arriba	Añasco	1	240
PR0306023	Corcovada	Añasco	1	360
PR0306043	Caguabo	Añasco	1	440
PR0306053	Comunidad Hatillo	Añasco	1	300
PR0306063	La Choza II	Añasco	1	84
PR0329013	Estación M.	Guánica	2	2,500
PR0401014	Las Cruces	Adjuntas	1	130
PR0401024	Guilarte Helechales	Adjuntas	1	25
PR0401034	Pellejas	Adjuntas	1	260
PR0401074	Sector Los Hernández	Adjuntas	1	245
PR0401144	Liman	Adjuntas	1	150
PR0401234	Garzas Juncos	Adjuntas	1	460
PR0401284	Juan González	Adjuntas	2	500
PR0422014	San Diego	Coamo	1	368
PR0422094	Comunidad Montería	Coamo	1	360
PR0439014	Colonia Santi	Juana Díaz	1	76
PR0439024	Fort Allen	Juana Díaz	3	1,000
PR0455114	Com. Sabana	Orocovis	1	720
PR0455134	Pellejas-Gallera I	Orocovis	1	48
PR0455164	Pellejas II	Orocovis	1	500
PR0455214	El Perico II	Orocovis	1	88
PR0455234	Damián Arriba	Orocovis	1	320
PR0455244	Asociación Sector Coli	Orocovis	1	200
PR0455274	Acueducto Taita	Orocovis	1	120
PR0455294	Com. Saltos Cabra	Orocovis	1	500
PR0455314	Corporación Saltos Pelleja	Orocovis	1	416
PR0457084	Corozal	Peñuelas	1	130
PR0457114	La Gelpa	Peñuelas	1	400
PR0458044	Bo. Monte Llanos	Ponce	1	432
PR0458054	La Yuca	Ponce	2	500
PR0458214	Ponce Darlington	Ponce	1	220
PR0476134	Vacas III	Villalba	1	500
PR0476314	Sierrita-Caonilla	Villalba	1	100
PR0478094	Mogote	Yauco	1	140
PR0478104	Comunidad Quebrada Grande	Yauco	1	300

Appendix 1: Continued

Region: East				
Pws ID	Name of the System	Town	# wells	Population
PR0510065	Tabor	Barranquitas	2	592
PR0510095	Acued. Com. Bo. Quebradillas	Barranquitas	1	2,500
PR0510115	Los Muchos	Barranquitas	1	280
PR0510125	La Tiza II	Barranquitas	1	210
PR0510145	Acude. Rural Palmarito	Barranquitas	1	800
PR0510165	Com. Doña Mayo (El Llano II)	Barranquitas	1	300
PR0510195	Helechar-Guayabo	Barranquitas	1	640
PR0510215	Com. Barrancas Centro	Barranquitas	1	620
PR0518025	Farallón	Cayey	1	450
PR0521025	Carrasquillo	Cidra	1	460
PR0521035	Pelegrin Santo	Cidra	1	352
PR0521075	Almirante	Cidra	1	236
PR0523095	Cedrito	Comerio	1	320
PR0523105	Acude. Doña Elena (Los Pinos)	Comerio	1	720
PR0556035	Bo. Quebrada Arriba	Patillas	1	800
PR0556045	Los Barros Marín	Patillas	1	108
PR0556055	Bo. Mamey	Patillas	1	340
PR0556075	Bo. Jacaboa-Higüero	Patillas	1	168
PR0556115	Comunidad Jagual	Patillas	1	50
PR0563015	Corporación Azucarera	Salinas	3	1,500
PR0604016	Las Corujas	Aguas Buenas	1	800
PR0604036	Com. Rivera	Aguas Buenas	1	440
PR0604046	Multas Centro	Aguas Buenas	1	800
PR0604056	Sector Tiza	Aguas Buenas	1	400
PR0604066	Juan Asencio	Aguas Buenas	1	920
PR0604076	Comunidad Madriguera	Aguas Buenas	1	720
PR0604096	Las Torres Andino	Aguas Buenas	1	380
PR0604166	Pajitas Falcón	Aguas Buenas	1	194
PR0613016	Com. Casa de Pidra	Caguas	1	480
PR0613036	Acued. Comunidad Parcelas	Caguas	1	440
PR0613046	Turabo Arriba	Caguas	1	880
PR0613056	Los Velázquez	Caguas	1	300
PR0613106	Sector Lozada y Pozo Dulce	Caguas	1	768
PR0613196	Asoc. Dueños El Paraíso	Caguas	1	88
PR0613246	Usuarios Pozo Profundo	Caguas	1	200
PR0613366	Acude. Com. Sector La Sierra	Caguas	1	2,100

Appendix 1: Continued

Region: East				
Pws ID	Name of the System	Town	# wells	Population
PR0613376	Buenos Aires	Caguas	1	204
PR0613426	El Manantial	Caguas	1	26
PR0633046	Jaguas	Gurabo	1	264
PR0644086	Com. Asomante	Las Piedras	1	800
PR0644106	Acueducto Rural Asomante 2	Las Piedras	1	748
PR0666016	Asoc. Vecino Sector	San Lorenzo	1	280
PR0666036	Los Díaz	San Lorenzo	1	240
PR0666046	Quemado I Sec. Los Ortiz	San Lorenzo	1	600
PR0666056	La Cuchilla	San Lorenzo	1	424
PR0666066	Acued. Comunal Sec. Manuel	San Lorenzo	2	440
PR0666076	Quemados II Sec. Vicente	San Lorenzo	1	348
PR0666088	Corporación Sec. Cantera	San Lorenzo	1	100
PR0666096	Comunidad Sector Los Gómez	San Lorenzo	1	248
PR0666106	El Cerro	San Lorenzo	1	180
PR0677016	Acued. Rural de Tejas	Yabucoa	1	1,440
PR0677056	Acued. Jacanas Piedras	Yabucoa	1	980
PR0677066	Sodoma	Yabucoa	1	800
PR0677146	Calabazas Arriba	Yabucoa	1	1,308
PR0677186	Asociación Vecinos	Yabucoa	1	168

Appendix 2: Selected Non-PRASA Communities for Evaluation

Region	Name of the System	Town	Population	Treatment Used
North	Cerro Gordo Carr. # 2 Km 139.2 Int. 419 Barrio Cerro Gordo Aguada, PR 00602	Aguada	740	Clorador Tablets
	Jagüey Chiquito PR 411 Km 5.6 Ramal 21 (Cerca de Escuela Segunda) Aguada, PR 00602	Aguada	680	Clorador Tablets
	Quebrada Larga Carr. # 2 Km 139.5 Ramal 191 Sector Quebrada Larga Aguada, PR 00602	Aguada	408	Clorador Tablets
	Cerro Gordo Arriba II Carr. 419 Km 1.5 Barrio Cerro Gordo Aguada, PR 00602	Aguada	304	Clorador Tablets
	Com. Aislada en Desarrollo Carr. 417 Km 7.7 Barrio Cerro Gordo Aguada, PR 00602	Aguada	440	Clorador Tablets
	Com. Cerro Gordo Sec. El Parque Barrio Cerro Gordo Carr. 419 Km 0.1 Aguada, PR 00602	Aguada	304	Clorador Tablets
	Escuela Atalaya Barrio Atalaya Carr. 416 Km 0.9 Aguada, PR 00602	Aguada	270	Clorador Tablets
South-West	Piñales Arriba PR 402 Km 5.6 Int. Añasco, PR 00610	Añasco	240	Clorador
	Corcovada Carr. 420 2.Final Barrio Corcovada Arriba Añasco, PR 00610	Añasco	360	Clorador Tablets
	Caguabo Carr. 115 Km 5.5 Int. Barrio La Tosca Añasco, PR 00610	Añasco	440	None
	Comunidad Hatillo PR 4401 Km 1.0 Final Añasco, PR 00610	Añasco	300	Clorador Tablets
	La Chozza II Ramal 402 Km 1.5 Buzón 2217-RR01 Añasco, PR 00610	Añasco	84	Clorador Tablets
	Estación M Carr. 332 Hm 1 Guánica, PR 00610	Guánica	2,500	Clorador Tablets

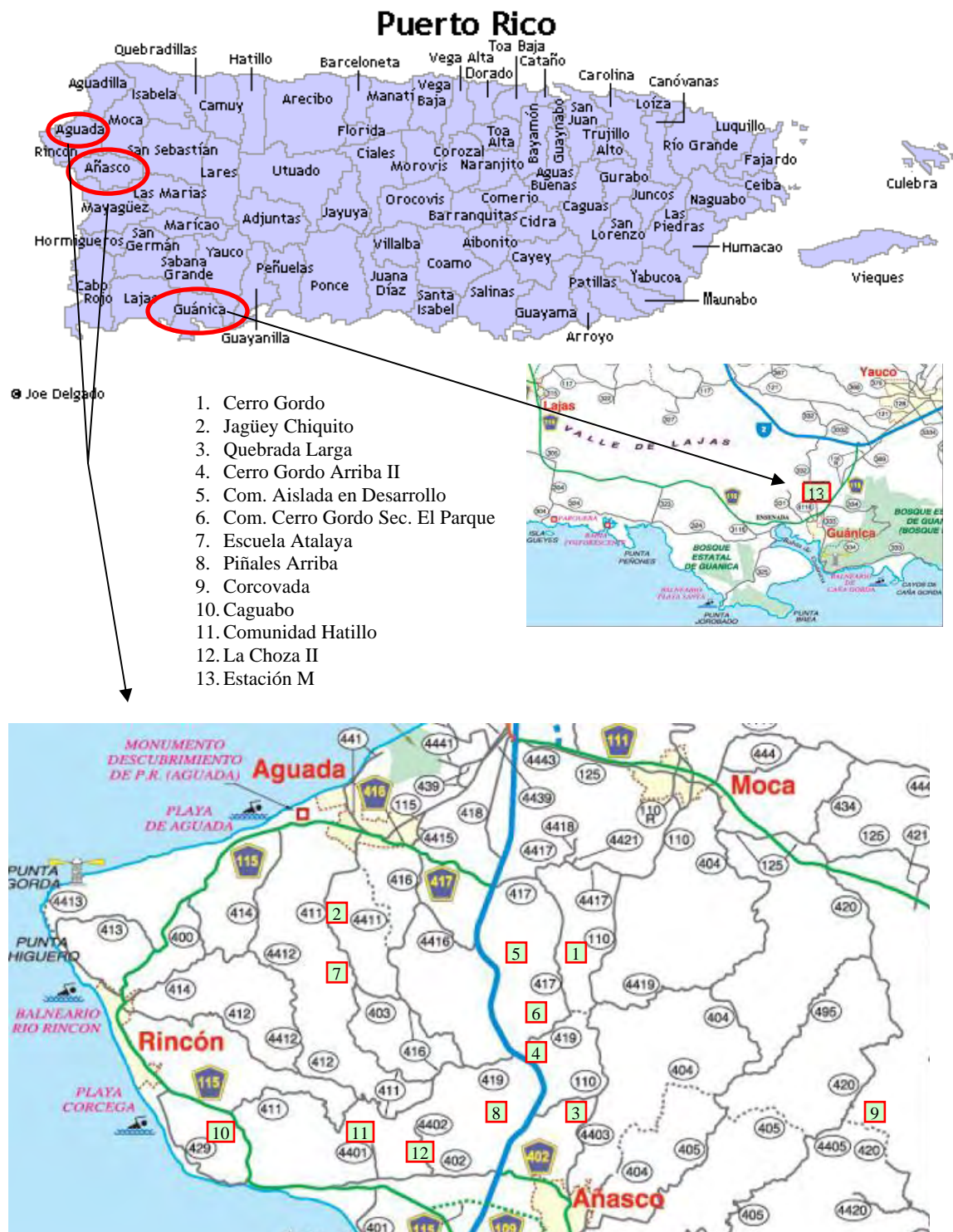


Figure A2.1: Location of Non-PRASA Communities Evaluated

Appendix 3: Sample of Non-PRASA Communities Questionnaire

Name of Non-PRASA Community:

Contact:

Date:

Location:

I. Well Specifications

- a. Diameter
- b. Depth
- c. Screened or open
- d. Water level
- e. Does it have pump?
- f. Does it have sampling point?

II. Sampling

- a. Is there a frequent sampling for water quality?
- b. Who makes the sampling?
- c. What is the sampling frequency?
- d. For what type of analysis is the sample taken?
- e. Who pays for the sampling?
- f. Are the analysis reports available?

III. Well Use

- a. How much is the pumping rate?
- b. How many hours the pump is in operation?
- c. How is the pump regulated?
- d. Where the water is delivered?
- e. What are the pipe dimensions?
- f. What are the storage tank dimension and storage volume?
- g. How many families and/or persons are connected to the well?
- h. Does the community have a Natural Resources permit of operation?
- i. Does the community pay for the well use?
- j. The community had or has water quantity problems? When and how much time in a year?

IV. Well Construction

- a. Where are design and construction documents of the well?
- b. Who constructed the well?
- c. When the well was constructed?
- d. Who paid for the well construction?

V. Others

Appendix 4: Answers to the Non-PRASA Communities Questionnaire

Thirteen Non-PRASA communities were visited during April and May 2002. Some of these communities provided detailed information of their wells. However, others provided very little information; those communities are not included in the questionnaire. Photos of the communities' wells visited are included following the questionnaire.

Non-PRASA Community: Cerro Gordo

Contact: Gavino Negro

Date: April 17, 2002

Time: 2:00 pm

I. Well Specifications

They have two wells.

a. Diameter	0.3048 meters (12 in.)
b. Depth	The first well is 70 m (230 ft), the second well is 123 m (405 ft).
c. Screened or open	Open
d. Water level	The first well is 30.5 m (100 ft) below surface level (bsl); the second well is 55 m (180 ft) bsl (without pump).
e. Does it have pump?	Yes, the first well has a pump at 50 m (165 ft); the second well does not have a pump.
f. Does it have sampling point?	Yes, there are.

II. Sampling

a. Is there a frequent sampling for water quality?	Yes, there are.
b. Who makes the sampling?	Department of Health
c. What is the sampling frequency?	Monthly
d. For what type of analysis is the sample taken?	Bacteriology
e. Who pays for the sampling?	\$50 monthly
f. Are the analysis reports available?	Yes, they are available.

III. Well Use

a. How much is the pumping rate?	~ 114 liters/min (30 gal/min)
b. How many hours the pump is in operation?	20 hours

c. How is the pump regulated?	The pump has an automatic timer.
d. Where the water is delivered?	To the storage tank located 610 m (2000 ft) apart and 91 m (300 ft) in altitude.
e. What are the pipe dimensions?	0.05 m (2") near 61 m (200 ft) of longitude but the conduction system is of 0.08 m (3") until storage tank and then of 0.10 m (4") to the distribution system.
f. What are the storage tank dimension and storage volume?	One square tank of 6.7 m x 6.7 m x 4.2 m (22'x22'x14') measured from exterior, approximately 151,372 liters (~40,000 gallons)
g. How many families and/or persons are connected to the well?	200 families ~ 800 to 1,000 people
h. Does the community have a Natural Resources permit of operation?	They are in discussion to obtain it.
i. Does the community pay for the well use?	Yes, they pay \$4380.
j. The community had or has water quantity problems? When and how much time in a year?	Yes, all the time they have water quantity problems because the water is not enough for all the community.

IV. Well Construction

a. Where are design and construction documents of the well?	No, they do not have it.
b. Who constructed the well?	A Cuban of Caguas constructed the first well, and the second well by Campos.
c. When the well was constructed?	The first well was constructed in November of 1969, due that this well is covered with sediments; the second well was constructed in 2000.
d. Who paid for the well construction?	The construction cost was covered by the Department of Public Works and by municipality funds.



Figure A4-1: Photos of the Cerro Gordo Community water wells

Non-PRASA Community: Jaguey Chiquito

(no photo)

Contact: Luis

Date: Feb 9, 2002

Time: 9:00 am

I. Well Specifications

They have two wells.

a. Diameter	Both wells are 0.2032 meters (8 in.)
b. Depth	The first well is 70 m (230 ft).
c. Screened or open	Both wells are open.
d. Water level	The first well is 15 m (49.4 ft) bsl with the pump off, and 23.5 m (77 ft) bsl with the pump on.
e. Does it have pump?	Yes, both well has pump.
f. Does it have sampling point?	No, there are not.

II. Sampling

a. Is there a frequent sampling for water quality?	Yes, there are.
b. Who makes the sampling?	Department of Health
c. What is the sampling frequency?	Monthly
d. For what type of analysis is the sample taken?	Bacteriology
e. Who pays for the sampling?	\$50 monthly
f. Are the analysis reports available?	---

III. Well Use

a. How much is the pumping rate?	~ 227 liters/min (60 gal/min).
b. How many hours the pump is in operation?	Only 6 hours, from 5pm to 11pm
c. How is the pump regulated?	They have an automatic timer, the 2 tanks are filled and the water is distributed to the houses at the same time.
d. Where the water is delivered?	The water is delivered to the storage tanks.
e. What are the pipe dimensions?	The pipe is 0.05 m (2") until storage tank.
f. What are the storage tank dimension and storage volume?	Two storage tanks of approximately 90,823 liters each (~24,000 gallons ea.)
g. How many families and/or persons are connected to the well?	250 families in the community, only 180-190 families use the well.
h. Does the community have a Natural Resources permit of operation?	---
i. Does the community pay for the well use?	---
j. The community had or has water quantity problems? When and how much time in a year?	Yes, they have problems.

IV. Well Construction

a. Where are design and construction documents of the well?	---
b. Who constructed the well?	---
c. When the well was constructed?	---
d. Who paid for the well construction?	---

V. Others

a. Comments	---
b. Additional well information	---

Non-PRASA Community: Piñales Arriba

(no photo)

I. Well Specifications

a. Diameter	0.1524 meters (6 in.)
b. Depth	49 m (160 ft)
c. Screened or open	Screened
d. Water level	---
e. Does it have pump?	Yes, the well has a pump.
f. Does it have sampling point?	Yes, there are.

II. Sampling

a. Is there a frequent sampling for water quality?	Yes, there are.
b. Who makes the sampling?	Department of Health
c. What is the sampling frequency?	Monthly
d. For what type of analysis is the sample taken?	Bacteriology
e. Who pays for the sampling?	\$50 monthly
f. Are the analysis reports available?	Yes, the reports are available.

III. Well Use

a. How much is the pumping rate?	It is about 114 liters/min (30 gal/min)
b. How many hours the pump is in operation?	The pump is operated 11 hours, then it waits 3 hours and then it works again another 6 hours.
c. How is the pump regulated?	The pump has an automatic timer.

d. Where the water is delivered?	To the storage tanks at the top of the mountain
e. What are the pipe dimensions?	0.05 m (2")
f. What are the storage tank dimension and storage volume?	Two square storage tanks, one tank of 3.1m x 3.1m, and the other tank of 5.5m x 5.5m
g. How many families and/or persons are connected to the well?	There are 72 families connected.
h. Does the community have a Natural Resources permit of operation?	Yes, they have.
i. Does the community pay for the well use?	Yes, they pay an annual amount.
j. The community had or has water quantity problems? When and how much time in a year?	No, they do not have problems.

IV. Well Construction

a. Where are design and construction documents of the well?	The community has the design documents for the first well.
b. Who constructed the well?	The first well was constructed by Campos, the second well by Chardón son from San Juan
c. When the well was constructed?	The well was constructed in 1997.
d. Who paid for the well construction?	The municipality and the community paid the well construction.

V. Others

a. Comments	They paid \$12 monthly per family to cover the electricity cost.
b. Additional well information	---



Figure A4-2: Photo of the Piñales Arriba Community water well

Non-PRASA Community: Quebrada Larga

(no photo)

Contact: Cleófilo Román

Date: April 24, 2002

Location: 18°19'40", 67°08'27"

Time: 9:00 am

I. Well Specifications

They have two wells.

a. Diameter	Both wells are 0.2032 meters (8 in.)
b. Depth	The first well is 87 m (285 ft) deep, the second well is 76 m (250 ft) deep; but they are not in the same vein.
c. Screened or open	Both wells are open
d. Water level	The first well is 56 m (185 ft) bsl; the second well is 49 m (160 ft) bsl. The separation between them is 6 m (20 ft).
e. Does it have pump?	Yes, the well has.
f. Does it have sampling point?	Yes, there are.

II. Sampling

a. Is there a frequent sampling for water quality?	Yes, there are.
b. Who makes the sampling?	Department of Health
c. What is the sampling frequency?	Monthly
d. For what type of analysis is the sample taken?	Bacteriology
e. Who pays for the sampling?	\$50 monthly
f. Are the analysis reports available?	Yes, the reports are available.

III. Well Use

a. How much is the pumping rate?	~ 114 liters/min (30 gal/min) enters the tanks.
b. How many hours the pump is in operation?	20 alternate hours (10 hrs each well)
c. How is the pump regulated?	The pump has an automatic timer, the 2 tanks are filled, and the water is distributed to the houses at the same time.
d. Where the water is delivered?	The water is delivered to the storage tanks.
e. What are the pipe dimensions?	0.05 m (2") until storage tank, 0.10 m (4"), then it reduces to 0.05 m (2") with access of 0.01m (1/2")
f. What are the storage tank dimension and storage volume?	One square tank of 4.2 m x 4.2 m x 3.7 m (14 ft x 14 ft x 12 ft), and a circular tank of 4.2 m (14 ft) in diameter, approximately 87,039 liters each (~23,000 gallons ea.)
g. How many families and/or persons are connected to the well?	115 families ~ 5 people per family
h. Does the community have a Natural Resources permit of operation?	Yes, they have a permit.

i. Does the community pay for the well use?	No, they do not pay.
j. The community had or has water quantity problems? When and how much time in a year?	No, they do not have problems.

IV. Well Construction

a. Where are design and construction documents of the well?	The community has the design documents only for the first well.
b. Who constructed the well?	The first well was constructed by Campos, the second well by Chardón son from San Juan.
c. When the well was constructed?	The first well was constructed in 1974, just in case the pump of the first well was damaged; the second well was constructed in 1993.
d. Who paid for the well construction?	Legislative budget – Senator by Moca gave \$10,000 (1 st well), and \$14,000 (2 nd well).

V. Others

a. Comments	---
b. Additional well information	---

Non-PRASA Community: Cerro Gordo Arriba II

Contact: Emiliano Cortés

Date: April 10, 2002

Time: 9:00 am

I. Well Specifications

a. Diameter	0.2032 meters (8 in.)
b. Depth	5.08 meters (200 ft)
c. Screened or open	Open
d. Water level	----
e. Does it have pump?	Yes, the well has a pump.
f. Does it have sampling point?	Yes, before chlorination.

II. Sampling

a. Is there a frequent sampling for water quality?	Yes, there are.
b. Who makes the sampling?	Department of Health
c. What is the sampling frequency?	Monthly
d. For what type of analysis is the sample taken?	Bacteriology
e. Who pays for the sampling?	\$50 monthly
f. Are the analysis reports available?	Yes, the reports are available.

III. Well Use

a. How much is the pumping rate?	It is about 265 liters/min (~ 70 gal/min)
b. How many hours the pump is in operation?	6 hours in use
c. How is the pump regulated?	The pump is regulated manually.
d. Where the water is delivered?	The water is delivered to the storage tank.
e. What are the pipe dimensions?	They are 4" of PVC.
f. What are the storage tank dimension and storage volume?	3.7 m x 4.3 m x 1.5 m ~ 23,781 liters (12 ft x 14 ft x 5 ft ~ 6,284 gal)
g. How many families and/or persons are connected to the well?	76 families ~ 3- 4 people per family
h. Does the community have a Natural Resources permit of operation?	Yes, they have a permit.
i. Does the community pay for the well use?	\$100 per year
j. The community had or has water quantity problems? When and how much time in a year?	No, they do not have problems.

IV. Well Construction

a. Where are design and construction documents of the well?	---
b. Who constructed the well?	The well was constructed by Campos.
c. When the well was constructed?	It was constructed in 1993.
d. Who paid for the well construction?	---

V. Others

a. Comments	---
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Figure A4-3: Photos of the Cerro Gordo Arriba Community water well

Non-PRASA Community: Comunidad Aislada Unida en Desarrollo, Inc.

Contact: Jorge Feliciano

Date: April 10, 2002

Time: 11:00 am

I. Well Specifications

a. Diameter	0.2032 meters (8 in.)
b. Depth	93 m (305 ft)
c. Screened or open	---
d. Water level	---
e. Does it have pump?	Yes, the pump is of 12 kW (16 hp), of 0.08 m (3 inches) in diameter
f. Does it have sampling point?	No, it does not have before the chlorination point.

II. Sampling

a. Is there a frequent sampling for water quality?	Yes, there are.
b. Who makes the sampling?	Department of Health
c. What is the sampling frequency?	Monthly
d. For what type of analysis is the sample taken?	Bacteriology
e. Who pays for the sampling?	\$50 monthly
f. Are the analysis reports available?	Yes, the reports are available.

III. Well Use

a. How much is the pumping rate?	568 liters/min (150 gal/min) and distributes at 379 liters/min (100 gal/min), we measured 295 liters/min (78 gal/min).
b. How many hours the pump is in operation?	6 hours in use, from 7 am to 12 m.
c. How is the pump regulated?	The well is operated manually.
d. Where the water is delivered?	To the storage tank located in a hill of 91 m (300 ft)
e. What are the pipe dimensions?	0.10 m (4") in diameter of PVC, with access of 0.05 m (2")
f. What are the storage tank dimension and storage volume?	5m x 5m ~ 128,666 liters (16.5' x 16.5' ~ 34,000 gal)
g. How many families and/or persons are connected to the well?	A total of 135 families, of which 5 families are connected with PRASA, and 4 families with both systems (PRASA and Non-PRASA)
h. Does the community have a Natural Resources permit of operation?	---
i. Does the community pay for the well use?	---
j. The community had or has water quantity problems? When and how much time in a year?	No, they do not have problems.

IV. Well Construction

a. Where are design and construction documents of the well?	---
b. Who constructed the well?	---
c. When the well was constructed?	The well was constructed in 1995.
d. Who paid for the well construction?	---

V. Others

a. Comments	Each family pays \$10 monthly; it will be reduced to \$5 monthly soon.
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Figure A4-4: Photos of the Comunidad Aislada Unida en Desarrollo, Inc. water well; and the chlorination treatment system used in this water

Non-PRASA Community: Corcovada

Contact: Luis Nieves Beauchamp

Date: April 10, 2002

Time: 5:00 pm

I. Well Specifications

a. Diameter	0.2032 meters (8 in.)
b. Depth	92 m (302 ft)
c. Screened or open	---
d. Water level	7 m (23 ft) at 95 liters/min (25 gal/min), 4.3 m (14 ft) bsl without pump, and 13 m (47 ft) bsl, with the pump turn on.
e. Does it have pump?	Yes, the pump is < 5.5 kW (7.5 hp) of 0.08 m (3") in diameter and of single-phase energy.
f. Does it have sampling point?	Yes, it has before chlorination.

II. Sampling

a. Is there a frequent sampling for water quality?	Yes, there are.
b. Who makes the sampling?	Department of Health
c. What is the sampling frequency?	Monthly
d. For what type of analysis is the sample taken?	Bacteriology
e. Who pays for the sampling?	\$50 monthly
f. Are the analysis reports available?	Yes, they are available.

III. Well Use

a. How much is the pumping rate?	It is 473 liters/min (125 gal/min) but it is extracted 189 liters/min (50 gal/min)
b. How many hours the pump is in operation?	It operates approximately 9 to 10 hours daily, in steps of 4 hrs on, and 3 hrs off. It does not operate from 5 to 10 pm.
c. How is the pump regulated?	The system is regulated automatically.
d. Where the water is delivered?	To a storage tank located at a height of 189 m (620 ft).
e. What are the pipe dimensions?	It is 0.08m (3") of PVC to the storage tank with access of 0.05m (2")
f. What are the storage tank dimension and storage volume?	A volume of ~ 87,039 liters (~ 23,000 gal)
g. How many families and/or persons are connected to the well?	140 families, of which 15 families are connected with PRASA and 125 families ~ 414 people are using non-PRASA system.
h. Does the community have a Natural Resources permit of operation?	---
i. Does the community pay for the well use?	---

j. The community had or has water quantity problems? Describe.	No, they do not have problems.
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IV. Well Construction

a. Where are design and construction documents of the well?	They are in the Añasco town house and/or in the Corporation of Rural Development
b. Who constructed the well?	The well was constructed by Chardón, and Guillermo Colón (contractor).
c. When the well was constructed?	The first well was constructed in 1966, and the second in 1995.
d. Who paid for the well construction?	A proposal of Rural Development pays for it.

V. Others

a. Comments	The energy cost is \$1,000 every 2 months.
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Figure A4-5: Photos of the Corcovada Community water well

Non-PRASA Community: Caguabo

Contact: Jesús González
Location: 18°18'05", 67°12'32"

Date: April 17, 2002
Time: 10:30 am

I. Well Specifications

They have two wells.

a. Diameter	Both wells are 0.2032 m (8 in.)
b. Depth	The first well is 62 m (205 ft), and the second well is 122 m (400 ft).
c. Screened or open	Open – rocks serves as screened 12 m (40 ft)
d. Water level	The first well is 21 m (70 ft) bsl; the second well is 12-15 m (40-50 ft) bsl in wet period.
e. Does it have pump?	The first well does not have pump, the second well has a pump of 11 kW (15 hp), with capacity of 227 liters/min (60 gal/min) and is located at a depth of 49 m (160 ft)
f. Does it have sampling point?	Yes, there are before chlorination.

II. Sampling

a. Is there a frequent sampling for water quality?	Yes, there are.
b. Who makes the sampling?	Department of Health
c. What is the sampling frequency?	Monthly
d. For what type of analysis is the sample taken?	Bacteriology
e. Who pays for the sampling?	---
f. Are the analysis reports available?	Yes, they are available.

III. Well Use

a. How much is the pumping rate?	It is 303 liters/min (80 gal/min), but only 151-170 liters/min (40-45 gal/min) reach the storage tank.
b. How many hours the pump is in operation?	It is operated for 16 hours each day.
c. How is the pump regulated?	They use a manual timer, although they have an automatic timer but it is disconnected.
d. Where the water is delivered?	The water is delivered to the houses, only the water in excess reaches the storage tank.
e. What are the pipe dimensions?	PVC of 0.05 m (2") until road, and then continue with 0.10 m (4").
f. What are the storage tank dimension and storage volume?	Two storage tanks, the first of 87,039 liters (23,000 gal) and the second of 28,382 liters (7,500 gal).
g. How many families and/or persons are connected to the well?	A total of 142 families ~ 4 people per family

h. Does the community have a Natural Resources permit of operation?	No, they do not have a permit.
i. Does the community pay for the well use?	No, they do not pay.
j. The community had or has water quantity problems? When and how much time in a year?	No, they do not have problems.

IV. Well Construction

a. Where are design and construction documents of the well?	They are in the Añasco town house and/or in the Corporation of Rural Development.
b. Who constructed the well?	Chardón
c. When the well was constructed?	The first well was constructed in January of 1967, and the second well in 1983.
d. Who paid for the well construction?	A proposal of Rural Development pays for it.



(a)



(b)

Figure A4-6: Photos of the Caguabo Community water wells (a), and chlorination treatment system used in the first well (b)

Non-PRASA Community: Hatillo

Contacto: Carlos Candelaria

Date: April 17, 2002

Localización tanque: 18°18'22", 67°11'38"

Time: 2:00 pm

I. Well Specifications

a. Diameter	0.1524 m (6")
b. Depth	45.7 m (150 ft)
c. Screened or open	Open.
d. Water level	The water level is 4.6-6.1 m (15-20 ft) bsl in rainy weather.
e. Does it have pump?	Yes, it has a pump at 40 m (130 ft) bsl.
f. Does it have sampling point?	Yes, there are before chlorination.

II. Sampling

a. Is there a frequent sampling for water quality?	Yes, there are.
b. Who makes the sampling?	Department of Health
c. What is the sampling frequency?	Monthly
d. For what type of analysis is the sample taken?	Bacteriology
e. Who pays for the sampling?	\$50 monthly
f. Are the analysis reports available?	Yes, they are available.

III. Well Use

a. How much is the pumping rate?	170 liters/min (~ 45 gal/min)
b. How many hours the pump is in operation?	16 hours in use
c. How is the pump regulated?	They have an automatic timer.
d. Where the water is delivered?	The water is delivered to a storage tank.
e. What are the pipe dimensions?	It has a diameter of 0.03 m (1¼") from the well to the storage tank, and 0.05 m (2") to the distribution system.
f. What are the storage tank dimension and storage volume?	4.9 m x 4.9 m x 3.4 m ~ 79,470 liters (16' x 16' x 11' ~ 21,000 gallons)
g. How many families and/or persons are connected to the well?	70 families ~ 4 persons per family
h. Does the community have a Natural Resources permit of operation?	Yes, they have.
i. Does the community pay for the well use?	No, they do not pay.
j. The community had or has water quantity problems? When and how much time in a year?	Yes, they had ten years ago, and they solved it by lowering the pump from 100 ft to 130 ft.

IV. Well Construction

a. Where are design and construction documents of the well?	---
b. Who constructed the well?	The well was constructed by Chardón from Ponce town.
c. When the well was constructed?	The well was constructed in 1960.
d. Who paid for the well construction?	The construction was paid by the Department of Education at the time of Governor Ferré.



(a)



(b)

Figure A4-7: Photos of the Hatillo Community water well (a), and its storage tank (b)

Non-PRASA Community: La Choza II

Contacto: José Matías Concepción

Date: April 17, 2002

Time: 1:30 pm

I. Well Specifications

a. Diameter	0.1524 m (6")
b. Depth	76.2 m (250 ft)
c. Screened or open	Unknown
d. Water level	The water level is 7.6 m (25 ft) bsl.
e. Does it have pump?	Yes, it has a pump at 60.7 m (200 ft) bsl.
f. Does it have sampling point?	Yes, there is a sampling point; there is not a water treatment.

II. Sampling

a. Is there a frequent sampling for water quality?	Yes, there are.
b. Who makes the sampling?	The Department of Health makes the sampling.
c. What is the sampling frequency?	They take samples every two months.
d. For what type of analysis is the sample taken?	Unknown
e. Who pays for the sampling?	They do not pay for the analysis.
f. Are the analysis reports available?	No, they do not have it.

III. Well Use

a. How much is the pumping rate?	It is 95 liters/min (~ 25 gal/min).
b. How many hours the pump is in operation?	It is turned off at 7 pm, and then it is turned on between 6 and 7 am for two days, and stays on 24 hours for five days.
c. How is the pump regulated?	They have a manual timer.
d. Where the water is delivered?	The water is delivered to a storage tank.
e. What are the pipe dimensions?	It is 0.05 m (2") from the well to the storage tank, and 0.10 m (4") to the distribution system.
f. What are the storage tank dimension and storage volume?	4.9 m x 4.9 m (16' x 16')
g. How many families and/or persons are connected to the well?	40 families ~ 200 people
h. Does the community have a Natural Resources permit of operation?	Yes, they have a permit.
i. Does the community pay for the well use?	No, they do not pay.
j. The community had or has water quantity problems? When and how much time in a year?	No, they do not have.

IV. Well Construction

a. Where are design and construction documents of the well?	The well description documents are available in the Añasco town house.
b. Who constructed the well?	---
c. When the well was constructed?	It was constructed in 1999.
d. Who paid for the well construction?	The well construction was paid by the Añasco municipality.

V. Others

a. Comments	They do not have an electric plant. They pay \$14 monthly/family
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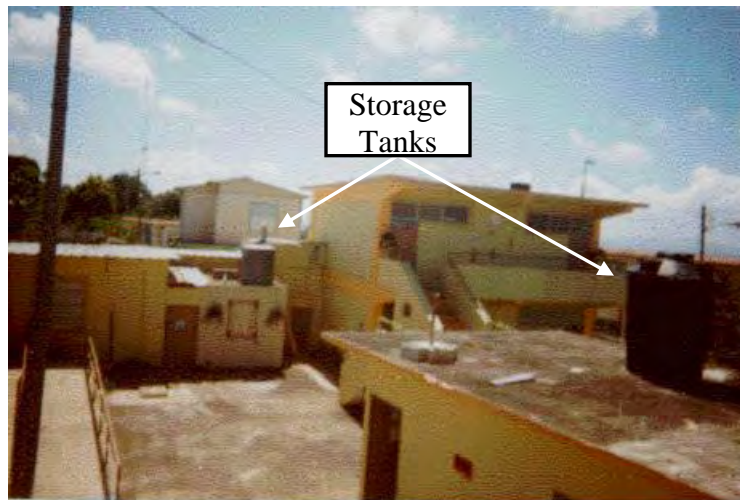


Figure A4-8: Photo of the La Choza II Community water well chlorination system

Non-PRASA Community: Escuela Atalaya
(No survey)



(a)



(b)

Figure A4-9: Photos of the Escuela Atalaya water well (a) and storage tanks (b)

Non-PRASA Community: Estación M
(No survey)



(a)



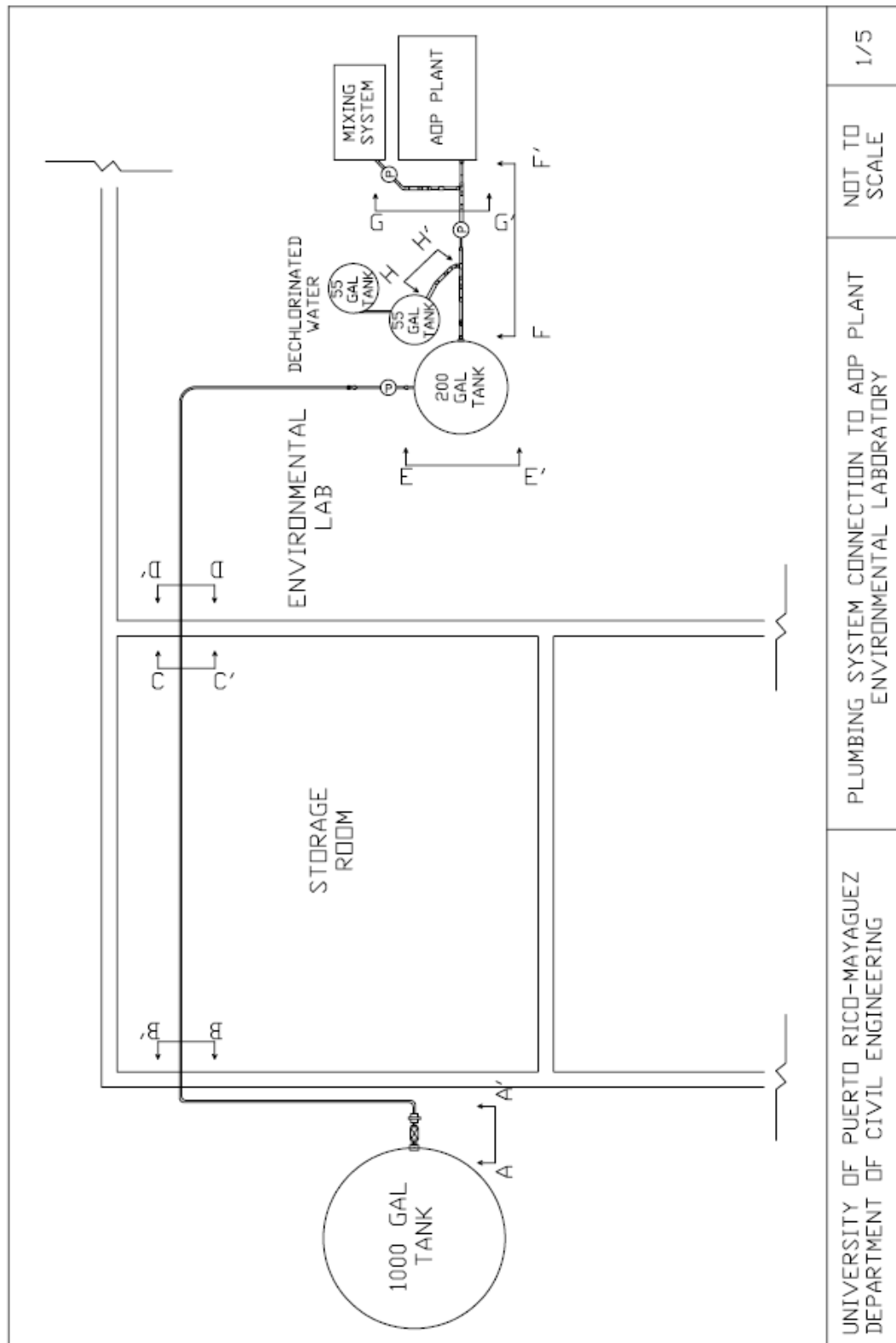
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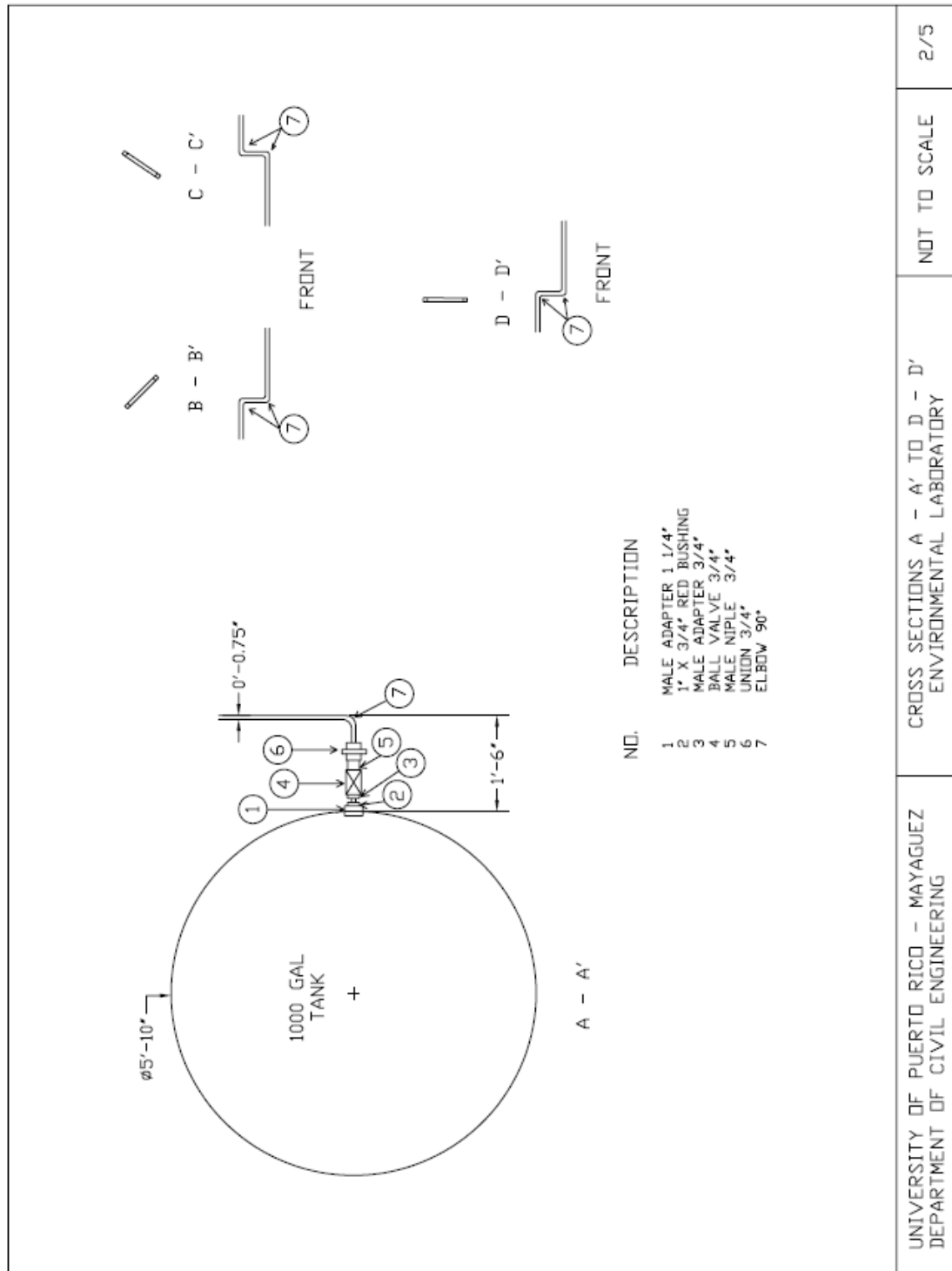


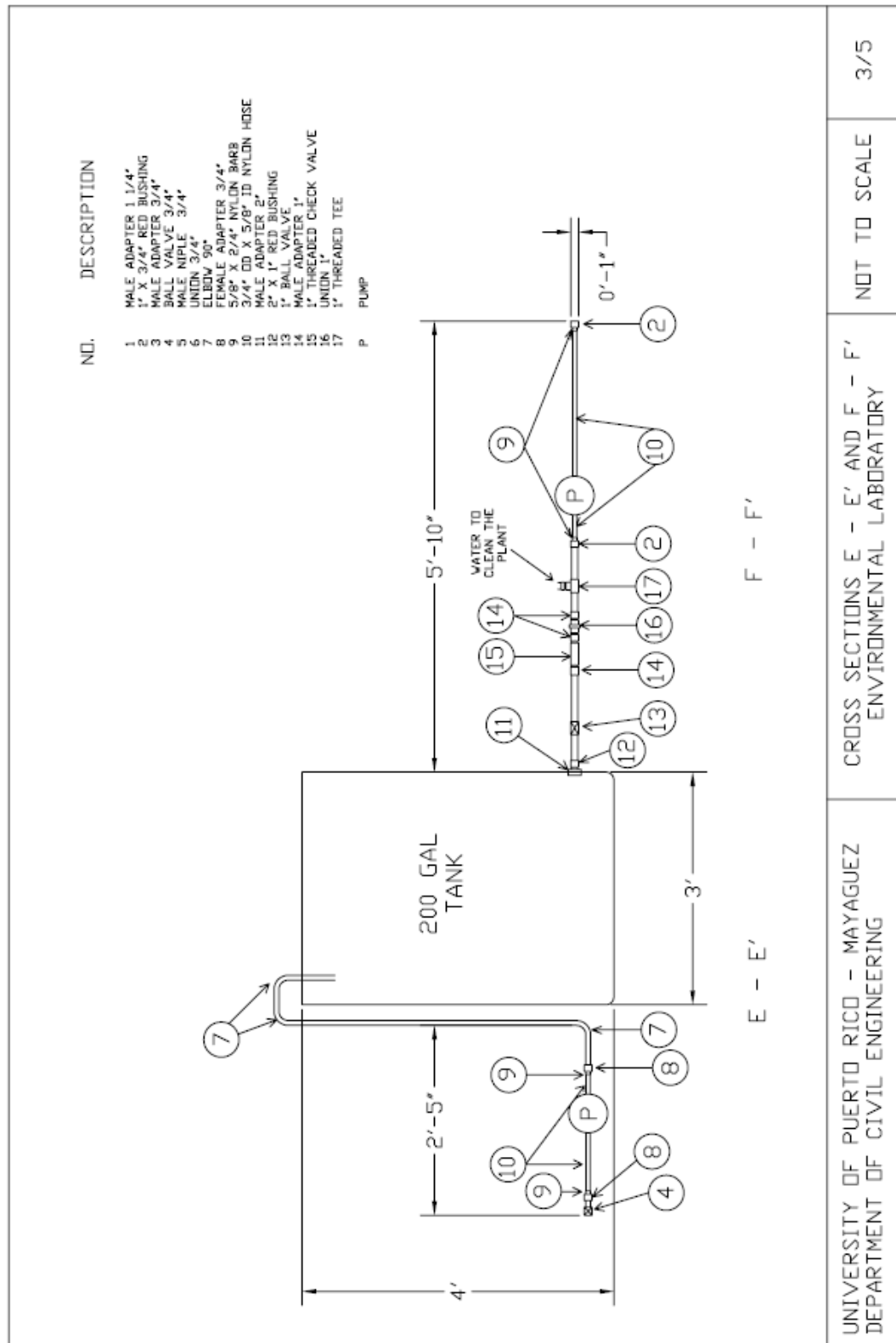
(c)

Figure A4-10: Photos of the Estación M Community water well, all system (a-c)

Appendix 5: Schematic drawings of the water delivery system at the EEL





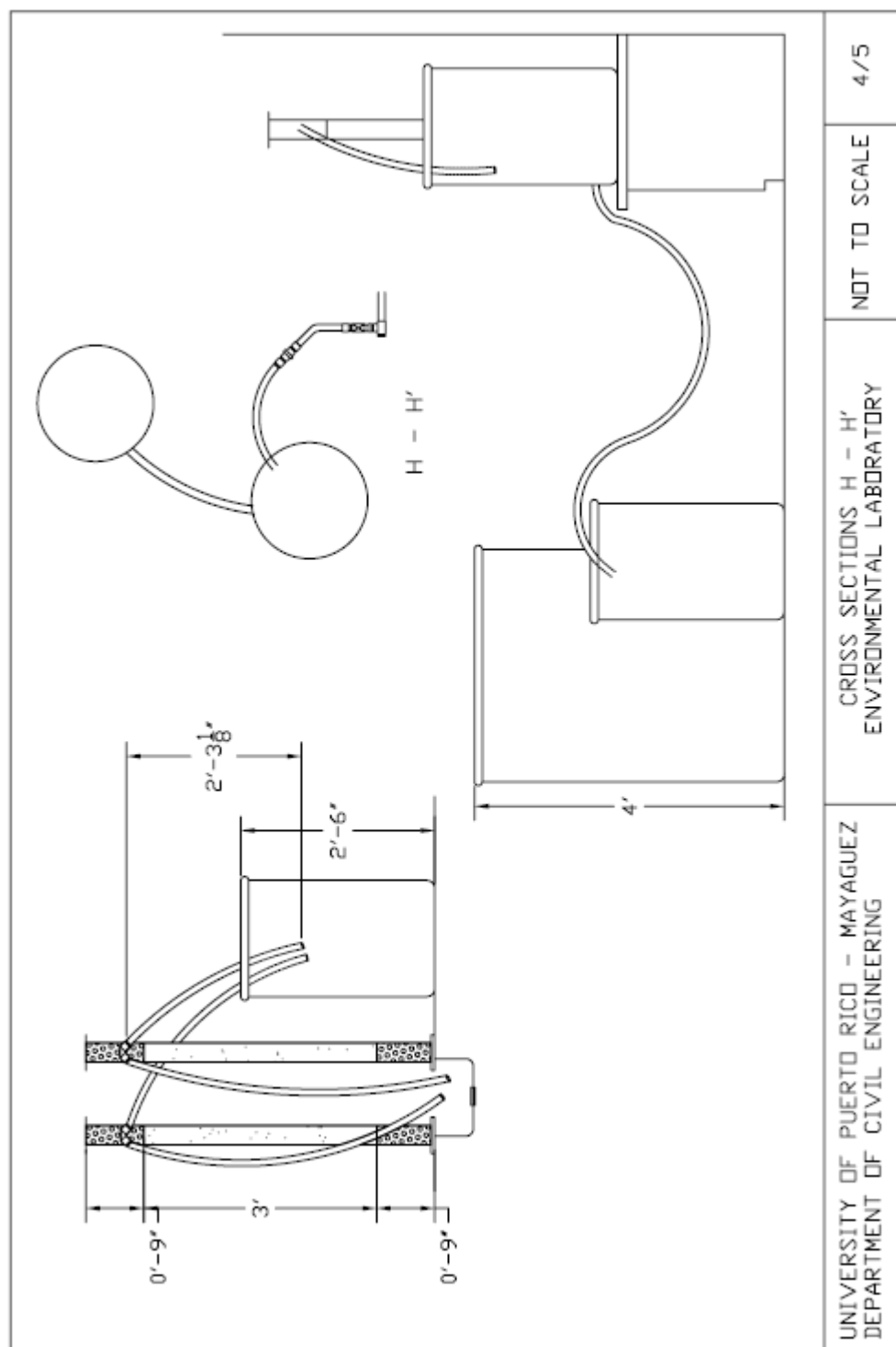


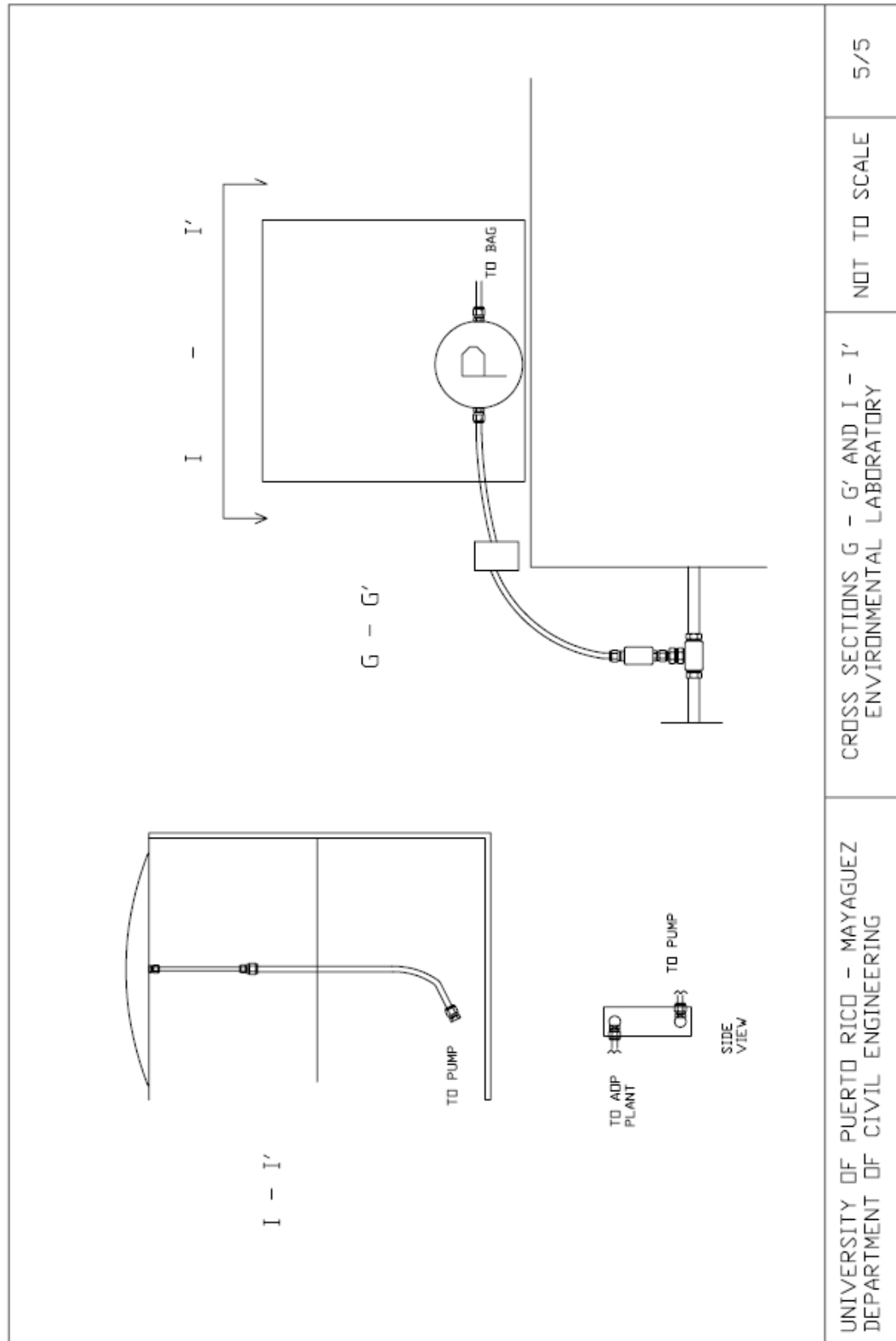
UNIVERSITY OF PUERTO RICO - MAYAGUEZ
DEPARTMENT OF CIVIL ENGINEERING

CROSS SECTIONS E - E' AND F - F'
ENVIRONMENTAL LABORATORY

NOT TO SCALE

3/5





Appendix 6: Standard Operating Procedures for the AOP Field Unit Plant

Modified from IT Corporation (2001)

Notes for all runs:

1. Turn on air dryer 1 to 2 hours before using ozone.
2. Optimize ozone generation by adjusting the Air Flow (SCFH), Fig. A6-3.
 - a. Note:
 - i. Safe ozone operating range:
 1. 5 to 20 SCFH airflow
 2. -5 “ to -15 “ Hg of vacuum
 - ii. Optimum:
 1. High airflow (e.g., 20 SCFH)
 2. Low vacuum (e.g., -5 “ Hg of vacuum)
3. Calibrate pH meter using pH 7.00 (yellow) and pH 10.00 (blue) calibration standards (1 time/day).
4. Record Electrical Usage in KWH at appropriate times (Air Dryer On, Before Purge, After Purge, Before Run, After Run, Before Purge, and After Purge).
5. Calibrate pH Meter using pH 7.00 (yellow) and pH 10.00 (blue) calibration standards (1 time/day).
6. Record Electrical Usage in KWH at appropriate times (Air Dryer On, Before Purge, After Purge, Before Run, After Run, Before Purge, and After Purge).

Section A6.1 describes the procedures for closed loop runs and section A6.2 for single pass with partial recirculation. Following is an outline of the operations by treatments; X is 1 for closed loop; and 2 for single pass with partial recirculation.

- 6.X.1 – Control Run (No-Treatment)
- 6.X.2 – UV Run
- 6.X.3 – Ozone Run
- 6.X.4 – UV/Ozone

Units Conversion

<i>Units</i>	<i>Multiply by</i>	<i>Obtain</i>
gallons/min (gpm)	3.78541	liters/minute (L/min)
Standard cubic feet per hour (SCFH)	0.28333	m ³ /hr
Psi	6.89476	kPa
inHg	25.4	mmHg
Ppb	1.0	µg/L

Figures A6-1 to A6-4 describes the components of the AOP plant. These figures are illustrated with the purpose to have an understanding in the operation procedures described later.

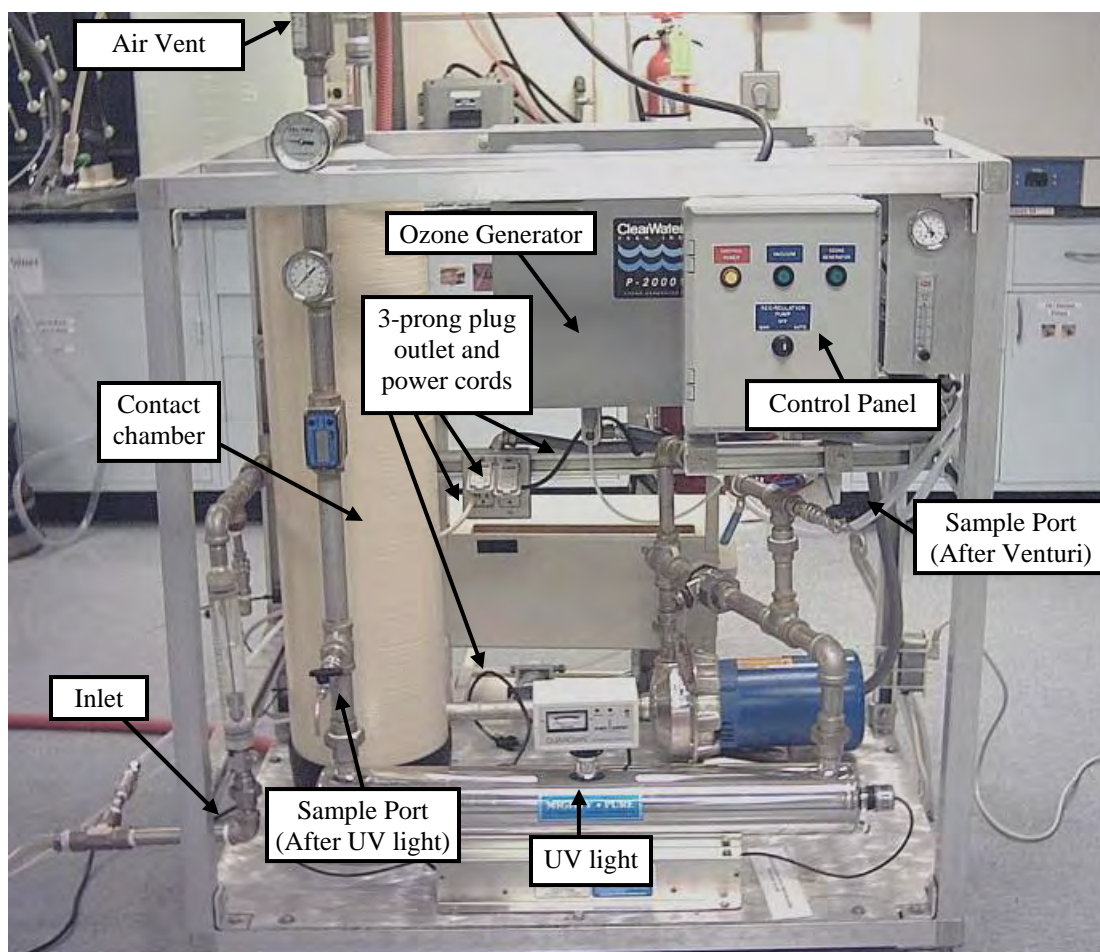


Figure A6-1: Advanced Oxidation Processes (UV/Ozone) Field Unit

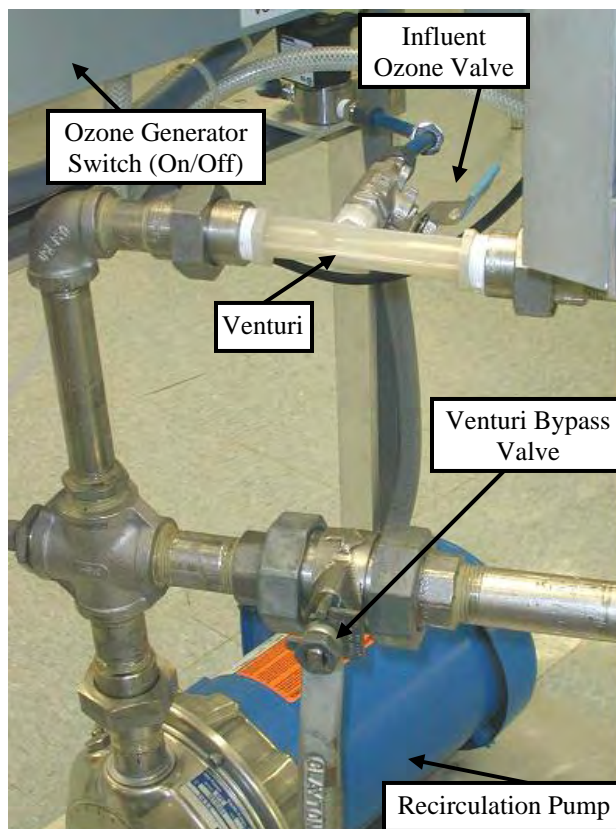


Figure A6-2: Advanced Oxidation Processes (UV/Ozone) Recirculation Loop

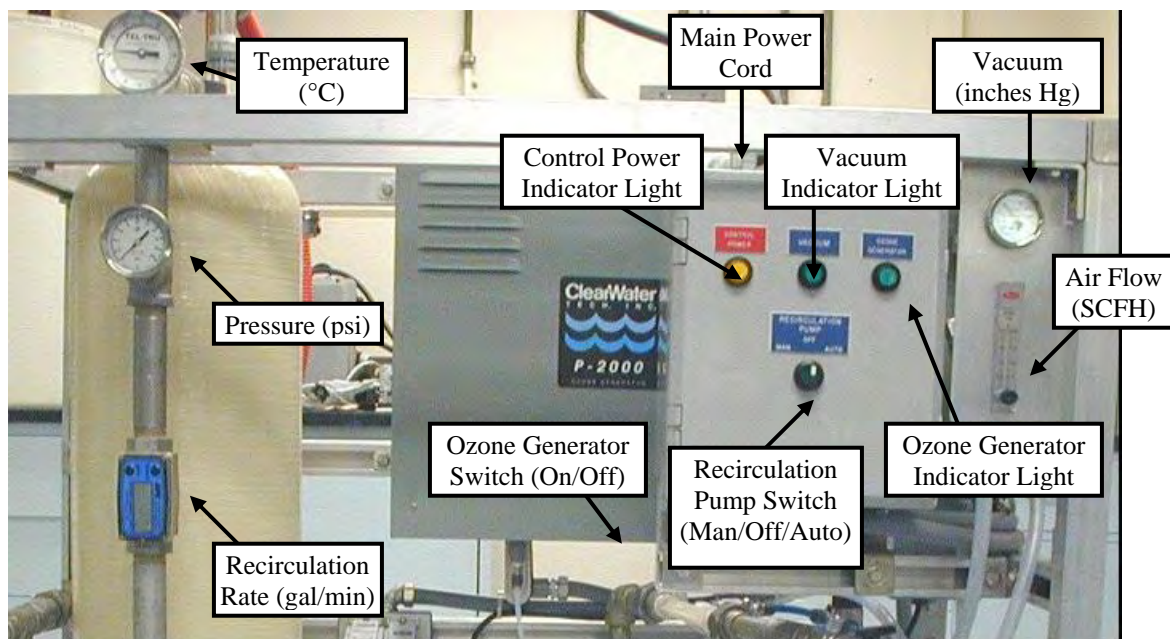


Figure A6-3: Advanced Oxidation Processes (UV/Ozone) Controls and Gauges

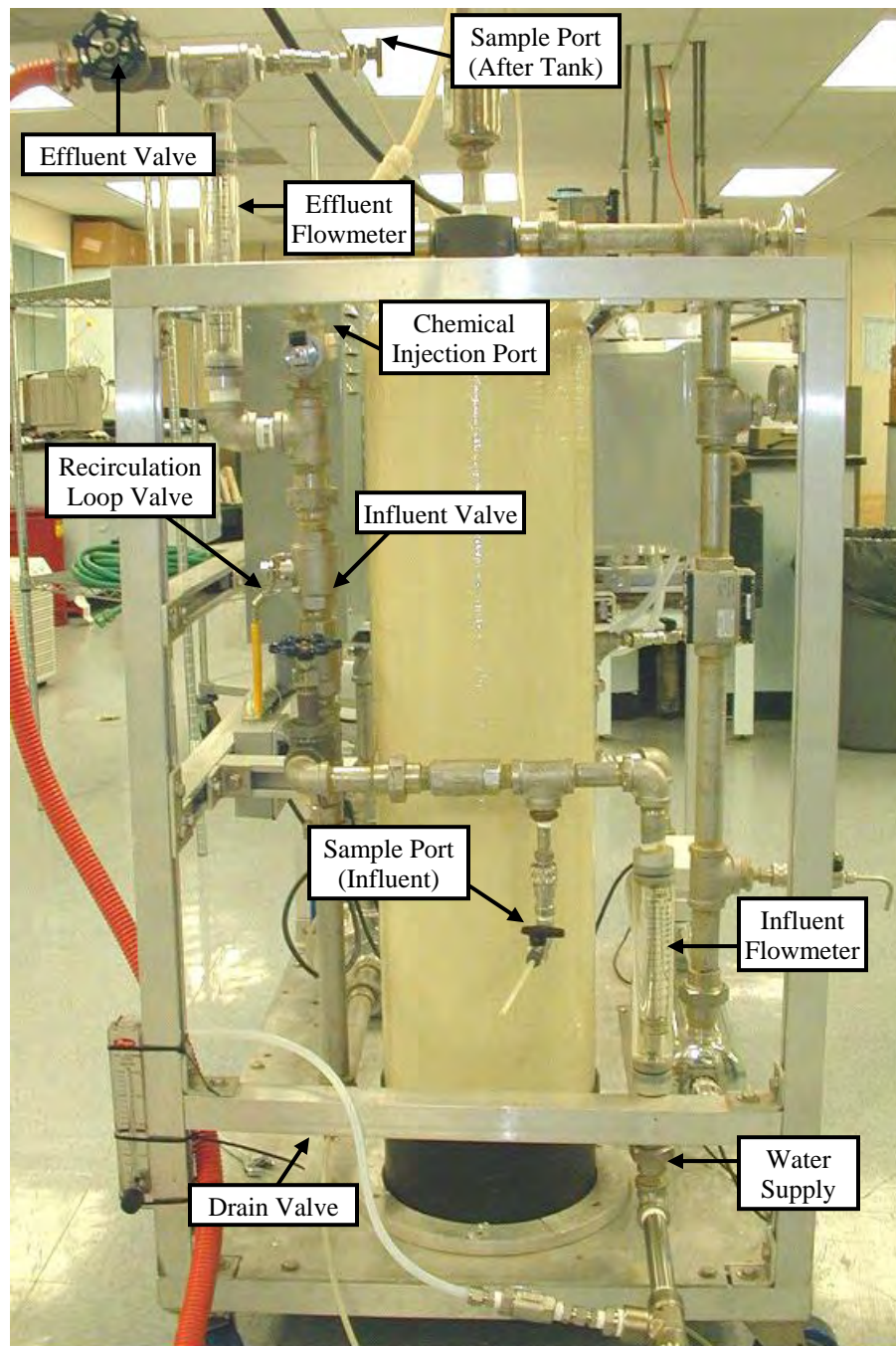


Figure A6-4: Advanced Oxidation Processes (UV/Ozone) Field Unit

Run:										
Date:		Location: UPRM Engineering Environmental Laboratory								
Tech:		Water: Hatillo's Community Well Water								
MTBE:										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
Average										

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH							
Time							

Elec. Usage in Run	
KWH	

Alkalinity (mg/L)	
-0 ALK	-61 ALK

Total Hardness (mg/L)	
-0THARD	-61THARD

TOC (mg/L)	
-0 TOC	-61 TOC

DOC (mg/L)	
-0 DOC	-61 DOC

Figure A6-5: Data sheet used to data acquisition in closed loop for the AOP Field Unit

A6.1 Closed loop

A6.1.1 Control Run (No-Treatment) – Closed Loop

1. Turn on circuit breakers. Plug main power cord into a three-prong plug outlet (Fig. A6-1).
2. Turn on air dryer 1 to 2 hours before using ozone.
3. Calibrate pH Meter using pH 7.00 (yellow) and pH 10.00 (blue) calibration standards.
4. Record Electrical Usage in KWH at appropriate times (Air Dryer On, Before Purge, After Purge, Before Run, and After Run).
5. Fill the system with Hatillo community well water as follows:
 - a. Open effluent and influent valves (Fig. A6-4).
 - b. Let water enter to the system using the upstream pump (before AOP plant) until the water exit by the effluent flowmeter (about 5 minutes).
 - c. Turn on recirculation pump switch to "Man" to fill contact tank and system piping.
6. Close influent and effluent valves (Fig. A6-4).
7. Inject MTBE at 0 minutes (Fig. A6-4).
8. Take MTBE samples and duplicates, and system readings at 1, 6, 11, 21, 31, and 61 minutes (Fig. A6-5).
9. Take particle count (PC), total organic carbon (TOC), dissolved organic carbon (DOC), total hardness (THARD), alkalinity (ALK), and metals (Ca, Fe) before and after each run (e.g., before 0 minutes and after 61 minutes).
10. Flush sampling port before taking samples. Prevent air from getting into amber vials. Take samples from the sample port to the left and above the UV light (After UV Light, Fig. A6-1) in 40 ml amber vials and preserve as follows:
 - MTBE - 25 mg of ascorbic acid (keep cool)
 - TOC-2 drops of sulfuric acid (keep cool)
 - DOC – filter and add 2 drops of sulfuric acid (keep cool)
 - Total Hardness - no preservatives
 - Alkalinity - no preservatives
 - Particle Count in 250 ml glass bottles - no preservatives
 - Metals – no preservatives
11. At the end of the Control run, plug in UV light power cord and turn on UV intensity meter.
12. Turn on recirculation pump switch to "Auto" (Fig. A6-3).
13. Open influent ozone valve by the venturi (Fig. A6-2).
14. Turn on ozone generator (Fig. A6-3). Set desired parameters (see note 2).
15. Run the UV/Ozone treatment for a minimum of one hour before open influent and effluent valves. (This is required to do not dispose MTBE to the drainage system).
16. Open influent and effluent valves (Fig. A6-4).
17. Purge MTBE from system using UV/Ozone for > 30 minutes using dechlorinated water.
18. Turn off ozone generator (Fig. A6-3).
19. Close influent ozone valve by the venturi (Fig. A6-2).
20. Turn off recirculation pump switch (Fig. A6-3).
21. Close influent and effluent valves (Fig. A6-4).
22. Remove main power cord from the three-prong plug outlet (Fig. A6-3).
23. Turn off circuit breakers.
24. Turn off water supply (Fig. A6-4).
25. Drain contact tank and system piping using valve on the discharge side and at the bottom of the contact tank (Fig. A6-4).

A6.1.2 UV Run – Closed Loop

1. Turn on circuit breakers. Plug main power cord into a three-prong plug outlet (Fig. A6-3).
2. Turn on air dryer 1 to 2 hours before using ozone.
3. Record Electrical Usage in KWH at appropriate times (Air Dryer On, Before Purge, After Purge, Before Run, and After Run).
4. Calibrate pH Meter using pH 7.00 (yellow) and pH 10.00 (blue) calibration standards.
5. Fill system with Hatillo community well water as follows:
 - a. Open effluent and influent valves (Fig. A6-4).
 - b. Let water enter to the system using the upstream pump (before AOP plant) until the water exit by the effluent flowmeter (about 5 minutes).
 - c. Turn on recirculation pump switch to "Man" to fill contact tank and system piping (Fig. A6-3).
6. Close influent and effluent valves (Fig. A6-4).
7. Plug in UV light power cord and turn on UV intensity meter (Fig. A6-1).
8. Inject MTBE at 0 minutes (Fig. A6-4).
9. Take MTBE samples/duplicates and system readings at 1, 6, 11, 21, 31, and 61 minutes (see Fig. A6-5).
10. Take particle count (PC), total organic carbon (TOC), dissolved organic carbon (DOC), total hardness (THARD), alkalinity (ALK), and metals (Ca, Fe) before and after each run (e.g., before 0 minutes and after 61 minutes).
11. Flush sampling port before taking samples. Prevent air from getting into amber vials. Take samples from the sample port to the left and above the UV light (After UV Light, Fig. A6-1) in 40 ml amber vials and preserve as follows:
 - MTBE - 25 mg of ascorbic acid (keep cool)
 - TOC-2 drops of sulfuric acid (keep cool)
 - DOC – filter and add 2 drops of sulfuric acid (keep cool)
 - Total Hardness - no preservatives
 - Alkalinity - no preservatives
 - Particle Count in 250 ml glass bottles - no preservatives
 - Metals – no preservatives
12. At the end of the UV run, turn on recirculation pump switch to "Auto" (Fig. A6-3).
13. Open influent ozone valve by the venturi (Fig. A6-2).
14. Turn on ozone generator (Fig. A6-3). Set desired parameters (see note 2).
15. Run the UV/Ozone treatment for a minimum of one hour before open influent and effluent valves. (This is required to do not dispose MTBE to the drainage system).
16. Open influent and effluent valves (Fig. A6-4).
17. Purge MTBE from system using UV/Ozone for > 30 minutes using dechlorinated water.
18. Turn off ozone generator (Fig. A6-3).
19. Close influent ozone valve by the venturi (Fig. A6-2).
20. Turn off recirculation pump switch (Fig. A6-3).
21. Close influent and effluent valves (Fig. A6-4).
22. Remove main power cord from the three-prong plug outlet (Fig. A6-3).
23. Turn off circuit breakers.
24. Turn off water supply (Fig. A6-4).
25. Drain contact tank and system piping using valve on the discharge side and at the bottom of the contact tank (Fig. A6-4).

A6.1.3 Ozone Run – Closed Loop

1. Turn on circuit breakers. Plug main power cord into a three-prong plug outlet (Fig. A6-3).
2. Turn on air dryer 1 to 2 hours before using ozone.
3. Calibrate pH Meter using pH 7.00 (yellow) and pH 10.00 (blue) calibration standards.
4. Record Electrical Usage in KWH at appropriate times (Air Dryer On, Before Purge, After Purge, Before Run, and After Run).
5. Fill system with Hatillo community well water as follows:
 - a. Open effluent and influent valves (Fig. A6-4).
 - b. Let water enter to the system using the upstream pump (before AOP plant) until the water exit by the effluent flowmeter (about 5 minutes).
 - c. Turn on recirculation pump switch to "Man" to fill contact tank and system piping.
6. Close influent and effluent valves (Fig. A6-4).
7. Turn on recirculation pump switch to "Auto" (Fig. A6-3).
8. Quickly open influent ozone valve by the venturi (Fig. A6-2).
9. Quickly turn on ozone generator (Fig. A6-3).
10. Set desired parameters (Fig. A6-3):

Optimize ozone generation by adjusting the Air Flow (SCFH), (Fig. A6-3)
 (Note: Safe ozone operating range: 5 to 20 SCFH air flow (optimum: high air flow (e.g., 20 SCFH)) and -5" to -15" hg of vacuum (optimum: low vacuum (e.g., -5" hg))
11. Run ozone generator for 10 minutes.
12. Take an ozone sample from the sample port to the left and below the venturi (After Venturi, Fig. A6-1), use indigo method for ozone detection > 1.0 mg/L, confirm using a D.I. blank with a high-range acuvacs (0-1.5 mg/L).
13. If ozone > 1.0 mg/L, inject MTBE at 0 minutes (Fig. A6-4).
14. Take MTBE samples and duplicates, and system readings at 1, 6, 11, 21, 31, and 61 minutes (Fig. A6-5).
15. Take particle count (PC), total organic carbon (TOC), dissolved organic carbon (DOC), total hardness (THARD), alkalinity (ALK), and metals (Ca, Fe) before and after each run (e.g., before 0 minutes and after 61 minutes).
16. Flush sampling port before taking samples. Prevent air from getting into amber vials. Take samples from the sample port to the left and above the UV light, (After UV Light, Fig. A6-1) in 40 ml amber vials and preserve as follows:

MTBE - 25 mg of ascorbic acid (keep cool)
 TOC-2 drops of sulfuric acid (keep cool)
 DOC – filter and add 2 drops of sulfuric acid (keep cool)
 Total Hardness - no preservatives
 Alkalinity - no preservatives
 Particle Count in 250 ml glass bottles - no preservatives
 Metals – no preservatives
17. Take ozone samples (After UV Light, Fig. A6-1) at 1, 6, 11, 21, 31, and 61 minutes and confirm using a D.I. blank with high-range acuvacs (0-1.5 mg/L).
18. At the end of the ozone run, plug in UV light power cord and turn on UV intensity meter.
19. Run the UV/Ozone treatment for a minimum of one hour before open influent and effluent valves. (This is required to do not dispose MTBE to the drainage system).
20. Open influent and effluent valves (Fig. A6-4).
21. Purge MTBE from system using UV/Ozone for > 30 minutes using dechlorinated water.
22. Turn off ozone generator (Fig. A6-3).
23. Close influent ozone valve by the venturi (Fig. A6-2).
24. Turn off recirculation pump switch (Fig. A6-3).

25. Close influent and effluent valves (Fig. A6-4).
26. Remove main power cord from the three-prong plug outlet (Fig. A6-3).
26. Turn off circuit breakers.
27. Turn off water supply (Fig. A6-4).
28. Drain contact tank and system piping using valve on the discharge side and at the bottom of the contact tank (Fig. A6-4).

A6.1.4 UV/Ozone Run – Closed Loop

1. Turn on circuit breakers. Plug main power cord into a three-prong plug outlet (Fig. A6-3).
2. Turn on air dryer 1 to 2 hours before using ozone.
3. Calibrate pH Meter using pH 7.00 (yellow) and pH 10.00 (blue) calibration standards.
4. Record Electrical Usage in KWH at appropriate times (Air Dryer On, Before Purge, After Purge, Before Run, After Run).
5. Fill system with Hatillo community well water as follows:
 - a. Open effluent and influent valves (Fig. A6-4).
 - b. Let water enter to the system using the upstream pump (before AOP plant) until the water exit by the effluent flowmeter (about 5 minutes).
 - c. Turn on recirculation pump switch to "Man" to fill contact tank and system piping.
6. Close influent and effluent valves (Fig. A6-4).
7. Turn on recirculation pump switch to "Auto" (Fig. A6-3).
8. Quickly open influent ozone valve by the venturi (Fig. A6-2).
9. Quickly turn on ozone generator (Fig. A6-3). Set desired parameters (Note 2).
 Optimize ozone generation by adjusting the airflow (SCFH), (Fig. A6-3)
 (Note: Safe ozone operating range: 5 to 20 SCFH air flow (optimum: high air flow (e.g., 20 SCFH)) and -5" to -15" hg of vacuum (optimum: low vacuum (e.g., -5" hg))
10. Run ozone generator for 10 minutes.
11. Take an ozone sample from the sample port to the left and below the venturi (after venturi, Fig. A6-1), use indigo method for ozone detection > 1.0 mg/L, confirm using a D.I. blank with a high-range acuvacs (0-1.5 mg/L).
12. If ozone > 1.0 mg/L, plug in UV light power cord (Fig. A6-1).
13. Inject MTBE at 0 minutes (Fig. A6-4).
14. Take MTBE samples and duplicates, and system readings at 1, 6, 11, 21, 31, and 61 minutes.
15. Take particle count (PC), total organic carbon (TOC), dissolved organic carbon (DOC), total hardness (THARD), alkalinity (ALK), and metals (Ca, Fe) before and after each run (e.g., before 0 minutes and after 61 minutes).
16. Flush sampling port before taking samples. Prevent air from getting into amber vials. Take samples from the sample port to the left and above the UV light (After UV Light, Fig. A6-1) in 40 ml amber vials and preserve as follows:
 - MTBE - 25 mg of ascorbic acid (keep cool)
 - TOC-2 drops of sulfuric acid (keep cool)
 - DOC – filter and add 2 drops of sulfuric acid (keep cool)
 - Total Hardness - no preservatives
 - Alkalinity - no preservatives
 - Particle Count in 250 ml glass bottles - no preservatives
 - Metals – no preservatives
17. Take ozone samples (After Venturi, Fig. A6-1) and confirm using a D.I. blank with a high-range acuvacs (0-1.5 mg/L) for the 1-minute reading and medium-range acuvacs (0-0.75 mg/L) for the remaining readings.

18. Take ozone samples (After UV Light, Fig. A6-1) and confirm using a D.I. blank with high-range acuvacs (0.1.5 mg/L) for the 1-minute reading and low-range acuvacs (0-0.25 mg/L) for the remaining readings.
19. At the end of the UV/ozone run, open influent and effluent valves (Fig. A6-4).
20. Purge MTBE from system using UV/Ozone for > 30 minutes using dechlorinated water.
21. Turn off ozone generator (Fig. A6-3).
22. Close influent ozone valve by the venturi (Fig. A6-2).
23. Turn off recirculation pump switch (Fig. A6-3).
24. Close influent and effluent valves (Fig. A6-4).
25. Remove main power cord from the three-prong plug outlet (Fig. A6-3).
26. Turn off circuit breakers.
27. Turn off water supply (Fig. A6-4).
28. Drain contact tank and system piping using valve on the discharge side and at the bottom of the contact tank (Fig. A6-4).

A6.2 *Single Pass with Partial Recirculation*

A6.2.1 *Control Run (No-Treatment) – Single Pass with Partial Recirculation*

1. Turn on circuit breakers. Plug main power cord into a three-prong plug outlet (Fig. A6-3).
2. Turn on air dryer 1 to 2 hours before using ozone.
3. Calibrate pH Meter using pH 7.00 (yellow) and pH 10.00 (blue) calibration standards.
4. Record Electrical Usage in KWH at appropriate times (Air Dryer On, Before Purge, After Purge, Before Run, and After Run).
5. Fill system with Hatillo community well water as follows:
 - a. Open effluent and influent valves to 4 gal/min (Fig. A6-4).
 - b. Let water enter to the system using the upstream pump (before AOP plant) until the water exit by the effluent flowmeter (about 5 minutes).
 - c. Turn on recirculation pump switch to "Man" to fill contact tank and system piping.
6. Close effluent and influent valves (Fig. A6-4).
7. Fill mixing bag with 30 liters of Hatillo community well water using the reverse function on the Q-pump.
8. Add MTBE to the mixing bag to obtain desired concentration. Let stand and mixing for at least 30 minutes.
9. Open effluent and influent valves to 4 gal/min (Fig. A6-4), and turn on the Q-pump in the forward option (mixing bag pump) and set the mixing system flowmeter to the desired flow.
10. Turn on recirculation pump switch to "Man" (Fig. A6-3).
11. Run system for 5 minutes.
12. Take RAW (MTBE), particle count (PC), total organic carbon (TOC), dissolved organic carbon (DOC), total hardness (THARD), alkalinity (ALK), and metals (Ca, Fe) metals samples from the influent sample port (Fig. A6-4) at Time 0 in 40 ml amber vials and preserve as follows:
 - MTBE - 25 mg of ascorbic acid (keep cool)
 - TOC - 2 drops of sulfuric acid (keep cool)
 - DOC - 2 drops of sulfuric acid (keep cool)
 - Total Hardness - no preservatives
 - Alkalinity - no preservatives
 - Particle Count in 250 ml glass bottles - no preservatives
 - Metals – no preservatives

13. Take MTBE samples and duplicates, and system readings at 5, 10, 15, and 20 minutes (Fig. A6-5).
14. Take particle count (PC), total organic carbon (TOC), dissolved organic carbon (DOC), total hardness (THARD), alkalinity (ALK), and metals (Ca, Fe) samples at 15 minutes.
15. Flush sampling port before taking samples. Prevent air from getting into amber vials. Take samples from the sample port above the contact tank (After Tank, Fig. A6-4) in 40 ml amber vials and preserve as follows:
 - MTBE - 25 mg of ascorbic acid (keep cool)
 - TOC - 2 drops of sulfuric acid (keep cool)
 - DOC - 2 drops of sulfuric acid (keep cool)
 - Total Hardness - no preservatives
 - Alkalinity - no preservatives
 - Particle Count in 250 ml glass bottles - no preservatives
 - Metals – no preservatives
16. At the end of the Control run, plug in UV light power cord and turn on UV intensity meter.
17. Turn on recirculation pump switch to "Auto" (Fig. A6-3).
18. Quickly open influent ozone valve by the venturi (Fig. A6-2).
19. Quickly turn on ozone generator (Fig. A6-3). Set desired parameters (see note 2).
20. Purge MTBE from system using UV/Ozone for > 30 minutes using dechlorinated water.
21. Turn off ozone generator (Fig. A6-3).
22. Close influent ozone valve by the venturi (Fig. A6-2).
23. Turn off recirculation pump switch (Fig. A6-3).
24. Close influent and effluent valves (Fig. A6-4).
25. Remove main power cord from the three-prong plug outlet (Fig. A6-3).
26. Turn off circuit breakers.
27. Turn off water supply (Fig. A6-4).
28. Drain contact tank and system piping using valve on the discharge side and at the bottom of the contact tank (Fig. A6-4).
29. Clean mixing bag using deionized water.

A6.2.2 UV Run – Single Pass with Partial Recirculation

1. Turn on circuit breakers. Plug main power cord into a three-prong plug outlet (Fig. A6-3).
2. Turn on air dryer 1 to 2 hours before using ozone.
3. Calibrate pH Meter using pH 7.00 (yellow) and pH 10.00 (blue) calibration standards.
4. Record Electrical Usage in KWH at appropriate times (Air Dryer On, Before Purge, After Purge, Before Run, and After Run).
5. Fill system with Hatillo community well water as follows:
 - a. Open effluent and influent valves to 4 gal/min (Fig. A6-4).
 - b. Let water enter to the system using the upstream pump (before AOP plant) until the water exit by the effluent flowmeter (about 5 minutes).
 - c. Turn on recirculation pump switch to "Man" to fill contact tank and system piping.
6. Plug in UV light power cord and turn on UV intensity meter (Fig. A6-1).
7. Close effluent and influent valves (Fig. A6-4).
8. Fill mixing bag with 30 liters of Hatillo community well water using the reverse function on the Q-pump.
9. Add MTBE to the mixing bag to obtain desired concentration. Let stand and mixing for at least 30 minutes.

10. Open effluent and influent valves to 4 gal/min (Fig. A6-4), and turn on the Q-pump in the forward option (mixing bag pump) and set the mixing system flowmeter to the desired flow.
11. Turn on recirculation pump switch to "Man" (Fig. A6-3).
12. Run system for 5 minutes.
13. Take RAW (MTBE), TOC, DOC, ALK and metals (Ca, Fe) metals samples from the influent sample port (Fig. A6-4) at Time 0 in 40 ml amber vials and preserve as follows:
 - MTBE - 25 mg of ascorbic acid (keep cool)
 - TOC - 2 drops of sulfuric acid (keep cool)
 - DOC - 2 drops of sulfuric acid (keep cool)
 - Total Hardness - no preservatives
 - Alkalinity - no preservatives
 - Particle Count in 250 ml glass bottles - no preservatives
 - Metals – no preservatives
14. Take MTBE samples and duplicates, and system readings at 5, 10, 15, and 20 minutes.
15. Take particle count (PC), total organic carbon (TOC), dissolved organic carbon (DOC), total hardness (THARD), alkalinity (ALK), and metals (Ca, Fe) samples at 15 minutes.
16. Flush sampling port before taking samples. Prevent air from getting into amber vials. Take samples from the sample port above the contact tank (After Tank, Fig. A6-4) in 40 ml amber vials and preserve as follows:
 - MTBE - 25 mg of ascorbic acid (keep cool)
 - TOC - 2 drops of sulfuric acid (keep cool)
 - DOC - 2 drops of sulfuric acid (keep cool)
 - Total Hardness - no preservatives
 - Alkalinity - no preservatives
 - Particle Count in 250 ml glass bottles - no preservatives
 - Metals – no preservatives
17. At the end of the UV run, turn on recirculation pump switch to "Auto" (Fig. A6-3).
18. Quickly open influent ozone valve by the venturi (Fig. A6-2).
19. Quickly turn on ozone generator (Fig. A6-3).
20. Purge MTBE from system using UV/Ozone for > 30 minutes.
21. Turn off ozone generator (Fig. A6-3).
22. Close influent ozone valve by the venturi (Fig. A6-2).
23. Turn off recirculation pump switch (Fig. A6-3).
24. Close influent and effluent valves (Fig. A6-4).
25. Remove main power cord from the three-prong plug outlet (Fig. A6-3).
26. Turn off circuit breakers.
27. Turn off water supply (Fig. A6-4).
28. Drain contact tank and system piping using valve on the discharge side and at the bottom of the contact tank (Fig. A6-4).
29. Clean mixing bag using deionized water.

A6.2.3 Ozone Run – Single Pass with Partial Recirculation

1. Turn on circuit breakers. Plug main power cord into a three-prong plug outlet (Fig. A6-3).
2. Turn on air dryer 1 to 2 hours before using ozone.
3. Calibrate pH Meter using pH 7.00 (yellow) and pH 10.00 (blue) calibration standards.

4. Record Electrical Usage in KWH at appropriate times (Air Dryer On, Before Purge, After Purge, Before Run, and After Run).
5. Fill system with Hatillo community well water as follows:
 - a. Open effluent and influent valves to 4 gal/min (Fig. A6-4).
 - b. Let water enter to the system using the upstream pump (before AOP plant) until the water exit by the effluent flowmeter (about 5 minutes).
 - c. Turn on recirculation pump switch to "Man" to fill contact tank and system piping.
6. Turn on recirculation pump switch to "Auto" (Fig. A6-3).
7. Quickly open influent ozone valve by the venturi (Fig. A6-2).
8. Quickly turn on ozone generator (Fig. A6-3).
9. Set desired parameters (Fig. A6-3):

Optimize ozone generation by adjusting the Air Flow (SCFH), (Fig. A6-3).
 (Note: Safe ozone operating range: 5 to 20 SCFH air flow (optimum: high air flow (e.g., 20 SCFH)) and -5" to -15" hg of vacuum (optimum: low vacuum (e.g., -5" hg))
10. Run ozone generator for 10 minutes.
11. Take an ozone sample from the sample port to the left and below the venturi (After Venturi, Fig. A6-1), use indigo method for ozone detection > 0.5 mg/L, confirm using a D.I. blank with a medium-range acuvacs (0-0.75 mg/L).
12. If ozone > 0.5 mg/L:

Turn off ozone generator (Fig. A6-3),
 Close influent ozone valve by the venturi (Fig. A6-2),
 Turn off recirculation pump switch (Fig. A6-3),
 Close effluent and influent valves (Fig. A6-4).
13. Fill mixing bag with 30 liters of Hatillo community well water using the reverse function on the Q-pump.
14. Add MTBE to the mixing bag to obtain desired concentration. Let stand and mixing for at least 30 minutes.
15. Open effluent and influent valves to 4 gal/min (Fig. A6-4), and turn on the Q-pump in the forward option (mixing bag pump) and set the mixing system flowmeter to the desired flow.
16. Turn on recirculation pump switch to "Auto" (Fig. A6-3).
17. Run system for 5 minutes.
18. Take RAW (MTBE), TOC, DOC, ALK and metals (Ca, Fe) metals samples from the influent sample port (Fig. A6-4) at Time 0 in 40 ml amber vials and preserve as follows:

MTBE - 25 mg of ascorbic acid (keep cool)
 TOC - 2 drops of sulfuric acid (keep cool)
 DOC - 2 drops of sulfuric acid (keep cool)
 Total Hardness - no preservatives
 Alkalinity - no preservatives
 Particle Count in 250 ml glass bottles - no preservatives
 Metals – no preservatives
19. Take ozone samples at 0, 5, 10, 15, and 20 minutes (After Tank, Fig. A6-4) and confirm using a D.I. blank with low-range acuvacs (0-0.25 mg/L) for the remaining readings.
20. Take MTBE samples and duplicates, and system readings at 5, 10, 15, and 20 minutes.
21. Take particle count (PC), total organic carbon (TOC), dissolved organic carbon (DOC), total hardness (THARD), alkalinity (ALK), and metals (Ca, Fe) samples at 15 minutes.
22. Flush sampling port before taking samples. Prevent air from getting into amber vials. Take samples from the sample port above the contact tank (After Tank, Fig. A6-4) in 40 ml amber vials and preserve as follows:

MTBE - 25 mg of ascorbic acid (keep cool)
 TOC - 2 drops of sulfuric acid (keep cool)
 DOC - 2 drops of sulfuric acid (keep cool)

Total Hardness - no preservatives
 Alkalinity - no preservatives
 Particle Count in 250 ml glass bottles - no preservatives
 Metals – no preservatives

23. At the end of the ozone run, plug in UV light power cord and turn on UV intensity meter.
24. Purge MTBE from system using UV/Ozone for > 30 minutes using dechlorinated water.
25. Turn off ozone generator (Fig. A6-3).
26. Close influent ozone valve by the venturi (Fig. A6-2).
27. Turn off recirculation pump switch (Fig. A6-3).
28. Close influent and effluent valves (Fig. A6-4).
29. Remove main power cord from the three-prong plug outlet (Fig. A6-3).
30. Turn off circuit breakers.
31. Turn off water supply (Fig. A6-4).
32. Drain contact tank and system piping using valve on the discharge side and at the bottom of the contact tank (Fig. A6-4).
33. Clean mixing bag using deionized water.

A6.2.4 UV/Ozone Run – Single Pass with Partial Recirculation

1. Turn on circuit breakers. Plug main power cord into a three-prong plug outlet (Fig. A6-3).
2. Turn on air dryer 1 to 2 hours before using ozone.
3. Calibrate pH Meter using pH 7.00 (yellow) and pH 10.00 (blue) calibration standards.
4. Record Electrical Usage in KWH at appropriate times (Air Dryer On, Before Purge, After Purge, Before Run, and After Run).
5. Fill system with Hatillo community well water as follows:
 - a. Open effluent and influent valves to 4 gal/min (Fig. A6-4).
 - b. Let water enter to the system using the upstream pump (before AOP plant) until the water exit by the effluent flowmeter (about 5 minutes).
 - c. Turn on recirculation pump switch to "Man" to fill contact tank and system piping.
6. Turn on recirculation pump switch to "Auto" (Fig. A6-3).
7. Quickly open influent ozone valve by the venturi (Fig. A6-2).
8. Quickly turn on ozone generator (Fig. A6-3).
9. Set desired parameters (Fig. A6-3):

Optimize ozone generation by adjusting the Air Flow (SCFH), (Fig. A6-3)
 (Note: Safe ozone operating range: 5 to 20 SCFH air flow (optimum: high air flow (e.g., 20 SCFH)) and -5" to -15" hg of vacuum (optimum: low vacuum (e.g., -5" hg))
10. Run ozone generator for 10 minutes.
11. Take an ozone sample from the sample port to the left and below the venturi (After Venturi, Fig. A6-1), use indigo method for ozone detection > 0.5 mg/L, confirm using a D.I. blank with a medium-range acuvacs (0-0.75 mg/L).
12. If ozone > 0.5 mg/L:

Turn off ozone generator (Fig. A6-3),
 Close influent ozone valve by the venturi (Fig. A6-2),
 Turn off recirculation pump switch (Fig. A6-3),
 Close effluent and influent valves (Fig. A6-4)
13. Fill mixing bag with 30 liters of Hatillo community well water using the reverse function on the Q-pump.

14. Add MTBE to the mixing bag to obtain desired concentration. Let stand and mixing for at least 30 minutes.
15. Open effluent and influent valves to 4 gal/min (Fig. A6-4), and turn on the Q-pump in the forward option (mixing bag pump) and set the mixing system flowmeter to the desired flow.
16. Turn on recirculation pump switch to "Auto" (Fig. A6-3).
17. Plug in UV light power cord and turn on UV intensity meter (Fig. A6-1).
18. Open influent ozone valve by the venturi (Fig. A6-2).
19. Turn on ozone generator (Fig. A6-3). Note: -5" Hg of vacuum, 10 SCFH air.
20. Run system for 5 minutes.
21. Take RAW (MTBE), TOC, DOC, ALK and metals (Ca, Fe) metals samples from the influent sample port (Fig. A6-4) at Time 0 in 40 ml amber vials and preserve as follows:
 - MTBE - 25 mg of ascorbic acid (keep cool)
 - TOC - 2 drops of sulfuric acid (keep cool)
 - DOC - 2 drops of sulfuric acid (keep cool)
 - Total Hardness - no preservatives
 - Alkalinity - no preservatives
 - Particle Count in 250 ml glass bottles - no preservatives
 - Metals - no preservatives
22. Take ozone samples at 0, 5, 10, 15, and 20 minutes (After Venturi, Fig. A6-1) and confirm using a D.I. blank with a medium-range acuvacs (0-0.75 mg/L).
23. Take ozone samples at 0, 5, 10, 15, and 20 minutes (After Tank, Fig. A6-4) and confirm using a D.I. blank with low-range acuvacs (0-0.25 mg/L) for the remaining readings.
24. Take MTBE samples and duplicates, and system readings at 5, 10, 15, and 20 minutes.
25. Take particle count (PC), total organic carbon (TOC), dissolved organic carbon (DOC), total hardness (THARD), alkalinity (ALK), and metals (Ca, Fe) samples at 15 minutes.
26. Flush sampling port before taking samples. Prevent air from getting into amber vials. Take samples from the sample port above the contact tank (After Tank, Fig. A6-4) in 40 ml amber vials and preserve as follows:
 - MTBE - 25 mg of ascorbic acid (keep cool)
 - TOC - 2 drops of sulfuric acid (keep cool)
 - DOC - 2 drops of sulfuric acid (keep cool)
 - Total Hardness - no preservatives
 - Alkalinity - no preservatives
 - Particle Count in 250 ml glass bottles - no preservatives
 - Metals - no preservatives
27. At the end of the UV/ozone run, open valve of the dechlorinated water.
28. Purge MTBE from system using UV/Ozone for > 30 minutes using dechlorinated water.
29. Turn off ozone generator (Fig. A6-3).
30. Close influent ozone valve by the venturi (Fig. A6-2).
31. Turn off recirculation pump switch (Fig. A6-3).
32. Close influent and effluent valves (Fig. A6-4).
33. Remove main power cord from the three-prong plug outlet (Fig. A6-3).
34. Turn off circuit breakers.
35. Turn off water supply (Fig. A6-4).
36. Drain contact tank and system piping using valve on the discharge side and at the bottom of the contact tank (Fig. A6-4).
37. Clean mixing bag using deionized water.

Appendix 7: Description of the VOA analysis calibration

This appendix will detail the volatile organic analysis calibration used with the EEL data presented on chapter 4. It is divided in three parts: (1) the preparation of the stock, and (2) the calibration standards, and (3) the development of the calibration standard curve for the volatile organic compound of interest.

a. Stock Standard

The following table corresponds to the spreadsheet created on Microsoft Excel to make the standard stock concentration for each VOC.

- The vial volume was calculated using an average of its weight, with several vials. Each VOA vial was weighted before and after the filling it with water to eliminate the headspace in side the vial.
- To make the standards, a pipette (class A) was used to deliver 30 mL of deionized (DI) water per VOA vial; consequently, the water volume is 30 mL.
- Five micro-liters (μL) of the organic compound of interest were added to the VOA vial using a syringe.
- The Henry's law constant used were:

<i>Organic Compound</i>	<i>Henry's Constant</i>
Acetone	0.0017
Acetaldehyde	0.0027
Methyl Acetate	0.0028
MTBE	0.0260
TBF	0.0111

- The total mass was obtained by difference in weights using,

$$M_{\text{water}} = M_{\text{weight after adding VOC}} - M_{\text{weight before VOC}}$$

$$\text{Example: } M_{\text{VOC}} = 55.8353[g] - 55.8327[g] = 2.6000 \text{ g}$$

- The water stock standard concentration was calculated assuming partition in water and air.

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Example:

$$C_{\text{water}} = \frac{2.600[mg]}{(0.026 \times 13.1[mL]) + (30[mL])} = \frac{2.600[mg]}{30.3406[mL]} \times \frac{1000mL}{1L} = 85.69 \text{ mg/L}$$

<i>MTBE Standards</i> <i>500 ppb MTBE</i>			
<i>Vial Properties</i>			
<i>Vial volume</i>		43.1 ml	
<i>Water volume</i>		30 ml	
<i>MTBE - Henry Law Constant</i>		0.026	
<i>Amount of MTBE added (μL)</i>		5.0	
<i>Weight of Vial + cap + water (g)</i>	<i>Weight of Vial + cap + water + MTBE (g)</i>	<i>MTBE Total Mass (mg)</i>	<i>MTBE Water Concentration Stock Standard (mg/L)</i>
55.8327	55.8353	2.600	85.694
<i>Stock Concentration</i>		85.69 mg/L	

<i>Desired Water Concentration ($\mu\text{g/L}$)</i>	<i>MTBE Total Mass (μg)</i>	<i>μl added of stock solution</i>	<i>ml added of stock solution</i>
0	0.0000	0	0.00
50	1.5170	18	0.02
150	4.5511	53	0.05
400	12.1362	142	0.14
600	18.2044	212	0.21

- The calibration standards were prepared by adding a specific amount of stock standard to a 40-mL VOA vial. To determine this amount, the above equations were used in the reverse way, as follow:

$$\mu\text{l of stock} = \frac{\text{Total Mass } [\mu\text{g}]}{\text{Stock Concentration } [\text{mg} / \text{L}]} \times \frac{1,000 \text{ mL}}{1 \text{ L}}$$

$$\text{Example: } \mu\text{l of stock} = \frac{1.5170 [\mu\text{g}]}{85.69 [\text{mg} / \text{L}]} \times \frac{1,000 \text{ mL}}{1 \text{ L}} = 18 \mu\text{L}$$

b. Calibration Standard

The calibration standard consists of preparing two VOA vials (duplicate) per VOC desired concentration per each SPME used; therefore, four vials were prepared per desired concentration of VOC.

- Each vial was weighted with cap after the addition of 7.5 grams of sodium chloride (NaCl), 30 mL of deionized water, a miniature magnetic stirrer. The total weight was annotated after the water acclimatizes to the vial.
- The amount of stock standard concentration, calculated in the previous section, was added in order to obtain the desired water VOC concentration.
- Then, the vial was placed in a magnetic plate until all the sodium chloride was dissolved in the solution. Once the solution was completely homogeneous, the

vial was retired from the magnetic plate and leaved to reach equilibrium in the air and water phase (approximately 30 minutes).

- Subsequently, the vial was weighted again and the difference in weight provided the VOC total mass in the VOA vial. Using the total mass equation, the water VOC concentration standard was determined. This step is required because the amount of VOC to be added to make the calibration standard was not easy to measure.

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Example:

$$C_{water} = \frac{1.6110[\mu g]}{(0.026 \times 13.1[mL]) + (30[mL])} = \frac{1.6110[\mu g]}{30.3406[mL]} \times \frac{1000mL}{1L} = 53.10 \mu g / L$$

Date: <i>July 15, 2004</i>							
<i>MTBE Standards</i> <i>500 µg/L MTBE</i>							
<i>Stock Concentration</i>			85.69 mg/L				
<i>Henry Law Constant</i>			0.026				
<i>SPME # 1</i>							
<i>Vial Name</i>	<i>Desired Water Conc. (µg/L)</i>	<i>MTBE Total Mass (µg)</i>	<i>Weight of Vial + NaCl + stirrer + water + cap (g)</i>	<i>Weight of Vial + NaCl + stirrer + water + cap + µL of stock standard (g)</i>	<i>MTBE Total Mass (µg)</i>	<i>Water MTBE Concentration Standard (µg/L)</i>	<i>Average Conc. (µg/L)</i>
50 ppb	50	1.5170	64.0459	64.0647	1.6110	53.10	51.12
50 ppb - dup	50	1.5170	63.8672	63.8846	1.4911	49.14	
150 ppb	150	4.5511	64.0681	64.1263	4.9874	164.38	163.96
150 ppb - dup	150	4.5511	64.0106	64.0685	4.9617	163.53	
400 ppb	400	12.1362	63.6974	63.8514	13.1968	434.96	431.57
400 ppb - dup	400	12.1362	64.0289	64.1805	12.9912	428.18	
600 ppb	600	18.2044	64.0152	64.2474	19.8981	655.82	654.84
600 ppb - dup	600	18.2044	63.9715	64.2030	19.8381	653.85	

The following table specifies the calibration standards prepared for each VOC measured at the EEL.

<i>MTBE Target Concentration ($\mu\text{g/L}$)</i>	<i>Desired Organic Compound for Standard Concentration</i>	<i>Standard Concentration prepared ($\mu\text{g/L}$)</i>
500	MTBE	50, 150, 400, 600
1800		500, 1000, 1500, 2000
2600		1500, 2000, 2500, 3000
500, 1800, 2600	TBF	0, 100, 300, 500
	Acetone	0, 75, 150
	Methyl Acetate	0, 50, 100
	Acetaldehyde	0, 50, 100

c. Standard Calibration Curve

The standard calibration curve was prepared extracting MTBE and MTBE by-products using SPME fibers as explained on chapter 3. Because there two SPME fibers used consecutively, a manual calibration was used to create the standard calibration curve.

- The chromatogram obtained from the GC/FID gives the time were the VOC was observed and its area.
- The concentration used for the calibration curve was the average of the two vials prepared for the SPME in calibration.
- To create the calibration curve, a linear regression with forced origin was used.
- Then, the concentration of the VOC standard was calculated using the linear regression curve obtained in the previous step.

- Next, a percent of difference between the known VOC concentration and the VOC calculated using the linear regression equation was computed for each vial, as follow.

$$\% \text{ Diff} = \frac{\text{known concentration} - \text{calculated concentration}}{\text{known concentration}} \times 100\%$$

$$\text{Example: } \% \text{ Diff} = \frac{51.12 \mu\text{g} / \text{L} - 78.12 \mu\text{g} / \text{L}}{51.12 \mu\text{g} / \text{L}} \times 100\% = 52.8 \%$$

- If the percent difference was superior than 15, that standard was not used for the calibration curve. Another standard were prepared instead, until a percent difference of less than 15 % were obtained.

Calibration Curve for 500 ppb MTBE									
Closed Loop - AOP Plant Runs									
SPME # 1									
Description					Calibration Curve		Calibration Verification		
Std. Conc. (µg/L)	File	Time (min)	Conc. (µg/L)	Area (µV*s)	Conc. (µg/L)	Area (µV*s)	Area (µV*s)	Calculated Conc. (µg/L)	% Diff
					0.00	0.00			
50	clos016 A	15.408	53.099	4072.85	51.12	4111.84	4072.85	77.38	-52.82
	clos017 D	14.658	49.144	4150.83			4111.84	78.12	
150	clos017 F	14.521	164.380	10609.21	163.96	10708.19	10609.21	201.57	-24.09
	clos017 I	14.123	163.532	10807.17			10708.19	203.46	
400	clos017 K	13.488	434.956	23746.38	431.57	24278.97	23746.38	451.18	-6.89
	clos017 M	13.803	428.178	24811.55			24278.97	461.30	
600	clos017 O	13.572	655.824	33898.86	654.84	32457.41	33898.86	644.08	5.83
	clos017 Q	13.197	653.847	31015.95			32457.41	616.69	
					Slope	0.0190			
					R ²	0.9849			

Appendix 8: Water quality for some visited Non-PRASA Communities

Thirteen Non-PRASA communities were visited, as discussed earlier, during April and May 2002. Some of these communities were revisited to take samples of their water. These samples were analyzed on-site for temperature, dissolved oxygen (DO), specific conductivity (SpC), oxidation/reduction potential (ORP), pH, total dissolved solids (TDS), chloride (Cl⁻), and ammonia (NH₄) concentration measured with an HYDROLAB[®]. The following table shows the results obtained for some communities revisited which has an available sampling port.

<i>Date (2002)</i>	<i>Community</i>	<i>TEMP °C</i>	<i>DO mg/L</i>	<i>SpC mS/cm</i>	<i>Sal ppt</i>	<i>TDS g/L</i>	<i>ORP</i>	<i>NH₄ Total mg/L-N</i>	<i>Cl- mg/L</i>	<i>PH s.u.</i>
June 6	Caguabo	27.55	5.29	0.6842	0.35	0.4380	554	0.31	54.41	7.16
June 7	La Choza II	27.08	5.72	0.7462	0.39	0.4783	572	0.23	35.67	6.93
June 8	Pinales	26.40	4.49	0.6165	0.32	0.3946	555	0.22	32.31	7.11
June 8	Bo. Piñales	26.52	4.36	0.6164	0.32	0.3945	555	0.22	32.15	7.60
June 8	Parque	24.81	5.02	0.5262	0.27	0.3368	545	0.20	18.82	7.17
June 8	Pinales Arriba	25.66	6.96	0.6894	0.36	0.4412	465	0.24	29.88	7.46
June 8	Cerro Gordo	25.65	5.70	0.4980	0.25	0.3187	417	0.29	17.37	7.09
June 8	Hatillo	26.82	3.38	0.6285	0.32	0.4023	536	0.48	23.55	7.07

Appendix 9: Maintenance Tasks for AOP Package Plant Components

The following sections address the maintenance done to the AOP plant by components. Sometimes, a component was revised more than once. It is because the components works as a group, if in one of those is found a problem also need to be checked the other components. First, an introduction to the function of all parts is included, and then is presented a maintenance done in that component. For components revised more than once, a summary is included later to the component maintenance section.

A9.1 Ozone Generator System

For the ozone generation, the AOP plant includes the following components: an air dryer model AD40, a Clearwater Tech 2000 Corona discharge ozone generator, a Mazzei® kynar venturi ozone injector, an Armstrong Air Vent model 11 AV, and an off-gas destruction system. Description maintenance task is given for each component.

A9.1.1 Air Dryer

For the air dryer (Figure A9-1), maintenance can be performed to the indicator diseccant cartridge, and non-indicating diseccant (inside the steel drier chamber), and, replacement of the fuse. Proper maintenance steps follow.

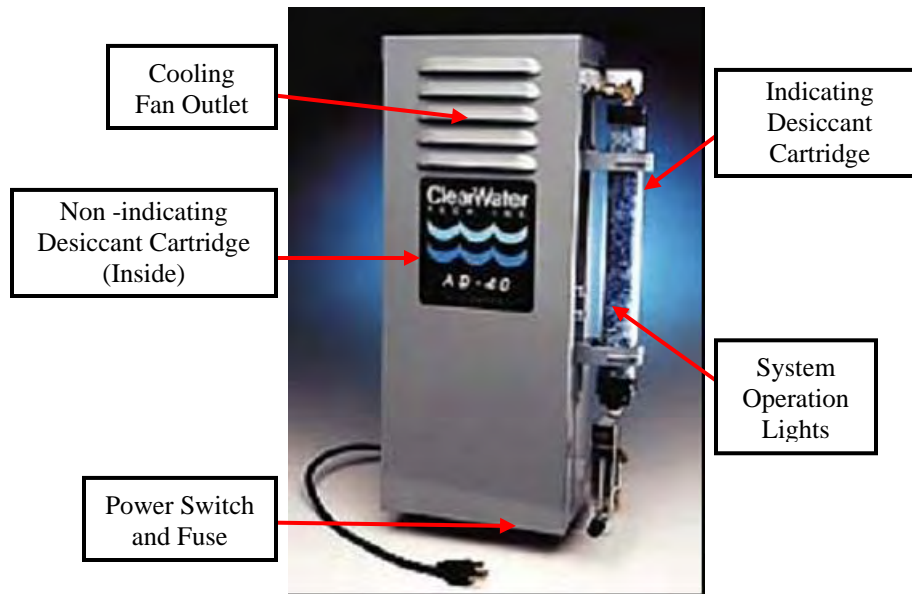


Figure A9-1: AD-40 Air Dyer from ClearWater Tech, LLC

From all parts of the air dryer, the easiest potential problem to determine is with the indicator desiccant cartridge. A simple inspection to the desiccant bead is required. The normal visible indicator cartridge is a 25 % desiccant bead, which should be blue in color. Two situations are frequent, one is if the desiccant beads are clear to white in appearance and the other is failure to meet the 25 % blue in color. For the first situation, the unit should be checked to be sure that the unit is working. In the case that the indicator beads change color often, the air dryer needs to cycle for 24 hours without the ozone generator. Otherwise, when the desiccant granules become clear to pink in appearance, they have absorbed too much moisture, and they must be dried to regain their efficiency. To dry the desiccant beads, these steps were followed (modified from user guide):

1. Disconnect the braided tube from the bottom and the brass compression fitting at the top of the desiccant cartridge.
2. Remove the desiccant cartridge by opening the clamps holding the cartridge to the body of the air dryer.

3. Unscrew the cap on the bottom of the cartridge and spread the granules evenly on a cookie sheet and microwave it on High for 30 seconds, take it out mix it up a little and the repeat the process until it becomes blue and white again. Check often. Once the desiccant granules regain their blue color, remove from the oven.
4. Return to the cartridge, recap, and reconnect to the air dryer.

To give maintenance to the non-indicating material it is necessary to disassemble the air dryer. Then:

1. Check conditions of desiccant, change if necessary
2. Rigorously inspect the steel driers (Figure A9-2a) and non-indicating desiccant beads (Figure A9-2b)
3. Inspect all electric connections
4. Test solenoid valve and fuse

Figure A9-3 shows the inside of the air dryer, and Figure A9-4 shows a top view of the steel drier chambers. To maintenance, the non-indicating desiccant beads (Figure A9-2b), it was necessary to disconnect the electric system inside it, and loosen the steel drier chambers.

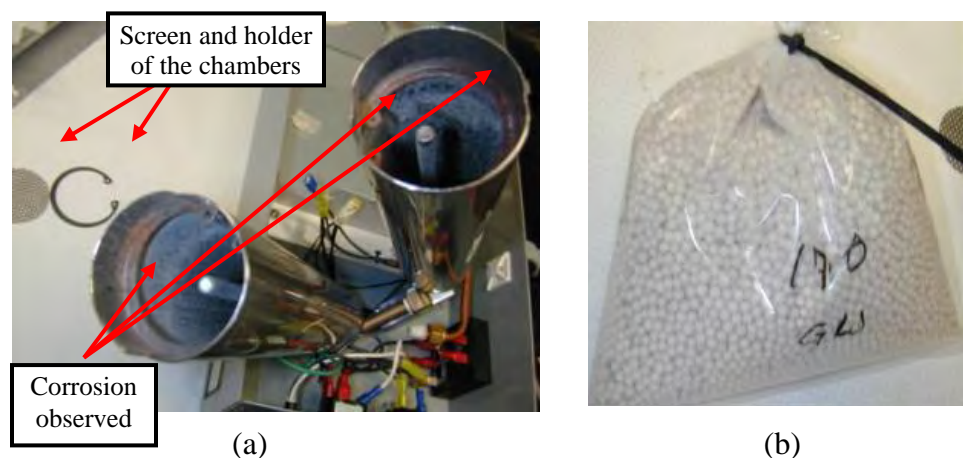


Figure A9-2: Inside the steel drier chambers (a); non-indicating desiccant beads (b)

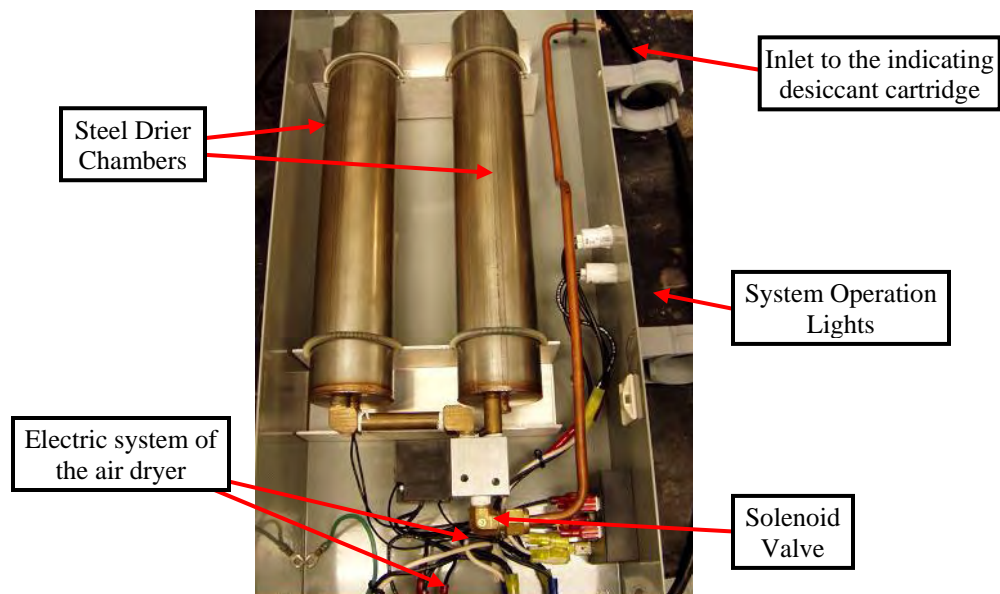


Figure A9-3: Inside of AD-40 Air Dryer

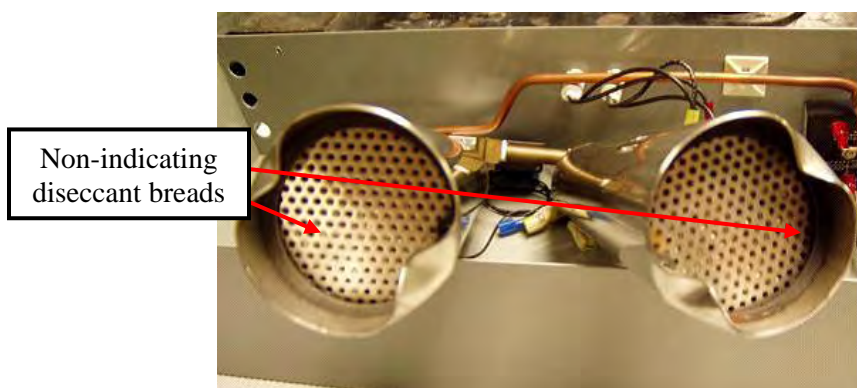


Figure A9-4: Top view of the steel drier chambers on the AD-40 Air Dryer

A9.1.2 Venturi

The AOP plant has a Mazzei® kynar venturi ozone injector model #684 to inject ozone into the water at negative pressure resulting in an efficient transfer of ozone. The principal function of the venturi is to inject ozone to the water stream in the treatment of ozone and UV/ozone.

Initially, the venturi injector must be thoroughly inspected. If properly assembled, the next step is to clean it thoroughly with mild soap and water; or by replacing it. If problems persist, other components from the ozone generator must be looked at (e.g. air dryer).

Figure A9-5 shows a schematic drawing for the venturi. This figure illustrates a deployed view of the venturi by parts and it was obtained from Mazzei® Injector Corporation (<http://www.mazzei.net/agriculture/tables/684.pdf>). This figure is essential in understanding the problems with the venturi. The model used in the AOP comes with a modified hose connection instead of a threaded connection. To convert to a thread connection, the hose connection needs to be cut with caution to provide a perfect adjustment between the parts.

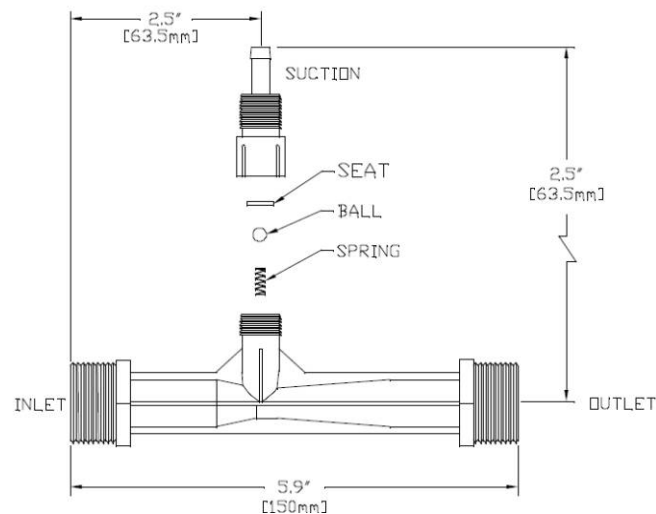


Figure A9-5: Schematic drawing of Mazzei® Venturi Injector model 684

To have a better understanding the steps followed to maintain and to troubleshoot the venturi, it is necessary to remember that the venturi work in conjunction with a check valve, an injection valve, a solenoid valve, and with the air dryer. Changes done to any of these parts are reflected on venturi performance.

A9.1.3 Ozone Generator

The AOP plant has a Clearwater Tech 2000 Corona discharge ozone generator with a maximum production of 5.6 grams O_3 /hr. The principal function of the ozone generator is to produce ozone for ozone and UV/ozone water treatments on the AOP plant. For the ozone generator (Figure A9-6), maintenance can be done changing check valves and/or particulate filter, cleaning the fans filters, replacing damage fuses, and maintaining the corona discharge reaction chambers.

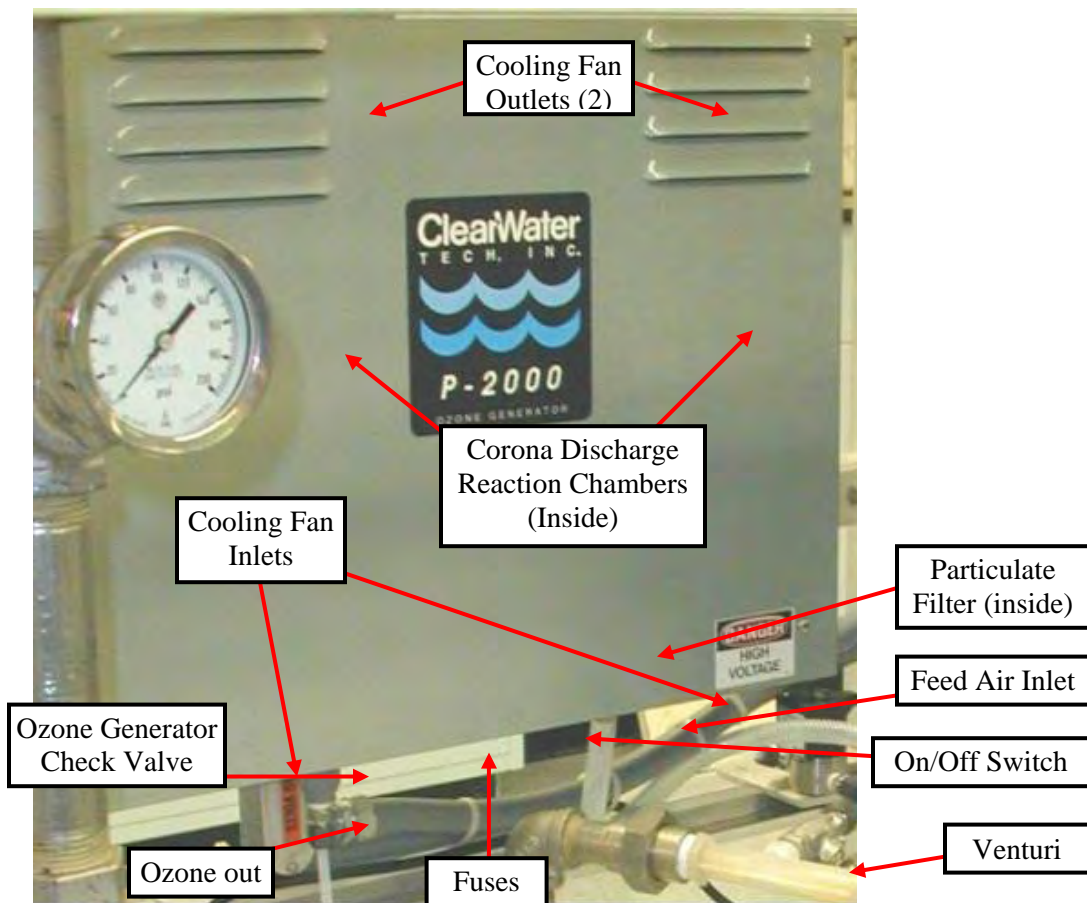


Figure A9-6: Pattern observed in the venturi seal

Maintenance procedure follows:

- Clean fan filter on a monthly basis with soap and water
- Disassemble the ozone generator and inspect it
- Change particulate filter (if necessary)
- Inspect check valves
- Check electrical fuse
- Clean the dielectric tubes and reaction chamber (Figure A9-7) with isopropyl alcohol

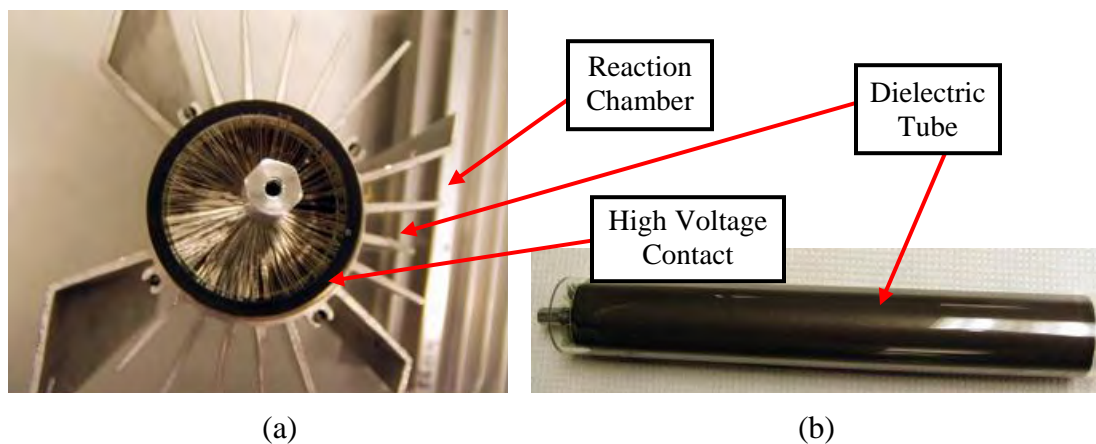


Figure A9-7: Reaction chamber (a) and dielectric tube (b)

A9.1.4 Air Vent

The AOP plant has an Armstrong Air Vent model 11 AV (Figure 3-9), which the principal function is to liberate air from the contact tank chamber. It is used in conjunction with the off-gas destruction system. This air vent is used in all water treatments tested on the AOP plant. The air vent does not require a detailed maintenance, but it requires a minimum inspection for the existence of hoses obstruction.

A9.1.5 Ozone Destructor

The AOP plant has an off-gas destruction system (Figure 3-10), which works in conjunction with the air vent to release air from the contact tank chamber. The principal objective of the off-gas destruction system is collect ozone from the contact tank chamber, transformed it to oxygen, and released it to the atmosphere. Like the air vent, the off-gas destruction system is used in all water treatments tested on the AOP plant. The ozone destructor component does not require a detailed maintenance; it only requires inspection to make sure is on and check that there are no obstructions.

A9.2 UV System

The AOP plant has an Atlantic Ultraviolet UV lamp (model MP36B) with a 0.045 m³/min (12 gal/min) capacity and a UV intensity monitor (Figure 3-11). This UV is a cylindrical low-pressure 254 nm reactor. The principal objective of the UV reactor is to provide the darkness and the contact time necessary to achieve a better disinfection treatment.

For the UV system (Figure 3-11), maintenance can be achieved by changing the UV lamp, changing or cleaning the quart sleeve, and by cleaning the inside of the stainless steel chamber with mild soap. In a yearly maintenance, it is desired to replace the UV lamp and inspect the quartz sleeve, O-rings, Teflon watcher seals, lamp socked, and lead wires, and replaces them if necessary.

A9.3 Water Delivery System

The water delivery system on the AOP plant includes the delivery of water to and from the AOP plant, as described in section 3.4.1.1.3. This system has 316 Schedule 40 stainless steel plumbing; many check valves, a bypass valve, two regulating valve

(influent and effluent), a recirculation pump, a series of liquid flowmeters (influent, recirculation, and effluent), temperature gauges, pressure gauges, and vacuum gauges.

Maintenance of water delivery system consists of cleaning the flowmeters and plumbing, checking valves, ports and gauges functionality, and operating the recirculation pump.

A9.4 Electronic Inspection

Maintenance and troubleshooting of the electronic system requires:

- The intervention of an electrician
- Electrical connection for each component (airflow valve, airflow meter, air dryer) must be tested.

Appendix 10: AOP Package Plant Electronic Component Calibration

To calibrate the electronic system, a procedure was followed and is explained below in steps using Figure A10-1:

1. Turn on the compressor (pump in vacuum mode), adjust it between 34.5 kPa and 41.4 kPa (5 and 6 psi) covering the air outlet, and shut it down.
2. Remove the hose that connects with the pressure gauge and connect it to the absorption line of the pump.
3. Adjust the airflow meter to read zero.
4. Turn on the compressor and make sure that the airflow meter indicates the same pressure in both. If the pressure is the same, the system is calibrated, otherwise, it requires calibration as follow:
 - a. Open the valve in the airflow meter until arriving at 89.6 kPa (13 psi).
 - b. Verify if the vacuum pressure gauge reads between -127 mmHg and -152.4 mmHg (-5 inHg and -6 inHg).
 - c. If the vacuum pressure gauge reads below -152.4 mmHg (-6 inHg), place a screwdriver in the adjustment of the valve of the pressure clock that is it. (Make sure that the screwdriver has the adequate size of the screw of adjustment).
 - d. Adjust turning counterclockwise to close or opposite to close it.
 - e. If the pressure is the same in the compressor and in the pressure gauge, then the system is calibrated, if not, follow steps (a) to (d) until the calibration can be achieved.

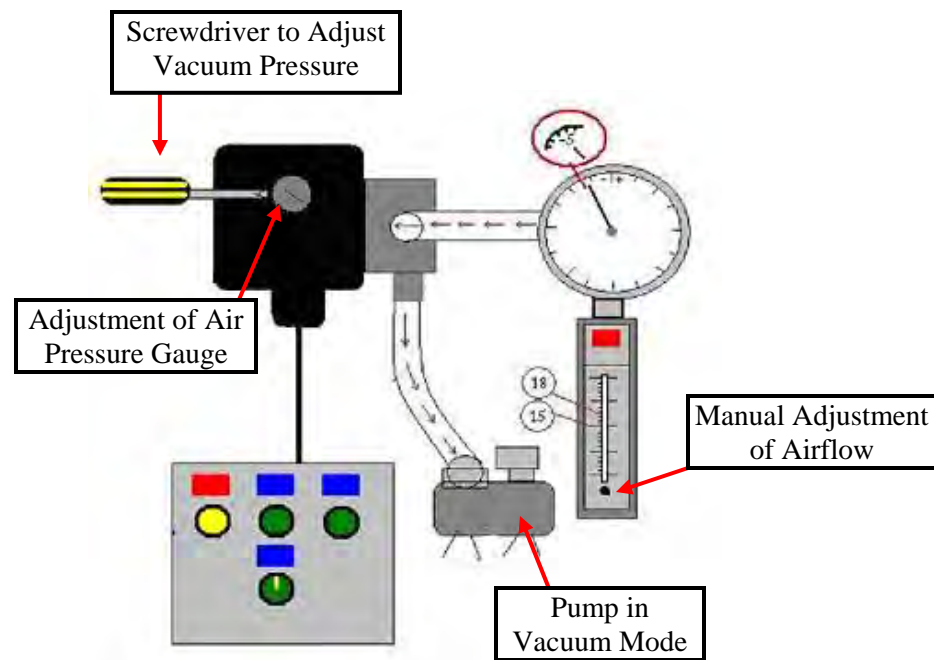


Figure created by Mr. Santiago

Figure A10-1: AOP Plant Vacuum Gauge System Calibration

Appendix 11: AOP plant results (UPRM – EEL)

As discussed on chapter 4, since the AOP plant arrived to the Environmental Engineering Lab (EEL) at the University of Puerto Rico at Mayaguez (UPRM), different tests to evaluate the performance of the AOP plant were tried. The tests that were successful are included on Table A11-1. All of these tests were operated on closed loop, with approximately 37.85 L/min (10 gal/min) recirculation rates. For the evaluation of the single pass with partial recirculation, the USEPA dataset is used instead of data obtained in EEL, because the AOP plant continually damaged.

Table A11-1: Summary of AOP plant runs at the EEL

<i>Date</i>	<i>Treatment</i>	<i>MTBE Target Concentration ($\mu\text{g/L}$)</i>
04/16/03	UV/Ozone	500
02/19/04	UV/Ozone	2600
05/05/04	Control	0
05/05/04	Control	0
05/27/04	Control	0
05/27/04	Control	0
06/07/04	Control	0
06/07/04	Control	0
06/11/04	UV	0
06/11/04	UV	0
06/24/04	Control	500
06/30/04	Control	500
07/23/04	Control	0
07/23/04	UV	0
07/23/04	Ozone	0
07/23/04	UV/Ozone	0
08/02/04	Control	500
08/04/04	UV	500
08/04/04	Ozone	500
08/05/04	Ozone	500
08/05/04	UV/Ozone	500
08/11/04	UV/Ozone	500
08/12/04	UV	500
08/15/04	UV/Ozone	1800
08/15/04	UV/Ozone	1800
08/15/04	UV/Ozone	2600
08/15/04	UV/Ozone	2600

This appendix presents all the results for the closed loop treatments runs performed at the EEL of the UPRM. Consequently, it is divided by treatment (A11.1 to A11.4), such as, control runs, UV, ozone, and UV/Ozone, which include a data sheet used for data acquisition in each closed loop treatment run. Following those subsections, there are the summary of the closed loop treatments (A11.5), which is also divided in analysis done to the samples, such as, particle counter, VOA analysis, TOC and/or DOC, alkalinity and total hardness.

A11.1 Control Runs (No treatment)

Ten tests were performed as control runs. Some of these tests were used as sample after a repair of the AOP plant. The tests with MTBE concentration were done to see the removal of MTBE by the AOP plant itself and to compare those results with the removal by other treatments.

<i>Date</i>	<i>Treatment</i>	<i>MTBE Target Concentration (µg/L)</i>	<i>VOA Analysis</i>	<i>TOC and/or DOC analysis</i>	<i>Particle Counter Analysis</i>
05/05/04	Control	0	x	no	x
05/05/04	Control	0	x	no	x
05/27/04	Control	0	x	no	x
05/27/04	Control	0	x	no	x
06/06/04	Control	0	x	x	x
06/06/04	Control	0	x	x	x
06/24/04	Control	500	x	x	x
06/30/04	Control	500	no	no	x
07/23/04	Control	0	x	x	x
08/02/04	Control	500	x	x	x

Run: CL-none-0ppb-1										
Date:	5/5/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	Control	Water: Hatillo's Community Well Water								
MTBE:	0 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	24.0	8.33	0	--	--	--	8.164	0.06	--	--
6.0	24.5	8.33	0	--	--	--	8.177	0.06	--	--
11.0	25.5	8.33	0	--	--	--	8.187	0.06	--	--
21.0	27.0	8.33	0	--	--	--	8.193	0.06	--	--
31.0	28.0	8.33	0	--	--	--	8.211	0.10	--	--
61.0	31.0	8.33	0	--	--	--	8.203	0.10	--	--
Average	26.7	8.33	0.00	--	--	--	8.19	0.07	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	---	48.153	---	48.359	49.058	---	---
Time	---	3:40 PM	---	4:55 PM	5:00 PM	---	---

Elec. Usage in Run	
KWH	0.699

Alkalinity (mg/L)	
-0 ALK	-61 ALK
---	---

Total Hardness (mg/L)	
-0THARD	-61THARD
---	---

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

Run: CL-none-0ppb-2										
Date:	5/5/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	Control	Water: Hatillo's Community Well Water								
MTBE:	0 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	24.0	8.49	0	--	--	--	8.332	0.15	--	--
6.0	24.5	8.49	0	--	--	--	8.354	0.05	--	--
11.0	25.5	8.49	0	--	--	--	8.342	0.10	--	--
21.0	26.0	8.49	0	--	--	--	8.314	0.13	--	--
31.0	28.0	8.49	0	--	--	--	8.347	0.15	--	--
61.0	31.0	8.49	0	--	--	--			--	--
Average	26.5	8.49	0.00	--	--	--	8.34	0.12	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	---	---	---	49.258	49.945	---	---
Time	---	---	---	5:15 PM	6:15 PM	---	---

Elec. Usage in Run	
KWH	0.687

Alkalinity (mg/L)	
-0 ALK	-61 ALK
---	---

Total Hardness (mg/L)	
-0THARD	-61THARD
---	---

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

Run: CL-none-0ppb-1										
Date:	5/27/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	Control	Water: Hatillo's Community Well Water								
MTBE:	0 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	23.0	8.49	0	--	--	--	8.08	0.20	--	--
6.0	24.0	8.49	0	--	--	--	8.11	0.20	--	--
11.0	24.0	8.49	0	--	--	--	8.28	0.20	--	--
21.0	25.0	8.49	0	--	--	--	8.30	0.20	--	--
31.0	26.5	8.49	0	--	--	--	8.38	0.15	--	--
61.0	29.0	8.49	0	--	--	--	8.31	0.15	--	--
Average	25.3	8.49	0.00	--	--	--	8.24	0.18	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	4.149	4.154	4.217	4.219	4.959	---	---
Time	4:15 PM	4:17 PM	4:27 PM	4:29 PM	5:30 PM	---	---

Elec. Usage in Run	
KWH	0.740

Alkalinity (mg/L)	
-0 ALK	-61 ALK
---	---

Total Hardness (mg/L)	
-0THARD	-61THARD
---	---

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

Run: CL-none-0ppb-2										
Date:	5/27/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	Control	Water: Hatillo's Community Well Water								
MTBE:	0 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	24.0	8.49	0	--	--	--	8.15	0.05	--	--
6.0	24.5	8.49	0	--	--	--	8.19	0.05	--	--
11.0	25.0	8.49	0	--	--	--	8.16	0.05	--	--
21.0	26.0	8.49	0	--	--	--	8.20	0.05	--	--
31.0	27.0	8.49	0	--	--	--	8.20	0.05	--	--
61.0	30.0	8.49	0	--	--	--	8.21	0.06	--	--
Average	26.1	8.49	0.00	--	--	--	8.19	0.05	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	---	---	5.238	5.288	5.992	---	---
Time	---	---	5:55 PM	6:00 PM	7:03 PM	---	---

Elec. Usage in Run	
KWH	0.704

Alkalinity (mg/L)	
-0 ALK	-61 ALK
---	---

Total Hardness (mg/L)	
-0THARD	-61THARD
---	---

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

Run: CL-none-0ppb-1										
Date:	6/7/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	Control	Water: Hatillo's Community Well Water								
MTBE:	0 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	24.0	8.65	0	--	--	--	8.11	0.10	--	--
6.0	24.5	8.49	0	--	--	--	8.09	0.08	--	--
11.0	25.0	8.49	0	--	--	--	8.07	0.10	--	--
21.0	26.0	8.49	0	--	--	--	8.09	0.08	--	--
31.0	27.0	8.49	0	--	--	--	8.12	0.08	--	--
61.0	29.0	8.49	0	--	--	--	8.06	0.08	--	--
Average	25.9	8.52	0.00	--	--	--	8.09	0.09	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	19.405	---	19.492	19.502	20.230	20.255	---
Time	2:51 PM	---	3:00 PM	3:01 PM	4:02 PM	4:05 PM	---

Elec. Usage in Run	
KWH	0.728

Alkalinity (mg/L)	
-0 ALK	-61 ALK
207	210

Total Hardness (mg/L)	
-0THARD	-61THARD
172.0	156.0

TOC (mg/L)	
-0 TOC	-61 TOC
0.739	0.754

DOC (mg/L)	
-0 DOC	-61 DOC
0.84	1.25

Run: CL-none-0ppb-2										
Date:	6/7/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	Control	Water: Hatillo's Community Well Water								
MTBE:	0 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	24.0	8.81	0	--	--	--	8.04	0.05	--	--
6.0	25.0	8.49	0	--	--	--	8.02	0.05	--	--
11.0	25.0	8.49	0	--	--	--	8.04	0.05	--	--
21.0	26.0	8.49	0	--	--	--	8.06	0.05	--	--
31.0	27.0	8.65	0	--	--	--	8.03	0.05	--	--
61.0	30.0	8.65	0	--	--	--	8.13	0.05	--	--
Average	26.2	8.60	0.00	--	--	--	8.05	0.05	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	---	20.453	20.483	20.488	21.170	---	---
Time	---	4:23 PM	4:27 PM	4:28 PM	5:30 PM	---	---

Elec. Usage in Run	
KWH	0.682

Alkalinity (mg/L)	
-0 ALK	-61 ALK
213	204

Total Hardness (mg/L)	
-0THARD	-61THARD
156	152

TOC (mg/L)	
-0 TOC	-61 TOC
0.740	1.092

DOC (mg/L)	
-0 DOC	-61 DOC
1.092	1.109

Run: CL-none-0ppb-1										
Date:	7/23/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	Control	Water: Hatillo's Community Well Water								
MTBE:	0 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	24.0	8.65	0	--	--	--	8.31	0.11	--	--
6.0	25.0	8.49	0	--	--	--	8.34	0.10	--	--
11.0	26.0	8.49	0	--	--	--	8.34	0.10	--	--
21.0	27.0	8.49	0	--	--	--	8.35	0.10	--	--
31.0	28.0	8.49	0	--	--	--	8.36	0.10	--	--
61.0	31.0	8.49	0	--	--	--	8.37	0.10	--	--
Average	26.8	8.52	0.00	--	--	--	8.35	0.10	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	---	40.040	40.122	40.122	40.792	---	---
Time	---	10:51 AM	11:44 AM	11:44 AM	12:54 PM	---	---

Elec. Usage in Run	
KWH	0.670

Alkalinity (mg/L)	
-0 ALK	-61 ALK
118	112

Total Hardness (mg/L)	
-0THARD	-61THARD
128	128

TOC (mg/L)	
-0 TOC	-61 TOC
0.428	0.545

DOC (mg/L)	
-0 DOC	-61 DOC
0.687	0.590

Run: CL-none-500ppb-1										
Date:	6/24/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	Control	Water: Hatillo's Community Well Water								
MTBE:	500 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	26.0	8.49	0	--	--	--	8.14	0.12	--	--
6.0	26.5	8.49	0	--	--	--	8.14	0.12	--	--
11.0	27.0	8.49	0	--	--	--	8.16	0.11	--	--
21.0	28.0	8.49	0	--	--	--	8.14	0.10	--	--
31.0	29.0	8.49	0	--	--	--	8.18	0.10	--	--
61.0	32.0	8.49	0	--	--	--	8.17	0.08	--	--
Average	28.1	8.49	0.00	--	--	--	8.16	0.11	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	---	---	34.915	34.962	35.613	---	---
Time	---	---	11:23 AM	11:28 AM	12:32 PM	---	---

Elec. Usage in Run	
KWH	0.651

Alkalinity (mg/L)	
-0 ALK	-61 ALK
210	197

Total Hardness (mg/L)	
-0THARD	-61THARD
144	144

TOC (mg/L)	
-0 TOC	-61 TOC
0.941	1.005

DOC (mg/L)	
-0 DOC	-61 DOC
2.761	1.787

Run: CL-none-500ppb-1										
Date:	6/30/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	Control	Water: Hatillo's Community Well Water								
MTBE:	500 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	25.0	8.49	0	--	--	--	8.28	0.10	--	--
6.0	25.5	8.49	0	--	--	--	8.30	0.10	--	--
11.0	26.0	8.49	0	--	--	--	8.31	0.10	--	--
21.0	27.0	8.49	0	--	--	--	8.30	0.09	--	--
31.0	28.5	8.49	0	--	--	--	8.31	0.10	--	--
61.0	31.0	8.49	0	--	--	--	8.32	0.08	--	--
Average	27.2	8.49	0.00	--	--	--	8.30	0.10	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge	Elec. Usage in Run	
KWH	---	36.725	36.780	36.806	37.424	39.105	---	KWH	0.618
Time	---	10:31 AM	10:39 AM	10:42 AM	11:44 AM	1:41 PM	---		

Alkalinity (mg/L)	
-0 ALK	-61 ALK
189	192

Total Hardness (mg/L)	
-0THARD	-61THARD
160	146

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

Run: CL-none-500ppb-1										
Date:	8/2/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	Control	Water: Hatillo's Community Well Water								
MTBE:	500 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	26.5	8.49	0	--	--	--	8.38	0.13	--	--
6.0	27.0	8.65	0	--	--	--	8.39	0.13	--	--
11.0	27.8	8.33	0	--	--	--	8.39	0.13	--	--
21.0	29.0	8.49	0	--	--	--	8.39	0.12	--	--
31.0	30.0	8.49	0	--	--	--	8.40	0.13	--	--
61.0	33.0	8.49	0	--	--	--	8.40	0.13	--	--
Average	28.9	8.49	0.00	--	--	--	8.39	0.13	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge	Elec. Usage in Run	
KWH	45.859	45.861	45.909	45.919	46.535	---	---	KWH	0.616
Time	3:27 PM	3:43 PM	3:51 PM	3:53 PM	4:50 PM	---	---		

Alkalinity (mg/L)	
-0 ALK	-61 ALK
126	112

Total Hardness (mg/L)	
-0THARD	-61THARD
128	128

TOC (mg/L)	
-0 TOC	-61 TOC
0.428	0.545

DOC (mg/L)	
-0 DOC	-61 DOC
0.687	0.590

A11.2 UV Runs

Five tests were done for the AOP plant UV treatment. During those test, the UV lamp was changed twice.

<i>Date</i>	<i>Treatment</i>	<i>MTBE Target Concentration (µg/L)</i>	<i>VOA Analysis</i>	<i>TOC and/or DOC analysis</i>	<i>Particle Counter Analysis</i>
06/11/04	UV	0	x	x	x
06/11/04	UV	0	x	x	x
07/23/04	UV	0	x	x	x
08/04/04	UV	500	no	x	x
08/12/04	UV	500	x	no	x

Run: CL-UV-0ppb-1										
Date: 6/11/2004		Location: UPRM Engineering Environmental Laboratory								
Tech: UV		Water: Hatillo's Community Well Water								
MTBE: 0 PPB										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	24.5	8.49	0	0.80	--	--	8.07	0.08	--	--
6.0	25.0	8.49	0	0.80	--	--	8.09	0.05	--	--
11.0	25.5	8.65	0	0.80	--	--	8.10	0.08	--	--
21.0	26.5	8.81	0	0.80	--	--	8.13	0.08	--	--
31.0	27.5	8.65	0	0.80	--	--	8.15	0.08	--	--
61.0	30.0	8.65	0	0.80	--	--	8.09	0.08	--	--
Average	26.5	8.62	0.00	--	--	--	8.11	0.08	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	24.833	---	24.915	24.935	25.692	25.720	---
Time	9:56 AM	---	10:04 AM	10:05 AM	11:08 AM	11:10 AM	---

Elec. Usage in Run	
KWH	0.757

Alkalinity (mg/L)	
-0 ALK	-61 ALK
198	201

Total Hardness (mg/L)	
-0THARD	-61THARD
160	156

TOC (mg/L)	
-0 TOC	-61 TOC
0.803	0.779

DOC (mg/L)	
-0 DOC	-61 DOC
0.996	1.007

Run: CL-UV-0ppb-2										
Date: 6/11/2004		Location: UPRM Engineering Environmental Laboratory								
Tech: UV		Water: Hatillo's Community Well Water								
MTBE: 0 PPB										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	25.0	8.49	0	0.80	--	--	8.11	0.08	--	--
6.0	25.5	8.65	0	0.80	--	--	8.15	0.08	--	--
11.0	26.0	8.49	0	0.80	--	--	8.16	0.05	--	--
21.0	27.0	8.49	0	0.80	--	--	8.15	0.08	--	--
31.0	28.0	8.65	0	0.80	--	--	8.16	0.08	--	--
61.0	31.0	8.49	0	0.80	--	--	8.14	0.08	--	--
Average	27.1	8.54	0.00	--	--	--	8.15	0.08	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	25.796	---	25.832	25.840	26.582	---	---
Time	11:16 AM	---	11:19 AM	11:20 AM	12:21 AM	---	---

Elec. Usage in Run	
KWH	0.742

Alkalinity (mg/L)	
-0 ALK	-61 ALK
204	201

Total Hardness (mg/L)	
-0THARD	-61THARD
164	168

TOC (mg/L)	
-0 TOC	-61 TOC
0.915	0.774

DOC (mg/L)	
-0 DOC	-61 DOC
1.878	1.229

Run: CL-UV-0ppb-1										
Date: 7/23/2004		Location: UPRM Engineering Environmental Laboratory								
Tech: UV		Water: Hatillo's Community Well Water								
MTBE: 0 PPB										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	25.0	8.49	0	0.75	--	--	8.34	0.10	--	--
6.0	25.0	8.49	0	0.75	--	--	8.34	0.09	--	--
11.0	26.0	8.49	0	0.75	--	--	8.35	0.09	--	--
21.0	27.0	8.49	0	0.75	--	--	8.32	0.09	--	--
31.0	29.0	8.49	0	0.75	--	--	8.36	0.10	--	--
61.0	32.0	8.49	0	0.70	--	--	8.35	0.10	--	--
Average	27.3	8.49	0.00	--	--	--	8.34	0.10	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	---	41.400	---	41.450	42.121	---	---
Time	---	1:57 PM	---	2:02 PM	3:05 PM	---	---

Elec. Usage in Run	
KWH	0.671

Alkalinity (mg/L)	
0 min	61 min
114	114

Total Hardness (mg/L)	
0 min	61 min
130	132

TOC (mg/L)	
0 min	61 min
0.550	0.514

DOC (mg/L)	
0 min	61 min
0.521	0.606

Run: CL-UV-500ppb-1										
Date: 8/4/2004		Location: UPRM Engineering Environmental Laboratory								
Tech: UV		Water: Hatillo's Community Well Water								
MTBE: 500 PPB										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	28.5	8.65	0	0.73	--	--	8.43	0.08	--	--
6.0	29.0	8.49	0	0.73	--	--	8.41	0.08	--	--
11.0	29.5	8.49	0	0.73	--	--	8.39	0.08	--	--
21.0	31.0	8.49	0	0.70	--	--	8.40	0.09	--	--
31.0	32.0	8.49	0	0.70	--	--	8.41	0.08	--	--
61.0	34.0	8.49	0	0.70	--	--	8.39	0.08	--	--
Average	30.7	8.52	0.00	--	--	--	8.41	0.08	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	---	47.391	47.433	47.556	48.205	---	---
Time	---	9:44 AM	9:52 AM	10:04 AM	11:05 AM	---	---

Elec. Usage in Run	
KWH	0.649

Alkalinity (mg/L)	
-0 ALK	-61 ALK
111	112

Total Hardness (mg/L)	
-0THARD	-61THARD
128	130

TOC (mg/L)	
-0 TOC	-61 TOC
0.511	0.681

DOC (mg/L)	
-0 DOC	-61 DOC
0.590	0.771

Run: CL-UV-500ppb-2										
Date: 8/12/2004		Location: UPRM Engineering Environmental Laboratory								
Tech: UV		Water: Hatillo's Community Well Water								
MTBE: 500 PPB										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	30.5	8.49	0	1.00	--	--	8.40	0.07	--	--
6.0	31.0	8.49	0	1.00	--	--	8.39	0.08	--	--
11.0	32.0	8.49	0	1.00	--	--	8.37	0.10	--	--
21.0	33.0	8.49	0	1.00	--	--	8.39	0.10	--	--
31.0	34.0	8.49	0	1.00	--	--	8.38	0.10	--	--
61.0	37.0	8.49	0	0.95	--	--	8.38	0.10	--	--
Average	32.9	8.49	0.00	--	--	--	8.39	0.09	--	--

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	---	61.267	---	61.366	62.053	---	---
Time	---	10:58 AM	---	11:10 AM	12:12 PM	---	---

Elec. Usage in Run	
KWH	0.687

Alkalinity (mg/L)	
-0 ALK	-61 ALK
218	208

Total Hardness (mg/L)	
-0THARD	-61THARD
194	200

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

A11.3 UV Runs

Only three tests were done for the AOP plant ozone treatment. Several runs for ozone without injection of MTBE were performed. Those tests are not included here, and they were used to test the AOP plant for ozone generation when the plant does not work well.

<i>Date</i>	<i>Treatment</i>	<i>MTBE Target Concentration (µg/L)</i>	<i>VOA Analysis</i>	<i>TOC and/or DOC analysis</i>	<i>Particle Counter Analysis</i>	<i>Calcium Analysis</i>
07/23/04	Ozone	0	X	no	X	no
08/04/04	Ozone	500	X	X	X	X
08/05/04	Ozone	500	no	X	X	X

Run: CL-OZ-0ppb-1										
Date: 7/23/2004		Location: UPRM Engineering Environmental Laboratory								
Tech: OZONE		Water: Hatillo's Community Well Water								
MTBE: 0 PPB										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	30.0	8.97	0	--	-5	12.0	8.42	0.15	--	0.45
6.0	30.0	8.81	0	--	-5	12.0	8.42	0.17	--	0.75
11.0	31.0	8.97	0	--	-5	12.0	8.42	0.22	--	0.67
21.0	32.0	8.97	0	--	-5	12.0	8.41	0.30	--	0.76
31.0	32.5	8.97	0	--	-5	12.0	8.41	0.25	--	0.78
61.0	34.0	9.13	0	--	-5	12.0	8.42	0.34	--	0.68
Average	31.6	8.97	0.00	--	-5.0	12.00	8.42	0.24	--	0.68

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	42.499	---	---	42.961	43.809	---	---
Time	3:41 PM	---	---	4:20 PM	5:21 PM	---	---

Elec. Usage in Run	
KWH	0.848

Alkalinity (mg/L)	
-0 ALK	-61 ALK
114	100

Total Hardness (mg/L)	
-0THARD	-61THARD
128	130

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

Run: CL-OZ-500ppb-1										
Date:	8/4/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	OZONE	Water: Hatillo's Community Well Water								
MTBE:	500 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	29.0	9.13	0	--	-5	12.0	8.38	0.06	--	0.54
6.0	29.0	9.28	0	--	-5	12.0	8.38	0.06	--	0.52
11.0	29.5	9.13	0	--	-5	12.0	8.39	0.06	--	0.49
21.0	30.0	9.13	0	--	-5	12.0	8.39	0.06	--	0.48
31.0	30.0	9.28	0	--	-5	12.0	8.36	0.06	--	0.49
61.0	31.0	9.28	0	--	-5	12.0	8.35	0.09	--	0.50
Average	29.8	9.20	0.00	--	-5.0	12.00	8.38	0.07	--	0.50

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge	Elec. Usage in Run	
KWH	---	49.045	49.125	49.729	50.621	---	---	KWH	0.892
Time	---	1:39 PM	1:52 PM	2:40 PM	3:44 PM	---	---		

Alkalinity (mg/L)	
-0 ALK	-61 ALK
113	---

Total Hardness (mg/L)	
-0THARD	-61THARD
130	---

TOC (mg/L)	
-0 TOC	-61 TOC
0.508	---

DOC (mg/L)	
-0 DOC	-61 DOC
0.612	---

Run: CL-OZ-500ppb-2										
Date:	8/5/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	OZONE	Water: Hatillo's Community Well Water								
MTBE:	500 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	27.5	9.13	0	--	-5	10.0	8.36	0.06	--	0.64
6.0	28.0	9.28	0	--	-5	10.0	8.35	0.08	--	0.52
11.0	28.5	9.13	0	--	-5	10.0	8.31	0.08	--	0.53
21.0	29.0	9.13	0	--	-5	10.0	8.29	0.08	--	0.54
31.0	30.0	9.28	0	--	-5	10.0	8.21	0.12	--	0.44
61.0	31.5	8.97	0	--	-5	10.0	8.07	0.50	--	0.43
Average	29.1	9.15	0.00	--	-5.0	10.00	8.27	0.15	--	0.52

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge	Elec. Usage in Run	
KWH	51.745	51.759	51.807	52.066	52.946	---	---	KWH	0.880
Time	12:06 AM	12:17 AM	12:24 AM	12:43 AM	1:44 AM	---	---		

Alkalinity (mg/L)	
-0 ALK	-61 ALK
235	166

Total Hardness (mg/L)	
-0THARD	-61THARD
268	202

TOC (mg/L)	
-0 TOC	-61 TOC
0.541	0.669

DOC (mg/L)	
-0 DOC	-61 DOC
0.598	0.746

A11.4 UV/Ozone Runs

Nine tests were done for the AOP plant UV/ozone treatment. Several runs using UV/ozone were used to test the AOP plant operation, therefore, only the completed runs, which extend for the 61 minutes of the run, are included as results.

<i>Date</i>	<i>Treatment</i>	<i>MTBE Target Concentration (µg/L)</i>	<i>VOA Analysis</i>	<i>TOC and/or DOC analysis</i>	<i>Particle Counter Analysis</i>	<i>Calcium Analysis</i>
04/16/03	UV/Ozone	500	no	no	X	no
02/19/04	UV/Ozone	2600	no	no	X	no
07/23/04	UV/Ozone	0	no	X	X	X
08/05/04	UV/Ozone	500	X	X	X	X
08/11/04	UV/Ozone	500	X	X	X	X
08/15/04	UV/Ozone	1800	X	no	no	X
08/15/04	UV/Ozone	1800	no	no	X	X
08/15/04	UV/Ozone	2600	X	no	X	X
08/15/04	UV/Ozone	2600	no	no	X	X

Run: CL-UVOZ-500ppb-1										
Date: 4/16/2003		Location: UPRM Engineering Environmental Laboratory								
Tech: UV/Ozone		Water: Hatillo's Community Well Water								
MTBE: 500 PPB										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	26.0	9.44	0	0.80	-5	5.5	8.10	0.20	-0.07	-0.01
6.0	27.0	9.44	0	0.80	-5	6.0	8.10	0.15	-0.13	-0.01
11.0	27.0	9.44	0	0.80	-5	6.0	8.08	0.20	-0.02	0.02
21.0	27.5	9.44	0	0.80	-5	6.0	8.00	0.20	0.02	-0.02
31.0	28.5	9.44	0	0.80	-5	6.0	8.08	0.15	0.01	0.00
61.0	30.0	9.44	0	0.75	-5	6.0	8.18	0.15	0.08	0.00
Average	27.7	9.44	0.00	0.79	-5.0	5.92	8.09	0.18	-0.02	0.00

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	---	---	---	---	---	---	---
Time	---	---	---	---	---	---	---

Elec. Usage in Run	
KWH	---

Alkalinity (mg/L)	
-0 ALK	-61 ALK
---	---

Total Hardness (mg/L)	
-0THARD	-61THARD
---	---

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

Run: CL-UVOZ-2600ppb										
Date:	2/19/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	UV/Ozone	Water: Hatillo's Community Well Water								
MTBE:	2600 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	25.0	8.97	0	0.95	-5	15.0	8.36	0.15	-0.02	0.02
6.0	25.0	8.97	0	0.95	-5	15.0	8.42	0.22	-0.24	0.02
11.0	26.0	8.65	0	0.95	-5	13.0	8.44	0.24	-0.15	0.02
21.0	27.0	8.97	0	0.95	-5	13.0	8.46	0.52	-0.15	0.01
31.0	28.0	8.97	0	0.90	-5	13.0	8.40	1.50	0.00	0.00
61.0	29.0	8.97	0	0.90	-5	13.0	8.36	3.50	-0.04	0.00
Average	26.7	8.92	0.00	0.93	-5.0	13.67	8.40	1.02	-0.10	0.01

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	---	---	---	---	---	---	---
Time	---	---	---	---	---	---	---

Elec. Usage in Run	
KWH	---

Alkalinity (mg/L)	
-0 ALK	-61 ALK
---	---

Total Hardness (mg/L)	
-0THARD	-61THARD
---	---

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

Run: CL-UVOZ-0ppb-1										
Date:	7/23/2004	Location: UPRM Engineering Environmental Laboratory								
Tech:	UV/Ozone	Water: Hatillo's Community Well Water								
MTBE:	0 PPB									
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	30.0	9.13	0	0.68	-5	12.0	8.38	0.14	0.29	0.01
6.0	30.5	8.95	0	0.68	-5	12.0	8.40	0.12	0.29	0.01
11.0	31.0	9.13	0	0.68	-5	12.0	8.42	0.10	0.32	0.01
21.0	32.5	9.13	0	0.65	-5	12.0	8.43	0.10	0.32	0.01
31.0	33.5	8.97	0	0.63	-5	12.0	8.44	0.10	0.32	0.02
61.0	35.0	9.13	0	0.65	-5	12.0	8.38	0.10	0.14	0.00
Average	32.1	9.07	0.00	0.66	-5.0	12.00	8.41	0.11	0.28	0.01

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	---	---	---	44.528	45.502	---	---
Time	---	---	---	6:13 PM	7:18 PM	---	---

Elec. Usage in Run	
KWH	0.974

Alkalinity (mg/L)	
-0 ALK	-61 ALK
110	76

Total Hardness (mg/L)	
-0THARD	-61THARD
128	130

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

Run: CL-UVOZ-500ppb-1										
Date: 8/5/2004		Location: UPRM Engineering Environmental Laboratory								
Tech: UV/Ozone		Water: Hatillo's Community Well Water								
MTBE: 500 PPB										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	29.0	9.13	0	0.65	-5.5	12.0	8.16	0.10	0.17	0.01
6.0	30.0	9.13	0	0.65	-5.5	12.0	8.14	0.10	0.17	-0.01
11.0	30.5	9.13	0	0.65	-5.5	12.0	8.12	0.13	0.18	0.01
21.0	32.0	9.13	0	0.65	-5.5	12.0	8.04	0.40	0.09	0.00
31.0	33.0	9.13	0	0.63	-5.5	12.0	8.07	0.45	0.17	0.02
61.0	36.0	8.97	0	0.56	-6	12.0	8.09	0.50	0.17	0.00
Average	31.8	9.10	0.00	0.63	-5.6	12.00	8.10	0.28	0.16	0.01

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	53.705	---	---	54.059	54.995	---	---
Time	3:40 AM	---	---	4:12 AM	4:14 AM	---	---

Elec. Usage in Run	
KWH	0.936

Alkalinity (mg/L)	
-0 ALK	-61 ALK
239	132

Total Hardness (mg/L)	
-0THARD	-61THARD
266	162

TOC (mg/L)	
-0 TOC	-61 TOC
0.742	0.344

DOC (mg/L)	
-0 DOC	-61 DOC
0.398	0.386

Run: CL-UVOZ-500ppb-2										
Date: 8/11/2004		Location: UPRM Engineering Environmental Laboratory								
Tech: UV/Ozone		Water: Hatillo's Community Well Water								
MTBE: 500 PPB										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	34.0	9.13	0	0.45	-5	10.0	8.36	0.16	0.10	-0.01
6.0	34.5	9.13	0	0.45	-5	10.0	8.24	0.32	0.06	-0.08
11.0	35.0	9.13	0	0.45	-5	10.0	8.31	0.38	0.05	0.00
21.0	36.0	9.13	0	0.45	-5	10.0	8.37	0.40	0.00	-0.01
31.0	37.0	9.13	0	0.45	-5	10.0	---	0.56	0.09	0.00
61.0	40.0	9.13	0	0.40	-5	10.0	8.35	2.00	0.06	0.00
Average	36.1	9.13	0.00	0.44	-5.0	10.00	8.33	0.64	0.06	-0.02

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	58.508	---	---	58.978	59.936	---	---
Time	10:01 PM	---	---	10:39 PM	11:41 PM	---	---

Elec. Usage in Run	
KWH	0.958

Alkalinity (mg/L)	
-0 ALK	-61 ALK
231	121

Total Hardness (mg/L)	
-0THARD	-61THARD
216	144

TOC (mg/L)	
-0 TOC	-61 TOC
0.385	0.475

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

Run: CL-UVOZ-1800ppb-1										
Date: 8/15/2004		Location: UPRM Engineering Environmental Laboratory								
Tech: UV/Ozone		Water: Hatillo's Community Well Water								
MTBE: 1800 PPB										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	31.5	8.97	0	0.97	-5	9.0	8.24	0.08	0.20	0.01
6.0	32.0	9.13	0	0.97	-5	9.0	8.18	0.08	0.14	0.00
11.0	32.5	9.13	0	0.97	-5	9.0	8.09	0.08	0.06	-0.01
21.0	34.0	9.13	0	0.95	-5	9.0	8.15	0.08	0.12	-0.01
31.0	35.0	8.97	0	0.95	-5	9.0	8.12	0.10	0.12	0.00
61.0	38.0	8.97	0	0.87	-5	9.0	8.21	0.12	0.19	0.00
Average	33.8	9.05	0.00	0.95	-5.0	9.00	8.17	0.09	0.14	0.00

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	62.493	---	---	62.917	63.856	---	---
Time	11:23 AM	---	---	11:58 AM	12:59 PM	---	---

Elec. Usage in Run	
KWH	0.939

Alkalinity (mg/L)	
-0 ALK	-61 ALK
210	---

Total Hardness (mg/L)	
-0THARD	-61THARD
232	---

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

Run: CL-UVOZ-1800ppb-2										
Date: 8/15/2004		Location: UPRM Engineering Environmental Laboratory								
Tech: UV/Ozone		Water: Hatillo's Community Well Water								
MTBE: 1800 PPB										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	32.0	9.13	0	0.93	-5	9.0	8.32	0.08	0.22	0.03
6.0	33.0	9.13	0	0.93	-5	9.0	8.15	0.06	0.13	0.00
13.0	34.0	9.13	0	0.93	-5	9.0	8.19	0.06	0.13	0.01
21.0	35.0	9.13	0	0.93	-5	9.0	8.15	0.08	0.15	0.01
31.0	35.5	9.13	0	0.90	-5	9.0	8.14	0.08	0.17	0.00
61.0	38.0	9.13	0	0.83	-5	9.0	8.24	0.10	0.21	0.01
Average	34.6	9.13	0.00	0.91	-5.0	9.00	8.20	0.08	0.17	0.01

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge
KWH	65.026	65.065	---	65.495	66.443	---	---
Time	12:39 AM	1:18 AM	---	1:53 AM	2:54 AM	---	---

Elec. Usage in Run	
KWH	0.948

Alkalinity (mg/L)	
-0 ALK	-61 ALK
208	128

Total Hardness (mg/L)	
-0THARD	-61THARD
220	154

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

Run: CL-UVOZ-2600ppb-1										
Date: 8/15/2004		Location: UPRM Engineering Environmental Laboratory								
Tech: UV/Ozone		Water: Hatillo's Community Well Water								
MTBE: 2600 PPB										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	30.0	9.13	0	0.95	-5	9.5	8.13	0.08	0.13	0.01
6.0	30.5	9.30	0	0.95	-5	9.5	7.98	0.06	0.06	0.01
11.0	31.0	9.30	0	0.95	-5	9.5	7.96	0.06	0.05	-0.01
21.0	32.0	9.30	0	0.95	-5	9.5	7.95	0.08	0.09	0.00
31.0	32.5	9.13	0	0.95	-5	9.5	8.05	0.08	0.07	0.00
61.0	35.0	9.13	0	0.90	-5	9.5	8.10	0.08	0.11	0.00
Average	31.8	9.21	0.00	0.94	-5.0	9.50	8.03	0.07	0.09	0.00

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge	Elec. Usage in Run	
KWH	66.709	---	---	67.008	67.942	---	---	KWH	0.934
Time	3:12 AM	---	---	3:48 AM	4:49 AM	---	---		

Alkalinity (mg/L)	
-0 ALK	-61 ALK
182	140

Total Hardness (mg/L)	
-0THARD	-61THARD
240	176

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

Run: CL-UVOZ-2600ppb-2										
Date: 8/15/2004		Location: UPRM Engineering Environmental Laboratory								
Tech: UV/Ozone		Water: Hatillo's Community Well Water								
MTBE: 2600 PPB										
Time (min)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity Scale of 1.00	Ozone Readings		pH (s.u.)	Turbidity (ntu)	Ozone (mg/l)	
					inches Hg	SCFH			After Venturi	After UV
1.0	32.0	9.28	0	0.90	-5	12.5	8.02	0.08	0.15	0.01
6.0	32.5	9.28	0	0.90	-5	12.5	8.00	0.10	0.08	0.00
11.0	33.0	9.28	0	0.90	-5	12.5	8.02	0.08	0.07	-0.01
21.0	34.0	9.13	0	0.90	-5	12.5	8.08	0.20	0.04	-0.01
31.0	35.0	9.28	0	0.90	-5	12.5	8.10	0.20	0.06	-0.01
61.0	37.0	9.13	0	0.83	-5	12.5	8.54	0.23	0.08	-0.01
Average	33.9	9.23	0.00	0.89	-5.0	12.50	8.13	0.15	0.08	-0.01

Elec. Usage	Dryer On	Before Purge	After Purge	Before Run	After Run	Before Purge	After Purge	Elec. Usage in Run	
KWH	68.581	---	---	69.189	70.147	---	---	KWH	0.958
Time	10:20 AM	---	---	11:05 AM	12:06 PM	---	---		

Alkalinity (mg/L)	
-0 ALK	-61 ALK
224	130

Total Hardness (mg/L)	
-0THARD	-61THARD
260	164

TOC (mg/L)	
-0 TOC	-61 TOC
---	---

DOC (mg/L)	
-0 DOC	-61 DOC
---	---

A11.5 Summary of closed loop treatments at EEL

A11.5.1 Temperature, pH, and Turbidity

<i>Run</i>	<i>Date</i>	<i>Temperature (°C)</i>				<i>pH (s.u.)</i>				<i>Turbidity (NTU)</i>			
		<i>1 min</i>	<i>61 min</i>	<i>Diff</i>	<i>Ave</i>	<i>1 min</i>	<i>61 min</i>	<i>Diff</i>	<i>Ave</i>	<i>1 min</i>	<i>61 min</i>	<i>Diff</i>	<i>Ave</i>
CL-none-0ppb-1	5/5/2004	24.0	31.0	7.0	26.7	8.16	8.20	0.04	8.19	0.06	0.10	0.04	0.07
CL-none-0ppb-2	5/5/2004	24.0	31.0	7.0	26.5	8.33	8.35	0.01	8.34	0.15	---	---	0.12
CL-none-0ppb-1	5/27/2004	23.0	29.0	6.0	25.3	8.08	8.31	0.23	8.24	0.20	0.15	-0.05	0.18
CL-none-0ppb-2	5/27/2004	24.0	30.0	6.0	26.1	8.15	8.21	0.06	8.19	0.05	0.06	0.01	0.05
CL-none-0ppb-1	6/7/2004	24.0	29.0	5.0	25.9	8.11	8.06	-0.05	8.09	0.10	0.08	-0.02	0.09
CL-none-0ppb-2	6/7/2004	24.0	30.0	6.0	26.2	8.04	8.13	0.09	8.05	0.05	0.05	0.00	0.05
CL-none-0ppb-1	7/23/2004	24.0	31.0	7.0	26.8	8.31	8.37	0.06	8.35	0.11	0.10	-0.01	0.10
CL-none-500ppb-1	6/24/2004	26.0	32.0	6.0	28.1	8.14	8.17	0.03	8.16	0.12	0.08	-0.04	0.11
CL-none-500ppb-1	6/30/2004	25.0	31.0	6.0	27.2	8.28	8.32	0.04	8.30	0.10	0.08	-0.02	0.10
CL-none-500ppb-1	8/2/2004	26.5	33.0	6.5	28.9	8.38	8.40	0.02	8.39	0.13	0.13	0.00	0.13
CL-UV-0ppb-1	6/11/2004	24.5	30.0	5.5	26.5	8.07	8.09	0.02	8.11	0.08	0.08	0.00	0.08
CL-UV-0ppb-2	6/11/2004	25.0	31.0	6.0	27.1	8.11	8.14	0.03	8.15	0.08	0.08	0.00	0.08
CL-UV-0ppb-1	7/23/2004	25.0	32.0	7.0	27.3	8.34	8.35	0.01	8.34	0.10	0.10	0.00	0.10
CL-UV-500ppb-1	8/4/2004	28.5	34.0	5.5	30.7	8.43	8.39	-0.04	8.41	0.08	0.08	0.00	0.08
CL-UV-500ppb-2	8/12/2004	30.5	37.0	6.5	32.9	8.40	8.38	-0.02	8.39	0.07	0.10	0.03	0.09
CL-OZ-0ppb-1	7/23/2004	30.0	34.0	4.0	31.6	8.42	8.42	0.00	8.42	0.15	0.34	0.19	0.24
CL-OZ-500ppb-1	8/4/2004	29.0	31.0	2.0	29.8	8.38	8.35	-0.03	8.38	0.06	0.09	0.03	0.07
CL-OZ-500ppb-2	8/5/2004	27.5	31.5	4.0	29.1	8.36	8.07	-0.29	8.27	0.06	0.50	0.44	0.15
CL-UVOZ-500ppb-1	4/16/2003	26.0	30.0	4.0	27.7	8.10	8.18	0.09	8.09	0.20	0.15	-0.05	0.18
CL-UVOZ-2600ppb	2/19/2004	25.0	29.0	4.0	26.7	8.36	8.36	-0.01	8.40	0.15	3.50	3.35	1.02
CL-UVOZ-0ppb-1	7/23/2004	30.0	35.0	5.0	32.1	8.38	8.38	0.00	8.41	0.14	0.10	-0.04	0.11
CL-UVOZ-500ppb-1	8/5/2004	29.0	36.0	7.0	31.8	8.16	8.09	-0.07	8.10	0.10	0.50	0.40	0.28
CL-UVOZ-500ppb-2	8/11/2004	34.0	40.0	6.0	36.1	8.36	8.35	-0.01	8.33	0.16	2.00	1.84	0.64
CL-UVOZ-1800ppb-1	8/15/2004	31.5	38.0	6.5	33.8	8.24	8.21	-0.03	8.17	0.08	0.12	0.04	0.09
CL-UVOZ-1800ppb-2	8/15/2004	32.0	38.0	6.0	34.6	8.32	8.24	-0.08	8.20	0.08	0.10	0.02	0.08
CL-UVOZ-2600ppb-1	8/15/2004	30.0	35.0	5.0	31.8	8.13	8.10	-0.03	8.03	0.08	0.08	0.00	0.07
CL-UVOZ-2600ppb-2	8/15/2004	32.0	37.0	5.0	33.9	8.02	8.54	0.52	8.13	0.08	0.23	0.15	0.15

A11.5.2 Alkalinity, Total Hardness, TOC, DOC, and Calcium

<i>Run</i>	<i>Date</i>	<i>Alkalinity</i> (mg/L as CaCO ₃)			<i>Total Hardness</i> (mg/L as CaCO ₃)			<i>TOC</i> (mg/L C)			<i>DOC</i> (mg/L C)		
		<i>1 min</i>	<i>61 min</i>	<i>Diff</i>	<i>1 min</i>	<i>61 min</i>	<i>Diff</i>	<i>1 min</i>	<i>61 min</i>	<i>Diff</i>	<i>1 min</i>	<i>61 min</i>	<i>Diff</i>
CL-none-0ppb-1	5/5/2004	---	---	---	---	---	---	---	---	---	---	---	---
CL-none-0ppb-1	5/27/2004	---	---	---	---	---	---	---	---	---	---	---	---
CL-none-0ppb-1	6/7/2004	207	210	3	172	156	-16	0.74	0.75	0.02	0.84	1.25	0.40
CL-none-0ppb-2	6/7/2004	213	204	-9	156	152	-4	0.74	1.09	0.35	1.09	1.11	0.02
CL-none-0ppb-1	7/23/2004	118	112	-6	128	128	0	0.43	0.55	0.12	0.69	0.59	-0.10
CL-none-500ppb-1	6/24/2004	210	197	-13	144	144	0	0.94	1.01	0.06	2.76	1.79	-0.97
CL-none-500ppb-1	6/30/2004	189	192	3	160	146	-14	---	---	---	---	---	---
CL-none-500ppb-1	8/2/2004	126	112	-14	128	128	0	0.43	0.55	0.12	0.69	0.59	-0.10
CL-UV-0ppb-1	6/11/2004	198	201	3	160	156	-4	0.80	0.78	-0.02	1.00	1.01	0.01
CL-UV-0ppb-2	6/11/2004	204	201	-3	164	168	4	0.92	0.77	-0.14	1.88	1.23	-0.65
CL-UV-0ppb-1	7/23/2004	114	114	0	130	132	2	0.55	0.51	-0.04	0.52	0.61	0.09
CL-UV-500ppb-1	8/4/2004	111	112	1	128	130	2	0.51	0.68	0.17	0.59	0.77	0.18
CL-UV-500ppb-2	8/12/2004	218	208	-10	194	200	6	---	---	---	---	---	---
CL-OZ-0ppb-1	7/23/2004	114	100	-14	128	130	2	---	---	---	---	---	---
CL-OZ-500ppb-1	8/4/2004	113	---	---	130	---	---	0.51	---	---	0.61	---	---
CL-OZ-500ppb-2	8/5/2004	235	166	-69	268	202	-66	0.54	0.67	0.13	0.60	0.75	0.15
CL-UVOZ-500ppb-1	4/16/2003	---	---	---	---	---	---	---	---	---	---	---	---
CL-UVOZ-2600ppb	2/19/2004	---	---	---	---	---	---	---	---	---	---	---	---
CL-UVOZ-0ppb-1	7/23/2004	110	76	-34	128	130	2	---	---	---	---	---	---
CL-UVOZ-500ppb-1	8/5/2004	239	132	-107	266	162	-104	0.74	0.34	-0.40	0.40	0.39	-0.01
CL-UVOZ-500ppb-2	8/11/2004	231	121	-110	216	144	-72	0.39	0.48	0.09	---	---	---
CL-UVOZ-1800ppb-1	8/15/2004	210	---	---	232	---	---	---	---	---	---	---	---
CL-UVOZ-1800ppb-2	8/15/2004	208	128	-80	220	154	-66	---	---	---	---	---	---
CL-UVOZ-2600ppb-1	8/15/2004	182	140	-42	240	176	-64	---	---	---	---	---	---
CL-UVOZ-2600ppb-2	8/15/2004	224	130	-94	260	164	-96	---	---	---	---	---	---

<i>Run</i>	<i>Date</i>	<i>Alkalinity</i> (mg/L as CaCO ₃)			<i>Total Hardness</i> (mg/L as CaCO ₃)			<i>Calcium</i> (mg/L)		
		<i>1 min</i>	<i>61 min</i>	<i>Diff</i>	<i>1 min</i>	<i>61 min</i>	<i>Diff</i>	<i>1 min</i>	<i>61 min</i>	<i>Diff</i>
CL-OZ-0ppb-1	7/23/2004	114	100	-14	128	130	2	---	---	---
CL-OZ-500ppb-1	8/4/2004	113	---	---	130	---	---	48	---	---
CL-OZ-500ppb-2	8/5/2004	235	166	-69	268	202	-66	130	94	-36
CL-UVOZ-500ppb-1	4/16/2003	---	---	---	---	---	---	---	---	---
CL-UVOZ-2600ppb	2/19/2004	---	---	---	---	---	---	---	---	---
CL-UVOZ-0ppb-1	7/23/2004	110	76	-34	128	130	2	---	---	---
CL-UVOZ-500ppb-1	8/5/2004	239	132	-107	266	162	-104	140	67	-73
CL-UVOZ-500ppb-2	8/11/2004	231	121	-110	216	144	-72	82	49	-33
CL-UVOZ-1800ppb-1	8/15/2004	210	---	---	232	---	---	108	---	---
CL-UVOZ-1800ppb-2	8/15/2004	208	128	-80	220	154	-66	104	58	-46
CL-UVOZ-2600ppb-1	8/15/2004	182	140	-42	240	176	-64	118	70	-48
CL-UVOZ-2600ppb-2	8/15/2004	224	130	-94	260	164	-96	107	56	-51

A11.5.3 Particle Counter

A11.5.3.1 Control Runs

NONE - 0 PPB - Run #1 - May 5, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	1392.9	171.9	122.4	73.0	32.4	14.1	6.3	3.8	1.6	4.4	0.8	0.3	0.2	0.1	0.0	1824.2
Counts/mL (61 min)	1122.1	146.0	102.3	61.8	25.9	11.9	6.2	3.0	1.9	3.9	0.4	0.2	0.1	0.0	0.0	1485.7
% Difference	-19.4	-15.1	-16.4	-15.3	-20.1	-15.6	-1.6	-21.1	18.8	-11.4	-50.0	-33.3	-50.0	-100.0	#DIV/0!	-18.6

NONE - 0 PPB - Run #2 - May 5, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	920.4	110.0	66.4	27.4	9.7	4.2	1.0	0.6	0.3	1.0	0.3	0.1	0.2	0.0	0.0	1141.6
Counts/mL (61 min)	2011.4	218.2	125.4	47.1	12.8	4.3	1.6	0.8	0.6	1.1	0.4	0.1	0.0	0.0	0.0	2423.8
% Difference	118.5	98.4	88.9	71.9	32.0	2.4	60.0	33.3	100.0	10.0	33.3	0.0	-100.0	#DIV/0!	#DIV/0!	112.3

NONE - 0 PPB - Run #1 - May 27, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	7963.8	423.3	219.8	99.7	34.8	11.8	4.6	2.0	1.2	1.2	0.3	0.2	0.2	0.0	0.0	8762.8
Counts/mL (61 min)	10274.4	205.8	100.4	43.2	13.6	4.3	1.8	1.1	0.4	0.6	0.1	0.1	0.1	0.0	0.0	10645.5
% Difference	29.0	-51.4	-54.3	-56.7	-60.9	-63.6	-62.0	-45.0	-70.8	-54.2	-66.7	-66.7	-66.7	#DIV/0!	#DIV/0!	21.5

NONE - 0 PPB - Run #2 - May 27, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50.6
Counts/mL (0 min)	9382.4	124.8	69.7	44.0	19.9	6.4	2.5	0.9	0.7	0.8	0.2	0.2	0.1	0.0	0.0	9652.4
Counts/mL (61 min)	1536.6	125.2	69.7	43.2	18.0	6.7	2.3	1.1	0.7	1.1	0.3	0.1	0.1	0.0	0.0	1804.7
% Difference	-83.6	0.3	-0.1	-1.9	-9.8	4.7	-8.2	22.2	0.0	46.7	25.0	-75.0	0.0	#DIV/0!	#DIV/0!	-81.3

NONE - 0 PPB - Run #1 - June 6, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50.6
Counts/mL (0 min)	2652.4	270.8	186.8	101.1	33.5	13.2	5.6	3.2	1.5	3.6	0.7	0.3	0.3	0.0	0.0	3272.6
Counts/mL (61 min)	1475.1	139.3	99.2	58.2	24.1	9.6	4.5	2.5	1.9	4.4	1.5	0.4	0.3	0.1	0.0	1820.8
% Difference	-44.4	-48.6	-46.9	-42.4	-28.1	-27.0	-20.5	-20.6	26.7	22.2	123.1	40.0	0.0	#DIV/0!	#DIV/0!	-44.4

NONE - 0 PPB - Run #2 - June 6, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50.6
Counts/mL (0 min)	711.8	75.5	63.1	50.7	25.7	13.1	5.4	3.2	2.2	4.8	1.2	0.5	0.3	0.0	0.0	957.1
Counts/mL (61 min)	1381.3	94.7	60.4	34.1	13.4	4.4	1.7	1.0	0.8	1.4	0.5	0.2	0.1	0.0	0.0	1593.5
% Difference	94.1	25.4	-4.4	-32.8	-48.0	-66.7	-69.2	-68.3	-63.6	-70.5	-60.9	-70.0	-80.0	#DIV/0!	#DIV/0!	66.5

NONE - 0 PPB - Run #1 - June 11, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50.6
Counts/mL (0 min)	775.2	85.7	67.9	51.5	26.2	12.9	7.4	3.9	2.9	6.6	2.0	0.4	0.2	0.0	0.0	1042.5
Counts/mL (61 min)	750.1	98.6	79.9	57.2	27.7	14.0	8.3	5.1	3.7	9.0	2.2	0.7	0.2	0.1	0.0	1056.3
% Difference	-3.2	15.0	17.7	11.1	5.7	8.6	12.9	31.2	25.9	35.6	7.5	100.0	0.0	#DIV/0!	#DIV/0!	1.3

NONE - 0 PPB - Run # 1 - July 23, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50.6
Counts/mL (0 min)	1189.2	259.9	86.7	33.1	12.1	5.4	3.7	2.6	1.6	4.0	0.8	0.1	0.2	0.1	0.0	1599.2
Counts/mL (61 min)	1696.3	88.5	44.8	21.0	7.1	2.5	1.3	0.9	0.5	0.8	0.3	0.1	0.2	0.1	0.0	1864.0
% Difference	42.6	-66.0	-48.4	-36.7	-41.5	-53.3	-65.8	-67.3	-68.8	-79.7	-62.5	-50.0	0.0	0.0	#DIV/0!	16.6

NONE - 500 PPB - Run # 1 - June 24, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	1622.9	101.0	56.8	30.5	11.2	3.8	1.5	0.8	0.4	1.1	0.9	0.4	0.6	0.1	0.0	1831.5
Counts/mL (61 min)	1015.0	70.9	41.4	22.2	7.4	2.1	0.9	0.6	0.3	0.5	0.2	0.1	0.1	0.0	0.0	1161.4
% Difference	-37.5	-29.8	-27.1	-27.1	-34.1	-45.3	-41.4	-31.3	-14.3	-52.4	-83.3	-71.4	-83.3	-100.0	#DIV/0!	-36.6

NONE - 500 PPB - Run # 2 - June 30, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	1186.1	70.2	35.2	23.3	10.9	5.0	3.1	1.9	1.3	2.2	0.6	0.1	0.2	0.0	0.0	1339.9
Counts/mL (61 min)	1201.4	48.8	30.8	23.2	9.9	3.7	2.1	1.2	1.0	1.8	0.5	0.1	0.0	0.0	0.0	1324.2
% Difference	1.3	-30.4	-12.5	-0.4	-9.6	-25.3	-33.9	-39.5	-24.0	-18.2	-25.0	-50.0	-100.0	#DIV/0!	#DIV/0!	-1.2

NONE - 500 PPB - Run # 1 - August 2, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	518.4	27.6	17.2	7.4	2.6	0.9	0.2	0.2	0.2	0.5	0.1	0.0	0.1	0.0	0.0	575.0
Counts/mL (61 min)	407.4	21.5	11.9	5.6	1.7	0.7	0.3	0.3	0.2	0.3	0.1	0.1	0.1	0.0	0.0	449.9
% Difference	-21.4	-22.1	-30.9	-24.3	-33.3	-27.8	100.0	100.0	0.0	-44.4	100.0	#DIV/0!	0.0	#DIV/0!	#DIV/0!	-21.8

A11.5.3.2 UV Runs

UV - 0 PPB - Run # 1 - June 11, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	654.9	72.4	56.9	42.5	23.2	10.6	6.2	3.9	2.3	5.8	1.2	0.3	0.2	0.0	0.0	880.3
Counts/mL (61 min)	712.3	99.9	81.9	61.4	30.4	14.7	9.9	6.0	4.4	12.9	4.1	1.5	0.4	0.1	0.0	1039.5
% Difference	8.8	38.0	43.9	44.5	31.0	38.2	60.2	52.6	91.3	123.5	237.5	383.3	100.0	#DIV/0!	#DIV/0!	18.1

UV - 0 PPB - Run # 2 - July 23, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	844.0	101.6	34.6	15.2	5.4	2.8	1.8	0.7	0.6	1.0	0.2	0.1	0.4	0.1	0.0	1008.2
Counts/mL (61 min)	1033.5	44.9	25.8	12.7	3.7	1.5	0.9	0.5	0.3	0.7	0.2	0.1	0.1	0.0	0.0	1124.5
% Difference	22.5	-55.8	-25.3	-16.8	-32.4	-47.3	-51.4	-35.7	-45.5	-26.3	0.0	0.0	-87.5	-100.0	#DIV/0!	11.5

UV - 500 PPB - Run # 1 - August 4, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	681.4	32.9	21.3	8.4	2.5	0.9	0.2	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	748.0
Counts/mL (61 min)	412.2	16.0	7.1	4.2	2.0	0.6	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	442.8
% Difference	-39.5	-51.4	-66.8	-50.0	-18.4	-38.9	0.0	300.0	0.0	-25.0	-100.0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	-40.8

A11.5.3.3 Ozone Runs

OZ - 0 PPB - Run # 1 - July 23, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	1180.6	326.8	89.6	25.7	7.7	2.8	1.5	0.9	0.5	1.3	0.3	0.1	0.2	0.0	0.0	1637.8
Counts/mL (61 min)	4558.8	390.2	220.6	108.9	38.4	18.5	9.7	5.2	3.1	4.1	0.4	0.1	0.2	0.1	0.0	5357.9
% Difference	286.2	19.4	146.2	323.5	398.7	558.9	565.5	472.2	588.9	211.5	16.7	-50.0	33.3	#DIV/0!	#DIV/0!	227.2

OZ - 500 PPB - Run # 1 - August 5, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	982.6	78.1	61.1	63.8	30.7	18.2	11.2	7.5	2.1	2.2	0.3	0.1	0.1	0.0	0.0	1254.9
Counts/mL (61 min)	5031.5	2441.6	2095.2	1180.1	302.9	65.8	21.8	7.4	3.4	3.2	0.3	0.3	0.2	0.1	0.0	11153.4
% Difference	412.1	3026.2	3331.9	1749.7	886.6	262.3	94.2	58.1	61.9	45.5	0.0	400.0	300.0	#DIV/0!	#DIV/0!	788.8

A11.5.3.4 UV/Ozone Runs

UV/OZ - 0 PPB - Run # 1 - July 23, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	3536.5	417.6	303.9	171.2	65.0	29.7	16.1	10.0	6.1	9.2	1.4	0.5	0.2	0.0	0.0	4567.3
Counts/mL (61 min)	2113.1	222.7	141.0	72.3	27.1	11.4	6.3	3.4	2.7	4.0	0.5	0.2	0.1	0.0	0.0	2604.4
% Difference	-40.2	-46.7	-53.6	-57.8	-58.4	-61.8	-61.2	-66.5	-55.7	-56.8	-63.0	-55.6	-75.0	#DIV/0!	#DIV/0!	-43.0

UV/OZ - 300 PPB - Run # 1 - October 10, 2002

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	1652.2	97.8	44.4	15.7	4.3	1.7	0.8	0.3	0.3	0.7	0.4	0.1	0.1	0.0	0.0	1818.4
Counts/mL (61 min)	2243.6	131.4	64.2	22.9	5.2	1.8	1.0	0.5	0.3	0.3	0.1	0.0	0.1	0.0	0.0	2471.1
% Difference	35.8	34.3	44.5	45.5	22.4	9.1	26.7	50.0	-16.7	-53.8	-71.4	-100.0	100.0	#DIV/0!	#DIV/0!	35.9

UV/OZ - 500 PPB - Run # 1 - August 5, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	1036.4	74.1	48.6	49.3	23.0	11.3	4.9	2.5	1.0	0.9	0.1	0.1	0.1	0.0	0.0	1252.1
Counts/mL (61 min)	21650.7	9894.3	9842.0	5909.6	1612.0	365.0	79.2	16.3	4.0	1.7	0.1	0.0	0.0	0.0	0.0	49374.6
% Difference	1989.0	13252.6	20150.9	11886.9	6908.5	3130.1	1515.3	565.3	321.1	88.9	0.0	-100.0	-100.0	#DIV/0!	#DIV/0!	3843.3

UV/OZ - 500 PPB - Run # 2 - August 11, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	2904.8	276.5	198.5	121.0	62.1	36.7	26.1	19.9	15.3	36.9	10.4	3.3	1.4	0.1	0.0	3712.7
Counts/mL (61 min)	17138.5	7566.3	9716.9	9177.7	4809.9	2192.4	992.1	432.4	178.7	116.2	6.2	1.2	0.4	0.1	0.0	52328.5
% Difference	490.0	2636.9	4795.1	7484.8	7651.7	5882.0	3701.1	2072.6	1068.0	215.2	-40.6	-65.2	-74.1	-50.0	#DIV/0!	1309.4

UV/OZ - 1800 PPB - Run # 1 - August 15, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	1142.1	112.5	92.8	62.3	31.6	19.6	14.7	11.8	9.8	52.5	36.5	11.6	8.6	0.3	0.0	1606.7
Counts/mL (61 min)	18949.1	5980.5	4063.8	1804.1	498.4	148.5	53.6	23.8	13.4	19.9	6.3	2.5	2.0	0.0	0.0	31565.9
% Difference	1559.1	5216.0	4279.1	2795.8	1477.2	657.7	264.6	101.7	36.7	-62.1	-82.7	-78.4	-76.7	-100.0	#DIV/0!	1864.6

UV/OZ - 2600 PPB - Run # 1 - February 19, 2003

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	3618.3	553.2	411.0	307.0	159.5	86.3	48.2	30.9	22.6	57.0	17.8	3.8	1.9	0.1	0.0	5317.6
Counts/mL (61 min)	15490.9	7588.9	9586.4	8965.7	4754.6	2162.7	970.8	402.6	155.4	106.8	12.2	3.5	1.2	0.0	0.0	50201.7
% Difference	328.1	1271.8	2232.5	2820.4	2880.9	2406.0	1914.1	1202.9	587.6	87.4	-31.5	-7.9	-36.8	-100.0	#DIV/0!	844.1

UV/OZ - 2600 PPB - Run # 1 - April 16, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	3699.6	656.9	667.8	582.9	298.0	132.6	60.3	25.1	10.1	10.4	1.2	0.2	0.1	0.1	0.0	6145.3
Counts/mL (61 min)	17629.3	7052.2	9049.4	8825.0	5065.8	2582.3	1317.6	682.1	329.4	301.4	12.3	2.6	1.1	0.1	0.0	52850.6
% Difference	376.5	973.6	1255.1	1414.0	1599.9	1847.4	2085.1	2617.5	3161.4	2798.1	925.0	1200.0	1000.0	0.0	#DIV/0!	760.0

UV/OZ - 2600 PPB - Run # 1 - August 15, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	1153.3	119.3	93.0	51.0	19.5	8.9	5.9	3.8	2.6	7.7	3.2	1.0	0.7	0.0	0.0	1469.6
Counts/mL (61 min)	5415.3	2149.7	1931.2	1486.3	870.5	518.7	336.9	215.4	131.2	166.9	14.8	4.6	2.2	0.0	0.0	13243.4
% Difference	369.5	1702.7	1977.6	2817.2	4364.1	5728.1	5659.0	5567.1	4944.2	2066.9	368.3	378.9	214.3	#DIV/0!	#DIV/0!	801.2

UV/OZ - 2600 PPB - Run # 2 - August 15, 2004

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	1247.7	121.6	93.3	53.0	18.8	6.2	1.9	0.7	0.3	0.6	0.5	0.7	1.1	0.1	0.0	1546.2
Counts/mL (61 min)	13692.1	409.0	45.0	4.6	1.3	0.7	0.3	0.2	0.1	0.4	0.0	0.1	0.1	0.0	0.0	14153.5
% Difference	997.4	236.4	-51.8	-91.4	-93.4	-89.5	-83.8	-71.4	-80.0	-41.7	-100.0	-92.3	-90.5	-100.0	#DIV/0!	815.4

A11.5.3.5 Average of particle counter runs used for comparison

NONE - 0 PPB

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	3123.5	190.2	110.3	60.1	24.3	10.1	4.5	2.5	1.5	3.3	0.8	0.2	0.2	0.0	0.0	3531.5
Counts/mL (61 min)	2530.9	139.5	85.2	45.7	17.8	7.2	3.4	1.9	1.3	2.8	0.7	0.2	0.1	0.0	0.0	2836.8
% Difference	-19.0	-26.7	-22.8	-23.9	-26.7	-28.8	-24.4	-23.2	-13.3	-15.4	-11.3	-15.4	-38.7	0.0	#DIV/0!	-19.7

NONE - 500 PPB

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	1109.1	66.2	36.4	20.4	8.2	3.2	1.6	1.0	0.6	1.2	0.5	0.2	0.3	0.0	0.0	1248.8
Counts/mL (61 min)	874.6	47.1	28.0	17.0	6.3	2.1	1.1	0.7	0.5	0.9	0.2	0.1	0.1	0.0	0.0	978.5
% Difference	-21.1	-29.0	-23.0	-16.6	-23.2	-33.3	-31.9	-29.8	-20.0	-31.1	-54.8	-44.4	-81.3	-100.0	#DIV/0!	-21.6

UV - 0 PPB

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	749.5	87.0	45.7	28.8	14.3	6.7	4.0	2.3	1.4	3.4	0.7	0.2	0.3	0.1	0.0	944.2
Counts/mL (61 min)	872.9	72.4	53.9	37.0	17.0	8.1	5.4	3.2	2.4	6.8	2.1	0.8	0.2	0.0	0.0	1082.0
% Difference	16.5	-16.8	17.8	28.4	19.1	20.6	35.4	39.1	64.9	102.2	211.1	287.5	-25.0	-50.0	#DIV/0!	14.6

UV - 500 PPB

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	681.4	32.9	21.3	8.4	2.5	0.9	0.2	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	748.0
Counts/mL (61 min)	412.2	16.0	7.1	4.2	2.0	0.6	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	442.8
% Difference	-39.5	-51.4	-66.8	-50.0	-18.4	-38.9	0.0	300.0	0.0	-25.0	-100.0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	-40.8

OZ - 0 PPB

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	1180.6	326.8	89.6	25.7	7.7	2.8	1.5	0.9	0.5	1.3	0.3	0.1	0.2	0.0	0.0	1637.8
Counts/mL (61 min)	4558.8	390.2	220.6	108.9	38.4	18.5	9.7	5.2	3.1	4.1	0.4	0.1	0.2	0.1	0.0	5357.9
% Difference	286.2	19.4	146.2	323.5	398.7	558.9	565.5	472.2	588.9	211.5	16.7	-50.0	33.3	#DIV/0!	#DIV/0!	227.2

OZ - 500 PPB

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	982.6	78.1	61.1	63.8	30.7	18.2	11.2	4.7	2.1	2.2	0.3	0.1	0.1	0.0	0.0	1254.9
Counts/mL (61 min)	5031.5	2441.6	2095.2	1180.1	302.9	65.8	21.8	7.4	3.4	3.2	0.3	0.3	0.2	0.1	0.0	11153.4
% Difference	412.1	3026.2	3331.9	1749.7	886.6	262.3	94.2	58.1	61.9	45.5	0.0	400.0	300.0	#DIV/0!	#DIV/0!	788.8

UV/OZ - 0 PPB

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	3536.5	417.6	303.9	171.2	65.0	29.7	16.1	10.0	6.1	9.2	1.4	0.5	0.2	0.0	0.0	4567.3
Counts/mL (61 min)	2113.1	222.7	141.0	72.3	27.1	11.4	6.3	3.4	2.7	4.0	0.5	0.2	0.1	0.0	0.0	2604.4
% Difference	-40.2	-46.7	-53.6	-57.8	-58.4	-61.8	-61.2	-66.5	-55.7	-56.8	-63.0	-55.6	-75.0	#DIV/0!	#DIV/0!	-43.0

UV/OZ - 300 PPB

Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	1652.2	97.8	44.4	15.7	4.3	1.7	0.8	0.3	0.3	0.7	0.4	0.1	0.1	0.0	0.0	1818.4
Counts/mL (61 min)	2243.6	131.4	64.2	22.9	5.2	1.8	1.0	0.5	0.3	0.3	0.1	0.0	0.1	0.0	0.0	2471.1
% Difference	35.8	34.3	44.5	45.5	22.4	9.1	26.7	50.0	-16.7	-53.8	-71.4	-100.0	100.0	#DIV/0!	#DIV/0!	35.9

UV/OZ - 500 PPB

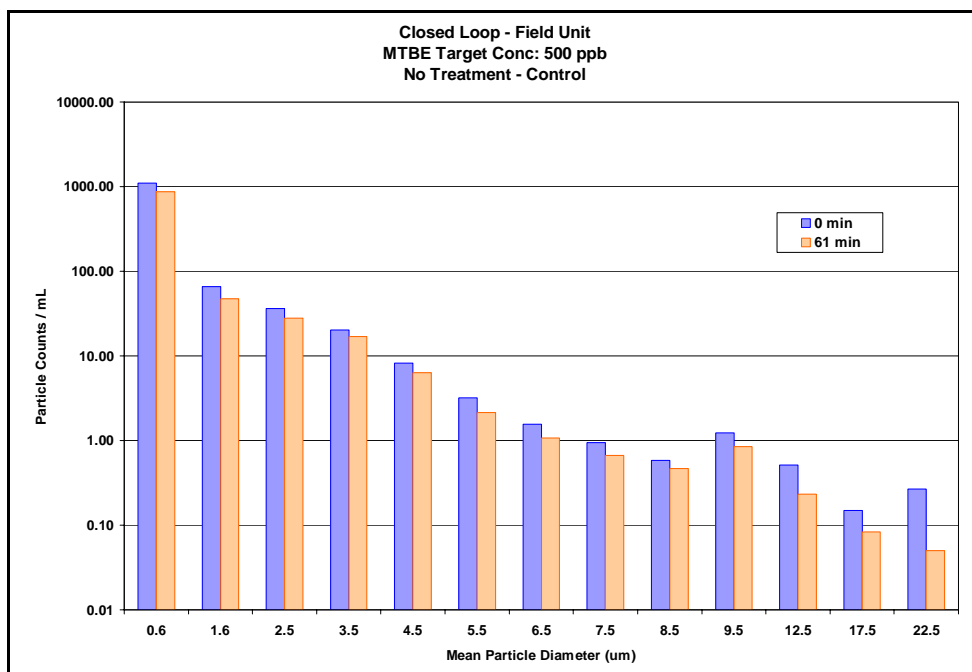
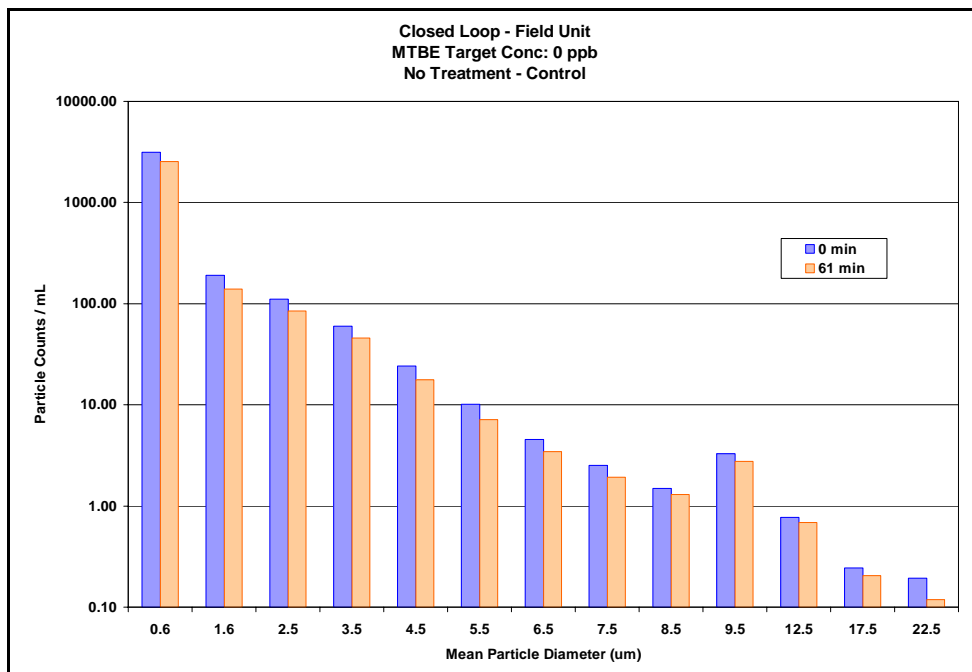
Channel Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	1970.6	175.3	123.6	85.2	42.5	24.0	15.5	11.2	8.1	18.9	5.2	1.7	0.7	0.1	0.0	2482.4
Counts/mL (61 min)	19394.6	8730.3	9779.4	7543.6	3210.9	1278.7	535.6	224.3	91.4	58.9	3.1	0.6	0.2	0.0	0.0	50851.6
% Difference	884.2	4880.9	7815.3	8759.2	7450.7	5233.5	3355.6	1907.4	1024.3	212.2	-40.2	-65.7	-75.0	-50.0	#DIV/0!	1948.5

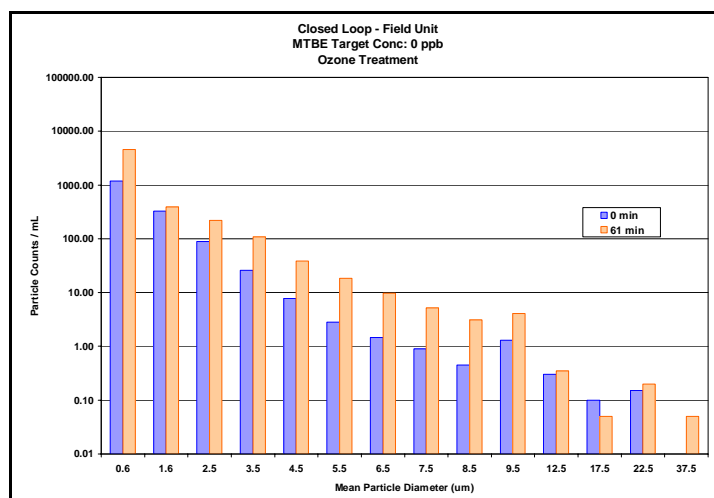
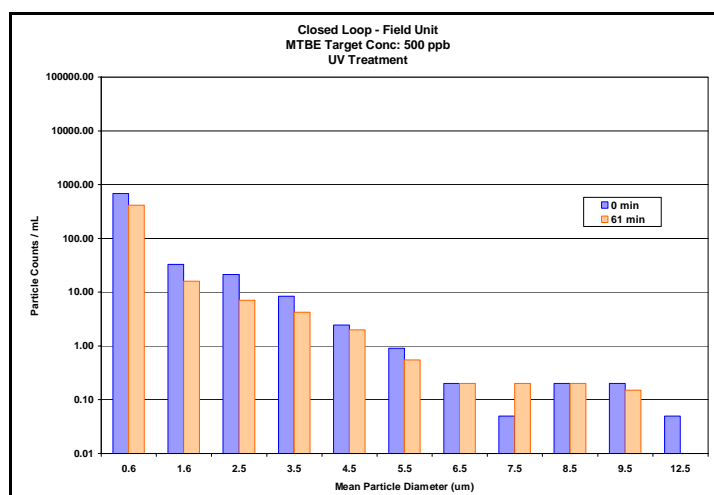
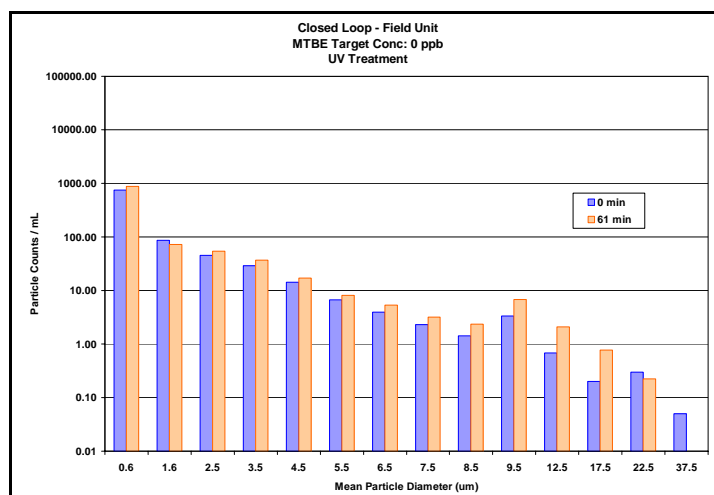
UV/OZ - 1800 PPB

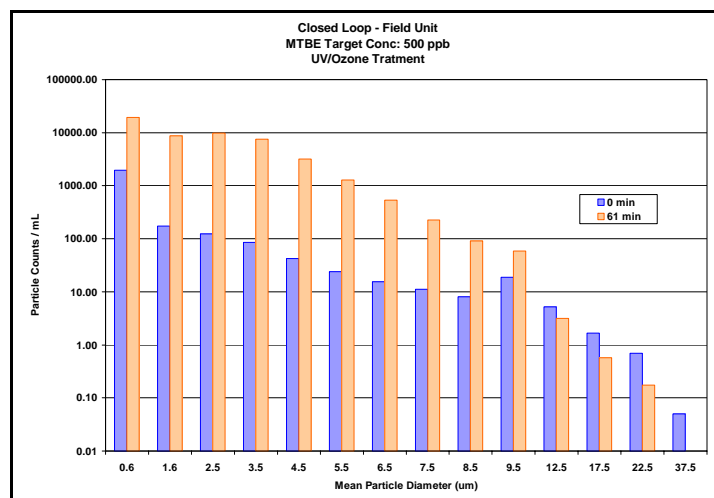
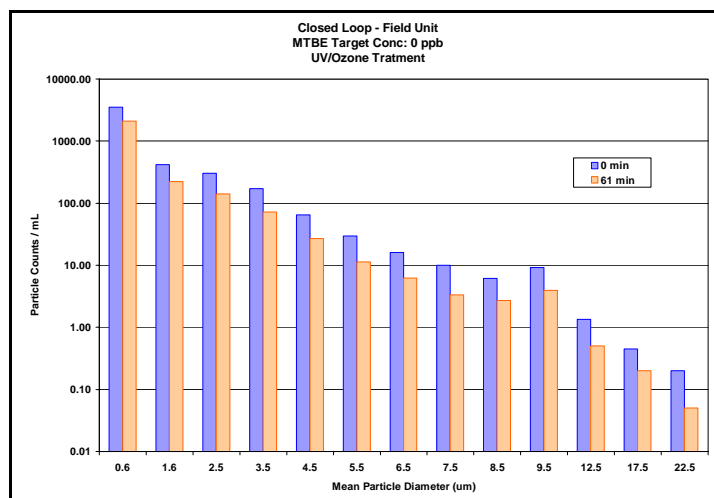
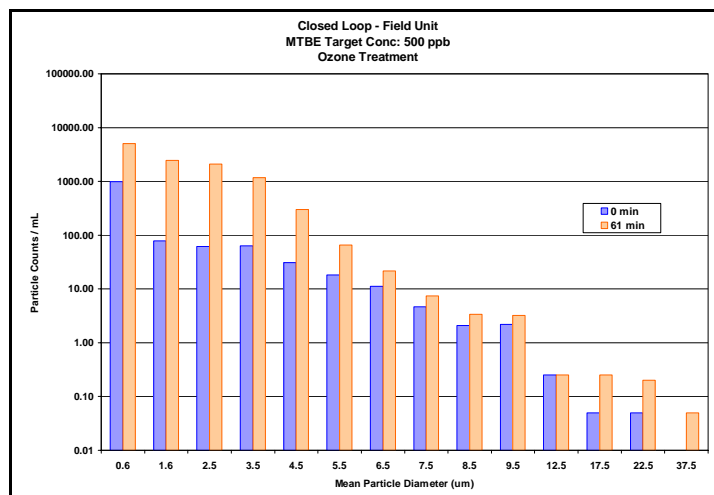
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	100 to 100	1.2 to 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50.6
Counts/mL (0 min)	1142.1	112.5	92.8	62.3	31.6	19.6	14.7	11.8	9.8	52.5	36.5	11.6	8.6	0.3	0.0	1606.7
Counts/mL (61 min)	18949.1	5980.5	4063.8	1804.1	498.4	148.5	53.6	23.8	13.4	19.9	6.3	2.5	2.0	0.0	0.0	31565.9
% Difference	1559.1	5216.0	4279.1	2795.8	1477.2	657.7	264.6	101.7	36.7	-62.1	-82.7	-78.4	-76.7	-100.0	#DIV/0!	1864.6

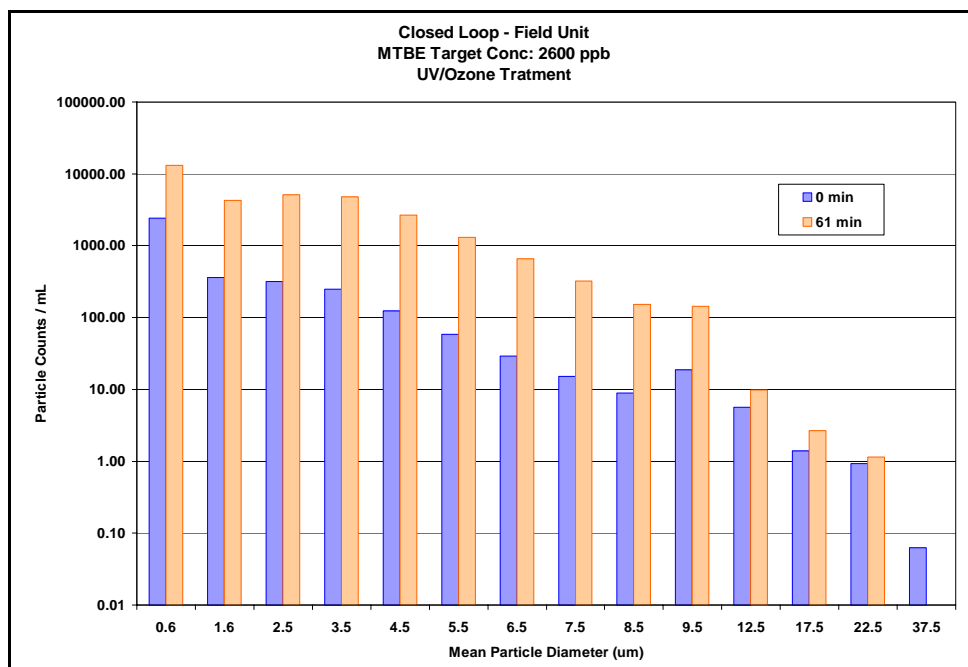
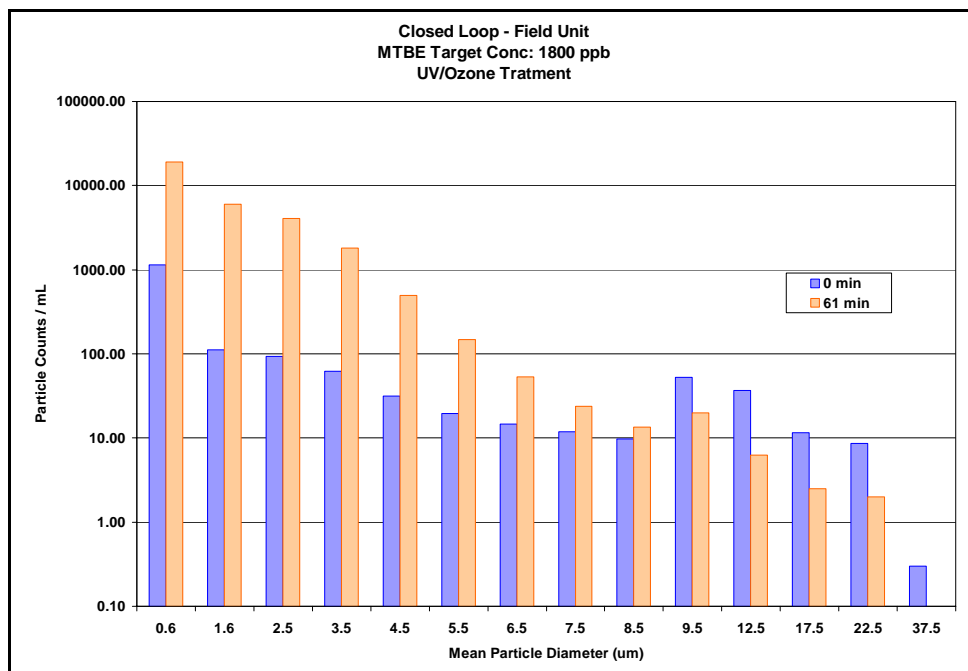
UV/OZ - 2600 PPB

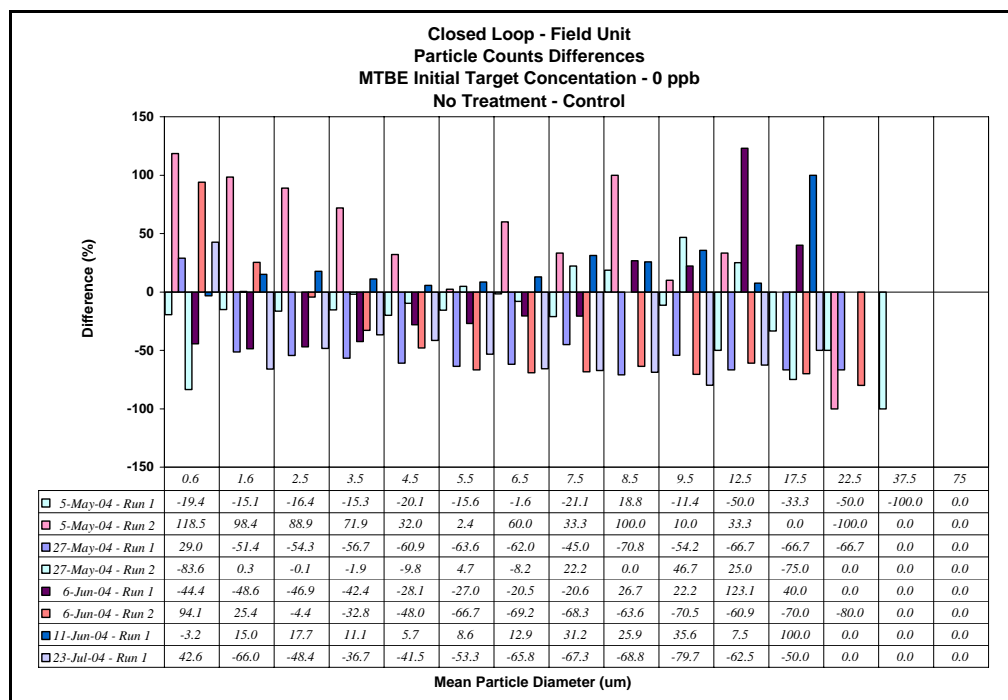
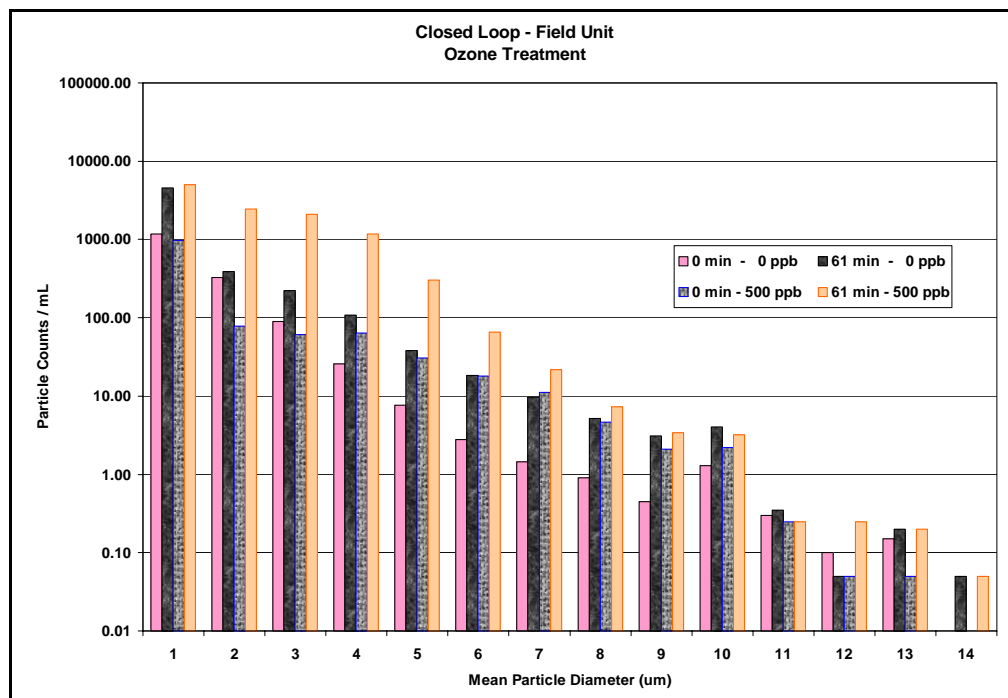
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Summary
Channel Range (um)	0 to 1.2	1.2 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 15	15 to 20	20 to 25	25 to 50	50 to 100	< 100
Channel Average	0.6	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	12.5	17.5	22.5	37.5	75	50
Counts/mL (0 min)	2429.7	362.7	316.3	248.5	124.0	58.5	29.1	15.1	8.9	18.9	5.7	1.4	0.9	0.1	0.0	3619.7
Counts/mL (61 min)	13056.9	4299.9	5153.0	4820.4	2673.0	1316.1	656.4	325.1	154.0	143.9	9.8	2.7	1.2	0.0	0.0	32612.3
% Difference	437.4	1085.5	1529.3	1840.1	2056.5	2149.7	2159.6	2049.2	1632.8	660.1	73.3	91.1	22.7	-60.0	#DIV/0!	801.0

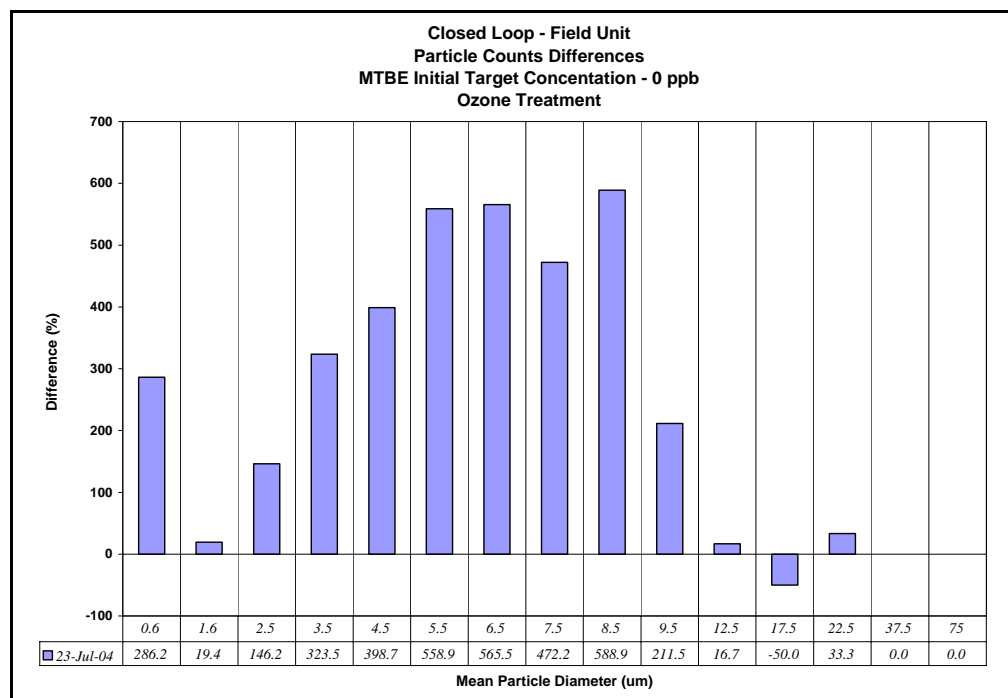
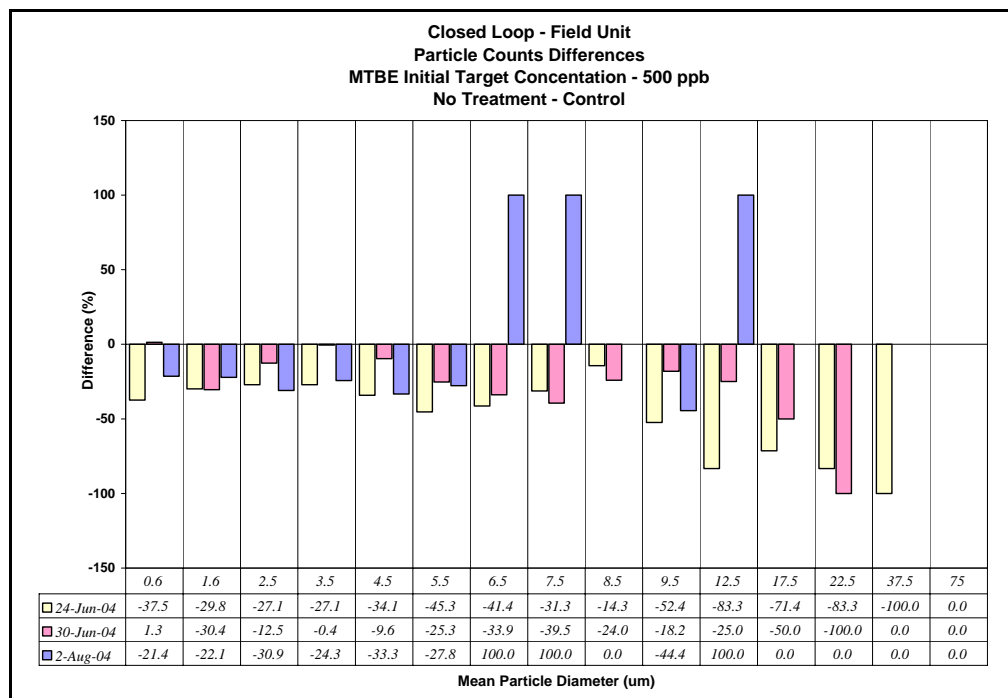
A11.5.3.6 Particle counter analysis graphs

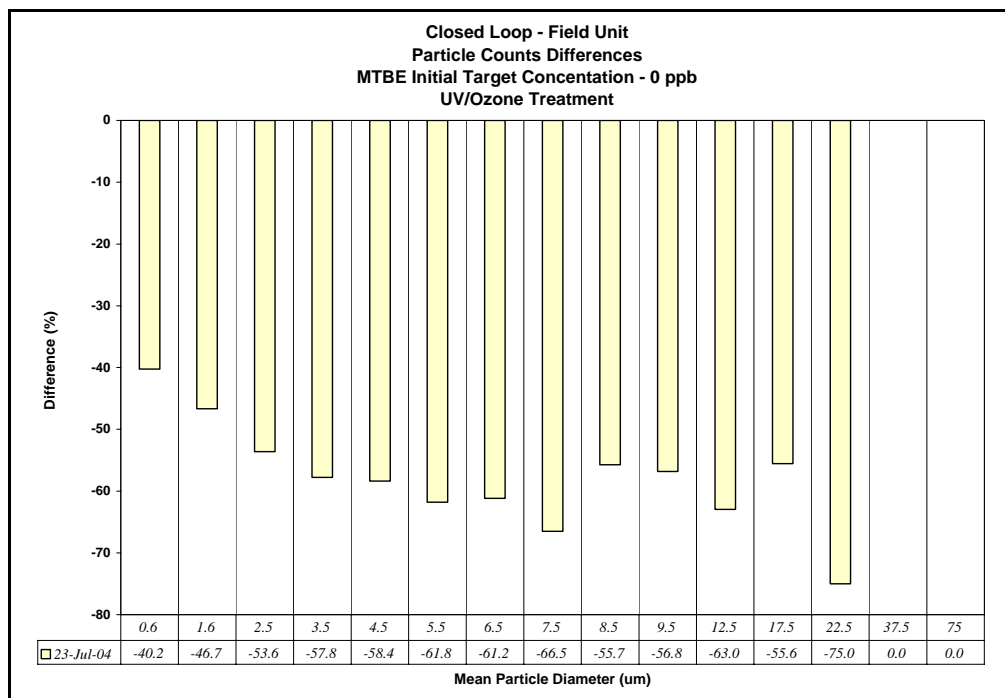
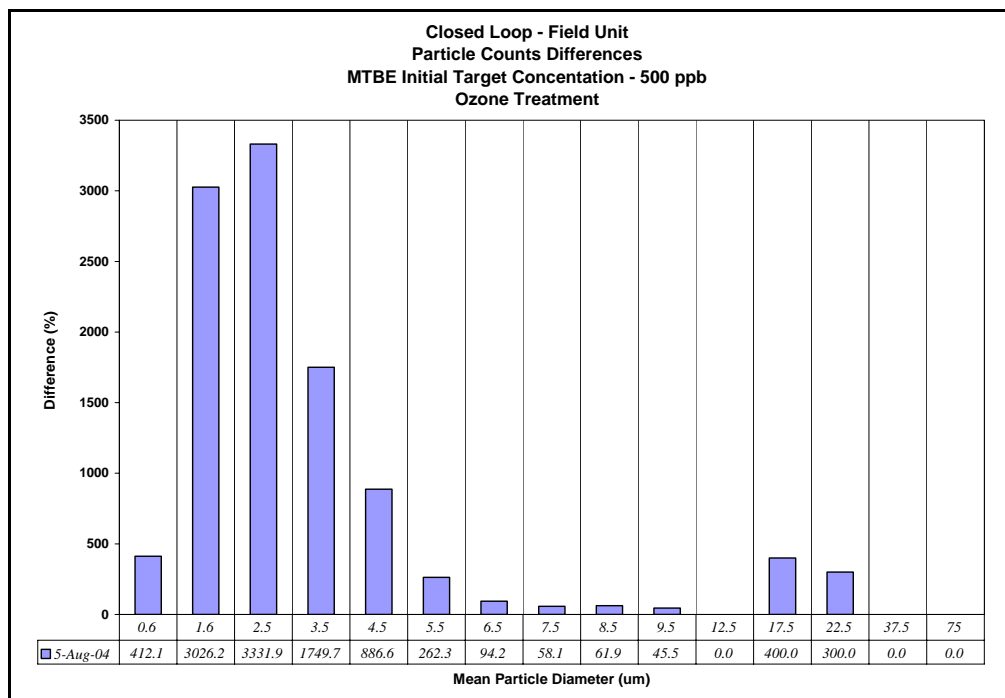


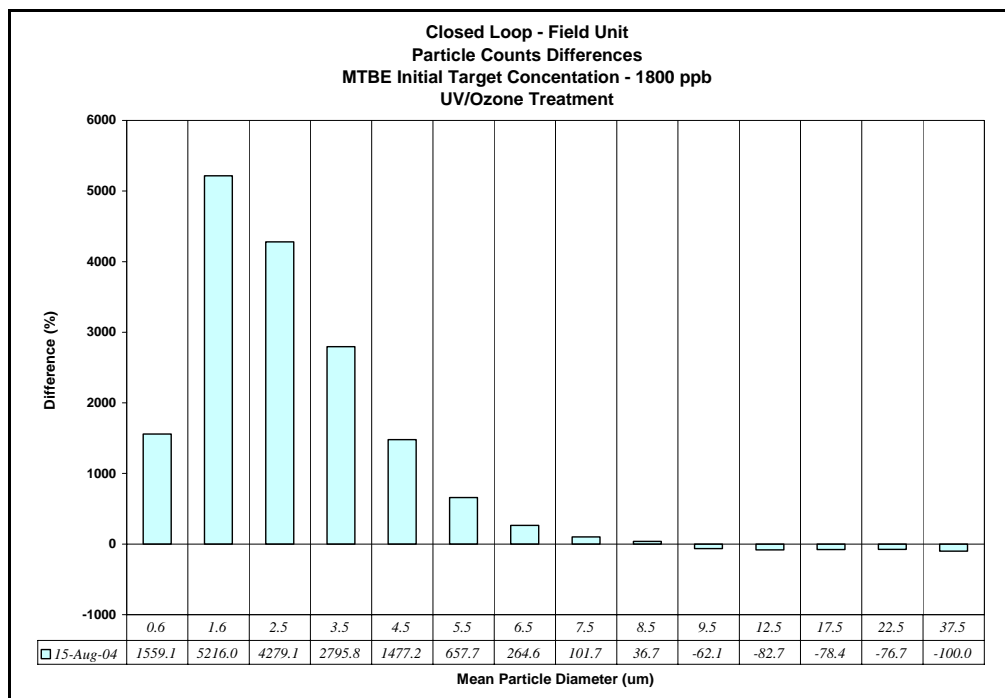
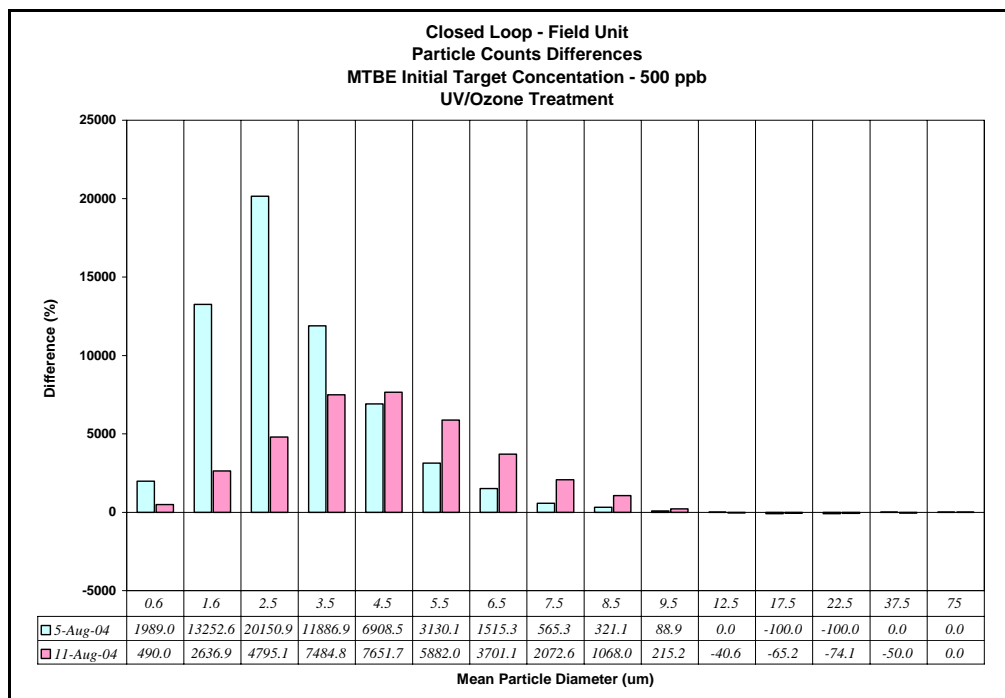












A11.5.4 Volatile Organic Carbon

A11.5.4.1 Control Runs

<i>Minutes</i>	<i>Sample</i>	<i>Acetone</i> ($\mu\text{g/L}$)	<i>Methyl</i> <i>Acetate</i> ($\mu\text{g/L}$)	<i>MTBE</i> ($\mu\text{g/L}$)	<i>TBF</i> ($\mu\text{g/L}$)
1	cl-none-500ppb-062404-1min	0.00	0.00	569.87	31.41
6	cl-none-500ppb-062404-6min	0.00	0.00	571.81	27.35
11	cl-none-500ppb-062404-11min	0.00	0.00	517.74	26.21
21	cl-none-500ppb-062404-21min	0.00	0.00	413.22	20.37

<i>Minutes</i>	<i>Sample</i>	<i>Acetone</i> ($\mu\text{g/L}$)	<i>Methyl</i> <i>Acetate</i> ($\mu\text{g/L}$)	<i>MTBE</i> ($\mu\text{g/L}$)	<i>TBF</i> ($\mu\text{g/L}$)
1	cl-none-500ppb-080204-1min	0.00	0.00	440.67	16.50
6	cl-none-500ppb-080204-6min	0.00	0.00	467.54	16.96
11	cl-none-500ppb-080204-11min	0.00	0.00	480.67	18.51
21	cl-none-500ppb-080204-21min	0.00	0.00	496.36	18.35
31	cl-none-500ppb-080204-31min	0.00	0.00	485.74	16.77
61	cl-none-500ppb-080204-61min	0.00	0.00	487.71	19.13

A11.5.4.2 UV Runs

<i>Minutes</i>	<i>Sample</i>	<i>Acetone</i> ($\mu\text{g/L}$)	<i>Methyl</i> <i>Acetate</i> ($\mu\text{g/L}$)	<i>MTBE</i> ($\mu\text{g/L}$)	<i>TBF</i> ($\mu\text{g/L}$)
1	CL-UV-500ppb-081204-1min	0.00	0.00	341.61	9.92
6	CL-UV-500ppb-081204-6min	0.00	0.00	281.34	23.99
11	CL-UV-500ppb-081204-11min	0.00	0.00	241.75	35.33
21	CL-UV-500ppb-081204-21min	0.00	0.00	246.27	63.78
31	CL-UV-500ppb-081204-31min	0.00	0.00	194.32	74.91
61	CL-UV-500ppb-081204-61min	0.00	0.00	92.34	73.17

A11.5.4.3 Ozone Runs

<i>Minutes</i>	<i>Sample</i>	<i>Acetone</i> ($\mu\text{g/L}$)	<i>Methyl</i> <i>Acetate</i> ($\mu\text{g/L}$)	<i>MTBE</i> ($\mu\text{g/L}$)	<i>TBF</i> ($\mu\text{g/L}$)
1	CL-OZ-500ppb-080404-1min	0.00	0.00	354.02	16.45
6	CL-OZ-500ppb-080404-6min	0.00	0.00	314.30	59.12
11	CL-OZ-500ppb-080404-11min	0.00	0.00	276.31	84.40
21	CL-OZ-500ppb-080404-21min	0.00	0.00	232.55	179.26
31	CL-OZ-500ppb-080404-31min	0.00	0.00	158.67	231.53
61	CL-OZ-500ppb-080404-61min	0.00	0.00	37.84	195.05

A11.5.4.4 UV/Ozone Runs

<i>Minutes</i>	<i>Sample</i>	<i>Acetone</i> ($\mu\text{g/L}$)	<i>Methyl</i> <i>Acetate</i> ($\mu\text{g/L}$)	<i>MTBE</i> ($\mu\text{g/L}$)	<i>TBF</i> ($\mu\text{g/L}$)
1	CL-UV/OZ-500ppb-080504-1min	0.00	0.00	336.87	94.38
6	CL-UV/OZ-500ppb-080504-6min	0.00	0.00	117.53	321.45
11	CL-UV/OZ-500ppb-080504-11min	0.00	12.63	31.56	345.56
21	CL-UV/OZ-500ppb-080504-21min	0.00	17.44	0.00	166.45
31	CL-UV/OZ-500ppb-080504-31min	0.00	23.24	0.00	96.00
61	CL-UV/OZ-500ppb-080504-61min	0.00	0.00	0.00	0.00

<i>Minutes</i>	<i>Sample</i>	<i>Acetone</i> ($\mu\text{g/L}$)	<i>Methyl</i> <i>Acetate</i> ($\mu\text{g/L}$)	<i>MTBE</i> ($\mu\text{g/L}$)	<i>TBF</i> ($\mu\text{g/L}$)
1	CL-UV/OZ-500ppb-081204-1min	0.00	0.00	324.44	70.81
6	CL-UV/OZ-500ppb-081204-6min	0.00	0.00	140.39	214.89
11	CL-UV/OZ-500ppb-081204-11min	0.00	0.00	77.84	320.54
21	CL-UV/OZ-500ppb-081204-21min	0.00	0.00	12.36	236.43
31	CL-UV/OZ-500ppb-081204-31min	0.00	10.61	0.00	114.42
61	CL-UV/OZ-500ppb-081204-61min	0.00	10.69	0.00	12.28

<i>Minutes</i>	<i>Sample</i>	<i>Acetone</i> ($\mu\text{g/L}$)	<i>Methyl</i> <i>Acetate</i> ($\mu\text{g/L}$)	<i>MTBE</i> ($\mu\text{g/L}$)	<i>TBF</i> ($\mu\text{g/L}$)
1	CL-UV/OZ-1800ppb-1 min	0.00	13.50	1538.49	162.60
6	CL-UV/OZ-1800ppb-6 min	61.74	40.11	569.15	440.67
11	CL-UV/OZ-1800ppb-11 min	93.33	40.78	187.23	472.90
21	CL-UV/OZ-1800ppb-21 min	201.13	58.33	49.38	553.10
31	CL-UV/OZ-1800ppb-31 min	287.42	45.68	0.00	219.40
61	CL-UV/OZ-1800ppb-61 min	647.12	73.44	0.00	66.99

<i>Minutes</i>	<i>Sample</i>	<i>Acetone ($\mu\text{g/L}$)</i>	<i>Methyl Acetate ($\mu\text{g/L}$)</i>	<i>MTBE ($\mu\text{g/L}$)</i>	<i>TBF ($\mu\text{g/L}$)</i>
1	CL-UV/OZ-2600ppb-1 min	0.00	0.00	2342.04	68.18
6	CL-UV/OZ-2600ppb-6 min	0.00	40.67	1452.09	520.87
11	CL-UV/OZ-2600ppb-11 min	120.80	77.28	757.29	742.10
21	CL-UV/OZ-2600ppb-21 min	187.53	72.15	296.98	877.78
31	CL-UV/OZ-2600ppb-31 min	311.94	102.47	153.68	1100.55
61	CL-UV/OZ-2600ppb-61 min	433.65	56.72	0.00	222.63

A11.5.5 Electricity utilized by treatment

<i>Instrument or Treatment</i>	<i>Average Time per Watt-Hour (seconds)</i>
Air dryer	42.5
UV	5.57
Ozone	4.26
UV/Ozone	3.85

Appendix 12: AOP plant results (IT Corporation)

As discussed on chapter 4, to solve the problem of the evaluation of the AOP plant without sufficient data, it was decided to use the USEPA dataset. This dataset includes runs for closed loop, and single pass with partial recirculation loop.

A12.1 Closed Loop Tests

Closed loop tests include two different AOP plant units as described on chapter 3. These units are field unit (FU) and T&E (TE) unit. Therefore, closed loop tests have a subdivision of the dataset by each AOP plant. The following table details the runs performed at the T&E Facility of the USEPA.

<i>AOP Plant Unit</i>	<i>Date</i>	<i>Treatment</i>	<i>MTBE Target Concentration ($\mu\text{g/L}$)</i>	<i>Turbidity (NTU)</i>
TE	12/26/00	Ozone	300	<0.5
TE	01/02/01	Control	1200	<0.5
TE	01/03/01	UV	1200	<0.5
TE	01/08/01	Ozone	1200	<0.5
TE	01/09/01	UV/Ozone	1200	<0.5
TE	01/15/01	UV	3000	<0.5
TE	01/15/01	Control	3000	<0.5
TE	01/23/01	UV	3000	<0.5
TE	01/23/01	Control	300	<0.5
FU	01/29/01	UV/Ozone	1200	<0.5
FU	01/29/01	Control	1200	<0.5
TE	02/05/01	UV/Ozone	3000	<0.5
TE	02/05/01	Ozone	3000	<0.5
FU	03/07/01	UV	1200	<0.5
FU	03/12/01	Ozone	1200	<0.5
FU	05/22/01	UV/Ozone	1200	2.0
FU	05/22/01	Ozone	1200	2.0
FU	05/30/01	UV/Ozone	1200	15.0
FU	05/30/01	Ozone	1200	16.0
FU	06/05/01	UV/Ozone	100	2.0
FU	06/05/01	Ozone	100	2.0
FU	06/19/01	UV/Ozone	1200	1.4
FU	06/19/01	Ozone	1200	1.6
TE	12/26/02	UV/Ozone	300	<0.5

Only the selected runs (in shadow) are used to discuss the AOP plant performance in closed loop. Those runs are desirable because a comparison between them can be done. Therefore, only the data of the selected runs are included.

A12.1.1 Control Runs (No treatment)

AOP Plant Unit	Date	Treatment	MTBE Target Concentration ($\mu\text{g/L}$)	Turbidity (NTU)
TE	01/02/01	Control	1200	<0.5
TE	01/15/01	Control	3000	<0.5
FU	01/29/01	Control	1200	<0.5

Run: # 2-5 Control
Date: 01/02/01
Flow: 10 gpm
Water: Dechlorinated tap water
Turbidity: < 0.5 ntu
MTBE: 1200 ppb
Tech: Control

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
Initial	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	14:25	7.70	0.23	18.0	10.56	2.5	-	-	-	-	-	2-5-1	925.0	0.0
2	14:26	8.21	0.19	18.0	10.60	2.5	-	-	-	-	-	2-5-2	955.9	6.9
3	14:27	8.28	0.40	18.0	10.60	1.5	-	-	-	-	-	2-5-3	1106.7	5.9
4	14:28	-	-	18.0	10.56	0.5	-	-	-	-	-	2-5-4	1106.7	10.9
5	14:29	-	-	18.0	10.51	0.5	-	-	-	-	-	2-5-5	1121.4	9.2
6	14:30	8.34	0.30	18.0	10.56	1.0	-	-	-	-	-	2-5-6	1139.0	10.9
11	14:35	8.37	0.22	18.5	10.51	1.0	-	-	-	-	-	2-5-11	1136.7	11.2
21	14:45	8.36	0.27	19.0	10.47	1.0	-	-	-	-	-	2-5-21	1021.4	6.5
31	14:55	8.32	0.27	20.0	10.43	1.0	-	-	-	-	-	2-5-31	1120.0	9.5
61	15:25	8.37	0.21	21.5	10.47	1.0	-	-	-	-	-	2-5-61	1103.3	9.7

Run: # 2-9 Control
Date: 01/15/01
Flow: 10 gpm
Water: Dechlorinated tap water
Turbidity: < 0.5 ntu
MTBE: 3000 ppb
Tech: Control

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
Initial	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	10:17	8.36	0.24	18.0	10.77	1.0	-	-	-	-	-	2-9-1	2560.6	9.1
2	10:18	8.34	0.25	18.0	10.56	1.0	-	-	-	-	-	2-9-2	2753.8	48.1
3	10:19	-	-	18.5	10.47	0.5	-	-	-	-	-	2-9-3	3167.3	19.9
4	10:20	-	-	18.5	10.39	0.5	-	-	-	-	-	2-9-4	3061.4	16.1
5	10:21	-	-	18.5	10.35	0.5	-	-	-	-	-	2-9-5	3132.7	21.8
6	10:22	8.32	0.16	18.5	10.39	0.5	-	-	-	-	-	2-9-6	3058.2	15.8
11	10:27	8.33	0.19	19.0	10.43	0.5	-	-	-	-	-	2-9-11	3119.0	18.7
21	10:37	8.35	0.34	20.0	10.43	0.5	-	-	-	-	-	2-9-21	3137.1	25.1
31	10:47	8.29	0.35	20.5	10.43	0.5	-	-	-	-	-	2-9-31	3099.7	16.6
61	11:17	8.33	0.28	22.0	10.47	1.0	-	-	-	-	-	2-9-61	2760.0	15.2

Run: FI-1
Date: 1/29/2001
Flow: 10 gpm
Water: Declorinated Potable Water
Turbidity: < 0.5 ntu
MTBE: 1200 ppb
Tech: Control

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
1	14:19	8.45	0.21	12.0	10.56	4.5	0	-	-	-	-	FI-1-1	1113.5	0.0
2	14:20	8.60	0.24	12.0	9.92	0.0	0	-	-	-	-	FI-1-2	1079.1	0.0
3	14:21	8.50	0.24	12.0	9.92	0.0	0	-	-	-	-	FI-1-3	1035.1	5.2
4	14:22	8.55	0.27	12.0	9.92	0.0	0	-	-	-	-	FI-1-4	1078.7	0.0
5	14:23	8.49	0.39	12.0	9.60	0.0	0	-	-	-	-	FI-1-5	1119.3	0.0
6	14:24	8.30	0.23	12.5	9.60	0.0	0	-	-	-	-	FI-1-6	1138.5	0.0
11	14:29	8.52	0.30	13.5	9.92	0.0	0	-	-	-	-	FI-1-11	1184.0	0.0
21	14:39	8.48	0.40	14.5	9.92	0.0	0	-	-	-	-	FI-1-21	1186.9	0.0
31	14:49	8.33	0.56	15.5	0*	0.0	0	-	-	-	-	FI-1-31	1163.0	0.0
61	*	*	*	*	*	*	0	-	-	-	-	FI-1-61	*	*

A12.1.2 UV Runs

AOP Plant Unit	Date	Treatment	MTBE Target Concentration (µg/L)	Turbidity (NTU)
TE	01/03/01	UV	1200	<0.5
TE	01/15/01	UV	3000	<0.5
FU	03/07/01	UV	1200	<0.5

Run: # 2-6 UV
Date: 01/03/01
Flow: 10 gpm
Water: Dechlorinated tap water
Turbidity: < 0.5 ntu
MTBE: 1200 ppb
Tech: UV

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
Initial	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	13:10	8.48	0.20	13.0	10.56	2.0	-	-	-	-	-	2-6-1	66.9	0.0
2	13:11	8.51	0.20	13.0	10.60	2.0	-	-	-	-	-	2-6-2	1160.2	9.5
3	13:12	-	-	13.0	10.51	1.0	-	-	-	-	-	2-6-3	1158.1	12.0
4	13:13	8.50	0.29	13.0	10.56	1.5	-	-	-	-	-	2-6-4	1166.8	13.0
5	13:14	-	-	13.0	10.47	1.5	-	-	-	-	-	2-6-5	1167.9	12.7
6	13:15	8.52	0.17	13.0	10.47	1.0	-	-	-	-	-	2-6-6	1162.6	-
11	13:20	8.47	0.36	13.5	10.56	1.0	-	-	-	-	-	2-6-11	1135.8	16.2
21	13:30	8.52	0.20	14.5	10.43	1.5	-	-	-	-	-	2-6-21	1135.7	21.7
31	13:40	8.49	0.16	15.5	10.47	1.5	-	-	-	-	-	2-6-31	1154.2	26.3
61	14:10	8.47	0.28	18.0	10.47	1.5	-	-	-	-	-	2-6-61	1121.0	45.2

Run: # 2-10 UV
Date: 01/15/01
Flow: 10 gpm
Water: Dechlorinated tap water
Turbidity: < 0.5 ntu
MTBE: 3000 ppb
Tech: UV

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
Initial	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	12:37	8.25	0.27	19.0	10.47	1.0	-	-	-	-	-	2-10-1	2762.6	18.2
2	12:38	8.05	0.17	19.0	10.47	2.0	-	-	-	-	-	2-10-2	3064.3	18.0
3	12:39	-	0.21	19.0	10.39	1.0	-	-	-	-	-	2-10-3	2752.9	15.3
4	12:40	8.28	0.24	19.0	10.39	1.0	-	-	-	-	-	2-10-4	2713.6	18.2
5	12:41	-	-	19.0	10.43	1.0	-	-	-	-	-	2-10-5	3000.3	26.9
6	12:42	8.32	0.43	19.0	10.43	2.0	-	-	-	-	-	2-10-6	3045.8	23.4
11	12:47	8.20	0.23	19.0	10.43	2.0	-	-	-	-	-	2-10-11	3005.4	31.1
21	12:57	8.20	0.19	20.0	10.35	2.0	-	-	-	-	-	2-10-21	3023.1	38.2
31	13:07	8.20	0.31	21.0	10.39	1.0	-	-	-	-	-	2-10-31	3020.4	53.2
61	13:37	8.17	0.27	23.0	10.43	1.0	-	-	-	-	-	2-10-61	2681.9	69.5

Run: F1-2
Date: 3/7/2001
Flow: 10 gpm
Water: Dechlorinated Potable Water
Turbidity: < 0.5 ntu
MTBE: 1200 ppb
Tech: UV

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
1	13:34	8.88	0.26	10.0	9.92	0.0	0.86	-	-	-	-	F1-2-1	1009.4	0.0
2	13:35	8.86	0.30	10.0	9.92	0.0	0.83	-	-	-	-	F1-2-2	1181.1	0.0
3	13:36	8.87	0.25	10.0	9.92	0.0	0.80	-	-	-	-	F1-2-3	1142.0	0.0
4	13:37	8.89	0.11	10.0	9.92	0.0	0.80	-	-	-	-	F1-2-4	1164.0	0.0
5	13:38	8.88	0.38	10.0	9.92	0.0	0.82	-	-	-	-	F1-2-5	1070.6	0.0
6	13:39	8.84	0.13	10.5	9.92	0.0	0.80	-	-	-	-	F1-2-6	1096.6	0.0
11	13:44	8.80	0.17	11.0	9.92	0.0	0.80	-	-	-	-	F1-2-11	1166.8	0.0
21	13:54	8.76	0.12	*	*	*	*	-	-	-	-	F1-2-21	1163.5	19.2
31	14:04	8.81	0.10	14.0	9.92	0.0	0.90	-	-	-	-	F1-2-31	1149.3	22.5
61	14:34	8.77	0.15	18.0	9.92	0.0	1.00	-	-	-	-	F1-2-61	1010.7	27.3

Alkalinity (mg/l)	
-0 ALK	53.6
-61 ALK	55.2

TOC (mg/l)	
-0 TOC	0.84
-61 TOC	0.92

Electrical Usage (KWH)			
Before Purge	-	After Run	-
Before Run	-	After Purge	-

A12.1.3 Ozone Runs

AOP Plant Unit	Date	Treatment	MTBE Target Concentration (µg/L)	Turbidity (NTU)
TE	01/08/01	Ozone	1200	<0.5
TE	02/05/01	Ozone	3000	<0.5
FU	03/12/01	Ozone	1200	<0.5
FU	05/22/01	Ozone	1200	2.0
FU	05/30/01	Ozone	1200	16.0

Run: # 2-7 Ozone
Date: 01/08/01
Flow: 10 gpm
Water: Dechlorinated tap water
Turbidity: < 0.5 ntu
MTBE: 1200 ppb
Tech: Ozone

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
Initial	11:57	-	-	-	-	-	-	-12	10	1.20	-	-	-	-
1	12:05	7.86	0.14	18.0	10.30	4.0	-	-12	10	-	-	2-7-1	1016.3	33.7
2	12:06	7.88	0.38	18.0	10.09	2.0	-	-12	10	-	-	2-7-2	992.8	61.0
3	12:07	7.71	0.76	18.0	10.05	2.0	-	-12	10	-	-	2-7-3	1023.2	74.3
4	12:08	7.66	0.16	19.0	10.05	2.0	-	-12	10	-	-	2-7-4	996.7	91.8
5	12:09	7.83	0.44	19.0	10.09	2.0	-	-12	10	-	-	2-7-5	930.6	103.8
6	12:10	7.87	0.15	19.0	10.05	2.0	-	-12	10	-	1.54	2-7-6	921.2	119.1
11	12:15	7.66	0.26	19.0	10.00	2.0	-	-12	10	-	> 1.5	2-7-11	871.7	190.7
21	12:25	7.63	0.20	19.0	10.00	1.0	-	-12	10	-	1.59	2-7-21	852.4	220.6
31	12:35	7.61	0.19	20.0	10.05	2.0	-	-12	10	-	1.55	2-7-31	621.2	394.1
61	13:05	7.67	0.25	22.0	10.05	2.0	-	-12	10	-	1.45	2-7-61	325.1	544.6

Run: # 2-11 Ozone
Date: 02/05/01
Flow: 10 gpm
Water: Dechlorinated tap water
Turbidity: < 0.5 ntu
MTBE: 3000 ppb
Tech: Ozone

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
Initial	10:08	-	-	-	-	-	-	-13	2	1.28	-	-	-	-
1	10:13	8.30	0.63	16.0	11.07	21.0	-	-5.5	7.5	-	1.64	2-11-1	3332.0	25.0
2	10:14	-	0.15	16.0	9.96	12.0	-	-9	10	-	-	2-11-2	3100.0	42.0
3	10:15	8.30	0.18	16.0	9.75	8.0	-	-10	10	-	-	2-11-3	3196.0	68.0
4	10:16	8.29	0.80	16.0	9.29	5.0	-	-11	11	-	-	2-11-4	3207.0	82.0
5	10:17	8.27	0.18	16.0	8.99	3.0	-	-12	11	-	-	2-11-5	3227.0	97.0
6	10:18	8.30	0.21	16.5	9.03	2.0	-	-12	11	-	> 1.5	2-11-6	3170.0	113.0
11	10:23	8.29	0.14	17.0	9.07	2.0	-	-12.5	11.5	-	1.59	2-11-11	3044.0	167.0
21	10:33	8.22	0.19	17.5	9.12	2.0	-	-13	11.5	-	1.55	2-11-21	2973.0	255.0
31	10:43	8.18	0.19	18.0	9.07	2.0	-	-13	11	-	1.25	2-11-31	2712.0	319.0
61	11:13	8.12	0.15	20.0	9.07	2.0	-	-12.5	11.5	-	1.4	2-11-61	2242.0	560.0

Run: F1-3
Date: 3/12/2001
Flow: 10 gpm
Water: Dechlorinated Potable Water
Turbidity: < 0.5 ntu
MTBE: 1200 ppb
Tech: Ozone

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
1	13:20	8.53	1.46	*	*	*	-	*	*	1.33	-	F1-3-1	1036.2	30.2
2	13:21	8.55	0.53	10.0	10.24	0.0	-	*	*	-	-	F1-3-2	1044.9	39.9
3	13:22	8.54	1.02	10.5	9.92	0.0	-	*	*	-	-	F1-3-3	1063.7	48.6
4	13:23	8.54	0.42	10.5	10.24	0.0	-	*	*	-	-	F1-3-4	1058.8	55.9
5	13:24	8.51	0.45	11.0	10.24	0.0	-	*	*	-	-	F1-3-5	1044.9	64.2
6	13:25	8.48	0.41	11.0	9.92	0.0	-	*	*	1.00	-	F1-3-6	1062.0	70.1
11	13:30	8.36	0.53	11.5	10.24	0.0	-	*	*	1.09	-	F1-3-11	998.3	106.1
21	13:40	8.20	0.34	13.0	10.24	0.0	-	-13	10.5	1.02	-	F1-3-21	890.8	143.2
31	13:50	8.02	0.40	14.0	10.24	0.0	-	-15	10	0.73	-	F1-3-31	872.5	170.8
61	14:20	8.15	0.39	18.0	10.24	0.0	-	-14	10.5	0.68	-	F1-3-61	712.3	218.5

Alkalinity (mg/l)	
-0 ALK	54.0
-61 ALK	51.2

TOC (mg/l)	
-0 TOC	1.14
-61 TOC	1.37

Electrical Usage (KWH)			
Before Purge	-	After Run	-
Before Run	-	After Purge	-

Run: MTBE-BATCH-OZONE-1200PPB-052201
 Date: 5/22/2001
 Flow: 10 gpm
 Water: Dechlorinated Potable Water/Mill Creek
 Turbidity: 2 ntu
 MTBE: 1200 ppb
 Tech: Ozone

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
1	8:25	8.07	1.90	25.0	9.60	0.0	-	-10	12	1.30	-	-1	1163.4	34.5
2	8:26	7.92	2.07	25.0	9.60	0.0	-	-10	12	-	-	-2	1070.0	64.4
3	8:27	7.85	1.86	25.0	9.60	0.0	-	-10	12	-	-	-3	1040.5	81.6
4	8:28	7.98	1.66	25.0	9.60	0.0	-	-10	12	-	-	-4	983.0	98.1
5	8:29	8.00	1.67	25.0	9.60	0.0	-	-11	12	-	-	-5	964.1	119.8
6	8:30	8.05	1.76	25.0	9.60	0.0	-	-10	12	0.62	-	-6	957.6	141.9
11	8:35	8.02	1.85	25.0	9.60	0.0	-	-10	12	0.96	-	-11	758.0	206.8
21	8:45	7.91	2.01	26.0	9.60	0.0	-	-10	12	0.89	-	-21	598.6	344.6
31	8:55	7.91	2.49	26.0	9.60	0.0	-	-11	12	0.77	-	-31	389.9	397.3
61	9:25	7.79	2.61	27.0	9.60	0.0	-	-11	12	0.82	-	-61	107.5	400.6

Alkalinity (mg/l)	
-0 ALK	73.2
-61 ALK	68.0

TOC (mg/l)	
-0 TOC	2.35
-61 TOC	2.05

Electrical Usage (KWH)			
Before Purge		After Run	0.986
Before Run	0.859	After Purge	-

Total Hardness (mg/l)	
-0 THARD	-
-61 THARD	-

DOC (mg/l)	
-0 DOC	1.60
-61 DOC	2.01

Run: MTBE-BATCH-OZONE-1200PPB-053001
 Date: 5/30/2001
 Flow: 10 gpm
 Water: East Fork Lake Water
 Turbidity: 16 ntu
 MTBE: 1200 ppb
 Tech: Ozone

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
1	8:01	8.05	17.60	24.0	9.92	0.0	-	-6	17	0.29	-	-1	1082.9	57.1
2	8:02	7.95	16.70	24.0	10.24	0.0	-	-6	17	-	-	-2	1093.6	105.2
3	8:03	8.01	16.20	24.0	10.24	0.0	-	-6	17	-	-	-3	967.7	140.2
4	8:04	8.00	14.90	24.0	10.24	0.0	-	-6	17	-	-	-4	932.3	189.4
5	8:05	7.96	14.70	24.0	10.24	0.0	-	-6	17	-	-	-5	861.0	229.5
6	8:06	8.01	14.40	24.0	9.28	0.0	-	-6	17	0.35	-	-6	762.1	249.3
11	8:11	7.86	14.00	24.0	9.92	0.0	-	-6	17	0.40	-	-11	551.2	371.8
21	8:21	7.86	15.50	25.0	9.60	0.0	-	-6	17	0.51	-	-21	241.0	440.0
31	8:31	7.94	15.50	25.0	9.60	0.0	-	-6	17	0.64	-	-31	111.8	447.8
61	9:01	7.93	17.10	28.0	9.60	0.0	-	-6	17	0.62	-	-61	16.8	245.7

Alkalinity (mg/l)	
-0 ALK	104.0
-61 ALK	88.8

TOC (mg/l)	
-0 TOC	8.37
-61 TOC	8.28

Electrical Usage (KWH)			
Before Purge	1.379	After Run	1.499
Before Run	-	After Purge	1.549

Total Hardness (mg/l)	
-0 THARD	149.0
-61 THARD	151.0

DOC (mg/l)	
-0 DOC	*
-61 DOC	*

A12.1.4 UV/Ozone Runs

AOP Plant Unit	Date	Treatment	MTBE Target Concentration (µg/L)	Turbidity (NTU)
TE	01/09/01	UV/Ozone	1200	<0.5
FU	01/29/01	UV/Ozone	1200	<0.5
TE	02/05/01	UV/Ozone	3000	<0.5
FU	05/22/01	UV/Ozone	1200	2.0
FU	05/30/01	UV/Ozone	1200	15.0

Run: # 2-8 UV/Ozone
Date: 01/09/01
Flow: 10 gpm
Water: Dechlorinated tap water
Turbidity: < 0.5 ntu
MTBE: 1200 ppb
Tech: UV/Ozone

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
Initial	10:17	-	-	-	-	-	-	-11	9	> 1.5	-	-	-	-
1	10:20	7.93	1.07	18.0	10.09	4.0	-	-12	10	0.62	> .75	2-8-1	672.4	257.3
2	10:21	7.99	0.15	18.0	9.92	2.0	-	-12	10	-	-	2-8-2	495.2	466.5
3	10:22	8.00	0.42	18.0	9.92	2.0	-	-12	10	-	-	2-8-3	400.4	551.6
4	10:23	7.99	0.18	18.0	9.84	2.0	-	-12	10	-	-	2-8-4	343.4	616.8
5	10:24	7.99	0.21	18.0	9.79	2.0	-	-12	10	-	-	2-8-5	289.3	639.4
6	10:25	7.84	0.29	18.0	9.88	2.0	-	-12	10	-	0.03	2-8-6	237.4	635.0
11	10:30	7.82	0.27	18.0	9.88	2.0	-	-12	10	0.34	0.04	2-8-11	103.2	598.3
21	10:40	7.83	0.23	19.0	9.84	2.0	-	-12	10	0.29	0.03	2-8-21	16.3	379.3
31	10:50	7.71	0.31	20.0	9.84	2.0	-	-12	10	0.21	*	2-8-31	0.0	158.2
61	11:20	7.59	0.17	21.0	9.92	2.0	-	-12	10	0.24	*	2-8-61	0.0	16.3

Run: # 2-12 UV/Ozone
Date: 02/05/01
Flow: 10 gpm
Water: Dechlorinated tap water
Turbidity: < 0.5 ntu
MTBE: 3000 ppb
Tech: UV/Ozone

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
Initial	12:40	-	-	-	-	-	-	-10	9.0	> 1.5	-	-	-	-
1	12:44	8.30	0.36	15.0	9.29	8.0	-	-13	10.0	1.61	0.84	2-12-1	3065.0	351.0
2	12:45	8.28	0.54	15.0	8.99	2.0	-	-14	10.5	-	-	2-12-2	2471.0	673.0
3	12:46	8.25	0.46	15.0	9.03	2.0	-	-14	10.5	-	-	2-12-3	2238.0	888.0
4	12:47	8.23	0.28	15.0	9.07	2.0	-	-14	10.5	-	-	2-12-4	1901.0	929.0
5	12:48	-	-	15.0	9.03	2.0	-	-14	10.5	-	-	2-12-5	1946.0	1036.0
6	12:49	8.18	0.58	15.0	8.95	2.0	-	-14	10.5	0.17	0.06	2-12-6	1935.0	1132.0
11	12:54	8.16	0.19	15.5	8.99	2.0	-	-14	10.0	0.19	0.06	2-12-11	1783.0	1347.0
21	13:04	8.01	0.26	16.0	8.90	2.0	-	-14	10.0	0.16	0.03	2-12-21	1329.3	1618.1
31	13:14	7.94	0.19	17.0	9.03	2.0	-	-14	10.0	0.15	0.03	2-12-31	910.0	1694.0
61	13:44	7.98	0.19	19.0	9.03	2.0	-	-14	10.2	0.14	0	2-12-61	208.0	1451.0

Run: F1-4
Date: 1/29/2001
Flow: 10 gpm
Water: Dechlorinated Potable Water
Turbidity: < 0.5 ntu
MTBE: 1200 ppb
Tech: UV/Ozone

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
1	16:15	8.36	0.23	11.0	10.24	0.0	1.00	-10	10.0	0.95	0.38	F1-4-1	588.3	325.7
2	16:16	8.30	0.32	11.0	10.24	0.0	1.00	-12	11.0	-	-	F1-4-2	372.4	439.2
3	16:17	8.28	0.45	11.0	9.92	0.0	0.90	-12	11.0	-	-	F1-4-3	320.8	470.5
4	16:18	8.25	0.30	11.0	10.24	0.0	0.95	-12	11.0	-	-	F1-4-4	300.7	482.3
5	16:19	8.23	0.26	11.0	9.92	0.0	1.00	-12	11.5	-	-	F1-4-5	307.5	516.6
6	16:20	8.22	0.27	11.0	10.56	0.0	0.95	-12	11.5	0.13	0.01	F1-4-6	270.0	490.6
11	16:25	8.15	0.23	12.0	10.56	0.0	1.00	-13	11.5	0.11	0.01	F1-4-11	260.5	576.2
21	16:35	8.05	0.32	14.0	10.24	0.0	1.00	-13	11.5	0.09	0.00	F1-4-21	123.2	578.2
31	16:45	7.92	0.47	15.0	10.56	0.0	1.00	-13	11.5	0.08	-0.01	F1-4-31	23.8	397.0
61	17:15	7.79	0.49	18.5	10.24	0.0	1.00	-13	11.5	0.13	0.01	F1-4-61	0.0	76.5

Run: MTBE-BATCH-UVOZ-1200PPB-052201
Date: 5/22/2001
Flow: 10 gpm
Water: Declorinated Potable Water/Mill Creek
Turbidity: 2 ntu
MTBE: 1200 ppb
Tech: UV/Ozone

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
1	10:17	8.31	1.92	23.0	9.60	0.0	0.95	-8	13	0.31	0.04	-1	1110.5	164.7
2	10:18	8.24	1.82	-	-	0.0	-	-	-	-	-	-2	873.9	239.9
3	10:19	8.24	1.48	-	-	0.0	-	-	-	-	-	-3	652.5	283.7
4	10:20	8.20	1.53	23.0	9.60	0.0	0.95	-9	13	-	-	-4	619.1	368.6
5	10:21	8.18	1.57	23.0	9.60	0.0	0.95	-9	13	-	-	-5	527.8	411.2
6	10:22	8.14	1.52	23.0	9.60	0.0	0.95	-10	13	0.26	0.03	-6	392.6	403.2
11	10:27	8.00	1.53	24.0	9.60	0.0	0.95	-8	16	0.27	0.04	-11	117.5	459.9
21	10:37	7.85	1.51	24.0	9.60	0.0	0.95	-8	14	0.30	-0.01	-21	5.1	228.2
31	10:47	7.84	1.61	25.0	9.60	0.0	1.00	-8	15	0.28	0.00	-31	0.0	66.5
61	11:17	7.85	1.52	27.0	9.60	0.0	1.00	-10	12	0.18	0.01	-61	0.0	0.0

Alkalinity (mg/l)	
-0 ALK	72.0
-61 ALK	64.8

TOC (mg/l)	
-0 TOC	1.44
-61 TOC	1.20

Electrical Usage (KWH)			
Before Purge	0.986	After Run	1.147
Before Run	-	After Purge	1.253

Total Hardness (mg/l)	
-0 THARD	1.32
-61 THARD	-

DOC (mg/l)	
-0 DOC	1.32
-61 DOC	1.28

Run: MTBE-BATCH-UVOZ-1200PPB-053001
Date: 5/30/2001
Flow: 10 gpm
Water: East Fork Lake Water
Turbidity: 15 ntu
MTBE: 1200 ppb
Tech: UV/Ozone

Time (minute)	Time (hh:mm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
								inches Hg	SCFH	After Venturi	After UV			
1	9:58	7.89	15.70	24.0	9.92	0.0	0.40	-6	18	0.22	-0.02	-1	1073.0	111.5
2	9:59	7.98	16.60	24.0	9.92	0.0	0.45	-6	18	-	-	-2	1196.6	169.6
3	10:00	7.87	16.00	24.0	9.92	0.0	0.40	-6	18	-	-	-3	1114.3	234.3
4	10:01	7.89	15.00	24.0	9.92	0.0	0.40	-6	18	-	-	-4	1031.8	282.3
5	10:02	7.80	15.10	24.0	9.92	0.0	0.45	-6	18	-	-	-5	931.0	331.3
6	10:03	7.83	14.80	24.0	9.92	0.0	0.40	-6	18	0.21	0.01	-6	853.4	460.1
11	10:08	7.85	14.70	25.0	10.24	0.0	0.45	-6	18	0.23	-0.03	-11	437.0	517.5
21	10:18	7.78	13.70	25.0	9.60	0.0	0.55	-6	18	0.19	-0.03	-21	136.4	338.9
31	10:28	7.85	12.90	26.0	9.60	0.0	0.65	-6	18	0.12	-0.02	-31	21.9	62.4
61	10:58	7.92	15.10	28.0	9.92	0.0	0.60	-6	18	0.11	-0.02	-61	-	-

Alkalinity (mg/l)	
-0 ALK	101.6
-61 ALK	84.0

TOC (mg/l)	
-0 TOC	8.14
-61 TOC	7.63

Electrical Usage (KWH)			
Before Purge	0.986	After Run	1.147
Before Run	-	After Purge	1.253

Total Hardness (mg/l)	
-0 THARD	152.0
-61 THARD	154.0

DOC (mg/l)	
-0 DOC	*
-61 DOC	*

A12.2 Single Pass with Partial Recirculation Loop Tests

In chapter 4, to solve the problem of the evaluation of the single pass with partial recirculation loop without data, it was decided to use the USEPA dataset. The following table details the runs performed at the T&E Facility.

<i>Date</i>	<i>Treatment</i>	<i>MTBE Target Concentration ($\mu\text{g/L}$)</i>	<i>Turbidity (NTU)</i>	<i>Influent Flowrate (L/min)</i>	<i>Influent Flowrate (gal/min)</i>
03/15/01	Control	50	0.5	18.93	5.0
04/03/01	Control	50	0.5	9.46	2.5
04/17/01	Control	50	1.0	9.46	2.5
04/24/01	Control	50	2.0	9.46	2.5
05/01/01	Control	50	2.0	15.14	4.0
03/15/01	UV/Ozone	50	0.5		5.0
04/03/01	UV/Ozone	50	0.5	9.46	2.5
04/16/01	UV/Ozone	50	1.0	9.46	2.5
04/23/01	UV/Ozone	50	2.0	9.46	2.5
05/01/01	UV/Ozone	50	2.0	15.14	4.0
05/07/01	UV/Ozone	1000	2.0	15.14	4.0
05/14/01	UV/Ozone	100	2.0	15.14	4.0
06/12/01	UV/Ozone	100	2.0	15.14	4.0
06/12/01	UV/Ozone	100	19	15.14	4.0

Only the selected runs (in blue color) are used to discuss the AOP plant performance under single pass with recirculation loop. Those runs are desirable because a comparison between them can be done. In addition, a small concentration of MTBE in the influent water and a lower turbidity are parameters expected for small community water. Therefore, only the data of those runs selected are included.

A12.2.1 Control Runs – Field AOP Plant Unit

<i>Date</i>	<i>Treatment</i>	<i>MTBE Target Concentration ($\mu\text{g/L}$)</i>	<i>Turbidity (NTU)</i>	<i>Influent Flowrate (L/min)</i>	<i>Influent Flowrate (gal/min)</i>
04/03/01	Control	50	0.5	9.46	2.5
04/17/01	Control	50	1.0	9.46	2.5
04/24/01	Control	50	2.0	9.46	2.5

Run: MTBE-SP-CTL-50PPB-040301
Date: 4/3/2001
Flow: 2.5 gpm
Water: Declorinated Potable Water
Turbidity: 0.5 ntu
MTBE: 50 ppb
Tech: Control

Time (minute)	Time (hh:mm)	Influent Flow (gpm)	Effluent Flow (gpm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
										inches Hg	SCFH	After Venturi	After UV			
0	12:05	2.5	2.2	8.12	0.34	13	5.14	0	-	-	-	-	-	RAW	47.4	0.0
5	12:10	2.5	2.2	8.50	0.22	13	5.14	0	-	-	-	-	-	-1	34.6	0.0
10	12:15	2.5	2.2	8.51	0.14	13	5.14	0	-	-	-	-	-	-4	39.2	0.0
15	12:20	2.5	2.2	8.49	0.15	13	5.14	0	-	-	-	-	-	-7	41.4	0.0
20	12:25	2.5	2.2	8.46	0.17	13	5.14	0	-	-	-	-	-	-10	39.4	0.0
25	12:30	2.5	2.1	8.44	0.26	13	4.83	0	-	-	-	-	-	-13	44.0	0.0
30	12:35	2.5	2.1	8.41	0.21	13	5.14	0	-	-	-	-	-	-16	44.0	0.0

Alkalinity (mg/L)	
-0 ALK	54.4
-15 ALK	56.0

TOC (mg/l)	
-0 TOC	0.94
-15 TOC	0.96

Electrical Usage (KWH)			
Before Purge	-	After Run	-
Before Run	-	After Purge	-

Run: MTBE-SP-CTL-50PPB-041701
Date: 4/17/2001
Flow: 2.5 gpm
Water: Declorinated Potable Water / Mill Creek
Turbidity: 1.0 ntu
MTBE: 50 ppb
Tech: Control

Time (minute)	Time (hh:mm)	Influent Flow (gpm)	Effluent Flow (gpm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
										inches Hg	SCFH	After Venturi	After UV			
0	14:35	2.5	2.2	8.48	1.20	21	4.83	0	-	-	-	-	-	RAW	32.2	0.0
5	14:40	2.5	2.3	8.51	1.18	20	5.46	0	-	-	-	-	-	-5	29.1	0.0
10	14:45	2.5	2.2	8.50	1.28	19	5.14	0	-	-	-	-	-	-10	30.7	0.0
15	14:50	2.5	2.2	8.53	1.06	19	5.46	0	-	-	-	-	-	-15	32.6	0.0
20	14:55	2.5	2.3	8.53	1.17	19	5.14	0	-	-	-	-	-	-20	36.2	0.0
25	15:00	2.5	2.2	8.56	0.99	19	5.14	0	-	-	-	-	-	-25	34.8	0.0
30	15:05	2.5	2.2	8.55	1.06	19	5.46	0	-	-	-	-	-	-30	33.6	0.0
35	15:10	*	*	8.52	1.18	*	*	*	-	-	-	-	-	-35	30.7	0.0

Alkalinity (mg/L)	
-0 ALK	60.0
-15 ALK	61.2

TOC (mg/l)	
-0 TOC	1.19
-15 TOC	1.18

Electrical Usage (KWH)			
Before Purge	-	After Run	-
Before Run	-	After Purge	-

Run: MTBE-SP-CTL-50PPB-042401
 Date: 4/24/2001
 Flow: 2.5 gpm
 Water: Dechlorinated Tap Water / Mill Creek
 Turbidity: 2 ntu
 MTBE: 50 ppb
 Tech: Control

Time (minute)	Time (hh:mm)	Influent Flow (gpm)	Effluent Flow (gpm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
										inches Hg	SCFH	After Venturi	After UV			
0	9:25	2.5	2.2	8.27	2.05	23	5.46	0	-	-	-	-	-	RAW	24.3	0.0
5	9:30	2.5	2.2	8.31	1.88	23	5.14	0	-	-	-	-	-	-5	18.0	0.0
10	9:35	2.5	2.2	8.45	1.72	23	5.14	0	-	-	-	-	-	-10	21.1	0.0
15	9:40	2.5	2.2	8.48	2.05	23	5.14	0	-	-	-	-	-	-15	20.9	0.0
20	9:45	2.5	2.2	8.46	1.76	23	4.83	0	-	-	-	-	-	-20	22.2	0.0
25	9:50	2.5	2.2	8.45	1.76	23	5.14	0	-	-	-	-	-	-25	22.5	0.0
30	9:55	2.5	3.5	8.48	1.86	23	5.14	0	-	-	-	-	-	-30	22.5	0.0
35	10:00	2.5	2.3	8.50	1.86	23	5.14	0	-	-	-	-	-	-35	22.9	0.0

Alkalinity (mg/l)	
-0 ALK	-
-15 ALK	-

TOC (mg/l)	
-0 TOC	1.41
-15 TOC	1.55

Electrical Usage (KWH)			
Before Purge	-	After Run	-
Before Run	-	After Purge	-

A12.2.2 UV/Ozone Runs – Field AOP Plant Unit

Date	Treatment	MTBE Target Concentration (µg/L)	Turbidity (NTU)	Influent Flowrate (L/min)	Influent Flowrate (gal/min)
04/03/01	UV/Ozone	50	0.5	9.46	2.5
04/16/01	UV/Ozone	50	1.0	9.46	2.5
04/23/01	UV/Ozone	50	2.0	9.46	2.5

Run: MTBE-SP-UVOZ-50PPB-040301
 Date: 4/3/2001
 Flow: 2.5 gpm
 Water: Dechlorinated Potable Water
 Turbidity: 0.5 ntu
 MTBE: 50 ppb
 Tech: UV/OZ

Time (minute)	Time (hh:mm)	Influent Flow (gpm)	Effluent Flow (gpm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
										inches Hg	SCFH	After Venturi	After UV			
0	15:05	2.5	2.2	8.39	1.83	14	5.46	0	*	-6.00	2.00	0.29	*	RAW	45.5	0.0
5	15:10	2.5	2.4	8.40	0.19	14	5.46	0	*	-8.00	2.00	0.31	0.00	-1	19.6	2.2
10	15:15	2.5	2.5	8.31	0.15	13	5.46	0	*	-8.00	2.00	0.27	0.00	-4	20.3	2.4
15	15:20	2.5	2.5	8.37	0.16	13	5.46	0	*	-8.00	2.00	0.32	0.00	-7	21.1	2.4
20	15:25	2.5	2.5	8.39	0.18	13	5.14	0	*	-8.00	2.00	0.31	0.00	-10	22.9	2.5
25	15:30	2.5	2.5	8.30	0.31	13	5.46	0	*	-8.00	2.00	0.31	0.00	-13	21.4	2.5
30	15:35	2.5	2.5	8.37	0.25	13	5.14	0	*	-8.00	2.00	0.30	0.01	-16	20.9	2.4

Alkalinity (mg/l)	
-0 ALK	55.2
-15 ALK	55.2

TOC (mg/l)	
-0 TOC	0.98
-15 TOC	0.96

Electrical Usage (KWH)			
Before Purge	-	After Run	-
Before Run	-	After Purge	-

Run: MTBE-SP-UVOZ-50PPB-041601
Date: 4/16/2001
Flow: 2.5 gpm
Water: Dechlorinated Potable Water / Mill Creek
Turbidity: 1.0 ntu
MTBE: 50 ppb
Tech: UV/OZ

Time (minute)	Time (hh:mm)	Influent Flow (gpm)	Effluent Flow (gpm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
										inches Hg	SCFH	After Venturi	After UV			
0	15:20	2.5	2.2	8.43	1.01	22	5.14	0	0*	-6.00	-	0.21	-	RAW	47.0	0.0
5	15:25	2.5	2.2	-	*	23	4.83	0	1.00	-10.00	-	-0.01	*	-5	39.4	6.1
20	15:40	2.5	2.3	8.28	1.11	23	5.79	0	1.00	-8.00	2.00	0.19	-0.01	-20	34.6	7.6
25	15:45	2.5	2.2	8.33	0.91	23	6.10	0	1.00	-8.00	2.00	0.20	0.02	-25	29.6	7.4
30	15:50	2.5	2.3	8.50	0.89	23	5.79	0	1.00	-8.00	2.00	0.16	0.00	-30	30.9	8.2
35	15:55	2.5	2.3	8.33	0.93	23	5.79	0	1.00	-8.00	1.00	0.16	0.00	-35	31.6	8.5
40	16:00	2.5	2.4	8.34	0.91	23	5.79	0	1.00	-8.00	1.00	0.15	0.01	-40	-	-
45	16:05	2.5	*	8.41	0.98	*	*	*	*	*	*	*	*	-45	45.1	0.0

Alkalinity (mg/l)	
-0 ALK	61.6
-15 ALK	61.6

TOC (mg/l)	
-0 TOC	1.34
-15 TOC	1.34

Electrical Usage (KWH)			
Before Purge	-	After Run	-
Before Run	-	After Purge	-

Run: MTBE-SP-UVOZ-50PPB-042301
Date: 4/23/2001
Flow: 2.5 gpm
Water: Dechlorinated Tap Water / Mill Creek
Turbidity: 2 ntu
MTBE: 50 ppb
Tech: UV/OZ

Time (minute)	Time (hh:mm)	Influent Flow (gpm)	Effluent Flow (gpm)	pH (s.u.)	Turbidity (ntu)	Temp. (°C)	Recirc. Rate (gpm)	Pressure (psi)	UV Intensity (scale of 1.00)	Ozone Readings		Ozone (mg/l)		Sample Number	MTBE Conc. (ppb)	TBF Conc. (ppb)
										inches Hg	SCFH	After Venturi	After UV			
0	11:01	2.5	2.3	8.33	3.67	21	5.79	0	0.90	-6.00	2.00	0.27	-	RAW	27.7	0.0
5	11:06	2.5	2.2	8.43	1.78	21	5.46	0	0.90	-6.00	2.00	0.25	0.00	-5	17.3	6.9
10	11:11	2.5	2.3	8.48	1.88	21	5.46	0	0.95	-8.00	2.00	0.12	0.00	-10	17.0	6.2
15	11:16	2.5	2.2	8.50	1.98	21	5.46	0	0.95	-8.00	2.00	0.08	-0.01	-15	19.5	5.0
20	11:21	2.5	2.3	8.50	1.95	21	5.46	0	0.95	-8.00	2.00	0.09	-0.01	-20	22.4	4.6
25	11:26	2.5	2.3	8.51	1.93	21	5.46	0	0.95	-8.00	2.00	0.08	-0.01	-25	25.1	0.0
30	11:31	2.5	2.2	8.52	1.86	21	5.46	0	0.95	-8.00	2.00	0.07	-0.02	-30	23.7	0.0
35	11:36	2.5	2.2	8.55	1.97	21	5.46	0	0.95	-8.00	2.00	*	*	-35	29.6	0.0

Alkalinity (mg/l)	
-0 ALK	-
-15 ALK	-

TOC (mg/l)	
-0 TOC	1.43
-15 TOC	1.46

Electrical Usage (KWH)			
Before Purge	-	After Run	-
Before Run	-	After Purge	-