Evaluation of Ozone and Peroxone for Water Quality Enhancement at the Del Valle and Patterson Pass Water Treatment Plants

Project Report

Prepared for

Zone 7 of Alameda County Flood Control
and Water Conservation District

October 16, 2009

WQTS
Water Quality and Treatment Solutions, Inc.
An environmental engineering and science consulting company.

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PREPARED FOR:

ZONE 7 OF ALAMEDA COUNTY FLOOD CONTROL
AND WATER CONSERVATION DISTRICT

PREPARED BY:

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EXECUTIVE SUMMARY

Zone 7 of Alameda County Flood Control and Water Conservation District (Zone 7) serves drinking water to the cities of Pleasanton, Livermore, and Dublin. Zone 7's main water source is the Sacramento-San Joaquin Delta delivered via the South Bay Aqueduct (SBA). The water is treated at two surface water treatment plants; the Patterson Pass Water Treatment Plant (PPWTP) and the Del Valle Water Treatment Plant (DVWTP). Two other water agencies also draw water from the SBA: the Alameda County Water District (ACWD) and the Santa Clara Valley Water District (SCVWD).

SBA water commonly contains chemicals that impart objectionable taste and odor (T&O) into the water. These chemicals are produced by algae growing in the water, mostly during the summer and early fall. While algae can produce many chemicals, the primary T&O-related ones in SBA water are geosmin and 2-methylisoborneol (MIB). These chemicals have no known adverse health effects, but they are easily detected by customers at low nanogram per liter (ng/L) levels, resulting in customer complaints about the quality of their drinking water. In 2003, the Zone 7 Board of Directors adopted the *Zone 7 Water Quality Policy, Goals, and Targets*, which included a target of "no events" for earthy/musty T&O, where an event is defined as three or more complaints over a seven-day period. The document also included targets of no more than 9 ng/L of MIB and 4 ng/L of geosmin in the drinking water served to Zone 7's customers.

To address the T&O challenge, Zone 7 has relied on the addition of powdered activated carbon (PAC) at both plants. PAC is effective, but is difficult to handle and is more expensive than most water treatment chemicals. The high PAC doses needed to effectively remove MIB and geosmin also generate large volumes of sludge and can adversely affect plant performance. An alternatives analysis conducted by Zone 7 concluded that PAC can only be used as a short-term solution to the T&O problem, with ozone addition being the reliable long term solution. Ozone is used by ACWD and SCVWD, as well as numerous other California water agencies to destroy chemicals that cause T&O in drinking water.

Historical data indicate that the occurrence of geosmin and MIB in SBA water is seasonal and highly variable. Data analysis shows that MIB levels in SBA water exceed the Zone 7 goal of 9 ng/L approximately one to two months per year, while the geosmin levels exceed the goal of 4 ng/L approximately five (5) months of the year. The maximum geosmin and MIB levels recorded by DWR in SBA water from 2001 to 2007 were 17 ng/L and greater than 50 ng/L, respectively. If Zone 7 were to meet its goals 99% of the time, then the last six years of data suggest that the new T&O treatment process should achieve greater than 73% removal of geosmin and greater than 71% removal of MIB. Since MIB is more difficult to remove with ozone than geosmin, then the MIB removal requirement is expected to set the process design requirements. For the purpose of this project, the ozone process will be evaluated with the goal of achieving no less than 71% destruction of MIB.

OZONE APPLICATION IN DRINKING WATER TREATMENT

For decades, ozone has been used to disinfect drinking water and to destroy T&O chemicals and other micropollutants that may be present in water. In California, many agencies that draw water from the State Water Project (SWP) system use ozone for meeting the disinfection requirement as well as improving the overall aesthetic quality of their drinking water. In Northern California, the list of agencies that use ozone for water treatment includes the following:

- Alameda County Water District
- Santa Clara Valley Water District
- Contra Costa Water District
- San Francisco Public Utilities Commission
- East Bay Municipal Utilities District
- City of Vallejo
- Cities of Vacaville & Fairfield
- City of Napa
- City of Martinez

The downside to ozone use for water treatment is twofold: First, it is an expensive process to construct and operate. Second, when ozone is added to water containing elevated levels of bromide, it could generate bromate (BrO_3^-) above the maximum contaminant level (MCL) of 10 µg/L. SBA water used by Zone 7 frequently contains elevated bromide levels. In fact, an analysis of historical water quality data indicated that the 50th percentile bromide level in SBA water between 1993 and 2007 was 100 µg/L, while the 90th percentile was 290 µg/L. The maximum bromide concentration was recorded at >500 µg/L. At the typical ozone doses applied in drinking water treatment, bromide concentrations above 100 µg/L will result in bromate formation above the MCL unless a bromate control strategy is implemented in conjunction with ozone application.

OZONE VS. PEROXONE

Two configurations of an ozone system can be used for T&O control. The first is a conventional configuration where ozone is added into the water as it flows through a multi-chamber, over-under contactor with an average contact time of about 8 to 10 minutes. This contact time is required to give the ozone sufficient time to react with the target contaminants. This configuration is referred to in this report as Conventional Ozone. All the agencies listed above utilize conventional ozone contactors. This type of ozonation serves two purposes: destruction of T&O compounds and disinfection of microorganisms. The other configuration is a process in which ozone and hydrogen peroxide are added to the water. The combination of ozone and hydrogen peroxide generates hydroxyl radicals ($OH^\bullet$), which are stronger oxidants than ozone itself and require much shorter contact time to achieve T&O destruction. This process is referred to in this report as the Peroxone process. Due to the fast reaction time, a Peroxone process requires a significantly smaller contactor (2 to 4 minutes) compared to conventional ozone (8 to 10 minutes), and in some cases requires a lower ozone dose to meet the same T&O destruction goals. However, because of its short contact time, and the fact that the added hydrogen peroxide rapidly destroys the ozone residual, it cannot be used for disinfection of microorganisms. Therefore, if Peroxone is implemented at Zone 7's treatment plants, disinfection requirements must continue to be met with chlorine. None of the agencies listed above utilize Peroxone, although some were designed to be able to do so.

OVERALL PROJECT DESCRIPTION

This project assessed whether ozone or Peroxone should be implemented at the Zone 7 treatment plants, and identified the practical and financial implications of the implementation of either process. The specific activities included the following:

1. Conduct pilot-scale testing of ozone vs. Peroxone to determine the design criteria required by each process to meet Zone 7's T&O goals.
2. Using the results of the pilot testing, determine whether the ozone-based T&O process should be applied to the raw water, settled water, or filtered water.
3. Develop the design criteria, hydraulic requirements, and general layouts of an ozone or Peroxone process at each plant.
4. Develop probable costs for constructing and operating either process at each plant.
5. Identify the permitting requirements for implementing either process at each plant.
6. Identify the impact of implementing either ozone or Peroxone on the operation of each of Zone 7's water treatment plants.

A significant portion of this project was dedicated to the pilot testing effort. If conventional ozone were the only process being considered, pilot testing would not have been required since there is ample experience with ozone for the treatment of SBA water. However, since Zone 7's primary reason for the ozone process is T&O destruction and not disinfection, there was a reasonable expectation that the implementation of Peroxone instead of conventional ozone could result in a T&O control process that is less costly to build and operate. Unfortunately, there is little to no full-scale experience with the design and operation of a Peroxone process for drinking water treatment. In order to quantify the expected cost savings of a Peroxone process over a conventional ozone process, and to determine its design and operational requirements, it was necessary to conduct side-by-side pilot testing of the two processes.

PILOT PLANT CONFIGURATION & TESTING PLAN

The pilot plant was installed at the Del Valle WTP in Livermore and operated from May to October 2008. The pilot plant consisted of two parallel trains: a five-chamber conventional ozone contactor with a hydraulic residence time (HRT) of 10 minutes at a flowrate of 6.5 gpm, and a pipeline Peroxone contactor with an HRT of 2.6 minutes at a flowrate of 3.5 gpm. The pilot plant could be supplied with either raw water or settled water.

The ozone or Peroxone process could be inserted at the raw, settled, or filtered water locations at the Del Valle WTP, or at the raw or filtered water locations at the Patterson Pass WTP. In order to determine the best application point, information had to be gathered regarding the performance of each technology at each location, and its impact on downstream processes. Since chlorine is added upstream of the full-scale filters at DVWTP, it was not possible to obtained unchlorinated filtered water for pilot testing. For the purposes of this project, the settled water ozone performance results were assumed to apply to ozonation of filtered water.

Based on historical data, a T&O event is most likely to occur during summer/fall testing period. In order to gather sufficient data for the full-scale application, three rounds of challenge testing were conducted (June, August, and October). Each round took approximately two weeks to complete. During each round, tests were conducted to evaluate MIB and geosmin destruction with ozone and Peroxone under varying conditions of ozone dose, water pH, contact time, water source (raw or settled), chloramine addition for bromate control, and Peroxone ratio (which is the ratio of hydrogen peroxide dose to ozone dose). MIB and geosmin were spiked into the feed water to both contactors to simulate a T&O event.

In between the three rounds of challenge testing, operational stability testing was conducted to evaluate general operational requirements and limitations of each unit process when treating SBA water. These tests were designed to address issues related to the diurnal fluctuations in water quality, primarily pH and temperature, as well as the stability of the ozone residual in a conventional ozone contactor versus a pipeline Peroxone contactor.

Additional testing was done to evaluate the formation of various byproducts. Samples were collected from the contactor influent and effluent streams for Simulated Distribution System (SDS) disinfection by-product (DBP) formation testing. These tests were conducted to evaluate the impact of either ozone or Peroxone on the formation of THMs and HAAs upon subsequent chlorination. Samples were also collected for Assimilable Organic Carbon (AOC) from both processes as a measure of the amount of biodegradable organic matter created by each process. And finally, tests were performed to evaluate the expected levels of "emerging byproducts" by each process such as iodinated DBPs.

PILOT TESTING RESULTS

A large volume of data was collected from the pilot testing effort. The results provided great insight into the design, operation, and performance of the ozone and Peroxone processes for T&O destruction. Based on the results obtained and discussed in this report, the following observations and conclusions are made:

T&O Destruction in Raw Water

MIB and geosmin destruction testing in raw water was conducted at different pH levels and with or without prechloramine addition for bromate control. The following observations are based on the raw water testing results:

1. When applied to raw water without prechloramine addition, the ozone dose required to meet the MIB and geosmin destruction goals in the Peroxone process ranged from 1.2 to 1.5 mg/L, while that required in the conventional ozone process ranged from 2.0 to 2.5 mg/L. However, when prechloramine was added to the raw water for bromate control, the Peroxone process advantage greatly decreased, and the ozone dose required for both processes was approximately the same (2 to 2.5 mg/L). This suggests that chloramine may react with the hydroxyl radicals formed in the Peroxone process, reducing the overall process efficiency.
2. With bromide spiked to above 400 µg/L under most conditions, bromate formation without prechloramine addition was much higher than the MCL of 10 µg/L, even at the reduced pH of 6.5. The addition of prechloramine ahead of either process greatly reduced bromate formation. Nevertheless, under high bromide conditions, prechloramine must be combined with pH suppression to 7.5 or lower.
3. With the ozone doses required to meet the MIB and geosmin destruction goals, the ozone residual leaving the 10-minute conventional ozone contactor ranged from <0.05 mg/L to as high as 0.5 mg/L. On the other hand, the ozone residual in the water leaving the 2.6-minute Peroxone contactor were predominantly below 0.1 mg/L. For operator safety reasons, it is important that the ozone residual in the water exiting the contactor does not exceed 0.1 mg/L. This suggests that the conventional ozone contactor

operated to achieve high removals of MIB and geosmin will likely require the addition of an ozone-quenching chemical, such as calcium thiosulfate, in the last chamber of the contactor.

In summary, the raw water testing results showed that the addition of prechloramine for bromate control is necessary, but the added chloramine greatly reduced the advantage of the Peroxone process over the ozone process.

T&O Destruction in Settled Water

As was done with the raw water, MIB and geosmin destruction testing in settled water was conducted at different pH levels and with or without prechloramine addition for bromate control. The following are important observations made based on the settled water testing results:

1. The ozone dose needed for T&O destruction in settled water at pH 6.6 or 6.0 using conventional ozonation was very high. Under both pH conditions, a projected ozone dose of up to 4.5 mg/L could not achieve the target MIB destruction goal of 71% (this dose was projected from the MIB destruction curve). The Peroxone process was able to achieve the required T&O destruction in settled water at a reasonable ozone dose range of 1.2 to 2.1 mg/L. However, similar to the raw water results, prechloramine addition caused a slight deterioration in the T&O-destruction efficiency of the Peroxone process.
2. Without prechloramine addition, the bromate level formed in the ozone or Peroxone process was well above the MCL of 10 µg/L, even though the pH was at or below 6.6. The addition of prechloramine to the Peroxone process at pH 6.6 reduced bromate formation to a range of 9 to 10 µg/L.
3. Under all conditions tested, the ozone doses required for T&O destruction in settled water resulted in ozone residual levels in the effluent of each contactor that were well above the maximum desirable level of 0.1 mg/L. Therefore, an ozone residual quenching chemical would be required if either ozone or Peroxone is applied to the settled water.

In summary, the settled water testing results showed that only the Peroxone process is capable of meeting the T&O destruction goals, but that prechloramine addition is still required for bromate control, and a quenching chemical is required to destroy the high ozone residual leaving the contactor.

Operational Stability Testing

A significant portion of the operational stability testing focused on the impact of diurnal changes in raw water pH on the stability of the ozone or Peroxone process. In a single 24-hr cycle, the pH of the SBA water increase from a low of approximately 7.5 during the early morning hours to a high of 8.5 to 9.0 during the afternoon hours. The testing results demonstrated the strong impact of these diurnal changes on the ozone demand of the water. At low water pH, the ozone dose required to achieve a specific residual is much lower than the dose required at higher pH. Therefore, if a specific ozone residual is required at any point in the contactor, then the ozone control system much constantly increase and decrease the ozone dose to account for the variation in pH. However, a better approach is to utilize acid addition (e.g., carbon dioxide) to temper the pH fluctuations and maintain a relatively constant pH entering the ozone contactor. This would greatly stabilize the operation of the ozone system, as well as contribute to bromate control. This type of pH stabilization and resulting consistency of ozone residual was demonstrated during the testing period.

The Need for Biofiltration

The vast majority of ozone plants utilize biofiltration downstream of the ozone process. The reason is that ozone breaks down the natural organic matter present in all waters into smaller, more biodegradable, organic molecules. There is concern that the introduction of higher biodegradable organic matter into the distribution system will result in higher potential for bacterial growth. One way to reduce the amount of biodegradable matter is to remove it with biofiltration at the treatment plant. Biofiltration has been shown to be very effective at removing biodegradable organic matter. One way of quantifying the amount of biodegradable organic matter is using the Assimilable Organic Carbon (AOC) measurement. There are no public health concerns associated with the presence of biodegradable organic matter or AOC in drinking water, and therefore, they have no numerical limits.

Biofiltration was not evaluated in this project. However, AOC measurements were made in the effluent of the ozone and Peroxone contactors, and compared to the AOC levels in the raw water and treated water from the Del Valle WTP. For example, on June 1, 2008, the AOC level in the raw water at the DVWTP was measured at 37 µg/L, while that in the treated water from the plant was 151 µg/L. This increase is due to the use of chlorine at the plant. However, with the addition of 1.8 mg/L ozone to the raw water, the AOC level increased to 420 µg/L in the effluent of both the ozone and Peroxone processes. This is more than a 3-fold increase in AOC formation through the treatment plant. Similarly, upon ozonation of settled water, the AOC level increased from approximately 125 µg/L in the DVWTP effluent to a range of 220 to 420 µg/L in the water treated by either ozone or Peroxone.

Unfortunately, there is no specific AOC value that is used to gauge the need for biofiltration. However, based on the results obtained, and the desire to minimize the potential for additional bacterial growth in the distribution system, it is recommended that biofiltration be implemented in conjunction with either ozone or Peroxone.

Impact on the Formation of THMs, HAAs, and other DBPs

Simulated distribution system (SDS) testing was conducted to evaluate the potential impact of ozone and Peroxone on the downstream of formation of disinfection by-products (DBPs) after chlorine addition. SDS samples were collected from the raw water, raw water treated with ozone, and raw water treated with Peroxone. Each sample was dosed with chlorine for a one (1) hour contact time, and then dosed with ammonia to form chloramine. After exposure to chloramine for 24 hrs, the samples were analyzed for trihalomethanes (THMs) and haloacetic acids (HAAs). Similar tests were conducted with settled water, settled water treated with ozone and settled water treated with Peroxone.

The results showed that the DBPs formed in the chloraminated waters treated with ozone or Peroxone were consistently lower than those formed in the non-ozonated chloraminated water. In some cases, the reduction in THM and HAA formation was as high as 30%. DBP reduction at the full-scale treatment plant is expected to be greater because the free chlorine contact time will be shorter than one (1) hour. These results suggest that the implementation of ozone or Peroxone should greatly reduce the levels of THMs and HAAs in Zone 7's water distribution system.

While not initially planned, additional testing was conducted to address concerns over the potential formation of non-regulated DBPs. These DBPs included six iodinated THMs (I-THMs) and nine halonitromethanes (HNMs). Samples were collected from the raw water, current DVWTP effluent, and effluents of the ozone and Peroxone contactors treating raw or settled waters under various conditions. The samples were sent to Clemson University, South Carolina, for I-THM and HNM analysis. The results indicate that the I-THM and HNM levels formed with ozone or Peroxone implementation are expected to be equal to or lower than those formed under the current DVWTP treatment train. In general, the I-THM levels ranged from <0.5 µg/L to 2.3 µg/L, while the HNM levels ranged from 0.7 µg/L to 1.9 µg/L. Based on the results obtained, the utilization of ozone or Peroxone treatment at DVWP and PPWTP is not expected to increase the I-THM or HNM levels beyond the background levels currently formed at DVWTP.

SHORT-LISTED ALTERNATIVES

At the beginning of this project, there were six alternative configurations of the ozone-based T&O destruction process: 1) raw water ozone, 2) raw water Peroxone, 3) Settled water ozone, 4) Settled water Peroxone, 5) filtered water ozone, and 6) filtered water Peroxone. Due to the need for post-ozone biofiltration, the filtered water application point was ruled out. Based on the results of the pilot testing effort, the application of ozone or Peroxone to the settled water was eliminated from consideration for a number of reasons including the following:

1. With T&O destruction as the primary goal, the pilot testing results showed that conventional ozonation of the settled water could not meet the minimum MIB and geosmin destruction goals of >71% and >73%, respectively, with a dose as high as 4.5 mg/L. It was not apparent what dose, if any, would be able to meet these goals in the settled water within the 10 minute contactor. Therefore, only the Peroxone alternatives remain viable for the settled-water.
2. For settled-water application, the ozone residuals in the effluent of the 2.6-minute Peroxone contactor were consistently too high. This would mandate that either the contactor needs to be much larger (e.g., 10 minute HRT), or a separate ozone-quenching chemical would need to be added to destroy the ozone residual before the water exits the contactor. However, since the reaction between the quenching chemical and the ozone residual is not instantaneous, additional contact time would need to be provided after the quenching chemical addition. This would translate into a larger overall contactor.
3. Installing ozone or Peroxone anywhere other than the raw water at PPWTP is problematic because settled water ozonation is not possible on the membrane train due to the potential damaging effect of ozone or peroxide residual on the membranes. For the membrane train, the only viable locations are either raw-water ozonation or filtered-water ozonation. Filtered-water ozonation is problematic because ozone would be added downstream of any possible biofiltration using existing filters. Since biofiltration for AOC removal has been deemed necessary, filtered-water ozonation is not a viable option. This leaves raw-water ozonation at PPWTP as the only viable option.
4. Raw water ozonation has been shown by many water agencies to greatly improve the performance of the downstream chemical coagulation, flocculation, sedimentation, and filtration processes. These benefits would be greatly reduced with settled-water ozonation.

Therefore only raw water application of ozone or Peroxone was considered to be viable options for Zone 7's water treatment plants. As for the choice between ozone or Peroxone, the pilot testing results did not provide sufficient information for a clear selection. Each process had its advantages and disadvantages compared to the other. While the smaller Peroxone process would be expected to cost less to construct than the larger ozone process, the differences in ozone dose required was not as great as originally expected. In addition, the ability to satisfy the disinfection requirements of the Surface Water Treatment Rule with ozone but not with Peroxone gave a number of advantages to the conventional ozone process. Specifically, the need for biofiltration after ozone or Peroxone meant that chlorine addition would need to be moved downstream of the existing media filters. If Peroxone is used, then a new chlorine contactor would need to be constructed after filtration to meet the disinfection CT requirements. Such a contactor would not be needed under the ozone option since the CT requirements would be met through the ozone process. In addition, without a long free chlorine contact time, implementation of the ozone process would significantly reduce the levels of THMs and HAAs formed in the distribution system.

Due to the lack of a clear advantage of one process over the other, it was decided that both raw water ozone and Peroxone would be further evaluated, and that the cost of both processes would be estimated before a selection between the two processes is made.

FULL-SCALE DESIGN CRITERIA, LAYOUTS, & HYDRAULIC CONSTRAINTS

A careful analysis was conducted to identify the required modifications at both plants under the raw water ozone or raw water Peroxone option. Figures ES-1 and ES-2 include schematics of the required modifications at the DVWTP and PPWTP, respectively.

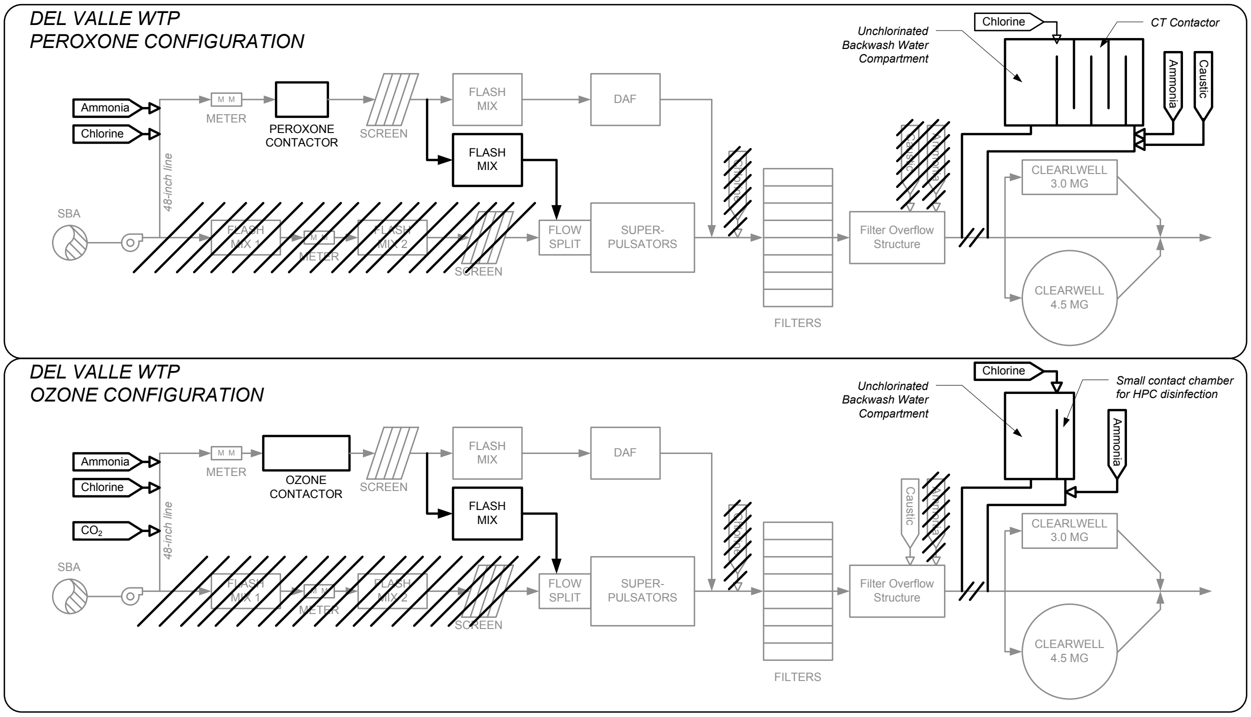

Figure ES-1 – Process Flow Diagrams for the Modified Del Valle WTP

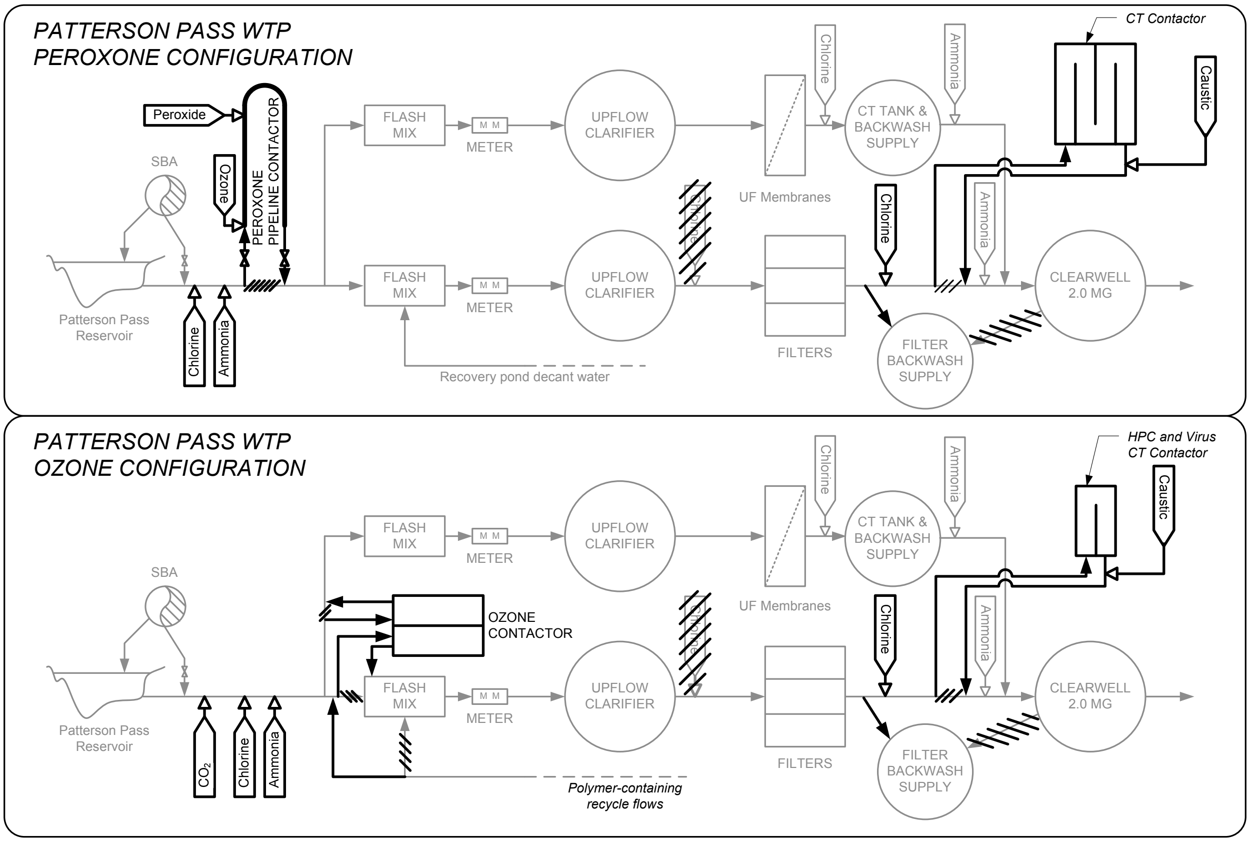

Figure ES-2 – Process Flow Diagrams for the Modified Patterson Pass WTP

As shown in Figures ES-1 and ES-2, implementing either ozone or Peroxone at DVWTP or PPWTP will require specific modifications and additions to each plant. For each plant, some modifications will need to be implemented with either technology, while some modifications are specific to just one technology. The following is a summary of the required modifications.

Required Modifications at the Del Valle Water Treatment Plant

The following modifications are required for the implementation of <u>either ozone or Peroxone</u> at the DVWTP:

1. Eliminate raw water pipe currently used to feed the Superpulsator® train, and feed the entire plant through the 48-inch diameter pipe currently feeding the DAF train. The existing influent meter station/vault will also be eliminated.
2. Retain the mechanical screen on the 48-inch diameter line.
3. Construct a new 48-inch line from the mechanical screen to the Superpulsator flow splitter box, and add a new flash mix on this line to allow for independent chemical treatment of the Superpulsator® train and the DAF Train.

4. Install new flowmeters on the DAF and Superpulsator® train feed pipes downstream of the mechanical screen.
5. Replace the existing 36-inch line between the raw water pumps and the 48-inch pipe with a 48-inch section.
6. Add a two-compartment tank in between the filtered water overflow structure and the clearwells. The first compartment will store unchlorinated backwash water source, and the second compartment will serve as a disinfection contact chamber.
7. Add a Liquid Oxygen (LOX) storage and feed system.
8. Add an air-scour system to supplement the water backwash system for the biofilters.

The following required modifications are specific to the implementation of ozone at DVWTP:

1. Add a CO_2 storage and feed system for raw water pH suppression.
2. Construct a multi-chamber ozone contactor
3. Construct an ozone-generation building containing three ozone generators and their ancillary equipment.

The following required modifications are specific to the implementation of Peroxone at DVWTP:

1. Construct a Peroxone contactor
2. Construct an ozone generation building containing two ozone generators and their ancillary equipment.
3. Add a hydrogen peroxide (H_2O_2) storage and feed system.

Required Modifications at the Patterson Pass Water Treatment Plant

The following modifications are required for the implementation of either ozone or Peroxone at the PPWTP:

1. Re-route the return washwater line (return flows without residual polymer) to a point in the raw water pipe upstream of the ozone or Peroxone process.
2. Add a LOX storage and feed system.
3. Add an air-scour system to supplement the water backwash system for the biofilters.
4. Re-plumb existing backwash water pump to draw from un-chlorinated filtered water to fill backwash water supply tank.
5. Possibly add new potable water supply, as it currently comes from backwash tank supply line.

The following required modifications are specific to the implementation of ozone at PPWTP:

1. Add a liquid CO_2 storage and feed system for raw water pH suppression.
2. Construct a dual-train ozone contactor with one train configured to serve the UF plant and one train configured to serve the conventional train.

3. Relocate the rapid mix of the UF train to a new location between the ozone contactor and the UF clarifier.
4. Relocate the return line of the pond decant to a location upstream of the conventional train ozone contactor.
5. Construct an ozone generation building containing three ozone generators and their ancillary equipment.

The following required modifications are specific to the implementation of Peroxone at PPWTP:

1. Construct a Peroxone pipeline contactor.
2. Construct an ozone generation building containing two ozone generators and their ancillary equipment.
3. Add a hydrogen peroxide (H_2O_2) storage and feed system.

OPINION OF PROBABLE COSTS

A planning level opinion of probable capital and annual O&M costs was developed for the application of ozone or Peroxone at DVWTP and PPWTP. The outcome of the analysis is presented in Table ES-1 below. It is noted that the ozone system was assumed to operate 365 days a year, while the Peroxone system was assumed to operate only 180 days each year, which is the anticipated maximum duration of the T&O season. The analysis demonstrated that the probable costs of implementing ozone and Peroxone at either plant are well within the accuracy of the cost projection. The total probable capital cost of implementing an ozone-based T&O control strategy at Zone 7's two treatment plants is projected at $33M, with the probable annual operating cost projected at $2.3 M/yr (both are in 2009 dollars). The average total probable annualized cost (capital and O&M) is projected at $5.3 M/yr. Using the annual Zone 7 water production in 2008 (45,216 AF), the impact of adding ozone or Peroxone at both plants is projected at $116/AF of total water produced.

Table ES-1 – Summary of Projected Probable Costs (2009 Dollars) of Implementing Ozone or Peroxone at DVWTP and PPWTP

Item	Del Valle WTP			Patterson Pass WTP			Probable Total
	Ozone	Peroxone	Average	Ozone	Peroxone	Average	
Capital Cost	$20.6 M	$20.0 M	$20.3 M	$13.3 M	$12.4 M	$12.9 M	**$33 M**
Amortized Capital Cost	$1.8 M/yr	$1.7 M/yr	$1.8 M/yr	$1.2 M/yr	$1.1 M/yr	$1.2 M/yr	**$3.0 M/yr**
Annual Operating Cost	$1.5 M/yr	$1.3 M/yr	$1.4 M/yr	$1.0 M/yr	$0.9 M/yr	$0.9 M/yr	**$2.3 M/yr**
Total Annual Cost	$3.3 M/yr	$3.0 M/yr	$3.2 M/yr	$2.2 M/yr	$2.0M/yr	$2.1 M/yr	**$5.3 M/yr**
Water Cost(1)	$73 /AF	$66 /AF	$70 /AF	$49 /AF	$44 /AF	$46 /AF	**$116 /AF**

(1) Based on 2008 total water production of 45,216 AF.

PROJECT SCHEDULE

The engineering portion of the project is expected to require 24 months from the selection of an engineering design firm, to selection of a construction contractor. Construction and startup activities are also expected to required 24 months. The exact start date for the project is not known at this time. However, based on an arbitrary start date of January 1, 2012, the ozone systems could be in operation by January 2016, a total of four years from start of design.

POTENTIAL IMPACT ON WTP OPERATIONS

The implementation of ozone or Peroxone at both plants is expected to result in improvements in the overall performance, and require changes in the current operations and maintenance practices at the plants. Specifically, the following impacts and changes are anticipated:

1. Pre-oxidation with either ozone or Peroxone is expected to result in lower filtered water turbidity and particle counts.
2. Pre-oxidation with ozone or Peroxone is also expected to significantly lower the ferric chloride coagulant dose required and the resulting sludge volume generated. The decrease in ferric chloride dose will also reduce the caustic soda dose required to raise the pH of the filtered water.
3. The need for biological filtration will require moving the chlorine addition point to a location downstream of the filters. This should not have an impact on the turbidity of the filtered water, but careful attention must be given to the selection of the appropriate filter aid polymer type and dose.
4. If conventional ozonation is implemented, the actual disinfection credit will change from the current value achieved with free chlorine. While the minimum requirements will always be met, the actual CT ratio during normal operation may be lower than the current values as plant operations will be set to minimize ozone usage.
5. Regardless of which option is implemented, the THM and HAA levels will be lower than those currently experienced at both plants.
6. If conventional ozone is implemented, the THM and HAA levels generated will be significantly lower than those generated under the Peroxone option. The reason is that under the Peroxone option, the disinfection requirements will still be met with free chlorine, while disinfection will be met with ozone under the conventional ozone option.
7. Implementing either ozone or Peroxone is expected to greatly improve the aesthetic quality of the water produced at both plants, including taste, odor, and color.
8. The Operations Plans for both plants will need to be updated with new Standard Operating Procedures (SOPs) pertaining to the various components of the ozone or Peroxone system.
9. A new disinfection sampling plan and calculation methodology will be needed, along with a new monthly report format.
10. Because both ozone and Peroxone will generate bromate, it will be important to monitor this regulated ozone by-product closely. When using ozone or Peroxone, monthly monitoring of

bromate is required, and the MCL of 10 µg/L must be complied with on a rolling 12-month average of monthly sampling results.

11. Additional online analyzers will be added with either ozone or Peroxone. These include ozone residual analyzers, as well as gas-phase ozone monitors.
12. Finally, implementing ozone or Peroxone at DVWTP and PPWTP will require staff additions. Specifically, one operator, one mechanic, one electrician, and one instrument technician should be added for both plants (i.e., half-time at each plant).

RECOMMENDED TECHNOLOGY

Based on the pilot testing results and all the analysis conducted in this effort, WQTS recommends that raw-water conventional ozonation be implemented at DVWTP and PPWTP. WQTS recommendation is primarily anchored in the following observations:

Cost – The primary reason for considering the Peroxone process was the belief that it is far less costly to construct and operate compared to a conventional ozone process. In the final analysis, these significant cost savings did not materialize, with the difference in the capital and O&M costs between the two processes being well within the uncertainty of the cost-estimating effort. While the cost of constructing a small Peroxone contactor is certainly less than that of a larger conventional contactor, a new filtered-water chlorine contactor is required under the Peroxone option, but not under the conventional ozone option. In addition, under some testing conditions, the ozone dose required for Peroxone was the same as that required under the conventional ozone option. This meant that the ozone generation system under the Peroxone option had to be designed to deliver the same dose as that under the ozone option. From an operational cost perspective, it was assumed that the Peroxone system will be operated only six (6) months each year, while the ozone system will be operated continuously (since it is the primary disinfection process). Even under this assumption, the annual O&M costs of the two technologies were similar.

Experience – To our knowledge, all California water agencies that use ozone utilize a conventional ozone system design. It is noted that disinfection, not T&O destruction, has been the primary goal of most other agencies. The experience gained by these agencies, which includes the two other SBA water users, ACWD and SCVWD, in the operation and troubleshooting of the conventional ozone system will help make the transition to ozone a smooth one. On the other hand, there is no known large-scale Peroxone process in operation at a surface water treatment plant. This lack of full-scale experience with the operation of this process means that Zone 7 staff would need to go through a long "learning curve" before they can comfortably operate the process.

Ease of Operation – In the operation of water treatment processes, there is always a benefit to a process that provides the operator with sufficient time to respond to operational upsets without compromising the overall treated water quality and water production. For example, large sedimentation basins in conventional treatment plants are more tolerant of sudden changes in water quality or interruptions in upstream chemical feeds compared to compact clarification processes. The same applies to a 10-minute conventional ozone process compared to a 2-minute or 3-minute Peroxone process. With such a short contact time, interruptions in the hydrogen peroxide feed system would almost immediately increase the ozone residual in the contactor effluent water to unacceptable levels before the operator has a chance to remedy the problem. Similarly, interruptions in the peroxide feed would have an immediate effect on the downstream chlorine residual. When applied to the treatment of a groundwater with stable water quality, a Peroxone process could be stable to operate. However, it is likely to be less stable when applied to the treatment of surface water with its constantly changing water quality.

In the final analysis, for Zone 7 to take on the risk of being the first to implement a large scale Peroxone process for T&O control, the process should offer a substantial economic advantage over the more-established conventional ozone process. This study showed that Zone 7 would not realize such an economic advantage. For this reason, WQTS recommends that a conventional ozone process be implemented at DVWTP and PPWTP for T&O control.

SECTION 1.0 –

INTRODUCTION

1.1 BACKGROUND

The Zone 7 Water Agency serves water to the cities of Pleasanton, Livermore, and Dublin. Zone 7's main water source is the Sacramento-San Joaquin Delta delivered via the South Bay Aqueduct (SBA). The water is treated at two surface water treatment plants; the Patterson Pass Water Treatment Plant (PPWTP) and the Del Valle Water Treatment Plant (DVWTP). Two other water agencies also use the SBA: the Alameda County Water District (ACWD) and the Santa Clara Valley Water District (SCVWD).

SBA water commonly contains chemicals that impart objectionable taste and odor (T&O). These chemicals are produced by algae growing in the water. While algae can produce many chemicals, the primary T&O-related ones in SBA water are geosmin and 2-methylisoborneol (MIB). While these chemicals have no known adverse health effects, they are easily detected by customers at low nanogram per liter (ng/L) levels, resulting in customer complaints about the quality of their drinking water. To treat the T&O problem, Zone 7 has been using powdered activated carbon (PAC) at both plants on a seasonal basis. PAC is effective, but it is difficult to handle, expensive, and the high doses needed to effectively remove MIB and geosmin can cause problems with the other plant processes.

1.2 OZONE APPLICATION IN DRINKING WATER TREATMENT

For decades, ozone has been used to disinfect drinking water and to destroy T&O chemicals and other micropollutants that may be present in water. In California, many agencies that draw water from the State Water Project (SWP) system use ozone for meeting the disinfection requirement as well as improving the overall aesthetic quality of their drinking water. In Northern California, the list of agencies that use ozone for water treatment includes the following:

- ☐ Alameda County Water District
- ☐ Santa Clara Valley Water District
- ☐ Contra Costa Water District
- ☐ San Francisco Public Utilities Commission
- ☐ East Bay Municipal Utilities District
- ☐ City of Vallejo
- ☐ Cities of Vacaville & Fairfield
- ☐ City of Napa
- ☐ City of Martinez

The downside to ozone use for water treatment is twofold: First, it is an expensive process to construct and operate. Second, when ozone is added to water containing elevated levels of bromide, it could generate bromate (BrO_3^-) above the maximum allowable limit (MCL) of 10 µg/L in drinking water. SBA water used by Zone 7 frequently contains elevated bromide levels. In fact, an analysis of historical water quality data indicated that the 50th percentile bromide level in SBA water between 1993 and 2007 was 100 µg/L, while the 90th percentile was 290 µg/L. The maximum bromide concentration was recorded at >500 µg/L. At the typical ozone doses applied in drinking water treatment, bromide concentrations above 100 µg/L could result in bromate formation above the MCL. For SWP water users, bromate control strategies must be implemented in conjunction with ozone application.

1.3 OZONE VS. PEROXONE

Two configurations of an ozone system can be used for T&O control. The first is a conventional configuration where ozone is added into the water as it flows through a multi-chamber, over-under contactor with an average contact time of about 8 to 10 minutes. This contact time is required to give the ozone sufficient time to react with the target contaminants. This configuration is referred to in this report as Conventional Ozone. All the agencies listed above utilize conventional ozone contactors.

The other configuration is a process in which ozone and hydrogen peroxide are added to the water. The combination of ozone and hydrogen peroxide generates hydroxyl radicals ($OH^\bullet$), which are stronger oxidants than ozone itself and require much shorter contact time to achieve T&O destruction. This process is referred to in this report as the Peroxone process. Due to the fast reaction time, a Peroxone process requires a significantly smaller contactor (2 to 4 minutes) compared to conventional ozone (8 to 10 minutes), and is believed to require a lower ozone dose to meet the same target T&O destruction goals. However, because of its short contact time, and the fact that the added hydrogen peroxide rapidly destroys the ozone residual, it is impractical to claim disinfection credit through a Peroxone contactor. Therefore, if Peroxone is implemented at Zone 7's treatment plants, disinfection requirements must continue to be met with chlorine.

1.4 OVERALL PROJECT DESCRIPTION

This project aimed at determining whether ozone or Peroxone should be implemented at the Zone 7 treatment plants, and defining the practical and financial implications of the implementation of either process. The specific activities included the following:

1. Conduct pilot-scale testing of ozone vs. Peroxone to determine the design criteria required by each process to meet Zone 7's T&O goals.
2. Determine whether the ozone-based T&O process should be applied on the raw-water or settled-water side.
3. Develop the design criteria, hydraulic requirements, and general layouts of an ozone or Peroxone process at each plant.
4. Develop probable costs for constructing and operating either process at each plant.
5. Identify the permitting requirements for implementing either process at each plant.
6. Identify the impact of implementing either ozone or Peroxone on the operation of each of Zone 7's water treatment plants.

A significant portion of this project was dedicated to the pilot testing effort. If conventional ozone were the only process being considered, pilot testing would not have been required since ample experience has been developing on applying conventional ozone for the treatment of SBA water. However, since Zone 7's primary reason for the ozone process is T&O destruction and not disinfection, there was a reasonable expectation that the implementation of Peroxone instead of conventional ozone could result in a T&O control process that is less costly to build and operate. Unfortunately, there is little to no full-scale experience with the design and operation of a Peroxone process for drinking water treatment. In order to quantify the expected cost savings of a Peroxone process over a conventional ozone process, and to determine its design and operational requirements, it was necessary to conduct side-by-side pilot testing of the two processes.

1.5 REPORT ORGANIZATION

Following this introductory section, Section 2 presents and discusses the T&O water quality goals. Section 3 presents a thorough review of the available literature on T&O destruction with ozone based processes. Section 4 presents the pilot testing plan, while Section 5 presents the pilot testing results obtained. Section 6 includes the design criteria, layouts, and hydraulic constraints for the addition of ozone or Peroxone at each plant. Section 7 presents the estimated capital and annual O&M costs of implementing ozone or Peroxone at each plant. Section 8 includes the permitting requirements of either process is added to each plant, as well as the anticipated schedule from design through construction. Finally, Section 9 presents the potential operational impacts of implementing ozone or Peroxone at DVWTP and PPWTP.

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SECTION 2.0 –
WATER QUALITY GOALS

The design of a Taste and Odor (T&O) control strategy is anchored at two end-points:

1. The design maximum concentrations of T&O chemicals in the raw water
2. The target finished water quality goals for these chemicals

The design maximum concentrations are selected based on the analysis of historical water quality information. In this Section, the historical levels of T&O causing compounds in South Bay Aqueduct (SBA) water are reviewed and analyzed with the purpose of identifying the design removal percentages required for each chemical. Depending on the selected percent of the time that the treated water from the plants will comply with the targets, the size (and therefore cost) of the system will vary.

2.1 TREATED WATER QUALITY TARGETS

Zone 7 Water Quality Policy, Goals, and Targets, adopted by the Zone 7 Board of Directors in 2003, were developed after extensive discussions with, and in cooperation with, local retail water contractors including the California Water Service Company, the Cities of Livermore and Pleasanton, and the Dublin San Ramon Services District. As part of the Water Quality Management Program, formally adopted Water Quality Targets have been defined, as listed in Table 2.1. With regard to taste and odor, Zone 7 has adopted a target of "no events" for earthy/musty T&O, as well as the targets of no more than 9 ng/L of MIB and 4 ng/L of geosmin in the finished water. An event is defined as three or more complaints over a seven-day period. The current project focuses on earthy/musty taste and odor control. However it is important that all of the other adopted water quality targets, as well as all of the drinking water regulations, are not adversely impacted by the selected T&O control strategy.

Zone 7's water quality targets are consistent with those of the general water industry as well as the other South Bay Aqueduct contractors. For example, K. Rakness in *Ozone in Drinking Water Treatment: Process Design, Operation, and Optimization* (2005) states that taste and odor thresholds for MIB and geosmin are in the range of 6 to 10 ng/L. MWH in *Water Treatment Principles and Design*, (2005) suggests that MIB and geosmin thresholds are "in the range of" 5 ng/L. McGuire et al. (1981) reported odor thresholds of 4 and 9 ng/L for the two compounds, while Simpson and MacLeod (1991) reported customer complaints at levels above 7 and 12 ng/L, respectively. The AWWA book *Water Quality & Treatment: A Handbook of Community Water Supplies* (1999) suggests a maximum level of 10 ng/L for either chemical. Alameda County Water District (ACWD) does not have formally-adopted targets for MIB and geosmin levels. Santa Clara Valley Water District (SCVWD) has a goal of less than 5 ng/L for both, and a "trigger level" of 8 ng/L for MIB and 10 ng/L for geosmin. Actions such as increased monitoring and PAC feed are taken if the trigger levels are exceeded. Both agencies have adopted goals of minimal to no taste and odor events. (Cabral, 2007 and Chun, 2007, personal communication).

Based on the above comparisons, it is clear that Zone 7's adopted MIB and geosmin targets are reasonable and consistent with others, and no changes to them are needed or recommended.

Table 2.1 – Zone 7 Water Quality Targets

Key Parameter of Concern	**Water Quality Target**
Appearance	Minimize air bubbles/cloudiness events
Arsenic (µg/L)[1]	<5
Chloramines	
Cl_2:NH_3-N	4:1 to 5:1
Total Residual (mg/L as Cl_2)	2.0 to 2.5 from water treatment plants (WTPs), wells will be operated to be as close to this target range as feasible
Minimize odor	Chloraminate above pH 8.0 for WTPs
Prevent Nitrification	
Free Ammonia Residual (mg/L as N)	<0.15
Nitrite (mg/L as N)	<0.02
Consistency	Provide consistent residual at all wells and WTPs
Chloride (mg/L)	<100
Chromium VI (µg/L)	<20, pending new regulations
Cryptosporidium	4-log removal, including multi-barrier control
Disinfection Byproducts	
Maximum Leaving WTP	Total Trihalomethanes (TTHMs) < 64 µg/L
	Five Haloacetic acids (HAA5) < 48 µg/L
Running Annual Average at Retailer Turnouts	TTHMs < 40 µg/L
	HAA5 < 30 µg/L
N-Nitrosodimethylamine (NDMA) (ng/L)	< 10, pending new regulations
Bromate	8 µg/L
Hardness (mg/L as CaCO3)	< 150 mg/L
pH (units)	Non-corrosive pH leaving WTPs at ± 0.2 units of target
Radon (pCi/L)	<1,000 pending new regulations
Taste and Odor (earthy/musty)	
2-Methyisoborneol (MIB)	9 ng/L
Geosmin	4 ng/L
Events	No Events (An event is defined as 3 or more complaints in a 7-day period.)
Total Dissolved Solids (TDS) (mg/L)	<500

2.2 RAW WATER MIB AND GEOSMIN CONCENTRATIONS

The primary source of the earthy/musty taste and odor compounds is algal byproducts that occur periodically in the South Bay Aqueduct. The most commonly measured T&O culprits are methylisoborneol (MIB) and geosmin. Figures 2.1 and 2.2 show the MIB and geosmin concentrations, respectively, for the past seven years measured by the Department of Water Resources at Del Valle Check 7.[2] This sample location is upstream of the Del Valle Water Treatment Plant, but does not include any blend water from Lake Del Valle. It is, therefore, representative of the raw water entering the Patterson Pass WTP and most of the water entering the Del Valle WTP.

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[1] µg/L = microgram per liter, ng/L = nanogram per liter, pCi/L = picoCurie per liter, mg/L = milligram per liter

[2] 2001 is the year that the Department of Water Resources began intensive monitoring for MIB and geosmin. Data prior to that time in the SBA are sparse.

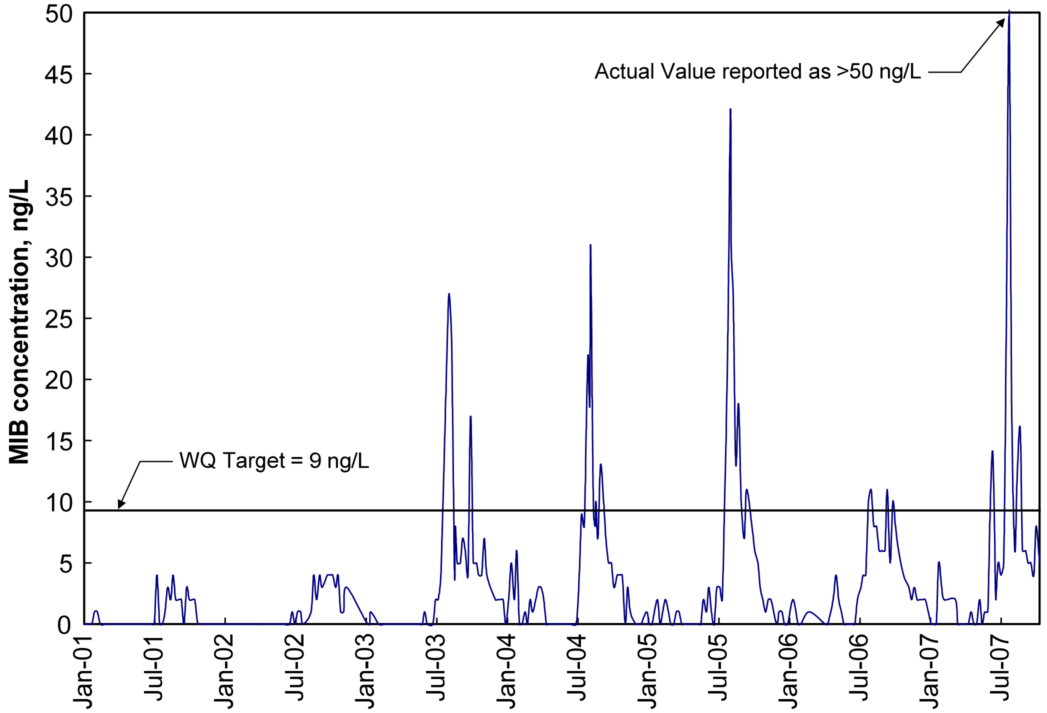

Figure 2.1 – Seven-Year Historical Levels of MIB Measured at Del Valle Check 7 (California Department of Water Resources)

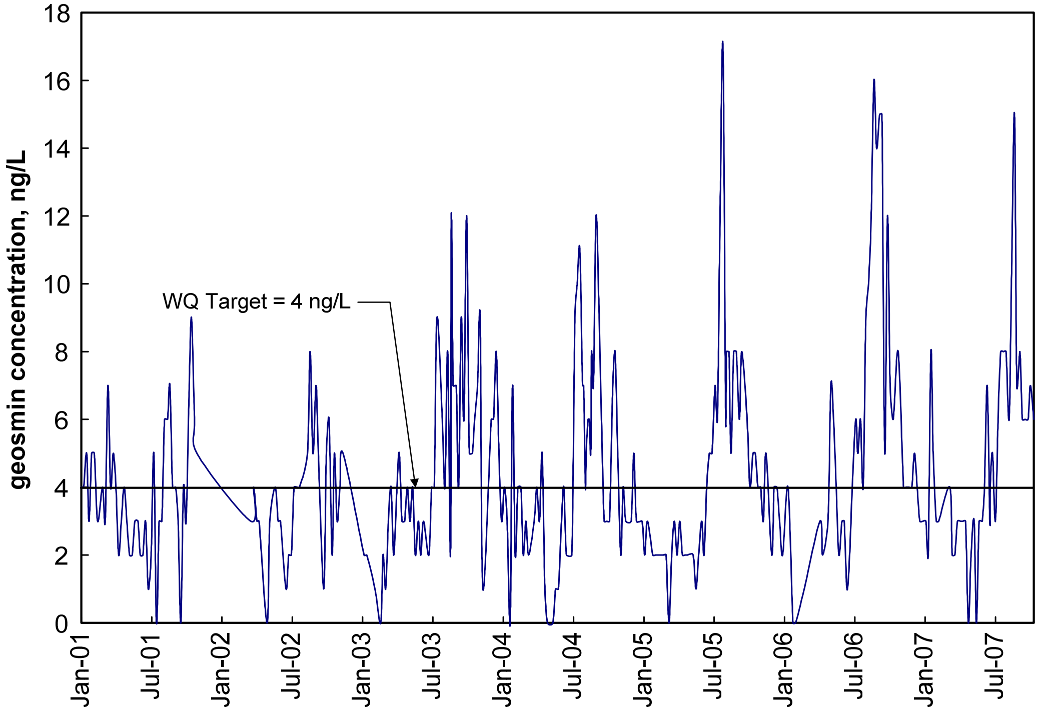

Figure 2.2 – Seven-Year Historical Levels of Geosmin Measured at Del Valle Check 7 (California Department of Water Resources)

The historical data indicate two things: 1) the occurrence of the two chemicals in SBA water is seasonal and highly variable, and 2) there are occasional spikes of very high concentrations. The sample collected on July 23, 2007 was reported to have an MIB concentration greater than 50 ng/L, but was not quantified beyond that point. With the exception of powdered activated carbon (PAC), the treatment processes used by the two water treatment plants remove insignificant amounts of these compounds. Therefore when PAC is not used, it can be assumed that the concentrations shown in Figures 2.1 and 2.2 are similar to the levels in the water supplied to the distribution system.

Water quality in the delta water is dependent on many factors. Making treatment process decisions in the absence of a very large set of data covering many years can be challenging, since historical levels do not necessarily predict future levels. One of the most important factors influencing delta water quality is the amount of rainfall in the watersheds. According to the Department of Water Resources (DWR) California Snow Survey, the years covered in the above MIB and geosmin graphs (2001 through 2007) were classified as Dry, Dry, Below Normal, Dry, Wet, Wet, and Critical for the Sacramento-San Joaquin River systems.

The data were sorted and ranked, and the percentage of time that the measured value was at or below a particular level was plotted (percentile graphs). These are shown in Figures 2.3 and 2.4 for MIB and geosmin, respectively. On each plot, lines are drawn showing the 95th and 99th percentile concentrations for each compound in SBA water, as well as lines showing the percentiles corresponding to each of Zone 7's goals.

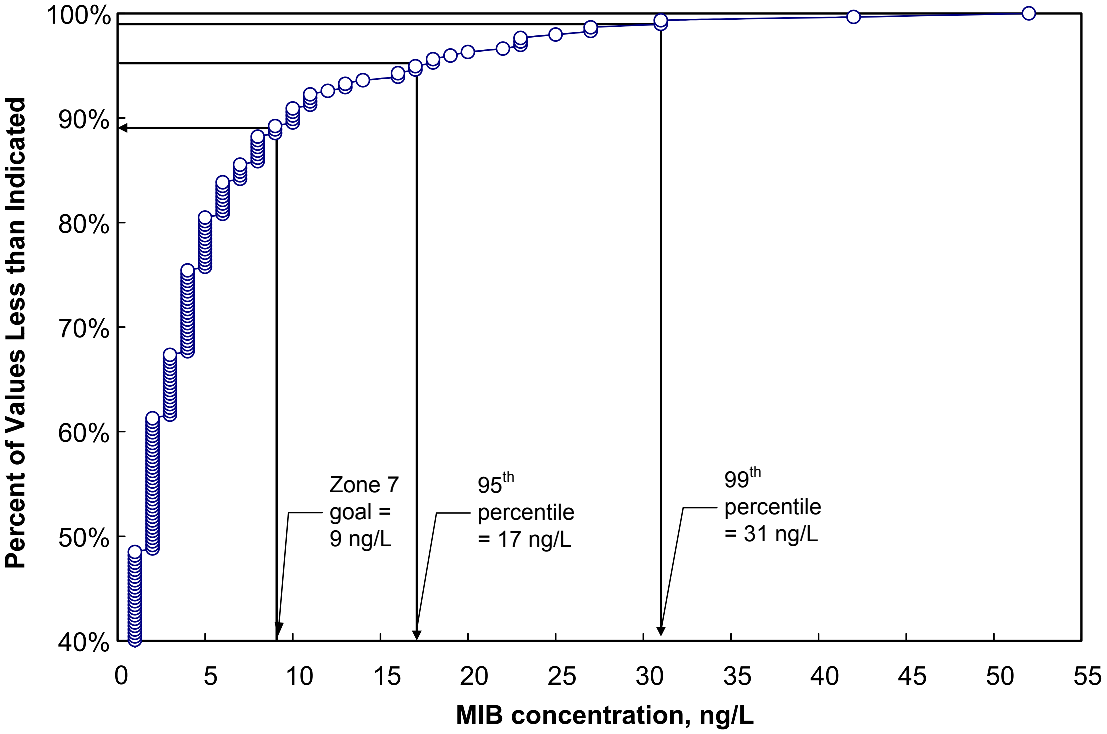

Figure 2.3 – Percentile Occurrence of MIB in SBA Water (2001 – 2007)

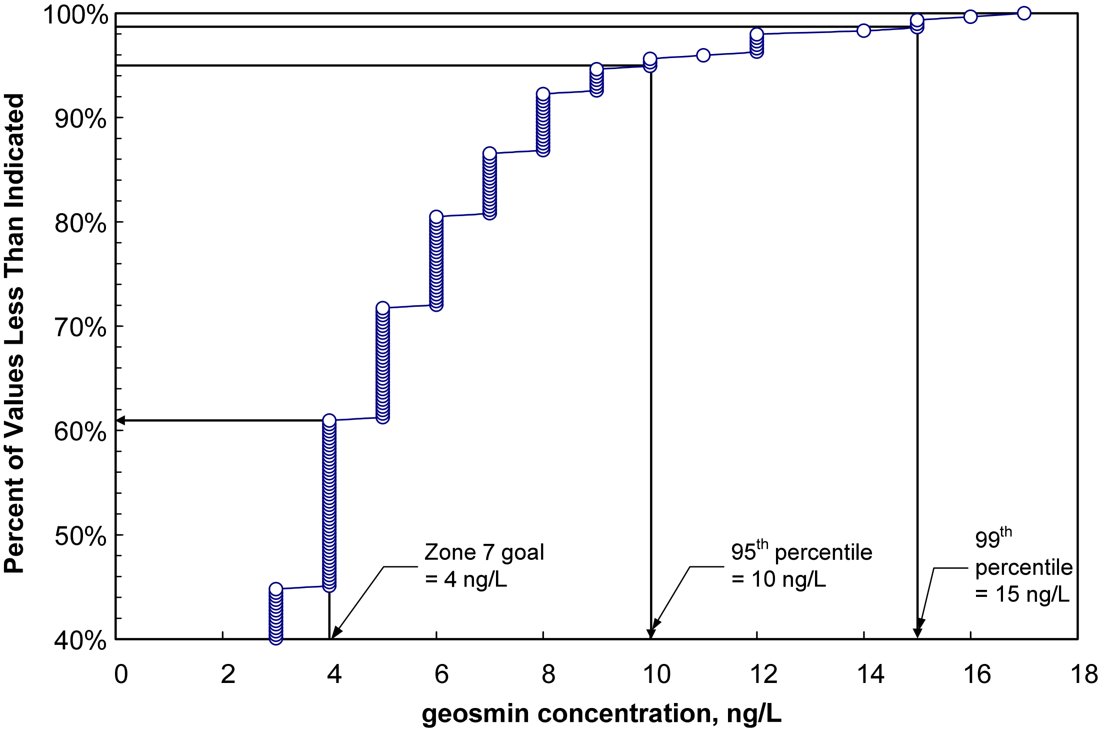

Figure 2.4 – Percentile Occurrence of Geosmin in SBA Water (2001 – 2007)

The data plotted in Figure 2.3 show that 89% of SBA water samples contained MIB levels at or below the Zone 7 goal of 9 ng/L. Therefore, T&O removal or destruction will be required up to 11% of the time, which translates into approximately 40 days of the year. Similarly, Figure 2.4 shows that 61% of SBA water samples contained geosmin levels at or below the Zone 7 goal of 4 ng/L. Therefore, T&O removal or destruction will be required up to 39% of the time, which translates to about 142 days (almost five months) of the year. These are significant durations of T&O treatment that should be considered when evaluating the overall operational cost.

Table 2.2 includes the calculated percentile rankings of the various concentrations of each compound and the corresponding percent reduction that would be required to meet Zone 7's water quality targets. For example, if the selected treatment system were to meet the target MIB concentration of 9 ng/L 95% of the time, then it would need to be designed to provide a maximum of 47% reduction in MIB ((17 – 9)/17). This would also mean that the MIB goal of 9 ng/L would not be met 5% of the time, which translates into approximately eighteen 18 days (2.5 weeks). On the other hand, if the treatment system is to meet the MIB goal of 9 ng/L 99% of the time, then it should be designed to achieve a maximum of 71% removal of MIB ((31 – 9)/31). With this treatment level, Zone 7 will not meet its MIB goal 1% of the time, which translates into approximately four (4) days of the year.

Table 2.2 – Analysis of MIB and Geosmin Occurrence Data (2001 – 2007)

	Concentration, ng/L		% reduction required to meet target levels	
Percentile	**MIB**	**Geosmin**	**MIB**	**Geosmin**
Average:	4	4	--	--
50th percentile:	2	4	--	--
75th percentile:	4	5	--	20%
90th percentile:	9	8	--	50%
95th percentile:	17	10	47%	60%
99th percentile:	31	15	71%	73%
100th percentile:	>50	17	83%	76%

A design criterion that meets the WQ goals 95% to 99% of the time is typical for taste and odor control processes. For example, the Altamont Water Treatment Plant (AWTP) is designed to use ozone to achieve the target removal of MIB and geosmin. As part of the Altamont WTP design, the anticipated range for MIB was up to 30 ng/L, and that for geosmin was up to 12 ng/L. These values correspond to approximately the 99th and 95th percentiles for these two compounds, respectively, based on the analysis presented in this Section. This is also in line with the testing conducted by ACWD in preparation for the design of Water Treatment Plant No. 2. During their evaluation, ACWD spiked the raw water with about 30 ng/L of MIB and geosmin, and the treatment goal was to reduce each chemical to less than 10 ng/L.

2.3 SUMMARY & RECOMMENDATIONS

The occurrence of MIB and geosmin in SBA water during the last seven years (2001 to 2007) was analyzed in this Section and compared to Zone 7's goals. The analysis showed that, during the last five years, SBA water exceeded Zone 7's MIB goal of 9 ng/L about forty (40) days each year, and exceeded Zone 7's geosmin goal of 4 ng/L about five (5) months each year.

The maximum geosmin and MIB levels recorded by DWR in SBA water since January 2001 were 17 ng/L and >50 ng/L, respectively. A frequency distribution analysis showed that the 99th percentile levels of geosmin and MIB were 15 ng/L and 31 ng/L, respectively. If Zone 7 were to meet its goals 100% of the time, based on the last five years of record, the new T&O treatment process should be designed to achieve up to 76% removal of geosmin and 83% removal of MIB (assuming the actually maximum MIB concentration was approximately 52 ng/L). On the other hand, if Zone 7 decides to meet its goals only 99% of the time, then the last five years of data suggest that the new T&O treatment process should be designed to achieve up to 73% removal of geosmin and up to 71% removal of MIB.

Since MIB is known to be more difficult to remove with ozone or other technologies than geosmin, then the MIB removal requirement is expected to set the process design requirements. Therefore, an MIB removal target of 71% would meet Zone 7's goals 99% of the time based on the last five years of T&O data in SBA water. This means that a T&O event may occur, on average, during four days each year. If this is to be eliminated and the target T&O removal is to be achieved 100% of the time, then the MIB removal target will be raised to 83%. For the purposes of this project, WQTS recommends that the pilot testing effort focuses on achieving MIB destruction greater than 71%.

SECTION 3.0 –
LITERATURE REVIEW

When this water quality improvements project was initiated, Zone 7 staff recognized that extensive work had already been conducted on the control of taste-and-odor (T&O) in water drawn from the Sacramento-San Joaquin Delta, particularly from the South Bay Aqueduct, which is the source of water for both the Del Valle WTP[3] and the Patterson Pass WTP. Before planning the pilot-testing activities to be conducted under this project, it was important to review the outcome of the previous work and identify the technical areas that require further investigation, with the idea that the pilot testing effort would then focus on those areas.

Information from past work was gathered from three sources: First, an extensive search of the published literature was conducted with specific focus on the application of ozone or Peroxone for T&O destruction in drinking water treatment. Second, while much of the previous work has been published, additional information is contained in internal reports of pilot-scale studies commissioned by the Alameda County Water District (ACWD) and the Santa Clara Valley Water District (SCVWD), as well as by Zone 7. Available pilot study reports were reviewed, and relevant data were analyzed. Third, WQTS staff met with ACWD and SCVWD staffs and obtained full-scale operational and disinfection byproduct (DBP) formation data from their full-scale plants after ozone implementation. This Section provides a summary of the data and information gathered from all three sources.

3.1 DRINKING WATER TASTES AND ODORS

3.1.1 Background

An Awwa Research Foundation (AwwaRF)[4] survey showed that approximately 70 percent of responding consumers cited factors such as clean, safe, healthy, and good quality as what was desired most from their utility (Hurd, 1993); only about 4 percent listed their top desire as having water that looks and tastes good. However, the same survey showed 65 percent of those who only drink bottled water do so because of having experienced problems with the taste of their tap water. On a scale from 0% (dangerously unsafe) to 100% (extra safe), with 75% assigned to the quality meeting Federal standards, bottled water users ranked the perceived safety of their tap water as 58%, on average. Objectionable taste leads consumers to bottled water, and indicates that the quality of their utility's water is suspect. Detection of T&O in water has improved a great deal since the 1970s (Suffet and Segall, 1971) with the development of rapid detection methods such as closed-loop stripping analysis (CLSA) (Hwang et al., 1984) and flavor profile analysis (FPA) (Bartels et al. 1986; Bartels et al., 1987; Meng and Suffet, 1992). Advanced techniques now allow detection of T&O at low levels equal to those causing objectionable taste in drinking water (Sclimenti, 2003). This allows utilities to more effectively monitor and control T&O.

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[3] While the PPWTP receives water only from the Delta, the DVWTP periodically receives water from Lake Del Valle in addition to the Delta water.

[4] In 2008, the Awwa Research Foundation was renamed: Water Research Foundation.

3.1.2 Occurrence

Section 2 included information on the occurrence of the earthy-musty T&O compound MIB in SBA water, and showed that peaks could exceed 50 ng/L. T&O surveys conducted by the American Water Works Association (AWWA) characterized water from 377 utilities across the United States (U.S.) and Canada, identifying T&O associations from chlorinous, to sour/metallic, and also earthy/musty as experienced by Zone 7 and many other utilities that treat water from the Delta (Suffet et al., 1996). Reservoir conditions and algal blooms are the primary causes of earthy/musty T&O found in surface waters—46 percent of the major causes for T&O in the survey. Earthy-musty algal blooms could also be associated with the production of algal toxins that are harmful to animals and humans (Gottler et al., 2007). It is prudent for utilities to control T&O compounds to increase consumer confidence. A report by Taylor and co-workers evaluated reservoir management practices that provide utilities tools to respond to T&O events (Taylor et al., 1994 & 2006). These tools include applying principles of limnology and system knowledge with a quick response because events can develop logarithmically and become uncontrollable very quickly. If these source-monitoring/treatment tools do not work or are not practical, then the resulting T&O levels must be handled at the water treatment plant before the water is served to the customers.

3.1.3 Treatment Options

Control of chemicals that cause T&O in drinking water has been extensively studied. Activated carbon, whether used in the granular form (GAC) or the powdered form (PAC) adsorbs these chemicals from water (Lalezary et al., 1986; Graham et al., 2000; Machenzie et al., 2005). PAC is moderately effective, but due to negative operational impacts is not being considered as Zone 7's long-term control strategy. GAC would require high cost for regeneration when used as an adsorption technology. Advanced oxidation processes (AOPs) are also effective treatment technologies for destroying T&O chemicals. AOP technologies promote the formation of hydroxyl radicals ($OH^{\bullet}$) which are highly efficient in oxidizing organic and inorganic impurities (Najm and Trussell, 1999). Several technologies generate hydroxyl radicals, and are therefore classified as AOPs. These include (1) the combination of ultraviolet light (UV) and hydrogen peroxide (Linden et al., 2004; Royce and Stefan, 2005), (2) ozone combined with UV (Mokrini et al., 1997; Oh et al., 2005), and (3) ozone combined with hydrogen peroxide (also known as Peroxone). Treatment of T&O chemicals with UV technology requires a significant amount of energy, especially when it is combined with ozone, and is not practical at the scale required by Zone 7. In addition, while UV-based AOPs have been evaluated at bench-scale or pilot-scale, to our knowledge, they have not been applied for T&O control at full-scale drinking water treatment plants. Ozone or Peroxone offer a more practical, cost effective means to control T&O, while potentially offering additional treatment benefits.

3.2 OZONE AND PEROXONE TREATMENT

3.2.1 Taste and Odor Control

Numerous studies have shown that ozone is significantly more effective for treating T&O compounds than chlorine, chloramines, or chlorine dioxide (Mallevialle and Suffet, 1987; Anselme et al., 1988; Lalezary et al, 1986). Glaze and co-workers further identified much of the functionality of how ozone is able to oxidize T&O-causing compounds in both Colorado River water (CRW) and State Water Project (SWP) water conveyed to southern California (Glaze et al., 1990). Their work showed ozone and Peroxone were the most efficient treatment techniques in controlling MIB and geosmin when compared to many other technologies that included chlorine dioxide, potassium permanganate, UV, UV with ozone, and UV with hydrogen peroxide. Oxidation of these T&O chemicals was more effective in SWP water than in CRW. Further work conducted by the Metropolitan Water District of Southern California (MWDSC) showed that MIB and geosmin could be effectively controlled in both pilot-scale and demonstration-scale (5 mgd) over/under contactor designs using either ozone or Peroxone (Ferguson et al., 1990 & 1991; MWDSC, 2000; MWDSC and JMM, 1991; Koch et al., 1992). In conflict with Glaze's bench-scale work, efficiency of T&O destruction was higher in CRW compared to SWP water. Demonstration-scale test results showed ≥80-percent removal of T&O in CRW with either 4 mg/L ozone or 2.5 mg/L ozone as Peroxone (hydrogen peroxide ratio of 0.2 mg/L per 1 mg/L ozone). Demonstration-scale tests with SWP water showed 4 mg/L ozone alone or 3.2 mg/L ozone with a 0.2 Peroxone ratio provided similar results. A recent study demonstrated that Peroxone more rapidly oxidizes geosmin than MIB and is more effective at higher pH and/or water temperature (Westerhoff et al., 2006).

3.2.2 Micro-pollutant Control

Using ozone or Peroxone for control of T&O compounds can have additional benefits such as destruction of micro-pollutants. A bench-scale study in buffered laboratory water found that as little as 1 mg/L applied ozone is able to completely oxidize high concentrations of algal toxin (up to 500 µg/L *Microcystin*-LR) at dissolved organic carbon (DOC) concentrations of up to 5 mg/L (Shawwa and Smith, 2001). In an AwwaRF-funded pilot-scale study with a DOC up to 6.5 mg/L, 20 µg/L of microtoxins were oxidized with ozone to below World Health Organization (WHO) guideline of <1 µg/L of algal toxins (Falconer, 1994), whereas GAC adsorption was not successful (Newcombe, 2002). Treatment of algal toxins by ozone-induced hydroxyl radicals, such as those produced by Peroxone, is more efficient in the oxidation of algal toxins than ozone alone (Onstad and von Gunten, 2005).

Further studies with Peroxone have shown it to be effective against several emerging micro-pollutants. Peroxone is more efficient than ozone in oxidizing trichloroethylene (TCE) and tetrachloroethylene (PCE) (Glaze and Kang, 1988) and readily oxidizes many pesticides (Roche and Prados, 1995; Nelieu et al., 2000; Dyksen et al., 1992). Peroxone is more efficient than ozone in oxidizing dissolved endocrine disrupting compounds (EDCs) and pharmaceuticals and personal care products (P/PCPs), while typical conventional treatment processes (metal-salt coagulation, flocculation, sedimentation, and filtration) were not successful (Snyder et al., 2007). To achieve the same EDC and P/PCP destruction rates with a technology such as UV photolysis, dosages of >5,000 millijoules per square centimeter (mJ/cm^2) were required (Adams et al., 2002). For comparison, this is roughly two orders of magnitude higher than typical disinfection doses used in water treatment. Peroxone is also an effective treatment to clarify water by oxidizing dissolved color (Tosik, 2005). Peroxone ratios required for treatments described above ranged from 0.1 to 0.7 by weight.

3.2.3 Disinfection

A benefit of ozone disinfection relative to other chemical disinfectants such as chlorine or chloramines is that it is able to provide inactivation of *Cryptosporidium* (Oppenheimer et al., 1997). When using the Peroxone process, hydrogen peroxide quenches the ozone residual to form $OH^{\bullet}$ that oxidize contaminants. This effectively cancels the ability to demonstrate compliance with the regulatory disinfection requirements. There are studies that have been conducted showing that Peroxone may have disinfection capabilities against the pathogens of concern (Wolfe et al., 1989; Scott et al, 1992). However, Peroxone is not accepted as a disinfectant by the United States Environmental Protection Agency (USEPA) or the California

Department of Public Health (CDPH) because disinfection requires the maintenance of a measurable disinfectant residual (USEPA, 1987). Therefore, when utilities use ozone for both disinfection and to achieve T&O control with Peroxone, it is common to employ separate areas of chemical contact—one area to maintain dissolved ozone for disinfection, followed by the addition of hydrogen peroxide as the water enters the second area where Peroxone reactions take place.

3.2.4 Bromate Formation and Control

Like chlorine, ozone is not without its by-products. Bromate, the primary ozone by-product of concern, has a State and Federal Maximum Contaminant Level (MCL) of 10 µg/L, based on a running annual average. For decades, ozone has been known to form bromate in waters containing bromide (Haag and Hoigne, 1983; Westerhoff et al., 1994 & 1998; von Gunten and Hoigne, 1993), and reviews of literature describing the highly complex reaction of bromate formation are available (Siddiqui et al., 1995). Bromate is formed either directly by ozone reacting with bromide, or indirectly by the reaction of $OH^\bullet$ with bromide.

Because of seawater intrusion into the Delta, SBA water periodically contains elevated levels of bromide such that bromate formation during ozone or Peroxone usage is a concern requiring the implementation of some sort of bromate mitigation strategy at the treatment plants (Krasner et al., 1994). Figure 3.1 contains measured SBA bromide concentrations approximately once per week since 1993 (measured by the Alameda County Water District). This percentile plot shows that the 50th percentile bromide concentration is 0.101 mg/L (101 µg/L), which is considered quite high nation-wide.

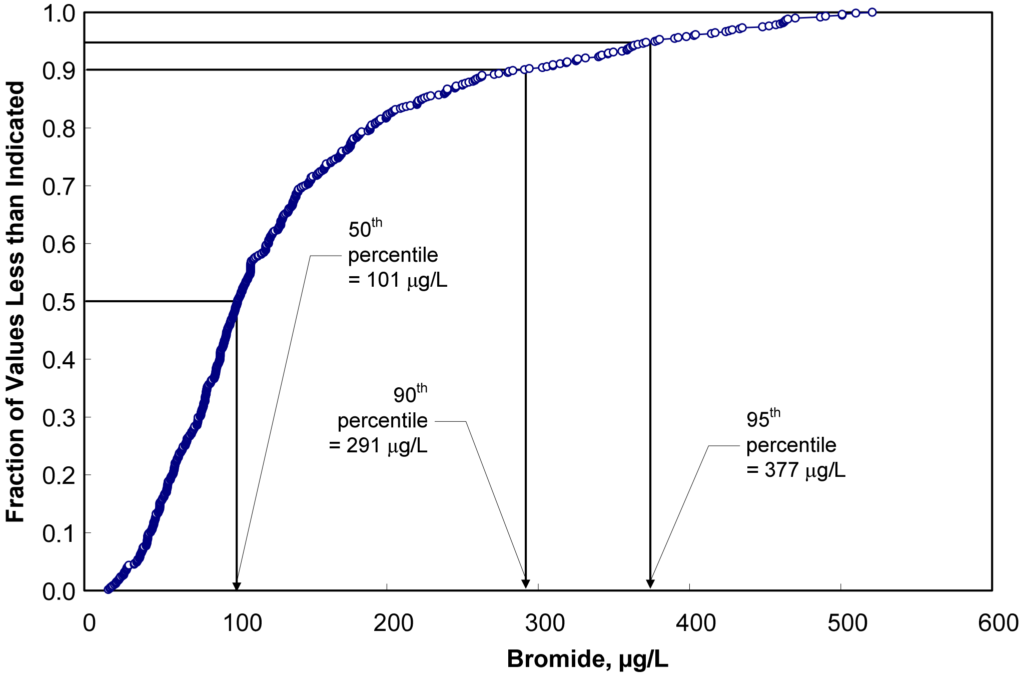

Figure 3.1 – Percentile Plot of Measured Bromide Concentrations in South Bay Aqueduct Water, 1993 – 2007, Alameda County Water District

Over the years, the most effective and reliable control strategy for bromate has been the addition of acid to reduce pH of the water before ozone addition (Coffey et al., 1998; Krasner et al., 1993; Galey et al., 2001; Williams et al., 2003). Alternative bromate control methods have included the application of ammonia or chlorine dioxide and more recently, chlorine-ammonia (chlorine added prior to ammonia) and chloramines (ammonia added prior to, or with, chlorine) (Krasner et al., 2004). If successful, these alternative bromate control methods can result in significantly lower operating costs compared to pH suppression.

Table 3.1 summarizes pilot-scale bromate-control tests with chlorine-ammonia and chloramines. These methods, established with bench-scale testing (Pinkernell and von Gunten, 2001), bind free bromide and restrict its availability for oxidation to bromate with ozone or $OH^\bullet$. Results from pilot tests show very low doses of chlorine and/or ammonia are required to inhibit bromate formation. Operationally, this bromate control strategy provides substantial cost savings to utilities compared to pH control. CRW results have been confirmed in full-scale tests. In SWP water, all conditions reduced bromate below the 10 µg/L MCL. The difference between the tests in CRW and SWP water shown in Table 3.1 are that the amount of chlorine added was substantially lower in CRW than it was in SWP water. It has not yet been shown if bromate reduction would be realized in SWP water with the low chlorine dosages applied during CRW testing. Full-scale tests with SWP water have not yet been reported, but some preliminary testing has been conducted by ACWD and the results appear promising. It should be noted that the bromide level in the SWP water is generally higher and more variable than in the CRW.

Table 3.1 – Bromate Control by Use of Chlorine-Ammonia or Chloramines When Ozonating CRW or SWP water at Ambient pH (~8 units)
(Wert et al., 2007; Krasner, 2007)

Water Type and Reference	Bromide Level (mg/L)	Ozone Dose (mg/L)	Chlorine Dose (mg/L)	Chlorine Contact (min)	Ammonia Dose (mg/L)	Bromate (µg/L)	Percent Bromate Reduction
Colorado River Water	0.1	1.5	0.50	7	0	32	0%
	0.1	1.5	0	0	0.1[a]	10	38%
	0.1	1.4	0.25	7	0.1[a]	14	44%
	0.1	1.6	0.50	7	0.3[a]	6	75%
	0.1	2.1	0.50	7	0.5[a]	2	93%
State Water Project Water	0.2	~1.5*	0	0	0.3[c]	18	0%
	0.2	~1.5*	**	5	0.3[b]	2	88%
	0.2	~1.5*	**	1	0.3[b]	2	88%
	0.2	~1.5*	**	6[d]	0.3[d]	3	84%
	0.2	~1.5*	**	1[d]	0.3[d]	4	76%
	0.3	~2*	**	1	0.3[b]	3	89%
	0.3	~2*	**	6[d]	0.3[d]	2	92%
	0.3	~2*	**	1[d]	0.3[d]	4	88%

a Ammonia was added immediately prior to the first ozone cell
b 1-min ammonia contact time
c 6-min ammonia contact time
d Ammonia added prior to, or at the same time as chlorine (chloramine contact)
* Ozone dose unknown, so it is approximated based on other information in the study
** Chlorine (dose unknown) was added to establish a 1 mg/L residual at end of contact time

3.2.5 Effect on Coagulation and Filtration

Careful, controlled research regarding the precise effects of ozone on coagulation is somewhat limited. While there is much anecdotal evidence regarding improved performance of conventional treatment plants when using ozone, there are few published reports containing this type of data. In general, plants report improvements in the coagulation and filtration processes when ozone is used compared to other pre-oxidants or no pre-oxidant at all. This is particularly true of plants using delta water. Reported benefits include lower coagulant doses, decreased susceptibility to rapid changes in raw water quality, lower filter effluent turbidity and particle count values, and longer filter run times (Panus and Parsons, 2007; Rakness, 2005; Gillogly et al., 2001; Chun et al., 2007; Cabral and Castro, 2007). Improvement of the coagulation process, rather than disinfection, was the original objective for ozone addition at the 600 mgd LA Aqueduct filtration plant (Rakness, 2005). Rakness notes in his book “the author of this book also has observed that lower filtered water turbidity values have resulted from the application of ozone.” He goes on to say that laboratory scale experiments often fail to show the same beneficial effects that are observed at full scale, perhaps due to differences in operation and design of the systems. Rakness cites several examples of full scale plants that experienced lower coagulant doses, lower turbidities, or both, when ozone was installed (Rakness, 2005). No information specifically describing the effects of Peroxone on coagulation or filtration could be found.

A study by Reckhow and co-workers showed mixed results when various waters were ozonated ahead of coagulation (Reckhow et al., 1993). Their data showed that ozone did not improve the alum coagulation process, but did improve coagulation when either using different polymers or in the presence of oxidized iron. Specifically, this study showed that ozonation reduced the particle stability of some algae, but the effect on subsequent coagulation is variable and highly dependent on raw water (and seasonal) parameters. Some pilot-scale studies have shown that ozone preoxidation (when compared to no preoxidant) can improve performance of downstream coagulation/filtration by reducing particle counts or turbidity (Becker et al., 2002; Yates et al., 1997). However, the beneficial effect was also observed evaluating other pre-oxidants (e.g., chlorine, chloramines, chlorine dioxide), and is not necessarily a benefit solely provided by ozone. Of course, pre-chlorination may not be an option for many plants due to excessive formation of chlorinated byproducts.

3.3 OZONE AND PEROXONE SYSTEM DESIGN AND OPERATION

Thompson and Drago conducted a Survey of U.S. ozone facilities (Thompson, 2005; Thompson et al., 2005). The database generated shows that in 1975 there was only a single, 4 MGD plant with an ozone capacity of 50 pounds per day. At the time the survey was presented in 2005, there were 204 plants with ozone treating a capacity of 12.6 billion gallons per day with 420,000 pounds per day of ozone generating capacity. While the first facility constructed in 1974 was designed to meet disinfection requirements, there has been an increased use of ozone for T&O control as well as for reduction in chlorinated disinfection byproducts. A few of these facilities operate to oxidize iron, manganese, color or to improve downstream particle removal by conventional treatment. Less than 20 percent of the facilities surveyed operate to inactivate *Cryptosporidium*. Many of the facility managers identified that these ozone facilities are anticipated to assist in the future control of EDCs and P/PCPs.

3.3.1 Over/Under Baffled Contactors

Ozone has been used as a disinfectant to treat both SBA water and other sources of SWP water. Figure 3.2 is an illustration of how ozone disinfection can be achieved in the front portion of an ozone contactor while Peroxone may be implemented toward the end of the contactor. This over/under baffled design provides multiple functions. Ozone disinfection allows utilities to obtain necessary disinfection credit while avoiding forming elevated levels of THMs and HAAs typically observed following application of chlorine. This type of dual-purpose contactor was the basis for the design of both ACWD's and SCVWD's ozone plants. Sufficient contactor depth (generally 20 feet or more) allows for nearly complete (99%) ozone transfer into the water.

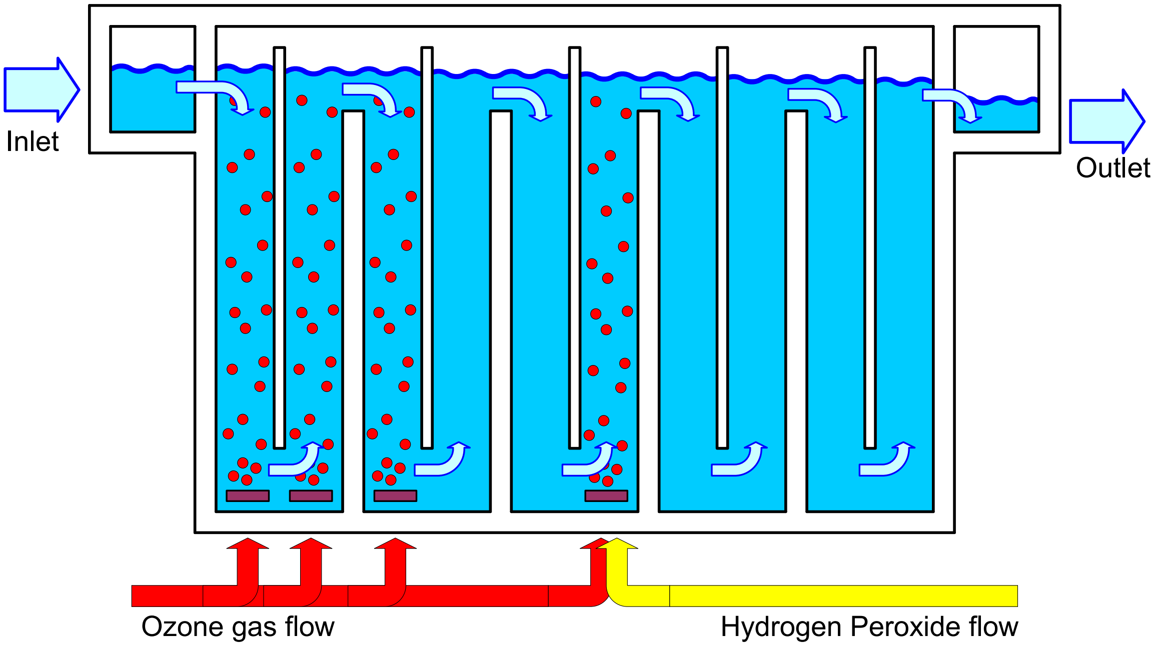

Figure 3.2 – Dual-Stage Contactor Design for Ozone Disinfection and Oxidation of Taste and Odor Compounds (Dyksen et al., 1992)

Due to the need to demonstrate adequate disinfection, however, typical ozone systems are understandably different in design compared to a system that would be strictly used for Peroxone addition. This is a challenge when designing a Peroxone process where, because no disinfection credit is intended, pilot work is necessary to evaluate operational challenges and to minimize construction and operational costs. Otherwise, cost effectiveness for Peroxone-only T&O control may not be beneficial compared to a typical, dual-purpose ozone/Peroxone contactor.

3.3.2 In-Line Injection and Pipe Contactors

Figure 3.3 illustrates a vertically-mounted, pipe-loop used in a pilot study funded by AwwaRF to evaluate in-line injection of ozone and Peroxone to oxidize TCE, PCE, and MTBE (Dyksen et al., 1992). Pilot work showed that entrained gases produced milky finished water unless proper air-relief was installed and injection was <50 psig. The issue of entrained air needs further research, but may be resolved by using a hydro-pneumatic tank, mechanical gas separation, or removing entrained gas from the side-stream ozone injection line prior to blending with the full flow at the water treatment plant.

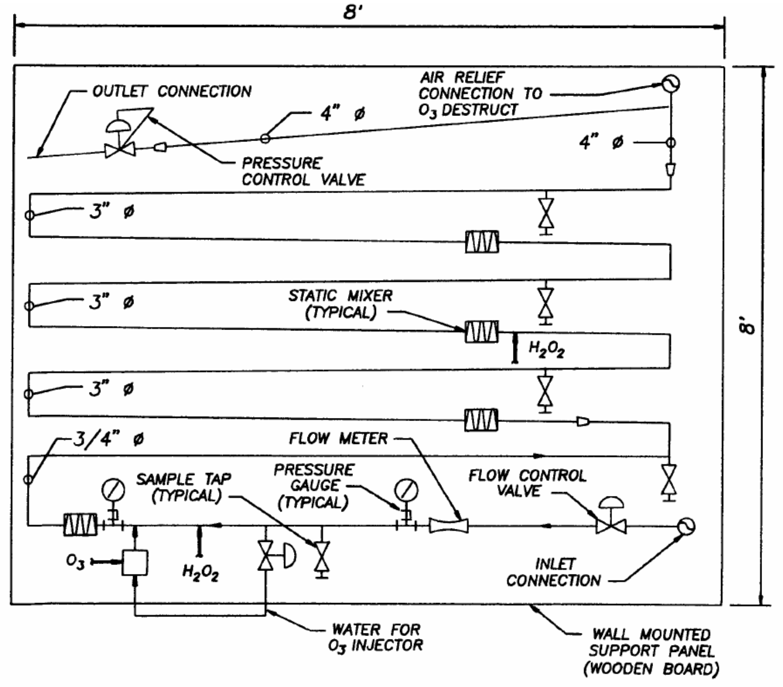

Figure 3.3 – In-Line, 5-gpm, Pilot-Scale Injection Pipe Loop Used to Evaluate Ozone and Peroxone (Dyksen et al., 1992)

Figure 3.4 illustrates a 5-MGD installation of side-stream ozone/Peroxone injection (MWDSC, 2000). The pipe is 24-inch diameter mortar lined steel with a 2-inch diameter side-stream pipe. When using the side-stream injection of ozone/Peroxone, water is bypassed towards the bottom of the figure past a side-stream ozone eductor. Side-stream injection at this and other facilities has been demonstrated to provide high gas transfer (>98%) and stable downstream ozone residuals (Neeman et al., 2002; Martin et al., 1992). Ozone with or without hydrogen peroxide is then fully-mixed by the downstream static mixer prior to continuing on to downstream treatment.

The City of Tacoma (Washington) adds ozone to its raw water by injecting it directly into raw-water pipelines, similar to what is shown in Figure 3.4. After obtaining the desired pipeline contact time with ozone, entrained-gas removal structures allow any remaining ozone to escape to the ozone destruct system (McMeen, 2007).

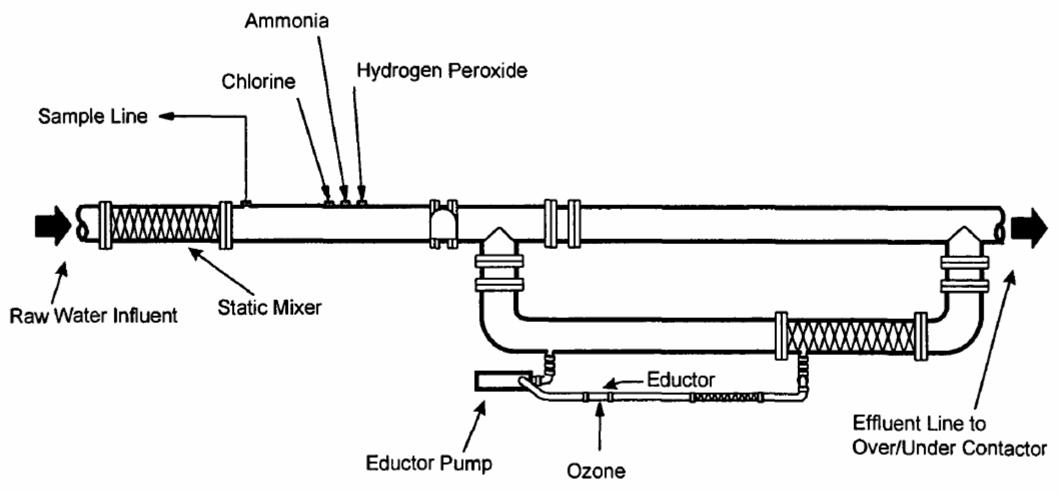

Figure 3.4 – In-Line, 5-MGD, Side-Stream Injection (Eductor Shown) Used to Evaluate Ozone and Peroxone (MWDSC, 2000)

Figures 3.5 and 3.6 illustrate an overview of the City of Seattle (Washington) ozone addition and contacting process (Nilson, 2007; Seattle Public Utilities, 2006). Seattle adds ozone gas into a concrete structure with fine-bubble diffusers with the capacity to remove excess, ozone-rich gas in its headspace. Ozone contact time is achieved in the downstream pipe (Nilson, 2007). This design offers a minimized version of the multi-cell, dual-purpose, disinfection/oxidation contactor shown above while providing the same type of ozone diffusion process—blending water and gas in a counter-current manner. Using a pipeline (instead of a concrete structure) to obtain ozone contact potentially allows for lower capital costs while saving precious hydraulic gradient.

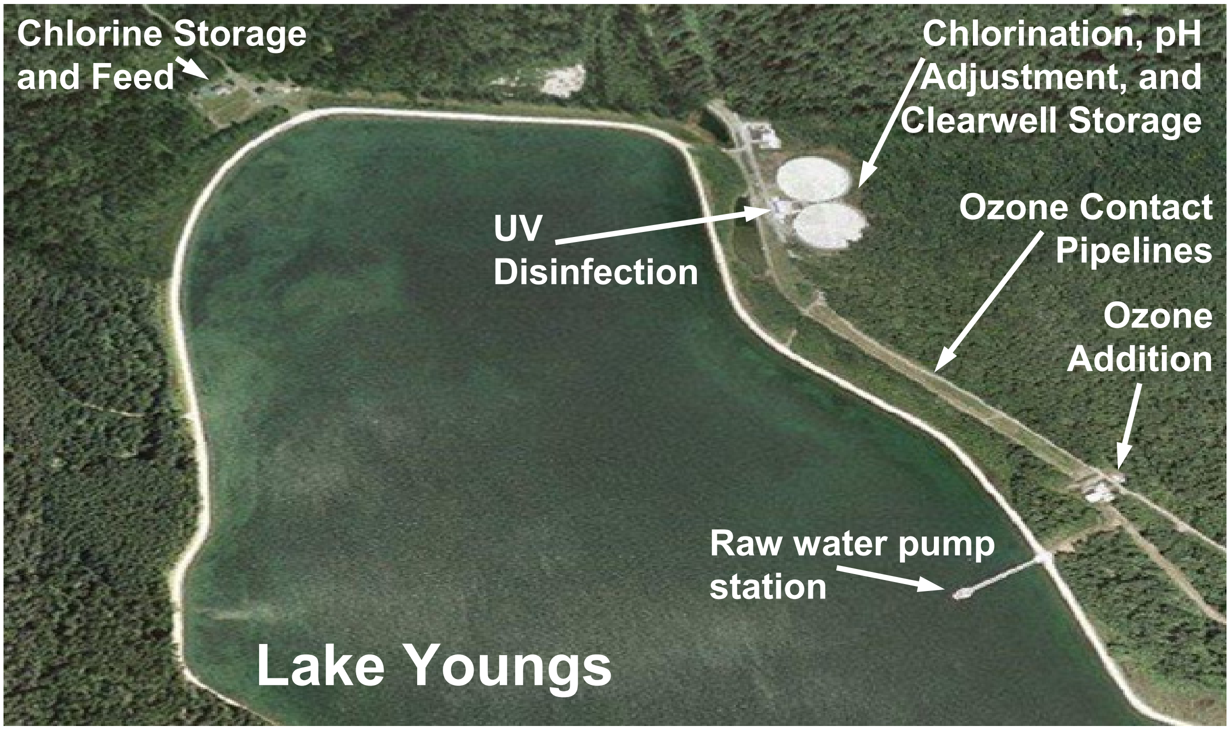

Figure 3.5 – Overview of the In-Line, 180-MGD, Pipeline Ozone Contactor System for City of Seattle's Lake Youngs Source (Nilson, 2007)

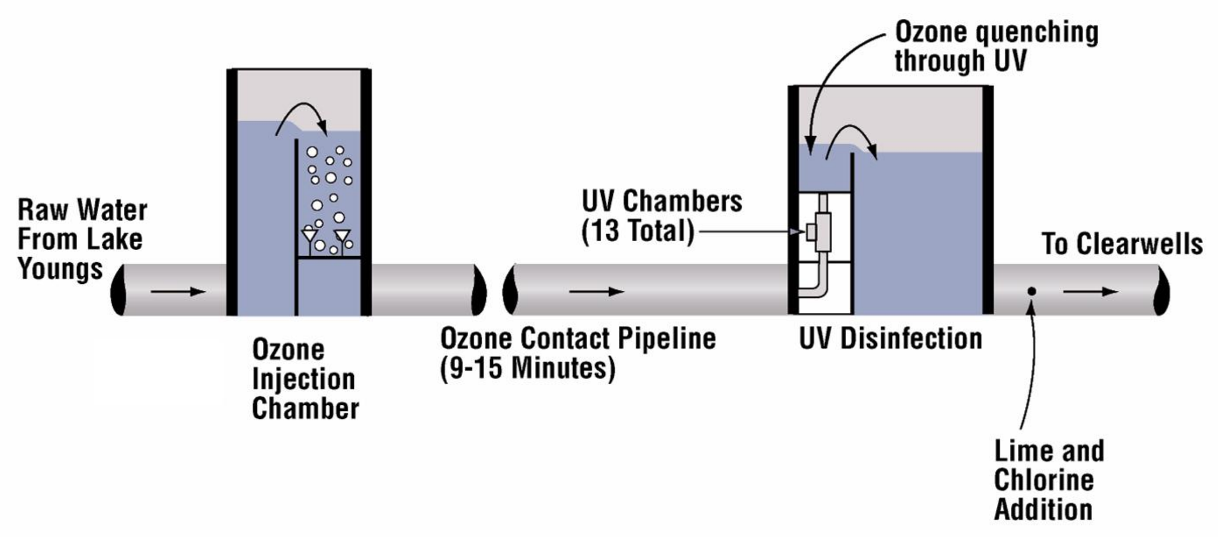

Figure 3.6 – Illustration of the Fine-Bubble, Ozone Injection Chamber Operated at the Cedar Water Treatment Facility (Seattle Public Utilities, 2006)

3.3.3 Peroxone Operations and Control

MWDSC has constructed full-scale ozone facilities with capability to add hydrogen peroxide when treating SWP water (Mofidi et al., 2005). Although having approximately 1 billion gallons per day Peroxone treatment capacity installed, MWDSC has not fed hydrogen peroxide (Kostelecky and Syfers, 2006). A challenge with the Peroxone process is related to the operational aspects of feeding hydrogen peroxide. This is a significant research gap that needs evaluation prior to designing full-scale facilities.

Key issues surrounding the operation of peroxide storage and feed systems include overcoming air-locking of pumps, deterioration and/or reaction of hydrogen peroxide solution stored over long periods of time, and personnel safety in handling high-concentration hydrogen peroxide solutions. Adequate safety and operating flexibility must be designed into the peroxide system such that any potential equipment/chemical dosing problems can be resolved without over-feeding peroxide and destroying downstream chlorine residual. Like many chemicals already in use at water treatment plants, hydrogen peroxide is a hazardous material and the facilities used to store and feed it will be under jurisdictional review of Alameda County Environmental Health Agency (ACDEHA). Similar to the MWDSC plants, both the ACWD and SCVWD ozone systems were designed to feed peroxide, but neither has fed this chemical on a regular basis. Also, CCWD's Randall Bold plant was designed to feed peroxide, but this has not been done. In all four cases, the plants' treatment goals have been achieved with ozone alone, and various problems were experienced with the peroxide storage and feed systems. In the case of CCWD, the tank has been emptied of peroxide and is being converted to storage of an ozone quenching chemical (Parsons, 2007). EBMUD has fed peroxide treatment at the Upper San Leandro Water Treatment Plant during extreme T&O events, but their system is a leased skid-mounted unit from the hydrogen peroxide vendor, and it is removed from the facility when not in use (Kachur, 2007).

Although their pilot studies indicated that it was necessary to meet their T&O control objectives, ACWD, SCVWD, MWDSC, and CCWD have not added peroxide with ozone and have no immediate plans to do so. The typical over-under ozone contactors designed for the dual-purpose of disinfection and oxidation have demonstrated that the addition of ozone alone adequately meets the required oxidation goals such that the cost and operational complexity of adding peroxide has not been warranted. Another consideration is that all four agencies have biologically active filtration following the ozone process. It may be that additional removal of T&O compounds occurs through these filters, but data to support this theory is very limited. The EBMUD case is clearly the exception, but only because the installed ozone capacity was not sufficient to oxidize the very high geosmin levels in their source water during a large algae bloom. In this case, geosmin levels were consistently near 100 ng/L, with peaks of over 350 ng/L. It is interesting to note that their pilot studies did not indicate that peroxide would be necessary for T&O control, and peroxide storage and feed equipment was not part of the original design of the ozone system. Fortunately, the capability to feed this chemical to the ozone contactors via a spray system was included.

3.3.4 Treatment-Train Placement

The location of ozone in the process train can affect the levels of chlorinated DBPs formed upon subsequent chlorine addition. Figure 3.7 shows results from a bench-scale comparison of pre-ozonation (prior to coagulation) and intermediate-ozonation (between flocculation and sedimentation) of various U.S. drinking waters (Singer et al., 2003). Results showed that subsequent THM and HAA formation was lower following pre-ozonation compared to intermediate ozonation. Either ozonation strategy, when compared to enhanced coagulation alone (without ozone), produced lower THMs and HAAs. These data were generated by holding the chlorinated samples for a 24-hour period at a pH of 8.0. Although the pre-ozonated DBP values were lower, they were not sufficiently low enough to warrant further pursuit.

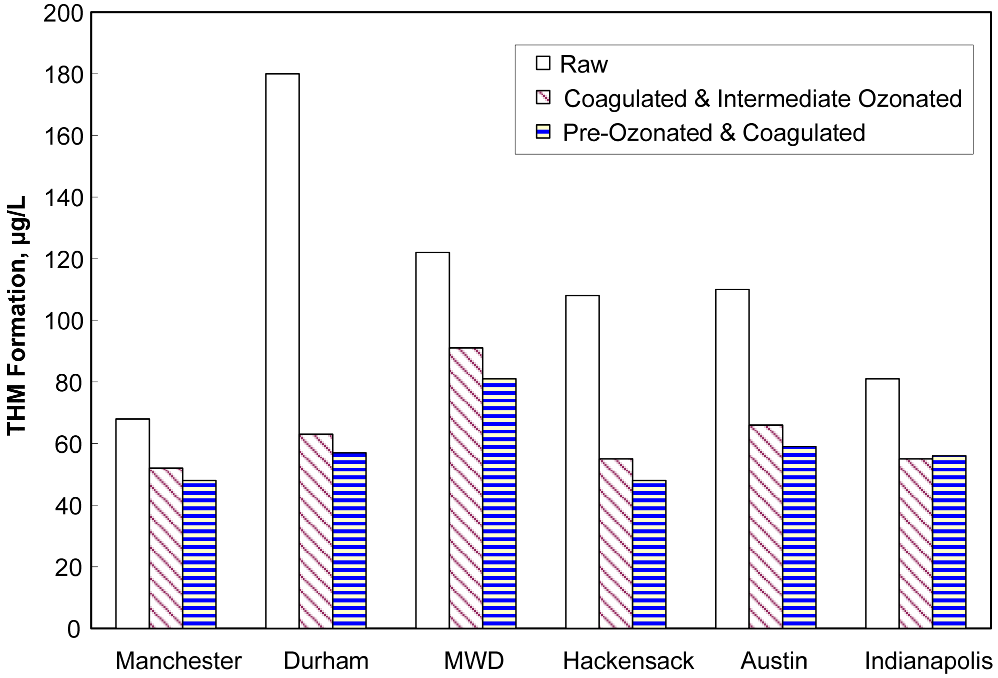

Figure 3.7 – THM Formation by Chlorination of Untreated (Raw), Intermediate-Ozonated, and Pre-Ozonated (Before Coagulation) Wate (Singer et al., 2003)

3.3.5 Biofiltration

In 1989, Glaze reported the production of low molecular weight ozonation by-products (i.e., aldehydes) when ozonating SWP water, many of which are readily biodegradable by naturally-occurring bacteria (Glaze et al., 1989). Subsequently, work has been conducted to study the use of biologically-active filtration (i.e., filtration without chlorine) downstream of ozone to remove this ozone-created biodegradable organic matter (BOM) (Weinberg et al., 1993). Reducing the amount of BOM entering the distribution system may decrease the likelihood of biofilm/bacterial growth. One study indicated that factors which increase the likelihood of bacteria growth in drinking water distribution systems include (1) water temperature >15 ^{o}C, (2) chloramine residuals <0.5 mg/L, and (3) AOC >100 µg/L (LeChevallier et al., 1996). This study showed that systems may be susceptible to these conditions whether they used ozone or chlorine as disinfectants. Increased levels of distribution system bacteria that subsist on AOC may be an indication of BOM-caused bio-regrowth (Miettinen et al., 1997).

The literature suggests risk factors such as declining residual chloramines and increasing water temperature increase the presence of bacteria and enhance growth of ammonia oxidizing bacteria (AOB). The literature also indicates that optimum conditions to grow AOB include the availability of free ammonia, low chloramine residual and poor system hydrodynamics (i.e., long retention times in water tanks and dead-ends) (Cohen et al., 2001; Wolfe and Lieu, 2002; Wolfe et al., 1990). The major group of AOB have been identified as chemolithotrophs—bacteria that oxidize inorganic compounds and subsequently excrete organic by-products that support growth of heterotrophic bacteria (AWWA, 1995).

In nearly all full-scale ozone installations, biofiltration is used after ozonation. It is unclear what implications would arise if biofiltration were not instituted downstream of ozonation. A southern California distribution system experiencing nitrification when fed ozonated and non-biofiltered SWP water throughout warm summer months was found to have elevated BOM and temperature while chloramine residual remained manageable (Mofidi, 2003). Furthermore, several monitoring points and storage tanks showed elevated BOM and temperature while the chloramine level remained stable. If elevated levels of BOM had initiated the degradation of chloramine and been responsible for the nitrification episode, it is expected that this would also have been observed in the tanks or at the distribution system sample locations. Also, BOM leaving the WTP did not degrade (average values remained similar to plant effluent values). This event occurred within one year of the ozone system startup. This nitrification event was hypothesized to take place because of poorly-baffled storage tanks, and not because of the ozonated BOM in the system. However, it was noted that once nitrification began, the presence of increased BOM from ozonation may have caused the bacteria to be difficult to control.

Surrogate measurements of BOM used to assess biofiltration performance have included assimilable organic carbon (AOC) and biodegradable dissolved organic carbon (BDOC) (Krasner et al., 1996) which are more generalized parameters and include the specific species of BOM actually removed (e.g., aldehydes, carboxylic acids, and many other low-molecular weight compounds). BOM is a fraction of the total organic carbon (TOC), and has been shown to be well removed by biofiltration. This removal has been seen to range between approximately 5 to 20 percent of the total amount of the TOC when biofiltration was practiced with rapid sand, or dual-media, filtration (Bouwer et al., 1995). This TOC removal can also help reduce the downstream formation of DBPs when chlorine is added.

An AwwaRF study assessed biological changes in distribution systems resulting from major changes in disinfection practices (Najm et al., 2000). In four full-scale systems, monitoring was done for 12 months before and 12 months after the changes in disinfection. In one case study, the primary disinfectant was switched from chlorine to ozone, and no biofiltration was used. This groundwater system did experience an increase in measured AOC concentrations after the switch, but there were not corresponding problems with distribution system regrowth in the year following the implementation of ozone. The authors stated that the high free chlorine residuals maintained throughout the system prevented bacteriological problems. They concluded that the bacterial concentrations in the distribution system were more sensitive to the chlorine residuals than to the changes in AOC or BDOC.

Biofiltration downstream of ozonation can also provide good removal of T&O compounds. An AwwaRF pilot study in Arizona and Colorado evaluated the removal of MIB and geosmin by sand, sand/anthracite, GAC, and GAC/sand biofiltration (Westerhoff et al., 2005). Empty bed contact time (EBCT) ranged between 2 to 4 minutes in these filters and provided between 6 to 19 percent removals in the sand and anthracite filters while the filters with GAC removed from 25 to 86 percent. It is important to note that the authors indicate that both degradation and adsorption were likely occurring in the GAC-containing filters whereas only bio-degradation was taking place in the non-GAC filters.

Biofilters are robust and provide a good buffer for changes in water treatment plant operations prior to water entering finished water reservoirs or the distribution system (Urfer et al., 1997;

Huck et al., 2000). If excess hydrogen peroxide is added upstream, demand across biofilters may aid in reducing peroxide residuals so that they do not destroy chlorine and/or chloramine in the clearwell or distribution system. Utilities in Texas and Florida have shown that when biofiltration is operating, stability in distribution system water quality is improved (Vokes, 2007; Marda et al., 2007) and biofiltration has also been shown to work well downstream of dissolved air floatation (DAF) (Wojcicka et al., 2005).

There is very limited full-scale experience with ozonation without subsequent biofiltration. Modesto Irrigation District has installed a membrane treatment train in parallel to their conventional treatment train at the Modesto Regional Water Treatment Plant (Modesto Irrigation District, 2004; Hidahl and Henderson, 2007), similar to the expansion of Zone 7's Patterson Pass WTP. The new membrane train has post-membrane ozone with no subsequent biofiltration. They did this because their existing conventional treatment plant has pre-ozone, but the filters are chlorinated, so there is no biofiltration as part of the existing treatment train, and they do not experience distribution system bacteriological problems. MID has fairly low-TOC raw water from the Tuolumne River and they use free chlorine as the residual disinfectant for the distribution system. Contra Costa Water District uses post-filtration ozone at the Randall Bold WTP; however, this plant also uses settled water ozone, and there is a biofiltration step in between the two ozone application points.

A significant concern in converting chlorinated filters to biofilters is a potential release of manganese (Mn) from the filter media. Manganese has a secondary MCL of 0.05 mg/L (50 µg/L), but a target of 20 µg/L is desirable to reduce discoloration at consumer's homes. Within 2 days of moving the point of chlorination from the influent to the filters effluent to begin biofiltration, MWDSC's Mills WTP filters released Mn in amounts that exceeded 60 µg/L, peaked over 100 µg/L after 7 days, and then did not drop below 50 µg/L until more than 14 days had passed (Gabelich et al., 2005). The filter media (anthracite/sand/gravel) was discovered to have been 'seeded' by several years' worth of combined addition of chlorine and ferric chloride. The ferric chloride was contaminated with Mn at a level of 0.7 µg for every 1 mg of ferric chloride (e.g., when adding 10 mg/L ferric chloride, 7 µg/L of Mn is added). WTPs using ferric chloride, or with significant raw-water levels of Mn, should evaluate potential Mn that may be oxidized onto the filter media prior to converting to biological filtration. Mn release chemistry is highly complex and is based on several water quality factors such as pH, presence of oxidants, as well as biological factors (Knocke, 1989).

Although the cause is not immediately clear, it has been observed that some filters – when switched from operating with chlorine to operating in a biological mode – have significantly decreased time of run. For example, MWDSC's WTPs treating 100-percent SWP water have experienced approximately 25-percent reduction in filter run time when chlorine was moved from the filter influent to the filters effluent application point. At this point, no resolve has come to this issue, although initial evaluation has indicated that it is not due to breakthrough of filter turbidity or change in the initial filter headloss, but an increasing of the slope of the headloss buildup rate during the filter run. The increased filter headloss accumulation rate could be due to changes in the chemistry or structure of particles entering the filter (i.e., they are not being oxidized by chlorine) or changes in coagulation chemistry (i.e., chlorine is not reacting with coagulant or filter polymers).

Similar to the MWDCS plants, CCWD (at the Bollman WTP) and SCVWD (at the Penitencia and Santa Teresa WTPs) have added settled water ozone and allowed the filters to operate in a biological mode. Staff from both Districts have not reported any significant changes in their filter run times when their filters were switched to biofiltration mode, although both note that periodic chlorination of the filters is necessary to control excessive biological growth.

No data are available regarding the need for biofiltration downstream of a peroxone process.

3.4 PILOT STUDIES CONDUCTED ON SBA WATER

Water from the SBA has been studied extensively by the three agencies using this water source. Over the past nearly 20 years, there have been six formal pilot-scale studies that evaluated ozone among other treatment technologies. Table 3.2 summarizes these pilot studies.

Table 3.2 – Pilot Studies of South Bay Aqueduct Water that Investigated Ozone

Title	Date of Testing	SBA Agency
South Bay Aqueduct Pilot Plant Studies	August to April 1989	ACWD
Ozonation By-Product Study	October to December 1991	ACWD
Water Quality Regulation Compliance Project	January 1993 to June 1994	SCVWD
Water Treatment Improvement Project – Stage 2	March to September 2000	SCVWD
Altamont WTP Phase 1 Pilot Study	July to December 2005	Zone 7
Altamont WTP Phase 2 Pilot Study	March to September 2007	Zone 7

In all of the studies listed in Table 3.2, ozone was evaluated as the primary disinfectant in lieu of chlorine. All of the SBA ozone systems were designed to achieve at least the necessary 0.5-log *Giardia* inactivation. Also, in all cases, the ozone systems were not intended for *cryptosporidium* inactivation. Control of T&O chemicals, while important, was only one of the objectives for evaluating ozone in these studies. This objective is markedly different from the current project at Zone 7 in which ozone is intended primarily for T&O control, and free chlorine would continue to be used as the primary disinfectant with chloramine as the secondary disinfectant.

One of the objectives of the current project is to compare a T&O-control-only ozone-based process to the disinfection-and-T&O-control ozone process more typical of delta water agencies. It may be that the former would be significantly less costly to construct and operate, but there may be other issues to consider. The existing pilot studies were reviewed for information regarding the “standard” ozonation parameters. The following paragraphs discuss information and conclusions from each of the pilot studies.

3.4.1 South Bay Aqueduct Pilot Plant Studies (CDM 1989)

This 8-month pilot study was conducted from August 1988 to April 1989 and was jointly funded by the three SBA contractors. This study served as the basis for the design of ACWD’s WTP2. The report states that “Ozone was found to be essential if the project’s water quality goals are to be met”. The project goals included meeting the disinfection requirements (0.5-log *Giardia* and 2-log virus inactivation) and keeping THM levels under 20 µg/L, which was consistent with the regulatory climate at the time, as well as removal of T&O causing compounds. During this period of time, there was much discussion regarding the revised THM standards, and numbers as low as 10 – 25 µg/L were being discussed as potential regulated values.

3.4.1.1 Disinfection Byproduct Formation

This study evaluated the impact of ozone and Peroxone on TOC removal. The findings indicated that ozone alone (before coagulation) resulted in some TOC removal. Also, Peroxone resulted in marginally greater TOC reduction than ozone alone (up to 0.3 mg/L difference). With regard to THM formation, Peroxone consistently produced water with higher THM formation compared to ozone alone. These results were based on 2-day THM formation testing with free chlorine – perhaps not relevant for utilities using chloramines. Interestingly, THM formation kinetics were "significantly retarded" by pre-ozonation. The study evaluated formation of other DBPs such as haloacetonitriles (HANs), haloacetic acids (HAAs), and chloropicrin, finding that Peroxone resulted in higher DBP levels than ozone alone. Bromate formation was not evaluated during this study since little was known about it at this time (late 1980's).

3.4.1.2 Taste and Odor Control

With regard to T&O control, geosmin was found to be more readily oxidized than MIB. The first phase of testing involved spiking the water with MIB and geosmin at 100 ng/L. During this phase, an ozone dose of 2.4 mg/L was needed to lower the geosmin levels to under 10 ng/L, and a dose of 3.2 mg/L was needed to reduce the MIB levels to under 10 ng/L. A Peroxone combination of 2.4 mg/L ozone and 0.7 mg/L peroxide was needed for the same level of MIB oxidation (a 25% reduction in ozone dose). During these T&O tests, no attempt was made to meet CT first, the ozone and peroxide were just added for MIB and geosmin oxidation.

Phase 2 pilot testing involved spiking at more "normal" geosmin and MIB levels of 30 ng/L. Percent removals of MIB and geosmin were similar to the first phase: 73% and 85% for MIB and geosmin, respectively. During this second phase, however, only an additional 3 to 5% reduction was observed when high-dose ozone was coupled with hydrogen peroxide.

Phase 3 was conducted with two different ozone doses (2.0 and 3.6 mg/L) and two contact times (3.6 and 7.2 minutes), while MIB and geosmin were spiked at "normal" levels of approximately 30 ng/L. T&O oxidation rates were very similar regardless of contact time, and they concluded that shorter contact times did not have an adverse impact on effectiveness. Times shorter than 3.6 minutes were not evaluated.

Bromide in the raw water was found to significantly impact T&O control performance. When bromide was spiked at 2 mg/L to simulate high-bromide delta water events, geosmin removal fell from 90% to 23%, and MIB removal decreased from 74% to 12%. The addition of peroxide negated this bromide effect – good removals were observed when using Peroxone in spite of high bromide concentrations. This report notes that raw water bromide levels as high as 2 mg/L have been reported in the Delta, based on data from Penitencia between 1982 and 1989.

Based on an evaluation of four separate studies, CDM concluded that for a target MIB reduction of 80%, an ozone dose between 2 and 4 mg/L was needed, depending on the water source. The recommended design dose, assuming a 90% transfer efficiency, was 3.5 mg/L. For disinfection, the raw water ozone dose needed to meet the CT requirements was estimated to be 2.5 mg/L, (and a contact time of 8 minutes) although there was wide scatter in the data. Therefore, the final recommendation was to select a dose of 4 mg/L and a contact time of 8 minutes. It should be noted that this was the total ozone dose – that needed for disinfection plus that needed for T&O control.

3.4.1.3 Process Location and Method of Ozone Addition

The study evaluated various filter media designs as well as the effects of different oxidants on filter performance. Oxidants are thought to alter the nature of the natural organic material and render them more susceptible to removal by subsequent coagulation. Better oxidation was observed when ozone was added to the settled water compared to the raw water, for the same ozone dose. There was significant degradation in filter performance, however, each time the settled water was ozonated (high filter effluent turbidity and short filter runs). Significant improvements in coagulation and filtration were reported when raw water was ozonated. (As further discussed in later sections of this Section, the filtration problems associated with settled water ozonation were resolved, and other agencies have installed and successfully operated settled water ozone systems.)

Compared to chlorine, raw water ozone and Peroxone were both found to yield lower filtered water turbidities, lower settled water turbidities, and longer filter runs when using the same coagulant dose. The optimum ozone dose for filtration was found to be 3.2 mg/L, although it was a function of the coagulant dose. The effect was more pronounced at higher coagulant doses. Tests were also done using an Accelerator (an up-flow solids-contact clarification unit). These tests compared ozone to chlorine as preoxidant. Neither had a noticeable effect on the required coagulant dose. However, ozone was found to yield lower settled water turbidities, lower filter effluent turbidities, and longer filter runs compared to chlorine.

Filters were operated in a biologically active mode. The importance of a short free-chlorine contact time post filtration was noted in order to control HPC bacteria in the filter effluent. Some testing was done comparing ozone and Peroxone in terms of AOC formation. The results were not consistent, which made it impossible to determine whether one process formed more AOC than the other during the pilot study.

Settled water required a lower ozone dose for both T&O control and disinfection. However, settled water ozonation adversely impacted filter performance in this pilot study, perhaps due to non-optimized coagulant dosing. A significant amount of the AOC removal was seen through the coagulation-sedimentation process, not just through the biofiltration process. The study also evaluated the idea of splitting the ozone between the raw water and the settled water. However, it was concluded that this approach did not have a significant advantage over a single point of ozonation.

No investigations were done regarding ozone residual quenching chemicals, since the ozone residual decayed so quickly and was not detectable at the end of the contact times studied.

3.4.2 Ozone By-Product Study (CDM 1991)

This study was conducted from October to December 1991 on SBA water. It was part of an AwwaRF project entitled "*Identification and Occurrence of Ozonation By-Products in Drinking Water*". This study evaluated reduced pH as a bromate control technology, and found it to be highly effective. There was an additional benefit observed: the ozone dose needed to meet the CT requirement in raw water was 4 mg/L at a pH of 8. When the pH was reduced to 6.0, the required ozone dose decreased to 3 mg/L. Figure 3.8 shows the bromate formation under various pH values for a constant level of disinfection (ozone dose varied between 1.6 mg/L and 4 mg/L).

This study also evaluated the addition of ammonia ahead of ozonation to reduce bromate formation. The results were mixed. Under some conditions, bromate formation was reduced when ammonia was added, but not in other cases. This was suggested as an area for further investigation.

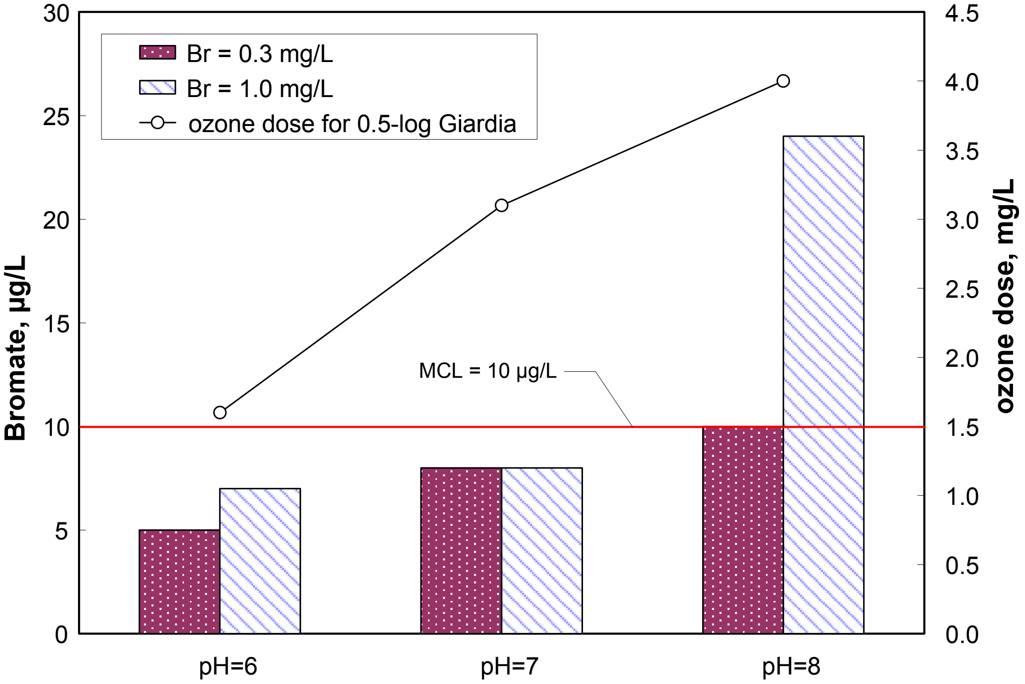

Figure 3.8 – Impact of pH on Bromate Formation For Equivalent Level of Disinfection (0.5- log *Giardia* inactivation)

Similar to the previous study, the relationship between raw water bromide levels and ozone's ability to control T&O compounds was observed in this study. When raw water bromide levels increased, there was a higher ozone dose needed to control T&O compounds. This increase in dose was not seen for Peroxone when raw water bromide levels were increased.

This study found that Peroxone resulted in much higher bromate formation than ozone alone. However, due to the manner in which these tests were conducted, these results are not applicable in Zone 7's case. The study authors increased the ozone dose when using peroxide such that the CT's were constant for both tests. Therefore, the ozone dose was 8 mg/L when using peroxide, compared to 4 mg/L when using ozone alone. In practice, the CT requirement would be met first with ozone only, and then peroxide would be added, which would result in a much lower overall ozone dose and presumably lower bromate formation.

The report contained a cautionary note as follows "*It is of interest to note that the ozone dose requirements during the period of this study were higher than those observed over the 10-month* *period of the South Bay Aqueduct pilot plant studies.*" This highlights the difficulty in capturing all water quality conditions during a pilot study.

3.4.3 Santa Clara Valley Water District's Pilot Study in support of the Water Quality Regulation Compliance Project – Volume 7 – Pilot Study Report (1997) and Subsequent Technical Memorandum regarding Full-Scale Implementation (2000)

This study was conducted by SCVWD and CDM from January 1993 to June 1994. Unlike the study conducted for ACWD, this study's goals for DBP levels were at the regulatory limits (80 µg/L and 60 µg/L for THMs and HAA5, 10 µg/L for bromate, etc.) not the more typical 80% of the limits. Later on, as part of the final TM on the ozone system (November 2000), the DBP goals were listed as half of the regulatory standards (40/30/5 for THM/HAA5/Bromate). Similar to the ACWD study, the goal for the ozonation system was to meet both the disinfection and T&O control objectives while controlling disinfection byproducts.

Ozone was found to be superior to chlorine for pre-oxidation, DBP control, settled water turbidity, coagulant demand, and T&O control. However, filter performance was about the same for both oxidants. Raw water Peroxone was found to have "excellent" T&O control performance at all doses tested, with MIB removals ranging from 93% to 98%, and geosmin removals were all 98% at the doses tested.

3.4.3.1 Disinfection Byproduct Formation

Bromate formation was higher when ozonating raw water compared to settled water. This is expected, because the ambient raw water pH was typically around 8, while the settled water pH was generally less than 7 as a result of the coagulant addition. At high (spiked) bromide levels, this difference between raw and settled water bromate formation was more pronounced. When using ozone to meet CT requirements, settled-water bromate levels were <10 µg/L when the bromide level was elevated (spiked at 0.5 to 0.7 mg/L). When additional ozone was applied to this settled water (1 to 2 mg/L more for T&O control) bromate levels were over 10 µg/L and additional bromate mitigation was necessary.

Ammonia addition ahead of ozone was found to be effective in controlling bromate, and the plants were initially designed with the ability to add up to 0.5 mg/L ammonia ahead of ozone. This is somewhat contradictory to the earlier ACWD pilot study which indicated that ammonia was not consistently effective in controlling bromate formation. A pre-ammonia dose of 0.5 mg/L was found to be effective in lowering bromate levels, although not sufficiently to meet the MCL of 10 µg/L. For raw water ozonation, bromate levels were less than 18 µg/L, and for the settled water they were less than 10 µg/L even under high ozone dose and high bromide conditions. For the full-scale design of the Penitencia WTP, the capability to add ammonia to the settled water was included for bromate control through most of the design process. The anticipated dose was 0.3 mg/L, with a range of 0.1 to 0.5 mg/L. However, the settled water ammonia addition capability was removed from the design near the end of the process, since pH suppression was thought to be sufficient for bromate control.

Under high bromide conditions (up to 0.7 mg/L), and high ozone doses (CT dose +1 mg/L and CT dose + 2 mg/L) it was necessary to lower the pH to 6.0 to keep the bromate levels less than 10 µg/L. This is in contrast to the MWDSC work that found no significant additional benefit in lowering the pH below 6.5. For the SCVWD work, the 6.5 pH bromate results were still above 10 µg/L when the ozone dose was greater than that needed for CT. It was predicted that the

District would need a sulfuric acid feed system for times of very high raw water bromide. However as of late 2007, additional pH suppression has not been needed to control bromate formation (see full scale bromate data below).

Interestingly, the type of filter media was found to have an impact on bromate levels. The GAC filters consistently produced water with bromate 15 to 30% lower than the anthracite filters. No explanation was given for this difference in media type.

Spreading the ozone dose out between multiple cells within the contactor was not consistently effective in lowering the bromate formation. Also, changing the percent ozone in the feed gas was not effective. It was recommended that the ozone addition scheme be further investigated at full scale due to the unique hydrodynamics of each ozone contactor.

3.4.3.2 Taste and Odor Control

Raw water ozonation was found to provide better T&O control than settled water ozonation. Because the objective for ozonation was both disinfection and T&O control, these tests were structured such that the disinfection requirements were always met first, and then the amount of additional ozone needed for T&O control was evaluated. For meeting the disinfection requirements, an ozone dose of 3 mg/L was needed for the raw water, and 1.5 mg/L for the settled water.

The use of peroxide was evaluated in this study, and it was found to improve T&O control. Peroxide was used in a second ozone application after disinfection already was achieved with ozone alone. The relative contributions of the ozone-alone and Peroxone portions of the contactor were not quantified. Contact times evaluated ranged from 7 to 11 minutes. The testing indicated that between 0.7 and 1.6 mg/L ozone was needed for settled water disinfection, and 0.5 to 1.0 mg/L additional ozone (beyond the CT dose) was needed for T&O control. Therefore, the recommended full-scale plant design criteria included 2.0 mg/L maximum ozone dose in the settled water. Raw water ozone doses to meet 0.5 to 1.5 log *Giardia* inactivation ranged from 2 to 4 mg/L for raw water, which was consistent with the ACWD testing results.

Hydrogen peroxide was added to the fourth cell of the contactor, so that CT could be met in the first three cells. MIB and geosmin were spiked at 100 ng/L. Raw water ozone doses between 1 and 4 mg/L were used, and MIB removal varied from 93% to 98%. Removal rates for MIB in the settled water were not as high, presumably due to the lower pH, which is known to hinder formation of hydroxyl radical. Ozone doses of 2 and 4 mg/L were used, and MIB removal was 56% and 84% for these two doses. Geosmin removal under these conditions was 71% to 92%. Adding peroxide did not affect T&O control in the raw water, since excellent removal of T&O chemicals was achieved with ozone alone at the doses tested (>90%). Ozone to peroxide ratios between 1:1 and 10:1 were tested, but the ratio did not seem to matter – MIB removal was about the same at all ratios tested. For settled-water ozonation, the GAC/sand filter performed better for MIB and geosmin removal compared to the anthracite/sand (15 to 35% better). MIB and geosmin removals through the deep bed GAC filters were better, but this was relatively fresh carbon and there was likely some adsorption of these compounds

The overall conclusion of the study was that even at low ozone doses between 2 and 4 mg/L in the raw water, excellent (>90%) T&O removal can been achieved without pH adjustment. However, this was not feasible due to the concern over bromate formation. For settled-water ozonation where the ozone dose required for CT compliance was between 1 and 2 mg/L, peroxide addition may be necessary after the disinfection goal is met in the early stages of the contactor. The full-scale peroxide feed system at SCVWD was designed to add between 0.2 and 1.5 mg/L to the seventh or eighth cell of the full-scale contactor.

3.4.3.3 Process Location and Method of Ozone Addition

Both raw water <u>and</u> settled water ozonation were found to produce excellent filter performance. This is inconsistent with the ACWD pilot testing which showed that settled water ozonation led to poor filter performance. The authors noted this discrepancy, and stated that careful control/adjustment of the coagulant dose was critical, and this was not done during the ACWD testing. Also, the filter aid polymer dose is very important when ozonating settled water. This pilot study indicated that a pre-oxidant is needed for optimizing filter production.

In order to achieve the disinfection goals, the ozone dose needed for raw water ozonation in this study was double that needed for settled water ozonation. Also, the dose needed was more variable when adding ozone to the raw water. This was mainly due to the variation in raw water pH values, whereas the settled water pH is much more stable.

Filtered water ozonation (followed by GAC contactors) was briefly considered at the beginning of this project. It was eliminated from further consideration because "*filtered water ozonation did not offer any reductions in ozone dose requirements for CT compliance nor any benefits for bromate control when compared to settled water ozonation.*"

The study also evaluated the removal of atrazine and 2,4-D with ozone and Peroxone. Ozone was effective, particularly with peroxide addition at higher pH values, but peroxide was necessary to ensure greater than 80% removal at the ozone doses required for disinfection.

Similar to other work, ozone was found to greatly increase AOC levels, both raw water and settled water ozonation. Biofiltration was found to reduce these concentrations to similar levels as the raw water. The authors noted the following:

> *"…the exact impact of higher AOC levels in the District's distribution system, which is chloraminated, is difficult to forecast. LeChevallier et al (1995) however, found that in a survey of 31 water systems, AOC levels greater than 118 µg/L in free chlorinated systems resulted in higher HPC levels and more positive coliform results than in systems with AOC levels below 82 µg/L. Other research by Van Der Kooij and Hijnen (1985) reported that HPC levels may be limited in waters with AOC levels less than 80 µg/L, while LeChevallier et al. (1990) reported that AOC levels greater than 50 µg/L were associated with increased incidence of coliforms. Note that no regrowth problems have been reported for the distribution system served by ACWD's WTP No. 2, which consistently has finished water AOC levels above 200 µg/L. (1995 data)."*

Both raw and settled water ozonation produced good filter effluent quality and good UFRVs. Turbidity and particles were consistently lower with raw water ozonation compared to settled water ozonation, but both met the project goals. Raw water ozonation was found to increase coagulation requirements (this is not consistent with the ACWD study and full-scale experience), and often resulted in marginally lower TOC removal. Turbidity breakthrough was a particular problem for settled water ozonation, but with careful coagulant control, this was avoided. It was noted that EBMUD, the City of Martinez, and Contra Costa Water District all modified conventional plants to use settled water ozonation, and none of them experienced filtered water turbidity breakthrough problems like those seen in the pilot study. Full scale filter performance at the Penitencia WTP has been good since the ozone system has been on line.

The sulfuric acid feed system was designed to lower the pH to 6.0. The acid dose ranged from a minimum of 5 mg/L and a maximum of 30 mg/L (average of 20 mg/L). As part of the project, SCVWD up-sized the caustic feed system in anticipation adjusting for the low pH needed for bromate control (typical pH leaving the plant is approximately 7.8).

3.4.4 Additional Pilot Testing by SCVWD for design of Phase 2 project (CDM, 2000)

This testing was intended to follow-up on the previous work, and was conducted from March through September 2000. The overall goals of the follow-up study were slightly different from those of the previous work. The disinfection focus was only *Giardia* inactivation as it was clear by that time that *cryptosporidium* inactivation would likely not be required. If it were, UV would be a better choice than expanding the ozone system. Another change was investigating ways to keep bromate below 5 μg/L, instead of the 10 μg/L goal adopted in the previous work.

An ozone dose as low as 0.5 mg/L was sufficient to meet the disinfection requirements in most cases. The maximum dose of 2.0 mg/L was confirmed as sufficient to handle T&O concerns when coupled with peroxide addition. Ozone alone at this dose was not capable of reducing T&O chemicals to acceptable levels. The testing found that adding hydrogen peroxide along with a second-stage ozone dose (after meeting CT in the first stage) significantly improved the destruction of these compounds. The required peroxide dose was a function of ozone dose and pH. The calculation of the peroxide dose is as follows: the second-stage ozone dose is multiplied by a number between 1/3 and 1, depending on pH, and then the remaining ozone residual from the first stage is added to this number to determine the peroxide dose. Contact time for these reactions was four minutes or less.

This study also evaluated ammonia addition for bromate control. An ammonia dose of 0.5 to 1.0 mg/L to the settled water was confirmed to reduce bromate formation to 5 μg/L or less under disinfection conditions.

Under most situations, the pH reduction resulting from the use of ferric chloride for coagulation was sufficient to maintain low bromate formation with intermediate ozonation. However, under high raw water bromide conditions, further pH suppression was needed, and they recommended using sulfuric acid rather than adding more ferric. A target pH of 6.0 was needed to keep bromate below 5 μg/L when raw water bromide levels exceeded 0.6 mg/L. Ammonia addition also helped reduce bromate, in lieu further reducing the pH to 6.0. Even at a pH of 6.8, the addition of ammonia helped maintain bromate below 5 μg/L at an ozone dose of 2.5 mg/L when bromide was as high as 0.5 mg/L.

The addition of an ozone quenching chemical at the end of the contactor was found to be necessary when pH was reduced to 6.0 because of the long-lasting ozone residual and the fact that the contact time was limited to only 8 minutes at design flow. The use of peroxide for ozone quenching was investigated, but this was found to be inadequate due to the excessive reaction time and potential for excess peroxide doses to exert a chlorine demand. Therefore, the peroxide system was designed just for advanced oxidation, not ozone residual quenching. Other ozone residual quenching chemicals and their necessary contact times were evaluated, and calcium thiosulfate with a 2-min contact time was identified as the best option. The necessary dose was one to three times the ozone residual (on a weight basis) present at the point of quenching.

Hydrogen peroxide dose for advanced oxidation was selected at 0.2 to 0.5 mg/L. The addition of peroxide was found to increase bromate formation, but the results were not consistent. Bromate formation seemed to vary with raw water source and other operational factors. The study authors called the relationship "difficult to assess" and stated that peroxide may increase or decrease bromate formation.

3.4.5 Zone 7 Altamont Design Pilot Studies

Pilot testing was done as part of the process selection for the Altamont Water Treatment Plant. Testing was conducted between July and December 2005. However, ozone testing was limited because the primary focus of the pilot study was on the performance of the membranes.

The authors concluded that post-membrane ozone application effectively oxidized geosmin and MIB. At ozone dosages required to meet disinfection requirements (0.5-log *Giardia* inactivation), MIB destruction was about 50 percent, whereas higher ozone dosages were required for higher destruction levels. Bromate formation was effectively controlled by lowering the pH of the feed water to the ozone system to less than 7.0.

The pilot plant demonstrated 49% to 83% destruction of MIB while applying ozone-only to the filter effluent at disinfection-level doses (0.6 to 1.3 mg/L) with the highest doses resulting in the highest removal percentages. The pilot plant was not spiked with MIB, it was naturally-occurring in the raw water during part of the study. No peroxide testing was done.

This study include one day of bromate mitigation testing (December 20, 2005). Three pH values were tested, ranging from ambient (7.7) to 6.4. When the pH was lowered to 7.1, the bromate formed was reduced to less than 5 µg/L. No additional ozone doses were tested other than that needed for CT compliance (1.0 – 1.1 mg/L). The raw water was not spiked with bromide, and the ambient bromide level on the day of testing was not reported in the study. However, according to ACWD's historical records, the SBA bromide level at that time was approximately 0.4 mg/L.

This study recommended installation of post-ozone GAC contactors in order to reduce the concentrations of biodegradable organic matter produced by the ozonation process. Two individual AOC samples were collected from the ozone contactor effluent at the pilot plant. These values were reported to be 170 and 120 µg/L. Two additional AOC samples were collected from the effluent of the biologically active GAC contactors, and these samples contained 100 µg/L and 110 µg/L of AOC. The AOC level in the effluent from the Patterson Plant was reported to be <10 µg/L, however this sample result is suspect. As described above for the work at ACWD and SCVWD, typical treated water AOC levels are generally between 100 and 200 µg/L.

As shown in Table 2, an additional phase of pilot testing for the Altamont WTP was done between March and September of 2007. As with the first phase, the primary focus was on the performance of the membrane system, and ozone testing was limited. A final report is not yet available for this second phase pilot test.

3.4.6 Other Studies and Ozone Plants

An AwwaRF tailored-collaboration project called "*Advanced Water Treatment of Estuarine Water Supplies*" included a pilot study at one of SCVWD's facilities in Los Gatos using SBA water during a 7-month period from September 2005 to March of 2006 (Briggs et al., 2007). The study focused on various disinfectant combinations, including ozone, and their ability to limit formation of byproducts. The study was not focused on T&O control, however, and very little T&O data were collected. Chlorine dioxide was used ahead of ozone, and was found to greatly limit, and in some cases completely prevent, the formation of bromate, even under high raw water bromide concentrations (up to 0.8 mg/L).

After the 1989 SBA pilot plant study was completed, Zone 7 commissioned a follow-up study by CDM in 1991 called "*Ozone Feasibility Study*" which was meant to evaluate the requirements and costs for installing ozone at the Del Valle and Patterson water treatment plants. No further pilot testing was done. The expected costs were found to be 7.7 to 13 million dollars for Del Valle, and 6.6 to 8.6 million dollars for Patterson (1991 dollars). An ozone dose of 4 mg/L and a contact time of 8 minutes was recommended for both plants. Raw water ozonation was recommended for both plants. They anticipated that hydraulic losses in piping and contactors would exceed available head, so intermediate low-lift pumping would be needed at both plants. This study indicated that the available head at both plants upstream of the flash mix was about six feet, and that the ozone contactor would take about eight feet.

Several surface water treatment plants in the Bay Area have added ozone to the settled water of existing conventional plants without intermediate pumping. These include East Bay Municipal Utility District's Upper San Leandro WTP and Sobrante WTP, Contra Costa Water District's Bollman WTP, and Santa Clara Valley Water District's Penitencia and Santa Teresa Water Treatment Plants. In the basis-of-design report for the SCVWD ozone project (CDM, 2000), which includes the calculated hydraulic profiles through the plants, the headloss through CCWD's Bollman contactor is referenced as 0.5 feet, and no intermediate pumping was required. The headloss across the 8-cell contactor at Penitencia is 0.9 feet, while that at Santa Teresa's contactor is 0.6 feet. These values are just through the contactors, they do not include yard piping, since the units are adjacent to each other. The DAF unit recently installed at the Del Valle WTP was designed to accommodate intermediate ozone without additional pumping. The Altamont WTP is designed for intermediate (post-membrane) pumping.

3.5 FULL SCALE EXPERIENCE WITH OZONATION OF SBA AND DELTA WATERS

There are two surface water treatment plants currently using ozone to treat water from the South Bay Aqueduct, and two additional plants are in the design stage. Information regarding these plants is summarized in Table 3.3.

Table 3.3 - Treatment Plants using Ozone for South Bay Aqueduct Water

Utility and Facility Names	Ozone Addition Point	Ozone On-Line Year	Plant capacity, mgd	Design Ozone Dose (mg/L)	Design Ozone Contact Time (min)
Zone 7, Altamont	Post-membrane, pre-GAC	~2010	24	1.2 average 2.0 maximum	10
ACWD – WTP2	Raw water	1993	28	4.0	13
SCVWD, Penitencia	Settled water	2006	42	1.5 (for CT) 2.0 (for T&O)	8
SCVWD, Rinconada	Settled water	~2013	80 (100 future)	1.5 (for CT) 2.0 (forT&O)	8

ACWD has been operating their raw-water ozonation facility since 1993. District staff report excellent control of T&O-causing compounds by this plant (Chun, 2007). Since the installation of a carbon dioxide (CO_2) feed system in early 2002, the plant has consistently been able to comply with the bromate MCL. Figure 3.9 includes the instantaneous bromate measurements taken from the plant effluent approximately every week since the plant came on line. Note that these individual data points are not compliance samples – compliance with the MCL is calculated as a rolling annual average, and is based on a single monthly sample. These data demonstrate that compliance with the bromate MCL can be achieved when using raw water ozonation on SBA water if a control technology such as pH suppression is used.

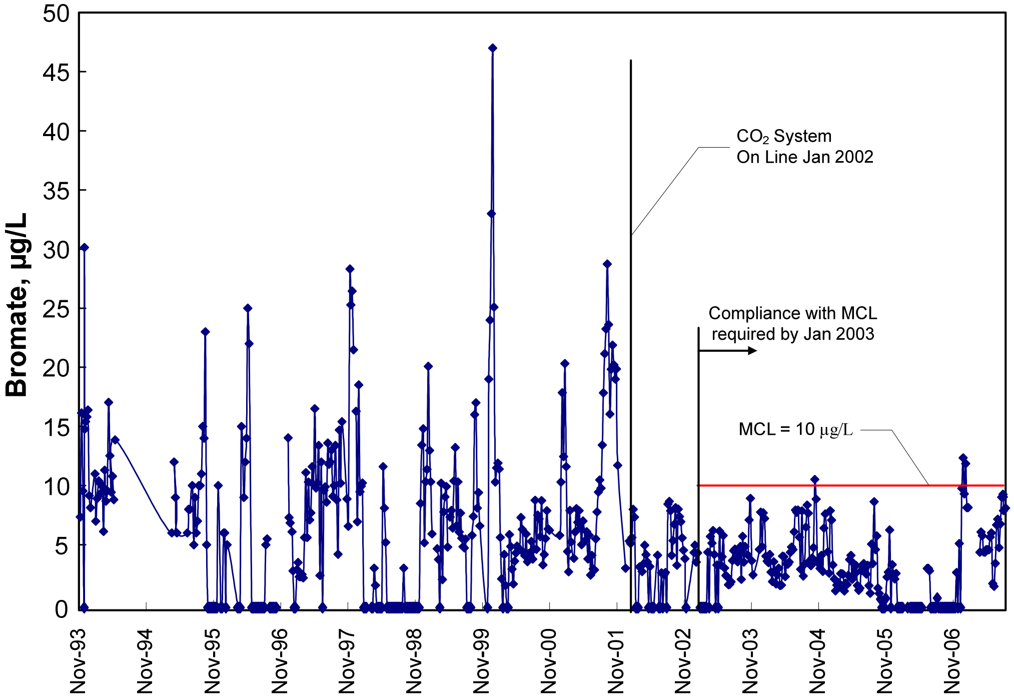

Figure 3.9 – Measured Plant Effluent Bromate from Water Treatment Plant No. 2 (note that MCL is based on Rolling Annual Average)

Since the carbon dioxide feed system was placed into service, the average ozone dose required for disinfection compliance has decreased. This was expected due to the greater persistence of the ozone residual at the lower pH values. However at times, the ozone dose required was higher than the design dose (this is possible by reducing the plant flow rate). Higher ozone doses have been used to control T&O events and resolve filter clogging problems caused by algal blooms in the source water. Table 3.4 includes the average, 99th percentile, and maximum recorded ozone doses for the past five full calendar years.

Table 3.4 – Ozone Dose data for Water Treatment Plant No. 2, in mg/L

Calendar year	Average dose	99th percentile dose	Maximum dose
2002	1.63	2.60	2.93
2003	1.86	3.40	3.58
2004	2.21	4.31	5.22
2005	2.25	6.21	7.50
2006	2.21	2.79	4.21

There are limited data regarding AOC formation from WTP2. During the spring and summer of 1995 some sampling was done and the results are shown in Figure 3.10. These data indicate that the ozonation process increased AOC levels significantly compared to the raw water levels, but that the filter effluent AOC levels were reduced to near those of the raw water. ACWD reports that they do not experience bacteriological regrowth problems in the areas of the distribution system supplied by WTP2 even though the measured AOC levels were much higher than that suggested in the literature as being associated with this type of problem (>50 to 100 µg/L). It is significant that ACWD's distribution system generally has relatively short detention times compared to Zone 7, and that their tanks and reservoirs are turned over regularly, and they have a rigorous distribution system flushing and tank cleaning program. Also, they have an extensive nitrification monitoring and response program. These factors all contribute to the low incidence of nitrification and regrowth problems for ACWD.

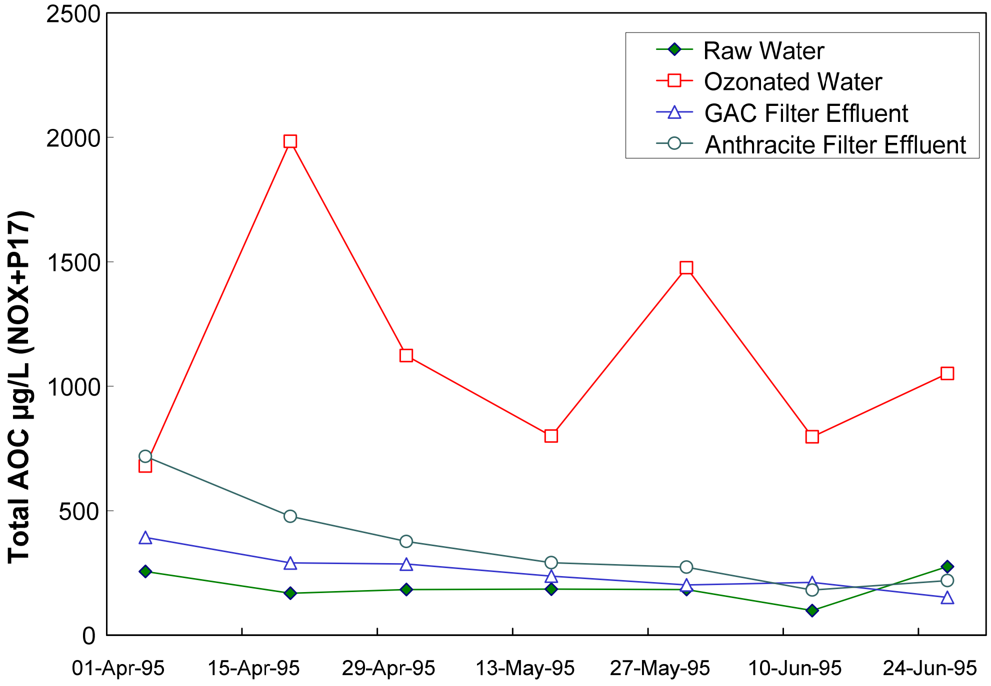

Figure 3.10 – Measured AOC from ACWD Water Treatment Plant No. 2

SCVWD's Penitencia plant began adding ozone to the settled water in early 2006. District staff report no T&O problems in the area served by this plant since the ozone system has been on line. Figure 3.11 includes the bromate data from the effluent of the Penitencia plant since the startup of the ozone system. Similar to the data in Figure 3.9, these are individual sample results collected each week, and not rolling annual averages based on monthly data. These data indicate that compliance with the bromate MCL can be achieved when ozonating settled water from the SBA. During the time shown on this graph, raw water bromide levels varied between 0.06 mg/L and 0.48 mg/L. It is noted that the single high value reported in October, 2006 was the result of testing the hydrogen peroxide feed system and an associated, very high, ozone dose. Similarly, the high result reported in August 2007 was also related to an incident with the hydrogen peroxide feed system. Also note that no sulfuric acid has yet been used, nor has ammonia been fed to the settled water for bromate control. The pH reduction resulting from the addition of alum (the plant's primary coagulant) has been sufficient to maintain bromate levels at less than the standard. The pilot work on which this system was based was all done using ferric chloride instead of alum as the primary coagulant; SCVWD has no immediate plans to switch the full-scale plants from alum to ferric.

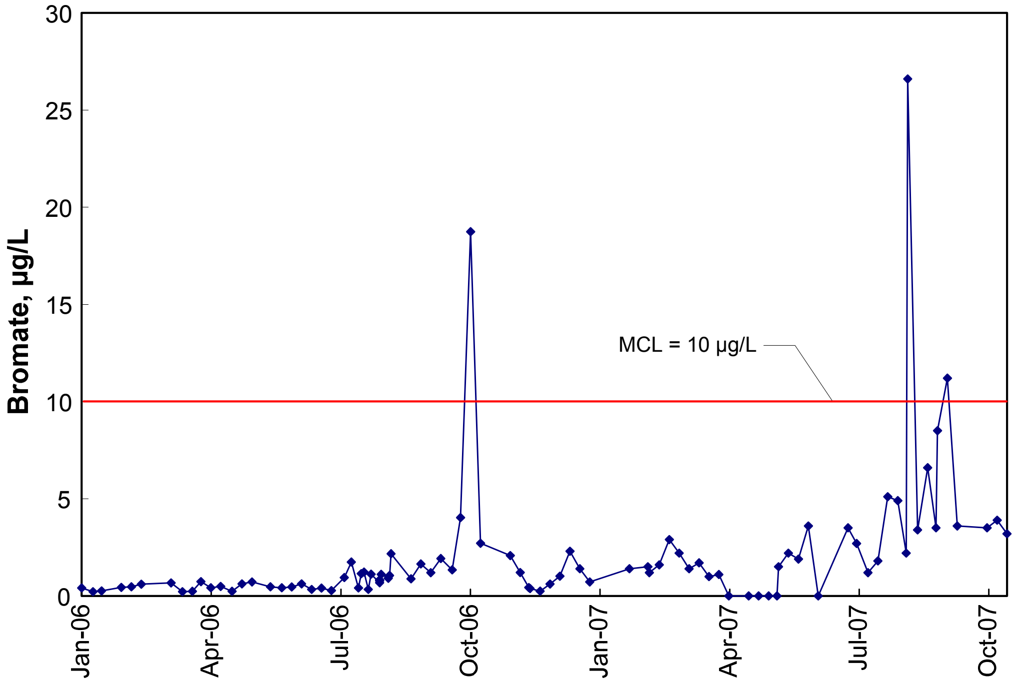

Figure 3.11 – Measured Plant Effluent Bromate from Penitencia WTP (note that MCL is based on Rolling Annual Average)

For the Penitencia system, the average ozone dose during the second half of 2006 was 1.0 mg/L, with a maximum of 1.7 mg/L. For January through October of 2007, the average has been 0.8 mg/L, with a maximum of 1.5 mg/L. The 0.5-log *Giardia* inactivation requirements are met with ozone whenever the ozone system is on line.

Consistent with the pilot plant studies, SCVWD staff reported that careful control of the filter aid polymer system is very important for full scale settled water ozonation in order to avoid turbidity breakthrough problems. SCVWD is currently using a non-ionic polyacrylamide (Polydyne N120P) as a filter aid, and report good success with this chemical when fed as a filter aid at the Penitencia WTP. When the ozone system is off line, this filter aid is not as important for good filter effluent quality.

Both the ACWD plant and the SCVWD plant were designed to use ozone in two separate areas within the ozone contactors. The first few cells were intended for disinfection, while the downstream cells were intended for advanced oxidation via the addition of hydrogen peroxide. It is interesting to note that, although both plants received deliveries of hydrogen peroxide into their tanks and tested the storage and feed facilities, neither has used peroxide to control taste and odor events. Both agencies report adequate control of T&O compounds when using ozone to meet their disinfection or pre-oxidation requirements. This is similar to the experience of CCWD at the Randall Bold WTP, were peroxide was added but later removed from the tank.

Finally, Table 3.5 provides a summary of several other full-scale WTPs in the Bay area using ozone to treat water originating from various locations within the Delta system. There are some significant differences in raw water quality among these various plants due to the locations at which water is drawn from the Delta and the influence of local storage reservoirs.

Table 3.5 - Other Bay Area Plants Using Ozone for Treating Delta Water (Not from the SBA)

Plant	Source Water	Location of ozone in process	Year ozone on line
SCVWD – Santa Teresa WTP	San Luis Reservoir	Settled water	2005
CCWD – Bollman WTP	Contra Costa Canal and Los Vaqueros Reservoir	Settled water	1999
CCWD – Randall Bold WTP*	Contra Costa Canal and Los Vaqueros Reservoir	Settled* and filtered water	1992
City of Vallejo – Fleming Hill WTP	North Bay Aqueduct	Raw and settled water	1994
Cities of Vacaville and Fairfield – North Bay Regional Plant	North Bay Aqueduct	Raw and filtered	1990
City of Napa – Jamieson Canyon WTP	North Bay Aqueduct	Raw water	2010 (projected)
City of Martinez	Contra Costa Canal and Los Vaqueros Reservoir	Settled water	1991

* Sedimentation basins added in 2007, the former raw water ozonation contactor was re-piped to be settled water ozonation, post-filtration ozone is original

3.6 SUMMARY

The purpose of the review reported in this Section was two-fold: First, to summarize the experience of other agencies in the design and operation of ozone and/or Peroxone systems for T&O control, and second, to identify any gaps in the data or information available to help focus the pilot testing effort and maximize the benefits of its results. The outcome of this review can be summarized as follows:

1. Ozone and Peroxone are effective for T&O control. Ozone and Peroxone have been demonstrated to be effective in destroying chemicals that cause taste and odor in water, particularly MIB and geosmin. There is much experience with the design and operation of such systems for treatment of Delta water, and there are several examples of successful full-scale plants using ozone for water treatment. The data on Peroxone is mostly limited to pilot scale studies, but these studies indicate effective control of T&O causing compounds with this chemical combination.

2. Bromate formation is a significant issue when using ozone. When implementing ozone, either alone or as Peroxone, the most significant issue in treating SBA water is bromate formation. Some sort of bromate mitigation strategy is needed when using ozone to ensure that the MCL is not exceeded. This is being done successfully by the two other SBA contractors. The extent to which bromate formation is an issue with a Peroxone-only application is not known.

3. Ozone is used primarily for disinfection; data on T&O-only (peroxone) applications is lacking. All of the ozone plants reviewed use ozone primarily for disinfection of Giardia and viruses and secondarily for the control of T&O chemicals. Most plants also realize other operational benefits such as improvements in the conventional treatment process and oxidation of other micro-pollutants. There are no examples of T&O-only ozone installations for treatment of Delta water, nor any examples of intermittent ozone use.

4. The best location for ozone in the process is not apparent. Regarding placement of the ozone process, the reviewed literature does not indicate whether water quality factors favor one location over another. Moving the ozone addition from the raw water to a more intermittent location has been shown to form similar levels of downstream chlorinated DBPs, but has not been shown to have a significant effect on the coagulation process or on filtered water quality. Ozone doses for similar levels of disinfection are lower in settled water, but T&O control performance is poorer at this location compared to raw water.

5. The ideal contactor design and peroxone addition scheme are not apparent. Contactor designs vary depending on whether or not disinfection credit is required. If disinfection is not necessary, hydrogen peroxide may be added simultaneously with ozone to generate $OH^{\bullet}$ (destroying ozone residual) for oxidation of T&O causing compounds. A 0.2 Peroxone ratio (hydrogen peroxide:ozone dose) has been shown to provide effective treatment of T&O compounds in Delta water with an ozone dose of about 3 mg/L. Peroxone designs may include single-cell concrete structures or in-pipe injection followed by pipeline contact to minimize construction cost of building large concrete contact basins. If pipe-injection is used, utilities have installed off-gas structures downstream with capability to destroy ozone off-gas. The effects of an intermittent, Peroxone-only system on bromate formation and on downstream treatment processes are not known.

6. Several full-scale peroxide applications have been built but subsequently removed from service. It is telling that all of the agencies that have designed and built hydrogen peroxide storage and feed systems to be used in conjunction with ozone for treatment of Delta water, are not using these systems. Ozone alone, when used to meet the disinfection requirements, has been adequate for controlling T&O chemicals that have been present in water entering these full-scale facilities. Furthermore, all of these systems use biofiltration downstream of the ozone contactors, and it is not known if ozone-only—or a combination of ozone and biofiltration—has been responsible for the control of T&O compounds at these facilities. A developing problem with the use of biofiltration that is very plant-specific is the issue of reduced filter run time when chlorine is discontinued ahead of filters. This issue is an area needing additional research.

7. Post-ozone biofiltration may or may not be required. If Peroxone is operated intermittently throughout the year, biofiltration may not be necessary to reduce BOM prior to entering the distribution system. If Peroxone is used continuously, then biofiltration may be needed, but this also is not clear. Based on the review reported herein, it is possible to prevent biological growth in the distribution system without biofiltration by maintaining an adequate disinfectant residual in the distribution system. However, when water is passed to other water wholesalers or retailers, it is unknown how those secondary systems will be affected. In these downstream systems, increased BOM may have detrimental effects. Biofiltration can also be an aid in controlling hydrogen peroxide residual, if there is excess following the Peroxone process.

8. Many pilot studies using ozone have been performed on SBA water. These tests show that CT can be effectively achieved while DBPs are kept below their regulated MCLs. However, the results show that Peroxone may increase THM/HAA levels when compared to ozone alone. Bromate can be controlled by a variety of methods. However, it is likely that the Peroxone process will be less effective at T&O control if acid is used to control bromate (assuming that bromate is an issue with peroxone, which is not known at this point). This is because reduced pH retards the formation of $OH^{\bullet}$, the driving force in Peroxone's T&O destruction capabilities. Both ammonia-alone and the chlorine-ammonia process have the potential to control bromate when ozonating SBA water. However, their impact on T&O destruction with ozone or Peroxone are not known.

Based on the analysis presented in this Section, the following gaps were identified in the available information when it comes to the application of ozone or Peroxone for Zone 7's Taste and Odor Control installations:

A. While there is ample information on the design and performance of conventional ozone systems, there is no information on the operation and performance of a Peroxone-only system for surface water treatment.

B. There is little understanding of whether disinfection credit could still be achieved with a Peroxone process since earlier work focused on meeting the disinfection goals upstream of the addition of hydrogen peroxide.

C. There is limited information on the levels of biodegradable organic matter formed with Peroxone alone, and whether these levels would necessitate biological filtration.

D. Data on the formation of bromate with a Peroxone process are inconclusive. In addition, the bromate mitigation strategies of pH depression or pre-chloramination have all been tested on ozone only, and not on a Peroxone process.

E. While T&O destruction with Peroxone is well documented, it is not clear whether the performance of the Peroxone process for T&O control would greatly diminish when coupled with a bromate mitigation strategy.

The information identified above is important for the decision on the design and operation of the Peroxone systems that may be implemented at Del Valle and Patterson Pass WTPs. The pilot testing plan was designed to fill in some, if not all, of these gaps.

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SECTION 4.0 –
PILOT TESTING PLAN

This section presents the detailed pilot testing plan developed in advance of the pilot testing activities.

4.1 PILOT EQUIPMENT SETUP

The pilot plant was installed at the Del Valle WTP in Livermore and operated from May to October 2008. The pilot plant consisted of two parallel trains: a conventional ozone contactor and a pipeline Peroxone contactor. The conventional ozone train was designed to mimic the type of standard over-under baffled contactors used by SCVWD and ACWD. At a flow rate of 6.5 gpm, the hydraulic residence time (HRT) through this contactor was 10 minutes. The pipeline contactor was designed to mimic a pipeline in which ozone and hydrogen peroxide are added in-line. At a flow rate of 3.5 gpm, the pipeline contactor had an HRT of 2.6 minutes. Figures 4.1 and 4.2 are schematic drawings of the two trains in the pilot plant. There was a holding tank upstream of the two parallel contactors; downstream of the tank, the flow split into the two separate contactors.

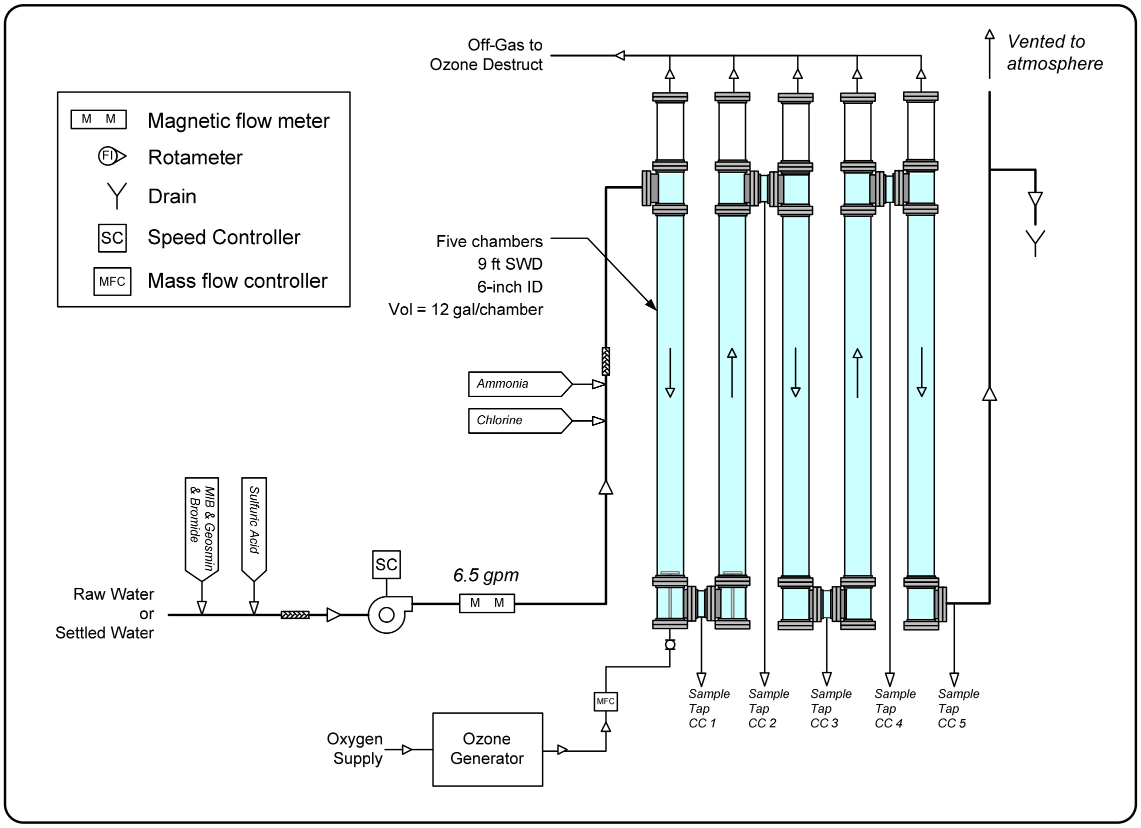

Figure 4.1 – Schematic of Conventional Contactor Showing Chemical Injection Points and Sampling Locations

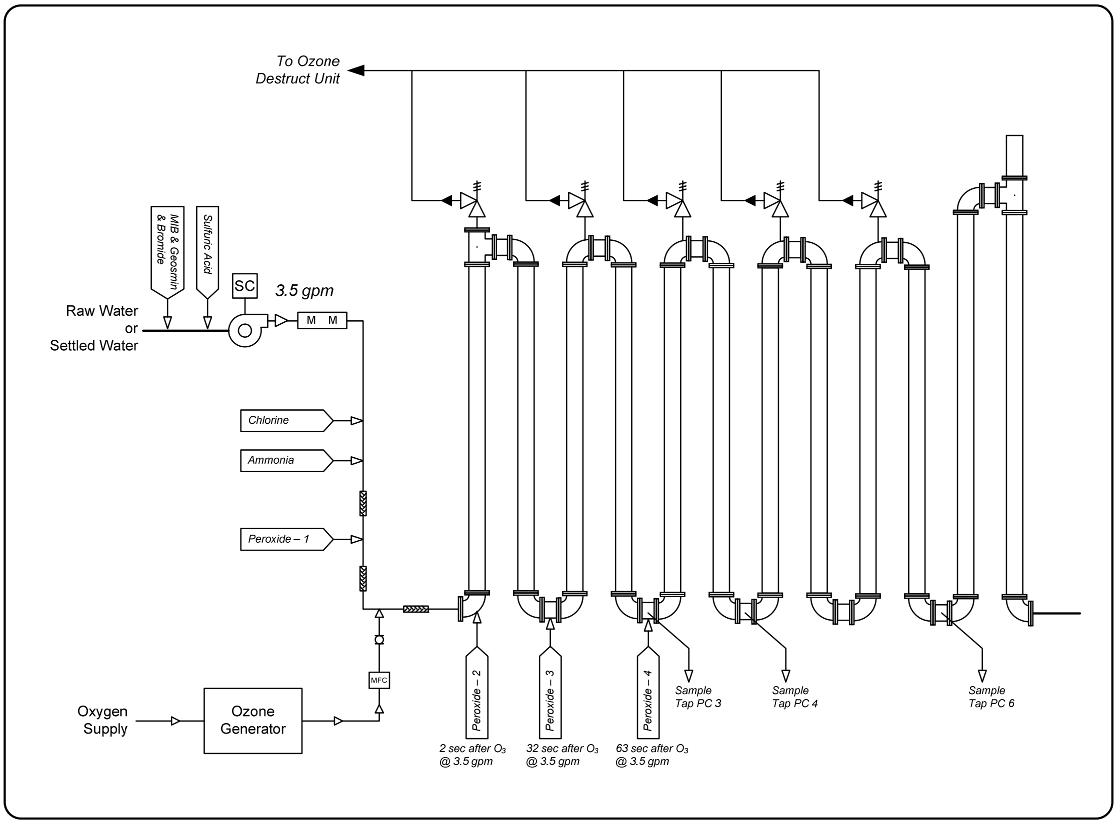

Figure 4.2 – Schematic of Pipeline Contactor Showing Chemical Injection Points and Sampling Locations

4.2 PILOT TESTING PROGRAM

The ozone or Peroxone process could be inserted at the raw, settled, or filtered water locations at the Del Valle WTP, or at the raw or filtered water locations at the Patterson Pass WTP. In order to determine the best application point, several questions had to be answered (these apply to each potential injection location):

1. *What ozone (alone) dose is necessary for T&O control?*
2. *What ozone (alone) contact time is necessary for T&O control?*
3. *How much less ozone is used with Peroxone (vs. ozone alone) for T&O control?*
4. *How does Peroxone affect the contact time (vs. ozone alone) for T&O control?*
5. *What is the optimum ratio of ozone:hydrogen peroxide for T&O control?*
6. *What levels of chlorinated byproducts can be expected when using ozone or Peroxone for T&O control followed by free-chlorine for disinfection?*
7. *What levels of bromate can be expected when using ozone or Peroxone for T&O control?*
8. *Do high bromide levels affect the efficiency of T&O control methods?*

9. *Do high TOC levels affect the efficiency of T&O control methods?*
10. *What is the impact of bromate-control technologies on T&O control performance?*
11. *What are the impacts on the downstream chlorination processes?*

Based on a review of work done by others (see Section 3 – Literature Review) it was assumed that the performance of ozone and Peroxone in settled water would be very similar to that of filtered water. Therefore, only the raw and settled waters were tested during this study, not filtered water. All findings related to settled water performance (ozone dose, contact time, etc.) will be assumed to be the same for a filtered-water application.

In addition to gathering information about T&O control, one of the objectives of the pilot study was to gather information on the stability of the Peroxone process in SBA water. The variability of the pH and temperature in this water has been discussed in this Report, and is highly important to monitor and assess during this testing. Figure 4.3 includes data from ACWD's ozone plant showing the measured raw water pH and temperature over a four-day period in the summer. This type of diurnal variability is also observed at the Del Valle WTP (the variability is not as pronounced at the PPWTP because of the raw water reservoir). Figure 4.4 includes data from ACWD for the same four-day period showing the measured variation in ozone residual. During this time, the ozone dose was constant. The stability of the ozone residual in water is highly dependent on both temperature and pH. As the pH and temperature rise, the rate at which the ozone residual decays increases. Therefore, for a constant ozone dose, the ozone residual measured at a fixed sampling point will vary.

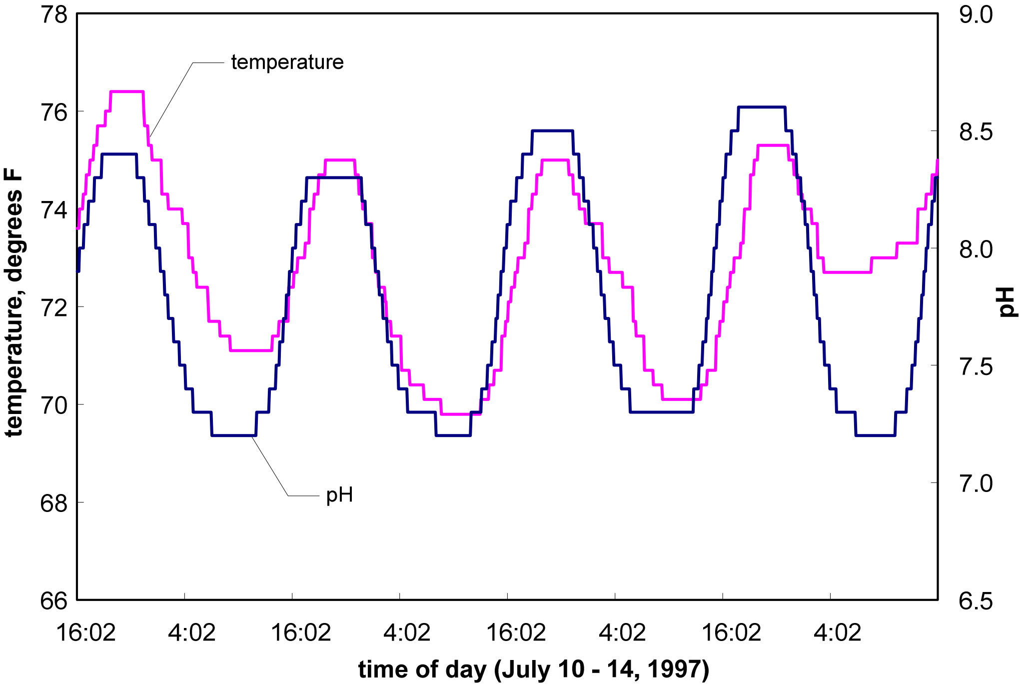

Figure 4.3 – Raw Water pH and Temperature Variability in SBA Water (ACWD 1997)

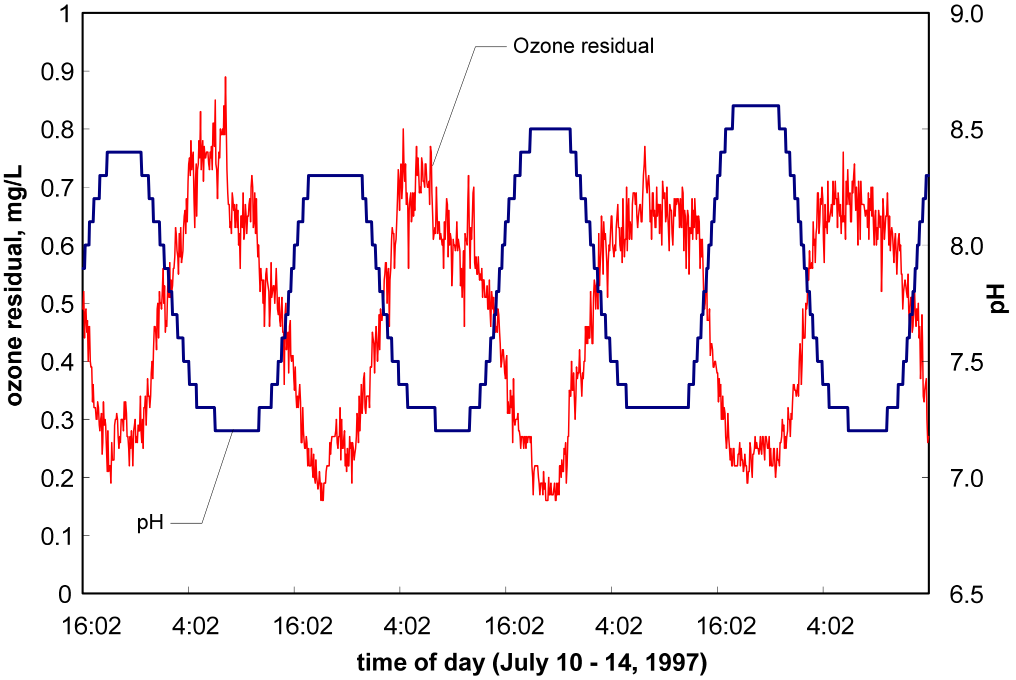

Figure 4.4 – Sample of Ozone Residual Variability in SBA Water (ACWD 1997)

This degree of variability in the ozone residual may make controlling a Peroxone system challenging. Several options for process control may be used, such as pacing the peroxide feed off the measured ozone residual, or adjusting the pH ahead of the ozone process in order to stabilize the ozone residual. It is not known if this type of variability will be observed when hydrogen peroxide is added ahead of the ozone, nor whether chloramine addition (a potential bromate control technique) will impact the results. Further, since this is a T&O control application and not a disinfection process, this type of variability may not be important. It may, however, have implications for the downstream processes (e.g. chlorine demand) and bromate formation. Finally, it is important to characterize the remaining ozone residual at various times to ensure that the design of the contactor does not allow for the presence of any unacceptable levels of ozone in the water leaving the contactor.

The pilot testing was conducted during the period of May through October of 2008 (a total of six (6) months of testing). Based on historical data, a T&O event was most likely to occur during this time. The pilot-testing program will include two phases. During Phase I, the pilot plant equipment will be set up and calibrated, and the various components will be checked to ensure that they are performing properly. During Phase II, testing will be conducted to evaluate and optimize the processes. The following sections describe the activities that were planned during each phase of testing.

4.2.1 Phase I – Startup and Unit Calibration

The first phase included system startup, which included completing the hydraulic and electrical connections to the pilot, preparing initial chemical feed solutions, refinement of analytical techniques, and initial quality control procedures. The following activities were conducted during system startup:

☐ Verify the accuracy of flow measurements
☐ Verify the accuracy of the chemical injections
☐ Calibration of online analyzers (pH, ozone residuals)
☐ Verify performance of automated control loops
☐ Refine sample collection and analytical techniques

4.2.2 Phase II – Process Performance Evaluations

Two types of information were gathered during this study:

☐ *Operational data* – such as flow rates, chemical dosages, contact times, etc.

☐ *Water quality data* – these included water quality analyses conducted on-site by WQTS (such as ozone residuals, pH, temperature), and analyses conducted by Zone 7's laboratory such as bromate, MIB, geosmin, TOC, THMs, etc.

All operational data were gathered by WQTS staff using the datasheets developed for this purpose and the automated data-logging capabilities of the pilot plant. All analyses that required laboratory support were handled by Zone 7's water quality laboratory. WQTS staff collected the samples in accordance with the experimental matrix and delivered the water samples to the Zone 7 laboratory. Zone 7 staff conducted the analyses (or sent them to a contracted laboratory) and reported the experimental and standard QC results to WQTS.

Testing during Phase II assessed the performance of ozone and Peroxone under various operating conditions that had been identified as a result of the data and literature review. These operating conditions are described herein. In developing the experimental matrix to answer the questions listed above, certain assumptions were made that influenced the decisions regarding the specific tests to be conducted. These assumptions were as follows:

1. *Adding ozone to raw SBA water without a bromate control strategy is not feasible due to the formation of bromate above the MCL of 10 µg/L. Therefore, when testing raw water ozonation, one or more bromate control technique(s) would always be used. A baseline bromate sample would be collected during each group of tests as a positive control, but this condition would not be fully evaluated.*

2. *The two strategies for bromate control that would be tested are pH suppression and chlorine/ammonia addition upstream of the ozone contactor.*

3. *Settled water pH is typically less than 7, and further pH suppression for bromate control would not likely be needed. Therefore, elevated pH values for the settled water would not be tested.*

4. *The chemical reactions associated with Peroxone were expected to be quite fast. Therefore, it was not necessary to test Peroxone under the long contact times associated with a conventional ozone contactor, since the oxidation of MIB and geosmin was likely to occur in the first few minutes.*

The quality of the water in the South Bay Aqueduct varies seasonally. During this 6-month pilot study, the temperature, turbidity, pH, alkalinity, and the nature and concentration of the natural organic matter in the water were expected to change significantly. In order to gather sufficient data for the full-scale application, the challenge testing matrix was repeated three times (June, August, and October). The matrix took approximately two weeks to complete. In between challenge testing, the pilot plant was run under steady-state conditions in order to gather continuous operational stability information. Table 4.1 includes the matrix of experimental conditions used during the three rounds of testing.

Table 4.1 – Summary of Experimental Variables during 2008 Matrix Testing

Parameter	**Round 1 June 16 - 27**	**Round 2 August 18 - 29**	**Round 3 October 13 - 24**
Raw water ozone doses, mg/L	2, 3, 4	1, 2, 3	1, 2, 3
Raw water pH	amb[2], 7, 6.5	amb[2], 7.5, 6.5	amb[2], 7.5, 6.5
Contact times, min	1, 3, 6,10	1, 3, 10	3, 10
Chloramine doses, mg/L	0, 0.75	0, 0.75	0, 0.75
Settled water ozone dose, mg/L	0.5, 1, 1.5	0.5, 1.5, 3	0.5, 1, 2.5
Settled water pH	amb[2], 6.0	amb[2], 6.0	amb[2], 6.0
Peroxone ratio[1]	0, 0.2, 0.8	0, 0.5, 1	0, 0.5, 1
Peroxide injection point[3]	1	3	1, 2, 3, 4
Total number of separate tests	54	61	63
Number of MIB/geosmin and bromate samples	162	160	99

[1] Peroxone ratio is equal to the H_2O_2 dose, expressed in mg/L, divided by the ozone dose, also expressed in mg/L

[2] "amb" refers to ambient pH (no acid added), which ranged from 7.7 to 9.0 for the raw water and from 6.5 to 6.8 for the settled water

[3] Peroxide injection points shown on Figure 6.

Throughout the study, sampling of the raw water for analyses conducted by the laboratory was done once per week. These data were used primarily to characterize the changes in raw water quality, and Table 4.2 includes the parameters measured. These parameters were routinely analyzed by Zone 7's laboratory (or by their contracted laboratory).

Table 4.2 – Parameters to be Measured in the Raw Water

Alkalinity	Dissolved Organic Carbon (DOC)
Bromide	TOC
Hardness	Turbidity
Conductivity	Ultraviolet Absorbance at 254nm (UV254)
Iron	pH
MIB	geosmin
Manganese	Temperature

Four primary tasks were accomplished during the pilot study as detailed in the following paragraphs. Tasks 1, 2, and 3 pertained to the experimental matrix (challenge testing with spiked MIB, geosmin, bromate and TOC) while Task 4 pertained to the operational stability testing.

Task 1 – Evaluate the Impact of Ozone Dose and Contact Time on MIB and geosmin Destruction with Ozone Alone

This task focused on identifying the ozone doses and contact times needed to destroy MIB and geosmin when present at a concentration of up to 30 ng/L. Based on prior work by others, the following conditions were evaluated:

- ☐ Raw water ozone doses of 2 and 4 mg/L
- ☐ Settled water ozone doses of 0.5 and 2 mg/L
- ☐ Contact times of 6 and 10 minutes in the conventional contactor
- ☐ Contact times of 1 and 2 minutes in the pipeline contactor
- ☐ pH values in raw water from ambient to 6.5
- ☐ pH values in settled water from ambient to 6.0
- ☐ Chloramine doses of 0 and 0.75 mg/L
- ☐ Peroxone ratios (H_2O_2:O_3) between 0.2 and 1

During each test, ozone residual measurements were collected along the length of each contactor.

Since MIB and geosmin are both biodegradable and highly volatile, fresh working solutions were prepared during each day of challenge testing. MIB and geosmin were spiked into the pilot plant up to a concentration of 30 ng/L for these tests. This spiking was only conducted during the three challenge testing periods. For each test condition, samples were collected from the contactor effluents for the constituents shown in Table 4.3.

Table 4.3 – Parameters to Be Measured for Each Test Condition in Experimental Matrix

By Zone 7 Lab	By WQTS Staff
bromate	ozone residuals
MIB and geosmin	pH
	temperature
	free chlorine*
	combined chlorine*
	peroxide residual*

* *only when chlorine or peroxide is added as part of testing*

Task 2 – Evaluate MIB Destruction with Peroxone

Task 2 focused on evaluating the impact of peroxide addition on the effectiveness of MIB and geosmin destruction. The range of tests included in the ozone-only portion of the matrix (various ozone doses and contact times) were repeated, but with peroxide added ahead of the contactors for each test condition. Hydrogen peroxide-to-ozone ratios –commonly referred to as the Peroxone Ratio– of 0.2, 0.4 and 0.8 by weight were used. For each test, ozone residual measurements were made along the length of the contactors and if possible, hydrogen peroxide residuals was measured.

Task 3 – Evaluate impact of bromate control strategies

The purpose of this Task was to evaluate the impact of different bromate control strategies on the performance of the ozone and Peroxone in reducing MIB and geosmin. Two bromate control strategies were evaluated:

- ☐ pH suppression in the raw water to 7.0 and 6.5 (settled water pH may not need adjustment)
- ☐ Chloramine addition ahead of ozonation for both raw and settled water

The same set of conditions listed in Tasks 1 and 2 (ozone doses, contact times, and Peroxone ratios) were tested, each with a bromate control technique applied. For each set of conditions, a baseline bromate sample was collected before the bromate control technology was started. For example, if pH suppression were to be tested, the pilot plant was configured appropriately, the ozone doses and contact times adjusted, and immediately before the acid feed was turned on, a sample was collected for bromate (not MIB/geosmin). This served as a positive control.

Task 4 – Evaluate the stability of the ozone and peroxone processes

The purpose of this Task was to assess the impact of varying raw water quality on the ozone and peroxone processes. The pilot plant was run nearly continuously during this portion of the study, and data were gathered by the online instruments as well as by collection of grab samples. Some of the issues evaluated included the following:

1. *How much does the ozone residual vary between day and night?*
2. *What is the impact of this variation on the peroxone process?*
3. *Does adjusting the pH help stabilize the ozone residual?*
4. *What is the maximum ozone dose that can be added such that there is no measurable ozone residual leaving the contactor?*
5. *What is the decay rate of the ozone residual, and how does it vary over time?*
6. *When adding peroxide, how fast does the ozone residual degrade in the contactor?*
7. *How sensitive is the ozone residual to the peroxide dose? In other words, if the peroxide dose is not correct, or if the peroxide feed is lost, what happens to the ozone residual?*
8. *What is the impact of residual peroxide on the subsequent chlorine demand?*

The Operational Stability testing was conducted in between the three rounds of challenge testing.

4.2.3 Additional Data Collected

During the Operational Stability testing, frequent samples were collected from the contactor effluent for Simulated Distribution System (SDS) DBP formation testing. To match full-scale plant conditions, the chlorine dose (as sodium hypochlorite) used by the plant operators was added to the sample bottles at the start of a 1-hour free chlorine contact period. After one hour, ammonia was added at a 4.5-to-1 ratio by weight, matching the full-scale plant conditions. This bottle was gently mixed by manual swirling, capped, and stored in the dark at room temperature (20 ± 2°C) for 24 hr. After this contact period, samples were collected for THMs, HAAs, and total chlorine. Additionally, weekly samples of carboxylic acid were collected from the raw water and the effluent of each contactor in service.

In addition to the MIB, geosmin, and bromate samples collected during the challenge testing periods, periodic samples (up to four per week) for these parameters were collected during the operational stability testing period.

One of the key questions to be answered is whether or not biological filtration should be installed downstream of a Peroxone process. Biofiltration downstream of a traditional ozone processes is commonly practiced in order to remove the increased amount of biodegradable organic matter (BOM) formed by ozone. As part of the pilot testing, the level of BOM formed by either the ozone or Peroxone process was measured using Assimilable Organic Carbon (AOC) as a surrogate parameter. However, the literature is not clear in the interpretation of how significantly BOM levels must increase to negatively impact distribution system regrowth and/or nitrification. One possible approach was to ensure that BOM levels following T&O control (or, eventually leaving the water treatment plant) were not greater than the BOM levels following the current, existing treatment processes. However, that may be too highly conservative and a less strict solution could be determined.

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SECTION 5.0 –
PILOT TESTING RESULTS

This section presents the results of the pilot testing program. The first subsection presents the general quality of the water received by the DVWTP during the pilot testing period. The second subsection presents the results of the three rounds of matrix testing that identified the ozone doses required to meet the T&O destruction goals and the resulting bromate formation. The third subsection focuses on various design and operational parameters relevant to the application of the ozone or Peroxone process.

5.1 GENERAL WATER QUALITY

During the course of the study, Zone 7's water quality staff collected raw water quality samples and analyzed them for various parameters. Some parameters were collected weekly, while others were collected monthly. The average, minimum, and maximum values of the parameters analyzed are presented in Table 5.1.

Table 5.1 – General Raw Water Quality during Pilot Testing

Parameter	Unit	Number of Samples	Average	Min.	Max.
TOC	mg/L	28	4.1	2.7	7.6
UV-254	cm^{-1}	28	0.125	0.081	0.203
Turbidity	NTU	28	6	2	22
Bromide	µg/L	6	203	80	390
Alkalinity	mg/L $CaCO_3$	28	76	61	102
Conductivity	µs/cm	7	481	317	642
Tot. Hardness	mg/L $CaCO_3$	6	106	80	131
Iron	µg/L	3	440	220	600
Manganese	µg/L	6	16	5	23

Of significance to the use of ozone or Peroxone are the organic content of the water (i.e., TOC and UV-254 absorbance levels) and the bromide concentration. While the bromide levels varied from 80 to 390 µg/L, the water entering the pilot plant was spiked with bromide as needed during the testing program to simulate high-bromide levels and assess their impact on bromate formation. However, the organic content of the water during the three rounds of testing is of significance because it greatly impacts the ozone demand of the water. It could also impact the ozone dose required to meet specific T&O destruction goals.

Figure 5.1 shows a timeline of the raw water TOC, filtered water TOC, raw water UV-254 absorbance, and raw water Specific UV absorbance (SUVA) measured by Zone 7 water quality laboratory during the study. The periods of Round 1, 2, and 3 are also shown on Figure 7. Round 1 was conducted between June 16 and 27, 2008. Figure 5.1 shows that the organic content of the water during that period was much higher than those during the other rounds of testing. Specifically, the TOC concentration during Round 1 was as high as 7.6 mg/L, while that during Round 2 was approximately 3.5 mg/L, and that during Round 3 was approximately 3.2 mg/L. During the study period, the plant achieved a consistent 50% removal of TOC, the filtered water from the plant was consistently half that in the raw water. The majority of the TOC is removed with coagulation and clarification compared to filtration. Therefore, it is expected that the filtered-water TOC profile shown in Figure 5.1 closely represents that of the settled water treated at the pilot plant during the study. The bottom portion of Figure 7 shows the SUVA levels. SUVA is calculated as the ratio between the UV-254 absorbance (in m^{-1}) and the TOC of the water (in mg/L). An increase in the SUVA value typically suggests an increase in the concentration of highly-reactive organic matter, while a decrease in SUVA values suggests a decrease in the concentration of reactive organics. While the TOC concentration during Round 1 was more than double that during Rounds 2 and 3, the SUVA value was virtually identical, if not slightly lower. This suggests that the increase in TOC was mostly due to nonreactive organic matter that should not greatly impact the ozone demand of the water.

In order to assess the impact of TOC on the ozone demand of the water, the results collected from the conventional ozone contactor during Rounds 1, 2, and 3 were compared. The comparison is shown in Figure 5.2 for the raw water and settled water. The plot contains the ozone residual measured in the outlet of the 1st chamber of the contactor as a function of the transferred ozone dose. The comparison shows that there was little to no difference in the ozone demand profile of the raw water between Rounds 1, 2, and 3, which confirms the SUVA observation discussed above. The same observation is made with settled water where there was no difference in the demand profile of the water between Rounds 1 and 2 in spite of the significant difference in the TOC concentration in the water between the two rounds of testing. Figure 5.2 also shows that there was little to no effect of water pH between 6.5 and 7.5 on the demand profile of the raw water.

The lack of impact of the higher TOC concentration on the ozone demand of the water during Round 1 does not necessarily mean that it would also have no impact on the performance of the ozone or Peroxone process for T&O destruction. As discussed later in this section, it is our suspicion that the change in the organic content of the water during Round 1 greatly impacted the performance of the Peroxone process when hydrogen peroxide was added upstream of ozone injection.

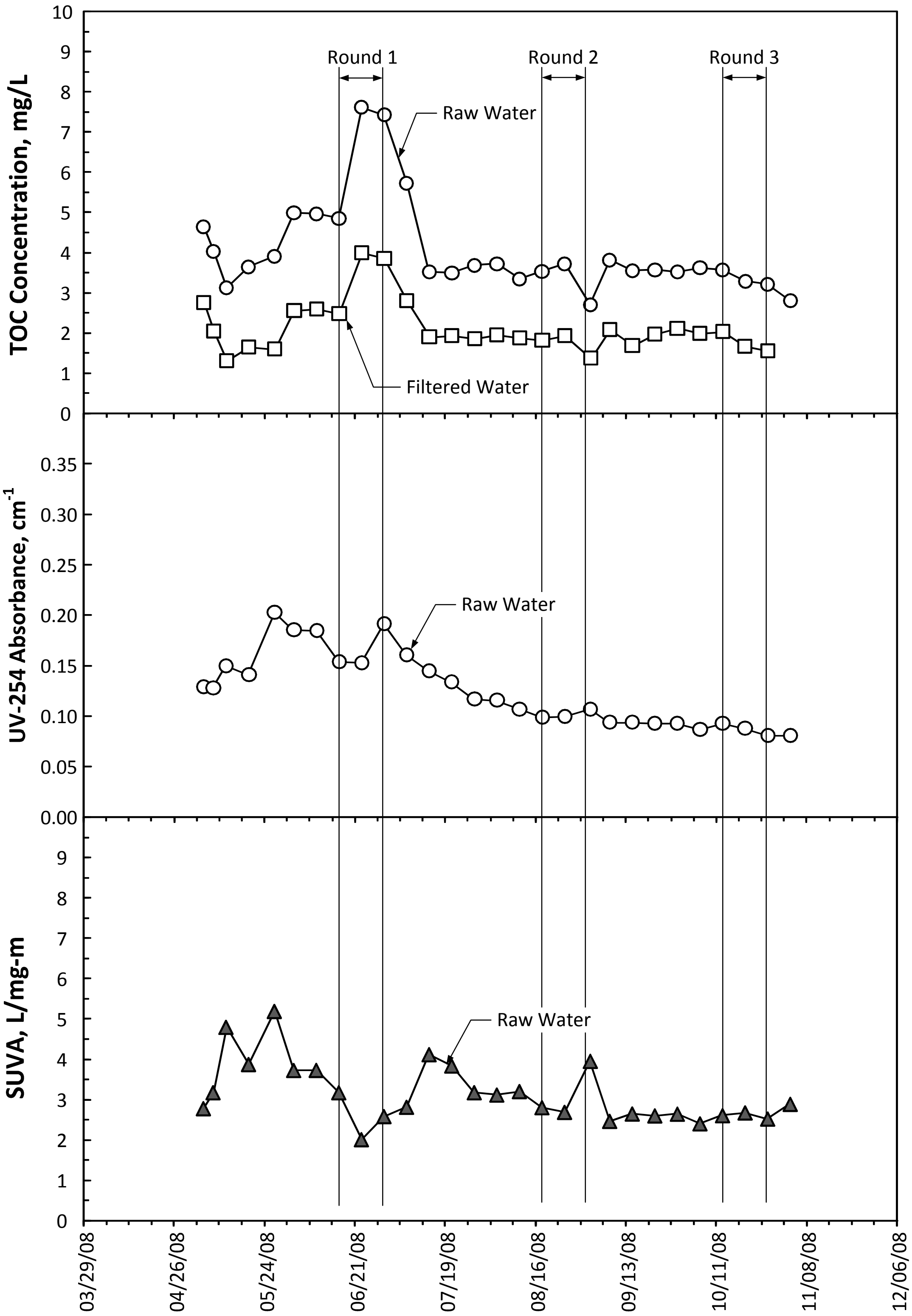

Figure 5.1 – Profile of TOC and UV-254 Levels in DVWTP Raw Water during Pilot Testing

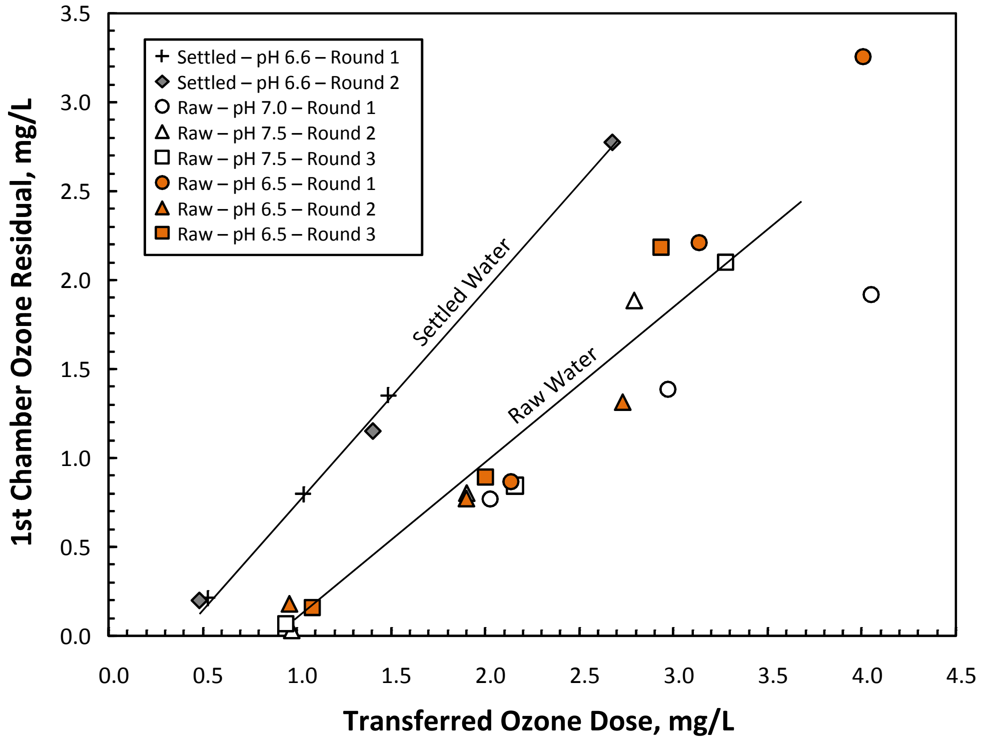

Figure 5.2 – Ozone Demand of Raw & Settled Water through the 1st Chamber of the Conventional Ozone Contactor

5.2 MATRIX TESTING RESULTS

Three matrix testing events were conducted over the six month pilot testing effort. Each matrix consisted of a large number of tests conducted over a two-week period. During each matrix test, the Peroxone process was compared side-by-side with the conventional ozone process treating either raw water or settled water. In the following subsections, results from all three rounds of testing of the conventional ozonation process are presented. For the Peroxone results, only the data obtained in Rounds 2 and 3 are presented and discussed. The Round 1 Peroxone results are not included in this analysis because the location of hydrogen peroxide addition was significantly different in Round 1 compared to Rounds 2 and 3. The effect of the peroxide addition point is discussed under section 3.3.

5.2.1 Raw Water Testing Results

A total of 54 tests were conducted on raw water during Round 1, 61 tests during Round 2 and 63 tests during Round 3. The conditions varied during these tests included pH, prechloramine addition for bromate control, Peroxone ratio (for the AOP process), and ozone dose. The raw water entering the pilot plant was spiked with 40 to 60 ng/L of both geosmin and MIB, as well as bromide during Rounds 1 and 2 (ambient bromide was high during Round 3). Appendix B includes the complete data from all three rounds of testing, as well as detailed graphs for most of the testing conditions.

In analyzing the results, the minimum ozone dose required to meet both the MIB destruction goal of >71% and the geosmin destruction goal of >73% was identified for each round and for each set of pH and prechloramine conditions. In all cases, the dose need to achieve MIB destruction was the higher of the two. One of the difficulties encountered in analyzing the results is that the performance of both processes varied significantly between the three rounds of testing. While such variability is expected with a natural water source, especially SBA water, it ultimately presents a challenge to the selection of the appropriate design criteria.

The raw water results summarized in Tables 5.2-A and 5.2-B, and in Figures 5.3 through 5.5. Note that the Peroxone results presented in this section focus on the H_2O_2:O_3 ratio (i.e., Peroxone ratio) of 0.5:1. The impact of various Peroxone ratios on the performance of the process is discussed later in this Section. Where only one value is shown (e.g. pH 6.5 with Peroxone) this condition was tested in only one round; therefore a range is not available.

Table 5.2-A – Conditions that Meet the MIB & Geosmin Destruction Goals in Raw Water <u>without</u> Prechloramine Addition

Type	pH	Ozone Dose to MIB & Geosmin Goals, mg/L	Bromate, µg/L	Effluent Ozone Residual, mg/L
Conventional Ozone	Ambient	--	--	--
	7.5	1.9 – 2.5	22 – 32	<0.05 – 0.4
	6.5	1.8 – 2.5	13 – 18	0.10 – 0.35
Pipeline Peroxone (0.5:1)	Ambient	--	--	--
	7.5	1.2 – 1.4	22 – 31	<0.05 – 0.1
	6.5	1.3 – 1.9 (est)[1]	24	<0.05 – ??

[1] This value is estimated from other tests with similar conditions.

Table 5.2-B – Conditions that Meet the MIB & Geosmin Destruction Goals in Raw Water <u>with</u> Prechloramine Addition

Type	pH	Ozone Dose to MIB & Geosmin Goals, mg/L	Bromate, µg/L	Effluent Ozone Residual, mg/L
Conventional Ozone	Ambient	1.3 – 2.4	14	<0.1 – 0.3
	7.5	1.4 – 2.8	7 – 11	<0.05 – 0.5
	6.5	--	--	--
Pipeline Peroxone (0.5:1)	Ambient	1.2 – 2.2	4 – 11	<0.05 – 0.15
	7.5	1.3 – 2.7 (est)[1]	4 – 11 (est)[1]	<0.1
	6.5	--	--	--

[1] This value is estimated from other tests with similar conditions.

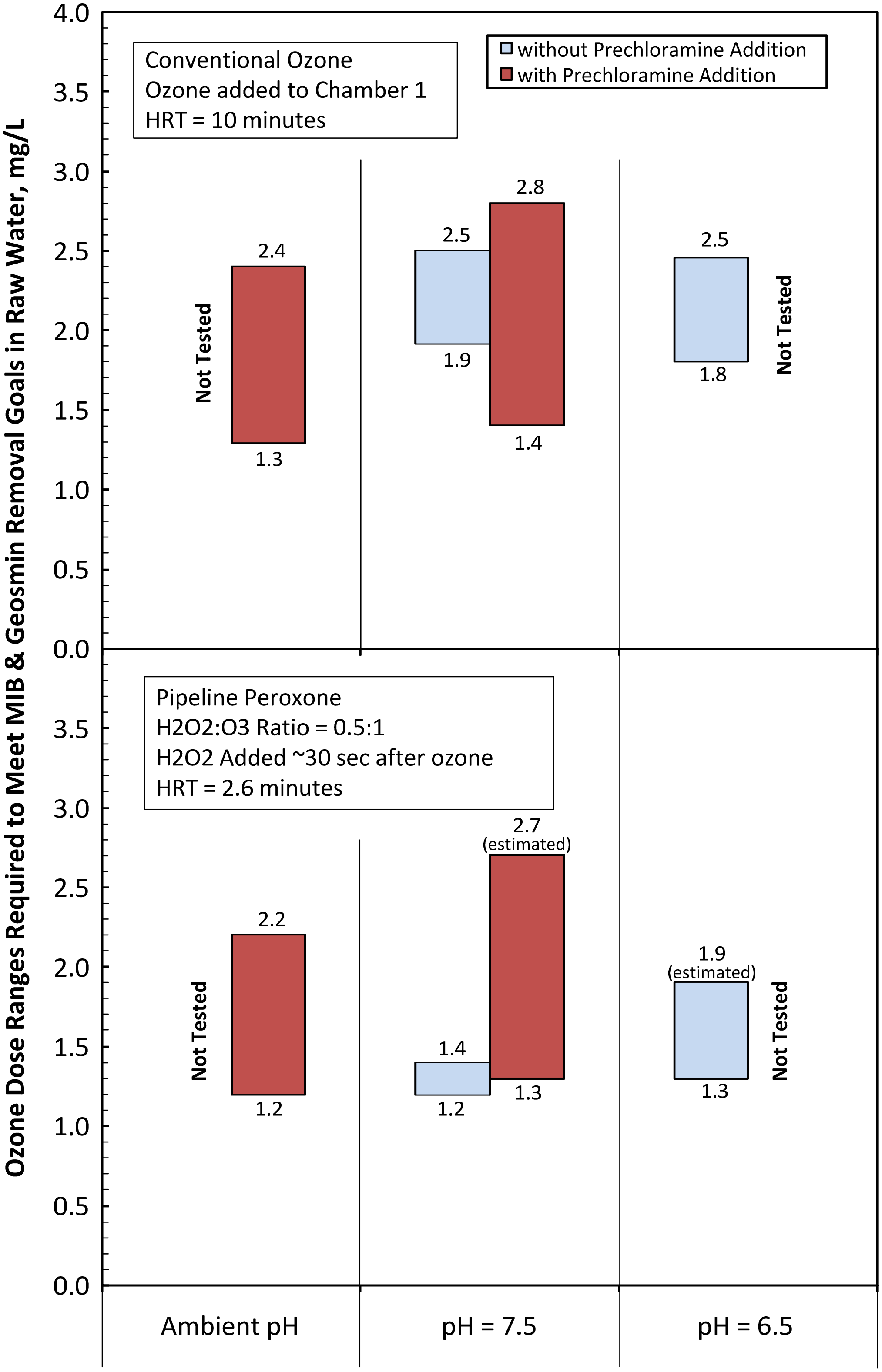

Figure 5.3 – Summary of Results for Raw Water – Range of Ozone Doses Required to meet the MIB & Geosmin Destruction Goals

Table 5.2-A summarizes the results obtained without prechloramine addition for bromate control, while Table 5.2-B summarizes the results obtained with prechloramine addition. Figure 5.3 shows a plot of the ozone dose ranges that were required to meet the MIB and geosmin destruction goals of 71% and 73%, respectively, in raw water during the testing period. The limits of each dose range are the doses obtained from the testing. In analyzing the information presented in Figure 5.3, the following observations are made:

1. Peroxide addition lowers the necessary ozone dose. Without chloramine addition (Table 5-A), the ozone dose required by the Peroxone process to meet the MIB and geosmin destruction goals in raw water is lower than the ozone dose required by the conventional ozone process. The advantage is most pronounced at pH 7.5 where the difference in ozone dose may be approximately 1.0 mg/L, while it is less significant at pH 6.5 where the difference may be only 0.5 mg/L.
2. However, the addition of chloramine adversely affects T&O destruction and lessens the effect of the peroxide (Table 5.2-B). The results suggest that when chloramine is added for bromate control, the two processes (i.e., Peroxone or ozone) may require the nearly same ozone dose to meet the MIB and geosmin destruction goals. It is speculated that the chloramine present in the water reacts with the hydroxyl radicals formed by the Peroxone process, thus reducing their ability to oxidize MIB and geosmin.

Figure 5.4 shows the bromate levels formed from the ozone dose range required to meet the MIB and geosmin destruction goals in raw water. It is important to emphasize that the bromide levels during the testing were as high quite high (generally >400 ppb). With this in mind, the following observations are made from Figure 5.4:

1. Without prechloramine addition ahead of the ozone or Peroxone process, and with the addition of sufficient ozone to achieve MIB and geosmin destruction, the bromate levels formed in the effluents of both processes were higher than the MCL of 10 µg/L by a significant margin. This was true even at the reduced pH of 6.5.
2. With the addition of 0.75 mg/L chloramine ahead of the conventional ozone process and the pipeline Peroxone process, bromate formation was significantly reduced.
3. With the addition of 0.75 mg/L chloramine ahead of both processes, the Peroxone process produced slightly lower levels of bromate compared to the conventional ozone process.

Figure 5.5 shows the range of ozone residuals measured in the effluent of each of the two contactors at the ozone doses required for sufficient MIB and geosmin destruction. While the ozone residual is neither a water-quality goal nor a regulatory limit, it is a safety and air-quality concern. If the ozone residual in the water leaving the contactor is above a certain level (typically 0.1 mg/L), off-gassing of the ozone will take place in the subsequent basins that would expose the operators to unhealthful levels of ozone in the air. Therefore, if elevated ozone residuals are present in the effluent of an ozone contactor, either the ozone dose must be reduced to reduce the effluent ozone to an acceptably low level, or an ozone-quenching chemical must be added and allowed to react with the residual ozone before the water exits the contactor. These chemicals include sodium thiosulfate or calcium thiosulfate. A third option is to increase the size of the contactor, thus allowing more time for the ozone residual to decay. In this application, since the ozone dose is selected based on the target MIB and geosmin destruction goals, the first remedy is not available, which means that the use of an ozone-quenching chemical or a larger contactor would be the only viable options. To reduce cost and operational complexity, it would be highly desirable that an ozone or Peroxone system is selected such that an ozone-quenching chemical would not be needed.

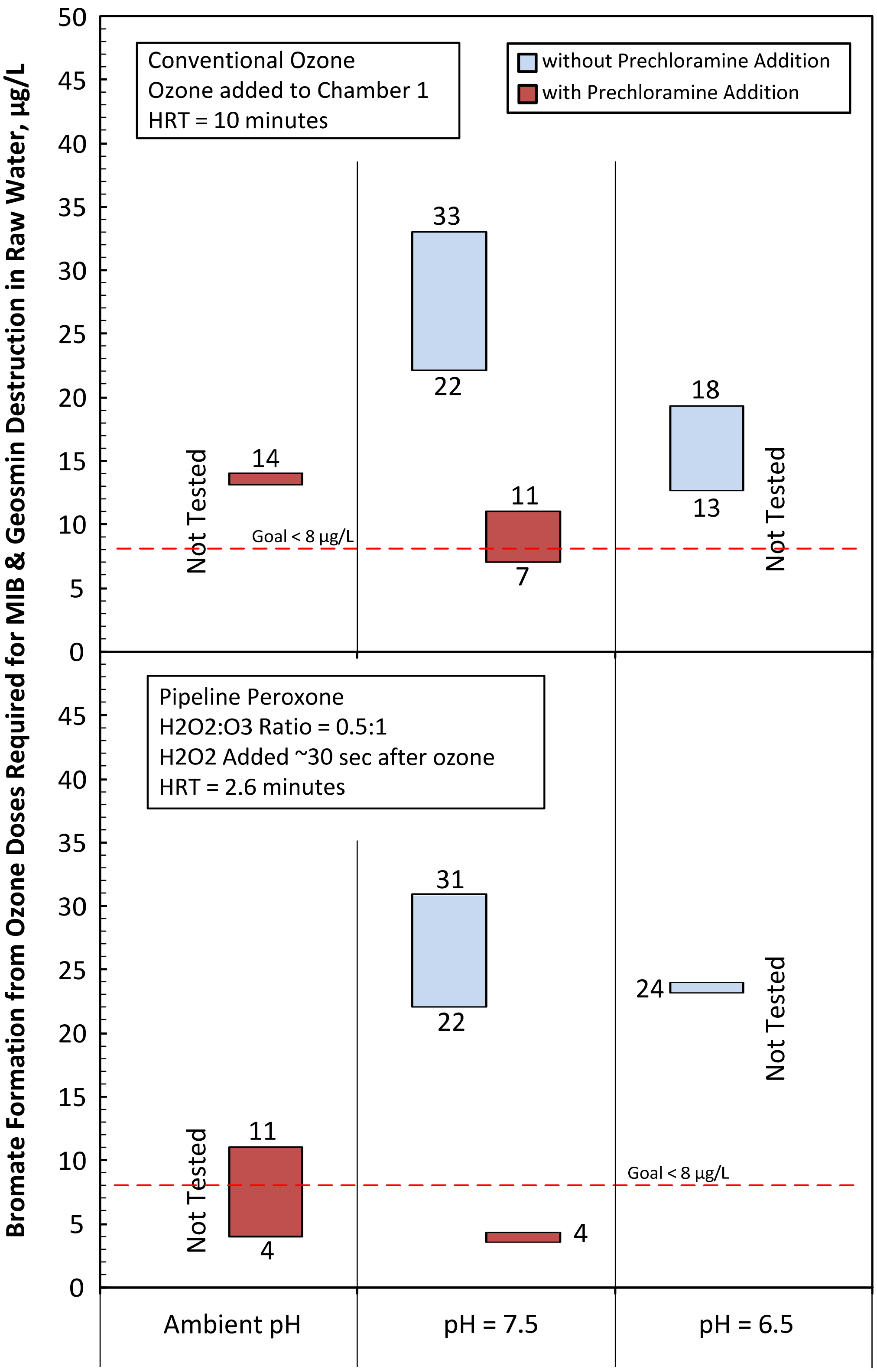

Figure 5.4 – Summary of Results for Raw Water – Bromate Formation under the Ozone Doses Required to meet the MIB & Geosmin Destruction Goals

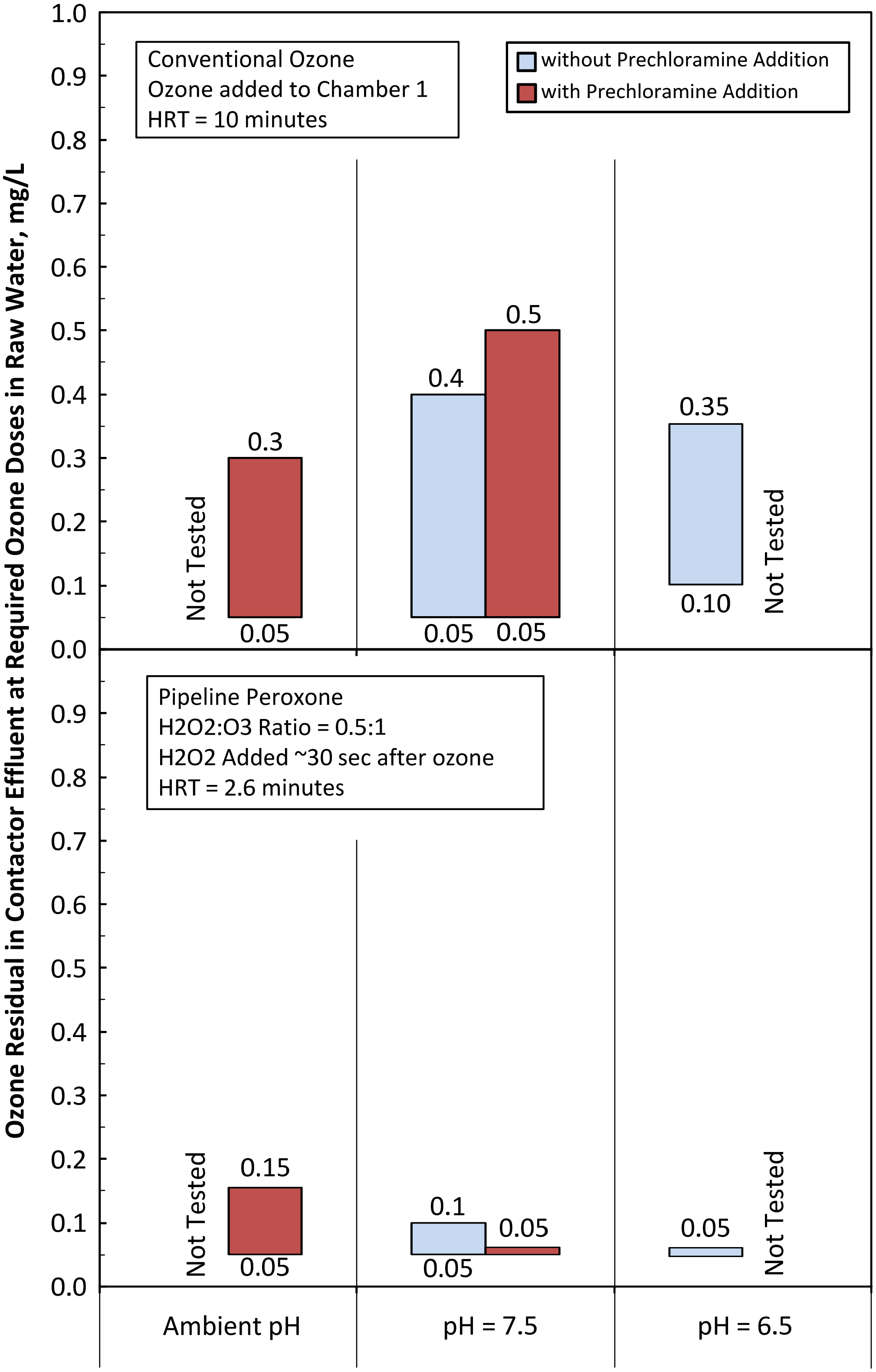

Figure 5.5 – Summary of Results for Raw Water – Ozone Residual Levels in Contactor Effluent Under the Ozone Dose Range Required to meet the MIB & Geosmin Destruction Goals

With the preceding discussion in mind, the following observations are made from Figure 5.5:

1. Under all conditions tested with the conventional ozone contactor, and under the ozone doses required for MIB and geosmin destruction, the ozone residual concentration in the effluent of the 10-minute contactor ranged from non-detectable (0.05 mg/L) to 0.5 mg/L. Some of these levels are well above the commonly acceptable level of 0.1 mg/L, which would require the addition of an ozone-quenching chemical or the use of a larger contactor.
2. However, with the ozone doses required in the 2.6-minute pipeline Peroxone process, the ozone residual under all but one condition tested were at or below the threshold level of 0.1 mg/L. This suggests that a pipeline Peroxone process may be operated to treat raw SBA water without the need for an ozone quenching chemical.

In summary, the raw water testing results obtained suggest that the use of a 2.6-minute Peroxone process could be more economical and more practical than the use of a 10-minute conventional ozone process, especially if the raw water pH is adjusted to approximately 7.5. The condition required the lowest ozone dose and had consistently low ozone residuals. However, during periods of elevated bromide levels, the addition of chloramine ahead of the Peroxone process would be necessary in order to control bromate formation, and this will reduce the economic benefit of the Peroxone process over the conventional ozone process.

5.2.2 Settled Water Testing Results

The settled water entering the pilot plant was pumped directly from the effluent of Superpulsator #4, upstream of the plant's chlorine addition point. As was done with the raw water testing, the settled water was also spiked with 40 to 60 ng/L of geosmin and MIB, as well as with bromide during Rounds 1 and 2 (the ambient bromide was sufficiently high during Round 3). The detailed graphs for each set of conditions are presented in Appendix A. In analyzing the results, the ozone dose ranges required to meet both the MIB destruction goal of >71% and geosmin destruction goal of >73% were identified for each set of pH and prechloramine conditions. As was the case with the raw water results, the dose required for MIB destruction was always higher than that required for geosmin destruction.

The summary of the results for the application of ozone or Peroxone to the settled water is presented in Tables 5.3-A and 5.3-B, and in Figures 5.6 through 5.8. Similar to the raw water results, the Peroxone results presented in this section focus on the H_2O_2:O_3 ratio (i.e., Peroxone ratio) of 0.5:1. The impact of the Peroxone ratio on the performance of the Peroxone process is discussed later in this Section.

Table 5.3-A – Conditions that Meet the MIB & Geosmin Destruction Goals in Settled Water without Prechloramine Addition

Type	pH	Ozone Dose to MIB & Geosmin Goals, mg/L	Bromate, µg/L	Effluent Ozone Residual, mg/L
Conventional Ozone	Ambient (6.5-6.7)	2.9 – 4.5 (est)[1]	37 - >70	1.0 - >2.0
	6.0	>4.5	>40	>2.0
Pipeline Peroxone (0.5:1)	Ambient (6.5-6.7)	1.1 – 1.2	21 – 23	0.25 – 0.5
	6.0	2.1	18 – 30	0.8 – 1.9

[1] This value is estimated; highest ozone dose applied was not able to meet goal

Table 5.3-B – Conditions that Meet the MIB & Geosmin Destruction Goals in Settled Water with Prechloramine Addition

Type	pH	Ozone Dose to MIB & Geosmin Goals, mg/L	Bromate, µg/L	Effluent Ozone Residual, mg/L
Conventional Ozone	Ambient (6.6)	>3.5 - >5 (est)[1]	ND - ??	>2.0
	6.0	--	--	--
Pipeline Peroxone (0.5:1)	Ambient (6.6)	1.3 – 1.7	9 – 10	0.3 – 0.9
	6.0	--	--	--

[1] This value is estimated; highest ozone dose applied was not able to meet goal

Table 5.3-A summarizes the results obtained without prechloramine addition for bromate control, while Table 5.3-B summarizes the results obtained with prechloramine addition. Figure 5.6 shows a plot of the ozone dose ranges required to meet the MIB and geosmin destruction goals of 71% and 73%, respectively, in settled water. The following observations are made from Figure 5.6:

1. The ozone dose needed for MIB destruction using conventional ozonation was very high. Under both the ambient settled water pH or an adjusted pH of 6.0, the conventional ozone process could not meet the MIB and geosmin destruction goals even with a projected ozone dose of up to 4.5 mg/L.
2. Peroxide addition significantly improved MIB destruction. Without the addition of chloramine for bromate control, an ozone dose of approximately 1.2 mg/L added to the 2.6-minute Peroxone contactor was sufficient to meet the MIB and geosmin destruction goals at ambient pH. This dose increased to 2.1 mg/L after adjusting the pH to 6.0.
3. With the addition of 0.75 mg/L prechloramine, the ozone dose required to meet the MIB and geosmin destruction goals in the Peroxone contactor increased to a range of 1.3 to 1.7 mg/L. Similar to the raw water results, prechloramine addition adversely affected the efficacy of the Peroxone process for T&O destruction.

Figure 5.7 shows a plot of the bromate levels formed from the ozone doses required to meet the MIB and geosmin destruction goals in settled water. It is important to emphasize that the bromide levels in the raw water during the two rounds of testing were high, ranging from 346 µg/L to 531 µg/L. With this in mind, the following observations are made from Figure 5.7:

1. Bromate formation in the conventional ozone process applied to the settled water cannot be quantified since the doses required to meet the MIB and geosmin goals were higher than the highest dose tested (>3.5 mg/L). Nevertheless, without prechloramine addition, the bromate level formed at the highest transferred ozone dose of 2.7 mg/L was as high as 70 µg/L at the ambient pH of 6.6, and 30 µg/L at an adjusted pH of 6.0.
2. Without prechloramine addition, the bromate level formed in the Peroxone process ranged from 21 to 23 µg/L at the ambient settled-water pH of 6.6. With the addition of prechloramine, the amount of bromate formed at the same pH decreased to 9 µg/L.
3. With a reduced settled water pH to 6.0, the addition of 2.1 mg/L ozone dose to the Peroxone process still resulted in the formation of approximately 18 to 30 µg/L of bromate. While reducing the pH to 6.0 would be expected to reduce bromate formation, the need for the higher ozone dose to meet the T&O destruction goals, eliminated the advantage of the lower pH value.

Figure 5.8 shows the range of ozone residuals measured in the effluent of each of the two contactors at the ozone dose ranges required for sufficient MIB and geosmin destruction. The following observations are made from Figure 5.8:

1. The anticipated ozone residual in the effluent of the conventional contactor could not be quantified since the doses required to meet the MIB and geosmin goals could not be determined. Nevertheless, based on the results collected, the residual ozone concentration is projected to be >2 mg/L. This is a very high residual value, and would certainly require the addition of an ozone-quenching agent before the water exits the contactor.
2. Even with the Peroxone process, the residual ozone concentration in the contactor effluent at the ozone doses required for MIB and geosmin destruction was still higher than the desired maximum of 0.1 mg/L. At the ambient settled water pH of 6.6, the ozone residual in the effluent of the 2.6-minute Peroxone process ranged from 0.25 to 0.5 mg/L without prechloramine addition, and from 0.4 to 0.75 mg/L with prechloramine addition.
3. At the adjusted pH of 6.0, the residual increases to a range of 0.8 to 1.9 mg/L without prechloramine addition. These levels are also quite high, and would require the addition of an ozone-quenching agent before the water exits the contactor.
4. The addition of a quenching agent is not trivial. Additional contact time would be required for the quenching chemical to destroy the ozone residual left in the water. The magnitude of this contact time required was not evaluated in the study. Further, the chemical may exert a chlorine demand, possibly affecting the downstream chlorination process.

In summary, the settled water testing results suggest that the application of conventional ozone to meet the MIB and geosmin destruction goals in the settled water at a pH of 6.6 or 6.0 requires an ozone dose that is likely to exceed 3.5 mg/L. However, an ozone dose of 1.7 mg/L applied to a 2.6-minute Peroxone process is sufficient to meet these goals at the ambient settled-water pH of 6.6. The dose increases to about 2.1 mg/L with a reduced pH of 6.0. However, the addition of an ozone-quenching chemical would be required to destroy the ozone residual before the water exits the contactor. Finally, during periods of elevated bromide levels, the addition of chloramine ahead of the AOP process would be required to control bromate formation.

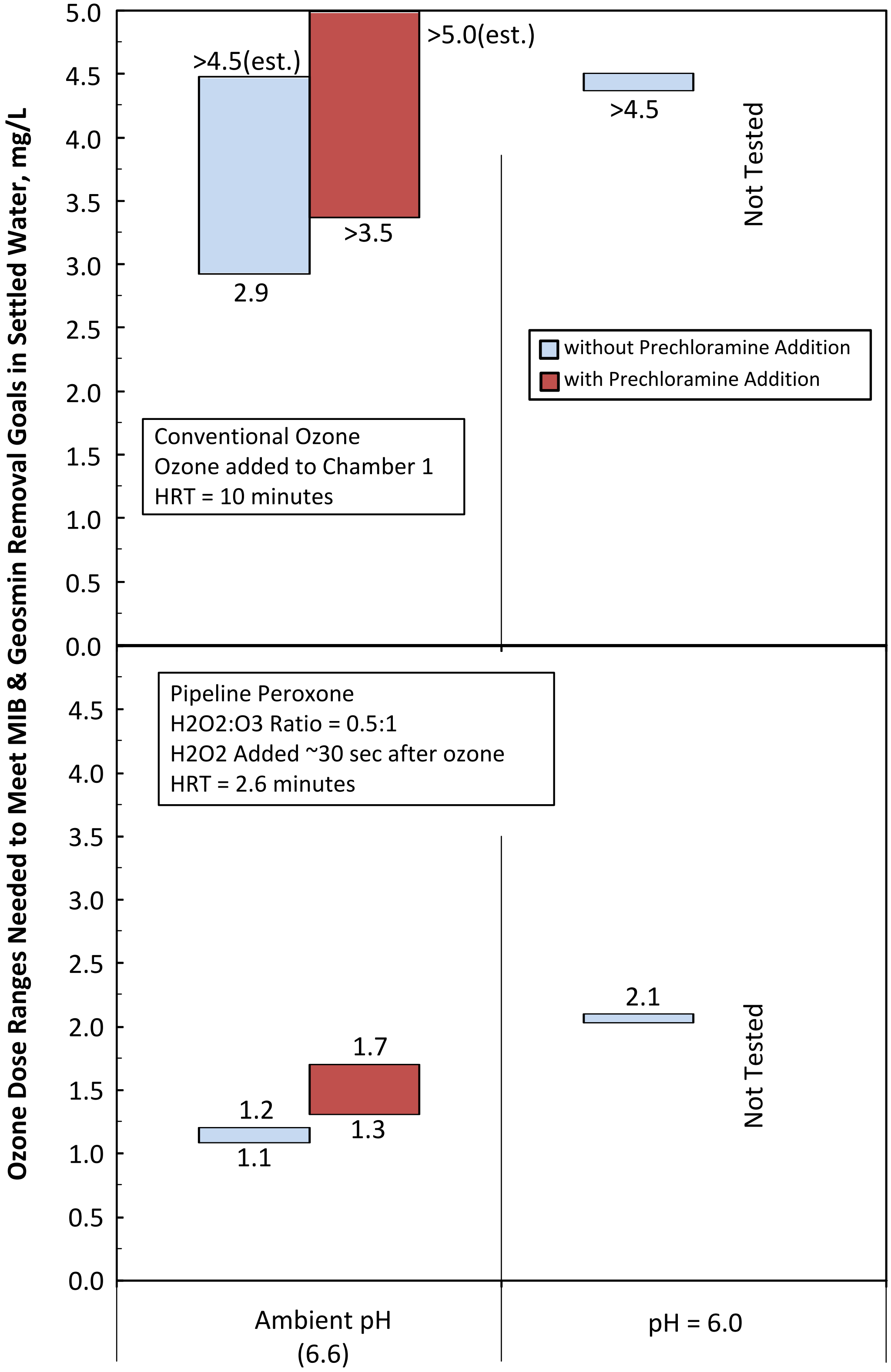

Figure 5.6 – Summary of Results for Settled Water – Range of Ozone Doses Required to meet the MIB & Geosmin Destruction Goals

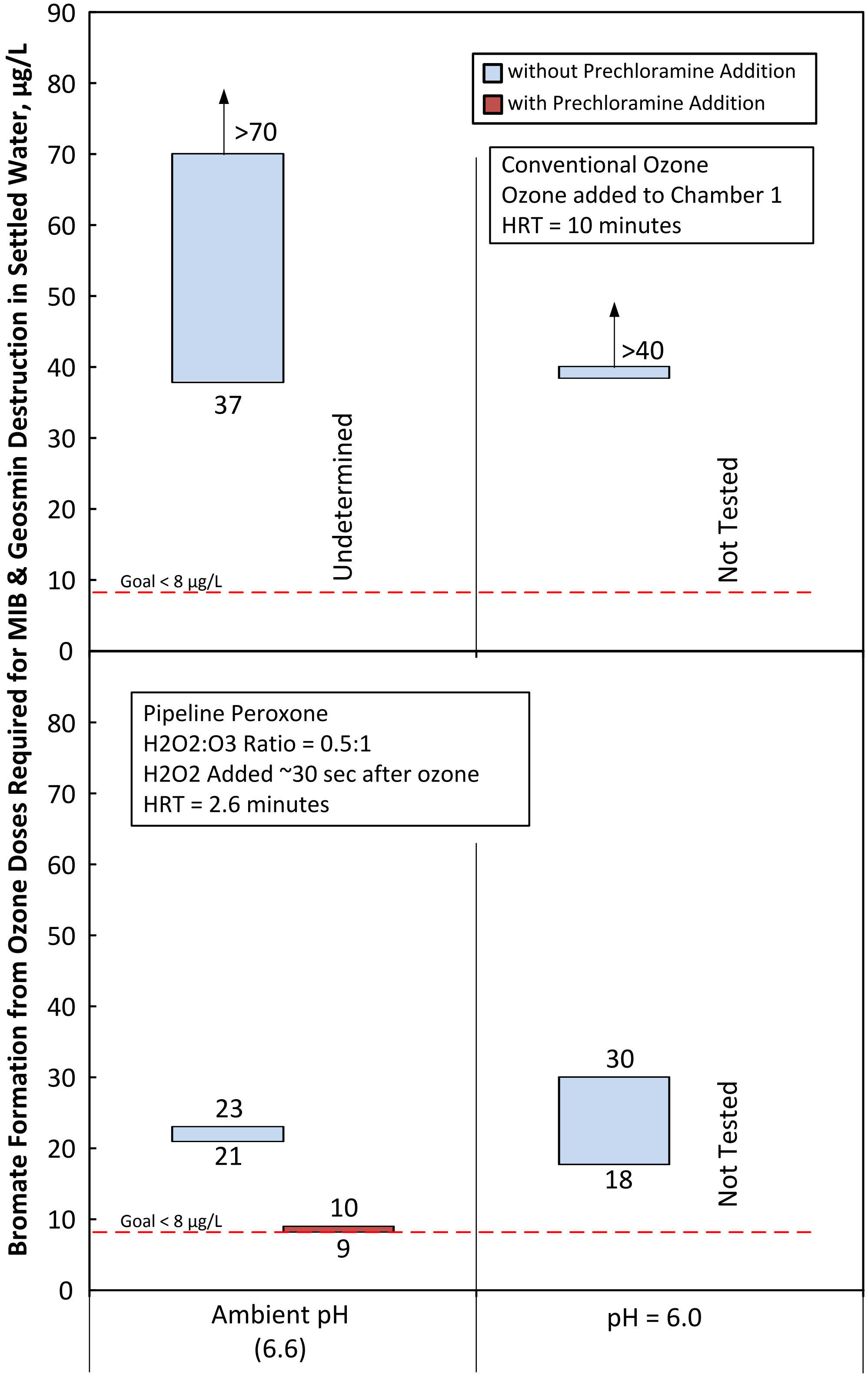

Figure 5.7 – Summary of Results for Settled Water – Bromate Levels Formed Under the Ozone Doses Required to meet the MIB & Geosmin Destruction Goals

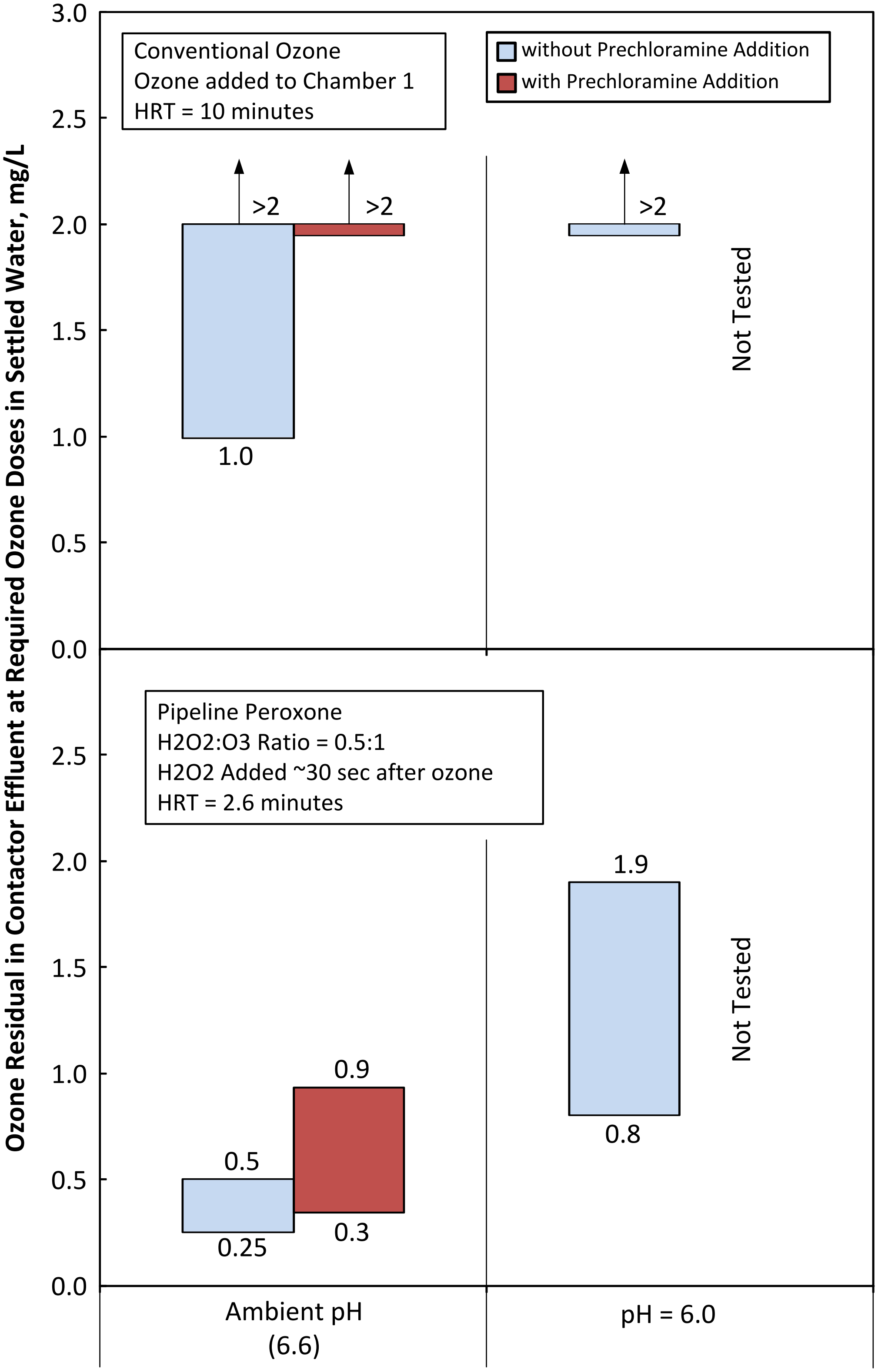

Figure 5.8 – Summary of Results for Settled Water – Ozone Residual Levels in Contactor Effluent Under the Ozone Dose Ranges Required to meet the T&O Destruction Goals

5.3 OTHER TESTING RESULTS

The previous section focused on identifying the ozone dose range required to meet the MIB and geosmin destruction goals in raw or settled water using a conventional ozone contactor or a pipeline Peroxone contactor. The previous section also evaluated the use of prechloramine for bromate control under elevated bromide levels in the raw and settled water. This section addresses some of the other design and operational questions related to the application of conventional ozone or Peroxone. Specifically, the following questions are addressed in this section:

1. How will the diurnal variations in the pH and temperature of SBA water affect the design and operation of the Peroxone process?
2. What is the impact, if any, of the location of the hydrogen peroxide injection point and the H_2O_2:O_3 ratio on the performance of the Peroxone process?
3. What are the by-products of the Peroxone process and how do they compare to those of the ozone process?

Each of the subsequent sections addresses one of the above questions.

5.3.1 Impacts of Diurnal Fluctuations in SBA Water Quality

One of the concerns with the use of ozone to treat SBA water is the wide diurnal fluctuations in the pH of and temperature in the water. Figure 5.9 shows a plot of these diurnal variations recorded by ACWD at WTP2. The plot shows that the water pH fluctuated between 7.3 in the morning to 8.7 in the evening. This is accompanied by a parallel fluctuation in temperature from 22 °C in the morning to 25 °C in the evening.[5] Similar fluctuations are recorded regularly at the Del Valle WTP during the summer and fall seasons. The lower portion of Figure 5.9 shows the impact of these fluctuations on the decay of ozone in the water. With a constant ozone dose of about 3.2 mg/L, the ozone residual measured at the effluent of the first chamber ranged from a high of about 0.8 mg/L when treating low-pH & low-temperature water, to a low of 0.15 mg/L when treating high-pH & high-temperature water. In 2001, ACWD installed a CO_2 feed system designed to maintain a stable pH in the water entering the ozone contactor by varying the CO_2 dose as the raw water pH varies during the day. This helps maintain a stable ozone system operation.

During the pilot testing effort, the impact of the diurnal fluctuations in raw water pH on the operation and performance of the Peroxone process was investigated because of its potential impact on the design of the system. This evaluation was conducted by operating the ozone and Peroxone processes in two modes: “constant residual” mode and “constant dose” mode. During the “constant residual” mode, the PLC was set to automatically adjust the ozone dose in order to maintain a constant ozone residual as measured by the online ozone analyzer. During “constant dose” mode, the ozone dose was fixed, regardless of the value of the ozone residual. The two pilot contactors were then operated in parallel for several 24-hour cycles.

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[5] Data gathered in July 1997.

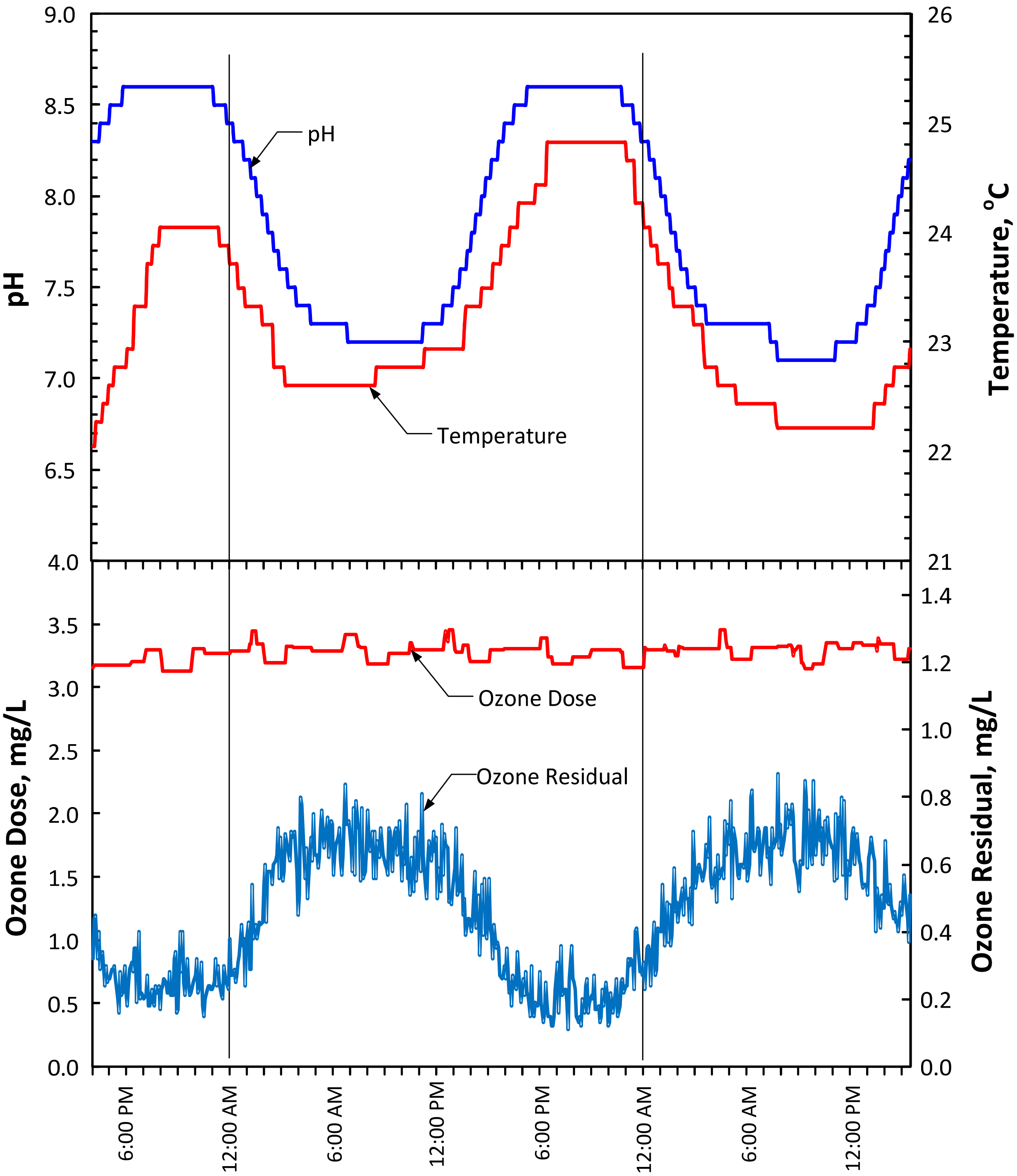


Figure 5.9 – Diurnal Fluctuations in SBA Water pH & Temperature, and their Impacts on the Decay of Ozone Applied to SBA Water (ACWD data)

5.3.1.1 Constant Residual Mode Test Results

Figures 5.10 and 5.11 show plots of the varying pH in the raw water, and the corresponding ozone residuals and ozone doses for the two contactors when they were operated in “constant residual” mode without pH adjustment. For the conventional ozone contactor, the analyzer was supplied by water drawn from the effluent of the 1st chamber. This method of operation is typical for conventional ozone contactors operating to achieve disinfection goals. For the pipeline Peroxone contactor, different analyzer locations were investigated. For the results shown in Figure 5.10, the ozone analyzer on the Peroxone process was supplied by water from the mid-point of the 2.6-minute contactor, approximately 60 seconds downstream of ozone injection. During these tests, the pH of the raw water varied significantly, decreasing from a high of approximately 8.6 to a low of approximately 7.6.

The top half of Figure 5.10 shows the ozone dose that was needed for the conventional ozone contactor in order to maintain the target ozone residual of 0.4 mg/L at the effluent of the 1st chamber. During the high pH period, the ozone dose was approximately 2.1 mg/L. As the pH decreased below 8.0, the required ozone dose decreased to approximately 1.2 mg/L. This translates into a dose difference of 0.9 mg/L, which is significant. The bottom half of Figure 5.10 shows the ozone dose that was needed for the Peroxone contactor in order to maintain the target ozone residual of 0.4 mg/L at the effluent of the 2.6-minute contactor during the same period of time. The results show that the impact of the change in water pH on the Peroxone process was far more significant than that on the conventional ozone process. As shown in the lower half of Figure 5.10, when the pH of the water was 8.3, the ozone dose required to maintain the target ozone residual was as high as 6.7 mg/L. As the pH decreased to less than 8.0, the ozone dose decreased to approximately 2.7 mg/L. This is a very large difference of 4.0 mg/L, and it is attributed to the fact that the system was trying to maintain a stable and measurable ozone residual one minute downstream of the ozone addition point. The rate of decay of the ozone residual in the presence of hydrogen peroxide at an elevated pH is very fast, therefore in order to maintain an ozone residual of 0.4 mg/L after a minute of reaction time, the required dose was very high.

A second test was conducted in which the ozone residual control point was moved upstream to a location only 30 seconds downstream of the ozone addition point, which is also the location of hydrogen peroxide addition. The two contactors were then operated in a “constant residual” mode, and the results are shown in Figure 5.11. Figure 5.11 is similar to Figure 5.10 in that it shows a plot of the varying pH values and corresponding ozone doses and ozone residuals when operated in “constant residual” mode with the relocated sample tap for the Peroxone contactor. The lower portion of Figure 5.11 shows that with the relocated sample point, the required ozone dose to maintain the target ozone residual was less variable (1.7 mg/L to 4.0 mg/L) compared to that reported in Figure 5.10 (2.0 mg/L to 6.7 mg/L). This variability in the ozone dose with the relocated control point is still quite variable (a difference of 2.3 mg/L), but it is closer to that needed for the conventional contactor shown in the upper portion of Figure 5.11.

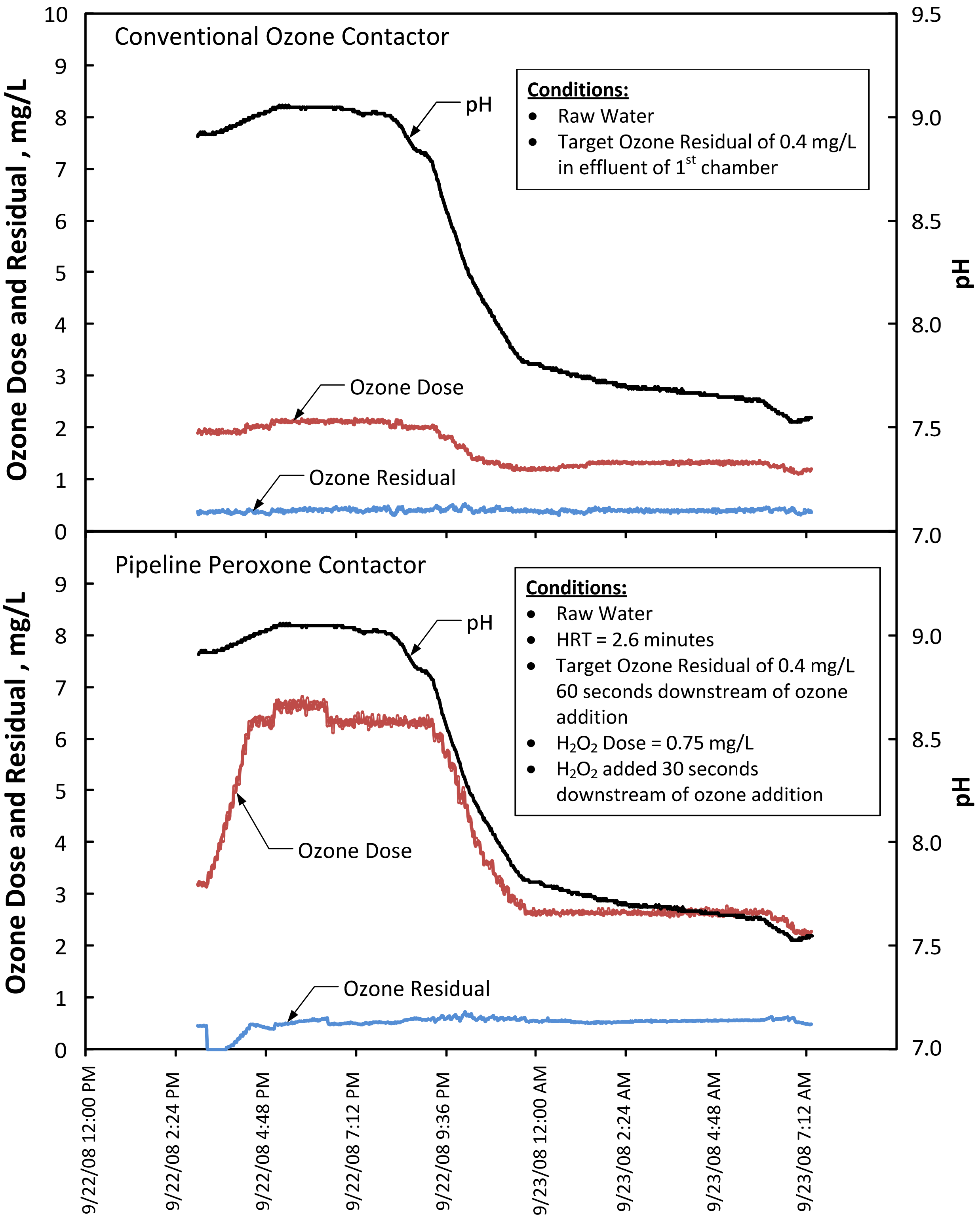


Figure 5.10 – Impact of Diurnal pH Changes on the Ozone Demand of the Raw Water Treated by a Conventional Ozone Contactor or a Pipeline Peroxone Contactor
[Control point located 60 seconds downstream of ozone injection]

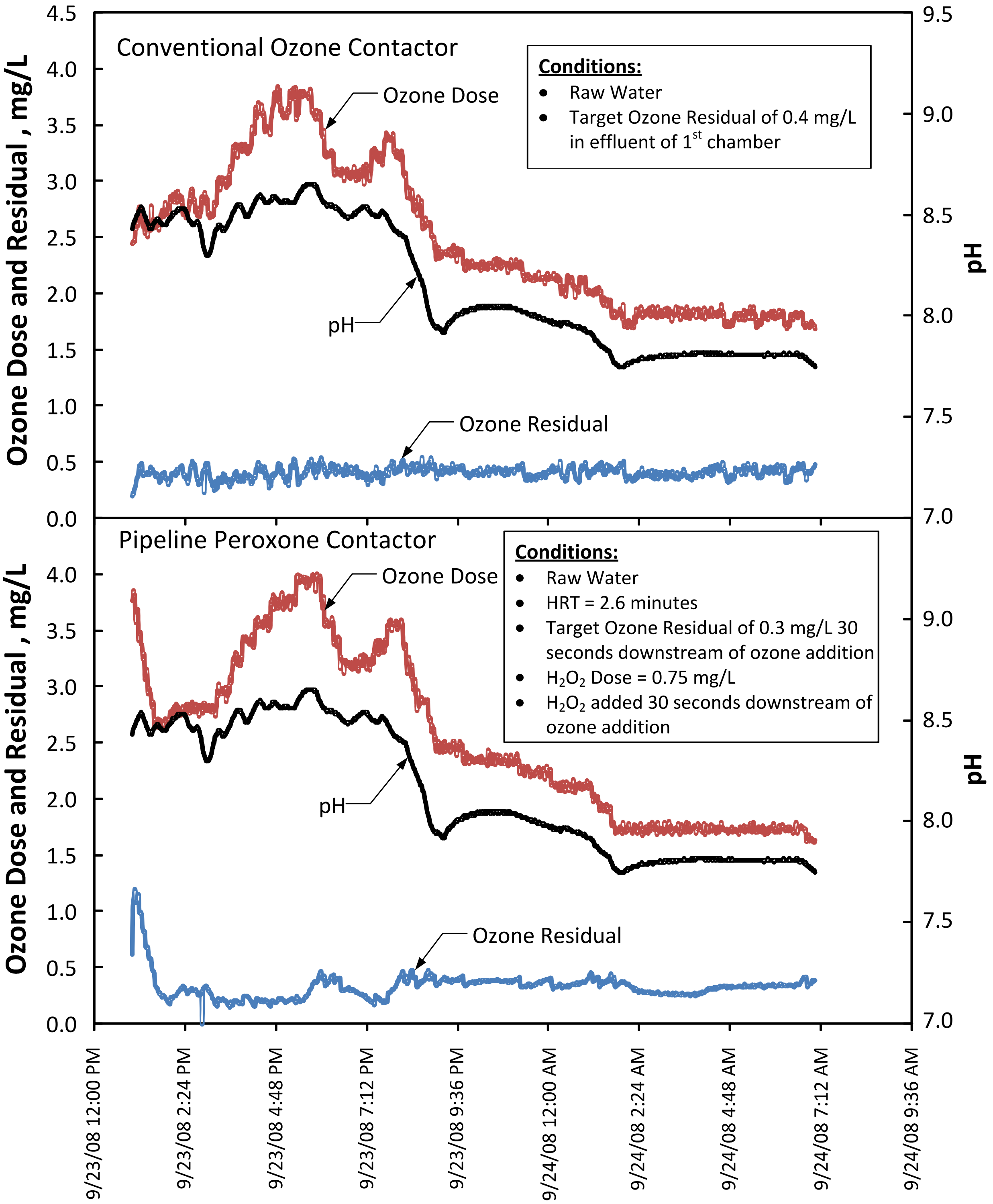


Figure 5.11 – Impact of Diurnal pH Changes on the Ozone Demand of the Raw Water Treated by a Conventional Ozone Contactor or a Pipeline Peroxone Contactor
[Control point located 30 seconds downstream of ozone injection]

The results presented in Figures 5.10 and 5.11 clearly demonstrate the strong impact of diurnal pH fluctuations on the ozone demand of the water for a conventional ozone contactor, as well as a pipeline Peroxone contactor. To eliminate this is effect, it is recommended to stabilize the pH upstream of the ozone or Peroxone process. This operational scenario was tested at the pilot plant. In this test, the ozone and Peroxone process were operated in a "constant residual" mode, but the pilot control system was set to maintain a constant pH in the influent water to both contactors. Sulfuric acid was added for pH adjustment. The pilot control system constantly adjusted the sulfuric acid dose to maintain the target pH as the raw water pH varied between night and day. The results of this 48-hr test are presented in Figure 5.12. During this test, the pH of the raw water varied between 9.4 and 7.7, and was adjusted at the pilot plant to a constant value of 7.3. The operating conditions were similar to those reported in Figure 5.11 in that the ozone dose to the conventional ozone contactor was varied to maintain a constant ozone residual of approximately 0.4 mg/L at the effluent of the 1st chamber. Since the pH of the water was stabilized at about 7.3, the ozone dose varied only between 1.4 and 1.9 mg/L. This is compared to a range of 1.5 to 3.8 mg/L shown in Figure 5.11. For the pipeline Peroxone contactor, the control system was also set up to vary the ozone dose so as to maintain a constant ozone residual of approximately 0.3 mg/L 30 seconds downstream of ozone injection (the same location as the hydrogen peroxide injection point). With the stable influent water pH at 7.3, the ozone dose varied only between 1.1 mg/L and 1.5 mg/L, compared to a range of 1.7 to 4.0 mg/L without pH adjustment (Figure 5.11).

The results reported in Figures 5.10, 5.11, and 5.12 clearly illustrate the following:

1. The varying pH of the SBA water has a profound impact on the ozone demand of the water, whether or not peroxide is used. Without pH adjustment, the required ozone dose to maintain a consistent ozone residual can vary by more than 2 mg/L between day and night.

2. When operating in "constant residual" mode, selection of the ozone residual control point for the Peroxone process is important. The control point should be very close to the ozone injection point in order to maintain a stable control system and to minimize the variations in the ozone dose required to maintain the target residual.

3. Stabilization of the pH greatly decreases the operational variability of both the ozone and Peroxone process, making the constant residual operating mode much more reliable.

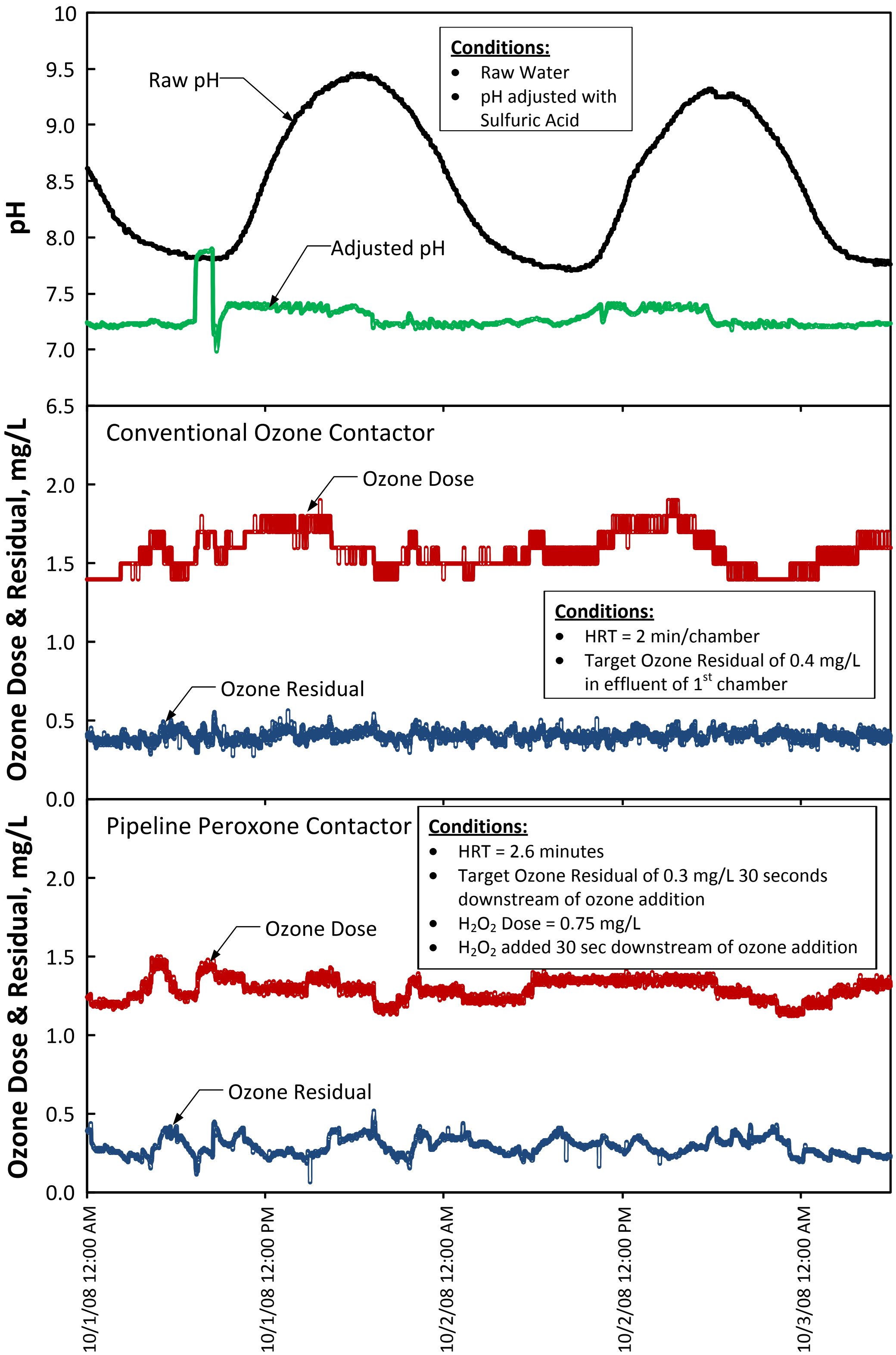


Figure 5.12 – Impact of pH Stabilization on the Ozone Demand of the Raw Water Treated by a Conventional Ozone Contactor or a Pipeline Peroxone Contactor

5.3.1.2 Constant Dose Mode Test Results

Tests were conducted using the “constant dose” mode. Consistent with the ACWD data shown in Figure 5.9, operation at a constant dose without adjusting the pH resulted in wide fluctuations in the ozone demand of the water, which translated into fluctuations in the ozone residual levels in the contactor. Figure 5.13 shows the results of the constant-dose tests conducted at the pilot plant in September. For the conventional contactor, the ozone dose was set at 2.5 mg/L. The top portion of Figure 5.13 shows that the decrease in pH from 8.7 in the afternoon to 7.4 in the morning of the following day resulted in an increase in the ozone residual from 0.6 mg/L (at pH 8.7) to 1.8 mg/L (at pH 7.4). For the pipeline Peroxone contactor, the ozone dose was set at 3.4 mg/L. The same shift in pH from 8.7 to 7.4 resulted in an increase in the ozone residual at the effluent of the ozone contactor (HRT = 2.6 minutes) from a low of non-detectable residual at pH 8.7 to a high of >2 mg/L at pH 7.4 (the online analyzer cannot measure values higher than 2 mg/L).

The results shown in Figure 5.13 illustrate the impact of pH changes in raw SBA water on the performance of an ozone-based process. This is important if a target ozone residual is to be maintained at all times (i.e., for disinfection CT calculation). However, if the plant is operated only for T&O oxidation and not for disinfection, then the measured ozone residual may not be as important. To investigate the need for maintaining an ozone residual, the pipeline Peroxone process was operated at a constant ozone dose for a period of seven (7) hours beginning at 10:30 AM and ending at 5:30 PM. The purpose of this test was to determine whether operating the Peroxone process under a constant ozone dose can still achieve the desired MIB and geosmin destruction goals, regardless of whether or not a residual ozone is maintained at some point in the contactor. During the seven-hour test period, the raw water entering the contactor was spiked with approximately 40 ng/L of each of MIB and geosmin. The Peroxone process was then monitored for influent and effluent MIB and geosmin levels every hour. During this period, the feed water pH was also monitored, along with the ozone residual concentrations at the middle and effluent of the Peroxone contactor. These locations are 60 seconds and 160 seconds from the point of ozone injection. The hydrogen peroxide was injected approximately 30 seconds downstream of the ozone injection point. The results are summarized in Figure 5.14. During the test period, the raw water pH increased from 8.1 at 10:30 AM to 8.9 at 5:30 PM. With the ozone dose maintained at 2.5 mg/L throughout the test, the ozone residual varied from a high of 0.15 mg/L to non-detectable levels at the mid-point of the contactor, and never exceeded 0.1 mg/L at the effluent of the contactor. The plot in the lower half of Figure 5.14 shows that the change in pH and lack of a measurable residual 30 seconds downstream of the hydrogen peroxide injection point had no effect on the destruction of MIB and geosmin. Throughout the seven-hour test, with the feed MIB and geosmin concentration held relatively constant between 40 and 45 ng/L each, the concentrations of MIB and geosmin in the effluent of the Peroxone process remained below 5 ng/L (approximately 90% destruction). These results suggest that maintaining a measurable residual for any appreciable amount of time downstream of hydrogen peroxide addition in a Peroxone process may not be necessary for satisfactory T&O destruction. It should be noted, however, that the need to control bromate formation remains to be a strong driver to reduce the pH of the water before ozonation.

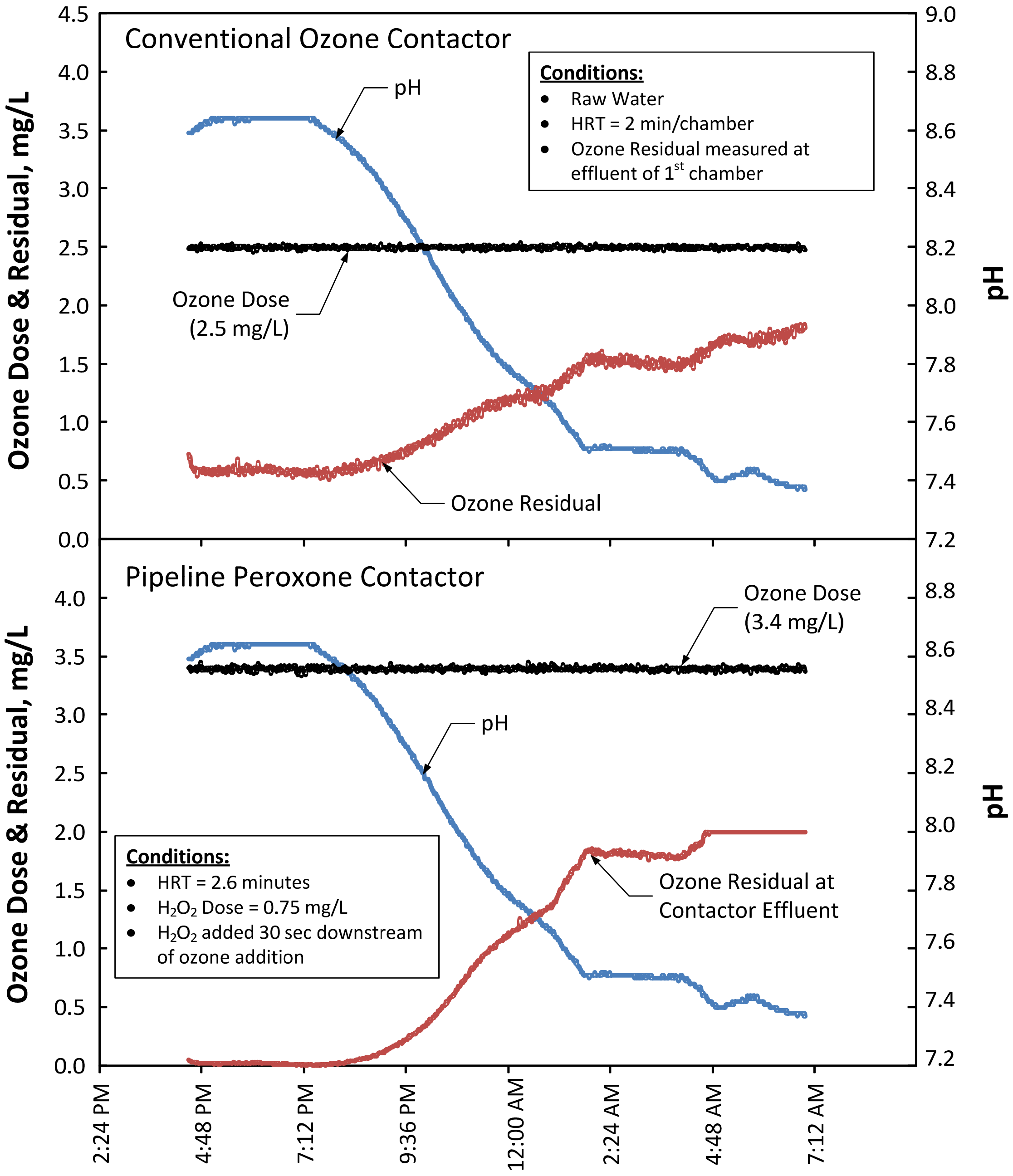


Figure 5.13 – Variability in Raw Water pH and its Impact on Ozone Residual in Both Contactors when Operated in Constant Dose Mode

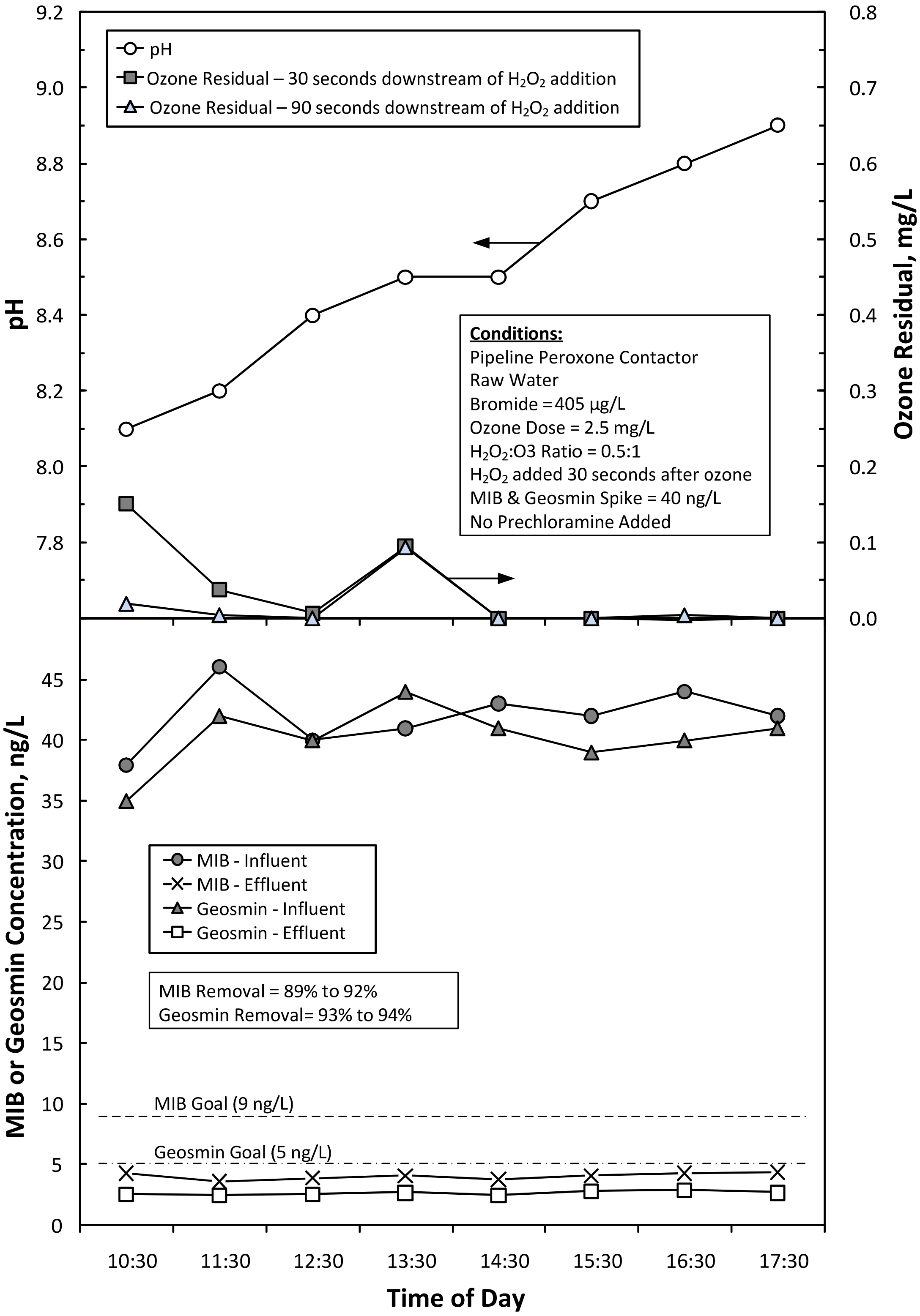


Figure 5.14 – Impact of Daily pH variation in the Raw Water on the Performance of the Pipeline Peroxone Process Operated at a Constant Ozone Dose

5.3.2 Impact of Peroxide Addition Point

One of the important questions to answer when designing a Peroxone process is "*where should the hydrogen peroxide be added?*" A Peroxone process is based on the principle that the combination of ozone and hydrogen peroxide generates hydroxyl radicals (OH•), which are stronger, less selective oxidants than molecular ozone, and should result in the same level of chemical destruction with lower ozone doses and shorter contact times. This principle suggests that the addition of hydrogen peroxide immediately upstream of ozone should result in the same level of OH• radical formation and the shortest process contact time, since the hydrogen peroxide will be immediately available to react with the ozone at the point of ozone addition.

With the above discussion in mind, the pilot testing was to be conducted with hydrogen peroxide addition immediately upstream of ozone injection, and the first round of matrix testing was conducted using this configuration. However, when the testing results were analyzed, it became apparent that the Peroxone process was not achieving the T&O destruction goals anticipated. Moreover, the results indicated that the addition of higher levels of peroxide had no effect on the destruction of MIB and geosmin with the Peroxone process, and the ozone residual in the effluent of the contactor was much higher than originally expected. An example of the unexpected outcome of the Round 1 tests is presented in Figure 5.15. The data plotted in Figure 5.15 were collected using raw water adjusted to pH 7.0. The "square" symbols represent MIB destruction as a function of the ozone dose applied to the Peroxone contactor with hydrogen peroxide added immediately upstream of the ozone injection point. The peroxone ratio was approximately 0.5:1. The contactor was operated at a flowrate resulting in a total hydraulic retention time of 2.3 minutes through the contactor. The "triangle" symbols represent the data points collected with the same Peroxone contactor, operated under the same conditions, but without the addition of any hydrogen peroxide. The "circle" symbols represent the MIB destruction measured across the conventional contactor with ozone added to the first chamber, and no hydrogen peroxide added to the water before or after ozone injection. Figure 5.15 clearly indicates that there was no discernable difference in the impact of ozone dose on MIB destruction through the pipeline Peroxone contactor or the conventional contactor, and, more importantly, that the addition of hydrogen peroxide at a ratio of 0.5:1 also had no noticeable effect on the ozone dose required for MIB destruction.

It is noted that Round 1 testing was conducted in June 2008. In light of the results obtained, tests were conducted in August 2008 to determine whether the lack of advantage of the Peroxone process over the conventional ozone process was due to the fact that the hydrogen peroxide was added upstream instead of downstream of the ozone injection point. The results, which are presented in Figure 5.16, clearly demonstrated that the peroxide addition point had a significant impact on the reaction between the ozone and hydrogen peroxide. In the test reported in Figure 5.16, the raw water flowrate was set at 2 gpm, which resulted in a 4-minute hydraulic retention time through the pipeline contactor. The ozone dose applied was 5 mg/L. With no hydrogen peroxide addition, the residual ozone at the outlet of the contactor was measured at 0.27 and 0.32 mg/L. With hydrogen peroxide addition upstream of the ozone injection point, the ozone residual at the outlet of the contactor was still measured at 0.24 mg/L at a H_2O_2:O_3 ratio of 1:1, and 0.23 mg/L at a H_2O_2:O_3 ratio of 2:1. However, when hydrogen peroxide was added 1 minute downstream of the ozone injection point, the ozone residual concentration in the effluent of the contactor was measured at 0.08 mg/L at a H_2O_2:O_3 ratio of 1:1, and ND at a H_2O_2:O_3 ratio of 2:1. Based on these findings, Rounds 2 and 3 tests were conducted with hydrogen peroxide addition downstream of ozone injection.

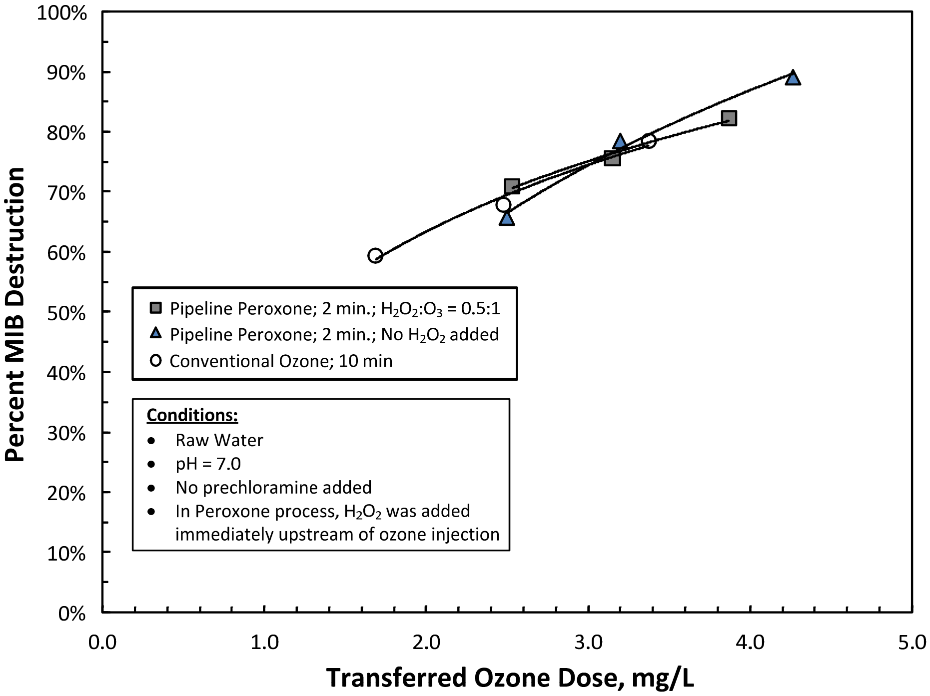


Figure 5.15 – Comparison in MIB Destruction between the Conventional Ozone Contactor and the Pipeline Peroxone Contactor with and without Hydrogen Peroxide Addition During Round 1 Testing

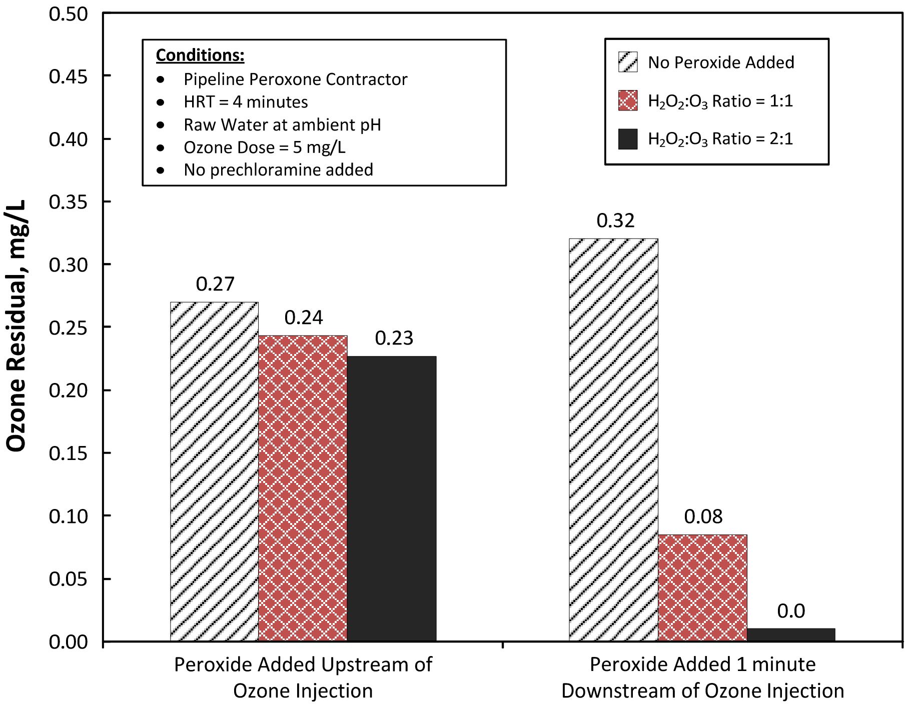


Figure 5.16 – Impact of Hydrogen Peroxide Addition Point on the Ozone Residual Measured at the Effluent of the Pipeline Peroxone Contactor (August 2008)

At the end of Round 3 testing conducted in October 2008, a test was conducted to determine whether the results of Round 1 and the follow up tests in August 2008 could be replicated. During this test, the hydrogen peroxide feed point was moved back upstream of the ozone injection point. The ozone residual concentrations in the Peroxone contactor effluent were then compared to those measured when the peroxide was added downstream of the ozone injection point, as well as to the levels measured when no peroxide was added. The results are shown in Figure 5.17. In this test, the addition of hydrogen peroxide upstream of ozone resulted in complete destruction of the ozone residual by the end of the contactor compared to the results with no peroxide addition. This is opposite from the results obtained during Round 1 and the subsequent testing conducted in August 2008 and reported in Figure 5.16 above. The results gathered with peroxide addition downstream of ozone injection were consistent with the previous results in that they too resulted in the destruction of the ozone residual to very low levels.

There is no clear explanation for why peroxide addition upstream of ozone performed so poorly during Round 1 and during the August testing, but then performed well during Round 3 in October. We speculate that the organic makeup of the water in July and August 2008 somehow affected the reactivity of hydrogen peroxide before the ozone was added, and that made it unavailable to react with the ozone in the Peroxone contactor to form hydroxyl radicals. This water quality characteristic then may have changed by October 2008 such that the addition of peroxide upstream of ozone performed as well as when it was added downstream of ozone. Unfortunately, we do not have the ability to prove or disprove this hypothesis. However, these findings suggest that adding hydrogen peroxide downstream of ozone injection is a more reliable approach to designing the Peroxone process for the DVWTP or PPWTP.

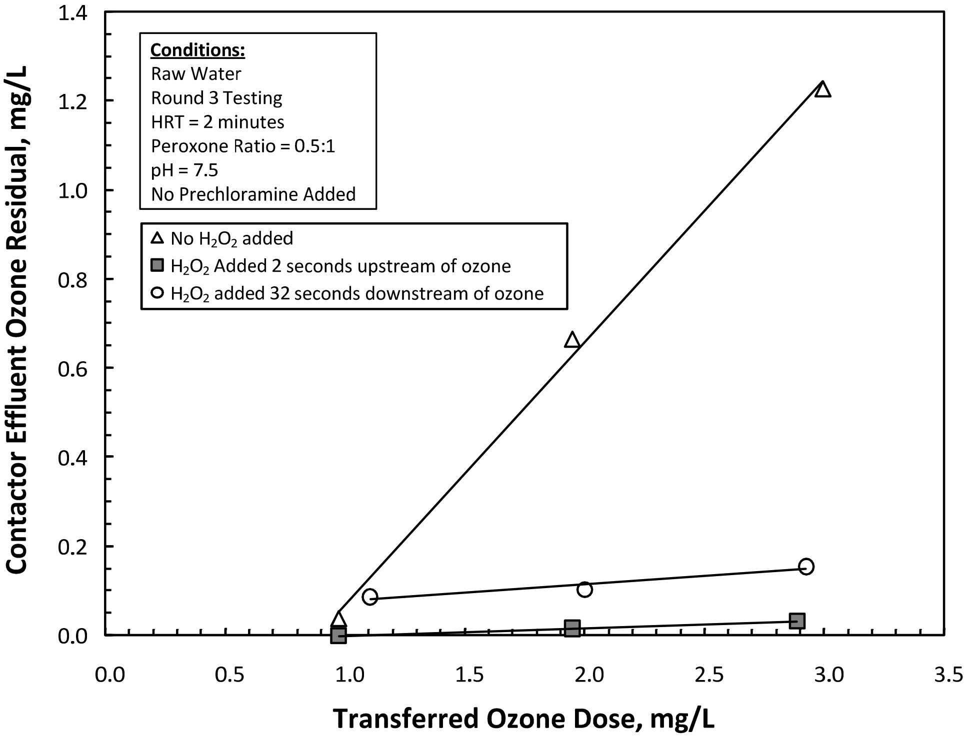


Figure 5.17 – Impact of Hydrogen Peroxide Addition Point on the Decay of Ozone through the Pipeline Peroxone Contactor During Round 3 Testing (October 2008)

The previous discussion focused on determining whether the peroxide should be added upstream or downstream of ozone. The conclusion is that adding hydrogen peroxide downstream of ozone resulted in more consistent performance. The only remaining question is whether the time between ozone addition and peroxide addition has an impact on the performance of the process. To answer this question, tests were conducted during Round 3 to evaluate and compare MIB and geosmin destruction through the Peroxone process when hydrogen peroxide is added immediately downstream of ozone, approximately 30 seconds downstream of ozone, and approximately 60 seconds downstream of ozone. The results are presented in Figure 5.18. These tests were conducted using raw water adjusted to pH 7.5 and spiked with 34 to 46 ng/L of MIB. The ambient bromide level in the water ranged from 343 and 381 µg/L during this test. The water was also dosed with 0.75 mg/L prechloramine upstream of the Peroxone process. The hydrogen peroxide dose was adjusted to result in a H_2O_2:O_3 ratio of 0.5:1.

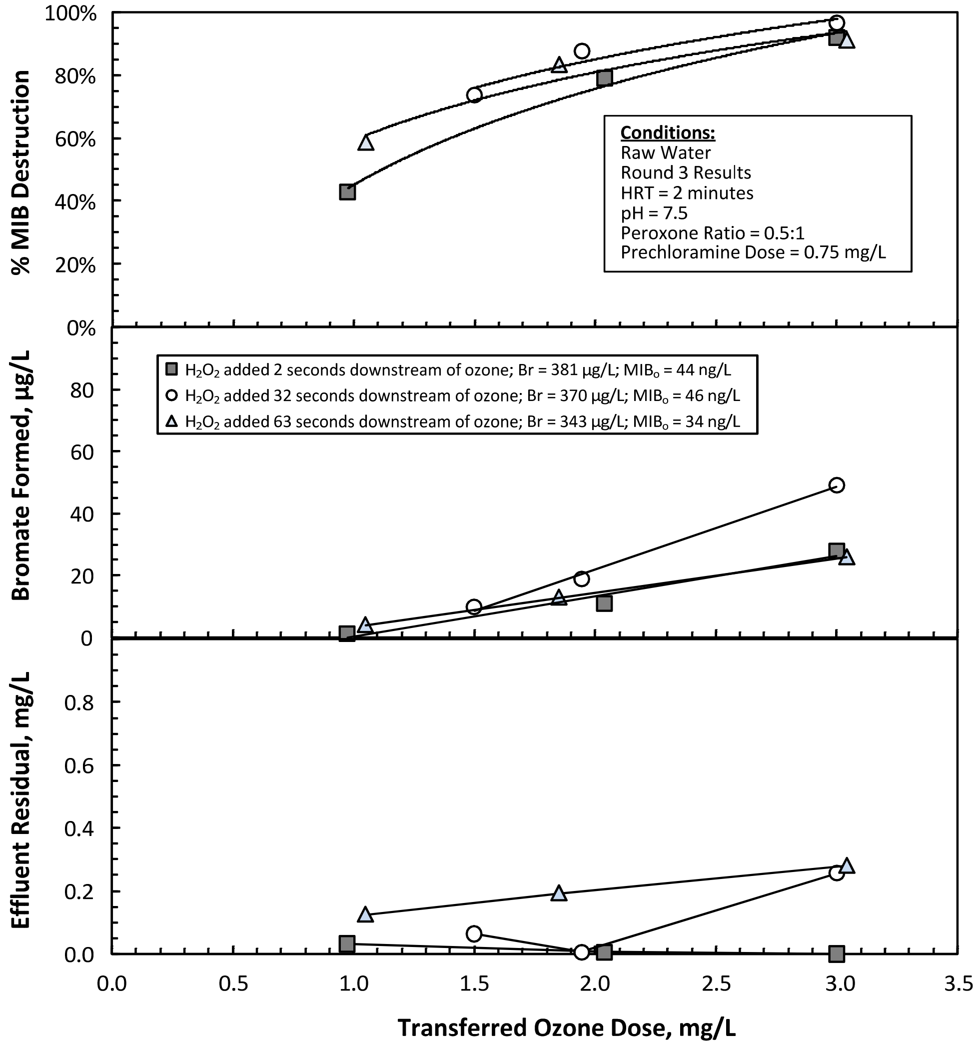


Figure 5.18 – Impact of Hydrogen Peroxide Addition Point on MIB Destruction, Bromate Formation, and Contactor Effluent Ozone Residual

The results reported in Figure 5.18 show that the lag time (2 to 60 seconds) between ozone and peroxide addition had no significant impact on the destruction of MIB or on bromate formation. It is interesting to note that the effluent residual from the 2.6-minute contactor was higher when the hydrogen peroxide was added 60 seconds after ozone injection. This is likely due to the fact that adding the hydrogen peroxide midway through the 2.6-minute contactor left only one minute from the peroxide injection point to the effluent of the contactor. The results suggest that this may be too short of a contact time for the reaction between ozone and peroxide to reach completion. For this reason, it would be desirable to add the hydrogen peroxide immediately downstream of the ozone addition point so as to provide adequate contact time for the peroxide to react with the ozone before the end of the contactor.

5.3.3 Impact of Peroxone Ratio

One of the important design factors for the Peroxone process is the H_2O_2:O_3 ratio (i.e., Peroxone ratio). The majority of the tests performed in this study were conducted with a ratio of 0.5:1. However, a number of tests were also conducted in Round 3 using a ratio of 1:1 and 2:1. The results were compared to determine the impact of the Peroxone ratio on the destruction of T&O chemicals, formation of bromate, and operation of the Peroxone process. The results presented in Figure 5.19. The top portion of Figure 5.19 shows that there was no discernable difference in MIB destruction between the three ratios tested. The middle portion of Figure 5.19 shows that the 1:1 and 2:1 ratios may produce slightly lower levels of bromate than the 0.5:1 ratio. However, it is important to emphasize that the results from the other tests conducted did not always show lower bromate formation with higher Peroxone ratio. In fact, some tests showed higher bromate formation with higher Peroxone ratios. Finally, the lower portion of Figure 5.19 shows that the ozone residual in the contactor effluent was low under all ratios. However, the higher Peroxone ratio of 2:1 resulted in completely non-detectable ozone residual levels in the contactor effluent.

Based on these results, while a Peroxone ratio of 0.5:1 is a reasonable target for the operation of the Peroxone process, it may be desirable to provide the flexibility of higher Peroxone ratios if needed by the operators to fully quench the ozone residual. A maximum ratio of 1:1 at the maximum ozone dose is a reasonable value for the design of the full-scale system.

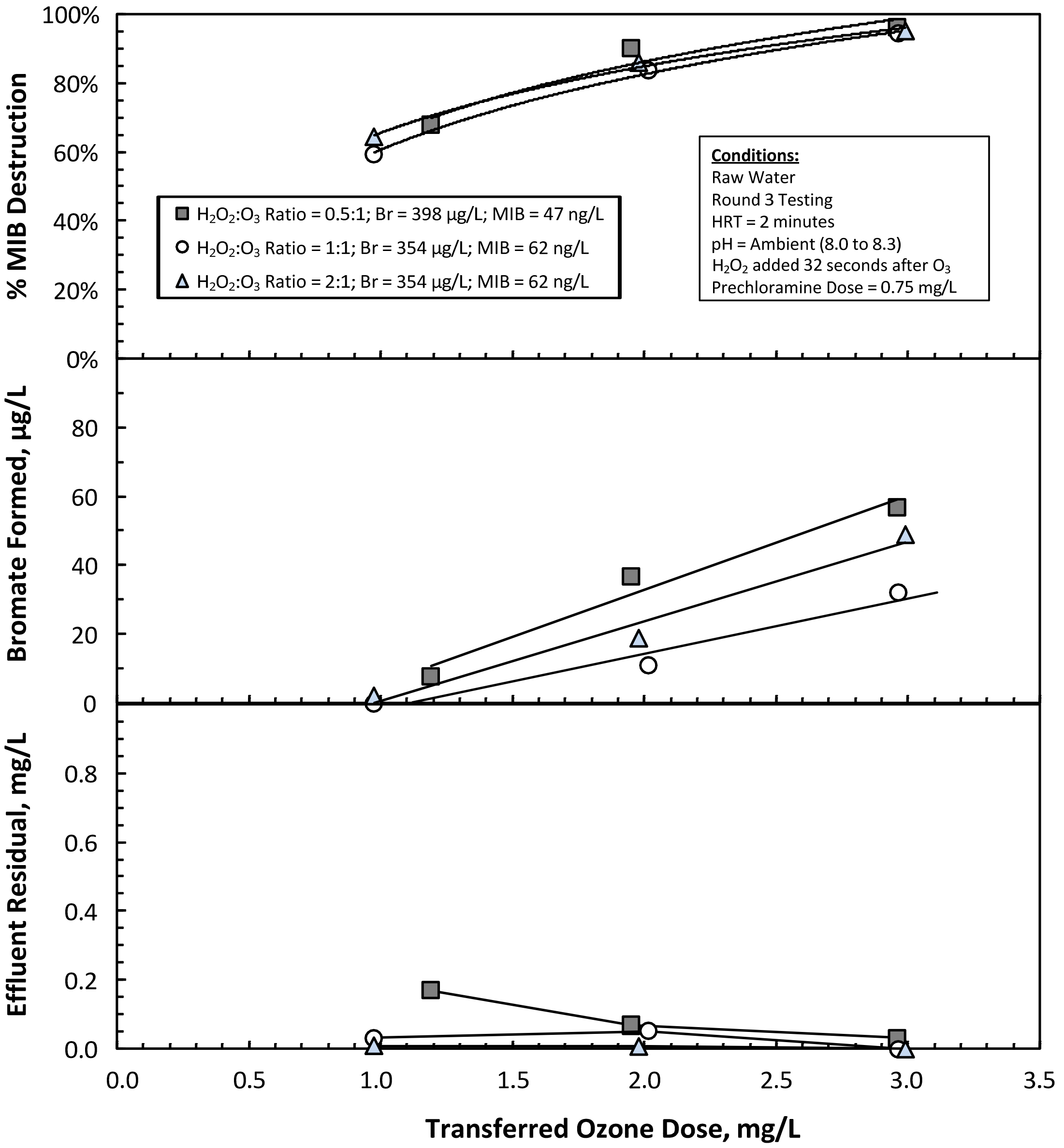


Figure 5.19 – Impact of Peroxone Ratio on MIB Destruction, Bromate Formation, and Contactor Effluent Ozone Residual Level

5.3.4 Evaluation of By-Product Formation

The results of the formation and control of bromate with ozone or Peroxone was thoroughly discussed earlier in this document. While bromate is the only regulated ozone by-product, the study also evaluated the impact of using ozone or Peroxone for the treatment of SBA water on three classes of by-products:

1. Assimilable Organic Carbon (AOC)
2. Chlorination by-products, primarily trihalomethanes (THMs) and haloacetic acids (HAAs)
3. Iodinated trihalomethanes (I-THMs) and halonitromethanes (HNMs)

This section presents the results of the investigation regarding the above DBPs.

5.3.4.1 AOC Formation

While naturally-occurring organic matter is not readily consumed by most bacteria, when it is exposed to ozone, the large non-biodegradable molecules are broken down to smaller, more biodegradable molecules. This translates into an increase in the concentration of biodegradable organic matter (BOM) in the water. The fact that some of the natural organic matter is more biodegradable after ozonation is of no health concern. However, the higher the concentration of "food" for natural bacteria in the water, the higher is the risk of bacterial growth in the distribution system, especially in zones where the chloramine residual is low. To help reduce this risk, biofiltration is typically practiced at the treatment plant downstream of ozone addition. Biofiltration simply employs attached micro-organisms on the filter media to consume some of the BOM before the water enters the distribution system, thereby reducing the "food" supply in the water. However, it should be emphasized that practicing biofiltration at the treatment plant does not guarantee a reduction in bacterial growth in the distribution system because bacterial growth is impacted by many water quality and operational factors that could be far more significant than the concentration of BOM in the water. Nevertheless, it is standard practice in the water industry to used biofiltration after ozonation to reduce the risk of bacterial growth in the distribution system.

This project did not evaluate biofiltration downstream of ozonation. However, sampling was conducted before and after ozone and Peroxone treatment and analyzed for the concentration of BOM in the water. The intent was to quantify the increase in the BOM concentration as a result of each process and compare them to the BOM levels in the current effluent of the DVWTP. There are numerous methods used to quantify BOM. The method used in this study is the Assimilable Organic Carbon (AOC) analysis, which is a Standard Method (SM-9217, approved 1997). In this method, a specific strain of bacteria is grown in a sample of water. The increase in the bacterial count over a specific period of time is translated into a concentration of AOC based on knowledge of the carbon demand of the specific bacteria used in the test. While this is not a direct measure of the BOM concentration, it is desirable because it is a Standard Method and is conducted by a number of commercial laboratories.

Figure 5.20 shows a plot of the AOC concentrations measured in the raw water treated with ozone and Peroxone. The samples were collected in June and July of 2008. The conditions under which the ozone and Peroxone systems were operated when these samples were collected are listed under the graph. Also shown in the graph are the AOC levels measured in the raw water and the DVWTP effluent on the same days. Figure 5.20 shows that the AOC concentration in the raw water ranged from 37 to 50 μg/L, while its concentration in the DVWTP effluent on the two days of sampling ranged from 126 μg/L to 151 μg/L. The addition of 1.8 mg/L ozone to a conventional ozone process or a Peroxone process, operated at a Peroxone ratio of 0.5:1 increased the AOC concentration to 418 μg/L. With an ozone dose of 2.5 mg/L, the AOC concentration in the ozonated water increased to 760 μg/L after conventional ozonation and to 381 μg/L after Peroxone treatment.

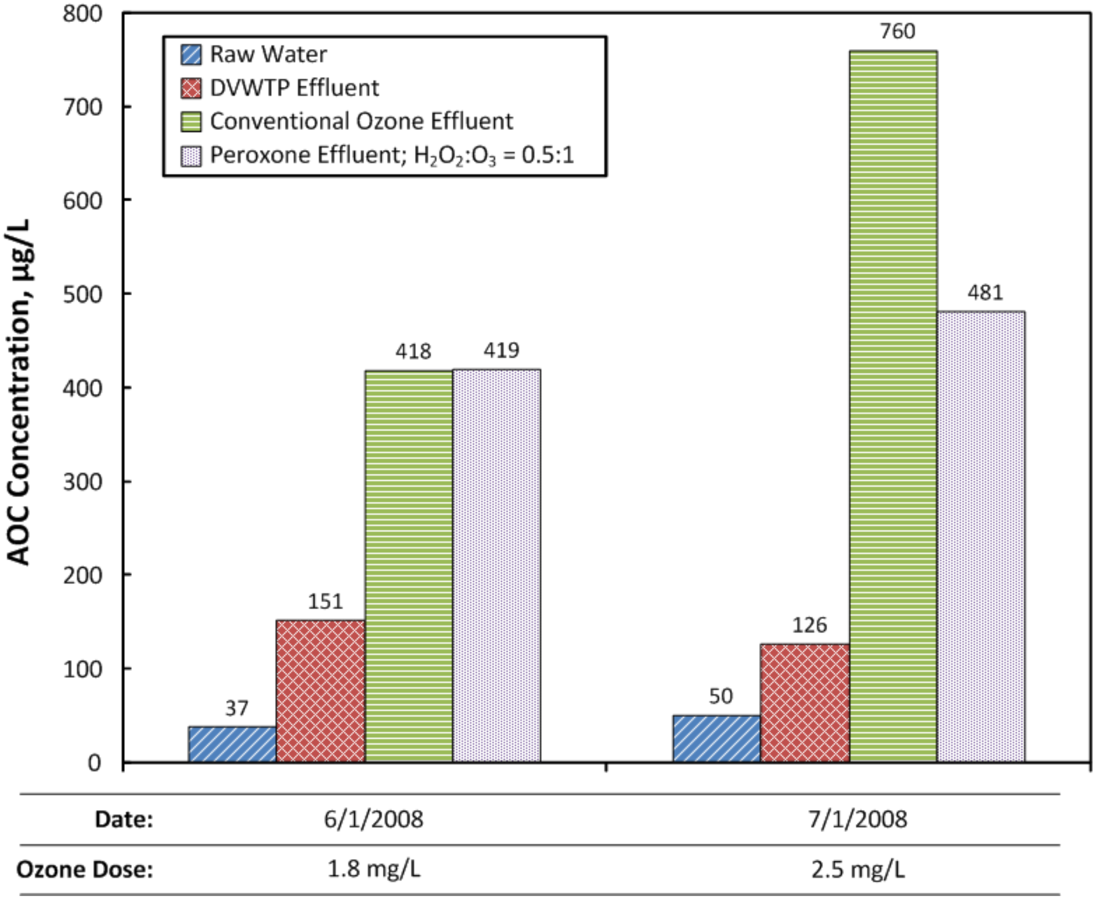
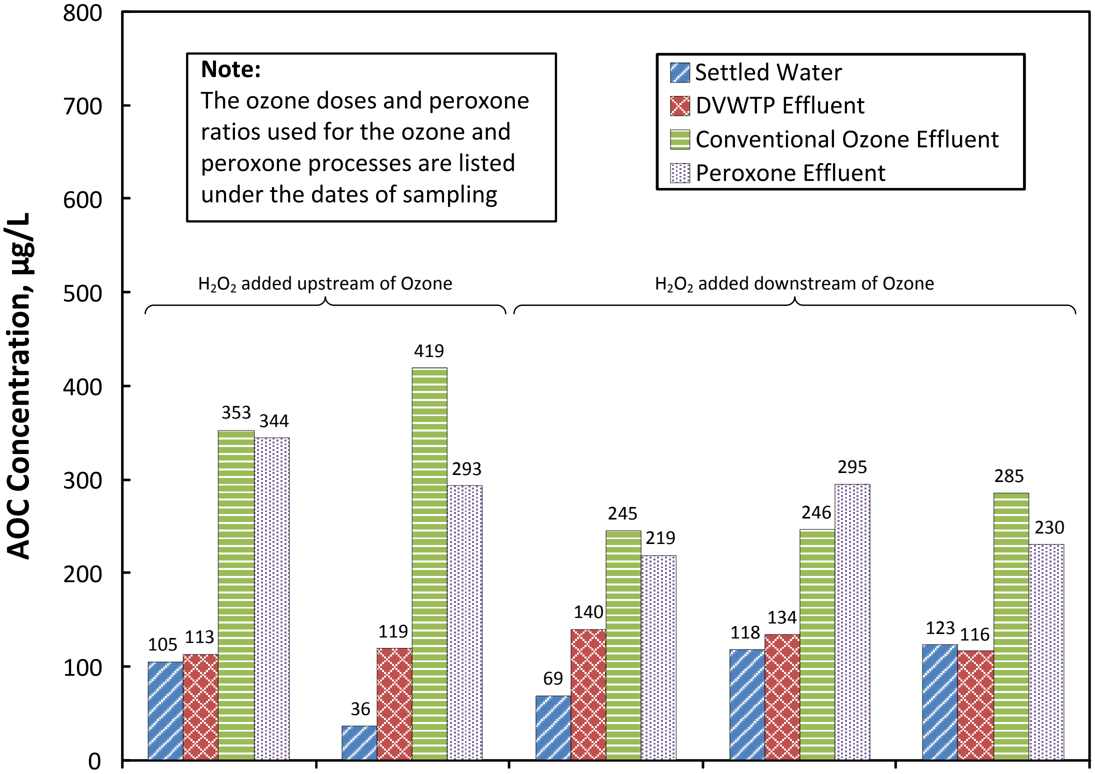


Figure 5.20 – AOC Formation in Raw Water

AOC samples were also collected from the effluent of the ozone and Peroxone processes on five different days when treating settled DVWTP water at the pilot plant. The results are plotted in Figure 5.21. Samples were also collected from the settled water and DVWTP effluent on the same days, and the AOC levels in those samples are also included in Figure 5.21. The operating conditions of the ozone and Peroxone processes at the time of sampling are listed under the graph. The results show that the AOC concentration in the settled water on these days ranged from a low of 36 µg/L to a high of 123 µg/L, while the concentration in the DVWTP effluent ranged from 113 µg/L to 140 µg/L. However, when the settled water was treated through conventional ozone or Peroxone, the AOC levels increased to a range of 219 µg/L to 419 µg/L.

Unfortunately, there is no criterion for determining whether a certain AOC concentration in a water sample is acceptable or too high for a normal distribution system. In fact, there are water treatment plants that use ozone but do not practice subsequent biological filtration. Ultimately, the decision whether to implement biological filtration after ozonation is a subjective decision made with several risk factors in mind. If one looks at the relative increase in AOC concentration from the current plant effluent to the expected ozonated water value, the AOC concentration will likely double or triple with the introduction of ozone to DVWTP and PPWTP. This may be sufficient for one to decide that this AOC level is too high and should be reduced with biological filtration. It is relevant to note that the current design for the Altamont WTP includes a post-membrane GAC contactor for removal of BOM after ozonation. There is ample full-scale data to demonstrate the biological filtration is effective at removing AOC in this water source.



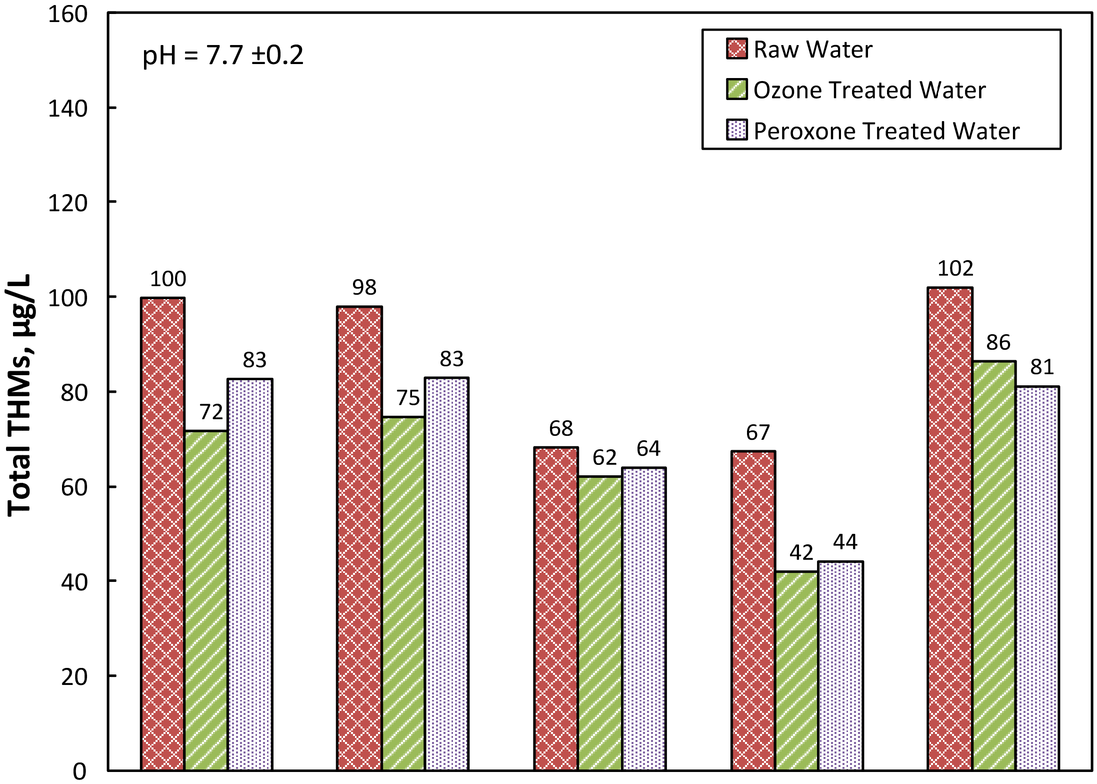
Date:	7/28/2008	8/11/2008	9/8/2008	9/22/2008	10/6/2008
Ozone Dose =	3 mg/L	1.5 mg/L	1 mg/L	1.5 mg/L	2 mg/L
pH =	6.6	6.8	6.9	6.6	6.7
H_2O_2:O_3 =	1.5:1	1:1	0.5:1	0.5:1	0.5:1

Figure 5.21 – AOC Formation in Settled Water

5.3.4.2 Impact on THM and HAA Formation

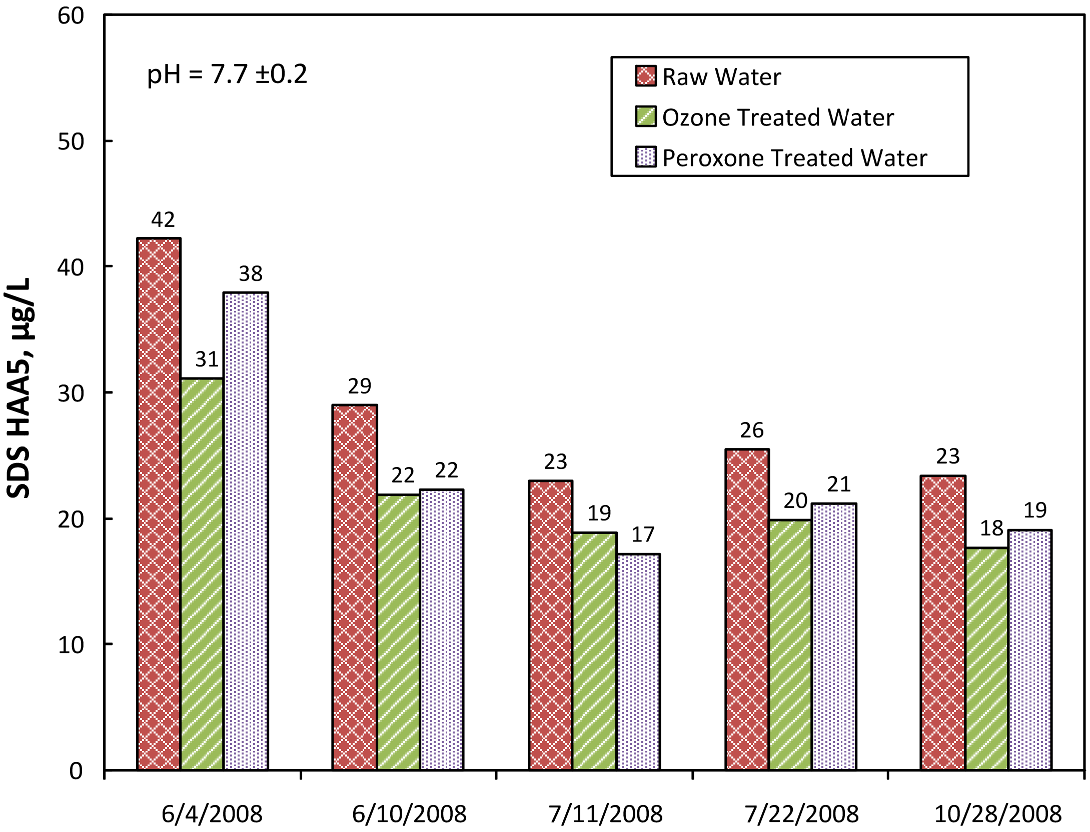
During the course of the pilot testing effort, a number of sampling events were conducted during which water samples were collected from the influent to the pilot plant, the effluent of the conventional ozone process, and the effluent of the Peroxone process, and utilized for Simulated Distribution System (SDS) DBP formation testing. This test is used to quantify the potential formation of THMs and HAAs in a distribution system after treatment with chlorine and chloramine. In this test, a sample of water was dosed with chlorine such that there was a chlorine residual of approximately 2.0 mg/L after 1 hour of contact time, and then the samples were dosed with ammonia to form chloramine. The water sample was then incubated in the dark for 24 hours at room temperature. After incubation, the water was analyzed for THMs and HAA5 levels.

The results of the raw water tests are summarized in Figure 5.22 for THMs and Figure 5.23 for HAA5 levels. The SDS tests were conducted in June, July, and October of 2008. The THM level in the chloraminated raw water ranged from a low of 67 µg/L to a high of 102 µg/L, while the concentration of HAA5 ranged from a low of 23 µg/L to a high of 42 µg/L. It is interesting to note that the concentration of THMs and HAA5 formed in the chloraminated waters treated with ozone or Peroxone were consistently lower than those formed in the chloraminated raw water. In some cases, the reduction in THM or HAA levels formed was as high as 30%. These results suggest that the implementation of ozone or Peroxone at the DVWTP and PPWTP should help reduce the levels of THMs and HAA5 in Zone 7's water distribution system, even without any changes to the current free-chlorine disinfection practice. To that extent, it is also expected that biological filtration will further reduce the organic content of the water by about 5 to 15%, which should also contribution to THM and HAA5 reduction in the distribution system.



Date:	6/4/2008	6/10/2008	7/11/2008	7/22/2008	10/28/2008
Ozone Dose =	1.8 mg/L	4 mg/L	2.5 mg/L	2.5 mg/L	3 mg/L
H_2O_2:O_3 =	0.8:1	0.2:1	0.5:1	0.5:1	0.5:1
Cl_2 Dose =	5 mg/L	3.5 mg/L	2.4 mg/L	3.0 mg/L	3.5 mg/L

Figure 5.22 – SDS THM Formation in Raw Water



Date:	6/4/2008	6/10/2008	7/11/2008	7/22/2008	10/28/2008
Ozone Dose =	1.8 mg/L	4 mg/L	2.5 mg/L	2.5 mg/L	3 mg/L
H_2O_2:O_3 =	0.8:1	0.2:1	0.5:1	0.5:1	0.5:1
Cl_2 Dose =	5 mg/L	3.5 mg/L	2.4 mg/L	3.0 mg/L	3.5 mg/L

Figure 5.23 – SDS HAA Formation in Raw Water

5.3.4.3 Impact on I-THMs and HNM Formation

While bromate, THMs, and HAAs are regulated DBPs, there is ongoing research looking at new by-products of chlorination and chloramination of drinking water. In the interest of evaluating the impact of either ozone or Peroxone on the formation of these emerging DBPs, some samples were collected from the pilot plant and DVWTP and sent to Clemson University to be analyzed for two classes of by-products: iondinated trihalomethanes (I-THMs) and halonitromethanes (HNMs). The specific chemicals in each class of by-products are listed in Table 5.4 for reference. There are six individual I-THMs, and nine individual HNMs. While Clemson University analyzed all individual chemicals, the total concentration of each class is presented in this report.

Table 5.4 – Iodinated Trihalomethanes (I-THMs) and Halonitromethanes (HNMs) Analyzed

Iodinated THMs	
Name	**Formula**
Dichloroiodomethane	$CHCl_2I$
Bromochloroiodomethane	$CHBrClI$
Dibromoiodomethane	$CHBr_2I$
Chlorodiiodomethane	$CHClI_2$
Bromodiiodomethane	$CHBrI_2$
Triiodomethane	CHI_3

Halonitromethanes	
Name	**Formula**
Chloronitromethane	CH_2ClNO_2
Dichloronitromethane	$CHCl_2NO_2$
Trichloronitromethane	CCl_3NO_2
Bromonitromethane	CH_2BrNO_2
Bromochloronitromethane	$CHBrClNO_2$
Bromodichloronitromethane	$CBrCl_2NO_2$
Dibromonitromethane	$CHBr_2NO_2$
Dibromochloronitromethane	CBr_2ClNO_2
Tribromonitromethane	CBr_3NO_2

Since I-THMs and HNMs are believed to be by-products of chlorine and chloramine, and not ozone or Peroxone, the intent of the testing was to quantify the impact of implementing ozonation at DVWTP and PPWTP on the formation of these by-products with subsequent chloramination. The testing evaluated adding ozone and Peroxone to either the raw water or the settled water. It also evaluated the use of either prechloramine or pH depression for bromate control. To accomplish this goal, a testing protocol was developed and implemented similar to the SDS DBP test conducted for evaluating THM and HAA formation.

Using raw water as, two ozone treatment scenarios and two Peroxone treatment scenarios were simulated and analyzed. One ozone treatment scenario included prechloramine treatment at a dose of 0.75 mg/L for bromate control, followed by 2.0 mg/L ozone. The second ozone treatment scenario included pH suppression to 7.0 for bromate control, followed by 2.0 mg/L ozone. After ozone treatment, the two samples were then adjusted to pH 8.0 and dosed with 2.5 mg/L chlorine. After 10 minutes of free chlorine contact, the samples were dosed with 0.63 mg/L ammonia to form chloramine, and then incubated at room temperature for 24 hrs. The Peroxone scenarios were identical to the ozone scenarios with the addition of 1.0 mg/L hydrogen peroxide 30 seconds downstream of ozone injection (H_2O_2:O_3 Ratio of 0.5:1). Control samples were also analyzed for I-THMs and HNMs. These included a raw water sample that underwent no treatment, and more importantly, a sample of current DVWTP effluent.

The results of the tests conducted to simulate raw water ozone or Peroxone treatment are presented in Figure 5.24 along with the results of the two control samples. The results indicate that the current treatment train at DVWTP results in the formation of 1.3 µg/L I-THMs and 1.8 µg/L HNMs. For the simulated ozone treatment train, the I-THM and HNM levels formed were comparable at 2.3 µg/L and 1.1 µg/L, respectively. Unfortunately, due to a contamination problem, the ozone treatment sample with prechloramine for bromate control was invalidated because it had a very low pH of <3. The two Peroxone treatment scenarios resulted in the formation of slightly lower levels of I-THMs and HNMs compared to the current DVWTP effluent and the ozone treatment scenario. With prechloramine for bromate control, the I-THMs were non-detectable, while the HNMs were measured at 0.7 µg/L. With pH suppression for bromate control, 0.7 µg/L of I-THMs were formed along with 1.5 µg/L of HNMs. In general, the utilization of raw water ozone or Peroxone treatment is expected to form I-THM and HNM levels equal to or slightly lower than those formed by the current treatment train.

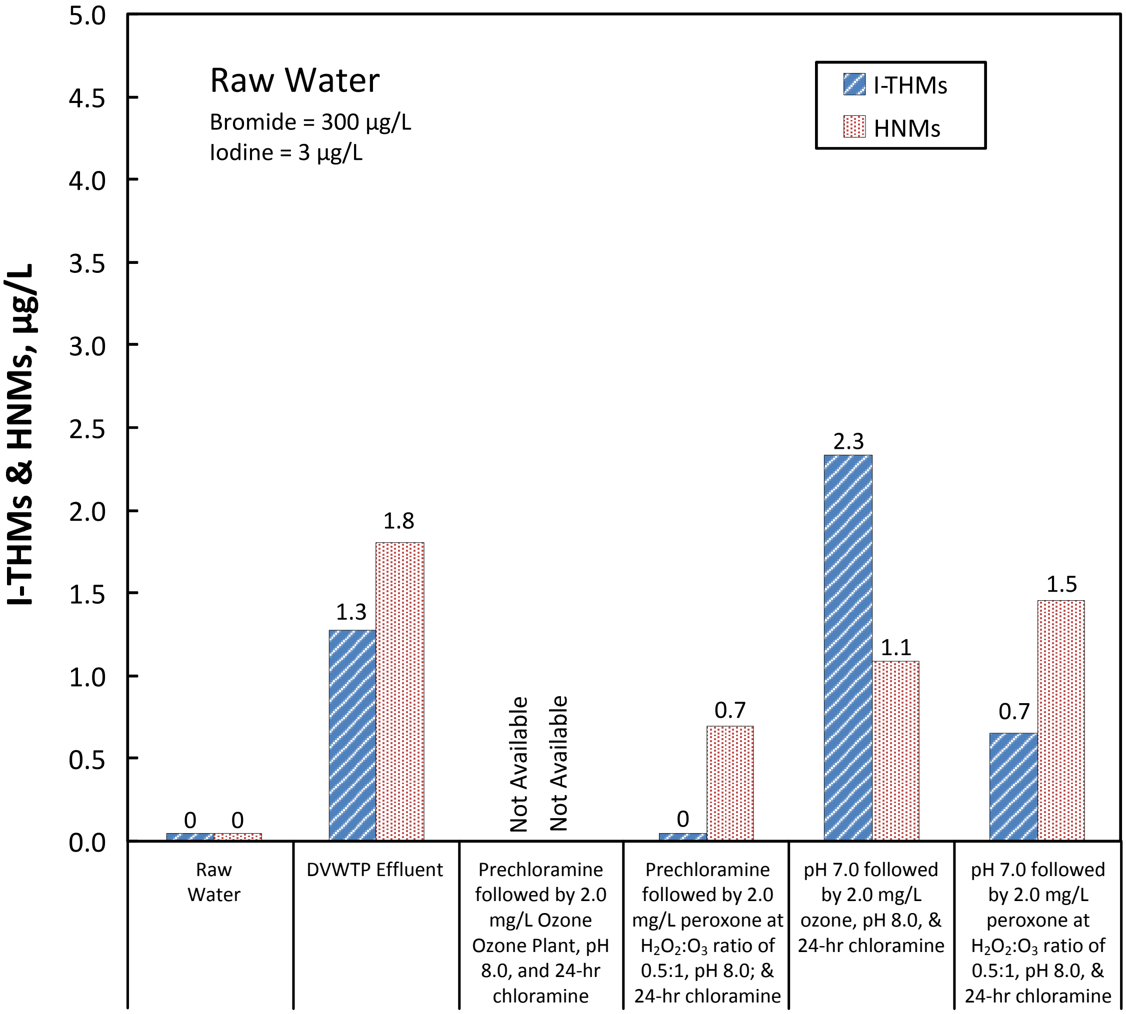


Figure 5.24 – Levels of I-THMs and HNMs Formed in Simulated Treatment of Raw Water with Ozone or Peroxone Compared to Current Treatment Train

The results of the tests conducted to simulate settled water ozone or Peroxone treatment are presented in Figure 5.25. Also shown in Figure 5.25 are the results of the DVWTP control sample as well as the results of a test conducted on settled water collected from DVWTP, adjusted to pH 8.0, dosed with 2.5 mg/L chlorine for 10 minutes, dosed with 0.63 mg/L ammonia to form chloramine, and then incubated at room temperature for 24 hrs. This test was conducted to compare the results of the simulated treatment protocol to those collected from the DVWTP.

The results indicate that the simulated chloramination of the settled water formed very similar levels of I-THMs and HNMs to those measured in DVWTP effluent. With the simulated settled-water ozone treatment train, the I-THM levels (1.2 µg/L) and HNM levels (1.9 µg/L). The simulated Peroxone treatment of the settled water with prechloramine for bromate control formed slightly lower levels of I-THM and HNMs compared to the other treatment scenarios.

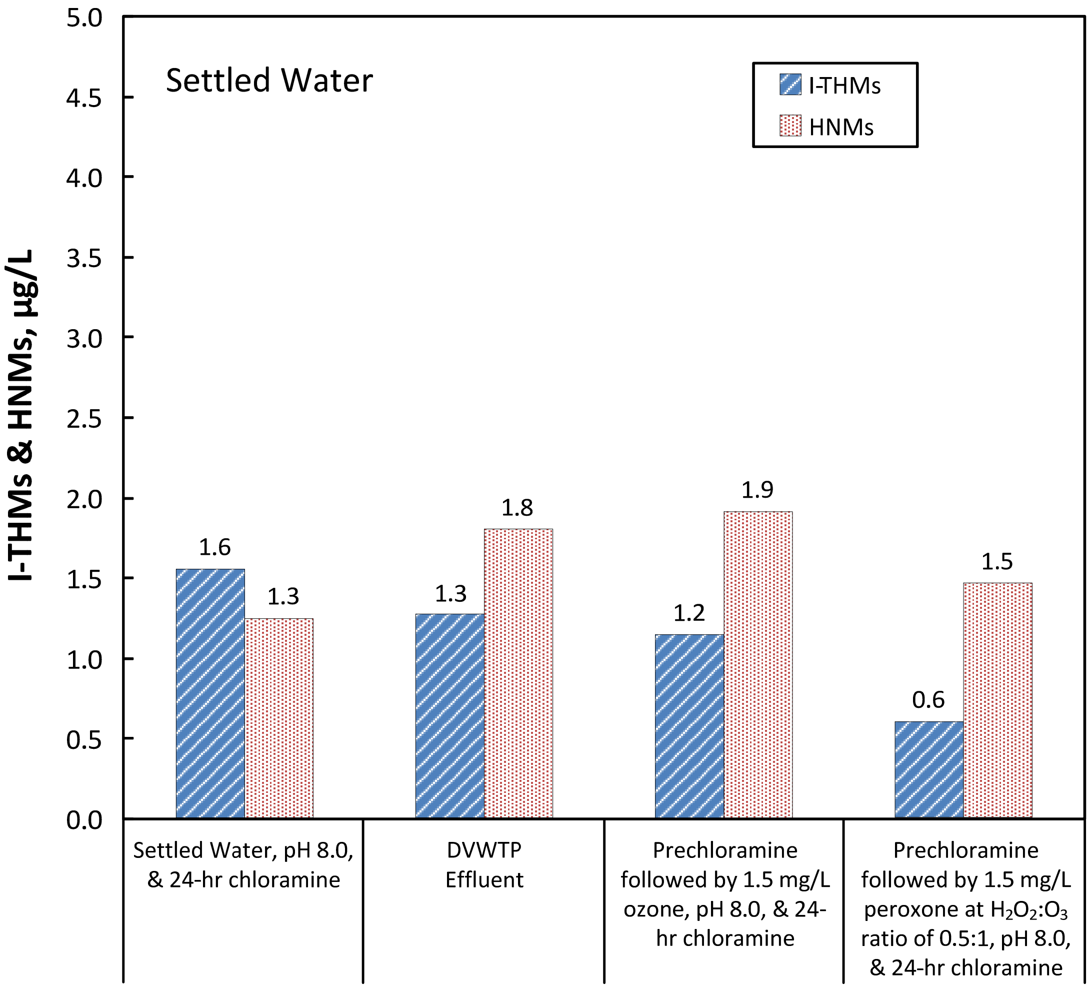


Figure 5.25 – Levels of I-THMs and HNMs Formed in Simulated Treatment of Settled Water with Ozone or Peroxone Compared to Current Treatment Train

Based on the results of the tests reported above, the utilization of ozone or Peroxone treatment at the raw water or settled water is expected to form I-THM and HNM levels equal to or slightly lower than those formed by the current treatment train.

5.4 ALTERNATIVES ANALYSIS & RECOMMENDATIONS

Section 5.3 presented and discussed the results of the pilot testing effort. In this section, the results are used to identify and evaluate the alternative ozonation scenarios for the DVWTP and the PPWTP. There are four combinations of alternatives for each treatment plant:

Alternative 1 – Raw water ozone
Alternative 2 – Raw water Peroxone
Alternative 3 – Settled water ozone
Alternative 4 – Settled water Peroxone

All four alternatives are viable for the DVWTP, but not for PPWTP. Due to the concern over the impact of ozone and/or peroxide residuals on the UF membranes, settled water ozone or Peroxone are not acceptable at this plant. During the July 2008 meeting of the Technical Advisory Committee (TRC), the option of adding either ozone or Peroxone to the filtered water in lieu of settled water at PPWTP was discussed as a viable option. The quality of the settled water in terms of ozone demand and MIB and geosmin destruction is expected to be quite similar to that of the filtered water such that the pilot results could be applied to either application point.

It is important to keep in mind that the selected process must work within the existing plants' process trains, and that all other water quality requirements must be met. The ozone or Peroxone process is intended to achieve the target destruction of T&O compounds, but the plants must continue meeting their particle removal and disinfection requirements. Any impact that the ozone or Peroxone process has on the existing plants' performance must be mitigated, and the costs for such mitigation must be included in the overall cost for the T&O control process.

5.4.1 Raw Water vs. Settled (or Filtered) Water Ozonation

Ozone systems have been implemented by many utilities to treat raw water, settled water, or filtered water. For example, raw water ozonation is practiced by ACWD at WTP2, the cities of Vacaville and Fairfield at the North Bay Regional Plant, and the city of Vallejo at the Fleming Hill WTP. Settled water ozonation is practiced by SCVWD at the Penitencia and Santa Teresa water treatment plants, and by CCWD at the Randall-Bold and Bollman water treatment plants. Filtered water ozonation is not as commonly practiced because of the desire to remove some of the BOM with biological filtration downstream of ozonation. Nevertheless, CCWD utilizes filtered-water ozonation at the Randall-Bold water treatment plant in addition to the settled water ozonation.

For all of the settled-water ozonation plants treating delta water, the systems were designed with disinfection as the primary treatment objective. Settled-water ozonation for disinfection is the clear choice from a cost point of view since it requires a significantly lower ozone dose to achieve the disinfection CT credit. Further, since the pH of settled water is typically lower than that of the raw water when alum or ferric chloride is used as a coagulant, additional pH suppression for bromate control may not be necessary. An examination of Figure 5.2 presented earlier in this report shows how the ozone demand of the settled water was approximately half that of the raw water. This means that the ozone dose required to achieve a particular 1st-chamber ozone residual in settled water is half that required to achieve the same 1st-chamber residual in raw water. For filtered-water application, the ozone demand is expected to be equal to or less than that of the settled-water.

While the above discussion favors settled-water application of ozone over raw water application, the following issues must be considered:

1. <u>With T&O destruction as the primary goal</u>, the pilot testing results showed that conventional ozonation of the settled water could not meet the minimum MIB and geosmin destruction goals of 71% and 73%, respectively, with a dose as high as 3.5 mg/L. This is a very high

dose for either raw or settled water ozonation. Therefore, only the Peroxone alternatives remain viable for settled-water or filtered-water ozonation.

2. When prechloramine is used for bromate control, the pilot testing results showed that the Peroxone dose required to meet the MIB and geosmin goals in settled water at its ambient pH of 6.6 is lower than that needed in raw water at pH 7.5 (1.7 mg/L in settled water vs. 2.7 mg/L in raw water).
3. However, in the absence of chloramine addition, the Peroxone dose required to meet the T&O goal in the settled water is similar to that needed in the raw water (1.2 mg/L in settled water vs. 1.4 mg/L in raw water). These results suggest that the use of chloramine for bromate control greatly affects the required ozone dose. Compliance with the bromate standard is calculated based on a rolling annual average of data collected each month. Since the T&O problem is seasonal, a Peroxone system could be operated seasonally. If the system were operated for only three months in one year, for example, the three bromate values measured would be averaged with nine months of no bromate formation, and Zone 7 could still be in compliance with the MCL as long as the average of the three bromate levels is less than 40 µg/L (i.e., four times the MCL). Chloramine addition would only be required under high raw water bromide conditions, and it is expected that the operating ozone dose would be significantly less than the design ozone dose.
4. For the settled water application, the ozone residuals in the effluent of the 2.6-minute Peroxone contactor were consistently too high. The contactor would either need to be much larger (e.g. 10 minutes), or a separate quenching chemical feed system would need to be constructed and utilized to destroy the ozone residual before the water exits the contactor. The utilization of the quenching agent itself would require a larger contactor since additional contact time would be required for the quenching chemical to react with the residual ozone.
5. It has been observed by a number of Delta water treatment plants that raw water ozonation greatly benefits the coagulation, flocculation, and clarification process, as well as produces lower filtered-water turbidity. With raw water ozone or Peroxone added for T&O control, improved performance of the downstream plant processes is expected.
6. Biofiltration is needed for reduction of BOM formed by both processes. This is most economically achieved by installing the process upstream of filtration and allowing the existing filters to run biologically. In the case of the filtered water application at the PPWTP, a new post-ozone biofiltration process would be needed. (It is understood that ozone or Peroxone application to the raw water at the PPWTP will only allow for biological filtration on the conventional train, but not on the membrane train. Therefore, only partial removal of the total BOM formed will be possible at the PPWTP with raw water ozonation.)
7. Biofiltration should also help with removal of most of the remaining residual peroxide in the effluent of the Peroxone process. Installing filtered-water Peroxone at PPWTP without biofiltration would be problematic because residual hydrogen peroxide will be present in the Peroxone contactor effluent. Hydrogen peroxide reacts rapidly with chlorine at a ratio of 2 mg/L chlorine for every 1 mg/L hydrogen peroxide present in the water. Any fluctuations in the concentration of hydrogen peroxide will result in fluctuations in the chlorine demand of the water. This will cause operational instability at a point where stability of the chlorine residual is necessary in order to meet the disinfection requirements. It is speculated that residual peroxide would be removed through the membrane train's clarification process, but this has not been confirmed.

For all the above reasons, WQTS recommends that only raw-water ozone or Peroxone be considered for the DVWTP and the PPWTP.

5.4.2 Peroxone vs. Conventional Ozone

A key question is whether a Peroxone process designed exclusively for T&O destruction provides significant financial advantages over conventional ozonation which is designed for both T&O control and disinfection. The results of the pilot testing effort have confirmed that a Peroxone process designed with a 3-minute contact time and operated intermittently is likely to require a lower average ozone dose than that required by a larger conventional ozone process to achieve the same T&O destruction goals. Therefore, the capital and O&M cost of a Peroxone process are likely to be substantially lower than those of a conventional ozone process. However, in selecting the appropriate process to implement, the following factors must also be considered:

1. If the Peroxone process is designed only for T&O control, then Zone 7 must continue to meet disinfection with chlorine. If biofiltration is to be implemented, the chlorine addition point must be moved to a location downstream of the filters. Currently, both DVWTP and PPWTP-conventional meet the disinfection requirement with free chlorine through the filters, and both plants rely on the low pH of the water to meet the *Giardia* disinfection requirements. If chlorination were to be delayed until after filtration, then either a dedicated chlorine contactor would need to be constructed downstream of the filters to meet the disinfection requirements, or modifications would need to be made to the clearwells such that disinfection could be achieved in these units. Ammonia and caustic addition would need to be moved further downstream, after disinfection is achieved. This will add to the cost of implementing the Peroxone alternative.
2. If the Peroxone process is designed for T&O destruction only, it is conceivable that it could be operated only during the T&O season, similar to the manner in which the current PAC systems are operated.
3. A Peroxone process designed solely for T&O control would likely decrease the degree of redundancy in equipment compared to an ozone process designed for disinfection.
4. The addition of Peroxone to the raw water will likely have an impact on the required coagulant dose; each time the system is turned on or off the coagulation/clarification process may need to be adjusted.
5. If the Peroxone process were to be operated only part of the year, then the bromate control strategy could be less stringent compared to that needed for a disinfection process that requires continuous operation. The reason is that periodic bromate levels above 10 µg/L during process operation would be averaged with zero bromate levels when the process is off-line.
6. The various systems associated with the Peroxone process (oxygen storage, ozone generation, peroxide storage and feed) would be off line for approximately nine months of the year, along with the analyzers, off-gas destruct system, etc. With most systems, an extended off-line period requires certain maintenance task to get everything up and running again. This may not be trivial as the type of equipment included with the Peroxone process is not expected to simply start up without any problems after being off line for nine months.

7. Even in the absence of MIB and geosmin, the addition of ozone or Peroxone could change the taste of the water. Many customer complaints about the taste of their water are due to changes in the water, and not necessarily due to the presence of a specific odorant. Turning the system on and off could result in an increase in such customer complaints.
8. An ozone process operated for both disinfection and T&O control would result in significantly lower levels of chlorinated DBPs such as THMs and HAAs compared to a free-chlorine based disinfection process.

5.4.3 Recommended Alternative

Tables 5.5 and 5.6 present summaries of the factors affecting the process selection for each water treatment plant based on the discussion presented earlier in this section. In Table 5.5, it is assumed that all four options include allowing the existing media filters at the DVWTP to become biologically active. For both tables, modifications are needed to allow for feeding both chlorine and ammonia upstream of the new ozone contactors.

Table 5.5 – Summary of Decision Factors for Del Valle Water Treatment Plant

Parameter	**Raw Water Ozone**	**Raw Water Peroxone**	**Settled Water Ozone**	**Settled Water Peroxone**
Design Ozone dose, mg/L	2.8	2.7	>3.5	1.7
HRT, min	10	3	12(1)	5(1)
pH adjustment?	Yes	No(2)	No	No
Peroxide storage and feed system	No	Yes	No	Yes
Quenching agent storage and feed	No	No	Yes	Yes
Disinfection	Ozone	Free chlorine(3)	Ozone	Free chlorine(3)
Improved downstream processes	Yes	Yes (intermittent)	No	No
THM and HAA5 levels	Very low	Somewhat lower (intermittent)	Very low	Somewhat lower (intermittent)
Residual peroxide	N/A	Should be removed through clarification and biofiltration	N/A	Should be removed through biofiltration

1. An additional two minutes is assumed to allow the quenching agent to destroy the ozone residual.
2. Although not needed for T&O destruction, might be necessary for bromate control
3. Either new chlorine contact chamber is needed or modifications to clearwells to allow for sufficient free chlorine contact time and relocation of ammonia and caustic feed points.

Table 5.6 – Summary of Decision Factors for Patterson Pass Water Treatment Plant

Parameter	Raw Water Ozone	Raw Water Peroxone	Filtered Water Ozone	Filtered Water Peroxone
Design Ozone dose, mg/L	2.8	2.7	>3.5	1.7
HRT, min	10	3	12(1)	5(1)
pH adjustment?	Yes	No(2)	No	No
Peroxide storage and feed system	No	Yes	No	Yes
Quenching agent storage and feed	No	No	Yes	Yes
Disinfection	Ozone	Free chlorine(3)	Ozone	Free chlorine(3)
Improved downstream processes	Yes	Yes (intermittent)	No	No
Biofiltration	Use existing conventional filters(4)	Use existing conventional filters(4)	New biofiltration contactors needed	New biofiltration contactors needed
THM and HAA5 levels	Very low	Somewhat lower (intermittent)	Very low	Somewhat lower (intermittent)
Residual peroxide	N/A	Should be removed through clarification and biofiltration	N/A	Should be removed through biofiltration

1. An additional two minutes is assumed to allow the quenching agent to destroy the ozone residual.
2. Although not needed for T&O destruction, might be necessary for bromate control
3. Either new chlorine contact chamber is needed or modifications to clearwells to allow for sufficient free chlorine contact time and relocation of ammonia and caustic feed points.
4. Since only a portion of the plant flow goes through the media filters, only a portion of the biodegradable organic material would be removed.

With all the factors discussed earlier, and those summarized in Tables 5.5 and 5.6, WQTS recommends that the ozone or Peroxone process be implemented on the raw water and not on the settled or filtered water. However, the choice between ozone and Peroxone is not yet clear based solely on the technical data gathered during the pilot study. As a result, it is WQTS' recommendation that the following two options be carried forward through cost estimation:

Option 1 – Conventional Ozone. This process will be applied to the raw water at each plant, and will utilize a conventional multi-chamber ozone contactor with standard average hydraulic residence time of 10 minutes. The process will be operated year-round and will satisfy two treatment goals: T&O control and disinfection. The chlorine addition point will be moved to a location immediately downstream of filtration. Ammonia will be added slightly downstream of chlorine addition to form chloramine.

Option 2 – Peroxone. This process will be applied to the raw water at each plant, and will utilize a smaller contactor with an average hydraulic residence time of three (3) minutes. Ozone and peroxide will be added only during T&O events. In order to permit biological activity in the media filters, the chlorine addition point will be moved to a location immediately downstream of filtration. Since disinfection is not achieved with the Peroxone process, a new chlorine contactor will be constructed downstream of filtration. Ammonia and caustic will be added to the effluent of the chlorine contactor.

SECTION 6.0 –
DESIGN CRITERIA, LAYOUTS, & HYDRAULICS

This project focused on evaluating conventional ozone and Peroxone for meeting the Zone 7 T&O destruction goals. "Conventional ozone" refers to a standard design of an ozone contactor where ozone is added to the first or second chamber of a multi-chamber contactor having an overall contact time of at least 10 minutes. This type of contactor provides sufficient ozone contact time to meet T&O destruction goals, as well as *Giardia* disinfection goals. "Peroxone" refers to an Advanced Oxidation Process (AOP) in which hydrogen peroxide is added with ozone to form hydroxyl radicals, which are stronger oxidants than ozone. A Peroxone process is typically designed for destruction of T&O chemicals, but is not suitable for meeting disinfection requirements because of its short contact time and fast-decaying ozone residual. A Peroxone contactor is smaller than a conventional ozone contactor, with an overall contact time of 3 minutes. Section 5 presented the results of the pilot testing effort. Based on the study results, the following conclusions and recommendations were made:

1. *Both the conventional ozone process and the Peroxone process should continue to be considered for either plant*
2. *Either process should only be applied on the raw water, and not on settled or filtered water.*

This Section addresses three issues for the application of either process at each plant:

1. Process design criteria
2. Site layouts
3. Hydraulic constraints

This Section describes the implementation of both processes at both plants in sufficient detail such that cost estimates can be developed. Once cost information is generated for each option, the project team will evaluate the water quality, operational, and cost impacts of each ozone-based option, and make a final recommendation regarding the preferred option for both plants.

6.1 GENERAL PROCESS IMPLEMENTATION REQUIREMENTS

6.1.1 General Plant Modifications Required

In order to incorporate either conventional ozone or Peroxone into each plant, specific modifications will need to be implemented. These modifications can be classified under four primary categories:

A. Acid addition for bromate control
B. New chlorine CT contactor for primary disinfection
C. New backwash water system
D. New chemical addition points

Table 6.1 below summarizes these modifications and describes which modifications are needed for each the two T&O treatment options.

Table 6.1 – Summary of General Plant Modifications Needed to Accommodate Each of the two Technologies at Either Plant

Category	Conventional Ozone	Peroxone
A. Acid addition for bromate control	CO_2 addition will be used to lower the pH for bromate control, stabilize the process, and lower the ozone dose needed for disinfection	No acid addition is necessary since the process will be operated only intermittently
B. New chlorine CT contactor for primary disinfection	No new chlorine CT contactor will be necessary since primary disinfection will be achieved with ozone	A new chlorine CT contactor will be needed downstream of the filters since they will no longer be used for disinfection
C. New backwash water supply tank and associated pumps and valving	An unchlorinated backwash water supply tank will be required to provide backwash water for the biofilters	An unchlorinated backwash water supply tank will be required to provide backwash water for the biofilters
D. New chemical addition points	A number of chemical addition points will be eliminated, relocated, or added to accommodate the need for bromate control, promoting biofiltration, and intermittent chlorination of the filter backwash water supply	A number of chemical addition points will be eliminated, relocated, or added to accommodate the need for bromate control, promoting biofiltration, achieving CT with a new chlorine contactor, and intermittent chlorination of the filter backwash water supply

The Peroxone process is designed to meet the T&O destruction goals. However, it will not achieve the plants' disinfection goals. The process will be operated only when required by T&O occurrence in the raw water. This is similar to the manner in which powdered activated carbon (PAC) is currently used at both plants. In some years, the T&O period may extend from June through October. In other years, a T&O event may not occur at all. The following issues are associated with the use of the Peroxone process at both plants:

1. pH reduction is not necessary. Since the Peroxone process is operated intermittently, bromate formation will be sufficiently controlled with prechloramine addition such that pH reduction is not necessary. Pilot testing results showed that the bromate level formed with prechloramine addition at ambient pH ranged from 4 to 11 µg/L, even with high raw water bromide concentrations. Since the bromate levels will be "zero" when the Peroxone process is off-line, then each plant should be able to maintain the annual average bromate at or below the MCL of 10 µg/L, or the Zone 7 goal of 8 µg/L. Therefore, pH suppression of the raw water is not recommended.

2. Biological filtration is needed. With the Peroxone process, primary disinfection at each treatment plant (0.5-log *Giardia* inactivation and 2-log virus inactivation) will continue to be met with free chlorine. Currently, chlorine is added at the filter influent at each conventional plant thus utilizing the contact time through the filters to meet the disinfection CT requirements. With the use of Peroxone, though intermittently, it is desirable that the assimilable organic carbon (AOC) formed be removed with biological filtration. This means

that the chlorine addition point will need to be delayed to a point downstream of the media filters. This action would take away the chlorine contact time through the filters, and thus eliminate the ability of each plant to meet its minimum CT requirements. To compensate for the loss of disinfection contact time, additional free chlorine contact time must be provided downstream of media filtration at conventional each plant. It should be noted that at the PPWTP, only one of the two trains is capable of biofiltration (the conventional train). Water passing through the UF train will have elevated levels of AOC due to the Peroxone process. This high-AOC water will be blended with the low-AOC water produced by the conventional train.

3. <u>Unchlorinated backwash water supply is needed</u>. Biologically active filters should be backwashed with water that does not contain chlorine or chloramine in order to maintain biological growth on the media. Therefore, a separate backwash water storage tank should be provided to store unchlorinated backwash water, and pumps and valving must be provided to fill this tank. However, occasionally, chlorine needs to be added to the backwash water to control excess bacterial growth in the biofilters. An additional chlorine feed system should be provided to inject chlorine directly into the water used to backwash the media filters whenever it is deemed necessary by the operators. Along with unchlorinated backwash water, the biological filters should be equipped with an air scour system to improve the backwash efficiency.

It should be noted that the on/off operation of a Peroxone system, while economically sound, may have potential negative impacts in two main areas: First, even in the absence of MIB and geosmin, there is a particular taste to SBA water. The use of Peroxone will likely change this taste. When the Peroxone process is turned on and off, the taste of the water will change, which may be falsely viewed by some customers as a water quality concern. Second, the required doses of coagulants and chlorine will change when Peroxone is turned on or off. This will require the operators to make adjustments to compensate. If these issues become problematic for Zone 7, the Peroxone process could be operated year-round.

The ozone process achieves the T&O destruction goals. In addition, it also has the long hydraulic detention time needed to meet the primary disinfection goals of 0.5-log *Giardia* and 2-log virus inactivation. As a primary disinfection process, it will have to be operated continuously with no interruptions. The following issues associated with the use of ozone at both plants will be addressed in this Section:

1. <u>pH suppression is needed.</u> Since the ozone process is operated year-round, compliance with the bromate MCL will require that both pH depression and prechloramination be implemented for bromate control. Carbon dioxide (CO_2) gas will be injected into the raw water to lower the pH to a range of 7.0 to 7.5, followed by chlorine and ammonia, all upstream of the ozone contactor. Further, the lowering of the pH lowers the ozone dose needed to meet the disinfection requirements. And finally, due to the significant diurnal variations in raw water pH in the SBA, stabilization of the pH is needed for good control of the ozonation process.

2. <u>Biological filtration is needed</u>. This will require that the chlorine addition point upstream of the filters be abandoned and moved to a location downstream of the filters. Since primary disinfection is achieved with the ozone process, no significant free chlorine contact time is required, and therefore, no additional chlorine CT contactor is needed at either plant. A short contact time (1 to 3 minutes) should be maintained between chlorine and ammonia addition points to adequately inactivate the HPC bacteria in the effluent of the biofilters. It

should be noted that at the PPWTP, only one of the two trains is capable of biofiltration (the conventional train). Water passing through the UF train will have elevated levels of AOC due to the ozone process. This high-AOC water will be blended with the low-AOC water produced by the conventional train.

3. <u>Unchlorinated backwash water supply is needed.</u> Biologically active filters should be backwashed with water that does not contain chlorine or chloramine. Occasionally, chlorine should be present in the backwash water to help control excess bacterial growth in the biofilters. Therefore, a separate backwash water storage tank should be provided to store unchlorinated backwash water supply, and an additional chlorine feed system should be provided to inject chlorine directly into the backwash water used to backwash the media filters whenever it is deemed necessary by the operators. Along with unchlorinated backwash water, the biological filters should be equipped with an air scour system to improve the backwash efficiency.

6.1.2 Del Valle Water Treatment Plant

To implement either ozone or Peroxone at the Del Valle Water Treatment Plant (DVWTP), various modifications will need to be made. Figure 6.1 shows a three-part schematic of the process-flow diagrams (PFDs) of the Del Valle WTP in (A) its current configuration, (B) with Peroxone addition, and (C) with ozone addition. In its current configuration (Figure 6.1-A), DVWTP includes two parallel pretreatment trains, each with its own rapid-mix system: 1) the Superpulsators® train and 2) the Dissolved Air Flotation (DAF) train. The clarified waters from the two trains then combine and pass through a set of eight (8) media filters, followed by clearwell storage. This analysis assumes that the pipeline from the raw water pump station currently feeding the Superpulsator® train will be abandoned and a new pipeline will be installed from the new DAF trash screen to feed the Superpulsators®.

6.1.2.1 DVWTP with Peroxone

Figure 6.1-B shows the anticipated PFD with Peroxone implementation. Currently each pretreatment train includes its own mechanical screen upstream of the clarification process, and this functionality will be preserved. The screens are needed to prevent plugging of the orifices in the Superpulsator® distribution laterals and the ports in the DAF basin. Since the DAF screen was designed to handle the entire plant flow, it was decided to supply the Superpulsator® train with a new line from the DAF screen, parallel to the line supplying the DAF basins. This will involve constructing a new flash mix unit (hydraulic pump-injection system similar to that used for the DAF train) for the Superpulsator® train, and abandoning the existing Superpulsator® supply line, flash mix, and screen.

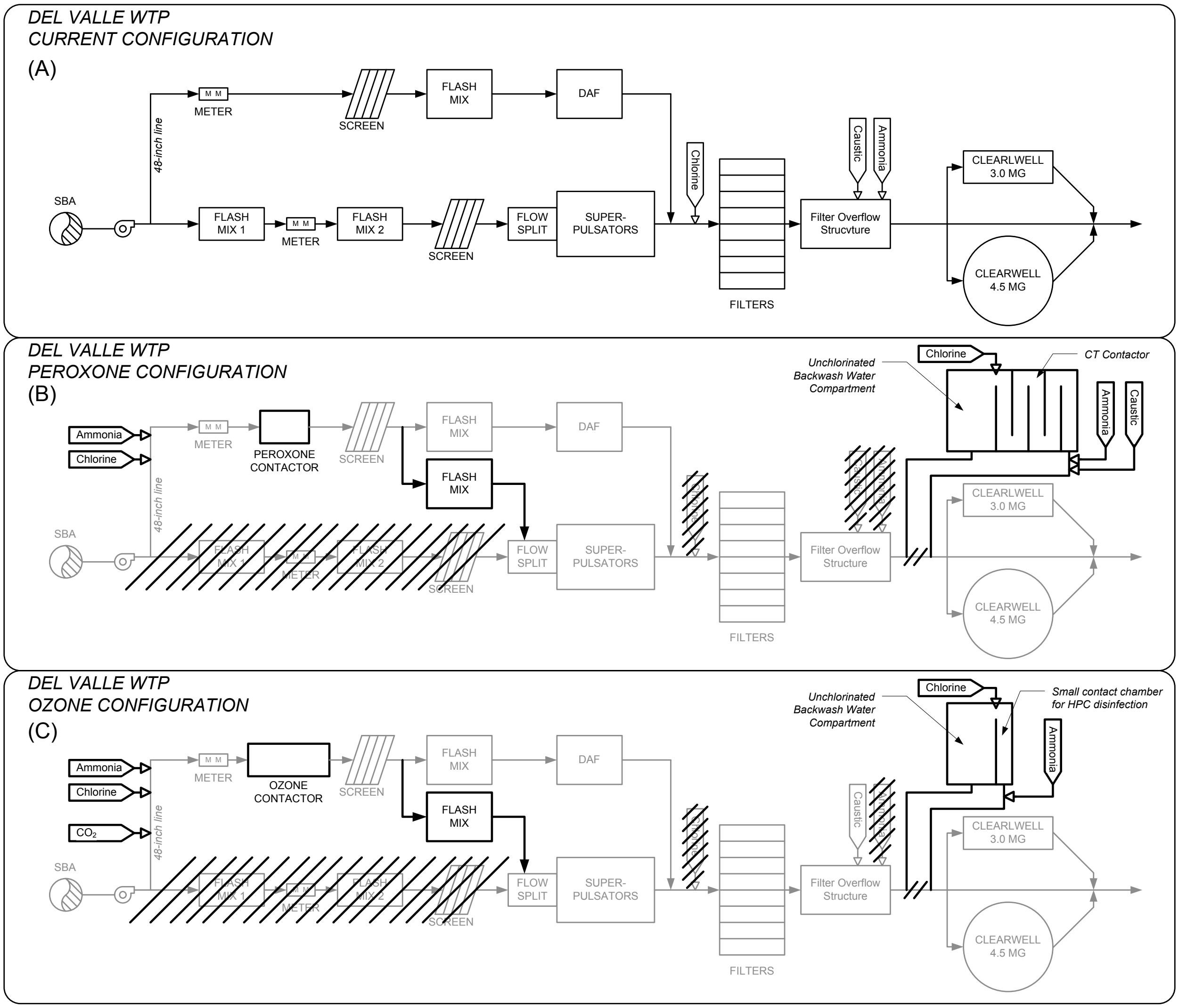


Figure 6.1 – Process Flow Diagrams for Current & Modified Del Valle WTP

Figure 6.1-B also shows that chlorine addition upstream of the media filters will be abandoned. This will allow the filters to become biologically active. However, this modification will eliminate the free chlorine contact time through the filters and a new disinfection contactor will be required. There are two available options: either convert one of the clearwells to a chlorine contactor, or construct a new CT contactor between the filter overflow structure and the clearwells. Preservation of the existing storage and operational flexibility provided by the clearwells is necessary. Therefore, Figure 6.1-B shows the latter option. A new two-compartment contactor will be constructed. Filtered water will flow into the first compartment, which will supply the unchlorinated backwash water to the backwash pumps. Chorine will be added at the inlet to the second compartment, which will serve as the CT contactor. The contactor is planned to have a serpentine flow pattern in order to ensure a high hydraulic efficiency. Ammonia and caustic will be added at the effluent of the chlorine contactor before the water flows into the existing clearwells. The online free and total chlorine residual analyzers and pH analyzer will need to be relocated and the control system adjusted accordingly.

Although not shown in the schematic, provisions should be made for chlorine to be added to the backwash water flow to the filters on an as-needed basis. This is commonly practiced in biological filtration plants in order to prevent excessive bacterial growth in the filters.

Finally, Figure 6.1-B shows that chlorine and ammonia will be added upstream of the Peroxone process as-needed for bromate control.

6.1.2.2 DVWTP with Ozone

Figure 6.1-C shows the PFD for the DVWTP with conventional ozone. Similar to the Peroxone process, the ozone process will be located on the feed line to the DAF train upstream of the DAF trash screen. This mechanical screen will then supply both clarification trains, and a new flash mix for the Superpulsator train will be added. The existing line supplying the Superpulsators, along with the corresponding flash mix and mechanical screen, will be abandoned.

The chlorine addition point upstream of the filters will be eliminated to allow the filters to operate in biological mode. Since the filters will be biologically active, a new two-chamber tank will need to be constructed to store unchlorinated filtered water for backwashing. With this modification, the existing backwash pumps will be used to backwash the biofilters with unchlorinated filtered water from the first chamber. The regular chlorine addition point will be relocated to the second chamber of the new filtered water tank, and the ammonia addition point will be moved to the effluent of this tank. This will allow for a 1 to 3 minute free-chlorine contact time before ammonia is added to form chloramine. The caustic feed point will remain in its current location. Unlike the Peroxone process, no new CT contactor will be required since primary disinfection will be achieved with the ozone process. Although not shown in the schematic, provisions should be made for chlorine to be added to the backwash water flow to the filters on an as-needed basis.

Figure 6.1-C also shows that CO_2, chlorine, and ammonia will be added upstream of the ozone process for bromate control. The CO_2 feed system will be used to maintain the raw water pH between 7.0 and 7.5. The lower pH, along with the prechloramine addition, will be needed to maintain bromate below the MCL of 10 μg/L. Also, the CO_2 feed will allow for stabilization of the raw water pH, which in turn will stabilize the ozone residual.

6.1.3 Patterson Pass Water Treatment Plant

To implement either ozone or Peroxone at the Patterson Pass Water Treatment Plant (PPWTP), various modifications will need to be implemented. Figure 6.2 shows a three-part schematic of the PFDs of the Patterson Pass WTP in (A) its current configuration, (B) with Peroxone addition, and (C) with ozone addition.

6.1.3.1 PPWTP with Peroxone

In its current configuration (Figure 6.2-A), the PPWTP includes two parallel trains: An ultrafiltration (UF) membrane train and a conventional media filtration train. The two filtered waters then combine in a 2.0 MG clearwell. Each train includes its own flash mix, flowmeter, and upflow clarifier. Therefore, the Peroxone process should be located upstream of the flow split between the two trains. Figure 6.2-B shows the anticipated PFD with Peroxone implementation at PPWTP. As discussed later in this Section, the plant flow rate and required contact time of the Peroxone process allows for the use of a pipeline contactor in lieu of a rectangular basin.

The plant receives its water from the Patterson Pass Reservoir, but also has a direct SBA connection in order to maintain operation when the reservoir is off line. To maintain this functionality, the Peroxone process should be located downstream of the direct SBA connection point as shown in Figure 6.2-B.

Figure 6.2-B also shows that chlorine addition upstream of the media filters will be abandoned and moved to a point downstream of the filters. This will allow the media filters to become biologically active (note that biofiltration is not possible in the UF train). However, this modification will eliminate the disinfection contact time through the filters and a new disinfection contactor will be required. Similar to the discussion for the DVWTP, two options were considered: 1) install a new chlorine contact chamber or 2) modify the existing clearwell to serve as a chlorine contact chamber. Modifying the clearwell to function as a contact chamber will decrease operational flexibility. Therefore, a new contact chamber will be added. This option will not require any changes to the existing service water and potable water pumps. The online free and total chlorine analyzers will need to be relocated and the control system reprogrammed for this new disinfection strategy.

Each train in the PPWTP already has its own backwash water supply tank. The tank providing backwash water to the UF membranes will continue to operate under its current configuration, although it will no longer be needed to meet the disinfection CT requirements. The backwash water storage tank for the conventional train currently receives chloraminated water from the 2.0 MG clearwell. Since the biologically active filters will require backwashing with unchlorinated water, Figure 6.2-B shows that the backwash water will now be drawn from the filtered water line upstream of chlorine addition. Provisions should be made for chlorine to be added to the backwash water flow to the filters on an as-needed basis. This is commonly practiced in biological filtration plants in order to prevent excessive bacterial growth in the filters.

Finally, Figure 6.2-B shows that chlorine and ammonia will be added upstream of the Peroxone process, as needed, for bromate control.

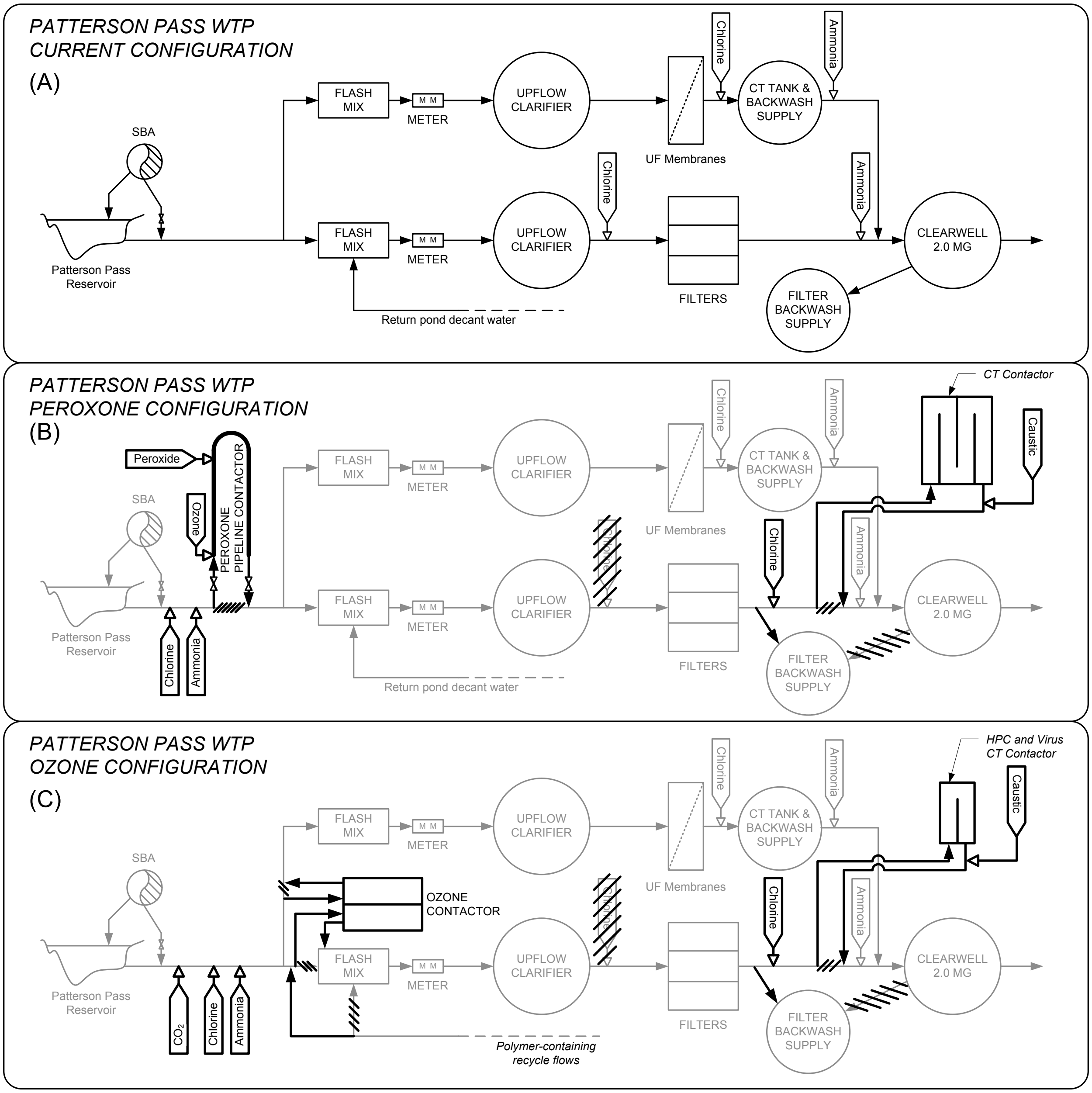


Figure 6.2 – Process Flow Diagrams for Current & Modified Patterson Pass WTP

6.1.3.2 PPWTP with Ozone

Figure 6.2-C shows the PFD for the PPWTP with conventional ozone. Similar to the Peroxone process, the ozone process will be located downstream of the direct SBA connection point, and upstream of the flow split to the two treatment trains. Similar to the discussion regarding Peroxone, the chlorine addition point upstream of the filters will be eliminated to allow the filters to operate in a biological mode (biofiltration is not possible for the UF train). The chlorine addition point will be relocated to a point downstream of the media filters and upstream of the ammonia addition point. No modifications to the 2.0 MG clearwell will be necessary since primary disinfection for will be achieved with the ozone process. However, a small chlorine

contact chamber is still necessary downstream of filtration because high counts of HPC bacteria are expected in the effluent of the biofilters, and a short contact time of 1 to 3 minutes of free chlorine is recommended to inactivate them.

Similar to the application of the Peroxone process, the tank providing backwash water to the UF membranes will continue to operate under its current configuration. The backwash water storage tank for the conventional train currently receives chloraminated water from the 2.0 MG clearwell. Since the biologically active filters will require backwashing with unchlorinated water, Figure 6.2-C shows that the existing backwash water pump will be plumbed to draw water from the filtered water line upstream of chlorine addition. Provisions should be made for chlorine to be added to the backwash water flow from the backwash water tank to the filters on an as-needed basis. Figure 6.2-C shows that CO_2, chlorine, and ammonia will be added upstream of the ozone process for bromate control. The CO_2 feed system will be used to maintain the raw water pH between 7.0 and 7.5. The lower pH, along with the prechloramine addition, will be needed to maintain bromate below the MCL of 10 μg/L and stabilize the ozonation process.

The implementation of ozone at PPWTP encounters a unique complication. Under the current PPWTP configuration, the decant water from the ponds is returned to the flash mix of the conventional train, and not the UF train. The reason is that the return water contains residual polymer from the sludge de-watering operation, and polymers are not compatible with the UF membranes at the plant. This practice needs to continue after ozone or peroxone implementation. However, under the ozone option, the ozone process, which is located upstream of the rapid mix points of both trains, will become the primary disinfection process at the plant. Any water returned to the rapid mix locations will not receive the required disinfection, and that is not acceptable. Therefore, the polymer-containing return decant water must be returned upstream of the ozone process. Since the use of polymers in the conventional train is necessary, and since the polymer-containing return water cannot be applied upstream of the UF train, a single ozone system upstream of the flow split between the two trains is not possible. At PPWTP, two parallel ozone contactors will be configured where one contactor will serve the conventional train and one contactor will serve the UF train. The influent to each contactor will be drawn from the raw water pipes after the flow split between the two trains. The polymer-containing decant washwater will then be returned to the influent of the conventional ozone contactor. This will allow for the proper disinfection of the return stream without exposing the UF train to residual polymers.

6.2 PROCESS DESIGN CRITERIA

The pilot testing results provided information on a number of important design parameters for either ozone or Peroxone. This section presents the design criteria for the new unit processes to be added under the ozone or Peroxone alternative at the Del Valle & Patterson Pass Water Treatment Plants. Design criteria are provided for the following components:

- ☐ Carbon dioxide storage & feed system (only for the ozone alternative)
- ☐ Ozone or Peroxone contactor
- ☐ Ozone generation building
- ☐ Hydrogen peroxide storage & feed system (only for the Peroxone alternative)
- ☐ Liquid oxygen (LOX) storage & feed system
- ☐ Prechloramination chemical feed rates (chlorine and ammonia)
- ☐ Disinfection CT contactor (only for the Peroxone alternative)

It is noted that the design flowrate through DVWTP was assumed at 44 MGD, which includes 40 MGD of raw water flow plus an estimated 4 MGD of recycled water flows. Similarly, the design flowrate through PPWTP was assumed at 24.5 MGD, which includes 22 MGD of raw water flow plus an estimated 2.5 MGD of recycled water flows.

6.2.1 Del Valle Water Treatment Plant

Tables 6.2, 6.3, and 6.4 present the design criteria for the various added components under the ozone and Peroxone alternatives for the DVWTP. Table 6.2 presents the criteria for the ozone and Peroxone processes and their components (contactor, generators, and generator building). Since the size of the Peroxone contactor is only 30% of the ozone contactor size, the Peroxone contactor is projected to be 28 ft long by 27 ft wide compared to a 50 x 50 ft^2 ozone contactor. The ozone contactor includes two parallel trains, each containing five chambers, with a 13-ft wide gallery between the two trains. The gallery is required to access monitoring stations along the length of the contactor and to locate various online instrumentation required for the operation of the ozone system. On the other hand, the Peroxone contactor is a single train process with three chambers in series. The water depth in the ozone contactor is set at 22 ft because ozone will be fed through porous diffusers in the first chamber, which will require this depth to achieve high ozone transfer efficiency. For the Peroxone process, the ozone will be injected in the pipe before the water enters the contactor. Therefore, the 22-ft depth is not necessary. The water depth in the Peroxone contactor was assumed at only 16 ft.

While the average ozone dose applied in a Peroxone process is lower than the average dose applied in a conventional ozone process, pilot testing showed that, at times, the dose required for both processes is the same. Therefore, for the purpose of design, the maximum ozone dose for both processes was set at 3.0 mg/L. This translates into a maximum ozone production of 1,100 lbs/day. Since the ozone process will be designed to meet the disinfection requirements, it is assumed that the system will include two duty generators and one stand-by generator. However, for the Peroxone process, no standby generator is necessary since the process will not be relied upon for meeting the disinfection requirements. For this reason, although the two processes will be designed for the same maximum ozone dose, the ozone process will require three 550 lbs/day generators, while the Peroxone process will require only two 550 lbs/day generators.

Liquid Oxygen (LOX) will be used to supply oxygen to the ozone generators. Assuming that the ozone content in the generator outlet will be 8% by wt., the plant will consume about 14,000 lbs of oxygen per day when the maximum ozone dose is applied to the maximum water flowrate through the plant. Assuming a target storage capacity of 15 days at maximum demand, approximately 22,000 gallons of LOX should be stored onsite. This can be accommodated in a vertical 14-ft diameter tank with an approximate height of 25 ft. A standard thermal/catalytic off gas destruct system, cooling water system, and nitrogen-boost/supplemental air system are assumed to be included with both the ozone and Peroxone options.

Table 6.2 – Design Criteria for the Ozone & Peroxone Systems at the Del Valle WTP

Process & Parameter	**Design Value** **Ozone**	 **Peroxone**	**Unit**	**Basis/Comment**
Plant Design Flow Rate	44	44	MGD	40 MGD + 4 MGD of Recycle Flow
Ozone or Peroxone Contactor				
Hydraulic Retention Time	10	3	minute	
No. of Contactors in Parallel	2	1		
Volume of Contactor	305,536	91,661	gallons	
Volume of Each Contactor	152,768	91,661	gallons	
Water Depth	22	16	ft	Assumed
Area of Each Contactor	928	766	ft^2	
Contactor Length	50	28	ft	
Contactor Width (each)	19	27	ft	
Total Contactor Width	50	27	ft	Includes 13-ft wide Gallery for ozone contactor only
Ozone Generation & Feed System				
Max. Ozone Dose	3.0	3.0	mg/L	Based on pilot testing results
Max. Ozone Production Rate	1,101	1,101	lbs/day	
Ozone dose during T&O season	2.5	2.5	mg/L	
Ozone dose during non-T&O season	1.5	0	mg/L	
Number of Duty Generators	2	2		
No. of Standby Generators	1	0		
Total Number of Generators	3	2		
Capacity per Generator	550	550	lbs/day	
Installed Capacity	1,650	1,100	lbs/day	
Feed Gas Type	LOX	LOX		
% Ozone in Generator Outlet	8%	8%	%	
LOX Storage Requirement	15	15	days	Based on max dosage
LOX Usage Rate	13,761	13,761	lbs/day	Based on max dosage
LOX Tank Capacity	206,415	206,415	lbs	
LOX Volumetric Usage Rate	1,446	1,446	gal/day	LOX S.G. = 1.141
Volume of LOX Tank	21,691	21,691	gallons	Minimum storage volume
Approx. LOX Tank Diameter	14	14	ft	
Approximate LOX Tank Height	25	25	ft	Includes 6 ft for freeboard & underside clearance
Ozone Generation Building				
Ozone Building Area	6,110	4,073	ft^2	3.7 ft^2/lb of Capacity(1)

(1). Langlais et al., 1991

Langlais et al. (1991) provide an estimate of the size of the ozone building required to house the ozone generators and their electrical components. Based on the factors provided by Langlais et al. (1991), the ozone generator building under the ozone option is projected to have a floor area of approximately 6,000 ft^2 while that under the Peroxone option is projected to require a floor area of approximately 4,000 ft^2. While both options will experience the same ozone consumption at maximum dose and flowrate, the ozone option has one extra standby generator that the Peroxone option does not. This is why the building under the ozone option is larger than that under the Peroxone option.

Table 6.3 presents the design criteria for the chemical addition systems required in conjunction with either ozone or Peroxone implementation at DVWTP. A hydrogen peroxide storage and feed system will be required for the Peroxone process. With a maximum design Peroxone ratio of 1:1 (mg H_2O_2-to-mg ozone), the maximum hydrogen peroxide dose is projected at 3.0 mg/L. At this dose, the maximum hydrogen peroxide usage rate is projected at 334 gallons/day to be fed by two duty and one standby pumps. With a desired storage capacity of 15 days under maximum usage conditions, a minimum operating volume of 5,000 gallons is required. For the purpose of this project, it is assumed that either plant will have a permanent H_2O_2 storage and feed system, similar to any other chemical at that plant. Alternatively, Zone 7 may chose to lease a system on an as-needed basis.

Table 6.3 presents the design criteria for the CO_2 feed system required under the ozone option only. The projected maximum CO_2 dose is 45 mg/L, which would reduce the pH of the raw water from a high of 9.5 to approximately 7.0. This dose was determined assuming an alkalinity of 150 mg/L as $CaCO_3$. Under maximum dose and flow conditions, approximately 1,900 gallons of liquid CO_2 will be consumed per day of operation. A 30,000 gallon tank would satisfy this consumption rate over a 15-day period. This is the same size as the CO_2 tank currently installed at ACWD's WTP2.

Finally, Table 6.3 lists the feed requirements for chlorine and ammonia to the raw water required to control bromate with pre-chloramination. DVWTP already has chlorine and ammonia storage and feed facilities. Therefore, the information in Table 6.3 is limited to sizing new feed pumps required to pump sodium hypochlorite and ammonia from the existing tanks to the raw water line. Under maximum flow conditions and a projected prechloramine dose of 1.0 mg/L, a total of 352 gallons of 12.5% hypochlorite and 62 gallons/day of 19% ammonia will be consumed each day. Since the prechloramine dose is not anticipated to vary greatly, only one duty and one standby pumps are required for each chemical. The turn-down ratio on one pump should be sufficient to accommodate changes in chemical feed rate with changing flow rate through the plant. Note that Zone 7 currently uses ammonia gas (anhydrous ammonia) and will continue to do so until the planned conversion to aqua ammonia.

Table 6.3 – Design Criteria for the Chemical Feed Systems Associated with the Implementation of Ozone or Peroxone at the Del Valle WTP

Process & Parameter	Design Value		Unit	Basis/Comment
	Ozone	Peroxone		
Hydrogen Peroxide Feed System				
Maximum H_2O_2 Dose	--	3.0	mg/L	Peroxone Ratio of 1:1
Average H_2O_2 Dose	--	0.65	mg/L	Peroxone Ratio of 0.5:1
Peroxide Strength	--	35	%	% active by weight
Peroxide Stock Concentration	--	3.3	lbs/gal	S.G. = 1.13
Max Feed Rate at Max Dose	--	1,101	lbs/day	
Max Feed Rate at Max Dose	--	334	gal/day	
Pumping Capacity	--	13.9	gal/hr	
Number of Duty Pumps	--	2		1 @ 4.5 gph & 1 @ 9.5 gph
Number of Standby Pumps	--	1		1 @ 4.5 gph
Total Number of Pumps	--	3		
Capacity per Pump	--	4.6	gal/hr	
Storage Capacity at Max Dose	--	15	days	
Min. Tank Operating Volume	--	5,006	gallons	
Approx. Tank Diameter	--	12	ft	
Approx. Solution Height in Tank	--	5.9	ft	
Approx. Total Tank Height	--	12	ft	
Carbon Dioxide Feed System				
Maximum CO_2 Dose	45	--	mg/L	Lower pH from 9.5 to 7.0
Average CO_2 Dose	16	--	mg/L	
CO_2 Gas Usage Rate	16,513	--	lbs/day	
Liquid CO_2 Usage Rate	1,922	--	gal/day	Liquid CO_2 S.G. = 1.03
Storage Capacity at Max Dose	15	--	days	
Minimum Storage Volume	30,000	--	gallons	
Pre-Chlorine Feed Rate				
Chlorine Dose	1.0	1.0	mg/L	
Hypochlorite Strength	12.5	12.5	%	percent active by wt.
Hypochlorite Strength	1.04	1.04	lbs/gal	S.G. = 1.0
Hypochlorite Usage Rate	367	367	lbs/day	
Hypochlorite Used from Tank	352	352	gal/day	
Number of Pumps on Duty	1	1		
Number of Pumps on Standby	1	1		
Total Number of Pumps	2	2		
Capacity of each pump	7.3	7.3	gal/hr	
Pre-Ammonia Feed Rate				
Ammonia Dose	0.25	0.25	mg/L	
Ammonia Strength	19.0	19.0	%	percent active by wt.
Ammonia Strength	1.5	1.5	lbs/gal	S.G. = 0.93
Ammonia Usage Rate	92	92	lbs/day	
Ammonia Used from Tank	62	62	gal/day	
Number of Pumps on Duty	1	1		
Number of Pumps on Standby	1	1		
Total Number of Pumps	2	2		
Capacity of each pump	1.3	1.3	gal/hr	

The implementation of the ozone or Peroxone alternative at DVWTP will require the addition of an unchlorinated backwash water storage tank and a chlorine disinfection contactor. Instead of building two separate contactors, the two functions will be combined inside a single tank to be constructed between the filters and the existing clearwells. The design criteria for the two tanks under the two options are listed in Table 6.4, and their configurations are illustrated in Figures 6.3-A and 6.3-B. Under each option, the tank will be divided into two compartments. The first compartment will serve as a source of un-chlorinated water for filter backwashes, and the second compartment will serve as a chlorine contactor. Water will flow over a weir from the first compartment to the second compartment and the water level in the first compartment will be 21 ft compared to 20 ft in the second compartment. Chlorine will be added at the weir between the first and second compartment. Under the Peroxone option, the contactor portion of the tank will be comprised of four serpentine flow channels (see Figure 6.3-A). Each channel will have a length of 180 ft and a width of 19 ft. The unchlorinated water compartment will comprise the first 93 ft of the first channel. The disinfection CT compartment will comprise the entire remaining volume of the overall contactor. Under the ozone alternative, the tank will be comprised of only two serpentine channels. Each channel will have a length of 93 ft and a width of 19 ft. The first channel will serve as the unchlorinated water storage compartment, while the second channel will serve as the disinfection contactor. Water will flow over a weir between the first compartment and the second, and chlorine will be added at the weir. The disinfection compartment will only be sized to achieve sufficient inactivation of HPC bacteria that may slough off the biofilters.

Under the Peroxone alternative, the disinfection compartment will be sized to meet the disinfection CT requirements of the Surface Water Treatment Rule for *Giardia* and viruses. The sizing requirements of the two compartments of this contactor are presented in Table 6.4. The unchlorinated water compartment will be sized to store two filter washes plus a 25% contingency volume. This translates into a total volume of 279,000 gallons. For the disinfection compartment, the volume required under the ozone alternative is set at 259,000 gallons, while that required under the Peroxone alternative is set at 1,781,000 gallons. The volume of the CT contactor is based on conservative assumptions of chlorine residual (1.5 mg/L), pH (8.0), and temperature (8 ^{o}C), at maximum flowrate. Under these conditions, the chlorine CT contactor will meet the minimum *Giardia* inactivation requirements (0.5 logs) with a 33% safety factor.

In addition, the filters should be retrofitted with an air scour system that improves backwashing efficiency, which is recommended for biologically active filters. Using a standard design criterion of 3 scfm/ft^2, a minimum air flow of 2,000 scfm is required. This can be achieved with only one blower.

Table 6.4 – Design Criteria for the New Filtered Water Tank and the Air-Scour System at the Del Valle WTP

Process & Parameter	Design Value		Unit	Basis/Comment
	Ozone	Peroxone		
Overall Length	93	180	ft	
Number of serpentine channels	2	4		
Width of each channel	19	19	ft	
Overall Width	38	76	ft	
Unchlorinated Backwash Water Storage Compartment (1st compartment of overall tank)				
Unit Filter Backwash Volume	165	165	gal/ft^2	Estimated
Area per Filter	676	676	ft^2	
Vol. of Backwash Water per filter	111,540	111,540	gallons	
Number of Backwashes Stored	2	2		
Volume of Washwater Required	223,080	223,080	gallons	
Volume Provided	278,850	278,850	gallons	125% of required vol.
Water Height in Compartment	21	21	ft	Assumed
Compartment Width	19	19	ft	
Compartment Length	93	93	ft	
Chlorine Disinfection CT Contactor (2nd compartment of overall tank)				
Length of water path	93	627	ft	serpentine contactor
Width of water path	19	19	ft	
Water depth	20	20	ft	
Length of each reach	93	180	ft	
Volume	34,570	238,096	cu-ft	
Volume	259,000	1,781,000	gallons	
HRT at Design Flow	8.5	58	minutes	
Hydraulic Efficiency (T_{10}/HRT)	0.3	0.5		Baffled Contactor
T_{10} at Maximum Flow	--	29	minutes	
Minimum Chlorine Residual	--	1.5	mg/L	
Minimum CT	--	43.7	mg-min/L	
Minimum Water Temperature	--	8.0	°C	
Maximum Water pH	--	8.0		
Min. Log *Giardia* Achieved	--	0.67	logs	
Log *Giardia* Required	--	0.5	logs	
Min. CT Ratio	--	1.33		(goal is Ratio > 1.0)
Air Scour System				
Design Air Scour Rate	3.0	3.0	scfm/ft^2	
Minimum total Air Flow	2,000	2,000	scfm	
Number of blowers	1	1		

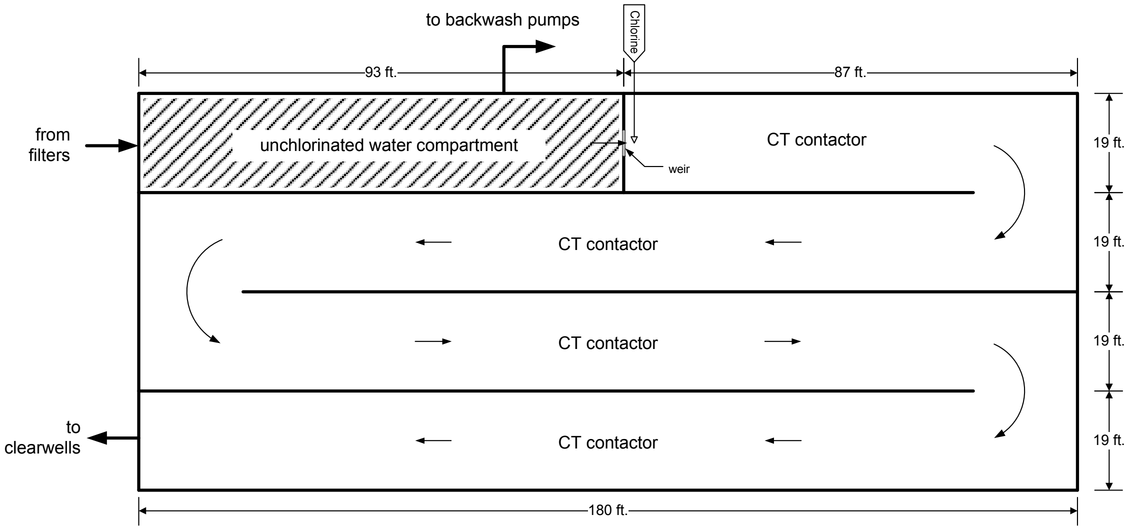


Figure 6.3-A – Potential Configuration (Plan View) of the New Filtered Water Tank under the Peroxone Option at DVWTP

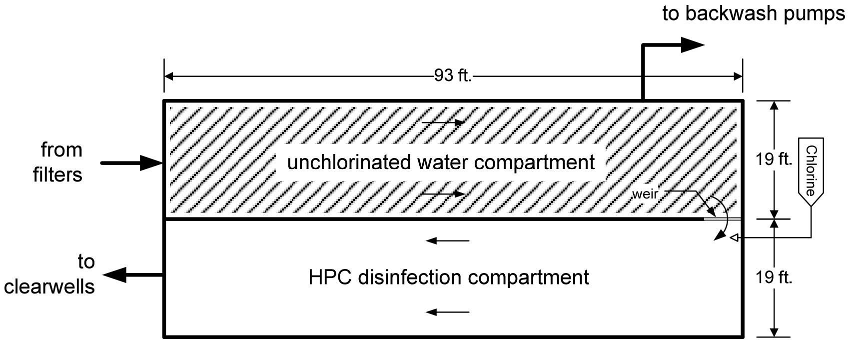


Figure 6.3-B – Potential Configuration (Plan View) of the New Filtered Water Tank under the Ozone Option at DVWTP

6.2.2 Patterson Pass Water Treatment Plant

Tables 6.5 and 6.6 present the design criteria for the additions and modifications required at the Patterson Pass Water Treatment Plant under the ozone and Peroxone options. The design treated water flowrate through the plant is 24.5 MGD, which includes 22.5 MGD of water production plus 2 MGD of return water flow. Table 6.5 presents the criteria for the ozone and Peroxone processes and their components (contactors, generators, and generator building). With a flow rate of only 24.5 MGD and a required contact time of 3 minutes, it was possible to utilize a pipeline Peroxone contactor for PPWTP. Specifically, 543 ft of 48-inch diameter pipe would provide the necessary contact time at the design flow. For the ozone option, two parallel over-under contactors would be used. Each train contains five chambers, with a 13-ft wide gallery between the two trains. Each contactor will be sized to provide 10 minute hydraulic retention time (HRT) at a flowrate of 15 MGD. This is the flowrate through the conventional train (13.5 MGD) plus 1.5 MGD of return flow to the conventional train. The gallery between the two contactors is required to access monitoring stations along the length of the contactors and to locate various online instrumentation required for the operation of the ozone system. The water depth in the ozone contactor is set at 22 ft.

Table 6.5 – Design Criteria for the Ozone & Peroxone Systems at the Patterson Pass WTP

	Design Value			
Process & Parameter	**Ozone**	**Peroxone**	**Unit**	**Basis/Comment**
Plant Design Flow Rate	24.5	24.5	MGD	22.5 MGD + 2 MGD of recycle flow
Conv. Train Capacity	15.0		MGD	13.5 MGD + 1.5 MGD of recycle flow
Ozone or Peroxone Contactor				
Hydraulic Retention Time	10(1)	3	minute	10-min HRT per contactor
Contactor Type	Basin	Pipeline		
Number of Contactors in Parallel	2(1)	1		
Volume of Contactor	208,320	51,042	gallons	
Volume of Each Contactor	104,160	51,042	gallons	
Water Depth	22	--	ft	Assumed
Area of Each Contactor	633	--	ft^2	
Contactor Length	40	--	ft	
Contactor Width (each)	16	--	ft	
Total Contactor Width	45	--	ft	includes 13-ft wide Gallery
Peroxone Pipeline Diameter	--	48	inches	
Peroxone Pipeline Length	--	543	ft	
Ozone Generation & Feed System				
Max. Ozone Dose	3.0	3.0	mg/L	Based on pilot testing results
Ozone Dose during T&O season	2.5	2.5	mg/L	
Ozone Dose during non-T&O season	1.5	0	mg/L	
Max. Ozone Production Rate	613	613	lbs/day	
Number of Duty Generators	2	2		
Number of Standby Generators	1	0		
Total Number of Generators	3	2		
Capacity per Generator	306	306	lbs/day	
Total installed capacity	918	612	lbs/day	
Feed Gas Type	LOX	LOX		
% Ozone in Generator Outlet	8%	8%		
LOX Storage Requirement	15	15	days	
LOX Usage Rate	7,660	7,660	lbs/day	
LOX Tank Capacity	115,000	115,000	lbs	
LOX Volumetric Usage Rate	805	805	gallons	LOX S.G. = 1.141
Volume of LOX Tank	12,000	12,000	gallons	
Approximate LOX Tank Diameter	14	14	ft	
Approximate LOX Tank Height	16	16	ft	Includes 6 ft for freeboard & underside clearance
Ozone Generation Building				
Ozone Building Area	3,800	2,500	ft^2	4.1 ft^2/lb of Capacity(2)

(2). Each contactor is sized for 10-min HRT for the conventional train (15.0 MGD)

(2). Langlais et al., 1991

Table 6.6 – Design Criteria for the Chemical Feed Systems Associated with the Implementation of Ozone or Peroxone at the Patterson Pass WTP

	Design Value			
Process & Parameter	**Ozone**	**Peroxone**	**Unit**	**Basis/Comment**
Hydrogen Peroxide Feed System				
Maximum H_2O_2 Dose	--	3.0	mg/L	Peroxone Ratio of 1:1
Average H_2O_2 Dose	--	0.65	mg/L	Peroxone Ratio 0.5:1
Peroxide Strength	--	35	%	% active by weight
Peroxide Stock Concentration	--	3.3	lbs/gal	S.G. = 1.13
Max Feed Rate at Max Dose	--	613	lbs/day	
Max Feed Rate at Max Dose	--	186	gal/day	
Pumping Capacity	--	7.7	gal/hr	
Number of Duty Pumps	--	2		One at 2.7 gph & one at 5.0 gph
Number of Standby Pumps	--	1		@ 2.7 gph
Storage Capacity at Max Dose	--	15	days	
Min. Tank Operating Volume	--	3,000	gallons	
Carbon Dioxide Feed System				
Maximum CO_2 Dose	45	--	mg/L	Based on ACWD Design
Average CO_2 Dose	16	--	mg/L	Based on ACWD Design
CO_2 Gas Usage Rate	9,195	--	lbs/day	
Liquid CO_2 Usage Rate	1,100	--	gal/day	Liquid CO2 S.G. = 1.03
Storage Capacity at Max Dose	15	--	days	
Minimum Storage Volume	16,000	--	gallons	
Pre-Chlorine Feed Rate				
Chlorine Dose	1.0	1.0	mg/L	
Hypochlorite Strength	0.8	0.8	%	percent active by wt.
Hypochlorite Strength	0.07	0.07	lbs/gal	S.G. = 1
Hypochlorite Usage Rate	367	367	lbs/day	
Hypochlorite Used from Tank	5,500	5,500	gal/day	
Number of Pumps on Duty	1	1		
Number of Pumps on Standby	1	1		
Capacity of each pump	114.6	114.6	gal/hr	
Pre-Ammonia Feed Rate				
Ammonia Dose	0.25	0.25	mg/L as N	
Ammonia Strength	19.0	19.0	%	percent active by wt.
Ammonia Strength	1.47	1.47	lbs/gal	S.G. = 0.93
Ammonia Usage Rate	51	51	lbs/day	
Ammonia Used from Tank	35	35	gal/day	
Number of Pumps on Duty	1	1		
Number of Pumps on Standby	1	1		
Capacity of each pump	0.7	0.7	gal/hr	

The ozone dose anticipated at the PPWTP is the same as that planned for DVWTP. Based on the pilot testing results, a design maximum applied ozone dose of 3.0 mg/L was selected for the ozone or Peroxone alternative. This translates into an ozone production of 613 lbs/day (at maximum water flowrate). Since the ozone process will be designed to meet the disinfection requirements, it is assumed that the system will include two duty generators and one stand-by generator. However, for the Peroxone process, no standby generator is necessary since the process will not be relied upon for meeting the disinfection requirements. For this reason, although the two processes will be designed for the same ozone dose, the ozone process will require three 306 lbs/day generators, while the Peroxone process will require only two 306 lbs/day generators.

Liquid Oxygen (LOX) will be used to supply oxygen to the ozone generators. Assuming that the ozone content in the generator outlet will be 8% by wt., the plant will consume about 7,660 lbs of oxygen per day when the maximum ozone dose is applied to the maximum water flowrate through the plant. Assuming a target storage capacity of 15 days at maximum demand, approximately 12,000 gallons of LOX should be stored onsite. This can be accommodated in a vertical 14-ft diameter tank with an approximate height of 16 ft. A standard thermal/catalytic off gas destruct system, cooling water system, and nitrogen-boost/supplemental air system are assumed to be included with both the ozone and Peroxone options.

Finally, based on the factors provided by Langlais et al. (1991), the ozone generator building under the ozone option is projected to require a floor area of approximately 3,800 ft^2 while that under the Peroxone option is projected to require a floor area of approximately 2,500 ft^2.

Table 6.6 presents the design criteria for the chemical addition systems required in conjunction with either ozone or Peroxone implementation at PPWTP. A hydrogen peroxide storage and feed system will be required for the Peroxone process. As indicated earlier for the DVWTP, Zone 7 may choose to lease a H_2O_2 feed system on an as-needed basis. With a maximum design Peroxone ratio of 1:1 (mg H_2O_2-to-mg ozone), the maximum hydrogen peroxide dose is projected at 3.0 mg/L. At this dose, the maximum hydrogen peroxide usage rate is calculated at 186 gallons/day to be fed by two duty pumps and one standby pump. With a desired storage capacity of 15 days under maximum usage conditions, a minimum storage volume of approximately 3,000 gallons is required. During design, a larger size may be selected in order to allow for full truck deliveries.

Table 6.6 also presents the design criteria for the CO_2 feed system required under the ozone option only. The projected maximum CO_2 dose is 45 mg/L, which would reduce the pH of the raw water from a high of 9.5 to approximately 7.0. This calculation was conducted assuming a high alkalinity of 150 mg/L as $CaCO_3$. Under maximum dose and flow conditions, approximately 1,100 gallons of liquid CO_2 will be consumed per day of operation. A 16,000 gallon tank would satisfy this consumption rate over a 15-day period.

Table 6.6 lists the feed requirements for chlorine and ammonia to the raw water required to control bromate with pre-chloramination. PPWTP already has chlorine and ammonia storage and feed facilities. Therefore, the information in Table 6.6 is limited to sizing new feed pumps required to pump sodium hypochlorite and ammonia from the existing tanks to the raw water line. It should be noted that PPWTP utilizes an on-site hypochlorite generation system that produces 0.8% hypochlorite solution (by wt.). In addition, Zone 7 plans to convert the existing anhydrous ammonia system to an aqua ammonia storage and feed system as part of the larger T&O project. Therefore, the design criteria quantities are shown for aqua ammonia. Under maximum flow conditions and a projected prechloramine dose of 1.0 mg/L, a total of

5,500 gallons of 0.8% hypochlorite and 35 gallons/day of 19% ammonia will be consumed each day. Since the prechloramine dose is not anticipated to vary greatly, only one duty and one standby pump is required for each chemical. The turn-down ratio on one pump should be sufficient to accommodate changes in chemical feed rate with changing flow rate through the plant.

Table 6.7 presents the design criteria for the new chlorine contactor and the air-scour system for the conventional filters. As discussed earlier, the contactor is added to the conventional plant filtered water before it blends with the treated water from the UF plant. Under the ozone option, the chlorine contactor is 30 ft long and 20 ft wide with a side water depth of 20 ft. The contactor is comprised of two 10-ft wide serpentine channels. At the design flowrate of 13.5 MGD through the conventional train, this contactor will have an average hydraulic retention time of 9.6 minutes which is sufficient for HPC bacteria inactivation. In addition, assuming a baffling factor of 0.3, this contactor will have an effective disinfection time, T_{10}, of 2.9 minutes at maximum flowrate. Combined with the conservative assumptions for temperature (8.0 ^{o}C) and chlorine residual (1.5 mg/L), this contactor will meet the minimum virus inactivation requirement of 2-logs as stipulated by the Surface Water Treatment Rule, and provide for a safety factor of 27%.

Under the Peroxone option, the chlorine contactor is 100 ft long and 40 ft wide with a side water depth of 20 ft. The contactor is comprised of four 10-ft wide serpentine channels. At the design flowrate of 13.5 MGD through the conventional train, this contactor will have an average hydraulic retention time of 63.8 minutes. Assuming a baffling factor of 0.5, this contactor will have an effective disinfection time, T_{10}, of 31.9 minutes at maximum flowrate. Combined with the conservative assumptions for pH (8.0), temperature (8.0 ^{o}C) and chlorine residual (1.5 mg/L), this contactor will meet the minimum disinfection requirements of 0.5-logs *Giardia* and 2-logs virus inactivation, along with a safety factor of 46%.

Table 6.7 projects the minimum air flow rate required to incorporate air-scour at the PPWTP. Air scour is recommended to improve filter backwashing, especially with the conversion of the filters to a biological filtration mode. Based on a filter surface area of 675 ft^2 and a standard air-scour rate of 3.0 scfm/ft^2, the minimum air flow required is estimated at 2,000 scfm.

Table 6.7 – Design Criteria for the New Chlorine Contactor and Air-Scour System at the Patterson Pass WTP

	Design Value			
Process & Parameter	**Ozone**	**Peroxone**	**Unit**	**Basis/Comment**
Overall Length	30	100	ft	
Number of serpentine channels	2	4		
Width of each channel	10	10	ft	
Overall Width	20	40	ft	
Water depth	20	20	ft	
Length of each reach	93	180	ft	
Volume	12,000	80,000	cu-ft	
Volume	89,760	598,400	gallons	
Design Flowrate	13.5	13.5	MGD	Conventional train
HRT at Design Flow	9.6	63.8	minutes	
Hydraulic Efficiency (T_{10}/HRT)	0.3	0.5		assumed
T_{10} at Maximum Flow	2.9	31.9	minutes	
Minimum Chlorine Residual	1.5	1.5	mg/L	
Minimum CT	4.3	47.8	mg-min/L	
Minimum Water Temperature	8.0	8.0	^{o}C	
Maximum Water pH	8.0	8.0		
Min. Log virus or *Giardia* Achieved	2.53	0.73	logs	Virus for Ozone option & *Giardia* for Peroxone option
Min. Log virus or *Giardia* Required for a Conventional Filtration Plant	2.0	0.5	logs	Virus for Ozone option & *Giardia* for Peroxone option
Min. CT Ratio	1.27	1.46		(goal is Ratio > 1.0)
Air Scour System				
Design Air Scour Rate	3.0	3.0	scfm/ft^2	
Minimum total Air Flow	2,000	2,000	scfm	
Number of blowers	1	1		

6.3 SITE CONSTRAINTS & PROCESS LAYOUT

Each of the two plants has specific site constraints that should be taken into consideration. While a detailed site layout and piping plan is outside the scope of this effort, it is important to evaluate how either technology may fit within the boundaries of each site. The location of the unit process will also impact the plant hydraulics, and the potential need to make other modifications at the plants to accommodate the new processes. All these factors ultimately impact the overall cost of implementation of either technology.

6.3.1 Del Valle Water Treatment Plant

Figure 6.4 shows a workable layout of the primary facilities with ozone implementation (Figure 6.4-A) or Peroxone implementation (Figure 6.4-B) at the Del Valle WTP. In siting the various components at the noted locations, the following factors were considered:

1. As discussed in subsequent sections in this Section, the hydraulic gradeline between the raw water pumps and the water surface elevation in the DAF unit or the splitter box to the Superpulsators® is limited. Therefore, minor hydraulic losses from elbows and tee's should be minimized.
2. The mechanical screen for the DAF train will be maintained, and the screen for the Superpulsator® train will be abandoned. The screen is needed for both of the clarification units, but not for the ozone contactor. Therefore, the ozone contactor can be located upstream of the screen.
3. A new flash mix unit for the Superpulsator® train will be needed. This unit can be installed adjacent to the existing flash mix unit for the DAF train immediately downstream of the mechanical screen.
4. Because of the off-gassing concerns when using hydrogen peroxide, it is important that the chemical line runs between the H_2O_2 tank and application point are as short as possible. Therefore, a site had to be selected where the H_2O_2 tank could be located adjacent to the Peroxone contactor.
5. No above-grade facilities can be located underneath the PG&E high-voltage power lines that cross over the site, as well as within five feet on either side.
6. The new solar panel project will be installed soon, and the layout must not encroach into the area to be used by this project.

With the above factors in mind, Figures 6.4-A & 6.4-B show potential locations for the ozone contactor, Peroxone contactor, ozone generation building, LOX tank and evaporators, CO_2 tank (for the ozone option) and hydrogen peroxide tank (for the Peroxone option). As indicated in Section 1.0, the entire plant will be fed through the 48-inch line added as part of the DAF design project. Immediately downstream of the raw water pumps and flowmeter, the water flow be diverted from the 48-inch line into the ozone or Peroxone contactor as shown in Figures 6.4-A and 6.4-B. The ozone building as well as the LOX tank and evaporators, will be located east of the pump building. The CO_2 tank and control panel (under the ozone option), or the H_2O_2 tank and feed system (under the Peroxone option) will be located next to the ozone or Peroxone contactor, respectively. It is noted that the sizes of the contactors and ozone building shown in Figures 6.4-A and 6.4-B are based on the process design criteria presented earlier in this Section. However, additional modifications could be made during preliminary design to further reduce the sizes of the facilities, especially the ozone building.

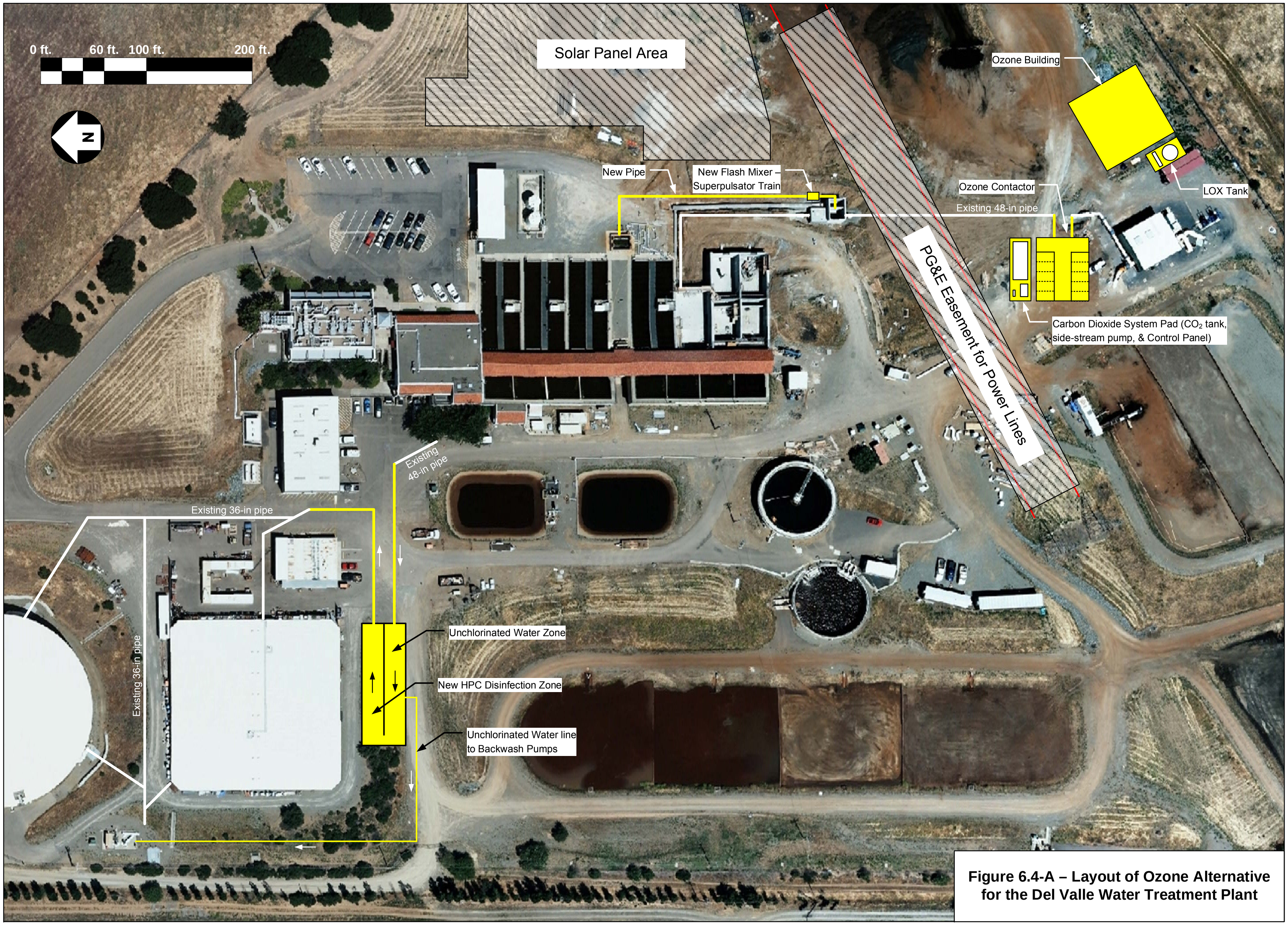


Figure 6.4-A – Layout of Ozone Alternative for the Del Valle Water Treatment Plant

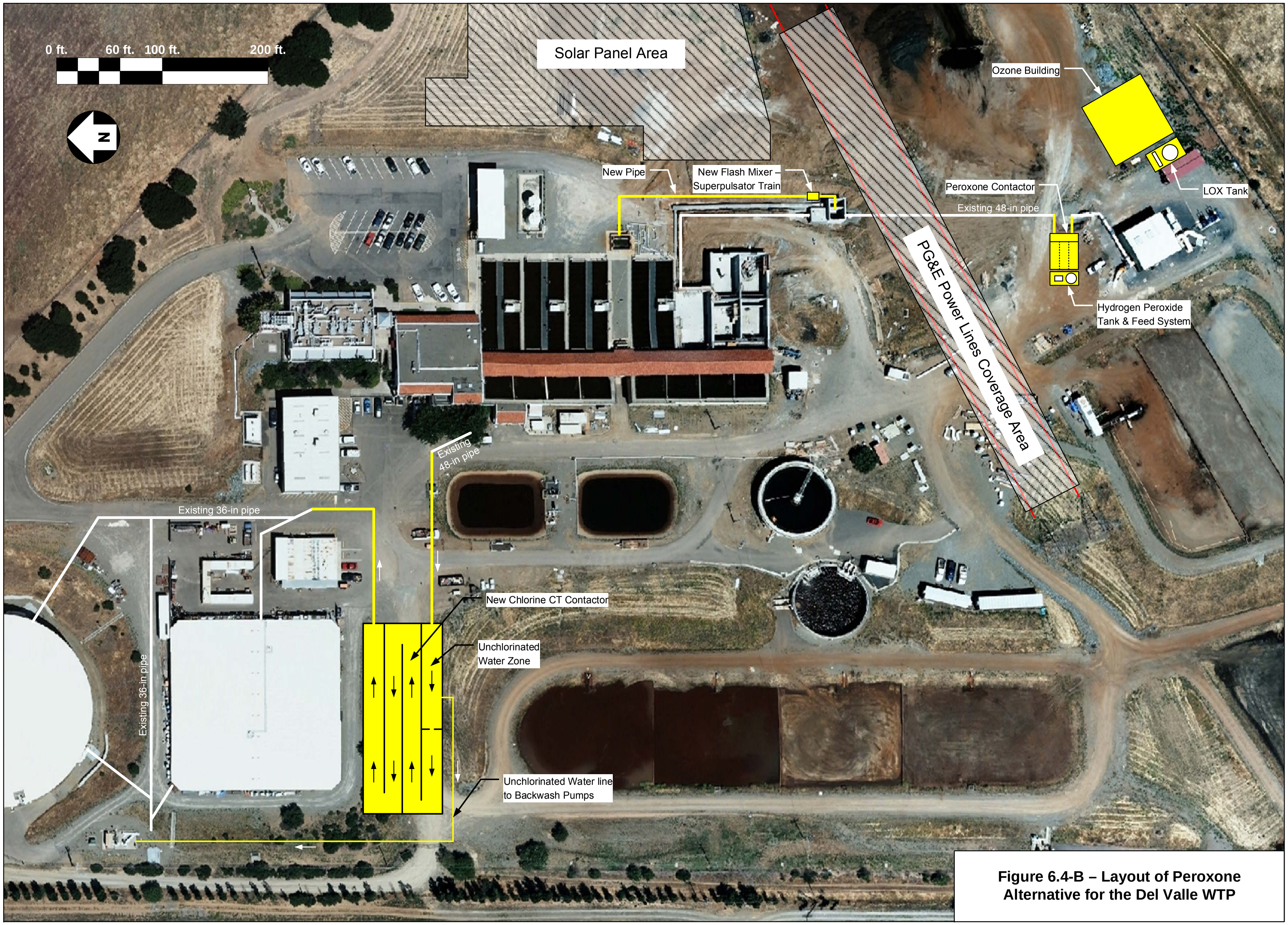


Figure 6.4-B – Layout of Peroxone Alternative for the Del Valle WTP

A new pipe will be constructed between the mechanical screen well and the flow splitter box for the Superpulsators. This line will also include a pumped jet flash mixer to allow for different chemical treatment scenarios for the Superpulsators and the DAF process.

The current piping configuration at the raw water pumps includes an above-ground 50-ft section of 30-inch line before it increases to the 48-inch line. This section includes the flow meter to the DAF train. The pipe diameter was set at 30 inches because of the need to maintain a high-enough velocity through the pipe as it feeds the 10 MGD DAF units. Zone 7's plan was to increase the diameter of this pipe to 48-inches as the entire plant capacity of 40 MGD is fed through that line. Therefore, under the modifications outlined in this Section, this pipe will be replaced with a 48-inch pipe. However, it is recommended that the flowmeter not be installed at that location, but rather install two flow meters on the two pipes downstream of the mechanical screen and flash mixers. This approach would provide for a separate flow measurement for each train.

Figure 6.4-A shows a potential location of the new filtered water tank under the ozone option and the associated piping required to bring filtered water to the tank and then return it to the inlet of the clearwells. The tank is 93 ft long and 38 ft wide. Figure 6.4-B shows the size and configuration of the tank under the Peroxone option (180 ft long and 76 ft wide). The backwash pumps will be re-plumbed to draw unchlorinated water from the first compartment of the new tank and utilize it to backwash the biofilters. This approach maintains the backwash pumps and piping configuration after conversion to biological filtration.

6.3.2 Patterson Pass Water Treatment Plant

Figures 6.5-A and 6.5-B show potential layouts of the new facilities under the ozone alternative and the Peroxone alternative, respectively. All the facilities were located on the north edge of the Zone 7 property in close proximity to the raw water line. It is noted that the UF train raw water supply take-off and vault are located immediately inside the property line. Therefore, the diversion of the water from the raw water line to the ozone or Peroxone contactor may have to take place within the DWR right-of-way, and then connect to the ozone or Peroxone contactor on the Zone 7 property. This will require permission from DWR. The Peroxone-treated water will then be returned to the raw water pipeline immediately upstream of the flow split between the two trains. The piping configuration for the ozone train is complicated since each of the two contactors must be fed from a location downstream of flow split, but upstream of the flash mix of each train. The decant from the washwater ponds will then be returned to the influent of the ozone contactor on the conventional train. The configurations of the ozone and Peroxone processes are shown in Figures 6.5-A and 6.5-B.

Figure 6.5-A shows the potential layout of the ozone contactor, ozone building, and LOX tank at the north edge of the Zone 7 property. Figure 6.5-A also shows the potential location of the CO_2 tank and control panel on the south side of the membrane building. The siting of this tank is not critical and may be moved to any other preferred location. The system will use filtered water to inject the CO_2 and the "carbonated water" will need to be piped to the raw water line upstream of the ozone or Peroxone contactor. This suggests that locating this facility closer to the north side of the plant would be desirable.

Figure 6.5-A – Potential Layout of the Ozone Alternative for the Patterson Pass WTP

Figure 6.5-B – Layout of Peroxone Alternative for the Patterson Pass Water Treatment Plant

Figure 6.5-B shows the potential layout of the Peroxone pipeline contactor, the ozone building, the LOX tank, and the H_2O_2 tank. The pipeline contactor is 543 ft of 48-inch diameter pipe. Ozone will be injected at the entrance to the contactor, and H_2O_2 will be injected approximately 100 ft downstream of the ozone injection point. During the detailed design of this system, close attention should be given to designing a reliable off-gassing system that minimizes the amount of gas bubbles that make it all the way to the clarifiers. Figure 6.5-B shows a small structure over the pipeline contactor after the water flow turns around and back to the head of the plant. This structure is intended to serve as a location for allowing the off-gas to be removed from the water. Ozone destruct units would be located at that location to destroy the any remaining ozone from the gas before it is discharged into the atmosphere.

The layouts shown in Figures 6.5-A and 6.5-B involve loss of some of the existing roadway on the site. Specifically, the looped access road around the back of the membrane building and membrane clarifier would be lost. However, vehicle access to these buildings will still be preserved, just not in a looped fashion. If a vehicle loop is desired, particularly for truck deliveries to the membrane building, then the access road around the back of the sludge drying beds can be evaluated and improved if necessary to allow for such looped access.

Figures 6.5-A and 6.5-B also show potential locations for the filtered water disinfection contactor. Under the ozone option, the contactor is small enough that it could fit next to the clearwell as shown in Figure 6.5-A. However, under the Peroxone option, the contactor is significantly larger (100ft x 40ft). One option is to locate this contactor to the east of the clearwell. The clearwell is shown to overlap some facilities. If these facilities are essential and cannot be removed, then the contactor could be moved further south.

6.4 HYDRAULIC CONSTRAINTS

Adding an ozone or Peroxone contactor in the raw water line of either plant is expected to increase the headloss between the source and the plant. This section includes a preliminary analysis of the anticipated headloss through each of the two alternatives at each plant and compares it to the available head. Three types of headloss estimates were made:

1. Friction losses through straight pipe runs were estimated using the Hazen-Williams equation with a Hazen-Williams C factor of 130.

2. Minor losses through various pipe fittings, as well as entrance and exit losses into and out of open basins. These estimates were slightly conservative in that the K factor used was that for smaller pipes (18 to 24 inches). Fittings for larger pipe diameters have lower K value than those for smaller pipe diameters.

3. Loss through a multi-chamber ozone or Peroxone contactor. This value was set at 1.0 ft for a 10-minute multi-chamber ozone contactor, and at 0.5 ft for a 3-minute Peroxone contactor. These values are also conservative, and were assumed based on ozone designs at ACWD and SCVWD.

Information on available head at each plant was obtained from previous work conducted by other engineering firms for Zone 7 and provided to WQTS by Zone 7 staff.

6.4.1 Del Valle Water Treatment Plant

Table 6.8 summarizes the estimated Hydraulic Gradeline (HGL) level at a number of critical points along the water path from the raw water pumps to the flow splitter box on the Superpulsator train. During the DAF design project, MWH estimated the water level in the flow splitter box at 658.96 ft with a flowrate of 36 MGD through the Superpulsator® train. This level was used in this analysis. With 34 MGD through the Superpulsator® train, the water level downstream of the mechanical screen was projected at 659.82 ft. With a flow of 44 MGD through the screen, the headloss through the screen was estimated at 0.26 ft (3.12 inches) based on the MWH DAF design report. With 44 MGD through the 48-inch pipe from the ozone/peroxone contactor to the mechanical screen, the water level at the end of the ozone/peroxone contactor was projected at 661.33 ft. Since a headloss of 1.0 ft was assumed for the 10-minute ozone contactor and a headloss of 0.5 ft was assumed for the 3-minute Peroxone contactor, the water level at the start of the ozone contactor was projected at 662.33 ft, while the water level at the start of the Peroxone contactor was projected at 661.83 ft. Finally, hydraulic calculations project the HGL level at the discharge of the raw water pumps required to push 44 MGD through the plant at 664.06 ft under the ozone alternative, and 663.56 ft under the Peroxone alternative.

Table 6.8 – Estimated HGL Levels (ft) Across the DVWTP Under the Ozone & Peroxone Alternatives

Component	Ozone Alt.	Peroxone Alt.
HGL at Raw Water Pump discharge	664.06	663.56
Water Level at Start of Ozone or Peroxone Contactor	662.33	661.83
Water Level at end of Ozone or Peroxone Contactor	661.33	661.33
Water Level before Mechanical Screen	660.07	660.07
Water Level after Mechanical Screen	659.82	659.82
Water Level in Superpulsator® Flow Splitter Box	658.96	658.96

The MWH DAF design report shows the HGL at the pump discharge at 666 ft. However, this assumed maximum water level in the SBA. Based on the Preliminary Design Report for Del Valle WTP Booster Pump Station (1999) prepared by CDM, fluctuating water level in the SBA would result in pump discharge HGL levels ranging from 663.0 ft to 666.0 ft. The projected required HGL level of 664.06 ft under the ozone alternative and 663.56 ft under the Peroxone alternative at 44 MGD is in the middle of the available range based on the existing pumps. This analysis shows that the maximum HGL required is only 1.06 ft above the current available HGL. Based on comments from Zone 7, planned SBA modifications downstream of the DVWTP will increase the water level in the SBA at DVWTP. In addition, Zone 7 staff indicated that minor changes in the operation of the pump VFDs could also increase the pump discharge pressures. Based on these two comments, it can be assumed that no significant modifications will be required to the raw water pumps at DVWTP to accommodate the implementation of either ozone or Peroxone on the raw water side. It should be emphasized that the hydraulic calculations made herein are based on the recommended modifications noted in Section 3. For example, it is assumed that the 36-inch diameter pipe spool on the pump discharge side will be replaced with a 48-inch diameter pipe.

6.4.2 Patterson Pass Water Treatment Plant

Table 6.9 summarizes the estimated headloss from the Patterson Pass reservoir to the flow split between the two trains (UF and conventional). During the design of the UF train, CDM developed a hydraulic gradeline showing that the HGL level at the point of takeoff for the new UF train is 700.1 ft when the overall flow is 20 MGD. Unfortunately, there is no indication of what the HGL level would be at 24.5 MGD. Based on hydraulic estimates, a flow increase from 20 MGD to 24.5 MGD would increase the friction and minor losses by approximately 50%. Based on the water levels in the clarifiers, it is estimated that the HGL at the point of takeoff of the UF train could increase from 700.1 ft at 20 MGD to 701.45 ft at 24.5 MGD. This level was set in the analysis presented herein. Based on the hydraulic calculations conducted and summarized in Table 6.9, the minimum required water level in the Patterson Pass Reservoir is projected at 705.43 ft under the ozone alternative, and 703.82 ft under the Peroxone alternative.

Table 6.9 – Estimated HGL Levels (ft) Across the PPWTP Under the Ozone & Peroxone Alternatives

Component	Ozone Alt.	Peroxone Alt.
Required Minimum Water Level in PP Reservoir	705.43	703.82
HGL Level at Start of Ozone or Peroxone Contactor	703.53	702.45
HGL Level at end of Ozone or Peroxone Contactor	702.53	702.05
HGL Level at Flow Split between Two Trains	701.45	701.45

In the 2003 CDM design report, the minimum water surface elevation in Patterson Pass reservoir is presented at approximately 703 ft. However, Zone 7 staff indicated that DWR and Zone 7 are currently making modifications to the SBA and PP Reservoirs that will result in an additional three feet of head in the Reservoir. With this improvement, the water level in Patterson Pass reservoir would increase to 706 ft, which would be sufficient to provide 24.5 MGD of flow to the PPWTP under either the ozone alternative or the Peroxone alternative as shown in Table 6.9.

6.5 SUMMARY OF REQUIRED MODIFICATIONS

As presented in this Section, implementing either ozone or Peroxone at the DVWTP or the PPWTP will require specific modifications and additions to each plant. For each plant, some modifications will need to be implemented with either technology, while some modifications are specific to one of the two technologies. This section summarizes these required modifications.

6.5.1 Required Modifications at the Del Valle Water Treatment Plant

The following modifications are required for the implementation of either ozone or Peroxone at the DVWTP:

1. Eliminate raw water pipe currently used to feed the Superpulsator® train, and feed the entire plant through the 48-inch diameter pipe currently feeding the DAF train. The existing influent meter station/vault will also be eliminated.
2. Retain the mechanical screen on the 48-inch diameter line.
3. Construct a new 48-inch line from the mechanical screen to the Superpulsator flow splitter box, and add a new flash mix on this line to allow for independent chemical treatment of the Superpulsator® train and the DAF Train.
4. Install new flowmeters on the DAF and Superpulsator train feed pipes downstream of the mechanical screen.
5. Replace the existing 36-inch line between the raw water pumps and the 48-inch pipe with a 48-inch section.
6. Eliminate chlorine feed to the settled water and allow the filters to operate in a biological mode.
7. Add a two-compartment tank in between the filtered water overflow structure and the clearwells.
   a. The first compartment will hold 223,000 gallons of unchlorinated water for backwashing
   b. The size of the second compartment will vary depending on which option is selected (2.8 MG for the Peroxone option, 259,000 for the ozone option).
8. Add a chlorine addition point at the effluent of the first compartment of the two-compartment tank.
9. Add an intermittent chlorine addition point to the backwash water line.
10. Add a chlorine addition point and an ammonia addition point immediately downstream of the raw water pumps.
11. Add a 22,000 gallon LOX storage and feed system.
12. Re-plumb the existing backwash water pumps to draw from the first chamber of the two-chamber tank
13. Add an air-scour system to supplement the water backwash system for the biofilters.

The following required modifications are specific to the implementation of ozone at DVWTP:

1. Add a CO_2 storage and feed system for raw water pH suppression.
2. Construct a 50 ft x 50 ft multi-chamber ozone contactor
3. Construct a 5,400-ft^2 ozone generation building containing three 550 lbs/day ozone generators and their ancillary equipment.

The following required modifications are specific to the implementation of Peroxone at DVWTP:

1. Construct a 27 ft x 28 ft Peroxone contactor
2. Construct a 4,000-ft^2 ozone generation building containing two 550 lbs/day ozone generators and their ancillary equipment.
3. Add a hydrogen peroxide (H_2O_2) storage and feed system with a minimum operating volume of 5,000 gallons.

6.5.2 Required Modifications at the Patterson Pass Water Treatment Plant

The following modifications are required for the implementation of either ozone or Peroxone at the PPWTP:

1. Re-route the return washwater line (return flows without residual polymer) to a point in the raw water pipe upstream of the ozone or Peroxone process.
2. Eliminate chlorine feed to the settled water and allow the filters to operate in a biological mode.
3. Add a chlorine addition point downstream of the filters and upstream of ammonia addition.
4. Add a chlorine addition point to the feed backwash water line.
5. Add a chlorine addition point and an ammonia addition point immediately downstream of the DWR meter and upstream of the new ozone or Peroxone process.
6. Add a LOX storage and feed system with a minimum operating storage volume of 12,078 gallons.
7. Add an air-scour system to supplement the water backwash system for the biofilters.
8. Re-plumb existing backwash water pump to draw from un-chlorinated filtered water to fill backwash water supply tank.
9. Possible add new potable water supply, as it currently comes from backwash tank supply line.

The following required modifications are specific to the implementation of ozone at PPWTP:

1. Add a 16,000-gallon liquid CO_2 storage and feed system for raw water pH suppression.
2. Construct a 40 ft x 45 ft multi-chamber dual-train ozone contactor with each train configured to serve the UF plant and one train configured to serve the conventional train.
3. Relocate the rapid mix of the UF train to a new location between the ozone contactor and the UF clarifier.
4. Relocate the return line of the pond decant to a location upstream of the conventional train ozone contactor.
5. Construct a 3,800-ft^2 ozone generation building containing three 306 lbs/day ozone generators and their ancillary equipment.

The following required modifications are specific to the implementation of Peroxone at PPWTP:

1. Construct a Peroxone pipeline contactor with a 48-diameter and a length of 543 ft.
2. Construct a 2,500-ft^2 ozone generation building containing two 306 lbs/day ozone generators and their ancillary equipment.
3. Add a hydrogen peroxide (H_2O_2) storage and feed system with a minimum operating volume of 3,000 gallons.

SECTION 7.0 –
COST ESTIMATE

This Section presents WQTS' opinion of the probable capital and annual O&M cost for implementing either the ozone or Peroxone alternative at the Del Valle Water Treatment Plant (DVWTP) and the Patterson Pass Water Treatment Plant (PPWTP). Section 6 discussed the details of the modifications required under each treatment alternative. Table 7.1 summarizes the primary modifications to be implemented at each plant under each alternative.

Table 7.1 – Summary of Primary Modifications at Each Plant under Each Alternative

Ozone Alternative	**Peroxone Alternative**
Ozone contactor	Peroxone contactor
Ozone generation equipment & bldg	Ozone generation equipment & bldg
Carbon dioxide storage & feed system	Hydrogen peroxide storage & feed system
Air scour system	Air scour system
Small chlorine contactor	Chlorine CT contactor

7.1 CAPITAL COST

In developing the opinion of probable capital cost, a planning level budgeting approach was utilized. In this approach, costs of basic components are projected based on unit cost values, and specific percent markups are added for various project components such as general conditions, site work & yard piping, electrical, instrumentation & control, contingency, and engineering. This planning level approach is projected to have an uncertainty range of ±30%.

Tables 7.2 through 7.5 present the breakdown of the probable capital costs for ozone or Peroxone implementation at DVWTP and PPWTP. The footnotes at the bottom of each table explain the basis for the unit cost factors used. Unit costs for the ozone contactor, LOX system, ozone generation system and building, hydrogen peroxide feed system, and air scour addition were based on unit cost equations developed by McGivney & Kawamura (2008).[6] The specific equations used are summarized in Table 6.

A few items should be noted regarding the capital cost breakdowns presented and the equations used:

1. McGivney & Kawamura (2008) does not have a specific equation for a H_2O_2 feed system. Therefore, the equation for a ferric chloride feed system was used as a substitute.

2. McGivney & Kawamura's equations were developed based on an ENR CCI of 8889. Therefore, the cost values generated by these equations were adjusted to ENR CCI 9755, which is the February 2009 ENR CCI for San Francisco.

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[6] McGivney & Kawamura, 2008. *Cost Estimating Manual for Water Treatment Facilities*, John Wiley & Sons, Hoboken, NJ.

Table 7.2 – Probable Capital Cost for Implementing Ozone at DVWTP

Capital Cost:				
Item	**Level**	**Unit**	**Note**	**Cost**
Ozone Contactor	306,000	gallons	(1)	$335,000
Ozone system & building	1,650	lbs/day	(1)	$4,124,000
Carbon Dioxide System			(2)	$675,000
Air Scour System	5,360	ft^2	(1)	$587,000
Chlorine Contactor	520,000	gallons	(3)	$780,000
			Subtotal "A" =	$6,500,000
General Conditions	15%	of "A"		$975,000
Site work & Yard Piping	40%	of "A"		$2,600,000
Electrical, Instrumentation & Control	40%	of "A"		$2,600,000
			Subtotal "B" =	$6,175,000
Construction Contingency	30%	of "A+B"		$3,803,000
Engineering, Legal, & Admin.	25%	of "A+B+Contingency"		$4,120,000
Probable 2009 Capital Cost (±30%)				**$20,600,000**

(1) McGivney & Kawamura (2008) adjusted to ENR CCI 9755 for San Francisco (S.F. ENR)
(2) TOMCO Budgetary Quote
(3) Estimated based on a unit cost of $1.5/gal of clearwell volume (for volumes less than 1.0 MG)

Table 7.3 – Probable Capital Cost for Implementing Peroxone at DVWTP

Capital Cost:				
Item	**Level**	**Unit**	**Note**	**Cost**
Ozone Contactor	92,000	gallons	(1)	$154,000
Ozone system & building	1,100	lbs/day	(1)	$3,171,000
Hydrogen Peroxide System	334	gal/day	(1)	$239,000
Air Scour System	5,360	ft^2	(1)	$587,000
Chlorine Contactor	2,140,000	gallons	(2)	$2,140,000
			Subtotal "A" =	$6,300,000
General Conditions	15%	of "A"		$945,000
Site work & Yard Piping	40%	of "A"		$2,520,000
Electrical, Instrumentation & Control	40%	of "A"		$2,520,000
			Subtotal "B" =	$6,000,000
Construction Contingency	30%	of "A+B"		$3,690,000
Engineering, Legal, & Admin.	25%	of "A+B+Contingency"		$3,998,000
Total Probable Capital Cost (±30%)				**$20,000,000**

(1) McGivney & Kawamura (2008) adjusted to S.F. ENR CCI 9755
(2) Estimated based on a unit cost of $1.0/gal of clearwell volume (for volumes greater than 1.0 MG)

Table 7.4 – Probable Capital Cost for Implementing Ozone at PPWTP

Capital Cost:					
Item	**Level**	**Unit**	**Note**		**Cost**
Ozone Contactor	208,320	gallons	(1)		$261,000
Ozone system & building	919	lbs/day	(1)		$2,823,000
Carbon Dioxide System			(2)		$570,000
Air Scour System	2,000	ft^2	(1)		$402,000
Chlorine Contactor	100,000	gallons	(3)		$150,000
				Subtotal "A" =	$4,200,000
General Conditions	15%	of "A"			$630,000
Site work & Yard Piping	40%	of "A"			$1,680,000
Electrical, Instrumentation & Control	40%	of "A"			$1,680,000
				Subtotal "B" =	$3,990,000
Construction Contingency	30%	of "A+B"			$2,457,000
Engineering, Legal, & Admin.	25%	of "A+B+Contingency"			$2,662,000
Probable 2009 Capital Cost (±30%)					**$13,300,000**

(1) McGivney & Kawamura (2008) adjusted to S.F. ENR CCI 9755
(2) TOMCO Budgetary Quote
(3) Estimated based on a unit cost of $1.5/gal of clearwell volume (for volumes less than 1.0 MG)

Table 7.5 – Probable Capital Cost for Implementing Peroxone at PPWTP

Capital Cost:					
Item	**Level**	**Unit**	**Note**		**Cost**
Ozone Pipeline Contactor	543	ft	(1)		$260,000
Ozone system & building	613	lbs/day	(2)		$2,172,000
Hydrogen Peroxide System	186	gal/day	(2)		$199,000
Air Scour System	2,000	ft^2	(2)		$402,000
Chlorine Contactor	600,000	gallons	(3)		$900,000
				Subtotal "A" =	$3,900,000
General Conditions	15%	of "A"			$585,000
Site work & Yard Piping	40%	of "A"			$1,560,000
Electrical, Instrumentation & Control	40%	of "A"			$1,560,000
				Subtotal "B" =	$3,705,000
Construction Contingency	30%	of "A+B"			$2,282,000
Engineering, Legal, & Admin.	25%	of "A+B+Contingency"			$2,472,000
Probable 2009 Capital Cost (±30%)					**$12,400,000**

(1) $480/ft of 48-inch pipe based on B&V’s cost estimate for AWTP
(2) McGivney & Kawamura (2008) adjusted to S.F.ENR CCI 9755
(3) Estimated based on a unit cost of $1.5/gal of clearwell volume (for volumes less than 1.0 MG)

Table 7.6 – Unit Cost Equations

Item	Unit Cost Equations (CCI = 8889)	Variable
Ozone Contactor	Cost = $89.217 \times X^{0.6442}$	X = Volume of contactor, gallons
Ozone System & Building	Cost = $31{,}015 \times X^{0.6475}$	X = ozone capacity, lbs/day
H_2O_2 Feed System	Cost = $34{,}153 \times X^{0.3190}$	X = chemical feed rate, gal/day
Air Scour	Cost = $50.157 \times X + 266{,}176$	X = filter surface area, ft

Table 7.7 summarizes the probable 2009 capital costs for implementing ozone or Peroxone at the DVWTP and PPWTP presented in Tables 7.2 through 7.5. For DVWTP, the probable capital cost for ozone was estimated at $20.6M, while that for Peroxone was estimated at $20.0 M. These values are within 1.5% of the average of $20.3M, which is well within the minimum accuracy of the capital costs developed (±30%). The same observation is made for the PPWTP where the cost of ozone or Peroxone is only within 3.9% of the average probable capital cost of $12.9M. Therefore, for all practical purposes, the probable capital cost of either ozone or Peroxone is approximately $20.3M for DVWTP and $12.9M for PPWTP, for a combined total probable cost of $33.2M for both plants.

Table 7.7 – Summary of Opinion of Probable 2009 Capital Cost

Plant	Ozone	Peroxone	Average	Relative Range
Del Valle WTP	$20.6 M	$20.0 M	$20.3 M	±1.5%
Patterson Pass WTP	$13.3 M	$12.4 M	$12.9 M	±3.5%
Total 2009 Capital Cost	**$33.9 M**	**$32.4 M**	**$33.2 M**	**±2.4%**

7.2 ANNUAL OPERATING & MAINTENANCE COST

The annual operating and maintenance (O&M) cost was developed for implementing ozone or Peroxone at both plants. The operating cost covered includes energy, chemicals, and labor costs. The development of the annual chemical usage rate required specific assumptions about the T&O duration and the anticipated ozone dose during the T&O season compared to the rest of the year. These are important assumptions because the ozone system will be in operation full-time under the ozone option, but only during the T&O season under the Peroxone option. Therefore, the following assumptions and estimations were made to develop the annual operation cost of each option:

1. Based on discussion with Zone 7 staff, while the duration and specific period of T&O season may vary from year to year, the typical T&O season was assumed to extend from June through November (6 months).

2. Based on the production data from 2006, 2007, and 2008 provided by Zone 7 staff, the average annual water production was calculated at 24 MGD for DVWTP and 11 MGD for PPWTP. These values were used for the development of the annual operating cost under the ozone option.
3. Based on the production data from 2006, 2007, and 2008 provided by Zone 7 staff, the average water production during the T&O season of June through November was estimated at 31 MGD for DVWTP and 13 MGD for PPWTP. These values were used for the development of the annual operating cost under the Peroxone option.
4. The ozone dose during the T&O season was assumed to be 2.5 mg/L under both options. During the non-T&O season (December through May), the ozone dose under the ozone option was assumed to be 1.5 mg/L. This is a typical ozone dose used by other SBA users for disinfection purposes.
5. A general annual maintenance cost is estimated at 1% of the capital cost. This estimate covers miscellaneous ozone-related maintenance items such as:
    a. Replacement dielectric cells (1/5th of total per year)
    b. One complete set of fuses every three years
    c. Specialized contractor for maintenance of cooling water system
    d. Replacement parts for water-phase and gas-phase ozone analyzers
    e. Complete set of gaskets for diffusers, every two years
    f. Complete set of gaskets for generators, every year
6. For labor cost, the addition of either technology was assumed to require 0.5 Full-Time-Equivalent (FTE) of each of the following: operator, mechanic, instrumentation technician, and electrician. The burdened labor rates were obtained from Zone for 2008.
7. The addition of chlorine and ammonia upstream of the ozone or Peroxone contactor was assumed to be implemented only six (6) months each year when bromide levels in SBA water are elevated enough to require a bromate control strategy.

The detailed breakdowns of the probable annual operating costs for the Ozone and Peroxone options at DVWTP and PPWTP are presented in Tables 7.8 through 7.11. The tables also include unit costs for chemicals that are based on information gathered from Zone 7 and other Northern California water agencies. It is also noted that individual line items in Tables 7.8 through 7.11 are rounded to the nearest $1000/yr, while the total is rounded to the nearest $100,000/yr.

Table 7.8 – Probable 2009 Operating Cost for Implementing Ozone at DVWTP

Annual O&M Cost:	**Note**	**Value**	**Unit**
Annual Average Flow Rate	(1)	24	MGD
Days of Operation		365	days
Average Ozone Dose	(2)	2.0	mg/L

	Value	**Unit**	**Unit Cost**	**Unit**	**Cost**
Energy Cost	8.0	kW-hr/lb	$0.16	/kW-hr	$187,000
LOX Cost	12.5	lb O_2/lb O_3	$0.25	/lb O_2	$457,000
CO_2 Cost	20	mg/L	$0.09	/lb	$137,000
Chlorine Cost (6 months only)	0.75	mg/L	$0.94	/lb	$26,000
Ammonia Cost (6 months only)	0.19	mg/L	$0.72	/lb	$5,000
Total Consumables Cost					$812,000
General Maintenance Cost	1.0	% of Capital			$206,000
Labor Cost (Operator)	0.5	FTE	$239,034	/yr	$120,000
Labor Cost (Mechanic)	0.5	FTE	$226,138	/yr	$113,000
Labor Cost (Instrument Tech.)	0.5	FTE	$253,261	/yr	$127,000
Labor Cost (Electrician)	0.5	FTE	$253,885	/yr	$127,000
Total Labor Cost					$487,000
Probable Annual Operating Cost (2009 Dollars)					**$1,500,000**

(1) Based on average day flow between January 2006 and December 2008
(2) Assuming 2.5 mg/L during 6-month T&O season & 1.5 mg/L during rest of year

Table 7.9 – Probable 2009 Operating Cost for Implementing Peroxone at DVWTP

Annual O&M Cost:	**Note**	**Value**	**Unit**
Average Flow Rate during T&O season	(1)	31	MGD
T&O season	(2)	180	days
Average Ozone Dose during T&O season	(3)	2.5	mg/L

	Value	**Unit**	**Unit Cost**	**Unit**	**Cost**
Energy Cost	8.0	kW-hr/lb	$0.16	/kW-hr	$149,000
LOX Cost	12.5	lb O_2/lb O_3	$0.25	/lb O_2	$364,000
H_2O_2 Cost	1.25	mg/L	$0.54	/lb	$31,000
Chlorine Cost	0.75	mg/L	$0.94	/lb	$33,000
Ammonia Cost	0.19	mg/L	$0.72	/lb	$6,000
Total Consumables Cost					$583,000
General Maintenance Cost	1.0	% of Capital			$200,000
Labor Cost (Operator)	0.5	FTE	$239,034	/yr	$120,000
Labor Cost (Mechanic)	0.5	FTE	$226,138	/yr	$113,000
Labor Cost (Instrument Tech)	0.5	FTE	$253,261	/yr	$127,000
Labor Cost (Electrician)	0.5	FTE	$253,885	/yr	$127,000
Total Labor Cost					$487,000
Probable Annual Operating Cost (2009 Dollars)					**$1,300,000**

(1) Based on average day flow during June – November of 2006, 2007, and 2008
(2) Assuming T&O season from June through November
(3) Assuming 2.5 mg/L during T&O season

Table 7.10 – Probable 2009 Operating Cost for Implementing Ozone at PPWTP

Annual O&M Cost:	**Note**	**Value**	**Unit**
Annual Average Flow Rate	(1)	11	MGD
Days of Operation		365	days
Average Ozone Dose	(2)	2.0	mg/L

	Value	**Unit**	**Unit Cost**	**Unit**	**Cost**
Energy Cost	8.0	kW-hr/lb	$0.16	/kW-hr	$86,000
LOX Cost	12.5	lb O_2/lb O_3	$0.25	/lb O_2	$209,000
CO_2 Cost	20	mg/L	$0.09	/lb	$63,000
Chlorine Cost (6 months only)	0.75	mg/L	$0.94	/lb	$12,000
Ammonia Cost (6 months only)	0.19	mg/L	$0.72	/lb	$2,000
Total Consumables Cost					$372,000
General Maintenance Cost	1.0	% of Capital			$133,000
Labor Cost (Operator)	0.5	FTE	$239,034	/yr	$120,000
Labor Cost (Mechanic)	0.5	FTE	$226,138	/yr	$113,000
Labor Cost (Instrument Tech)	0.5	FTE	$253,261	/yr	$127,000
Labor Cost (Electrician)	0.5	FTE	$253,885	/yr	$127,000
Total Labor Cost					$487,000
Probable Annual Operating Cost (2009 Dollars)					**$1,000,000**

(1) Based on average day flow between January 2006 and December 2008
(2) Assuming 2.5 mg/L during 6-month T&O season & 1.5 mg/L during rest of year

Table 7.11 – Probable 2009 Operating Cost for Implementing Peroxone at PPWTP

Annual O&M Cost:	**Note**	**Value**	**Unit**
Average Flow Rate during T&O season	(1)	13	MGD
T&O season	(2)	180	days
Average Ozone Dose during T&O season	(3)	2.5	mg/L

	Value	**Unit**	**Unit Cost**	**Unit**	**Cost**
Energy Cost	8.0	kW-hr/lb	$0.16	/kW-hr	$62,000
LOX Cost	12.5	lb O_2/lb O_3	$0.25	/lb O_2	$152,000
H_2O_2 Cost	1.25	mg/L	$0.54	/lb	$13,000
Chlorine Cost	0.75	mg/L	$0.94	/lb	$14,000
Ammonia Cost	0.19	mg/L	$0.72	/lb	$3,000
Total Consumables Cost					$244,000
General Maintenance	1.0	% of Capital			$124,000
Labor Cost (Operator)	0.5	FTE	$239,034	/yr	$120,000
Labor Cost (Mechanic)	0.5	FTE	$226,138	/yr	$113,000
Labor Cost (Instrument Tech)	0.5	FTE	$253,261	/yr	$127,000
Labor Cost (Electrician)	0.5	FTE	$253,885	/yr	$127,000
Total Labor Cost					$487,000
Probable Annual Operating Cost (2009 Dollars)					**$900,000**

(1) Based on average day flow during June – November of 2006, 2007, and 2008
(2) Assuming T&O season from June through November
(3) Assuming 2.5 mg/L during T&O season

Table 7.12 presents a summary of the probable 2009 annual operating costs for the ozone or Peroxone option at each plant. The annual operating cost of the Peroxone system is projected to be slightly lower than that of the ozone system at either plant. The primary driver behind the difference is the fact that the Peroxone system is operated only 6 months per year, while the ozone system is operated full time. The 2009 operating cost for the ozone option at DVWTP is projected at $1.5M/yr, while that of the Peroxone option is projected at $1.3M/yr. Similarly, for the PPWTP, the 2009 operating cost for the ozone option is projected at $1.0M/yr, while that of the Peroxone option is projected at $0.9M/yr. If the ozone option is implemented at both plants, the 2009 annual operating cost is projected at $2.5M/yr compared to $2.2M/yr if the Peroxone process is implemented at both plants.

Table 7.12 – Summary of Opinion of Probable Annual O&M Cost (2009 Dollars)

Plant	Ozone	Peroxone
Del Valle WTP	$1.5 M/yr	$1.3 M /yr
Patterson Pass WTP	$1.0 M/yr	$0.9 M/yr
Total Annual O&M Cost (2009)	**$2.5 M/yr**	**$2.2 M/yr**

Unlike the development of the capital costs, the development of the annual operating costs is based on current pricing for chemicals and energy, as well as on the results of the pilot study and the operational information gathered from other water agencies using the same source water. Therefore, there is much less uncertainty in them compared to the capital cost estimates.

7.3 TOTAL ANNUAL COST

The total cost of implementing ozone or Peroxone includes the sum of the annual debt payment on the capital investment and the annual O&M cost. The debt payment was calculated based on an amortization rate of 6% and a debt-payment period of 20 years. The amortized capital cost was then added to the annual O&M cost to determine the total annual cost. It is important to emphasize that these costs are based on 2009 dollars since there is no current schedule for implementing this project at DVWTP or PPWTP. Tables 7.13 and 7.14 present the calculated total probable annual costs for implementing ozone or Peroxone at DVWTP and PPWTP, respectively. The total values are rounded to the nearest $100,000/yr.

Table 7.13 – Total Probable Annual Cost for Implementing Ozone or Peroxone at DVWTP

Item	Ozone	Peroxone
Capital Cost	$20,600,000	$20,000,000
Annualized Capital Cost (6%, 20 yrs)	$1,796,000	$1,744,000
Annual O&M Cost	$1,500,000	$1,300,000
Probable Total Annual Cost	**$3,300,000**	**$3,000,000**

Table 7.14 – Total Probable Annual Cost for Implementing Ozone or Peroxone at PPWTP

Item	Ozone	Peroxone
Capital Cost	$13,300,000	$12,400,000
Annualized Capital Cost (6%, 20 yrs)	$1,160,000	$1,081,000
Annual O&M Cost	$1,000,000	$900,000
Probable Total Annual Cost	**$2,200,000**	**$2,000,000**

Table 7.15 summarizes the total annualiz costs for implementing ozone or Peroxone at DVWTP and PPWTP. Due to the difference in the annual operating cost, the cost of implementing the Peroxone process is projected to be slightly lower than that of implementing the ozone process. For example, implementing the Peroxone process at DVWTP is projected to be $300,000/yr less costly than that of implementing the ozone process at the plant, which is ±5% from the average cost of $3.2M/yr. This is significantly lower than the minimum uncertainty of ±30% in the probable capital cost which makes up more than half of the total probable annual cost. For this reason, it is appropriate to assume that the difference in the probable annual cost between the two options is not significant, and that the average total probable annual costs listed in Table 7.15 should be assumed for either option.

Table 7.15 – Summary of Opinion of Probable Total 2009 Annual Cost

Plant	**Ozone**	**Peroxone**	**Average**	**Relative Range**
Del Valle WTP	$3.3 M/yr	$3.0 M/yr	$3.2 M/yr	±5%
Patterson Pass WTP	$2.2 M/yr	$2.0 M/yr	$2.1 M/yr	±5%
Total Annual Cost (2009)	**$5.5 M/yr**	**$5.0 M/yr**	**$5.3 M/yr**	**±5%**

7.4 SUMMARY

The cost analysis presented in this Section demonstrated that the probable costs of implementing ozone and Peroxone at either plant are well within the accuracy of the cost projection. A summary of the cost information developed in this Section is presented in Table 7.16. The total probable capital cost of implementing an ozone-based T&O control strategy at Zone 7's two treatment plants is projected at $33.2M, with the probable annual operating cost projected at $2.3 M/yr (both are in 2009 dollars). Table 7.16 also includes an estimate of the impact of implementing ozone and/or Peroxone at either or both plants on the total water cost to Zone 7. This was determined by dividing the annual cost under each option by the 2008 total water production of 45,216 AF. Using this approach, the water cost impact of implementing either technology at both plants is projected at $116/AF of total water produced by Zone 7.

Table 7.16 – Summary of Projected Probable Costs (2009 Dollars) of Implementing Ozone or Peroxone at DVWTP and PPWTP

	Del Valle WTP			Patterson Pass WTP			Probable Total
Item	**Ozone**	**Peroxone**	**Average**	**Ozone**	**Peroxone**	**Average**	
Capital Cost	$20.6 M	$20.0 M	$20.3 M	$13.3 M	$12.4 M	$12.9 M	**$33.2 M**
Amortized Capital Cost	$1.8 M/yr	$1.7 M/yr	$1.8 M/yr	$1.2 M/yr	$1.1 M/yr	$1.2 M/yr	**$3.0 M/yr**
Annual Operating Cost	$1.5 M/yr	$1.3 M/yr	$1.4 M/yr	$1.0 M/yr	$0.9 M/yr	$0.9 M/yr	**$2.3 M/yr**
Total Annual Cost	$3.3 M/yr	$3.0 M/yr	$3.2 M/yr	$2.2 M/yr	$2.0M/yr	$2.1 M/yr	**$5.3 M/yr**
Water Cost(1)	$73 /AF	$66 /AF	$70 /AF	$49 /AF	$44 /AF	$46 /AF	**$116 /AF**

(1) Based on 2008 water production of 45,216 AF.

SECTION 8.0 –
PERMITTING & SCHEDULE

This Section provides a summary of the necessary permits that Zone 7 must obtain in order to implement the project and a summary of the anticipated project bidding and construction schedule.

8.1 PERMITS

8.1.1 California Department of Public Health

Public water systems must have an operating permit issued by California Department of Public Health (CDPH), and this permit must be amended any time there is "any addition or change in treatment". Zone 7 has an existing permit covering the operation of all facilities (treatment plants, wells, and distribution system components). In order to incorporate the new facilities, the permit will need to be amended. Application for a permit amendment must be made to CDPH, and the amendment must be approved prior to implementation of the change. For this project, CDPH staff representatives have been present at various meetings of the Technical Review Committee and are familiar with the proposed changes. We do not anticipate any obstacles to obtaining a permit amendment provided all the necessary documentation is submitted to CDPH in a timely fashion. Currently, CDPH requires that the complete permit amendment package be submitted at least four (4) months prior to startup.

Implementation of either Peroxone or ozone technologies at both plants will require a change in the way the plants demonstrate compliance with the disinfection requirements of the surface water treatment rules. Both plants must demonstrate adequate treatment of three classes of pathogen: *Giardia*, viruses, and *cryptosporidium*. Overall, the plants must demonstrate reductions of 3-log, 4-log, and 2-log, respectively, for these three groups of microorganisms. Zone 7 has completed the required source water monitoring under the Long-Term 2 Enhanced Surface Water Treatment Rule, and the water source is classified as being in "Bin 1" which means that no additional treatment for *cryptosporidium* is required beyond the standard level of treatment.

Compliance with the microbial reduction can be achieved by either physical removal or inactivation, or a combination of the two. For conventional filtration plants operated in conformance with the prevailing turbidity standards, the following levels of physical removal are credited: 2.5 logs of *Giardia*, 2 logs of viruses, and 3 logs of *cryptosporidium*. The difference between the overall required reduction for each pathogen and the removal credit must be achieved by disinfection. Table 8.1 summarizes the requirements and removal credits for a well-operated conventional water treatment plant. As detailed in the 2003 amendment to the operating permit, for the ultrafiltration train at the PPWTP, a removal credit of 4-log *Giardia*, 4-log *cryptosporidium* and 4-log viruses has been granted to the membrane process. In addition, in order to ensure a multi-barrier treatment approach, the clarification process must be operated at all times and 2-log virus disinfection must be achieved. If the clarification process is bypassed, then the level of disinfection that must be achieved increases to 0.5-log *Giardia*.

Table 8.1 – Summary of Disinfection Credits and Requirements

	Overall Reduction Required	Removal Credit for Treatment	Balance Needed via Disinfection
Del Valle WTP and Patterson Pass Conventional WTP			
Giardia	3-log	2.5-log	0.5-log
Viruses	4-log	2-log	2-log
Cryptosporidium	2-log	3-log	None
Patterson Pass UF Train			
Giardia	3-log	4-log	None[1]
Viruses	4-log	4-log	2-log[2]
Cryptosporidium	2-log	4-log	None

[1] If the clarification process is bypassed, then an additional 0.5-log *Giardia* inactivation must be achieved.
[2] Although the entire virus reduction credit is met via removal through the membranes, an additional 2-log inactivation is required by CDPH.

At both the DVWTP and the PP conventional plant, disinfection is currently achieved with free chlorine through the sand/anthracite filters. At the PP UF plant, disinfection is accomplished with free chlorine in the post-membrane chlorine contactor. For implementation of either ozone or Peroxone, the filters will be operated biologically, which means that no chlorine will be added upstream of the filters. Under this condition, disinfection must be achieved somewhere else in the treatment process and thus a change in each plants' disinfection strategy is needed.

If ozone is implemented, it will be designed and operated to meet the overall disinfection requirements for both plants (0.5-log *Giardia* and 2-log virus). For ozone at the DVWTP, the process is straightforward: the two parallel ozone contactors will be operated to meet the disinfection requirements, and the water leaving these contactors can be fed to either or both of the downstream clarification processes (Superpulsators or DAF). For ozone at the PPWTP, there is a minor complication. Because the UF membranes at the PPWTP cannot tolerate any residual polymers, the polymer-containing recycled water flows from the dewatering process must be returned to the conventional train only. Since there will be two parallel ozone contactors, one will be dedicated for each train, and the polymer-containing recycle flows will be returned to the head of the conventional-train ozone contactor. This means that the two ozone contactors must be operated independently, similar to the manner in which the two flash mix systems are currently operated. The water flows will be different and thus the contact times and required ozone doses will be different between the two trains. Each train's level of disinfection will be calculated independently.

For implementation of Peroxone at either plant, disinfection will be accomplished with free chlorine. Since the sand/anthracite filters will not be chlorinated, new post-filter chlorine contact basins will be added. These basins will be sized to allow for adequate contact time to satisfy the 0.5-log *Giardia* inactivation requirements. For both plants, there will be only one raw water Peroxone contactor. At Del Valle, the recycled water will be returned upstream of the Peroxone process. However, as noted above in the discussion about ozone, the recycled water flows containing polymer residuals cannot be introduced into the UF train at the Patterson Pass plant. Therefore, the recycled water must be introduced downstream of the Peroxone process at the head of the conventional train (which is its current location).

Although recycled water flows are generally returned to the head of the plant upstream of all processes, the proposed recycled water injection point at Patterson will be downstream of one process (Peroxone). Since the Peroxone process is used only intermittently for T&O control and not for disinfection, this recycled water injection point should be acceptable to CDPH. According to the Federal Filter Backwash Water Recycle Rule:

> *"Any system that recycles spent filter backwash water, thickener supernatant, or liquids from dewatering processes must return these flows through the processes of a system's existing conventional or direct filtration system as defined in § 141.2 or at an alternate location approved by the State"*

The referenced Section 141.2 includes the definition of the conventional filtration system (coagulation, flocculation, sedimentation, and filtration). The proposed recycle location meets this federal requirement. The California version of the filter backwash rule is slightly different, as follows:

> *"A supplier that uses conventional filtration or direct filtration and recycles spent filter backwash water, thickener supernatant, or liquids from dewatering processes shall…return all recycle flows to the headworks of the treatment plant or an alternative location approved by the Department."*

Since the Peroxone process is designed for T&O control only, is not part of the filtration or disinfection processes, and may be operated only seasonally, CDPH should not object to introducing the recycled water stream at a point downstream of Peroxone but upstream of all other processes. There are no specific requirements (e.g. studies) needed to request permission for this type of recycle practice; the request would be made to the Department via the standard permit amendment process.

The ozone generation system will likely have a single-pass cooling water system. The water from this system will be combined with the water from the water management basins and recycled to the head of the plants along with the other recycled water flow streams. This operation must be described in the request for the amended permit.

Along with the application for an amended permit, Zone 7 will need to submit an updated Operations Plan. This updated plan will include the details of how the systems will be monitored and operated, and how the various treatment requirements will be met.

No impact is expected on the level of certification needed for the new facilities. The Chief Operator is already required to hold a T5 certification, and shift operators must hold at least a T3. The new facilities will not require a higher certification level.

Implementation of either ozone or Peroxone is not expected to impact any other drinking water regulatory compliance issues. All remaining CDPH requirements, such as monitoring for various inorganic and organic chemicals, radionuclides, etc., will remain the same, and the new processes are not expected to impact the levels of these constituents in the finished water. With regard to disinfection byproducts, in the case of the ozonation option the levels of THMs and HAAs in the finished water are expected to be significantly lower. Regular monitoring for bromate will need to be conducted.

8.1.2 Alameda County Department of Environmental Health

The Alameda County Department of Environmental Health (ACDEH) Certified Unified Program Agency (CUPA) is the administrative agency that coordinates and enforces numerous local, state, and federal hazardous materials management and environmental protection programs in the county. The CUPA administers the Hazardous Materials Business Plan Program. Chapter 6.95 of the Health and Safety Code establishes minimum statewide standards for Hazardous Materials Business Plans (HMBP's). HMBP's contain basic information on the location, type, quantity, and health risks of hazardous materials. Each business must prepare a HMBP if that business uses, handles, or stores a hazardous material and/or waste or an extremely hazardous material in quantities greater than or equal to the following:

- ☐ 55 gallons for a liquid
- ☐ 500 pounds of a solid
- ☐ 200 cubic feet for any compressed gas
- ☐ Threshold planning quantities of an extremely hazardous substance

Zone 7 already has HMBPs for both sites. These HMBPs will need to be amended for implementation of either ozone or Peroxone. The storage and feed systems for hydrogen peroxide, oxygen, carbon dioxide, and ozone must be described. Inventory information regarding the chemicals to be used, such as average and maximum quantities stored, chemical properties, chemical forms (e.g. gas, liquid, solid) must be provided, along with a Facility Site Plan and Storage Map. The HMBP also includes an Emergency Response Plan (ERP) /Contingency Plan (CP), and these must be updated to incorporate the new chemical and facilities. An updated Training Plan must also be included.

Businesses that handle extremely hazardous substances (EHS) equal to or greater than the threshold planning quantities (TPQ) listed in Appendix A, Part 355, Title 40, of the Code of Federal Regulations, are additionally subject to the Federal Emergency Planning and Community Right-to-Know Act (EPCRA). This program is implemented in California by the California Accidental Release Prevention Program (Cal ARP). Hydrogen peroxide and ozone are both on the list. However, when stored in strengths of less than 52%, hydrogen peroxide is not subject to these additional requirements. The TPQ for ozone is 100 pounds. Since ozone will be generated and used continuously and not stored, the amount of ozone on hand at any time is much less than this quantity. Therefore, it is expected that the Right-to-Know Act requirements for the facilities will not change with the implementation of either ozone or Peroxone.

The California Office of Emergency Services (OES) has merged with the Office of Homeland Security (OHS) to become the Emergency Management Agency (EMA). This agency handles the statewide emergency response programs. Zone 7's Emergency Response Plan will need to be updated to incorporate the new facilities and this plan must be submitted to EMA.

Specific elements will be included in the design to ensure acceptance of the HMBP. Where allowed by the 2007 California Fire code and the 2007 California Building code, chemical feed equipment will be housed inside of buildings to protect them from the elements and facilitate maintenance. Chemical piping will be designed with spill containment systems from the points of chemical delivery through the metering pump systems and to the feed points. The containment systems will consist of tank secondary containment, chemical duct banks or double-contained pipes. The chemical duct banks consist of chemical feed piping routed in conduit, compatible with the chemical being transmitted, and then encased in concrete. The tank secondary containment will be designed consistent with requirements of UFC Article 80 and all other applicable regulations. Emergency eyewash fixtures and showers will be provided in the chemical building, as well as at the truck unloading stations. A natural gas-fired water heater with a mixing valve will be provided in the cold water supply to the emergency shower/eyewash fixtures to maintain the temperature of water to be supplied to the fixtures in the range of 60°F to 90°F.

Ozone will be generated on-site using oxygen as the source. In addition, under the ozone option, carbon dioxide will be used for pH suppression. Both oxygen and carbon dioxide will be delivered as liquids by pressurized trucks and stored onsite in bulk tanks as liquids. Both liquids will be converted to gases through the use of ambient vaporizers. The pressure of the oxygen storage tank will provide the driving force for the flow of oxygen out of the tanks, through the vaporizers, to the ozone generators, and into the ozone contactor. Similarly, under the ozone option, the pressure in the carbon dioxide tank will provide the driving force for the flow of carbon dioxide through the vaporizer and into the carrier water stream.

8.1.3 California Regional Water Quality Control Board

The Water Boards regulate wastewater discharges to both surface water (rivers, ocean, etc.) and to groundwater (via land), and also storm water discharges from construction, industrial, and municipal activities; discharges from irrigated agriculture; dredge and fill activities; the alteration of any federal water body, and several other activities with practices that could degrade water quality. Zone 7 is under the jurisdiction of the San Francisco Bay Regional Water Quality Control Board (RWQCB).

Discharges from Zone 7's Del Valle WTP and Patterson Pass WTP are covered under the Region-wide NPDES permit for Discharges from Surface Water Treatment Facilities for Potable Supply (NPDES No. CAG382001, Order No. R2-2003-0062), which is administered by the San Francisco Bay RWQCB. Implementation of either ozone or Peroxone is not expected to impact these permits since they only regulate the pH, chlorine residual, and total suspended solids (TSS) of the periodic wastewater (storm water) discharges and these parameters are not anticipated to be impacted by the new processes.

Neither site is connected to a sanitary sewer system, so there are no pre-treatment permits. At both plants, the domestic discharges from the buildings and the laboratory are sent to a septic tank system. Septic tanks in the area are regulated by Zone 7. No impact is expected to the septic tank systems from either the ozone or Peroxone process. A Report of Waste Discharge (ROWD) will be needed for the construction period. No impacts to waterways are expected, and there are no known wetlands on either site. It is likely that the construction will involve more than one acre of disturbance, therefore coverage under the General Construction Permit will need to be obtained. This program is administered by the State Water Resources Control Board.

8.1.4 Bay Area Air Quality Management District (BAAQMD)

The Bay Area Air Quality Management District's Regulation 2, Rule 1, describes the permit requirements for sources of air pollution. In general, any equipment or operation that emits pollutants into the atmosphere, and any pollution control equipment associated with that source, require a Permit to Operate unless it is specifically exempted. The ozone off-gas treatment system will require a Permit to Operate from the BAAQMD. It is expected that the off-gas treatment system will be designed in the standard fashion whereby the concentration of ozone in the vent gas (downstream of the ozone destruct units) is continuously monitored and if the level exceeds a particular amount, the ozone generation system will be automatically shut down.

Ozone is on the Toxic Air Contaminants List and as such, emission calculations are required (annual, maximum daily, and maximum 1-hour amounts). None of the other air program requirements such as Offsets, Prevention of Significant Deterioration (PSD), or modeling are expected to apply, since the expected levels of ozone discharged to the atmosphere from the off-gas treatment system will be very low. Since Zone 7 intends to install and continuously operate a treatment system, a request for operation without such a treatment system will not be made.

8.1.5 Alameda County Fire Code Compliance

Fire suppression and emergency hazardous materials response services are provided by the Alameda County Fire Department (ACFD). A wet-pipe fire protection system should be incorporated in the design to meet the requirements of NFPA for each structure where required by applicable code and by the local fire department. If required by Alameda County Fire, the pumps should be located in a dedicated room. The fire protection system should have one main backflow preventer located in the same room as the pumps. A fire distribution line should be provided to each of the buildings and fire hydrants located on this line.

Both project sites are located outside city limits in unincorporated Alameda County. Strictly speaking, no building permit is required from the County for the proposed ozone building at each treatment plant site. Zone 7 is exempt from the building permit requirements for any treatment process and related facilities. However, based on the review process for other recent Zone 7 projects, (e.g. Chain of Lakes Wells 1 & 2) ACDEH's staff requested that Zone 7 "satisfy" ACFD requirements on chemicals being used (and quantity being stored) for each new process. ACFD normally conducts its reviews under the Alameda County Building permit process. Therefore, although Zone 7 is exempt from an Alameda County Building permit, the County Building official, per recommendations of their County Counsel, provided a "courtesy" review of building plans to help expedite the review by ACFD.

8.1.6 California Building Code Compliance

No changes in the access roads to either site are anticipated with the implementation of either ozone or Peroxone at either plant. Therefore, no specific permission is needed from the Alameda County Road Planning and Design Division.

The new buildings should be designed to conform to the California Building Code (2007), and California Title 24 Energy Code. Each building should be categorized by the building's functional occupancy, and a basic code study is recommended for each one. The materials, colors and textures used in the design and construction should be selected to blend with the existing materials on the site. Windows and skylights should be utilized to provide natural lighting where appropriate. The PG&E Savings-By-Design Program should be implemented on this project. This program will be considered in coordination with Title 24 Energy Conservation Requirements for all buildings.

Mechanical design must conform to the latest editions of all applicable standards and codes such as the following:

- ☐ National Fire Protection Association Recommended Practices (NFPA) and Manuals
- ☐ Council of American Building Officials (CABO) Model Energy Code
- ☐ American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) handbooks and standards
- ☐ American Society of Plumbing Engineers (ASPE) handbooks
- ☐ Sheet Metal and Air Conditioning Contractors National Association (SMACNA) handbooks
- ☐ Part 4, California Mechanical Code (CMC), based on the Uniform Mechanical Code (UMC)
- ☐ Part 5, California Plumbing Code (CPC), based on the Uniform Plumbing Code (UPC) (including backflow protection devices)
- ☐ State of California, Title 24, Part 4 Mechanical Systems
- ☐ Occupational Safety and Health Act (OSHA) Standards Manual
- ☐ 8.2.1 Title 24 and Savings-By-Design Compliance
- ☐ Electrical Code

8.1.7 United States Fish and Wildlife Services (USFWS) and California Department of Fish and Game (CDFG)

No permits are required from either of these two agencies. The projects will be constructed within the existing developed sites and will have no impact on fish, wildlife, or game in the area.

8.1.8 California Department of Water Resources (DWR)

The California Department of Water Resources (DWR) owns and operates the South Bay Aqueduct, which is the source of water for both treatment plants. The ozone or Peroxone project will not involve any change in the quantity of water to be treated through the plants, and therefore no specific permission is needed from DWR. However, in the case of the Patterson Pass site, there may be encroachment onto DWR property needed in order to place all of the necessary facilities. In this case, an easement or some other form of permission must be acquired. DWR staff has indicated that locating underground facilities in close proximity to the property line is not likely to be a problem. However, DWR needs to retain access to the site to store sediment material periodically dredged from the bottom of Patterson Reservoir.

8.1.9 California Environmental Quality Act (CEQA) / National Environmental Policy Act (NEPA) Requirements

The addition of a new treatment process to an existing water treatment plant is generally assumed to qualify for a Negative Declaration or Mitigated Negative Declaration rather than requiring an Environmental Impact Report. A Negative Declaration is prepared when the proposed project will not have a significant impact on the environment. A Mitigated Negative Declaration is prepared when the proposed project potentially has a significant impact on the environment but can be mitigated to a less than significant level and there is no substantial evidence that the proposed project may have a significant effect on the environment. As the

Lead Agency, Zone 7 will need to prepare an Initial Study to determine the appropriate CEQA document necessary for the ozone or Peroxone installations.

NEPA requirements do not apply because there is no federal nexus between the proposed project and the federal government.

8.1.10 California Division of Occupational Safety and Health (Cal/OSHA)

According to the California Occupational Safety and Health Act, Zone 7 must have a written, effective Injury and Illness Prevention (IIP) Program. The IIP Program will need to be updated to include the new chemicals and facilities and it must be made available to the Division of Occupational Safety and Health (A.k.a. Cal/OSHA) upon request. The IIP and its updates are also available on Zone 7's web site. In particular, there may be new confined spaces associated with the new facilities, and an update of the respiratory protection component of the Program may be needed to address hazards associated with the ozone systems.

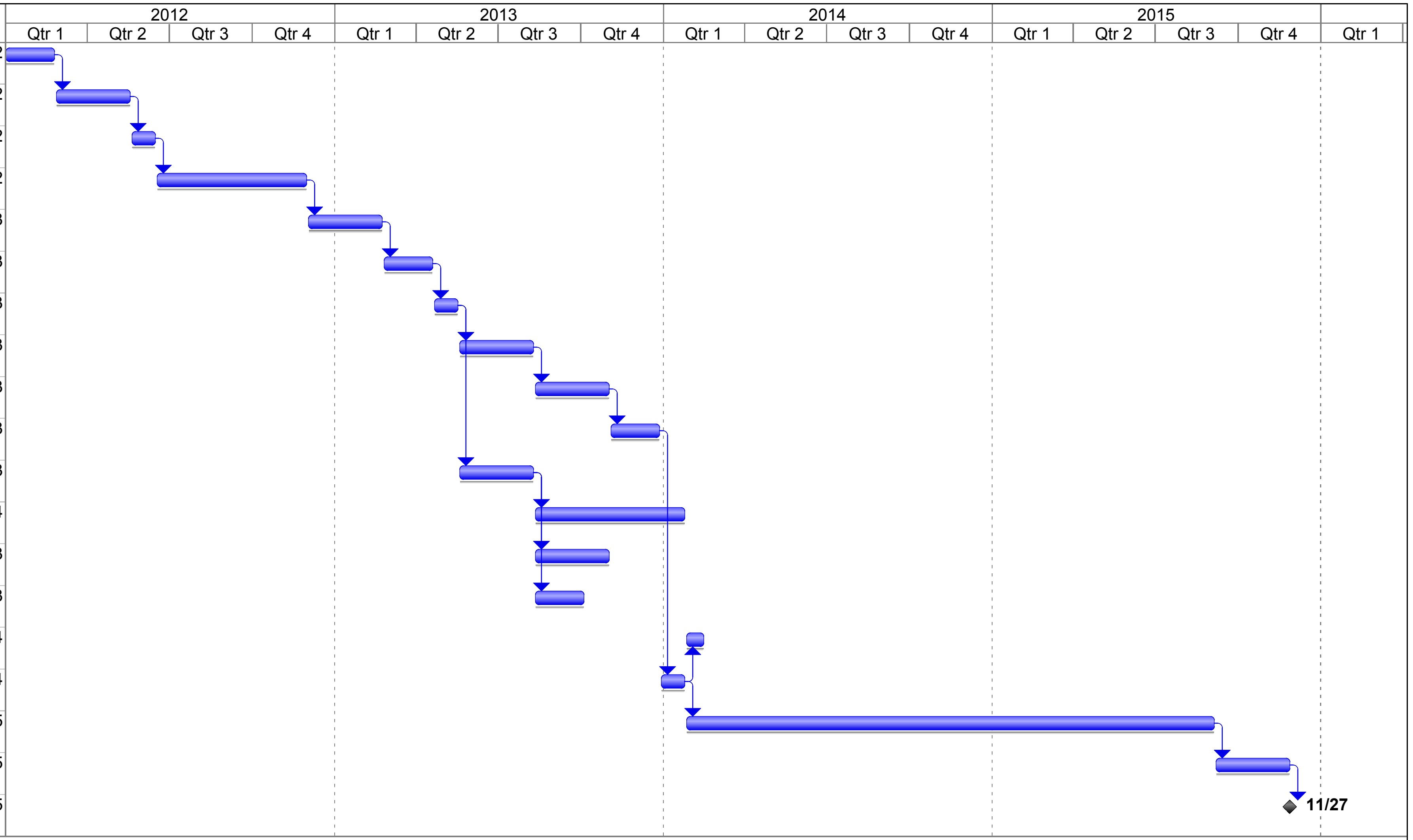
8.1.11 Alameda County Building Department

Both project sites are located outside the city limits and in unincorporated Alameda County. No building permit is required from this Department for the proposed Ozone building at each treatment plant site. Zone 7 is exempt from a building permit for any treatment process and related facilities, such as the Ozone building. See Section 1.5 above for information about the relationship between the building permit process and the fire code compliance process.

8.2 PROJECT SCHEDULE

Figure 8.1 includes the major tasks associated with the planning, design, construction, and startup of the new facilities. The exact start date is not known at this time, but for purposes of schedule development an arbitrary date of January 1, 2012 was used. From this date, it is expected to take 24 months to contract with an engineering design firm, complete the design, advertise and award the construction contract per Alameda County procedures for public bids, and issue a Notice to Proceed. Construction and startup are expected to take 24 months, such that the project would be in service by late 2015. This puts the overall schedule from the decision to issue a design RFP to having fully operational ozone or Peroxone plants at four (4) years.

ID	ℹ	Task Name	Duration	Start	Finish
1		Develop RFP for Engineering Design	40 days	Mon 1/2/12	Fri 2/24/12
2		Advertise, Evaluate Proposals, Interview, Select Engineering Firm	60 days	Mon 2/27/12	Fri 5/18/12
3		Negotiate Design Engineering Contract	20 days	Mon 5/21/12	Fri 6/15/12
4		Level 1 Design Submittal (30% complete)	120 days	Mon 6/18/12	Fri 11/30/12
5		Level 2 Design Submittal (50% complete)	60 days	Mon 12/3/12	Fri 2/22/13
6		Level 3 Design Submittal (90% complete)	40 days	Mon 2/25/13	Fri 4/19/13
7		Finalize Design	20 days	Mon 4/22/13	Fri 5/17/13
8		Advertise Construction Contract	60 days	Mon 5/20/13	Fri 8/9/13
9		Evaluate Proposals, Interview, Select Construction Contractor	60 days	Mon 8/12/13	Fri 11/1/13
10		Negotiate Construction Contract	40 days	Mon 11/4/13	Fri 12/27/13
11		File Negative Declaration	60 days	Mon 5/20/13	Fri 8/9/13
12		Request DPH Permit Amendment	120 days	Mon 8/12/13	Fri 1/24/14
13		Request ACDEH HMBP Update	60 days	Mon 8/12/13	Fri 11/1/13
14		File for BAAQMD Operating Permit	40 days	Mon 8/12/13	Fri 10/4/13
15		PG&E Relocations/Connections	15 days	Mon 1/27/14	Fri 2/14/14
16		Construct Temporary Facilities	20 days	Mon 12/30/13	Fri 1/24/14
17		Construction	420 days	Mon 1/27/14	Fri 9/4/15
18		Startup Period	60 days	Mon 9/7/15	Fri 11/27/15
19		Project Completion	0 days	Fri 11/27/15	Fri 11/27/15



Project: WQ Enhancement Project
Date: Thu 10/15/09

Task	▬	Progress	▬	Summary	▬	External Tasks	▬	Deadline	⇩
Split	⋯	Milestone	◆	Project Summary	▬	External Milestone	◆		

Figure 8.1 - Potential Project Schedule

SECTION 9.0 – OPERATIONAL IMPACTS

Either ozone or Peroxone will be implemented in the raw water for the Del Valle and Patterson Pass Water Treatment Plants. The new process will have an impact on the performance of the existing plants as well as on the level of operation and maintenance resources needed. This section has two objectives:

1. Identify the expected changes in plant performance,
2. Recommend changes to the current Operations & Maintenance (O&M) practices, procedures, and documentation necessitated by the new facilities.

9.1 EXPECTED CHANGES TO TREATMENT PLANT PERFORMANCE

9.1.1 Particle Removal (coagulation, clarification, filtration)

At both existing plants, no pre-oxidant is used under normal operating conditions. The addition of ozone or Peroxone ahead of the coagulation process is expected to result in lower ferric chloride dosages, lower filtered water turbidity and particle counts, and a corresponding decrease in sludge volume. Further, since the ferric chloride dose will be lower, the amount of caustic needed to restore the pH before delivery to the distribution system is expected to be lower. Precise quantification of the expected reduction in ferric dose is beyond the scope of this project.

Whether ozone or Peroxone is selected for implementation, the granular media filters at each plant will be operated biologically. This means that chlorine will no longer be applied to the filter influent, but will be moved downstream (to the filter effluent). When filters are operated biologically, particular care must be taken when dosing the filter aid polymer. Both SCVWD and ACWD report that their biologically-active filters are very sensitive to small changes in filter aid polymer, particularly during cold weather. Both agencies report that low filtered water turbidity and particle count values are achievable, but that the filter performance is highly dependent on proper dosing of the filter aid polymer. Both DVWTP and PPWTP already have filter aid polymer storage and feed systems in place and these are currently used for feeding cationic polymer. Therefore, no new facilities are anticipated for filter aid polymers.

Finally, biologically active filters can develop excess attached microbial growth that can adversely impact filter performance by increasing the rate of headloss buildup. Both ACWD and MWDSC report that periodic addition of chlorine to the backwash water is necessary to remove this excess growth and restore performance. During the summer months, these agencies add several milligrams per liter of chlorine to the backwash water every few backwash cycles to control excess growth. Their data indicate that this intermittent application of chlorine does not impede the ability of the filters to remove biodegradable organic material, but it does slow the rate of headloss buildup during the filter runs, thus lengthening the filter run times.

9.1.2 Disinfection

The new ozone system would be operated to achieve the minimum disinfection requirements of 0.5-log reduction of *Giardia* and 2-log reduction of viruses plus some reasonable margin of safety. While the minimum required level of disinfection will not change, the actual level of disinfection achieved at Zone 7's plants may decrease if ozone is used as the primary disinfectant, with chloramines used for maintenance of a distribution system residual. This is because the chlorine dose currently added to the settled water is determined by two parameters: 1) the disinfection requirements, and 2) maintenance of a chlorine residual in the distribution system. The higher of these two values controls the chlorine dose. Therefore, even when the chlorine dose needed for disinfection is low, a higher dose may be needed to ensure that the residual in the distribution system is sufficient. The net result is that the level of disinfection achieved is sometimes much higher than the minimum requirement. Ammonia is added to the chlorinated water after filtration, forming chloramines, which are a much weaker disinfectant compared to free chlorine. For an ozone system, the operational goal would be disinfection only, not residual maintenance. Chlorine and ammonia would be added only to the filter effluent, with a very short free-chlorine contact time. Therefore, the actual level of disinfection is likely to be less than the historical levels and closer to the required levels.

Table 9.1 includes the monthly average CT ratios for the DVWTP and PPWTP. These data are based on the minimum CT ratio calculated each day; then the average of these minimum daily values was calculated for each month of calendar year 2008. The CT ratio is calculated as follows:

$$CT_{ratio} = \frac{CT_{achieved}}{CT_{required}}$$

Where $CT_{achieved}$ is based on the actual measured chlorine residual and contact time through the filters, and $CT_{required}$ is the required value from the regulations for the given water quality conditions. This ratio must be at least 1.0 in order to satisfy the disinfection requirements. In general, treatment plants target a CT ratio of 1.2 to 1.4 in order to ensure continuous compliance with the requirements. As shown in Table 9.1, the ratio for Zone 7's plants is often significantly higher than the minimum requirement. It is expected that for an ozone disinfection system, these ratios would be closer to 1.0.

Under the Peroxone option, disinfection will continue to be achieved with free chlorine. The same operational strategy will be used in that the higher of the two chlorine doses will be added (disinfection vs. residual maintenance). The result is that the disinfection profile for the Peroxone process will likely be similar to the historical values shown in Table 9.1.

Table 9.1 – Monthly Average CT Ratios for DVWTP and PPWTP During 2008

Month	Del Valle WTP	Patterson Pass Conventional WTP	Patterson Pass UF WTP
January	2.6	1.7	out of service
February	2.0	2.1	out of service
March	2.3	2.1	out of service
April	1.8	2.3	2.3
May	2.8	2.8	2.5
June	2.8	2.9	6.2
July	3.1	3.4	6.7
August	3.3	3.4	7.2
September	3.3	2.9	8.6
October	2.9	2.1	6.6
November	2.4	2.7	out of service
December	2.0	out of service	out of service
Minimum	**1.8**	**1.7**	**2.3**
Maximum	**3.3**	**3.4**	**8.6**

9.1.3 Enhanced Coagulation (TOC Removal) and DBP formation

Both plants currently meet the Step 1 TOC removal requirements of the Stage 1 Disinfectants/Disinfection Byproduct Rule. No significant change is expected in TOC removal as a result of either ozone or Peroxone implementation, although there may be slight improvement due to the biofilters. In the case of ozone implementation, it is expected that the levels of THMs and HAAs formed will be significantly lower, since there will be much less contact time with free chlorine. For example, the typical THM concentrations in the finished water at ACWD's WTP2 range from 5 to 10 ppb. In the case of Peroxone implementation, THM and HAA levels are expected to be higher than those with ozone, but lower than the current levels. Tests conducted during the pilot study showed that a reduction in THMs and HAAs of approximately 20% can be expected as a result of just raw water ozone or Peroxone. Additional removal of DBP precursors is expected to result from the biological filtration process.

9.1.4 Aesthetics (Taste, Odor, and Color)

Implementation of either ozone or Peroxone will result in improved taste and odor of the water. It is expected that the current practice of monitoring of the raw water for MIB and geosmin will continue to be done on a weekly basis during the T&O season, and the ozone or Peroxone doses will be adjusted accordingly to ensure that the MIB and geosmin goals are met.

Aside from MIB and geosmin, there are other naturally-occurring compounds in the SBA water that impart taste, odor, and/or color to the water. Ozone and bio-filtration have been demonstrated to improve the overall taste and appearance of the water. As an example, Figure 9.1 shows two samples of the raw SBA water collected during the pilot study. The bottle on the left is the untreated water, while the bottle on the right was ozonated but not filtered or otherwise treated. This figure shows the color removal performance of the ozonation process.

Figure 9.1 – Raw and Ozonated Water, Del Valle WTP, August 2008

When the taste, odor, or color of the water changes, customer complaints often result. This occurs regardless of whether or not a particular compound is present; merely a change in the aesthetics of the water can be a cause for concern. The on/off operation of the Peroxone system is likely to result in periodic changes to the taste, odor, or color of the water. Therefore customer complaints may result each time the system is turned on or off, even when MIB and/or geosmin is not present (as was the case when the photo in Figure 9.1 was taken), other organic compounds in the water may change the appearance and flavor of the water.

There is a potential for manganese release from the media filter after implementation of ozone or Peroxone and conversion of the filters to biological mode. Manganese is known to be contained in ferric chloride, and this manganese can accumulate on the media from historical use of ferric chloride, as well as manganese captured from the raw water. This manganese will remain bound to the filter media as long as a chlorine residual is present in the water passing through the media. Once that chlorine is removed, the manganese may slough off the media into the filtered water, potentially causing turbidity spikes and aesthetic concerns. This issue should be carefully evaluated during design. The evaluation may determine that the filter media will need to be replaced with new media before implementation of either ozone or peroxone.

9.2 DOCUMENTATION NEEDS

Implementation of either ozone or Peroxone will require an amendment to the existing operating permit from the California Department of Public Health (CDPH). In both cases, a new (updated) Operations Plan will be needed as part of the permit amendment process. Per Zone 7's current practice, the Standard Operating Procedures (SOPs) pertaining to the various components of the ozone or Peroxone systems will be included in the updated Operations Plan. New SOPs will need to be developed for processes such as startup and shutdown of the system, chemical ordering and delivery, and monitoring and controlling the processes. Existing SOPs such as filter backwashing will need to be updated to reflect the changes in operation.

The manner in which disinfection is demonstrated will change and a new disinfection calculation methodology will be needed. The new disinfectant sampling plan and calculation methods will be included in the updated Operations Plan, and a new monthly report format will be required.

Updated plant drawings per standard Zone 7 practices will be needed. All new equipment will need to be included in the computerized maintenance management system (CMMS) system along with the corresponding manufacturer's manuals. An inventory of spare parts associated with the ozone or Peroxone system will be needed as well as routine maintenance tasks for each piece of equipment.

9.3 ADDITIONAL WATER QUALITY MONITORING

Because the biofiltration process is new, it should be monitored carefully to ensure that it is working correctly. In addition to the regular plant monitoring (turbidity profiles, headloss curves, chlorine residuals, pH, etc.) samples should be taken for heterotrophic plate count (HPC) bacteria across the plant. This will provide an indication of the level of biological activity in the filters. Additionally, it would be helpful to monitor for indicators of the removal of biodegradable organic matter (BOM) such as aldehydes or Assimilable Organic Carbon (AOC) upstream and downstream of the biofilters.

Because both ozone and Peroxone will create bromate, it will be important to monitor this regulated parameter closely. When using ozone, monthly monitoring for bromate is required, and the MCL is based on a rolling 12-month average of these monthly values. Higher-frequency monitoring, such as once per week, is recommended at least for the first year of operation to ensure that adjustments are made as needed. For example, the addition of chloramine to the contactor inlet has been shown to be effective in suppressing bromate formation, but is not necessary when the raw water bromide level is low (below approximately 80 - 100 ppb).

9.4 ADDITIONAL ON-LINE ANALYZERS AND SPECIALIZED EQUIPMENT

In the case of ozone, it is best to monitor the ozone residual in the water continuously (similar to the chlorine residual under the current operation). The online water-phase analyzers should be verified by periodic grab samples. Older ozone analyzers were problematic, but recent models have shown much improvement in reliability. Two or more ozone analyzers per contactor are recommended to allow for precise calculation of disinfection.

Ozone in the gas phase must also be monitored continuously. Typically, three locations are monitored: the ozone concentration in the feed gas, the off-gas, and the vent gas after the ozone destruct system. Additionally, ambient ozone monitors are needed in enclosed areas to ensure that personnel are not exposed to dangerous level of ozone resulting from leaks.

For the Peroxone option, pH control is not needed. The raw water ambient pH will continue to fluctuate between approximately 7 and 9 as is does under current operation. Therefore, no new pH analyzers will be needed. However for ozone, the pH should be stabilized at a moderate level such as 7.3 units by the addition of carbon dioxide. This will have more than one benefit: it will stabilize the ozone residual, reduce the amount of ozone needed to achieve the disinfection goals, and improve TOC removal with the downstream processes. For ozone implementation, additional pH analyzers will be needed to monitor and control the carbon dioxide feed system.

9.5 EXPECTED IMPACT ON STAFFING LEVELS

Currently, both the DVWTP and PPWTP are staffed continuously (24 hours per day, 7 days per week) in three shifts: day, swing, and graveyard. Only one operator is present at each site during the swing and graveyard shifts, while multiple operators are present during day shifts. There are 20 operators, and these operators share responsibility for operating the Del Valle WTP, the conventional and UF plants at Patterson Pass, the well fields, distribution system, and the new demineralization plant. Maintenance is centralized, with one lead mechanic, four mechanics, one laborer, two electricians, and four instrument technicians to cover all facilities. Several tasks are contracted out such as solids dewatering, certain instrumentation maintenance, and PLC/PC system maintenance.

It is likely that the ozone or Peroxone process can be implemented without adding any new operators, although existing schedules may need to be adjusted. Some plants using ozone in the SF Bay area (SCVWD and ACWD) employ double coverage: two operators on shift at all times, while others (CCWD) have only one operator at night. It is difficult to generalize, since some plant operators monitor solids handling processes, some control distribution systems, and some operate other remote facilities in addition to on-site plant operational duties. However, it is reasonable to assume that an ozone or Peroxone process could be added to each plant, and assuming that the design incorporated modern automated control features, these processes could be operated with existing staff. Ozonation is expected to be fairly continuous and stable, particularly with pH adjustment. Further, there are good online instruments to measure and trend the ozone residual as well as other performance parameters. This means that reliable automation is possible, similar to that used for chlorine feed or caustic feed. In the case of the Peroxone process, operation would be simpler since it would be run at a constant dose. Once the system is in place and running, the operator must monitor it in a similar fashion to the existing chlorination or caustic feed systems. It should be emphasized that this operator staffing assumption is dependent on the quality of the ozone system design: gas flows must be able to be controlled by the PC/PLC system, online analyzers must be properly located and accurate, and the computer control system must be well thought out an operator-friendly. If the system is not well designed, more operator attention will be needed. Based on discussions with Zone 7 staff, an additional operator, split equally between the two plants, will be needed due to the additional workload associated with other duties such as operating of the distribution system and the new demineralization plant.

Maintenance staff will need to be increased to handle the new equipment. The new LOX storage and feed systems, ozone generation and control systems, off-gas destruct systems, and either hydrogen peroxide or carbon dioxide storage and feed systems will require mechanical, electrical, and instrumentation support. At least one additional full-time mechanic, one new control system/instrumentation technician, and one new electrician will be needed to maintain the equipment for both sites (0.5 FTE per trade per site).

There are examples of local surface water treatment plants in which ozone was added to an existing plant. WQTS contacted three agencies regarding the impact of ozone implementation on the level of operations and maintenance staff needed. The following are summaries of the feedback received:

East Bay Municipal Utility District: Settled water ozone was added to both the Upper San Leandro WTP and Sobrante WTP in 1991. No new operators were hired, but operator trainees were added. Maintenance staff size was increased. Maintenance was centralized at the time, which makes it difficult to determine the impact of the ozonation system on the maintenance needs. However, at least two new mechanics, two electricians, and three instrument technicians were added. It should be noted that these projects also included other significant changes to the plants, aside from ozone, such as new chemical handling facilities and changes in backwash water recycle systems.

Santa Clara Valley Water District: Settled water ozone was added to the Penitencia WTP in 2006 and to the Santa Teresa WTP in 2005. The plants had been operated in single shifts at night, but a few years before ozone was added, the District changed to double shifts at all plants (two operators per shift at all times). This was done partly in anticipation of ozone addition, but also to deal with the new washwater clarification facilities and for safety and workforce/continuity concerns. The Rinconada plant (which has no ozone) also employs double coverage for all shifts. For the addition of ozone, the District added one new control technician at each plant, plus one new electrician and one new mechanic for the combined facilities. It should be noted that the distance between SCVWD's plants is significant; consideration of travel time was part of the decision to station a dedicated control tech and each site.

Contra Costa Water District: Settled water ozone was added to the Bollman WTP in 1999. There is single operator coverage during the night shift, with double coverage during most day shifts. No new operators were added specifically for the implementation of ozone as the existing staff at the Bollman plant incorporated the new duties into normal operations. CCWD estimates that ozone requires 3 – 4 hours of operator attention per 24 hour day, but that this is highly dependent on the quality of the operator interface with the PLC. Programming flaws such as common alarms that do not inform the operator of the source of a problem or shutdown have resulted in unnecessary resources being expended to determine the cause of the problem and conduct needed repairs.

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APPENDIX A
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APPENDIX B
RAW PILOT TESTING DATA

Zone 7 Water Agency - Ozone & Peroxone Pilot Testing

Results of 1st Round of Testing - June & July 2008

						Ozone	Residual (mg/L) at HRT (min) Past 1st Chamber					CT	MIB			Geosmin				
Test ID	**Contactor**	**Water**	**pH**	**NH_2Cl**	**H_2O_2:O_3**	**Dose**	**0**	**2**	**4**	**6**	**8**	**mg-min/L**	**Influent**	**Effluent**	**% Rem.**	**Influent**	**Effluent**	**% Rem.**	**Bromide**	**Bromate**
R-2-0-7-0	**Conventional**	**Raw**	7.0	0	0	2.0	0.77	0.37	0.14	0.06	0.07	0.83	9.4	3.8	60%	9	2.8	69%	658	20
R-3-0-7-0						3.0	1.38	0.35	0.56	0.36	0.90	2.81	9.4	3.0	68%	9	2.2	76%	651	35
R-4-0-7-0						4.0	1.91	1.23	1.08	0.69	0.53	4.58	9.4	2.0	79%	9	1	89%	604	49
R-2-0-6.5-0			6.5	0	0	2.1	0.87	0.86	0.13	0.11	0.06	1.51	9.4	3.4	64%	9	2.3	74%	612	14
R-3-0-6.5-0						3.1	2.21	1.78	0.75	0.88	0.93	5.65	42	6.6	84%	33	3.9	88%	661	25
R-4-0-6.5-0						4.0	3.25	2.49	1.68	1.53	1.41	9.24	42	4.4	90%	33	2.1	94%	562	52
R-2-0-A-0.75			8.7	0.75	0	2.0	0.60	0.22	0.14	0.08	0.06	0.64	42	16	62%	33	8	76%	726	23
R-3-0-A-0.75			9.0	0.75	0	3.0	1.35	0.51	0.14	0.17	0.18	1.30	42	7.5	82%	33	3	91%	675	51
R-4-0-A-0.75			9.2	0.75	0	4.0	1.90	0.79	0.33	0.20	0.14	1.89	42	4.7	89%	33	1	97%	676	78
S-0.5-0-6.5-0		**Settled**	6.0	0	0	0.43	0.24	0.20	0.11	0.11	0.09	0.66	38	26	32%	40	27	33%	632	2.5
S-1-0-6.5-0						1.0	0.70	0.50	0.31	0.27	0.18	1.63	38	22	42%	40	20	50%	606	2.5
S-1.5-0-6.5-0						1.5	1.35	1.02	0.71	0.60	0.50	3.68	43	27	37%	38	20	47%	606	2.5
S-0.5-0-A-0			6.7	0	0	0.52	0.21	0.08	0.05	0.03	0.01	0.22	38	30	21%	40	27	33%	689	2.5
S-1-0-A-0						1.0	0.79	0.41	0.30	0.23	0.17	1.44	38	24	37%	40	18	55%	660	7.8
S-1.5-0-A-0						1.5	1.35	0.83	0.62	0.57	0.41	3.15	38	17	55%	40	14	65%	587	17
S-0.5-0-A-0.75			6.6	0.75	0	0.50	0.22	0.21	0.11	0.11	0.12	0.73	43	27	37%	38	24	37%	664	2.5
S-1-0-A-0.75						1.0	0.63	0.40	0.26	0.21	0.17	1.36	43	27	37%	38	18	53%	659	2.5
S-1.5-0-A-0.75						1.5	1.06	1.03	0.60	0.52	0.41	3.33	43	24	44%	38	18	53%	680	2.5

						Ozone	Residual (mg/L) at HRT (min) from Ozone Injection				CT	MIB			Geosmin				
Test ID	**Contactor**	**Water**	**pH**	**NH_2Cl**	**H_2O_2:O_3**	**Dose**	**0**	**1**	**1.5**	**2.6**	**mg-min/L**	**Influent**	**Effluent**	**% Rem.**	**Influent**	**Effluent**	**% Rem.**	**Bromide**	**Bromate**
R-2-0-6.5-0	**Pipeline**	**Raw**	6.5	0	0	3.0			1.9			9.4	2.3	76%	9	1	89%	594	32
R-3-0-6.5-0						3.9			2.7			42	5.0	88%	33	1	97%	549	64
R-4-0-6.5-0						4.6			3.8			42	3.1	93%	33	2.3	93%	479	105
R-2-0-7-0			7.0	0	0	3.0			1.1			9.4	3.2	66%	9	2.1	77%	643	43
R-3-0-7-0						3.8			2.1			9.4	2.0	79%	9	1	89%	545	91
R-4-0-7-0						5.1			3.8			9.4	1.0	89%	9	1	89%	468	158
R-2-0-A-0.75			8.7	0.75	0	3.0			2.5			42	13	69%	33	6.2	81%	691	39
R-3-0-A-0.75			9.0	0.75	0	4.5			2.3			42	6.4	85%	33	2.3	93%	626	89
R-4-0-A-0.75			9.2	0.75	0	6.0			2.9			42	3.4	92%	33	1	97%	608	143
R-2-0.4-6.5-0			6.5	0	0.14	2.8			1.1			30	8.5	72%	19	4.5	76%	723	33
R-3-0.6-6.5-0					0.16	3.8			1.8			30	6.5	78%	19	2.7	86%	687	45
R-4-0.8-6.5-0					0.18	4.6			2.2			30	5.6	81%	19	2.2	88%	631	69
R-2-0.4-7-0			7.0	0	0.13	3.0			1.2			30	7.3	76%	19	3.9	79%	691	45
R-3-0.6-7-0					0.15	4.0			1.4			30	6.0	80%	19	2.8	85%	672	65
R-4-0.8-7-0					0.17	4.6			2.5			30	5.4	82%	19	2.1	89%	630	90
R-2-0.4-A-0.75			8.2	0.75	0.13	3.0			0.49			30	7.7	74%	19	3.4	82%	738	50
R-3-0.6-A-0.75			8.3		0.13	4.5			0.78			30	5.4	82%	19	2.2	88%	741	72
R-4-0.8-A-0.75			8.3		0.13	6.0			1.13			30	3.8	87%	19	1	95%	719	93
R-2-1.6-6.5-0			6.5	0	0.53	3.0			0.69			24	7.6	68%	20	3.7	82%	612	19
R-3-2.4-6.5-0					0.62	3.9			1.25			24	5.1	79%	20	2.2	89%	553	38
R-4-3.2-6.5-0					0.69	4.6			1.56			24	4.4	82%	20	1	95%	528	60
R-2-1.6-7-0			7.0	0	0.53	3.0			0.64			24	6.9	71%	20	3.8	81%	622	38
R-3-2.4-7-0					0.63	3.8			1.13			24	5.8	76%	20	2.6	87%	567	65
R-4-3.2-7-0					0.69	4.6			1.50			24	4.2	83%	20	1	95%	510	101
R-2-1.6-A-0.75			8.2	0.75	0.53	3.0			0.72			24	6.8	72%	20	3.2	84%	594	28
R-3-2.4-A-0.75			8.2	0.75	0.53	4.5			1.04			24	5.3	78%	20	1	95%	588	49
R-4-3.2-A-0.75			8.3	0.75	0.53	6.0			1.36			24	4.0	83%	20	1	95%	558	71
S-0.5-0-6.5-0		**Settled**	6.0	0	0	0.95			0.91			38	22	42%	40	22	45%	621	2.5
S-1-0-6.5-0						1.62			1.03			38	18	53%	40	12	70%	567	7.3
S-1.5-0-6.5-0						2.22			2.00			43	17	60%	38	11	71%	547	18
S-0.5-0-A-0			6.7	0	0	0.93			0.63			38	26	32%	40	21	48%	663	2.5
S-1-0-A-0						1.64			1.34			38	18	53%	40	14	65%	585	21
S-1.5-0-A-0						2.25			1.57			38	13	66%	40	8.7	78%	526	42
S-0.5-0-A-0.75			6.6	0.75	0	0.75			0.43			43	26	40%	38	20	47%	596	2.5
S-1-0-A-0.75						1.5			1.42			43	21	51%	38	16	58%	589	5.2
S-1.5-0-A-0.75						2.25			1.90			43	21	51%	38	13	66%	629	2.5
S-0.5-0.1-6.5-0			6.0	0	0.13	0.8			0.76			36	20	44%	19	9.3	51%	619	2.5
S-1-0.2-6.5-0					0.14	1.4			1.42			36	14	61%	19	6.1	68%	611	5.7
S-1.5-0.3-6.5-0					0.16	1.89			1.48			36	13	64%	19	6.1	68%	509	2.5
S-0.5-0.1-A-0			6.6	0	0.11	0.93			0.44			36	25	31%	19	11	42%	714	2.5
S-1-0.2-A-0					0.13	1.52			1.16			36	16	56%	19	5.2	73%	698	17
S-1.5-0.3-A-0					0.15	1.98			1.83			36	12	67%	19	4.7	75%	486	23
S-0.5-0.1-A-0.75			6.6	0.75	0.11	0.93			0.76			36	23	36%	19	11	42%	583	2.5
S-1-0.2-A-0.75					0.13	1.52			1.35			36	19	47%	19	7.6	60%	574	2.5
S-1.5-0.3-A-0.75					0.15	1.98			2.14			24	11	54%	20	6.3	69%	538	2.5
S-0.5-0.4-6.5-0			6.0	0	0.53	0.76			0.81			24	15	38%	14	10	29%	590	2.5
S-1-0.8-6.5-0					0.51	1.56			1.17			24	13	46%	14	9	36%	515	2.5
S-1.5-1.2-6.5-0					0.56	2.16			1.73			24	8.6	64%	14	4.8	66%	487	9.1
S-0.5-0.4-A-0			6.6	0	0.43	0.93			0.80			24	14	42%	14	6.8	51%	601	2.5
S-1-0.8-A-0					0.50	1.6			1.25			24	14	42%	14	7.3	48%	545	5.7
S-1.5-1.2-A-0					0.58	2.07			1.87			24	10	58%	14	5	64%	497	23
S-0.5-0.4-A-0.75			6.5	0.75	0.43	0.93			0.75			24	14	42%	14	9.4	33%	529	2.5
S-1-0.8-A-0.75					0.50	1.6			1.38			24	13	46%	14	7.7	45%	558	2.5
S-1.5-1.2-A-0.75					0.58	2.07			1.82			24	10	58%	14	5.6	60%	567	2.5

Zone 7 Water Agency - Ozone & Peroxone Pilot Testing

Results of 2nd Round of Testing - September 2008

Test ID	Contactor	Water	pH	NH_2Cl	H2O2 Dose	$H_2O_2:O_3$	Target Ozone Dose	Transferred Ozone Dose	Transfer Efficiency	Residual (mg/L) at HRT (min) Past 1st Chamber					CT	MIB				Geosmin				Bromide	Bromate		NH_2Cl	Free NH_3-N
										0	2	4	6	8	mg-min/L	Influent	Mid PC	Effluent	% Rem.	Influent	Mid PC	Effluent	% Rem.		Mid PC	Effluent		
1	**Conventional**	**Raw**	6.5	0		0	1	1.0	96%	0.18	0.09	0.08	0.08	0.08	0.43	31		15	52%	26		10	62%	394		5.1		
2			6.5				2	1.9	95%	0.77	0.36	0.19	0.10	0.13	1.01	31		7.9	75%	26		4.1	84%	394		13		
3			6.5				3	2.7	91%	1.31	0.72	0.48	0.30	0.24	2.26	31		6.0	81%	26		3.2	88%	394		22		
4			7.5	0		0	1	1.0	97%	0.03	0.06	0.03	0.05	0.03	0.22	31		16.0	48%	26		12	54%	394		1.3		
5			7.5				2	1.9	95%	0.80	0.42	0.23	0.21	0.14	1.30	26		9.6	63%	22		6.3	71%	265		13		
6			7.5				3	2.8	93%	1.88	1.02	0.69	0.51	0.49	3.52	26		6.8	74%	22		3.5	84%	265		26		
7			7.5	0.75		0	1	1.0	95%	0.20	0.08	0.10	0.10	0.10	0.49	26		20	25%	22		13.7	38%	265		0.3	0.48	0.23
8			7.5	0.75			2	1.9	95%	0.99	0.51	0.30	0.18	0.13	1.46	26		12.6	52%	22		8.7	60%	265		4.4	0.42	0.17
9			7.5	0.75			3	2.7	91%	1.99	1.22	0.81	0.60	0.46	4.02	31		8.6	72%	28		5.5	80%	349		6.3	0.39	0.12
10			7.8	0.75		0	1	1.0	95%	0.21	0.16	0.21	0.15	0.16	0.88	31		18	42%	28		15	46%	349		0.5	0.58	0.17
11			7.8	0.75			2	1.9	93%	0.84	0.43	0.21	0.16	0.18	1.27	31		11	65%	28		7.8	72%	349		7.8	0.52	0.13
12			8.1	0.75			3	2.8	92%	1.53	1.15	0.56	0.43	0.34	3.22	31		8	74%	28		3.8	86%	349		18	0.41	0.13
13		**Settled**	6.0		0	0	0.5	0.48	96%	0.23	0.13	0.12	0.13	0.14	0.68	20		16	20%	16		10	38%	415		0.4		
14			6.0				1.5	1.4	94%	1.24	0.86	0.76	0.74	0.62	3.87	20		11	45%	16		7	58%	415		4.2		
15			6.0				3	2.7	89%	2.55	2.32	2.21	2.21	1.71	11.0	20		8	60%	16		5	67%	415		32		
16			6.5		0	0	0.5	0.48	96%	0.20	0.16	0.12	0.11	0.13	0.68	20		14	30%	16		10	38%	415		0.2		
17			6.6				1.5	1.4	93%	1.15	0.89	0.69	0.93	0.60	4.04	20		10	50%	16		6	63%	415		14		
18			6.5				3	2.7	89%	2.77	2.60	2.27	2.21	2.06	11.9	18		7	59%	17		6	67%	381		68		
19			6.46	0.75	0	0	0.5	0.48	96%	0.34	0.28	0.19	0.21	0.21	1.16	18		16	11%	17		13	24%	381		0.5	0.49	0.13
20			6.47	0.75			1.5	1.4	93%	1.30	1.09	0.81	0.84	0.64	4.39	18		12	33%	17		8	54%	381		1.1	0.21	0.14
21			6.5	0.75			3	2.6	88%	2.75	2.45	1.96	1.95	1.70	10.5	18		8	58%	17		6	68%	381		1.3	0.05	0.1

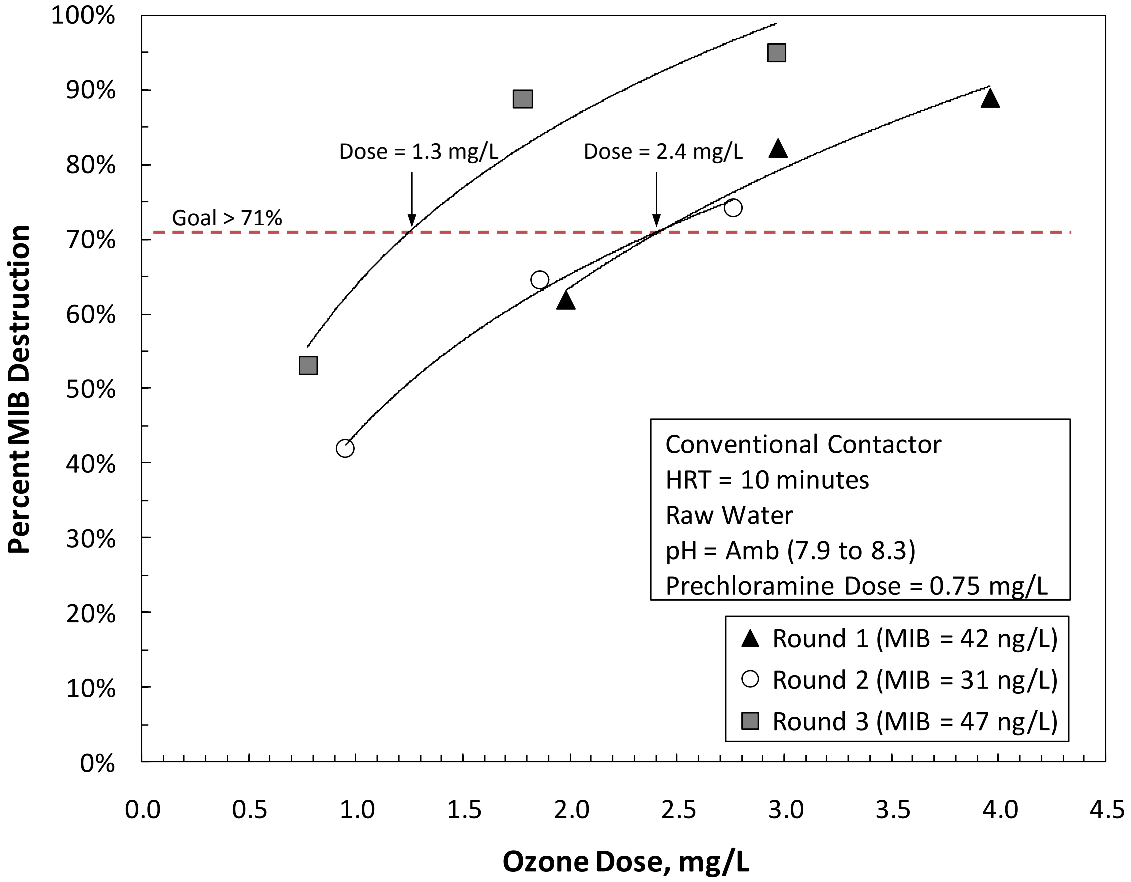
Test ID	Contactor	Water	pH	NH_2Cl	H2O2 Dose	$H_2O_2:O_3$	Ozone Dose	Ozone Dose	Transfer Efficiency	Residual (mg/L) at HRT (min) from Influent			CT	MIB				Geosmin				Bromide	Bromate		NH_2Cl	Free NH_3-N
										1	1.5	2.6	mg-min/L	Influent	Mid PC	Effluent	% Rem.	Influent	Mid PC	Effluent	% Rem.		Mid PC	Effluent		
1a	**Pipeline**	**Raw**	6.5	0		0	1	1.0	96%	0.1		0.09	0.23	31	16	14	55%	26	10	9.2	65%	394	5.5	5.7		
2a			6.5				2	1.7	87%	0.6		0.3	1.06	31	12	9.3	70%	26	7.5	5.7	78%	394	19	18		
3a			6.5				3	2.3	77%	1.0		0.96	2.40	31	9.3	9.2	70%	26	5.5	5.2	80%	394	31	27		
31			6.5	0	0.5	0.59	1	0.9	85%	0.0		0	0.03	44	21	21	52%	35	13	12	66%	524	8.2	7.7		
32			6.5		1	0.61	2	1.6	82%	0.4		0.06	0.52	44	11	7.0	84%	35	6.2	3.3	91%	524	25	34		
33			6.5		1.5	0.71	3	2.1	70%	0.7		0.06	0.75	44	7.4	3.5	92%	35	3.5	1.6	95%	524	61	55		
49			6.5	0	1	1.33	1	0.8	75%	0.20		0.21	0.50	32	15	15	53%	27	8.5	9.5	65%	498	6.5	4.2		
50			6.5		2	1.41	2	1.4	71%	0.49		0.14	0.69	32	9.4	7.2	78%	27	5.1	3.5	87%	589	15	19		
51			6.5		3	1.37	3	2.2	73%	0.50		0.21	0.80	32	5.7	3.2	90%	27	5.2	1.6	94%	589	22	25		
4a			7.5	0		0	1	0.9	87%	0.1		0.07	0.16	31	16	15	52%	26	9.4	10	62%	394	10	4.3		
5a			7.5				2	1.7	86%	0.8		0.52	1.53	26	15	12.4	52%	22	9.9	7.6	65%	265	16	16		
6a			7.5				3	2.4	81%	1.8		1.48	3.94	26	13	9.7	63%	22	7.9	6	73%	265	30	25		
7a			7.5	0.75			1	0.9	86%	0.4		0.27	0.76	26	19.8	19	29%	22	14	13.6	38%	265	2.3	3.8	0.42	0.17
8a			7.5	0.75			2	1.7	87%	1.0		0.72	2.05	26	16.7	14.6	44%	22	12.6	10.1	54%	265	5.2	4	0.43	0.14
9a			7.5	0.75			3	2.4	80%	1.7		1.9	4.42	31	17	14	55%	28	12	9.7	65%	349	13	12	0.36	0.18
34			7.5	0	0.5	0.69	1	0.7	72%	0.02		0	0.02	44	21	20	55%	35	12	12	66%	524	18	29		
35			7.5		1	0.60	2	1.7	83%	0.10		0.02	0.13	44	8.5	8.1	82%	35	4	3.8	89%	524	32	29		
36			7.5		1.5	0.69	3	2.2	72%	0.23		0.01	0.24	44	6.9	5	89%	35	3.3	2.1	94%	524	41	40		
52			7.6	0	1	1.37	1	0.7	73%	0.14		0.14	0.34	32	16	16	50%	27	10	11	59%	589	3.2	8.8		
53			7.4		2	1.22	2	1.6	82%	0.09		0.12	0.26	32	7	7.2	78%	27	3.4	3.4	87%	589	23	23		
54			7.5		3	1.37	3	2.2	73%	0.02		0.06	0.11	32	3.5	3.9	88%	27	1.6	1.7	94%	589	41	39		
10a			7.8	0.75			1	1.0	95%	0.2		0.27	0.63	31	21	19	39%	28	16	15	46%	349	1.8	0.5	0.54	0.14
11a			7.8	0.75			2	1.7	86%	0.8		0.41	1.37	31	17	14	55%	28	12	9.1	68%	349	5.7	9.3	0.4	0.12
12a			8.1	0.75			3	2.4	80%	1.2		0.81	2.37	31	8.7	7.6	75%	28	5.5	5	82%	349	22	18	0.39	0.12
37			8.4	0.75	0.5	0.68	1	0.7	73%	0.06		0.04	0.12	44	25	27	39%	35	18	19	46%	524	0.2	1.3	0.36	0.12
38			8.7	0.75	1	0.57	2	1.7	87%	0.01		0	0.01	44	17	15	66%	35	10	9.4	73%	524	4.3	1.8	0.39	0.15
39			8.7	0.75	1.5	0.63	3	2.4	80%	0.04		0.01	0.05	44	12	12	73%	35	6.1	5.8	83%	524	6.8	5.2	0.27	0.15
55			8.2	0.75	1	1.37	1	0.7	73%	0.15		0.08	0.27	32	20	19	41%	27	13	13	52%	589	0.4	0.8	0.48	0.1
56			8.4	0.75	2	1.19	2	1.7	84%	0.11		0.13	0.30	32	10	10	69%	27	5.6	5.5	80%	589	7.1	7.7	0.41	0.1
57			8.4	0.75	3	1.43	3	2.1	70%	0.08		0.17	0.33	32	4.6	4.3	87%	27	2	2	93%	589	39	36		
13a		**Settled**	6.0		0	0	0.5	0.48	96%	0.27		0.29	0.69	20	17	16	20%	16	10	12	25%	415	0.8	0.5		
14a			6.0				1.5	1.29	86%	1.10		0.89	2.39	20	9.3	10	50%	16	5.4	9	47%	415	3.3	5.8		
15a			6.0				3	2.19	73%	2.34		2.35	5.75	20	13	11	45%	16	8.7	7	55%	415	29	27		
16a			6.5	0	0		0.5	0.48	96%	0.38		0.29	0.80	20	15	13	35%	16	9.9	12	25%	415	1.1	0.7		
17a			6.6				1.5	1.32	88%	1.13		1.02	2.61	20	13	12	40%	16	8.6	8	52%	415	15	18		
18a			6.5				3	2.19	73%	2.26		1.98	5.13	18	11	10	44%	17	8.2	7.3	57%	381	50	51		
19a			6.5	0.75	0		0.5	0.48	96%	0.40		0.33	0.88	18	16	15	17%	17	14	12	29%	381	0.2	0.1	0.47	0.13
20a			6.5	0.75			1.5	1.31	87%	1.05		0.97	2.46	18	14	14	22%	17	9.6	10	44%	381	0.1	0.4	0.21	0.08
21a			6.5	0.75			3	2.19	73%	2.50		2.16	5.63	18	13	10	44%	17	10	8	55%	381	2.4	1.9	0.16	0.06
22			6.0	0	0.25	0.52	0.5	0.48	96%	0.04		0	0.04	33	23	19	42%	27	15	13	52%	531	0.1	0.4		
23			6.0		0.75	0.60	1.5	1.25	83%	0.68		0.47	1.36	33	18	17	48%	27	13	10	63%	531	2.4	1.3		
24			6.0		1.5	0.75	3	2.01	67%	1.27		0.86	2.52	33	13	8	75%	27	8.6	4.4	84%	531	16	17		
25			6.7		0.25	0.52	0.5	0.48	96%	0.09		0.04	0.15	33	24	22	33%	27	17	15	44%	531	0.6	1.2		
26			6.8		0.75	0.61	1.5	1.22	81%	0.66		0.36	1.18	33	15	10	71%	27	9.6	5.2	81%	531	19	22		
27			6.8		1.5	0.74	3	2.04	68%	1.24		0.48	1.94	33	7.6	2	93%	27	3.8	1.2	96%	531	59	56		
28			6.7	0.75	0.25	0.52	0.5	0.48	96%	0.21		0.13	0.40	33	28	27	18%	27	21	18	33%	531	0.7	1	0.5	0.11
29			6.8	0.75	0.75	0.61	1.5	1.22	81%	0.71		0.37	1.25	33	22	16	52%	27	14	10	63%	531	2.5	3.1	0.4	0.1
30			6.8	0.75	1.5	0.74	3	2.04	68%	1.25		0.49	1.96	33	12	5	84%	27	7.6	2.5	91%	531	17	13	0.35	0.07
40			6.0	0	0.5	1.04	0.5	0.48	96%	0.23		0.18	0.49	25	19	18	28%	24	14	13	46%	498	1.8	1.5		
41			6.0		1.5	1.20	1.5	1.25	83%	0.89		0.57	1.72	25	6.2	6	75%	24	3.2	3.5	85%	498	2.2	5.3		
42			6.0		3	1.43	3	2.1	70%	1.68		0.99	3.12	25	11	3.9	84%	24	6.2	1.8	93%	498	16	11		
43			6.7		0.5	1.04	0.5	0.48	96%	0.16		0.13	0.35	25	23	22	12%	24	15	15	38%	498	0.2	1.3		
44			6.7		1.5	1.20	1.5	1.25	83%	0.74		0.35	1.25	25	13	6.5	74%	24	7.6	2.9	88%	498	20	20		
45			6.8		3	1.47	3	2.04	68%	1.04		0.18	1.30	25	4.2	1.6	94%	24	1.7	1.1	95%	498	38	35		
46			6.7	0.75	0.5	1.04	0.5	0.48	96%	0.32		0.25	0.68	25	30	28	-12%	24	20	21	13%	498	0.8	0.6	0.51	0.12
47			6.7	0.75	1.5	1.23	1.5	1.22	81%	0.81		0.38	1.36	25	20	13	48%	24	13	7.4	69%	498	3.2	4.5	0.38	0.1
48			6.7	0.75	3	1.49	3	2.01	67%	0.97		0.24	1.32	25	5.2	2	92%	24	2	1.1	95%	498	31	29	0.18	0.21

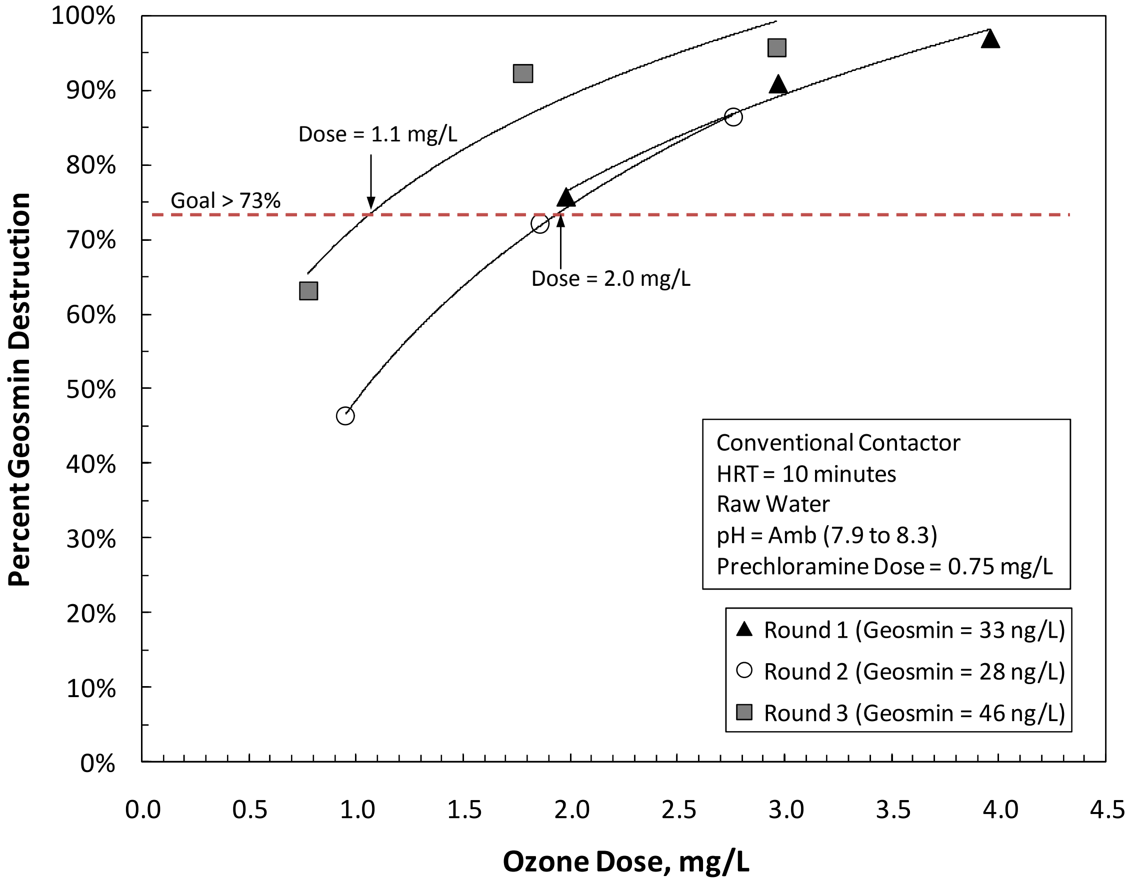
Zone 7 Water Agency - Ozone & Peroxone Pilot Testing

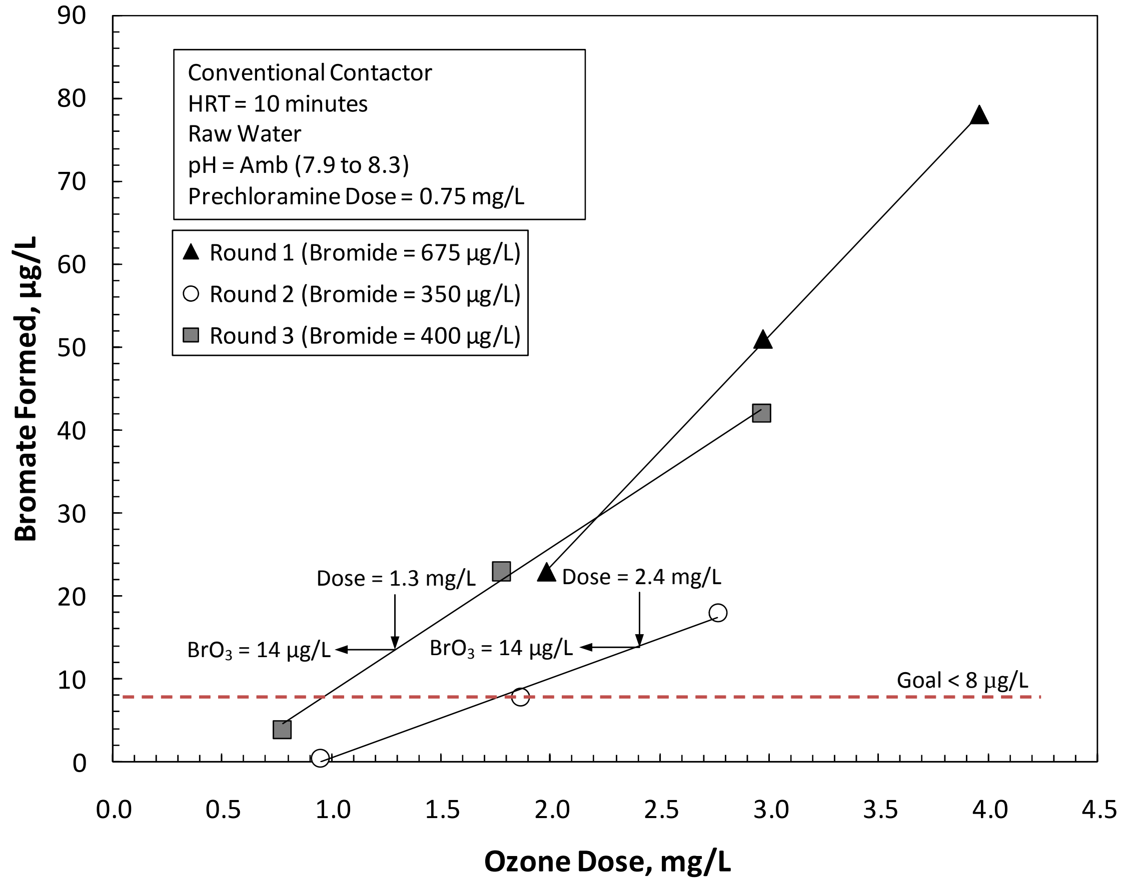
Results of 3rd Round of Testing - October 2008

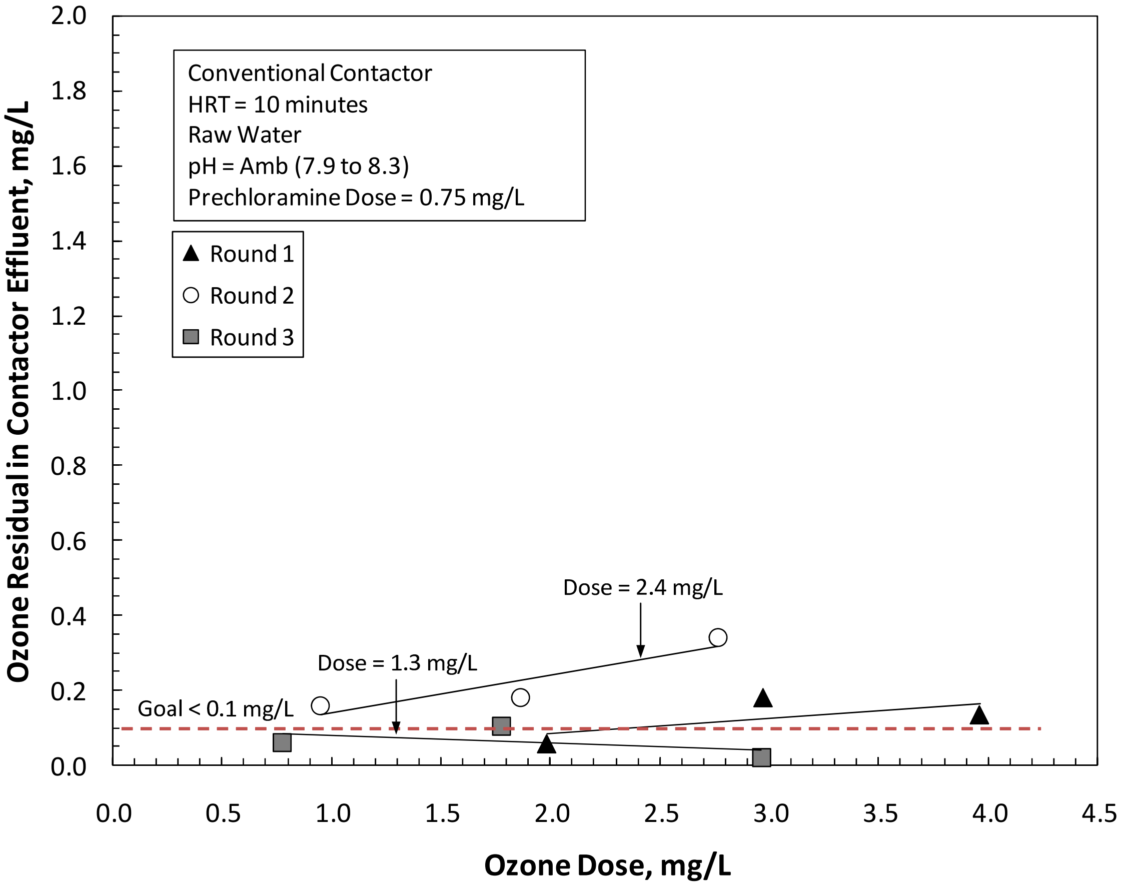
Test ID	Contactor	Water	pH	NH_2Cl	H2O2 Dose	H_2O_2:O_3	Applied Ozone Dose	Transferred Ozone Dose	Transfer Efficiency	Residual (mg/L) at HRT (min) Past 1st Chamber					CT	MIB			Geosmin			Bromide	Bromate	NH_2Cl	Free NH_3-N
										0	2	4	6	8	mg-min/L	Influent	Effluent	% Rem.	Influent	Effluent	% Rem.				
1	**Conventional**	**Raw**	6.5	--	--	0	1.5	1.1	72%	0.16	0.01	0.00	0.02	0.01	0.05	40	21	48%	40	17	58%	423	0		
2			6.5	--	--	0	2.6	2.0	77%	0.89	0.61	0.41	0.24	0.19	1.89	40	13.0	68%	40	10	75%	423	12		
3			6.5	--	--	0	3.75	2.9	78%	2.18	1.90	1.39	1.06	0.64	6.49	40	9.3	77%	40	7	83%	423	31		
4			7.6	--	--	0	1.4	0.9	67%	0.07	0.01	0.00	0.02	0.11	0.19	40	23.0	43%	40	21	48%	423	3.1		
5			7.6	--	--		2.8	2.2	77%	0.84	0.47	0.19	0.08	0.01	0.97	40	6.8	83%	40	4.6	89%	423	35		
6			7.6	--	--		4.2	3.3	78%	2.10	1.03	0.60	0.45	0.38	3.21	40	4.6	89%	40	3	93%	423	82		
7			7.5	0.75	--	0	1.8	1.0	54%	0.46	0.19	0.06	0.03	0.08	0.46	47	20	57%	46	15	67%	398	3.3	NA	NA
8			7.6	0.75	--		2.8	2.0	70%	0.91	0.33	0.07	0.00	0.03	0.54	47	7	85%	46	4.6	90%	398	21	0.53	0.15
9			7.4	0.75	--		4	3.0	75%	1.47	0.47	0.13	0.02	0.09	0.93	47	2.6	94%	46	2.2	95%	398	39	0.37	0.2
10			8.3	0.75	--	0	1.25	0.8	62%	0.10	0.14	0.07	0.05	0.06	0.42	47	22	53%	46	17	63%	398	4	0.76	0.14
11			8.3	0.75	--		2.5	1.8	71%	0.43	0.08	0.06	0.12	0.10	0.48	47	5.3	89%	46	3.6	92%	398	23	0.59	0.14
12			8.7	0.75	--		4	3.0	74%	0.58	0.02	0.07	0.10	0.02	0.27	47	2.4	95%	46	2	96%	398	42	0.42	0.16

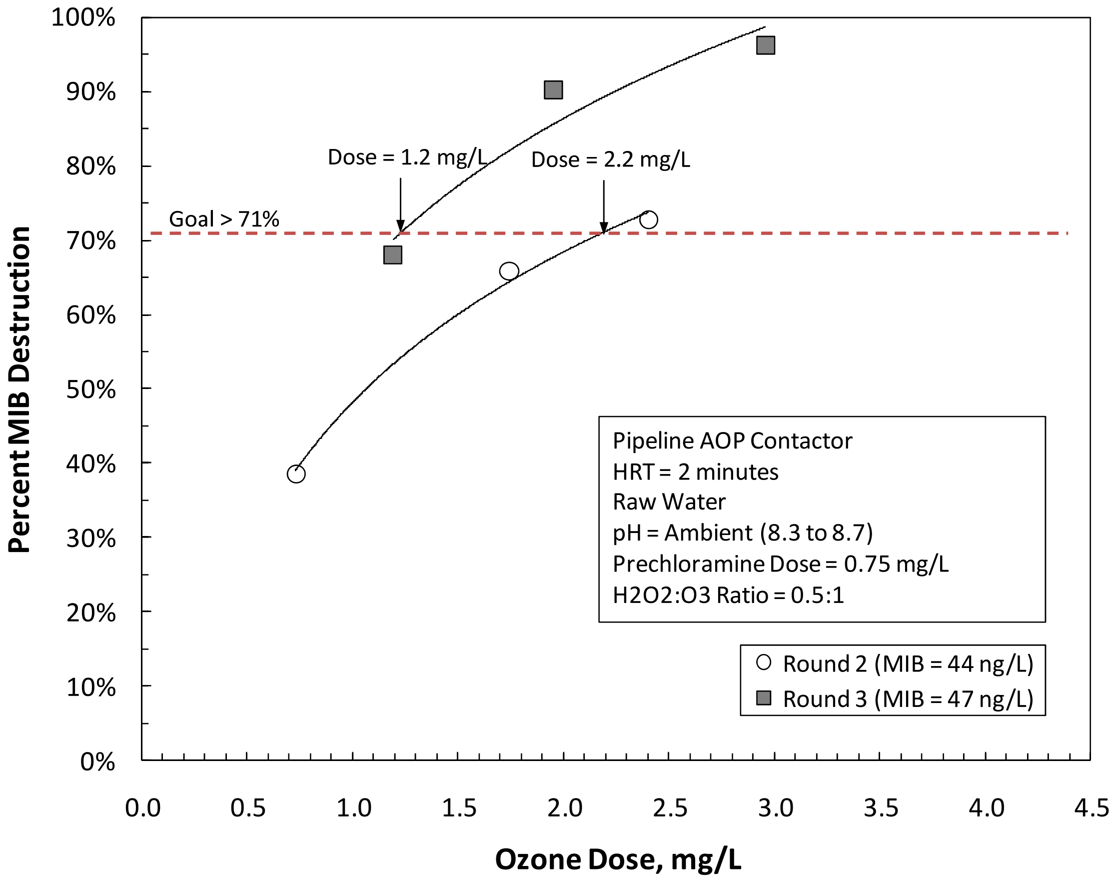
Test ID	Contactor	Water	pH	NH_2Cl	H2O2 Dose	H_2O_2:O_3	Ozone Dose	Ozone Dose	Transfer Efficiency	Residual (mg/L) at HRT (min) from Influent			CT	MIB			Geosmin			Bromide	Bromate	NH_2Cl	Free NH_3-N
										1.0	1.5	2.6	mg-min/L	Influent	Effluent	% Rem.	Influent	Effluent	% Rem.				
4a	**Pipeline**	**Raw**	7.6	--	0.5	0.5	1.3	1.1	85%	0.2		0.09	0.37	40	16	60%	40	11	73%	423	13		
5a	H2O2 added		7.6	--	1	0.5	2.5	2.0	80%	0.3		0.10	0.51	40	4.8	88%	40	3.5	91%	423	40		
6a	32 seconds		7.6	--	1.5	0.5	3.75	2.9	78%	0.5		0.16	0.72	40	1.9	95%	40	1.7	96%	423	70		
7a	**DOWNSTREAM**		7.5	0.75	1	1.0	1.3	1.0	75%	0.2		0.05	0.31	47	16	66%	46	12	74%	398	2.4	0.63	0.12
8a	of ozone		7.6	0.75	2	1.0	2.4	2.0	83%	0.1		0.25	0.55	47	5.3	89%	46	3.1	93%	398	17	0.54	0.06
9a	addition		7.4	0.75	3	1.0	3.6	3.0	82%	0.2		0.07	0.36	47	2.4	95%	46	2	96%	398	37	0.31	0.02
31			7.4	0.75	0.5	0.3	2	1.5	75%	0.52		0.06	0.62	46	12	74%	44	7.4	83%	370	10	0.6	0.11
32			7.6	0.75	1	0.5	2	1.9	81%	0.77		0.01	0.78	46	5.6	88%	44	3.8	91%	370	19	0.42	0.13
33			7.5	0.75	1.5	0.5	4	3.0	75%	0.83		0.26	1.24	46	1.5	97%	44	1.76	96%	370	49	0.43	0.08
34			7.5	--	1.0	1.1	1.25	0.9	74%	0.2		0.04	0.23	46	10	78%	44	7.3	83%	370	15		
35			7.5	--	2.0	1.0	2.75	2.0	73%	0.3		0.01	0.30	46	2.6	94%	44	2.2	95%	370	54		
36			7.5	--	3.0	1.0	3.65	3.0	82%	0.1		0.01	0.10	46	1.0	98%	44	1.7	96%	370	93		
10a			8.3	0.75	0.5	0.4	1.4	1.2	85%	0.12		0.17	0.39	47	15	68%	46	11	76%	398	8	0.63	0.13
11a			8.3	0.75	1	0.5	2.5	2.0	78%	0.00		0.07	0.11	47	4.6	90%	46	2.7	94%	398	37	0.47	0.1
12a			8.7	0.75	1.5	0.5	3.4	3.0	87%	0.05		0.03	0.10	47	1.8	96%	46	1	98%	398	57	0.39	0.1
37			8.0	0.75	1.0	1.0	1.3	1.0	75%	0.13		0.03	0.18	62	25	60%	55	18	67%	354	0	0.58	0.14
38			8.0	0.75	2.0	1.0	2.4	2.0	84%	0.07		0.05	0.15	62	10	84%	55	5.3	90%	354	11	0.46	0.09
39			8.0	0.75	3.0	1.0	3.8	3.0	78%	0.03		0.00	0.03	62	3.4	95%	55	2.8	95%	354	32	0.35	0.03
40			8.1	0.75	2.0	2.1	1.3	1.0	75%	0.04		0.01	0.06	62	22	65%	55	15	73%	354	2.3	0.65	0.05
41			8.3	0.75	4.0	2.0	2.3	2.0	86%	0.00		0.01	0.01	62	8.6	86%	55	4.4	92%	354	19	0.32	0.05
42			8.4	0.75	6.0	2.0	3.6	3.0	83%	0.01		0.00	0.01	62	2.9	95%	55	1.9	97%	354	49	0.29	0.01
43	**Pipeline**	**Raw**	7.5	0.75	0.5	0.5	1.3	1.0	75%	0.24		0.03	0.29	44	25	43%	44	18	59%	381	1.3	0.47	0.14
44	H2O2 added		7.5	0.75	1	0.5	2.4	2.0	85%	0.39		0.01	0.40	44	9.1	79%	44	5.2	88%	381	11	0.34	0.12
45	2 seconds		7.5	0.75	1.5	0.5	3.8	3.0	80%	0.56		0.00	0.56	44	3.5	92%	44	2.1	95%	381	28	0.34	0.12
46	**DOWNSTREAM**		7.5	0.75	1.0	1.0	1.3	1.0	75%	0.11		0.08	0.23	44	20	55%	44	14	68%	381	2.1	0.48	0.14
47	of ozone		7.4	0.75	2.0	1.0	2.3	2.0	86%	0.07		0.00	0.06	44	10	77%	44	5.7	87%	381	6.3	0.34	0.1
48	addition		7.5	0.75	3.0	1.0	3.8	2.9	78%	0.04		0.00	0.04	44	2.4	95%	44	1.8	96%	381	24	0.3	0.06
52	**Pipeline**	**Raw**	7.5	0.75	0.5	0.5	1.4	1.1	75%		0.33	0.13	0.63	34	14	59%	35	11	69%	343	4.1	0.58	0.11
53	H2O2 added		7.5	0.75	1	0.5	2.5	1.9	74%		0.68	0.19	1.24	34	5.6	84%	35	3.5	90%	343	13	0.46	0.11
54	63 seconds		7.5	0.75	1.5	0.5	3.8	3.0	80%		1.00	0.28	1.81	34	3.0	91%	35	1.988	94%	343	26	0.44	0.09
55	**DOWNSTREAM**		7.5	0.75	1.0	1.0	1.3	1.0	75%		0.18	0.04	0.31	34	16.8	50%	35	12.7	64%	343	0.4	0.58	0.13
56	of ozone		7.6	0.75	2.0	1.0	2.5	2.0	80%		0.50	0.05	0.81	34	5.9	83%	35	3.8	89%	343	9.2	0.49	0.06
57	addition		7.6	0.75	3.0	1.1	3.8	2.7	71%		0.49	0.06	0.80	34	2.4	93%	35	1.9	95%	343	21	0.42	0.03
58	**Pipeline**	**Raw**	7.6	--	0.5	0.5	1.3	1.0	75%	0.26		0.00	0.26	33	11.35	66%	33	8.163	75%	358	14		
59	H2O2 added		7.5	--	1.0	0.5	2.5	2.0	78%	0.46		0.02	0.49	33	2.8	92%	33	2.2	93%	358	41		
60	2 seconds		7.5	--	1.5	0.5	3.8	2.9	77%	0.37		0.03	0.42	33	1.2	96%	33	1.6	95%	358	71		
61	**UPSTREAM**		7.6	--	1.0	1.0	1.3	1.0	76%	0.37		0.11	0.55	33	13.9	58%	33	11.0	67%	358	14		
62	of ozone		7.5	--	2.0	0.9	2.5	2.2	86%	1.11		0.75	2.31	33	2.5	92%	33	2.0	94%	358	29		
63	addition		7.5	--	3.0	1.0	3.7	3.0	81%	0.04		0.07	0.15	33	1.0	97%	33	1.6	95%	358	48		
	Pipeline		7.5	--	0	0.00	1.3	0.98	75%	0.3		0.04	0.36										
	no H2O2 Added		7.5	--	0	0.00	2.5	1.95	78%	1.2		0.66	2.22										
			7.5	--	0	0.00	3.89	3.00	77%	2.0		1.23	4.00										
13	**Pipeline**	**Settled**	5.9	--	0.25	0.5	0.63	0.4725	75%	0.28		0.17	0.55	44	30	32%	43	27	37%	436	0.5		
14	H2O2 added		6.0	--	0.5	0.6	1.25	0.875	70%	0.90		0.66	1.96	44	27	39%	43	22	49%	436	6		
15	32 seconds		6.0	--	1.25	0.6	3	2.16	72%	2.00		1.88	5.01	44	11	75%	43	8	81%	436	31		
16	**DOWNSTREAM**		6.0	--	0.5	1.0	0.70	0.49	70%	0.47		0.35	1.03	44	25	43%	43	22	49%	436	0		
17	of ozone		6.0	--	1	1.1	1.25	0.90	72%	0.93		0.68	2.01	44	21	52%	43	16	63%	436	3.6		
18	addition		6.0	--	2.5	1.1	3.40	2.38	70%	2.09		1.34	4.24	44	5	90%	43	3	93%	436	28		
19			6.8	--	0.25	0.48	0.7	0.53	75%	0.40		0.30	0.89	44	28	36%	43	23	47%	436	5		
20			6.8	--	0.5	0.50	1.4	0.99	71%	1.02		0.64	2.05	44	8	81%	43	5.1	88%	436	11		
21			6.7	--	1.25	0.53	3.4	2.35	69%	1.95		1.18	3.83	44	3	93%	43	2.1	95%	436	85		
22			6.7	--	0.5	0.95	0.7	0.53	75%	0.44		0.28	0.89	72	28	61%	63	19	70%	470	12		
23			6.8	--	1.0	1.19	1.25	0.84	67%	0.70		0.48	1.47	72	7	90%	63	4.1	93%	470	18		
24			6.8	--	2.5	1.08	3.1	2.33	75%	1.03		0.14	1.25	72	1	99%	63	1.6	97%	470	65		
25			6.8	0.75	0.25	0.48	0.7	0.53	75%	0.53		0.37	1.11	72	42	42%	63	33	48%	470	4.5	0.9	0.18
26			6.8	0.75	0.5	0.57	1.3	0.88	68%	1.22		0.79	2.48	72	32	56%	63	20	68%	470	1.9	0.74	0.22
27			6.8	0.75	1.25	0.53	3.3	2.34	71%	1.95		1.20	3.86	72	6	91%	63	3.2	95%	470	21	0.66	0.13
28			6.8	0.75	0.5	0.95	0.7	0.53	75%	0.54		0.34	1.08	72	28	61%	63	17	73%	470	12	0.83	0.19
29			6.7	0.75	1.0	1.05	1.3	0.95	73%	0.89		0.42	1.55	72	15	79%	63	7.9	87%	470	14	0.73	0.19
30			6.8	0.75	2.5	1.04	3.3	2.41	73%	1.02		0.14	1.24	72	2.4	97%	63	1.9	97%	470	29	0.54	0.05
49	**Pipeline**		6.9	--	0.25	0.48	0.7	0.525	75%		0.40	0.33	0.97	34	21	37%	35	20	43%	343	1.4		
50	H2O2 added		6.8	--	0.5	0.51	1.3	0.975	75%		0.89	0.77	2.18	34	16.1	53%	35	14	60%	343	18		
51	63 seconds		6.8	--	1.25	0.54	3.1	2.294	74%		1.74	1.22	3.95	34	5.6	84%	35	3	91%	343	55		
	DOWNSTREAM																						
	of ozone																						
	addition																						


Percent MIB Destruction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Dose = 1.3 mg/L
Dose = 2.4 mg/L
Goal > 71%
Conventional Contactor
HRT = 10 minutes
Raw Water
pH = Amb (7.9 to 8.3)
Prechloramine Dose = 0.75 mg/L
▲ Round 1 (MIB = 42 ng/L)
○ Round 2 (MIB = 31 ng/L)
■ Round 3 (MIB = 47 ng/L)

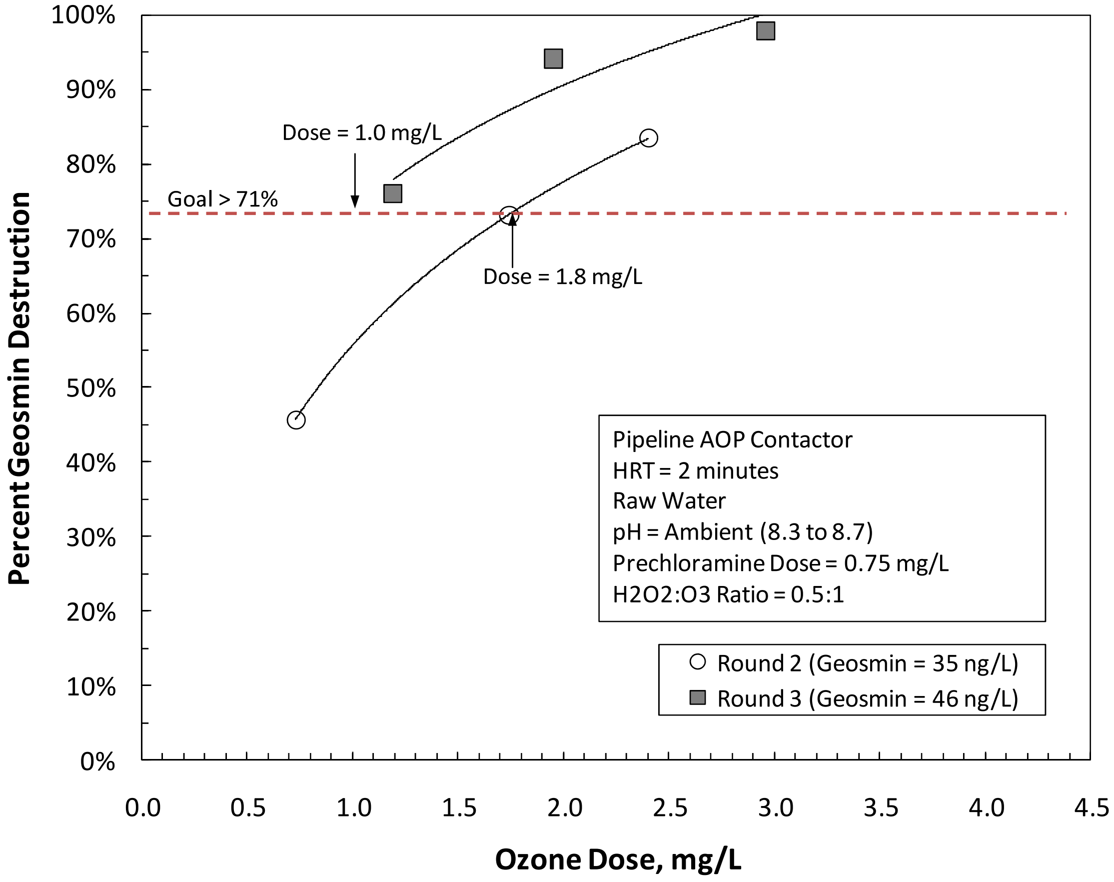

Percent Geosmin Destruction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Dose = 1.1 mg/L
Goal > 73%
Dose = 2.0 mg/L
Conventional Contactor
HRT = 10 minutes
Raw Water
pH = Amb (7.9 to 8.3)
Prechloramine Dose = 0.75 mg/L
▲ Round 1 (Geosmin = 33 ng/L)
○ Round 2 (Geosmin = 28 ng/L)
■ Round 3 (Geosmin = 46 ng/L)


Conventional Contactor
HRT = 10 minutes
Raw Water
pH = Amb (7.9 to 8.3)
Prechloramine Dose = 0.75 mg/L
▲ Round 1 (Bromide = 675 µg/L)
○ Round 2 (Bromide = 350 µg/L)
■ Round 3 (Bromide = 400 µg/L)
Dose = 1.3 mg/L
Dose = 2.4 mg/L
BrO_3 = 14 µg/L
BrO_3 = 14 µg/L
Goal < 8 µg/L
Bromate Formed, µg/L
0
10
20
30
40
50
60
70
80
90
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L

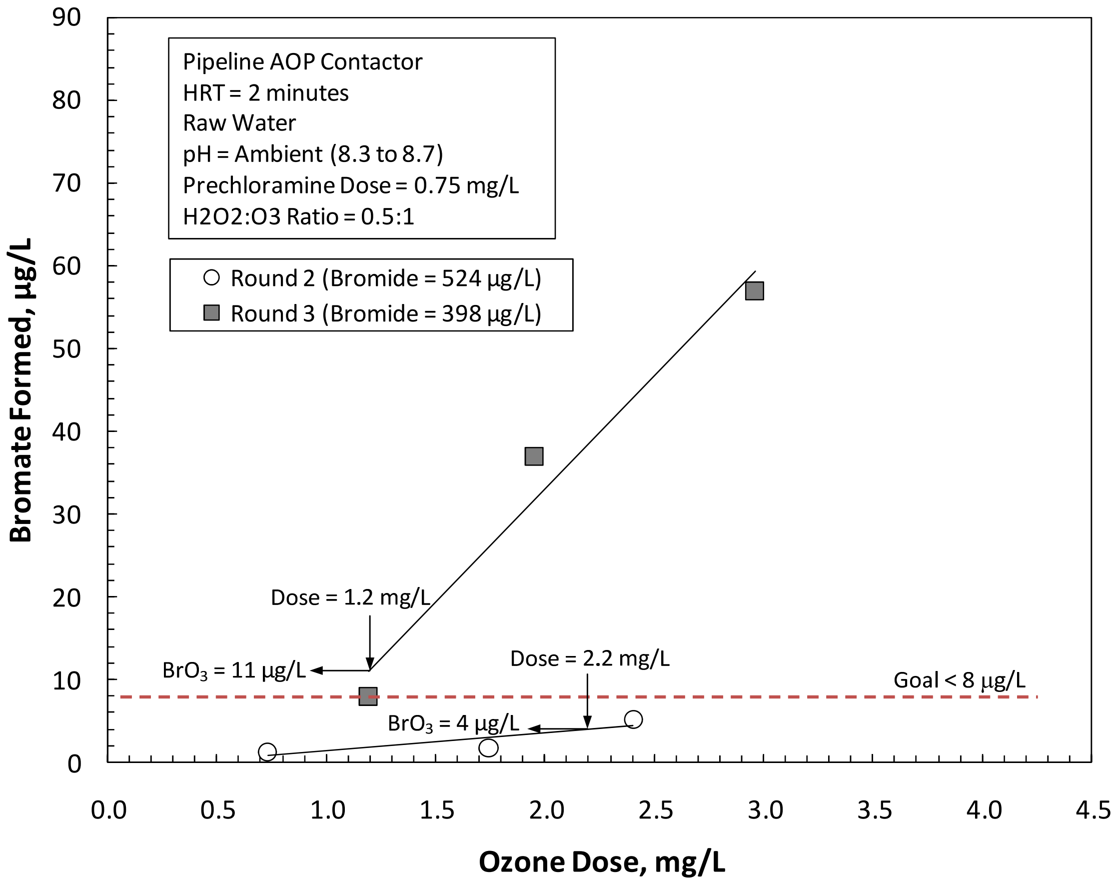

Conventional Contactor
HRT = 10 minutes
Raw Water
pH = Amb (7.9 to 8.3)
Prechloramine Dose = 0.75 mg/L
▲ Round 1
○ Round 2
■ Round 3
Dose = 2.4 mg/L
Dose = 1.3 mg/L
Goal < 0.1 mg/L
Ozone Residual in Contactor Effluent, mg/L
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L

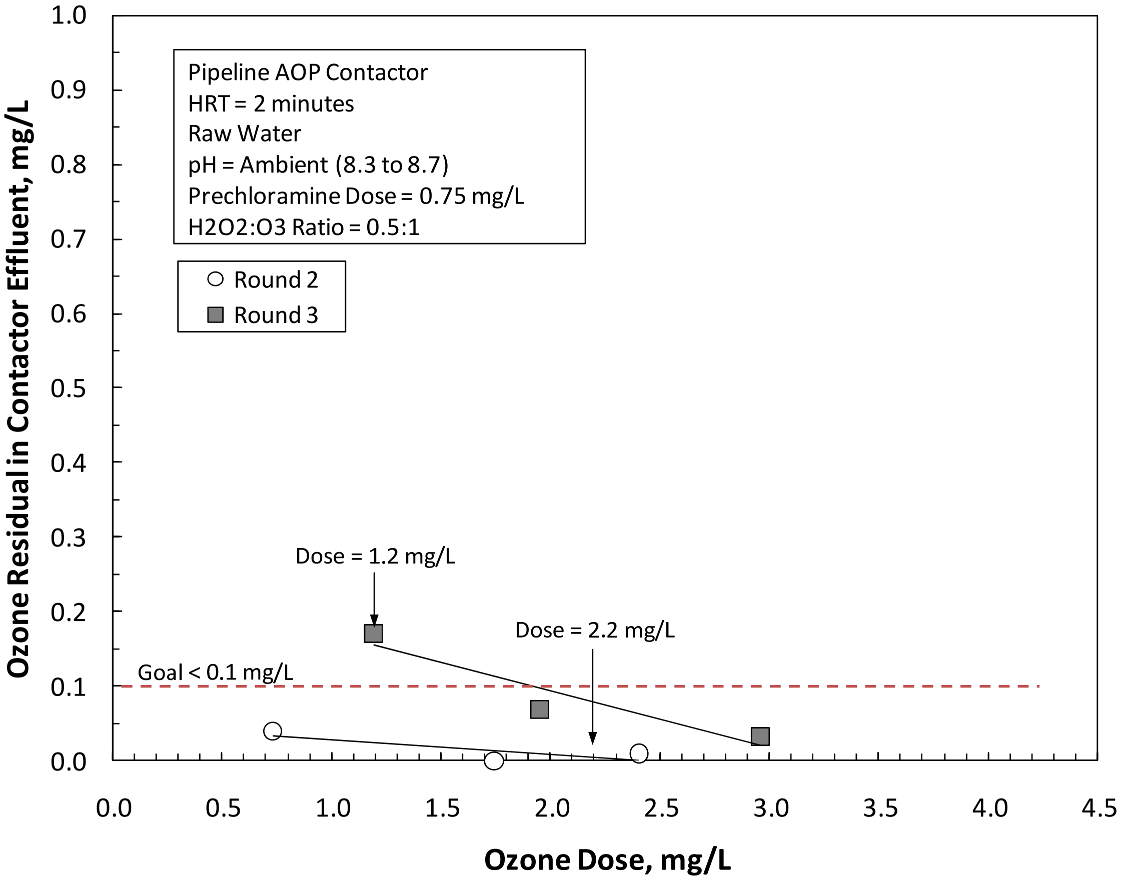


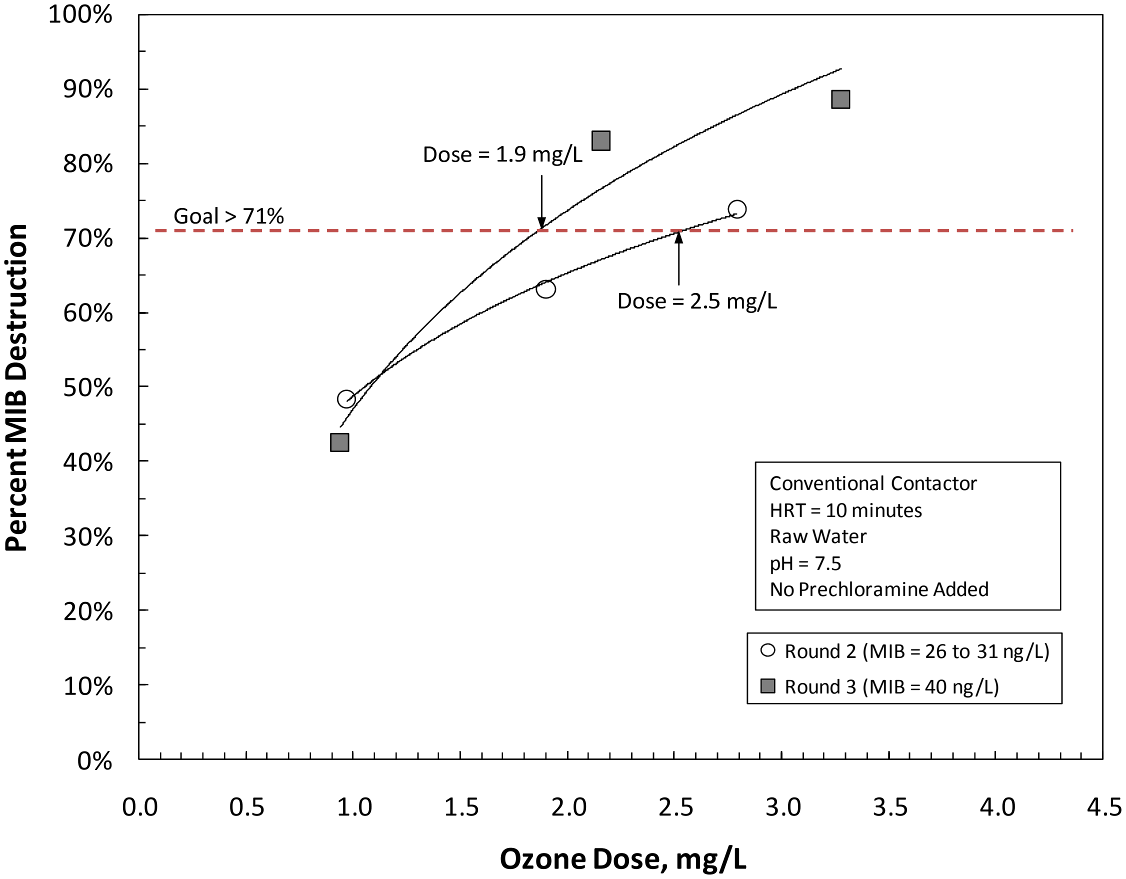
Percent MIB Destruction
Ozone Dose, mg/L
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Goal > 71%
Dose = 1.2 mg/L
Dose = 2.2 mg/L
Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = Ambient (8.3 to 8.7)
Prechloramine Dose = 0.75 mg/L
H2O2:O3 Ratio = 0.5:1
○ Round 2 (MIB = 44 ng/L)
■ Round 3 (MIB = 47 ng/L)

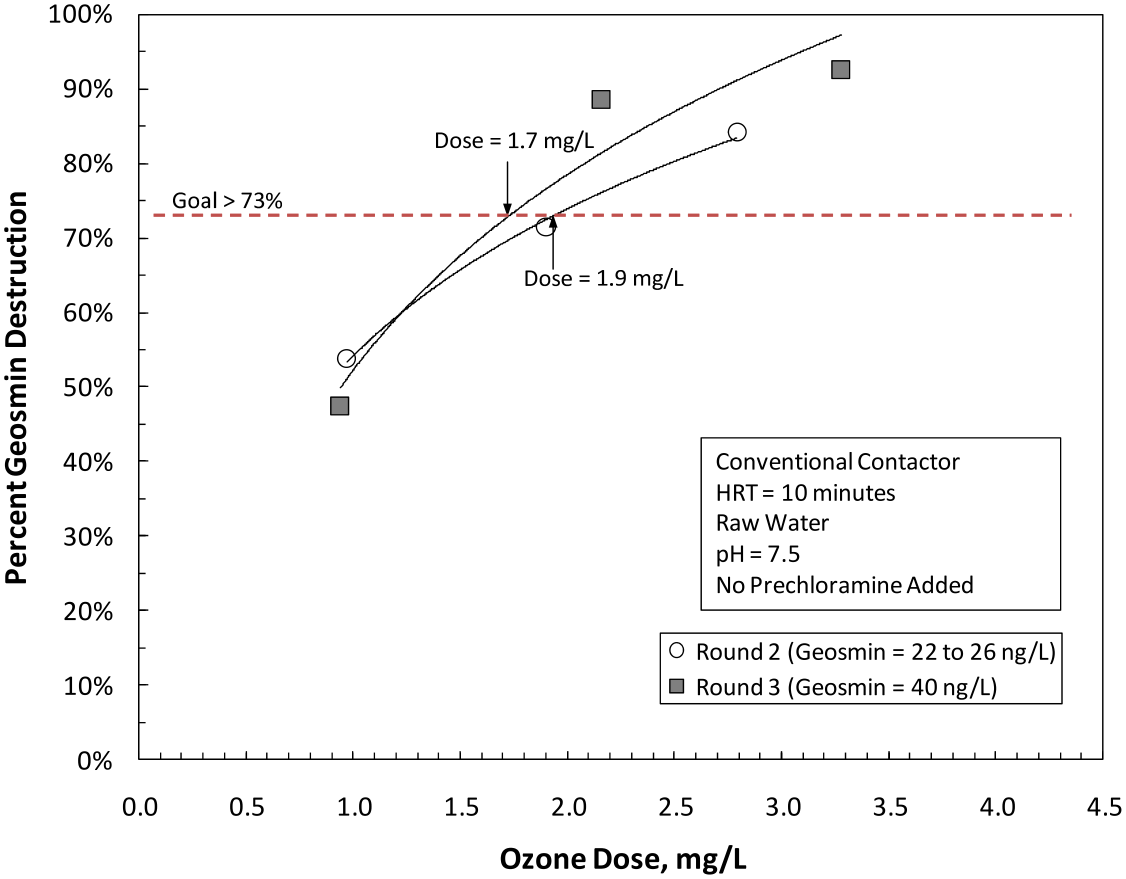


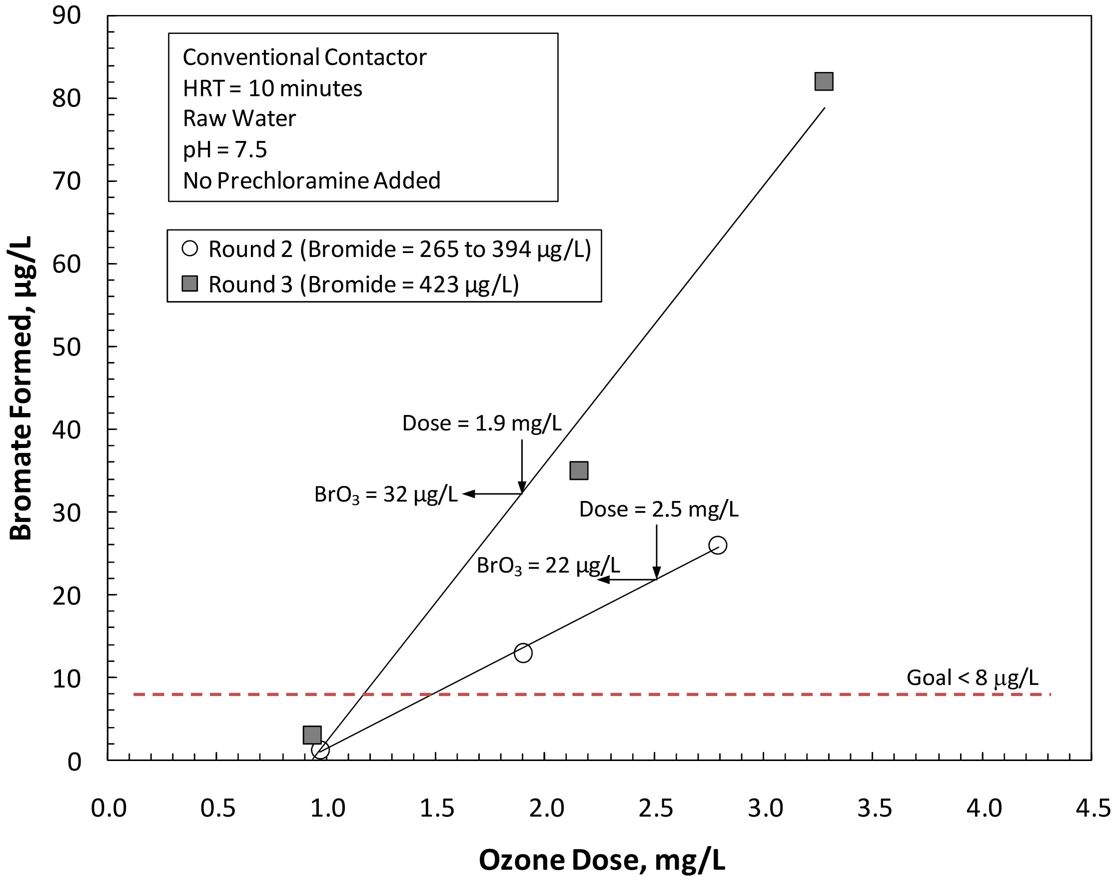
Percent Geosmin Destruction
Ozone Dose, mg/L
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Goal > 71%
Dose = 1.0 mg/L
Dose = 1.8 mg/L
Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = Ambient (8.3 to 8.7)
Prechloramine Dose = 0.75 mg/L
H2O2:O3 Ratio = 0.5:1
○ Round 2 (Geosmin = 35 ng/L)
■ Round 3 (Geosmin = 46 ng/L)

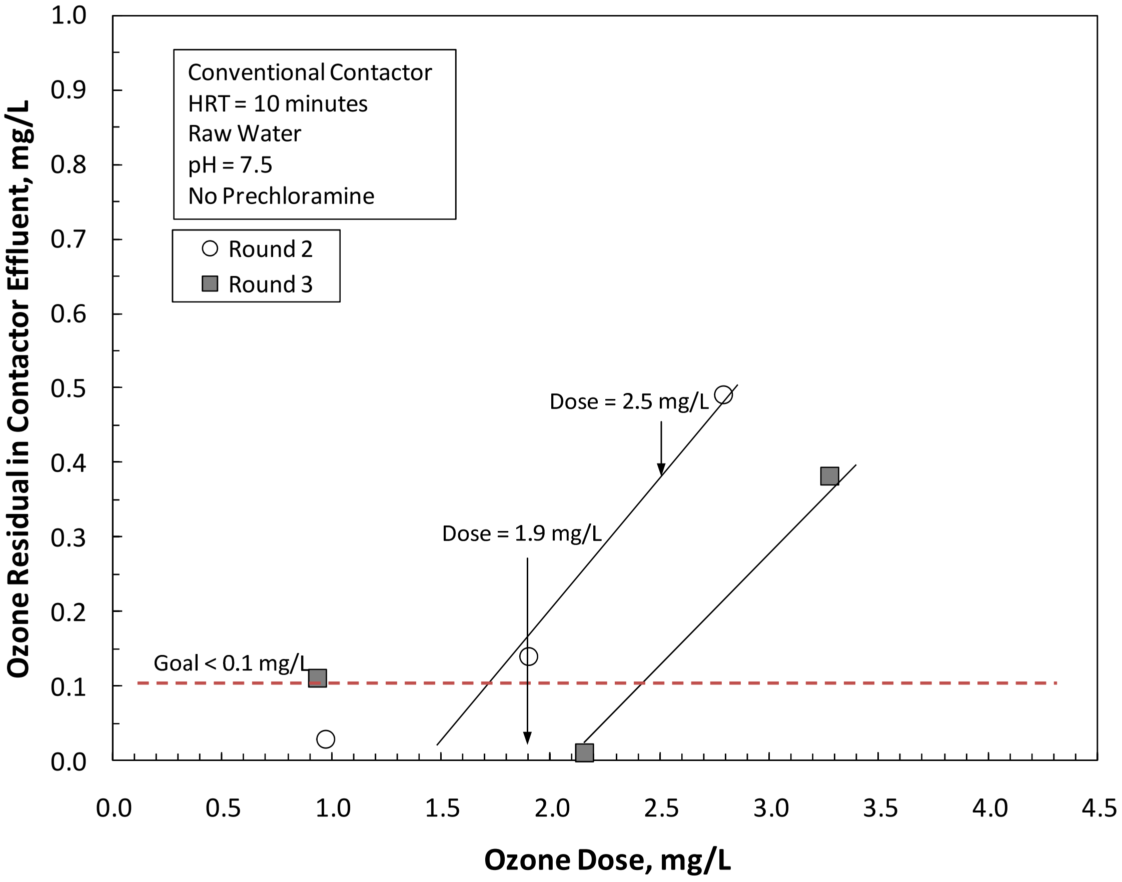

Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = Ambient (8.3 to 8.7)
Prechloramine Dose = 0.75 mg/L
H2O2:O3 Ratio = 0.5:1
○ Round 2 (Bromide = 524 µg/L)
■ Round 3 (Bromide = 398 µg/L)
Dose = 1.2 mg/L
BrO3 = 11 µg/L
Dose = 2.2 mg/L
Goal < 8 µg/L
BrO3 = 4 µg/L
Bromate Formed, µg/L
0
10
20
30
40
50
60
70
80
90
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L

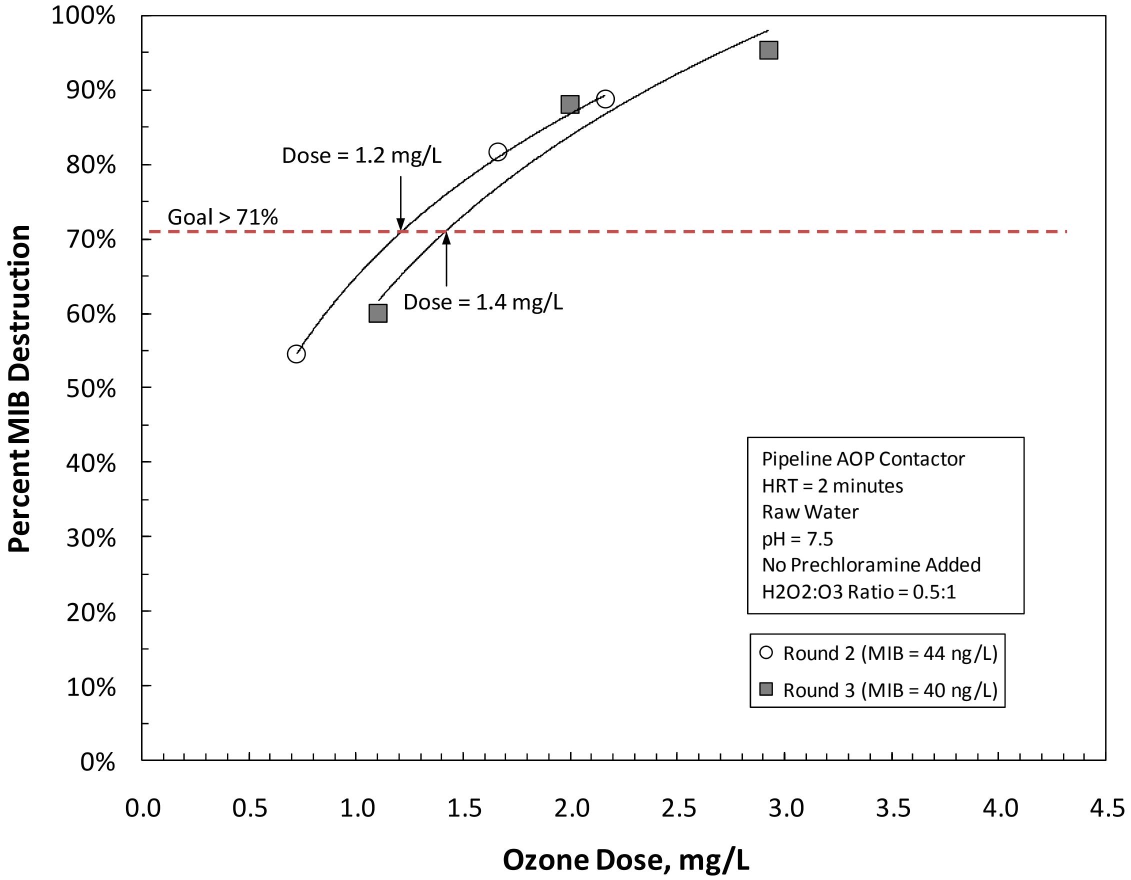

Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = Ambient (8.3 to 8.7)
Prechloramine Dose = 0.75 mg/L
H2O2:O3 Ratio = 0.5:1
○ Round 2
■ Round 3
Dose = 1.2 mg/L
Dose = 2.2 mg/L
Goal < 0.1 mg/L
Ozone Residual in Contactor Effluent, mg/L
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L

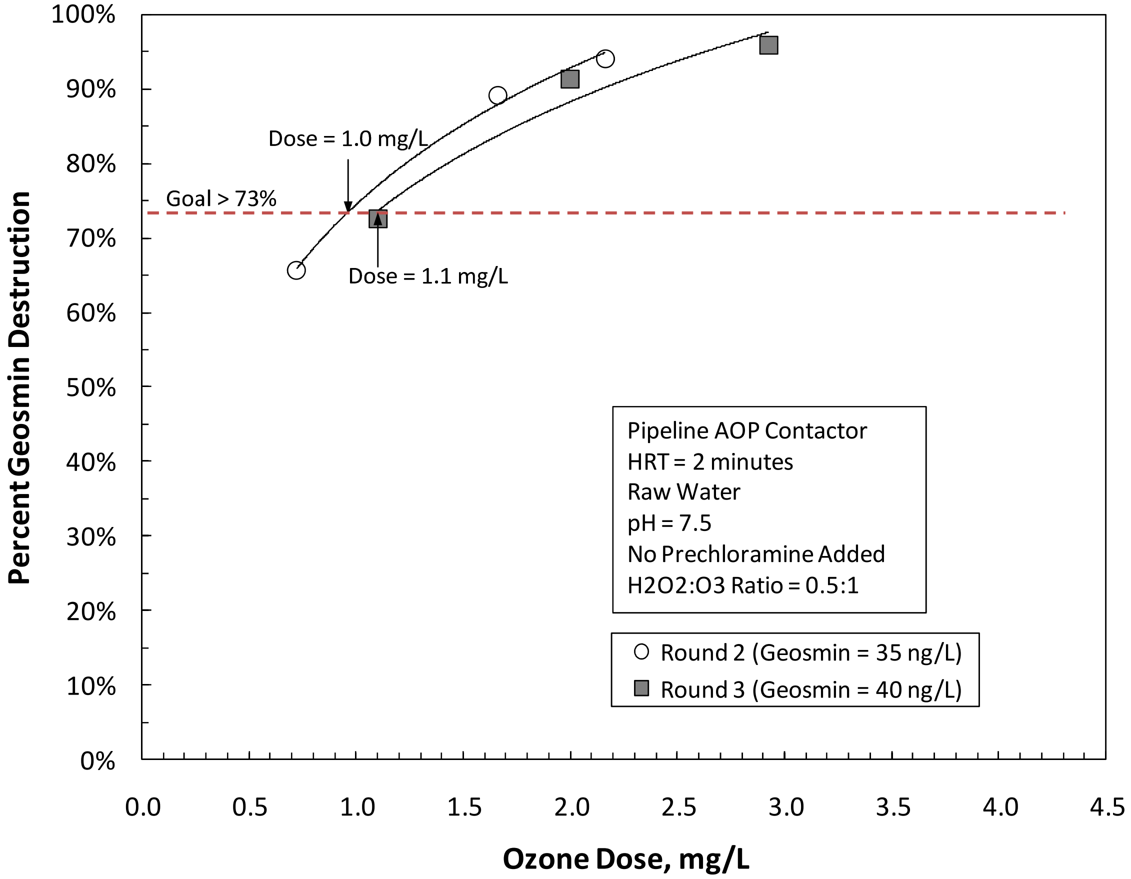

Percent MIB Destruction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Goal > 71%
Dose = 1.9 mg/L
Dose = 2.5 mg/L
Conventional Contactor
HRT = 10 minutes
Raw Water
pH = 7.5
No Prechloramine Added
○ Round 2 (MIB = 26 to 31 ng/L)
■ Round 3 (MIB = 40 ng/L)

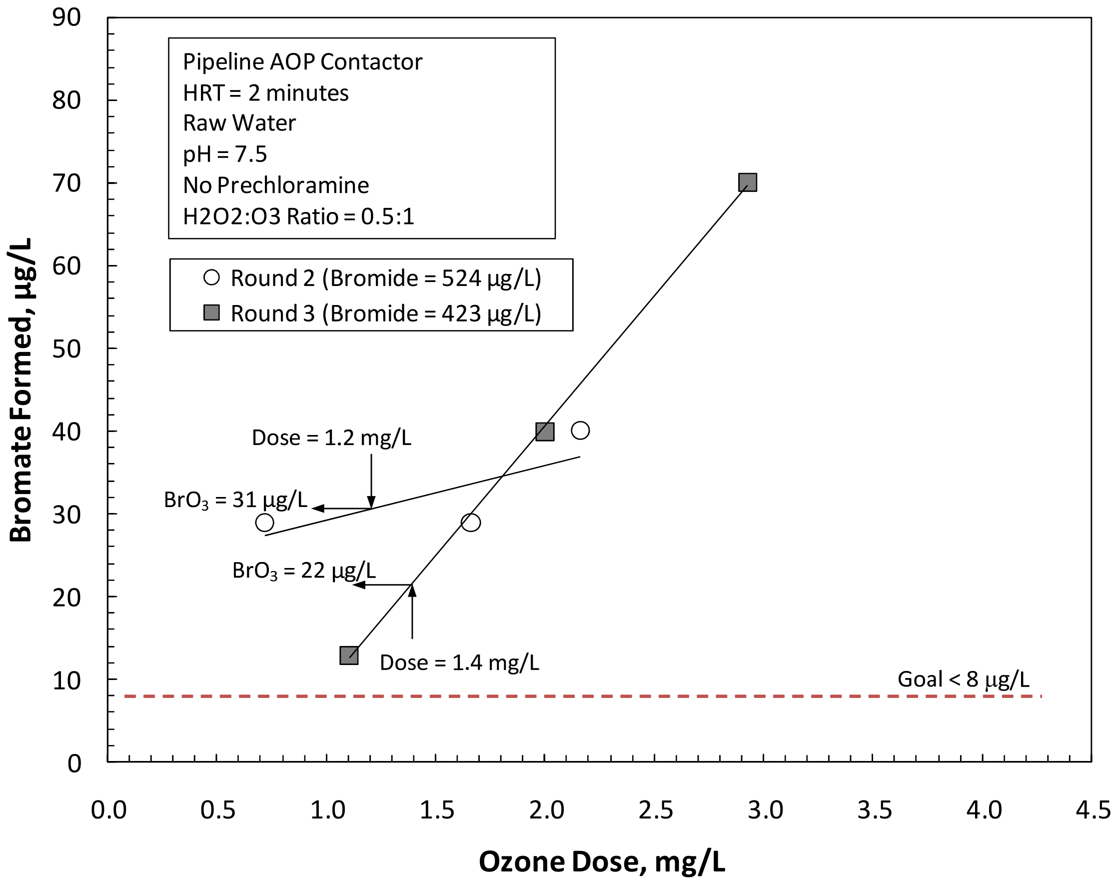

Percent Geosmin Destruction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Goal > 73%
Dose = 1.7 mg/L
Dose = 1.9 mg/L
Conventional Contactor
HRT = 10 minutes
Raw Water
pH = 7.5
No Prechloramine Added
○ Round 2 (Geosmin = 22 to 26 ng/L)
■ Round 3 (Geosmin = 40 ng/L)


Conventional Contactor
HRT = 10 minutes
Raw Water
pH = 7.5
No Prechloramine Added
○ Round 2 (Bromide = 265 to 394 µg/L)
■ Round 3 (Bromide = 423 µg/L)
Dose = 1.9 mg/L
BrO$_3$ = 32 µg/L
Dose = 2.5 mg/L
BrO$_3$ = 22 µg/L
Goal < 8 µg/L
Bromate Formed, µg/L
0
10
20
30
40
50
60
70
80
90
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L

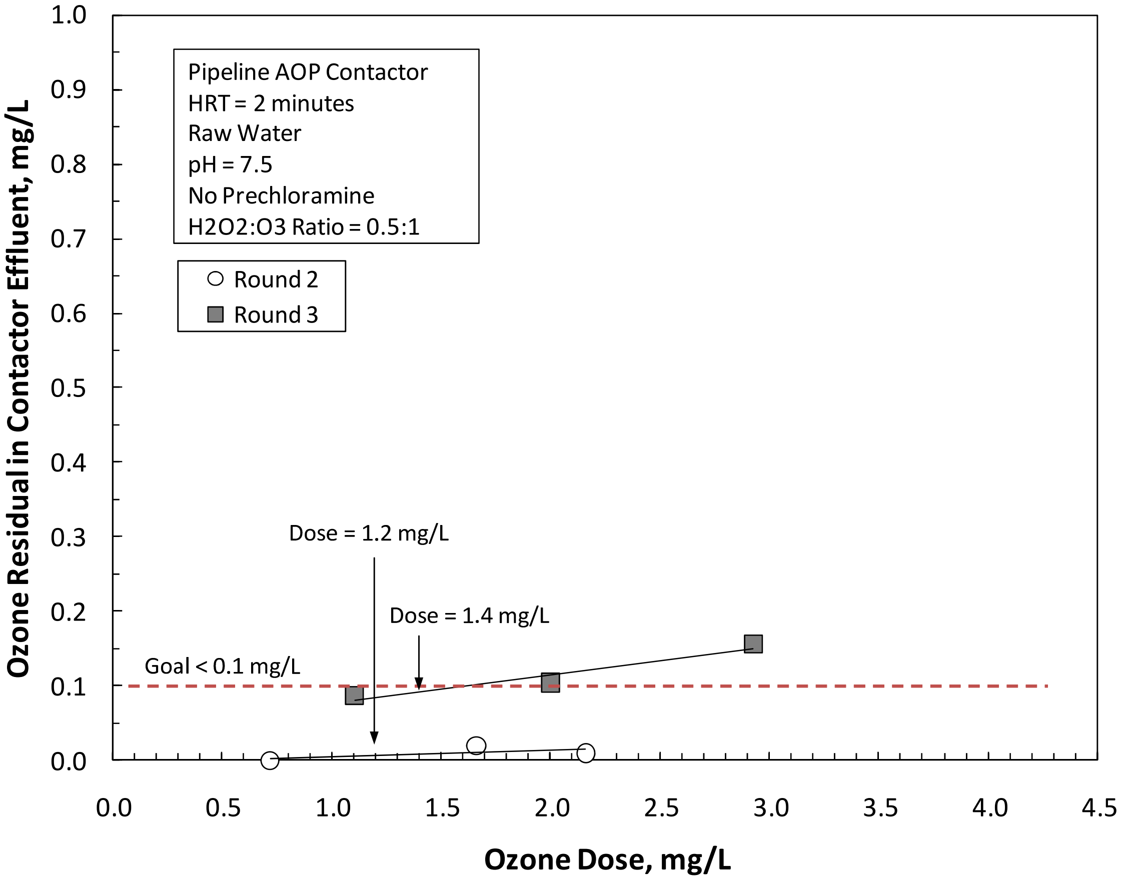

Conventional Contactor
HRT = 10 minutes
Raw Water
pH = 7.5
No Prechloramine
○ Round 2
■ Round 3
Dose = 2.5 mg/L
Dose = 1.9 mg/L
Goal < 0.1 mg/L
Ozone Residual in Contactor Effluent, mg/L
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent MIB Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Goal > 71%
Dose = 1.2 mg/L
Dose = 1.4 mg/L
Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = 7.5
No Prechloramine Added
H2O2:O3 Ratio = 0.5:1
○ Round 2 (MIB = 44 ng/L)
■ Round 3 (MIB = 40 ng/L)

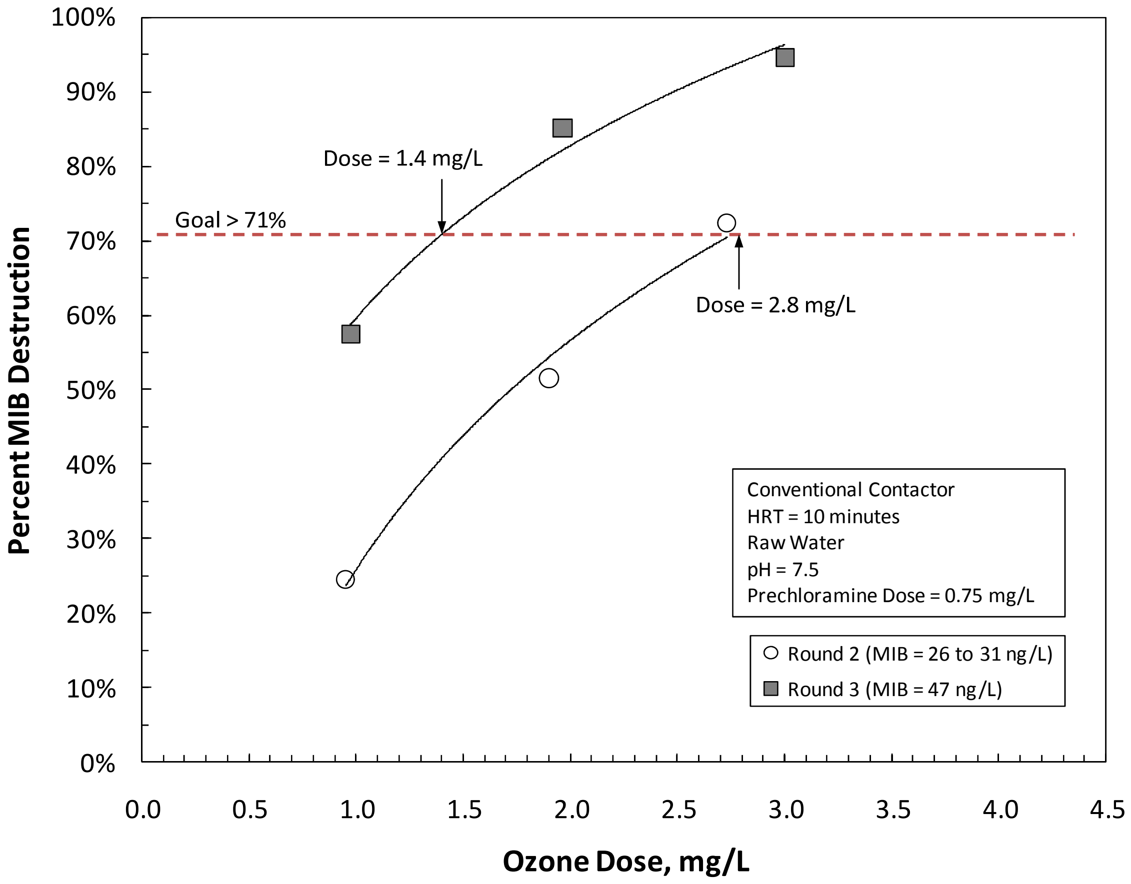

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Geosmin Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Goal > 73%
Dose = 1.0 mg/L
Dose = 1.1 mg/L
Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = 7.5
No Prechloramine Added
H2O2:O3 Ratio = 0.5:1
○ Round 2 (Geosmin = 35 ng/L)
■ Round 3 (Geosmin = 40 ng/L)

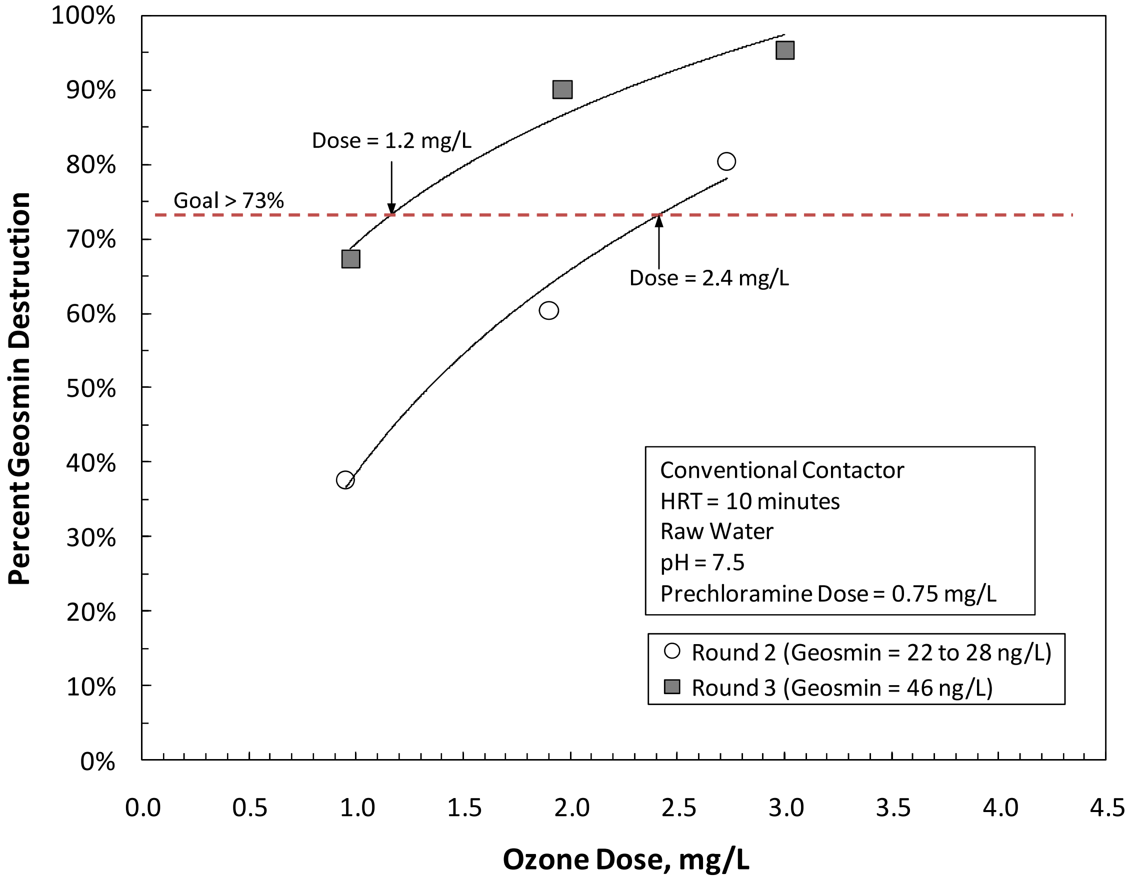


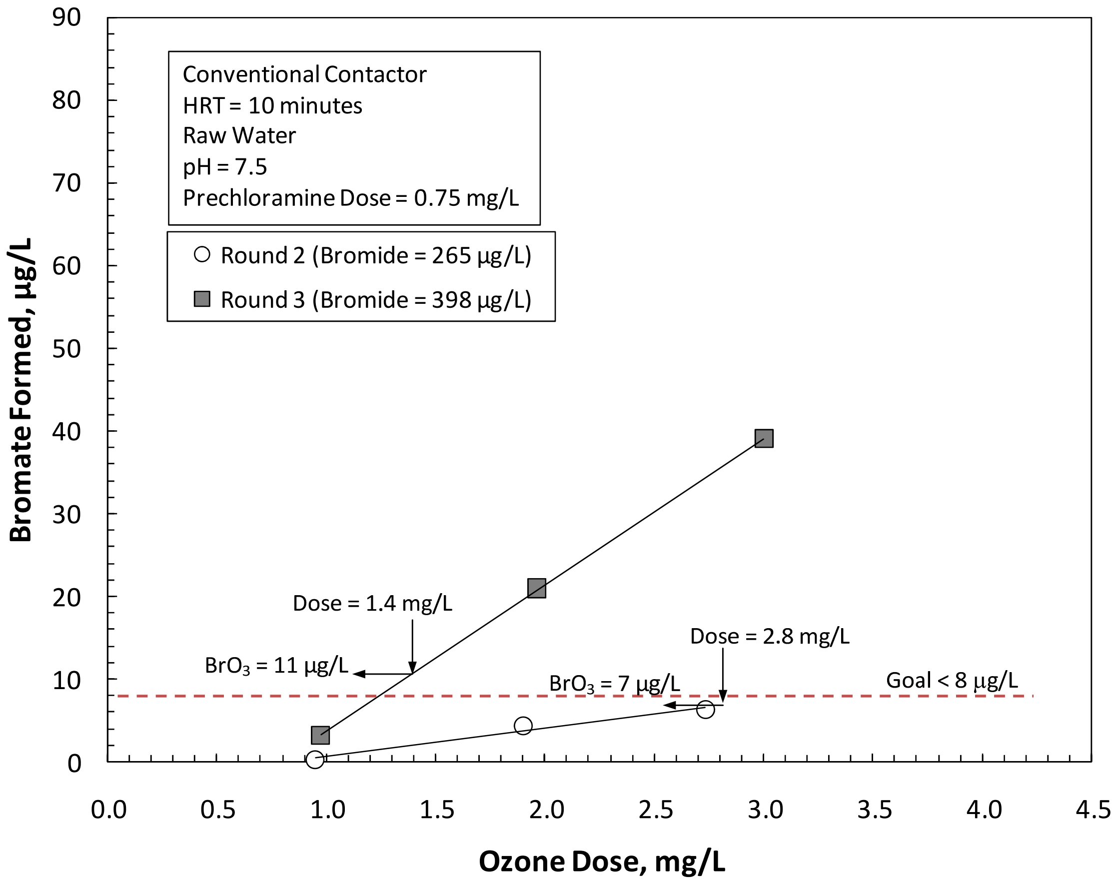
Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = 7.5
No Prechloramine
H2O2:O3 Ratio = 0.5:1
○ Round 2 (Bromide = 524 μg/L)
■ Round 3 (Bromide = 423 μg/L)
Dose = 1.2 mg/L
BrO₃ = 31 μg/L
BrO₃ = 22 μg/L
Dose = 1.4 mg/L
Goal < 8 μg/L
Bromate Formed, μg/L
0
10
20
30
40
50
60
70
80
90
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L

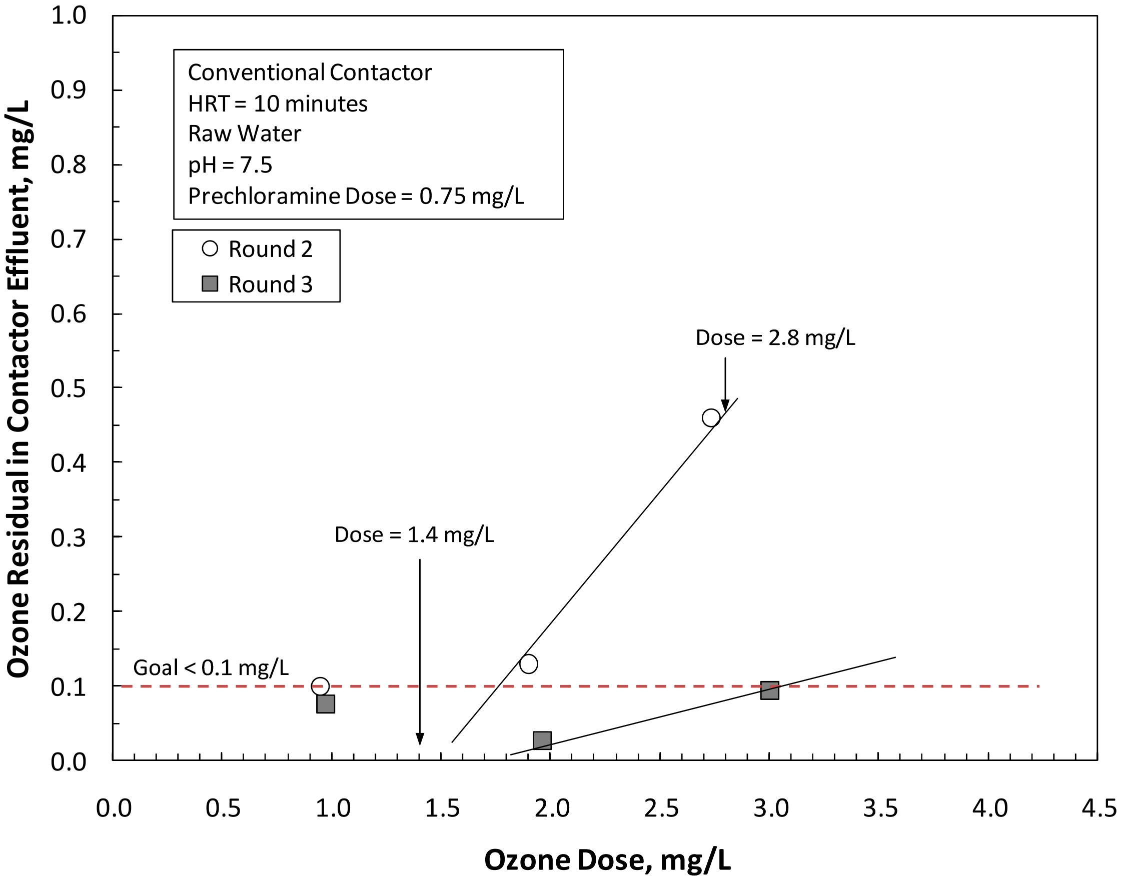


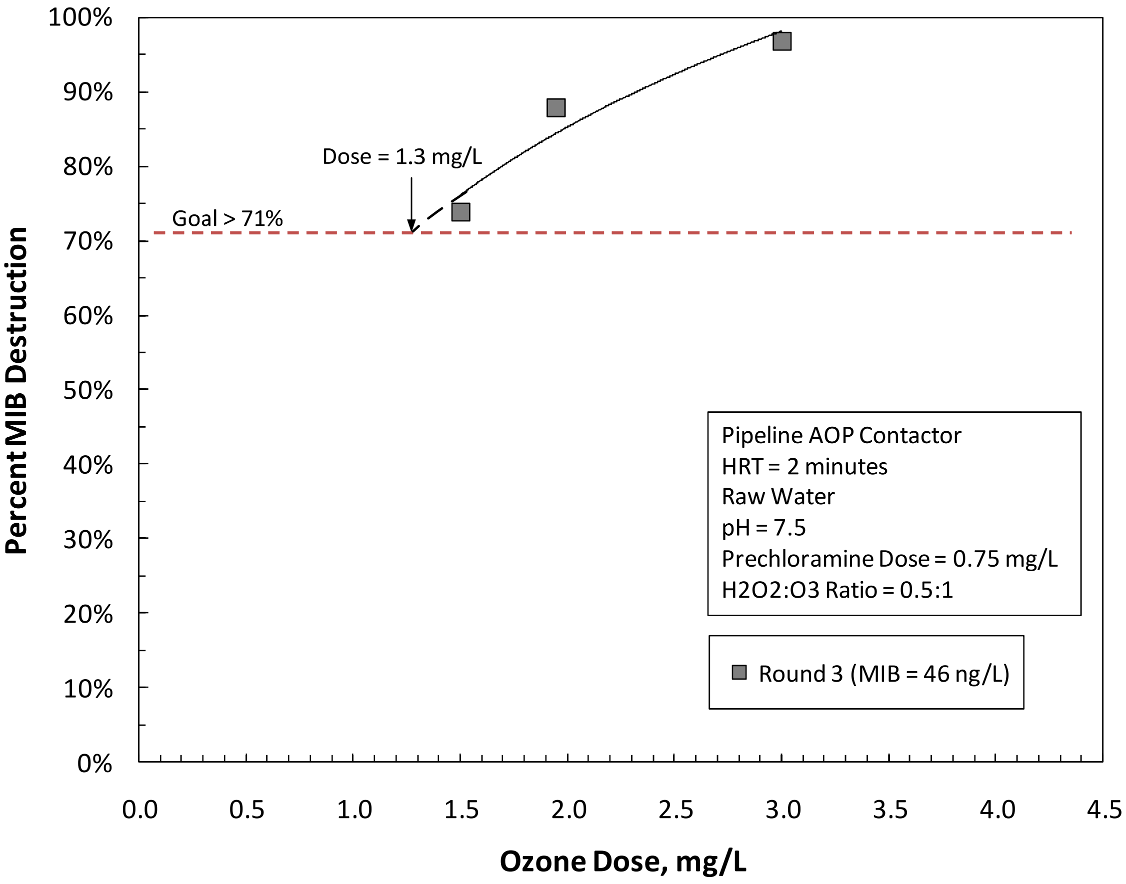
Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = 7.5
No Prechloramine
H2O2:O3 Ratio = 0.5:1
○ Round 2
■ Round 3
Dose = 1.2 mg/L
Dose = 1.4 mg/L
Goal < 0.1 mg/L
Ozone Residual in Contactor Effluent, mg/L
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L

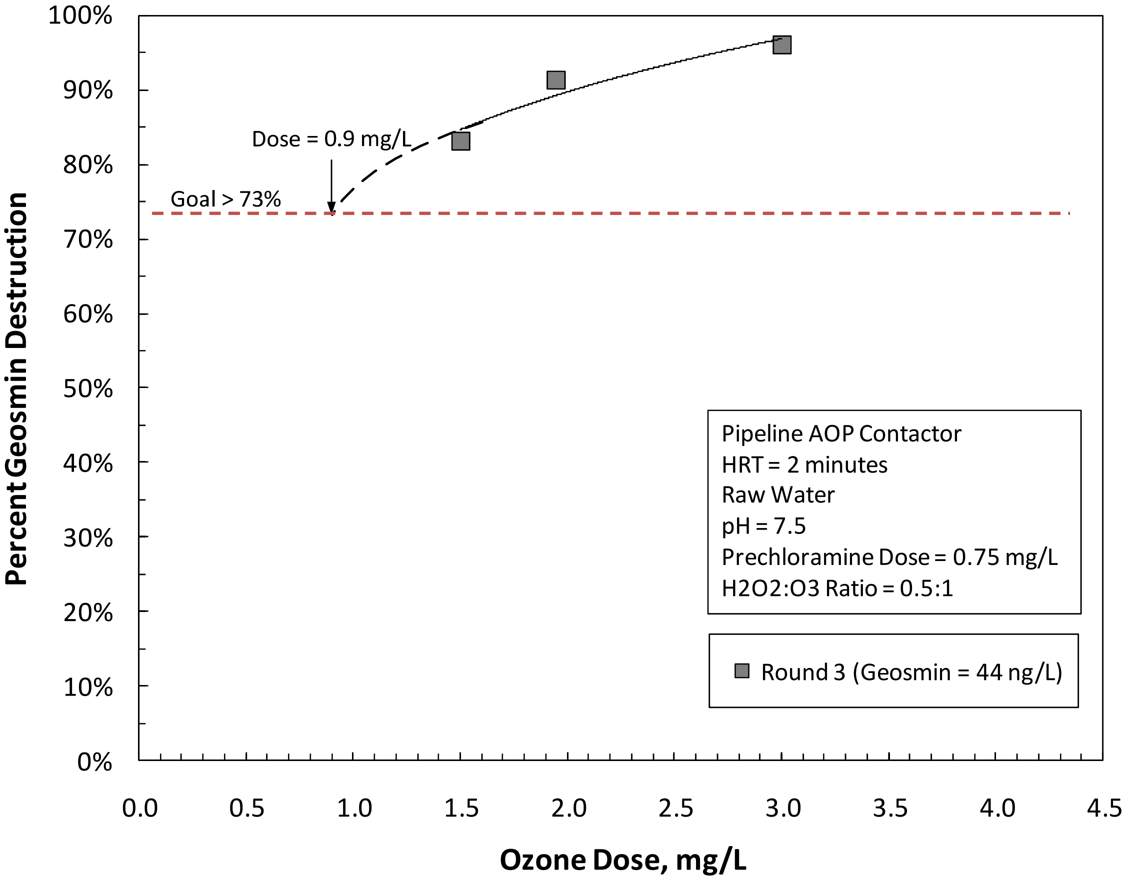

Percent MIB Destruction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Goal > 71%
Dose = 1.4 mg/L
Dose = 2.8 mg/L
Conventional Contactor
HRT = 10 minutes
Raw Water
pH = 7.5
Prechloramine Dose = 0.75 mg/L
○ Round 2 (MIB = 26 to 31 ng/L)
■ Round 3 (MIB = 47 ng/L)

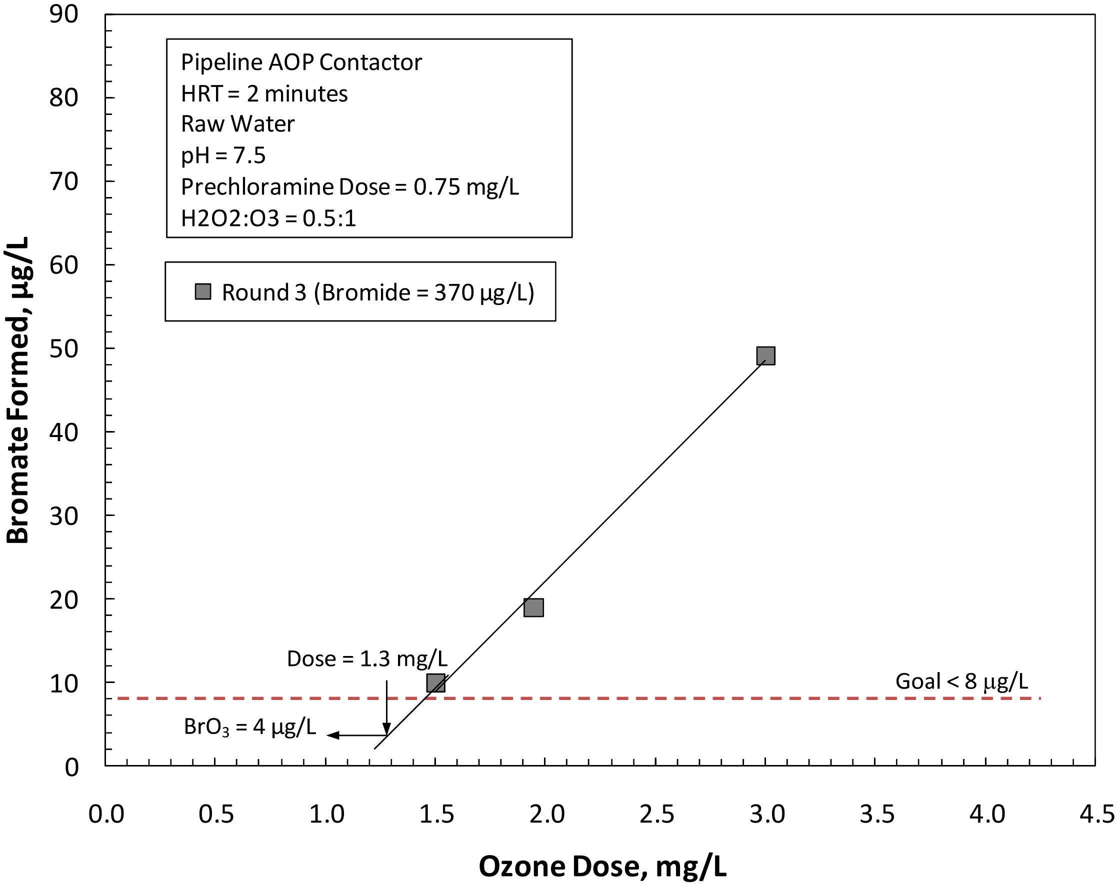

Percent Geosmin Destruction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Goal > 73%
Dose = 1.2 mg/L
Dose = 2.4 mg/L
Conventional Contactor
HRT = 10 minutes
Raw Water
pH = 7.5
Prechloramine Dose = 0.75 mg/L
○ Round 2 (Geosmin = 22 to 28 ng/L)
■ Round 3 (Geosmin = 46 ng/L)


Conventional Contactor
HRT = 10 minutes
Raw Water
pH = 7.5
Prechloramine Dose = 0.75 mg/L
○ Round 2 (Bromide = 265 µg/L)
■ Round 3 (Bromide = 398 µg/L)
Dose = 1.4 mg/L
BrO3 = 11 µg/L
Dose = 2.8 mg/L
BrO3 = 7 µg/L
Goal < 8 µg/L
Bromate Formed, µg/L
0
10
20
30
40
50
60
70
80
90
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L

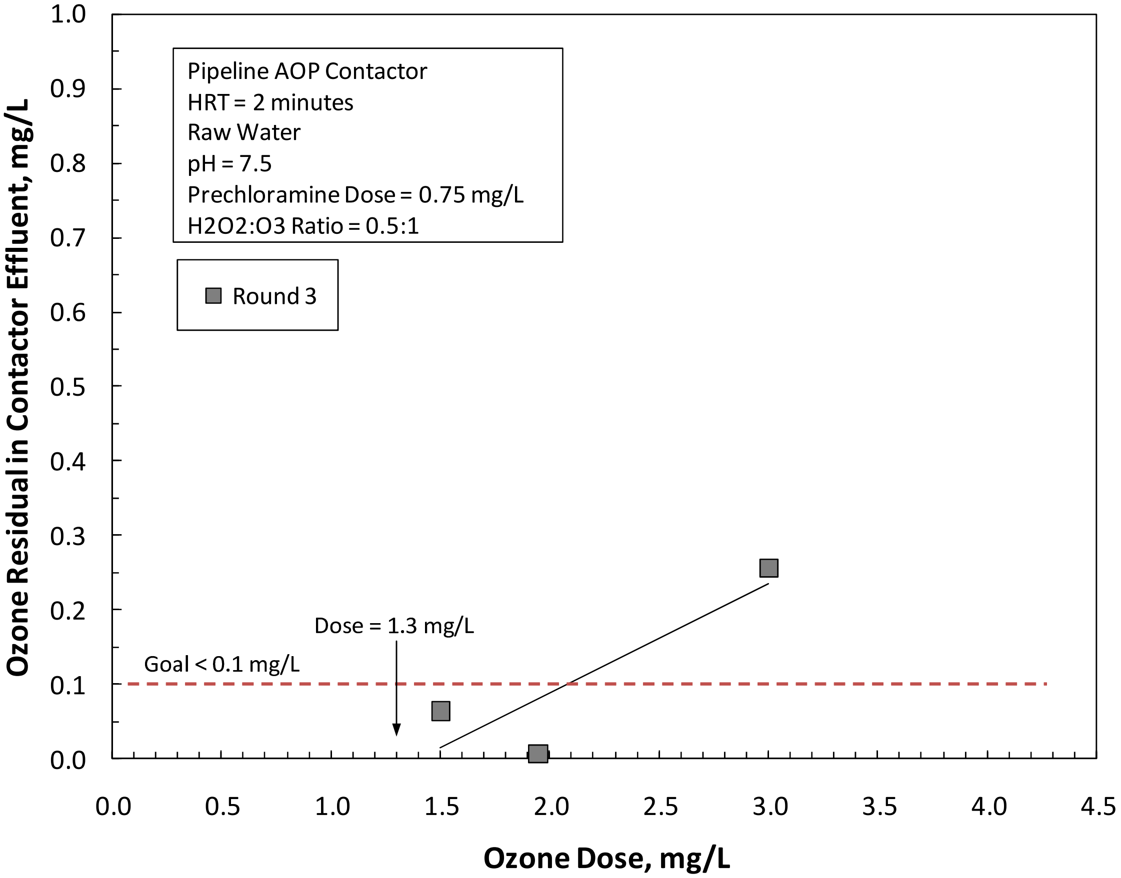

Conventional Contactor
HRT = 10 minutes
Raw Water
pH = 7.5
Prechloramine Dose = 0.75 mg/L
○ Round 2
■ Round 3
Dose = 2.8 mg/L
Dose = 1.4 mg/L
Goal < 0.1 mg/L
Ozone Residual in Contactor Effluent, mg/L
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent MIB Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Dose = 1.3 mg/L
Goal > 71%
Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = 7.5
Prechloramine Dose = 0.75 mg/L
H2O2:O3 Ratio = 0.5:1
■ Round 3 (MIB = 46 ng/L)

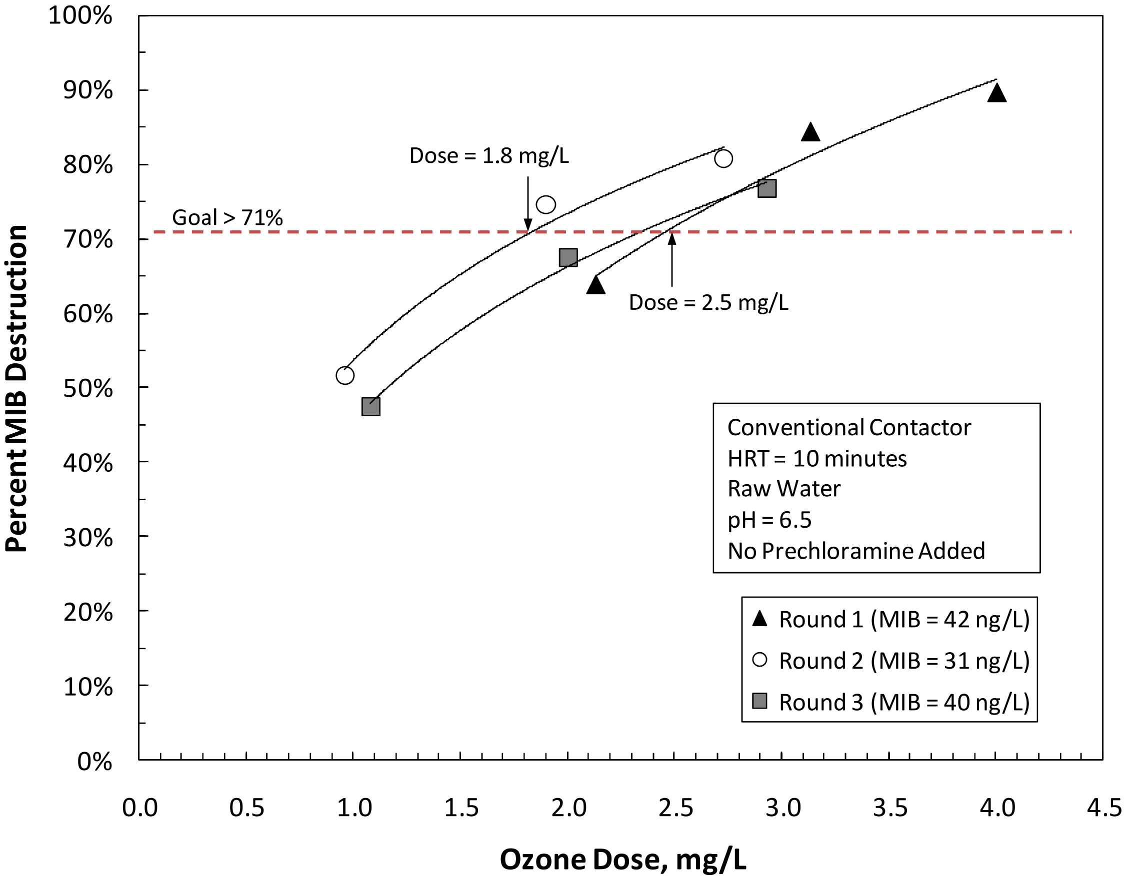

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Geosmin Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Dose = 0.9 mg/L
Goal > 73%
Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = 7.5
Prechloramine Dose = 0.75 mg/L
H2O2:O3 Ratio = 0.5:1
■ Round 3 (Geosmin = 44 ng/L)



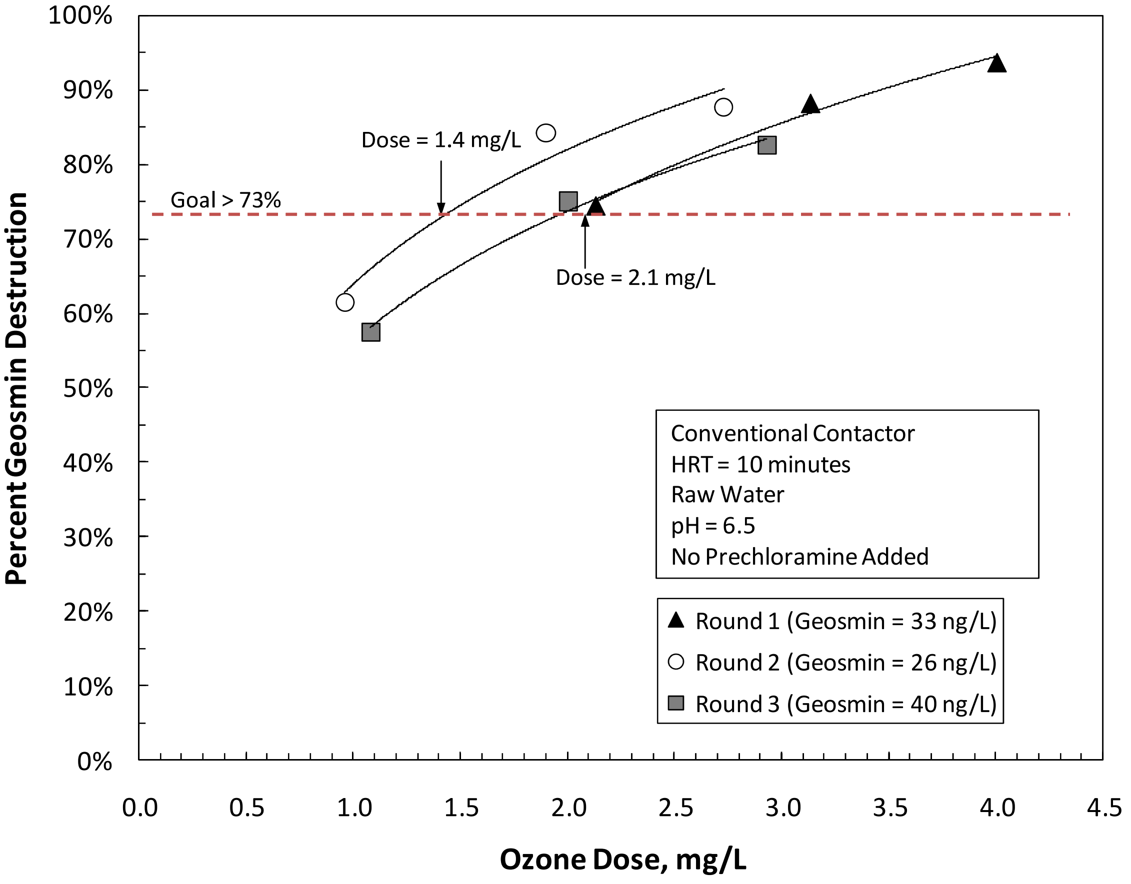
Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = 7.5
Prechloramine Dose = 0.75 mg/L
H2O2:O3 = 0.5:1
Round 3 (Bromide = 370 μg/L)
Dose = 1.3 mg/L
BrO₃ = 4 μg/L
Goal < 8 μg/L
Bromate Formed, μg/L
0
10
20
30
40
50
60
70
80
90
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L



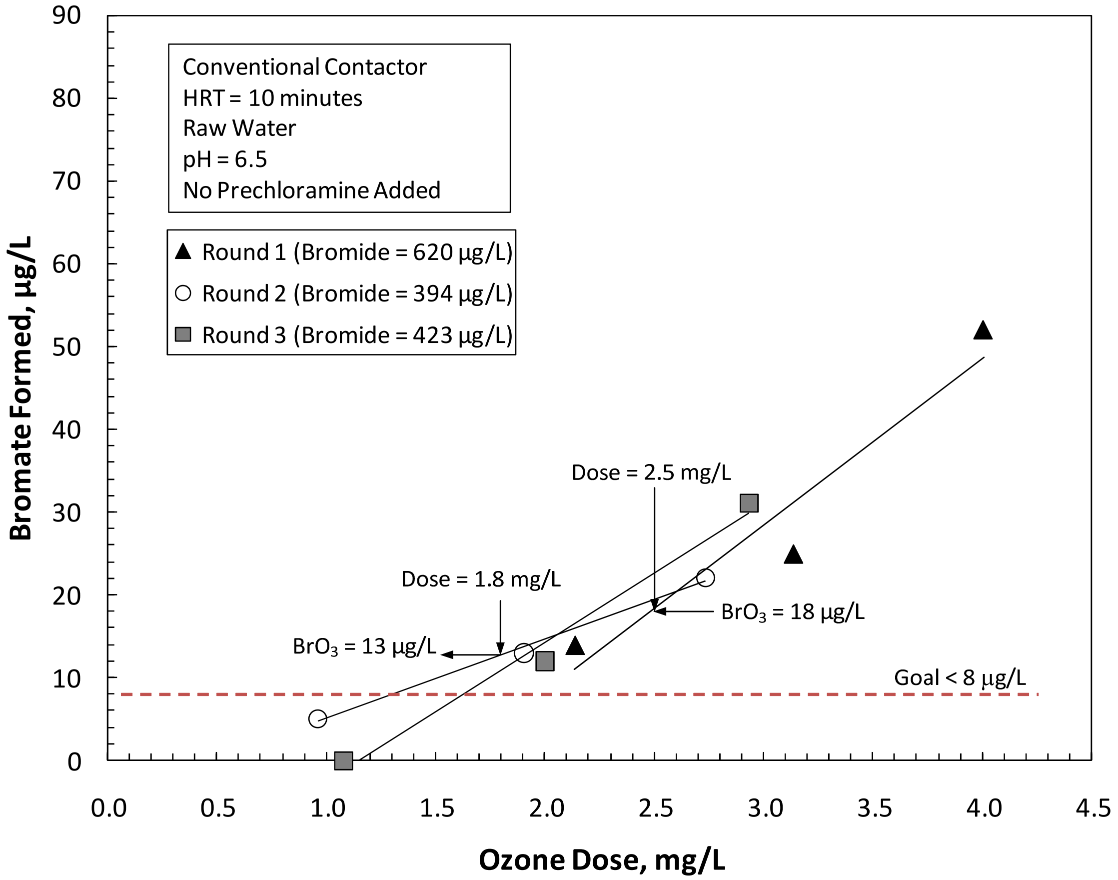
Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = 7.5
Prechloramine Dose = 0.75 mg/L
H2O2:O3 Ratio = 0.5:1
Round 3
Dose = 1.3 mg/L
Goal < 0.1 mg/L
Ozone Residual in Contactor Effluent, mg/L
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L

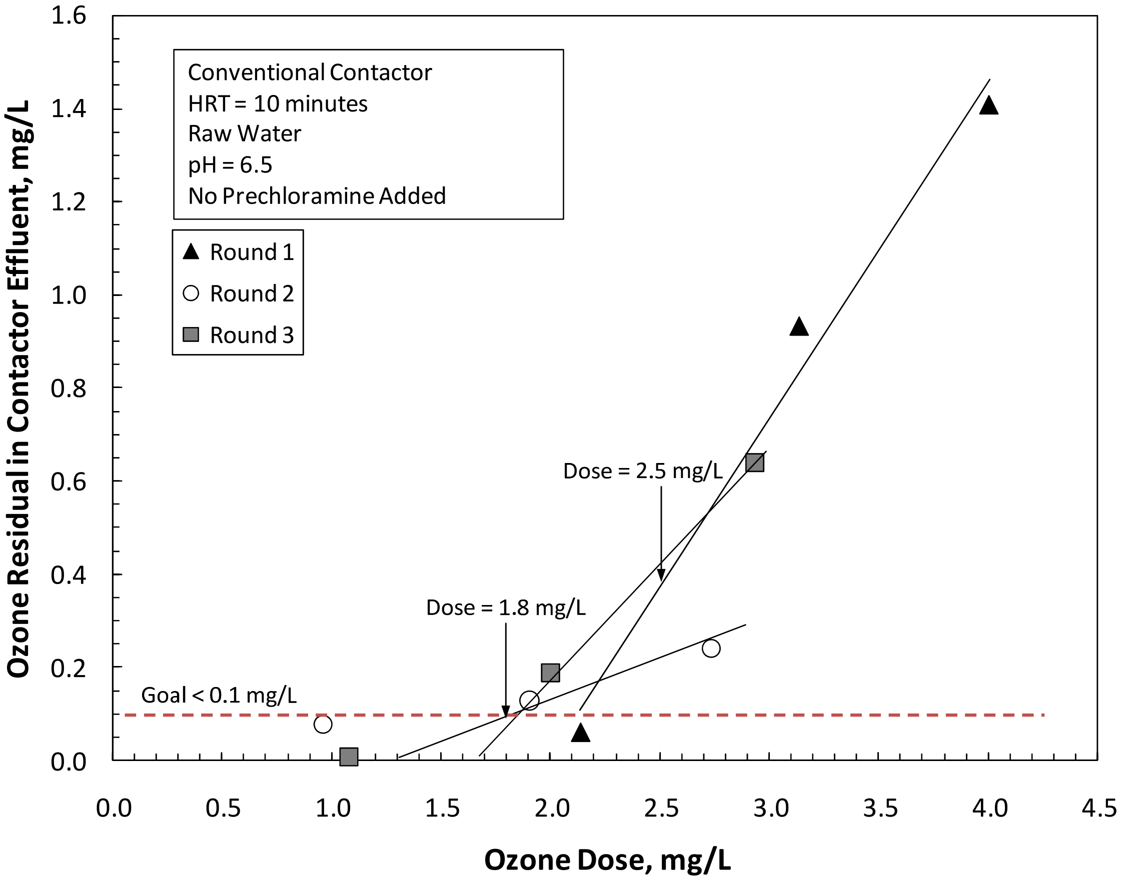


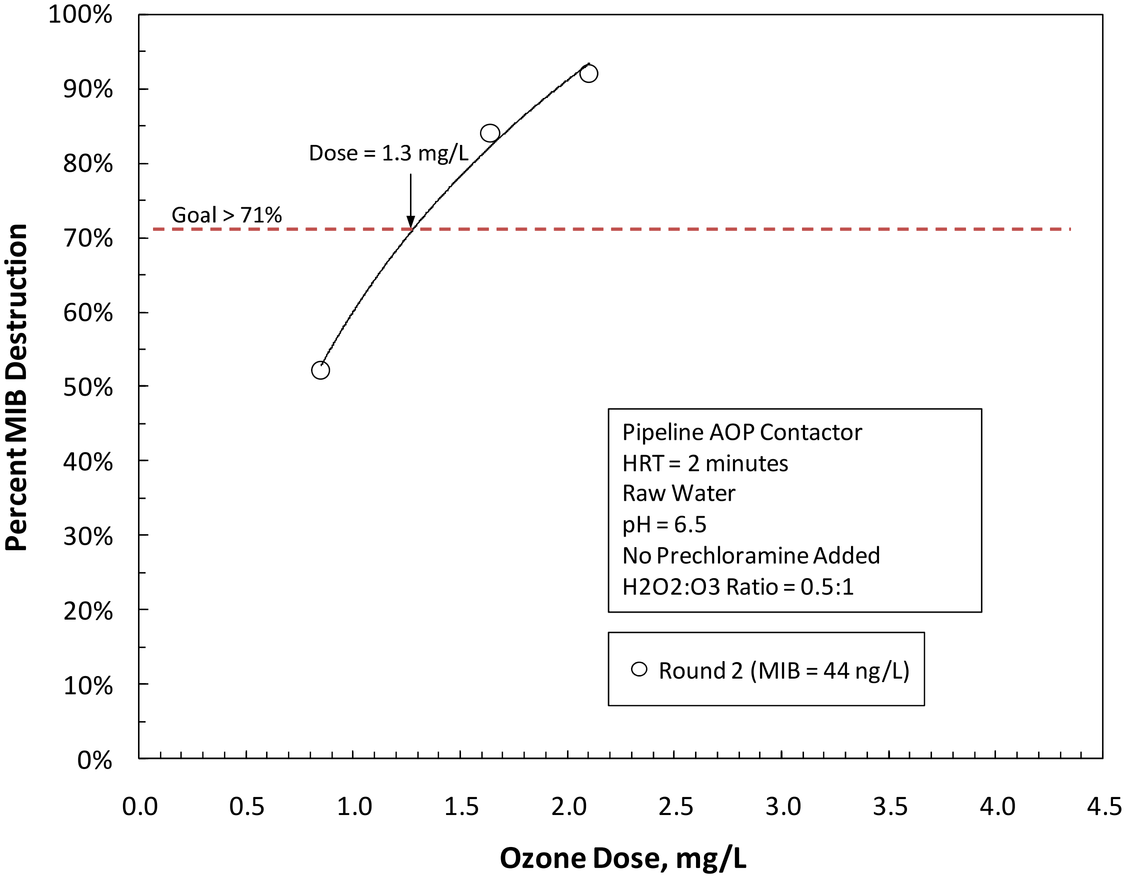
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent MIB Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Goal > 71%
Dose = 1.8 mg/L
Dose = 2.5 mg/L
Conventional Contactor
HRT = 10 minutes
Raw Water
pH = 6.5
No Prechloramine Added
▲ Round 1 (MIB = 42 ng/L)
○ Round 2 (MIB = 31 ng/L)
■ Round 3 (MIB = 40 ng/L)

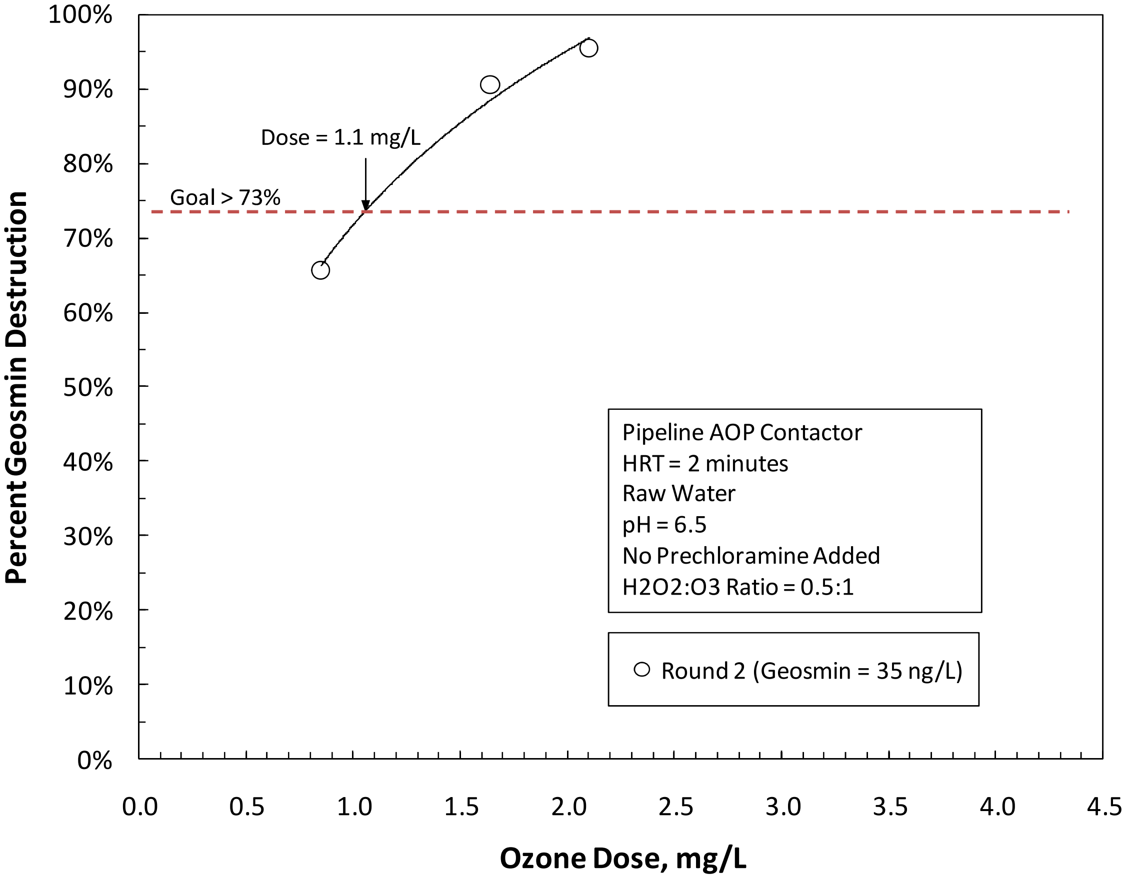


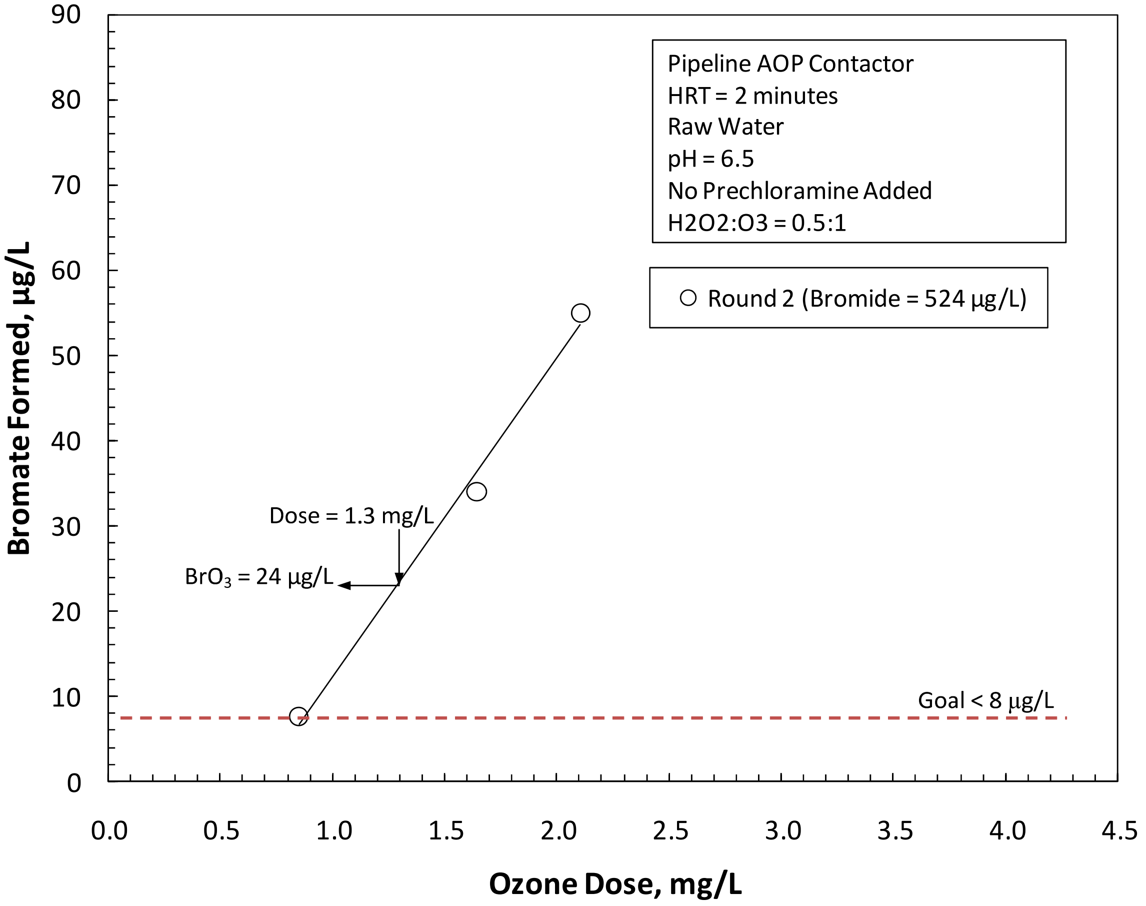
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Geosmin Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Goal > 73%
Dose = 1.4 mg/L
Dose = 2.1 mg/L
Conventional Contactor
HRT = 10 minutes
Raw Water
pH = 6.5
No Prechloramine Added
▲ Round 1 (Geosmin = 33 ng/L)
○ Round 2 (Geosmin = 26 ng/L)
■ Round 3 (Geosmin = 40 ng/L)

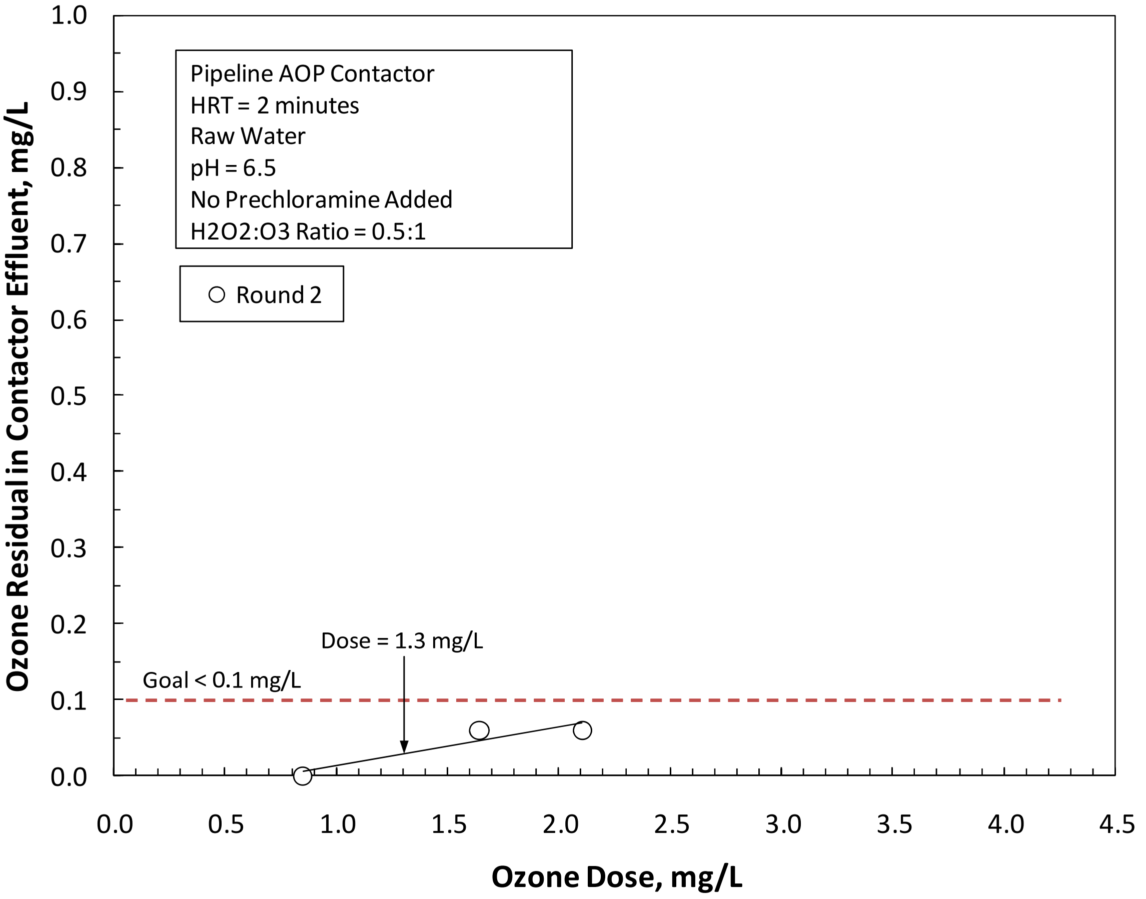

Conventional Contactor
HRT = 10 minutes
Raw Water
pH = 6.5
No Prechloramine Added
▲ Round 1 (Bromide = 620 µg/L)
○ Round 2 (Bromide = 394 µg/L)
■ Round 3 (Bromide = 423 µg/L)
Dose = 2.5 mg/L
Dose = 1.8 mg/L
BrO_3 = 13 µg/L
BrO_3 = 18 µg/L
Goal < 8 µg/L
Bromate Formed, µg/L
90
80
70
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L

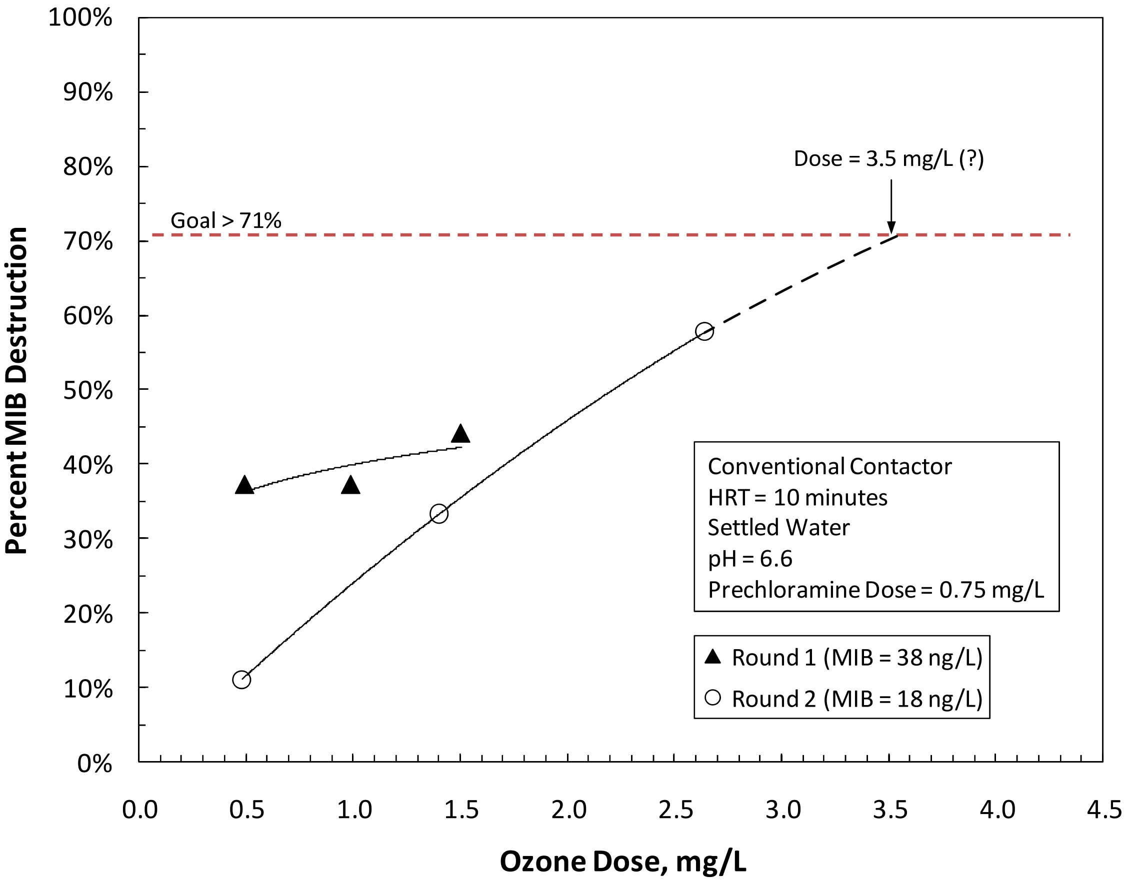

Conventional Contactor
HRT = 10 minutes
Raw Water
pH = 6.5
No Prechloramine Added
▲ Round 1
○ Round 2
■ Round 3
Dose = 2.5 mg/L
Dose = 1.8 mg/L
Goal < 0.1 mg/L
Ozone Residual in Contactor Effluent, mg/L
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L

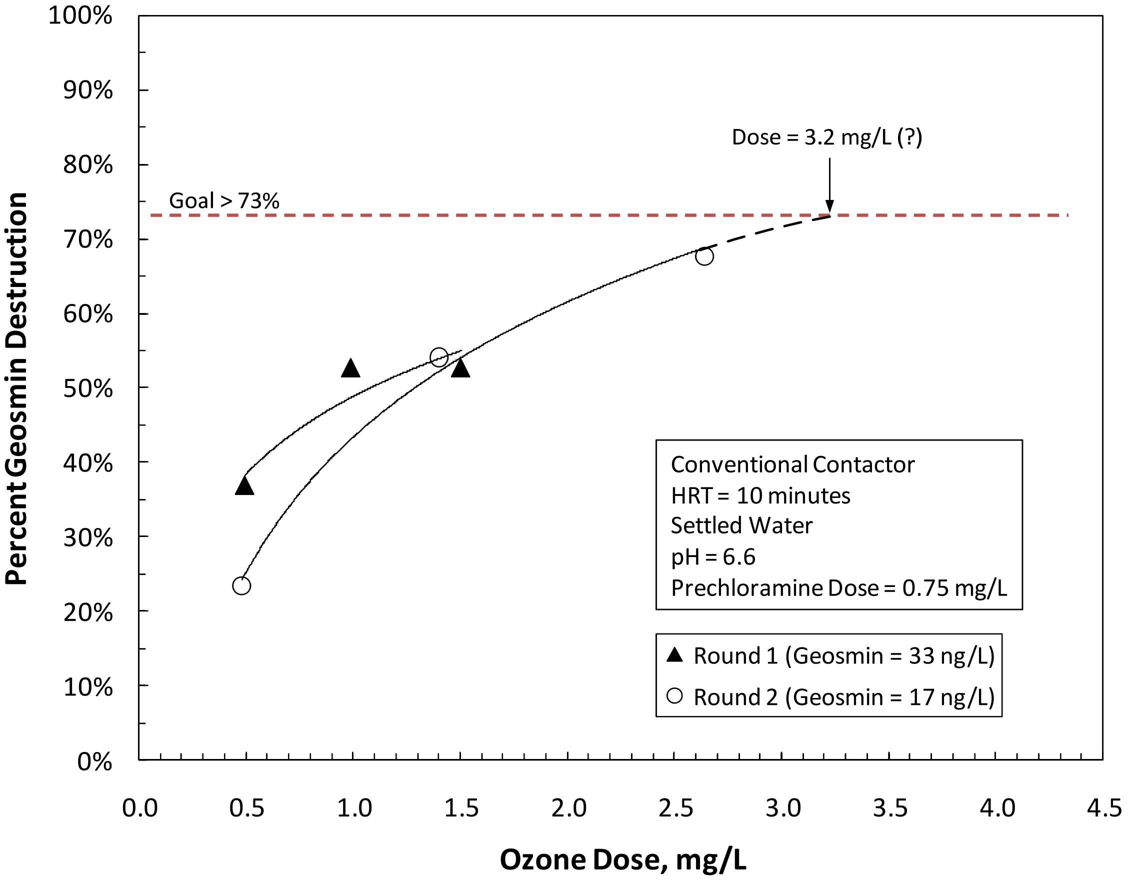

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent MIB Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Dose = 1.3 mg/L
Goal > 71%
Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = 6.5
No Prechloramine Added
H2O2:O3 Ratio = 0.5:1
○ Round 2 (MIB = 44 ng/L)

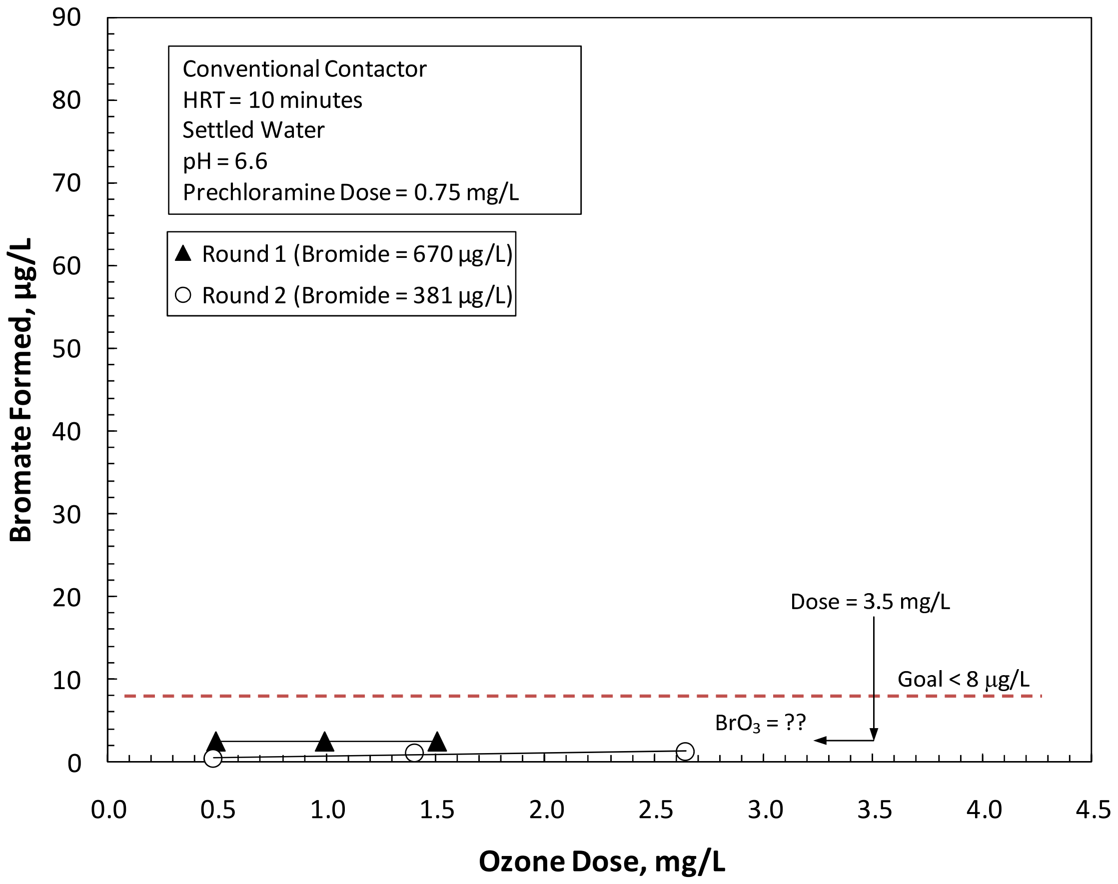

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Geosmin Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Dose = 1.1 mg/L
Goal > 73%
Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = 6.5
No Prechloramine Added
H2O2:O3 Ratio = 0.5:1
○ Round 2 (Geosmin = 35 ng/L)

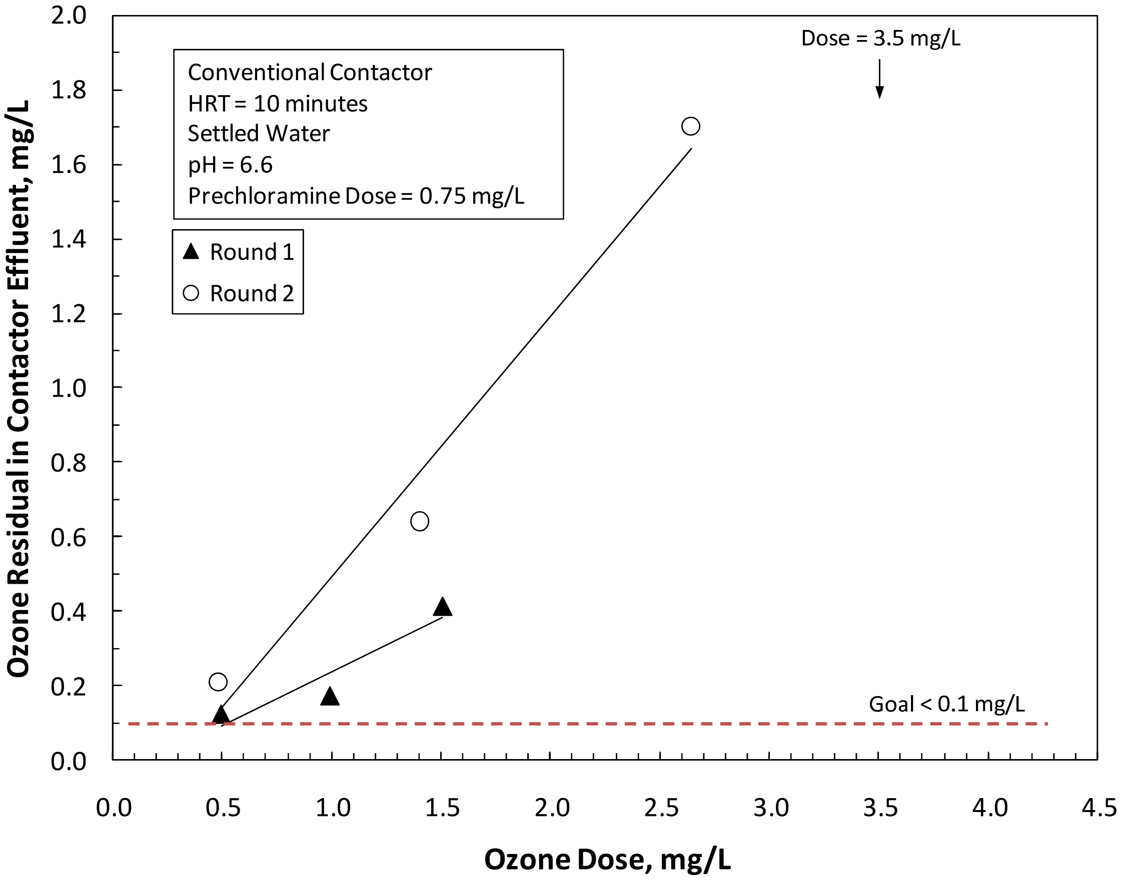

Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = 6.5
No Prechloramine Added
H2O2:O3 = 0.5:1
○ Round 2 (Bromide = 524 µg/L)
Dose = 1.3 mg/L
BrO3 = 24 µg/L
Goal < 8 µg/L
Bromate Formed, µg/L
Ozone Dose, mg/L
0
10
20
30
40
50
60
70
80
90
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

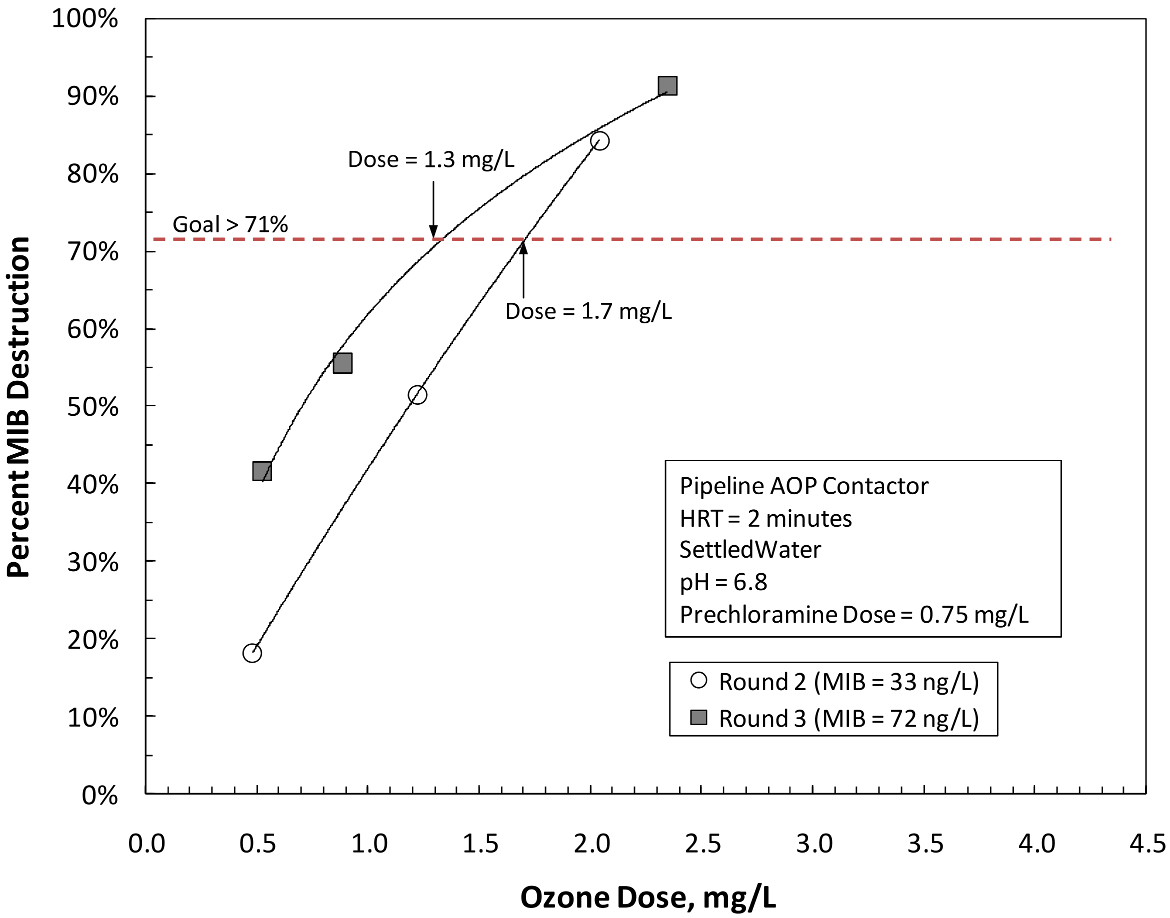

Pipeline AOP Contactor
HRT = 2 minutes
Raw Water
pH = 6.5
No Prechloramine Added
H2O2:O3 Ratio = 0.5:1
○ Round 2
Dose = 1.3 mg/L
Goal < 0.1 mg/L
Ozone Residual in Contactor Effluent, mg/L
Ozone Dose, mg/L
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

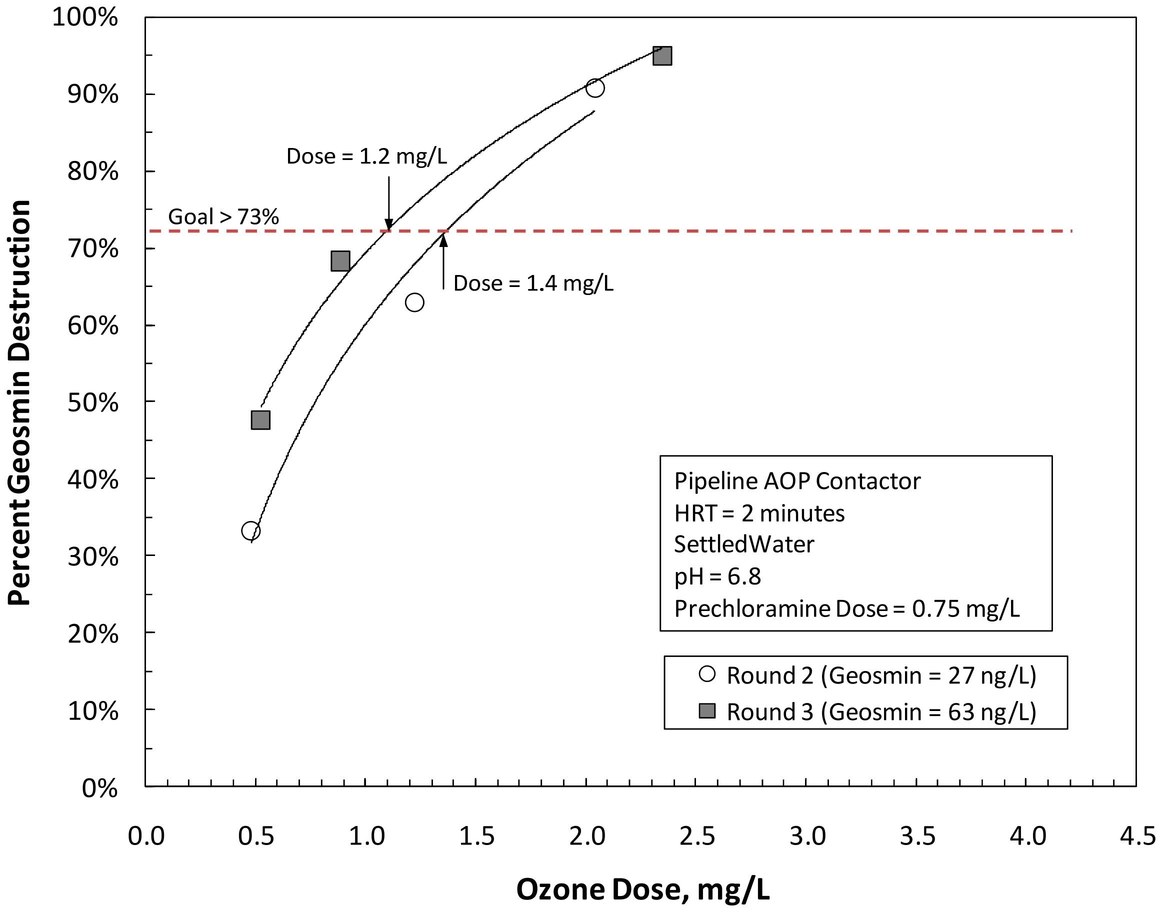

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent MIB Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Goal > 71%
Dose = 3.5 mg/L (?)
Conventional Contactor
HRT = 10 minutes
Settled Water
pH = 6.6
Prechloramine Dose = 0.75 mg/L
▲ Round 1 (MIB = 38 ng/L)
○ Round 2 (MIB = 18 ng/L)

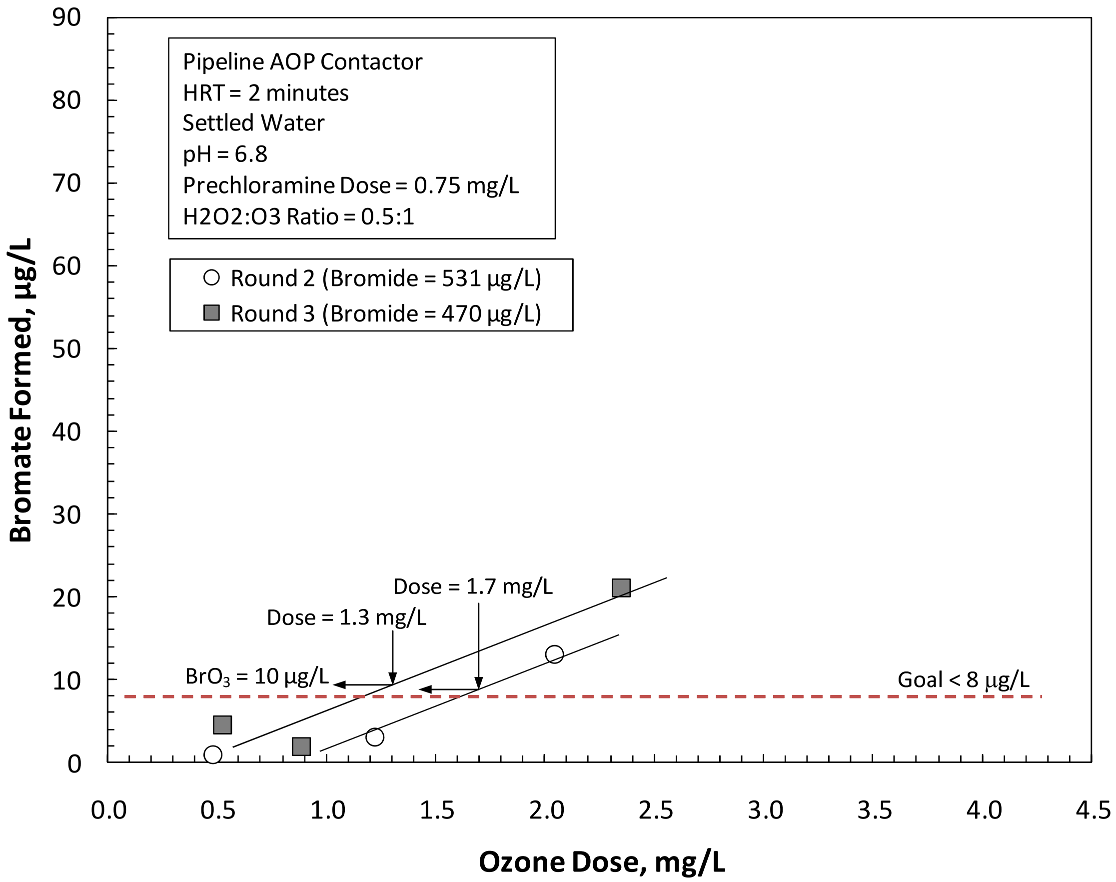

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Geosmin Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Goal > 73%
Dose = 3.2 mg/L (?)
Conventional Contactor
HRT = 10 minutes
Settled Water
pH = 6.6
Prechloramine Dose = 0.75 mg/L
▲ Round 1 (Geosmin = 33 ng/L)
○ Round 2 (Geosmin = 17 ng/L)


Conventional Contactor
HRT = 10 minutes
Settled Water
pH = 6.6
Prechloramine Dose = 0.75 mg/L
▲ Round 1 (Bromide = 670 µg/L)
○ Round 2 (Bromide = 381 µg/L)
Dose = 3.5 mg/L
Goal < 8 µg/L
BrO_3 = ??
Bromate Formed, µg/L
0
10
20
30
40
50
60
70
80
90
Ozone Dose, mg/L
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

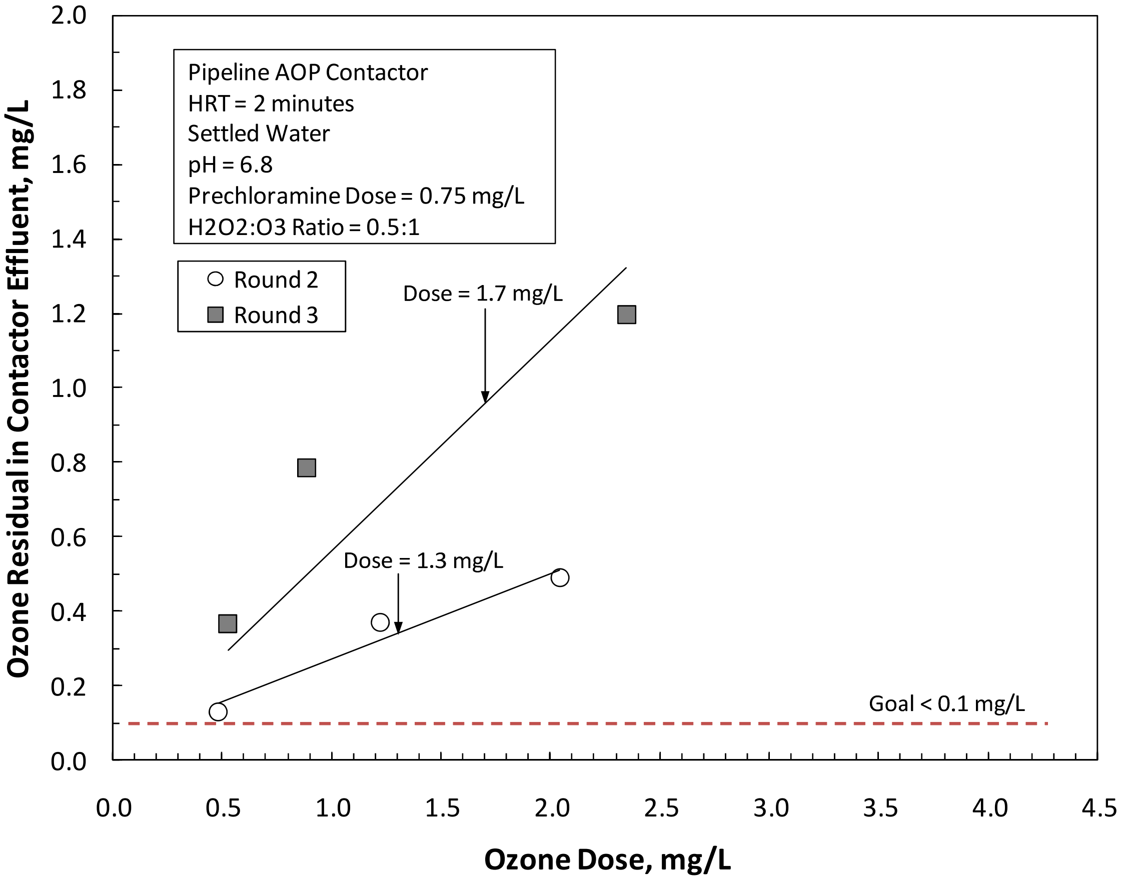

Conventional Contactor
HRT = 10 minutes
Settled Water
pH = 6.6
Prechloramine Dose = 0.75 mg/L
▲ Round 1
○ Round 2
Dose = 3.5 mg/L
Goal < 0.1 mg/L
Ozone Residual in Contactor Effluent, mg/L
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Ozone Dose, mg/L
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent MIB Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Dose = 1.3 mg/L
Goal > 71%
Dose = 1.7 mg/L
Pipeline AOP Contactor
HRT = 2 minutes
Settled Water
pH = 6.8
Prechloramine Dose = 0.75 mg/L
○ Round 2 (MIB = 33 ng/L)
■ Round 3 (MIB = 72 ng/L)

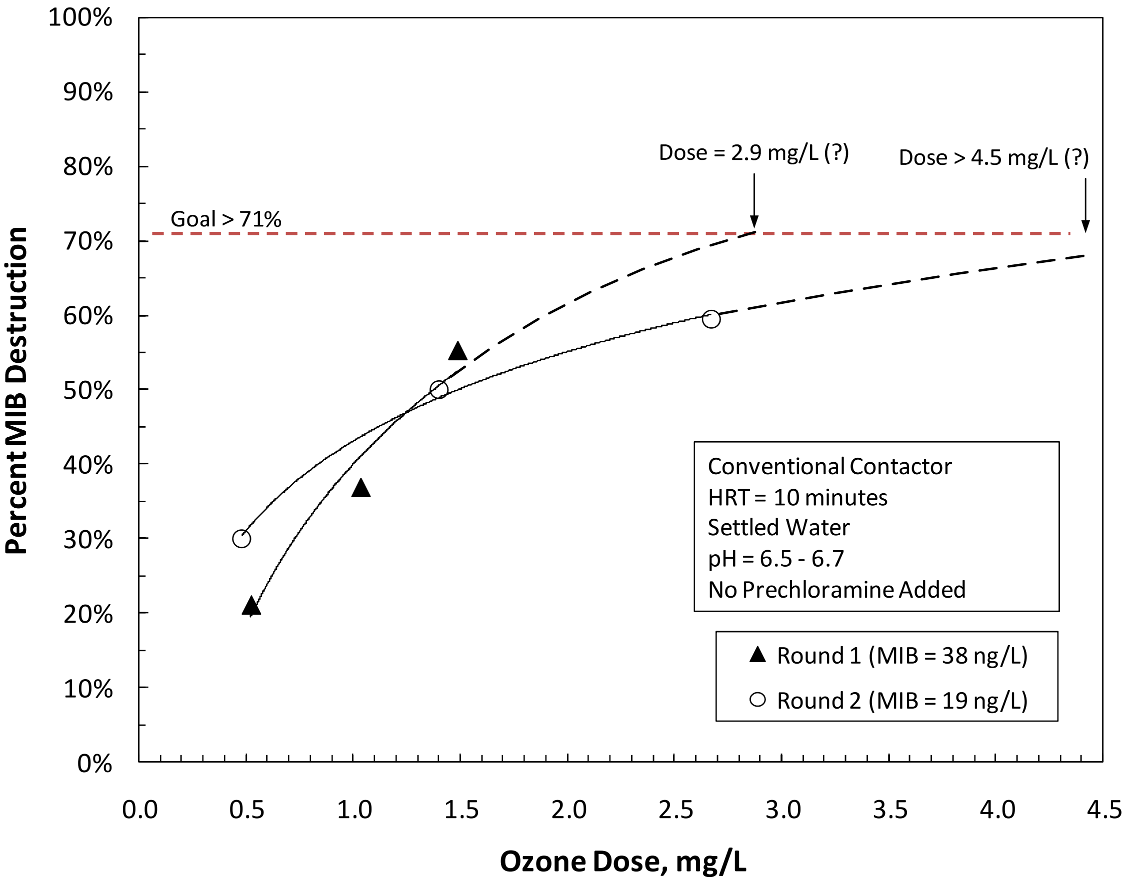

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Geosmin Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Dose = 1.2 mg/L
Goal > 73%
Dose = 1.4 mg/L
Pipeline AOP Contactor
HRT = 2 minutes
Settled Water
pH = 6.8
Prechloramine Dose = 0.75 mg/L
○ Round 2 (Geosmin = 27 ng/L)
■ Round 3 (Geosmin = 63 ng/L)

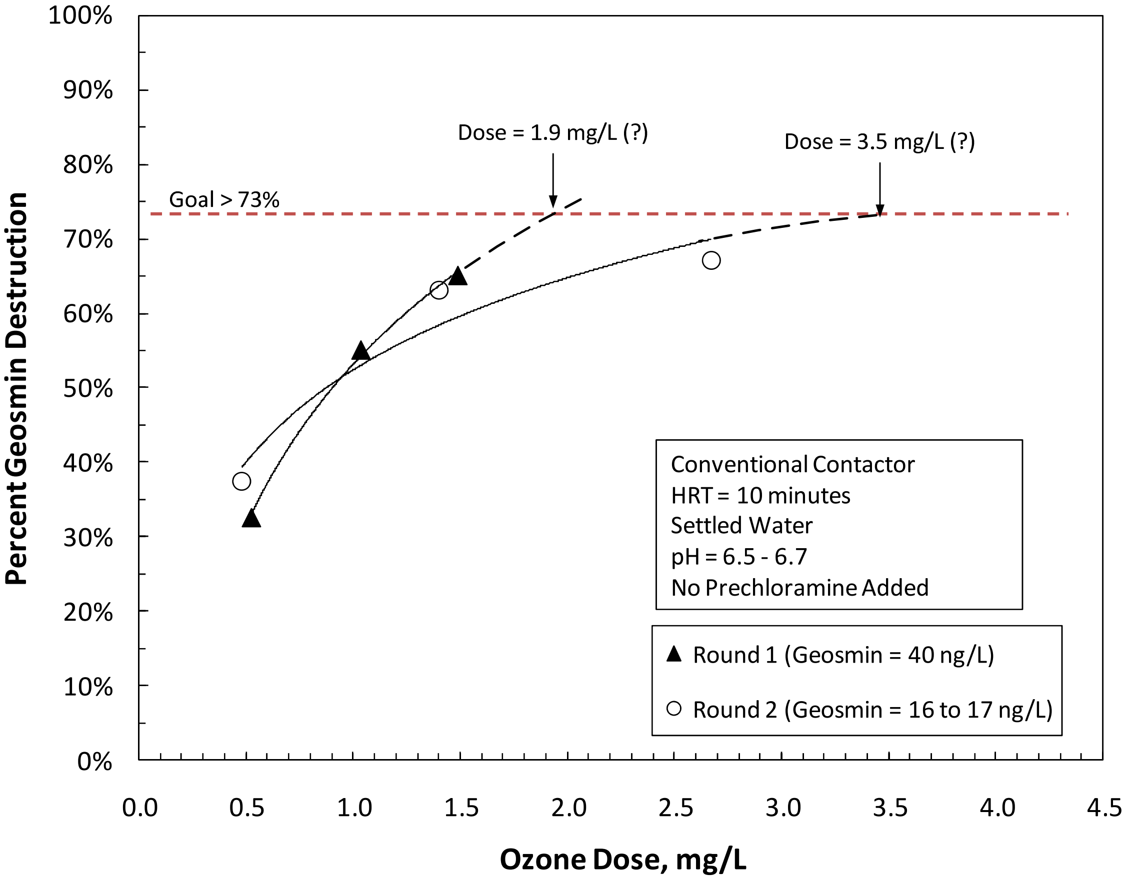


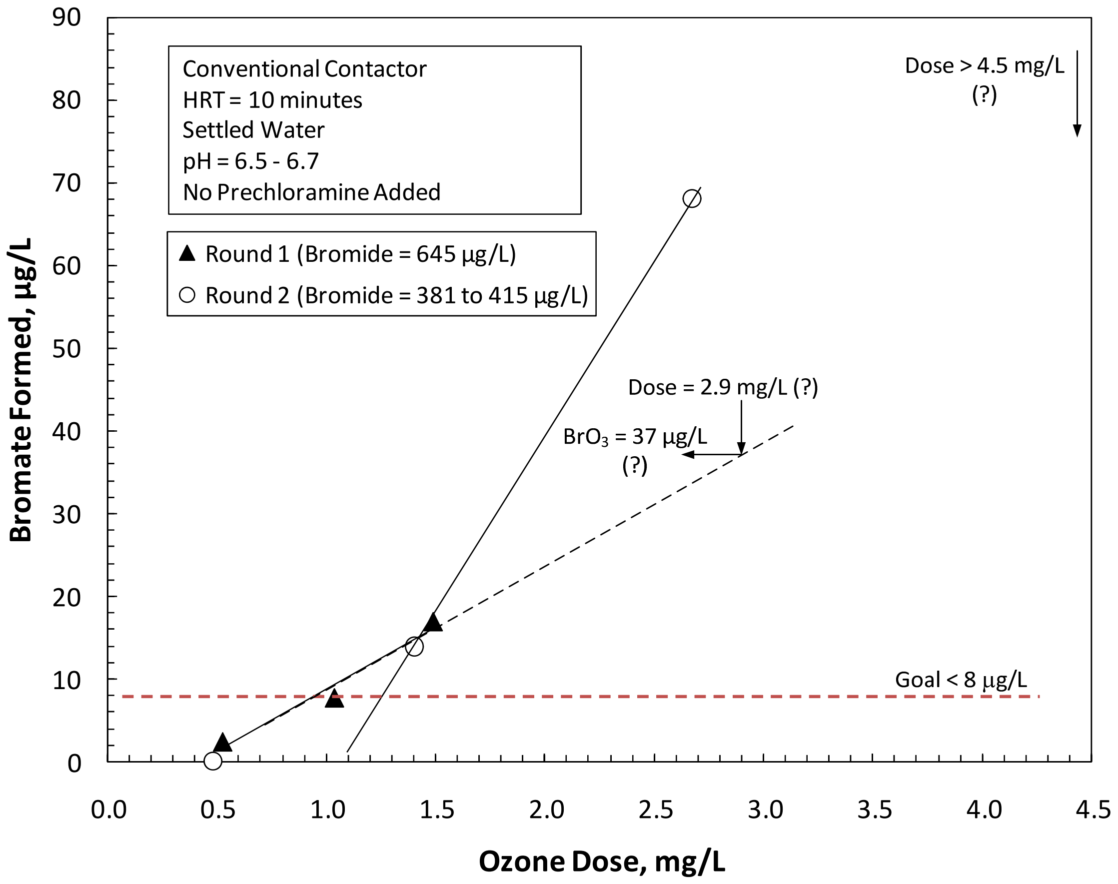
Pipeline AOP Contactor
HRT = 2 minutes
Settled Water
pH = 6.8
Prechloramine Dose = 0.75 mg/L
H2O2:O3 Ratio = 0.5:1
○ Round 2 (Bromide = 531 µg/L)
■ Round 3 (Bromide = 470 µg/L)
Dose = 1.7 mg/L
Dose = 1.3 mg/L
BrO₃ = 10 µg/L
Goal < 8 µg/L
Bromate Formed, µg/L
0
10
20
30
40
50
60
70
80
90
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L



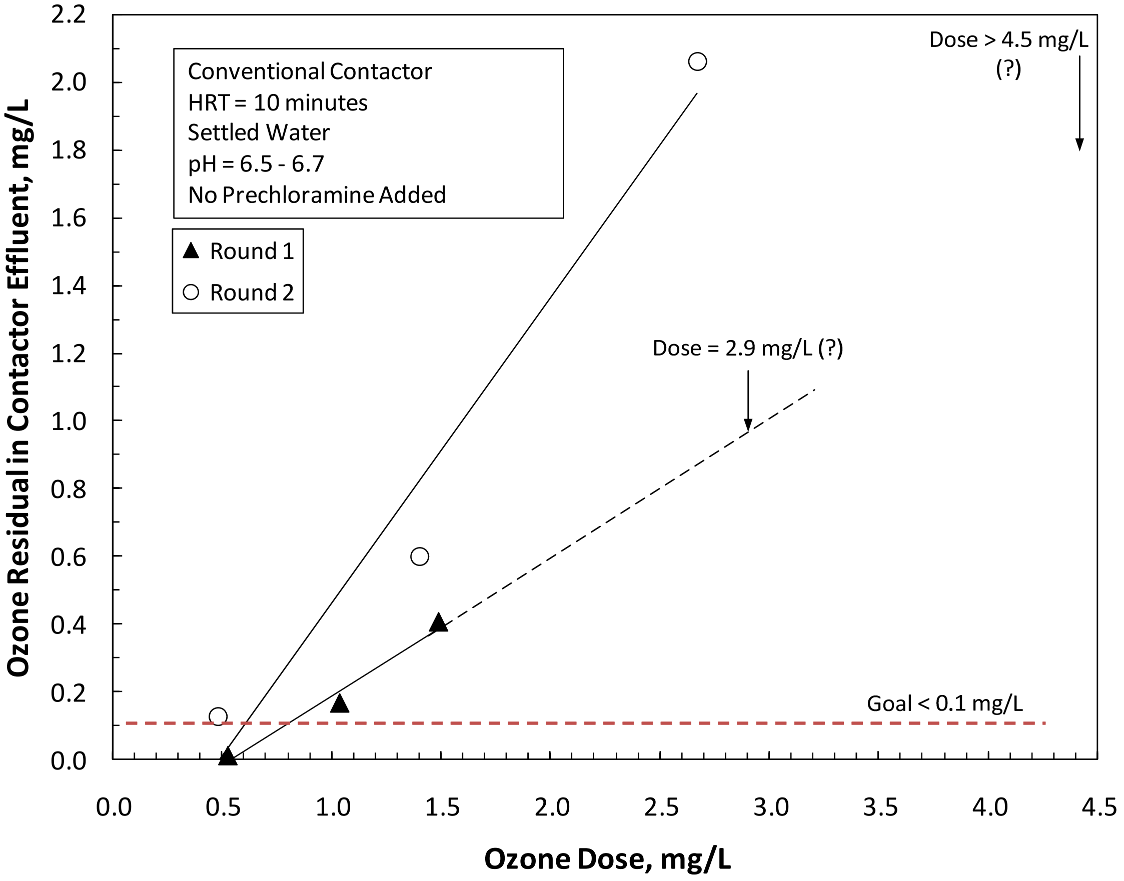
Pipeline AOP Contactor
HRT = 2 minutes
Settled Water
pH = 6.8
Prechloramine Dose = 0.75 mg/L
H2O2:O3 Ratio = 0.5:1
○ Round 2
■ Round 3
Dose = 1.7 mg/L
Dose = 1.3 mg/L
Goal < 0.1 mg/L
Ozone Residual in Contactor Effluent, mg/L
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent MIB Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Goal > 71%
Dose = 2.9 mg/L (?)
Dose > 4.5 mg/L (?)
Conventional Contactor
HRT = 10 minutes
Settled Water
pH = 6.5 - 6.7
No Prechloramine Added
▲ Round 1 (MIB = 38 ng/L)
○ Round 2 (MIB = 19 ng/L)

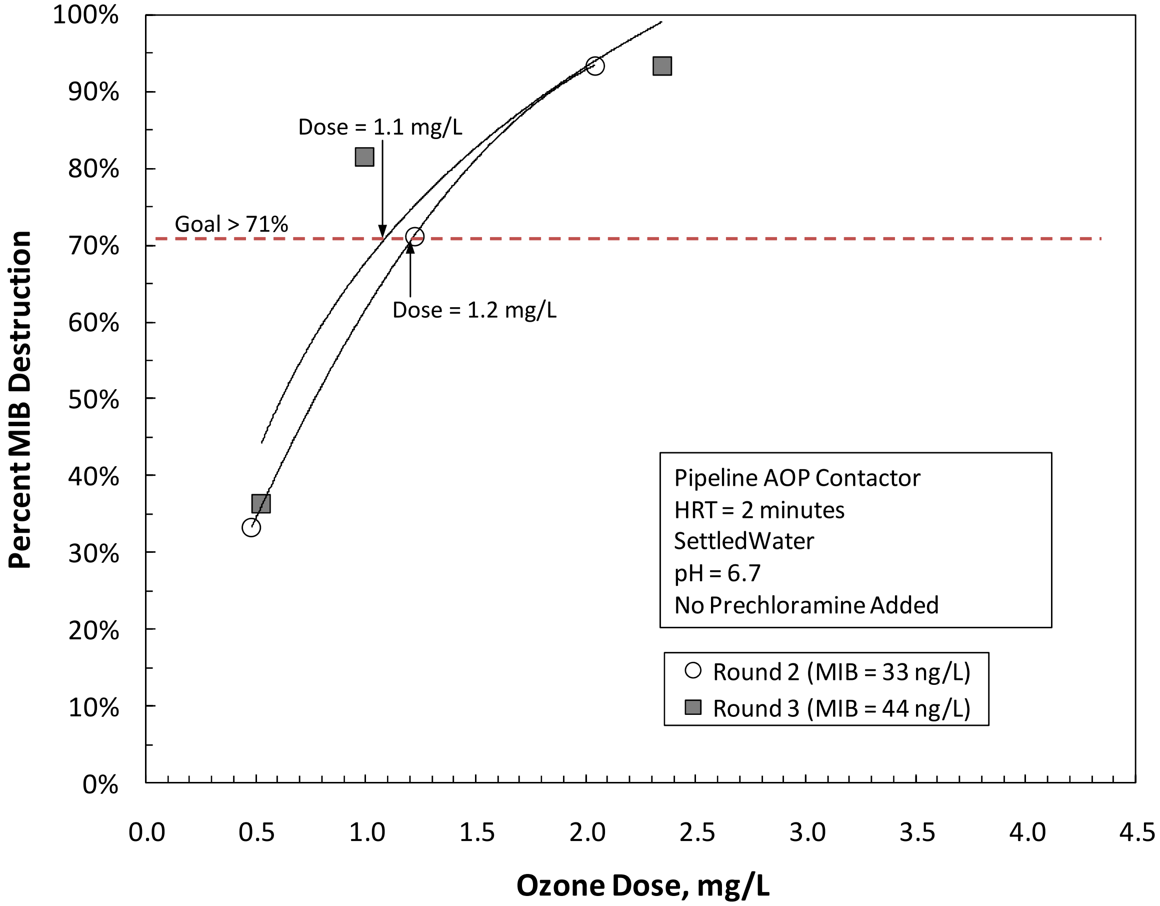

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Geosmin Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Goal > 73%
Dose = 1.9 mg/L (?)
Dose = 3.5 mg/L (?)
Conventional Contactor
HRT = 10 minutes
Settled Water
pH = 6.5 - 6.7
No Prechloramine Added
▲ Round 1 (Geosmin = 40 ng/L)
○ Round 2 (Geosmin = 16 to 17 ng/L)

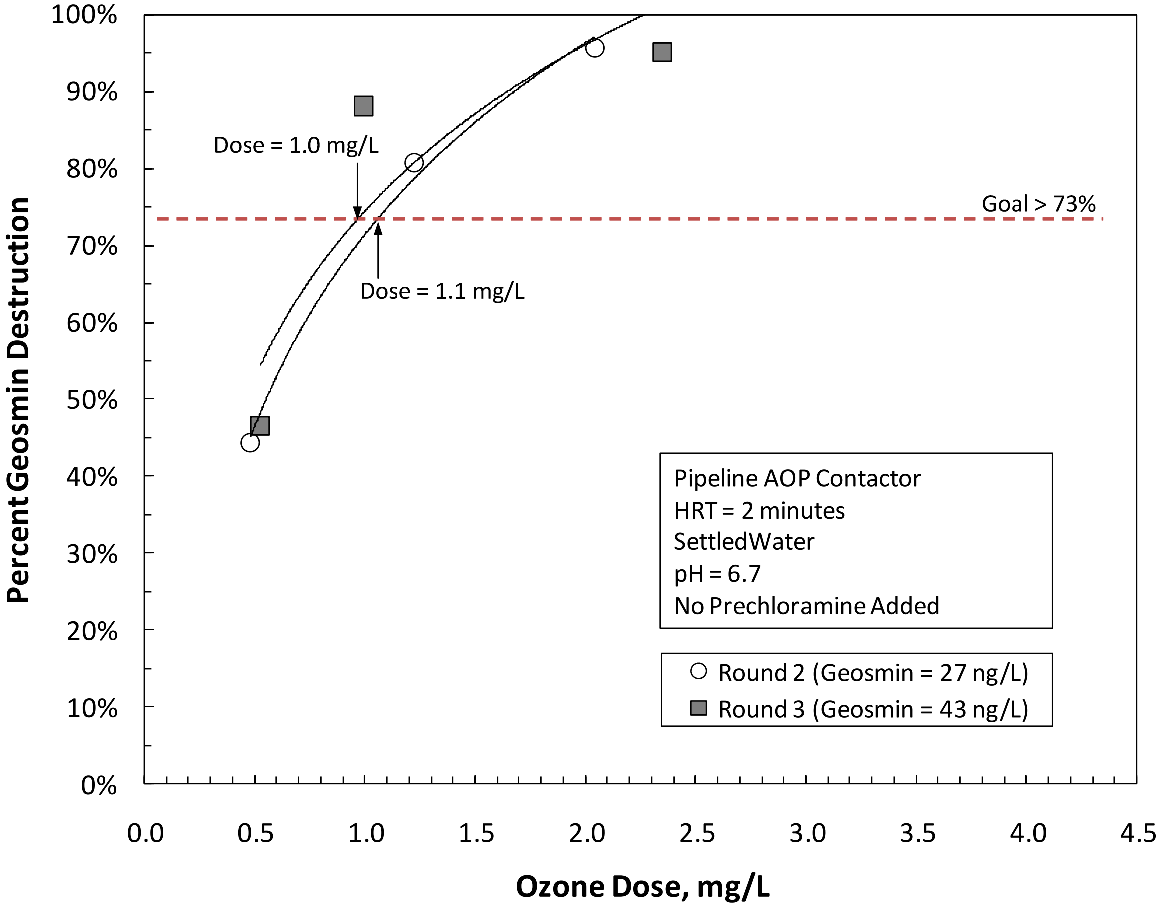


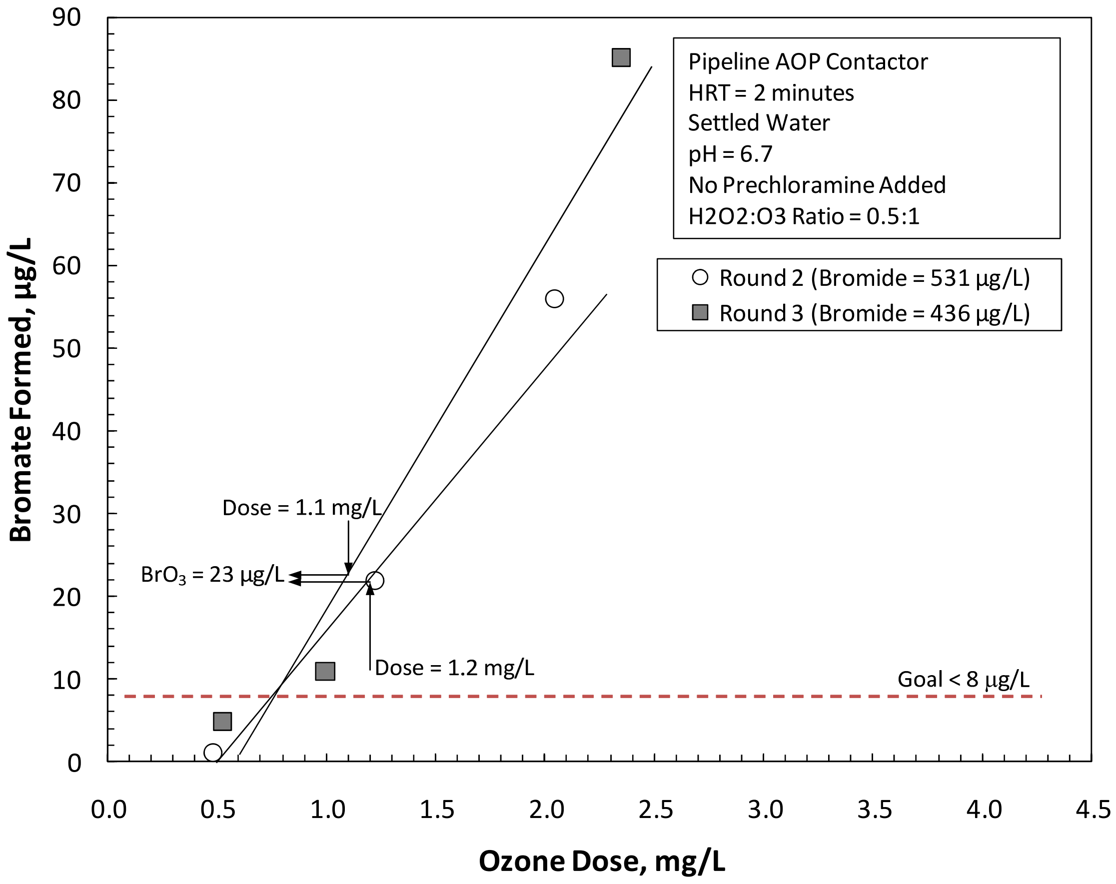
Conventional Contactor
HRT = 10 minutes
Settled Water
pH = 6.5 - 6.7
No Prechloramine Added
▲ Round 1 (Bromide = 645 µg/L)
○ Round 2 (Bromide = 381 to 415 µg/L)
Dose > 4.5 mg/L (?)
Dose = 2.9 mg/L (?)
BrO3 = 37 µg/L (?)
Goal < 8 µg/L
Bromate Formed, µg/L
90
80
70
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L

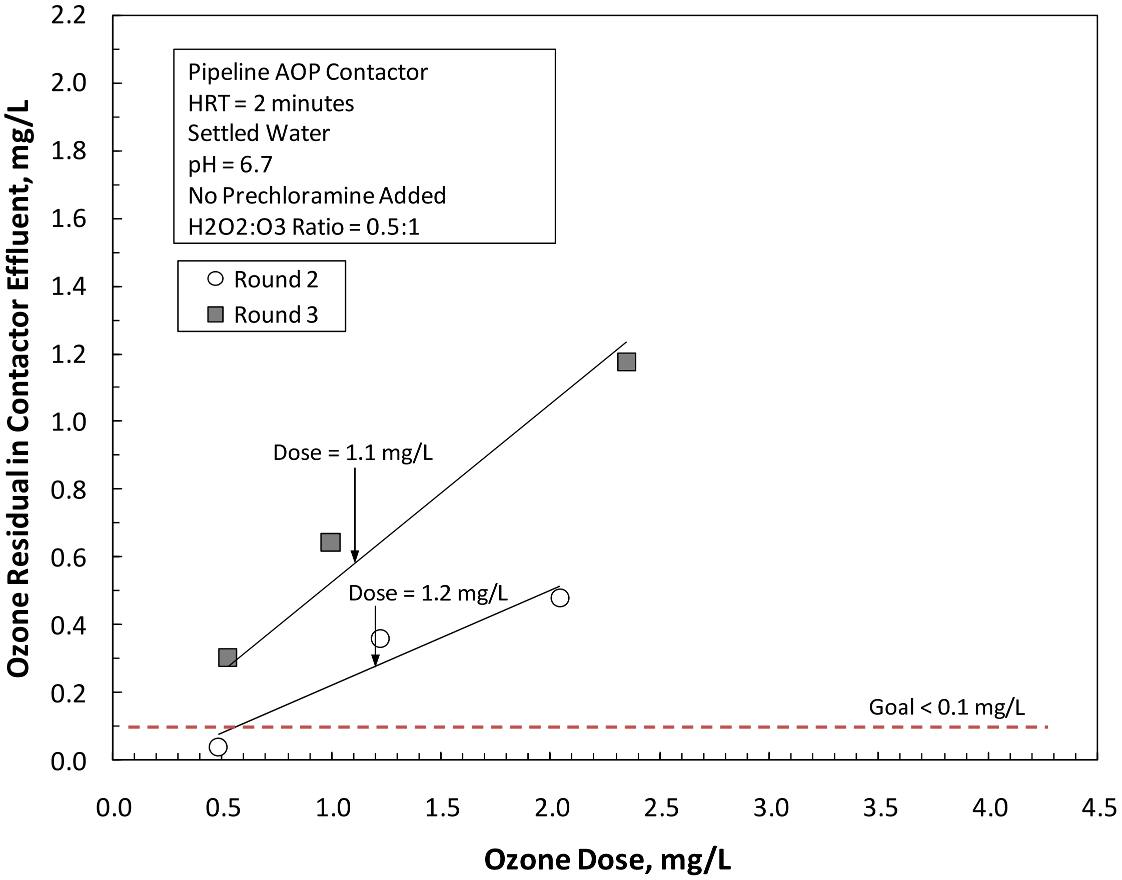


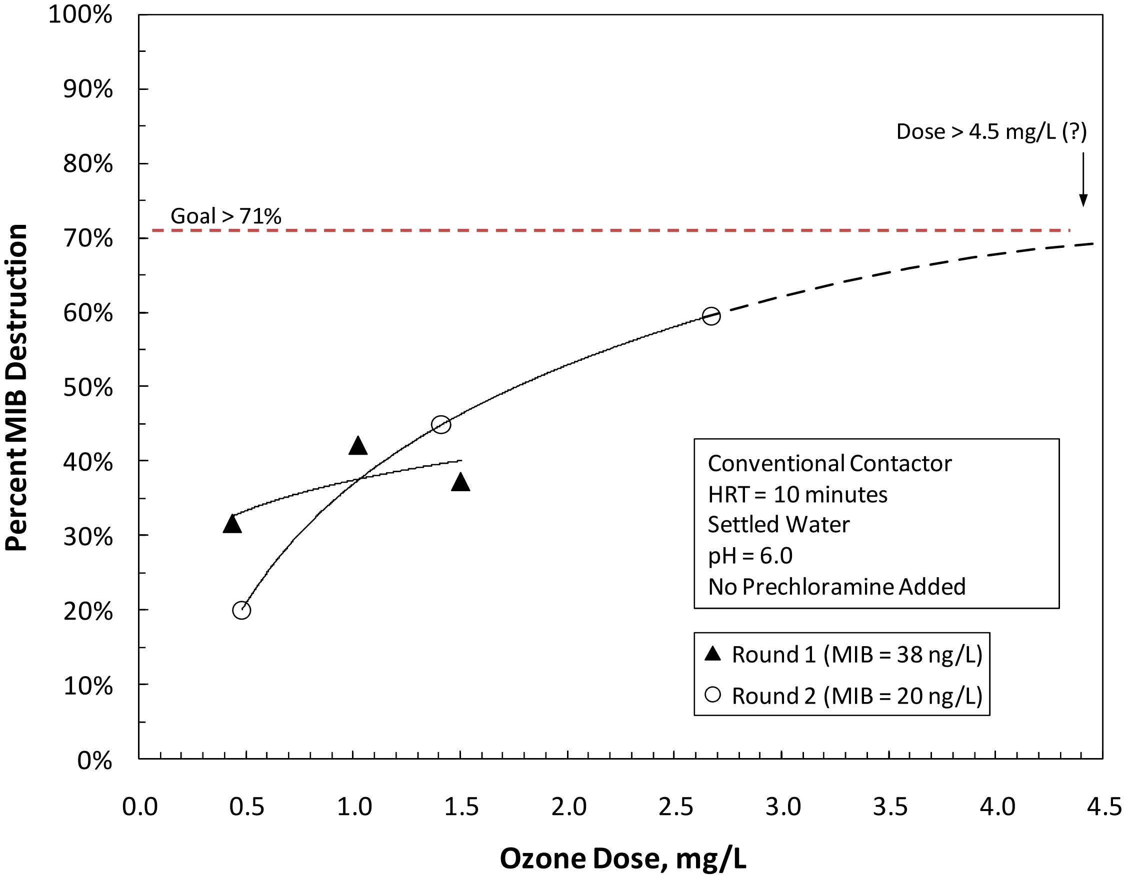
Conventional Contactor
HRT = 10 minutes
Settled Water
pH = 6.5 - 6.7
No Prechloramine Added
▲ Round 1
○ Round 2
Dose > 4.5 mg/L (?)
Dose = 2.9 mg/L (?)
Goal < 0.1 mg/L
Ozone Residual in Contactor Effluent, mg/L
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent MIB Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Dose = 1.1 mg/L
Goal > 71%
Dose = 1.2 mg/L
Pipeline AOP Contactor
HRT = 2 minutes
SettledWater
pH = 6.7
No Prechloramine Added
○ Round 2 (MIB = 33 ng/L)
■ Round 3 (MIB = 44 ng/L)

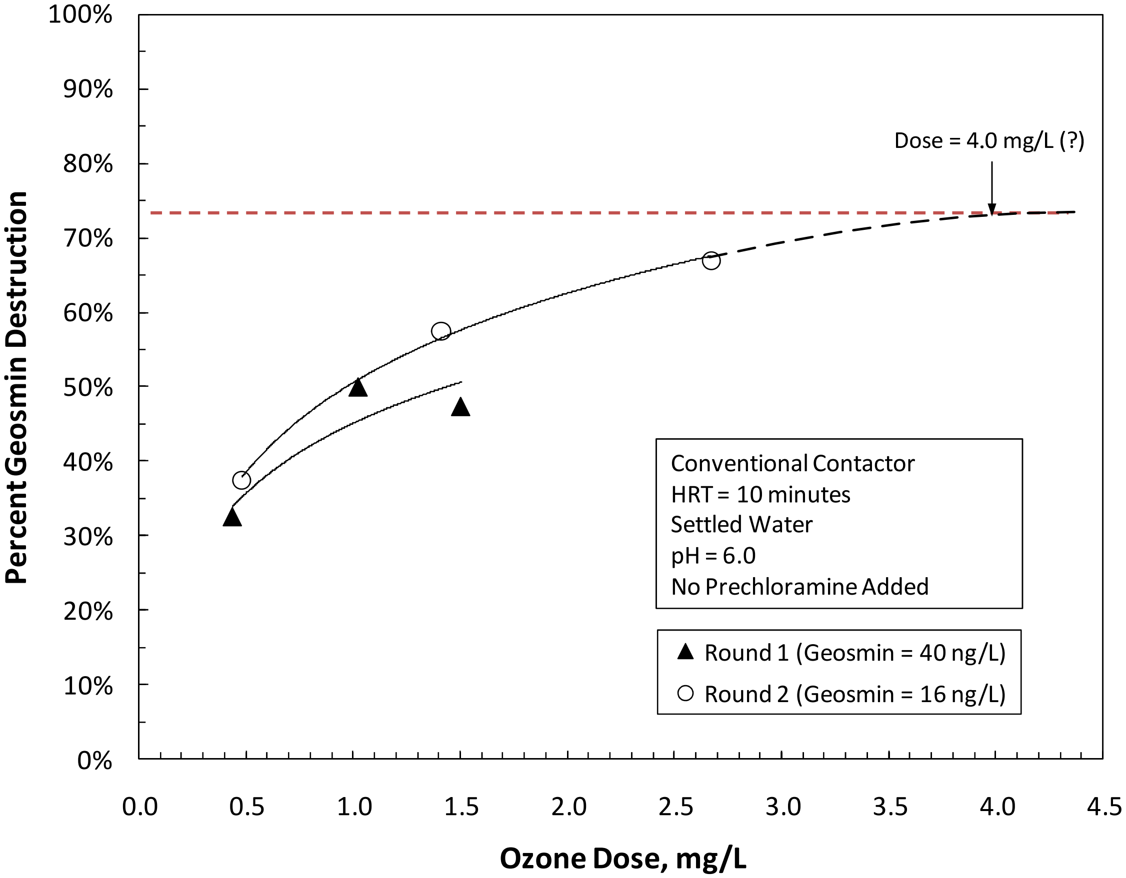

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Geosmin Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Dose = 1.0 mg/L
Goal > 73%
Dose = 1.1 mg/L
Pipeline AOP Contactor
HRT = 2 minutes
SettledWater
pH = 6.7
No Prechloramine Added
○ Round 2 (Geosmin = 27 ng/L)
■ Round 3 (Geosmin = 43 ng/L)


90
80
70
60
50
40
30
20
10
0
Bromate Formed, µg/L
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Pipeline AOP Contactor
HRT = 2 minutes
Settled Water
pH = 6.7
No Prechloramine Added
H2O2:O3 Ratio = 0.5:1
○ Round 2 (Bromide = 531 µg/L)
■ Round 3 (Bromide = 436 µg/L)
Dose = 1.1 mg/L
BrO_3 = 23 µg/L
Dose = 1.2 mg/L
Goal < 8 µg/L

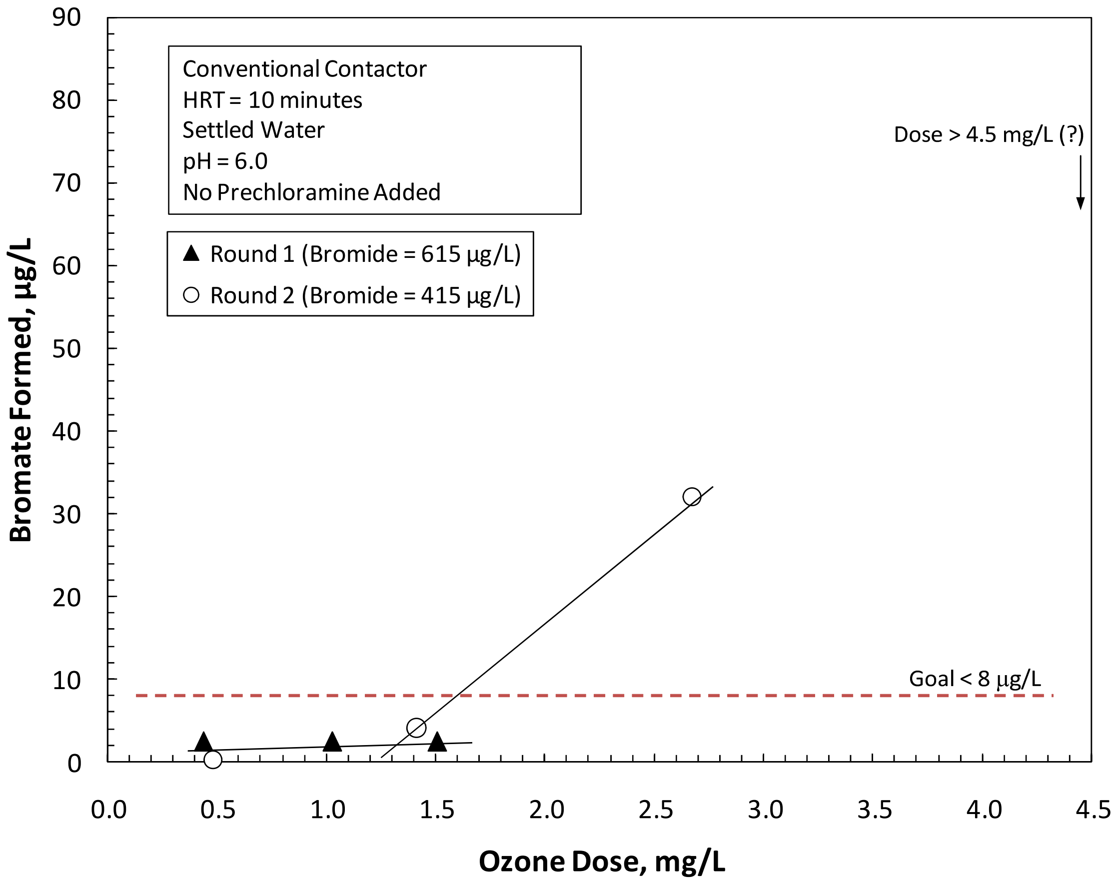

2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Ozone Residual in Contactor Effluent, mg/L
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Pipeline AOP Contactor
HRT = 2 minutes
Settled Water
pH = 6.7
No Prechloramine Added
H2O2:O3 Ratio = 0.5:1
○ Round 2
■ Round 3
Dose = 1.1 mg/L
Dose = 1.2 mg/L
Goal < 0.1 mg/L



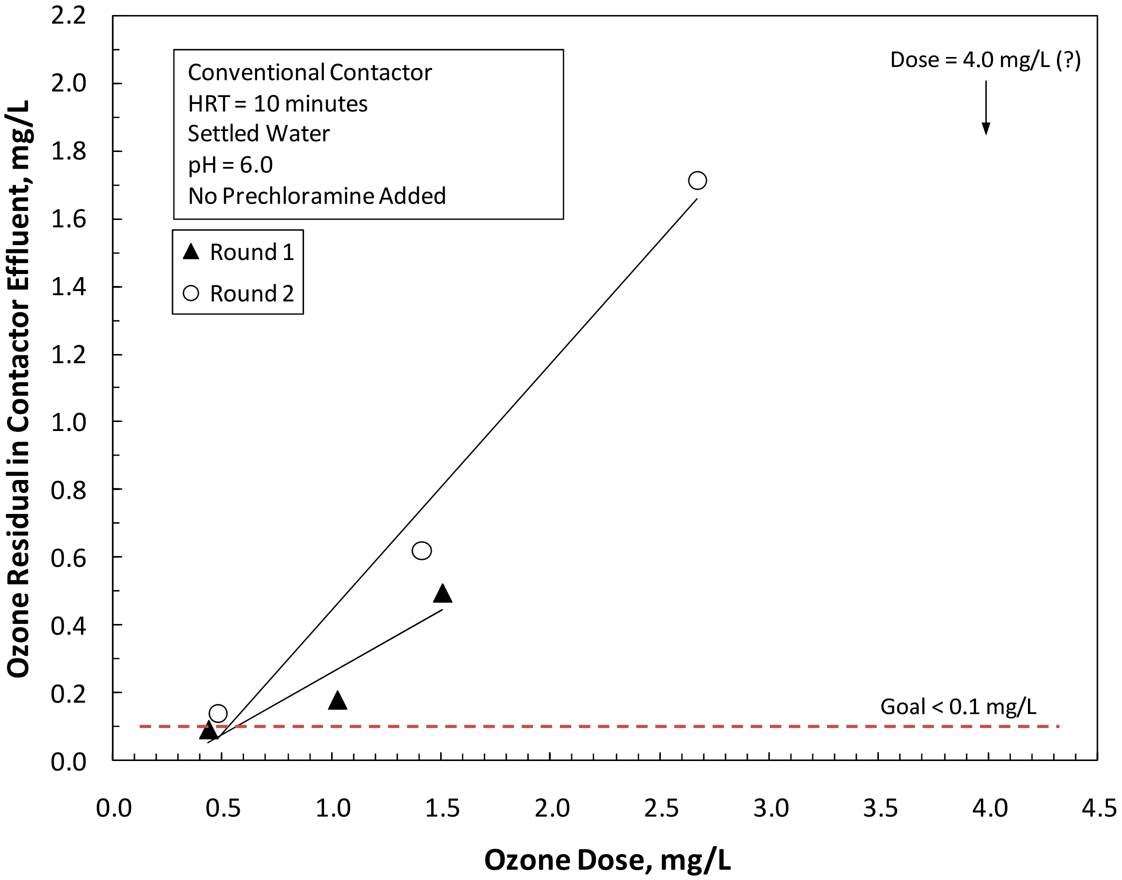
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent MIB Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Goal > 71%
Dose > 4.5 mg/L (?)
Conventional Contactor
HRT = 10 minutes
Settled Water
pH = 6.0
No Prechloramine Added
▲ Round 1 (MIB = 38 ng/L)
○ Round 2 (MIB = 20 ng/L)



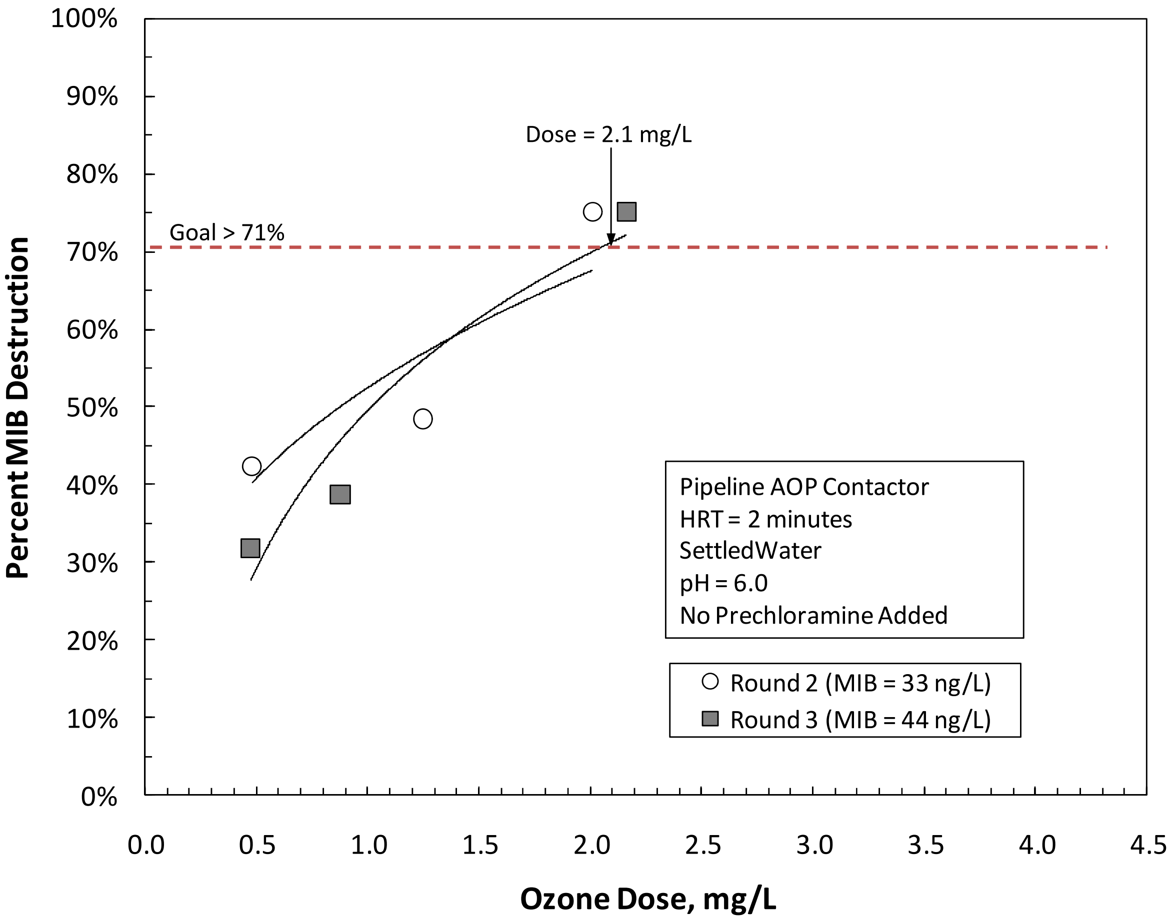
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Geosmin Destruction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Dose = 4.0 mg/L (?)
Conventional Contactor
HRT = 10 minutes
Settled Water
pH = 6.0
No Prechloramine Added
▲ Round 1 (Geosmin = 40 ng/L)
○ Round 2 (Geosmin = 16 ng/L)

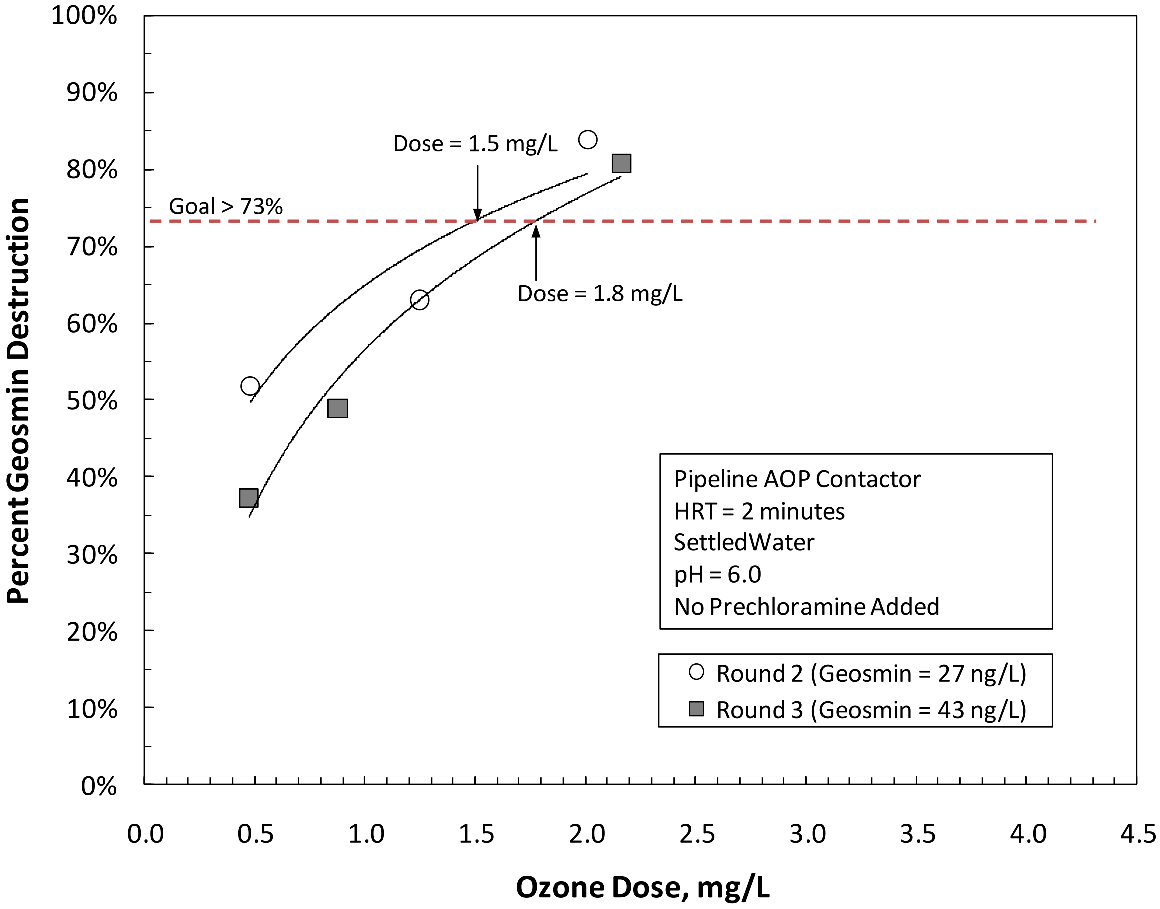


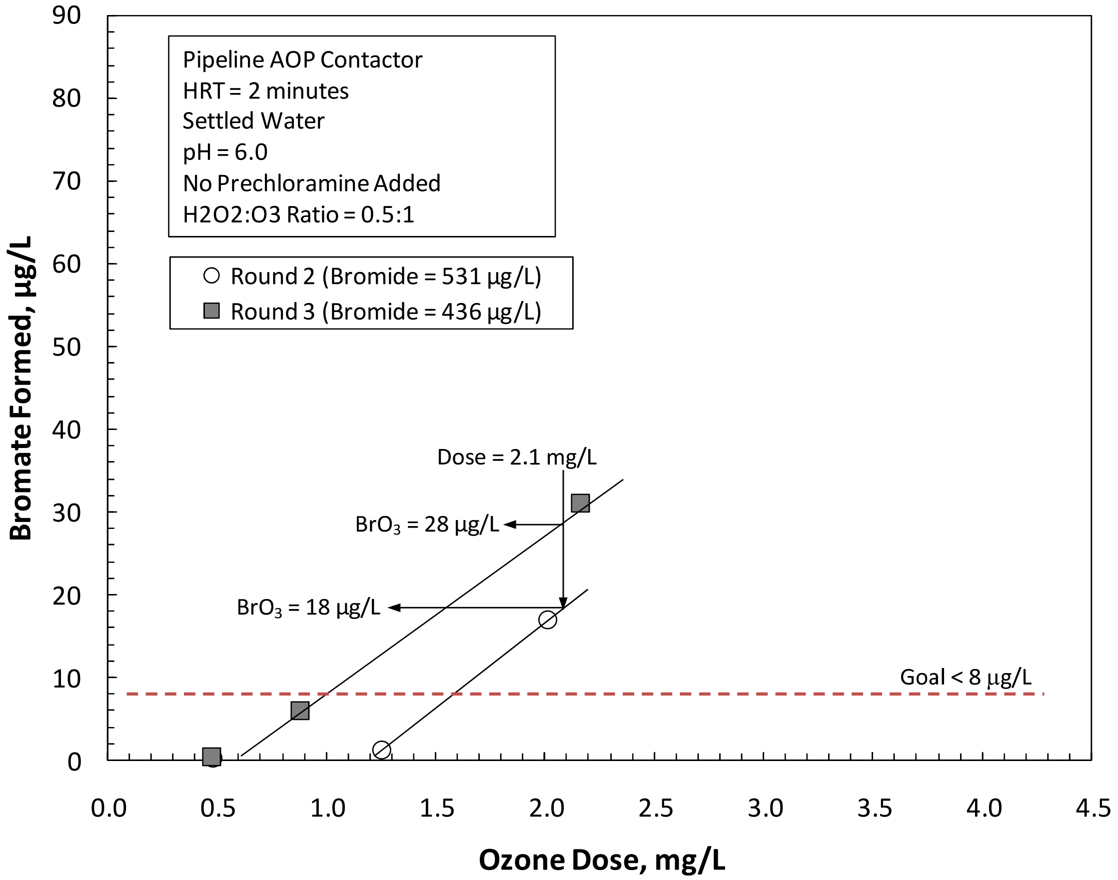
Conventional Contactor
HRT = 10 minutes
Settled Water
pH = 6.0
No Prechloramine Added
▲ Round 1 (Bromide = 615 µg/L)
○ Round 2 (Bromide = 415 µg/L)
Dose > 4.5 mg/L (?)
Goal < 8 µg/L
Bromate Formed, µg/L
0
10
20
30
40
50
60
70
80
90
Ozone Dose, mg/L
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

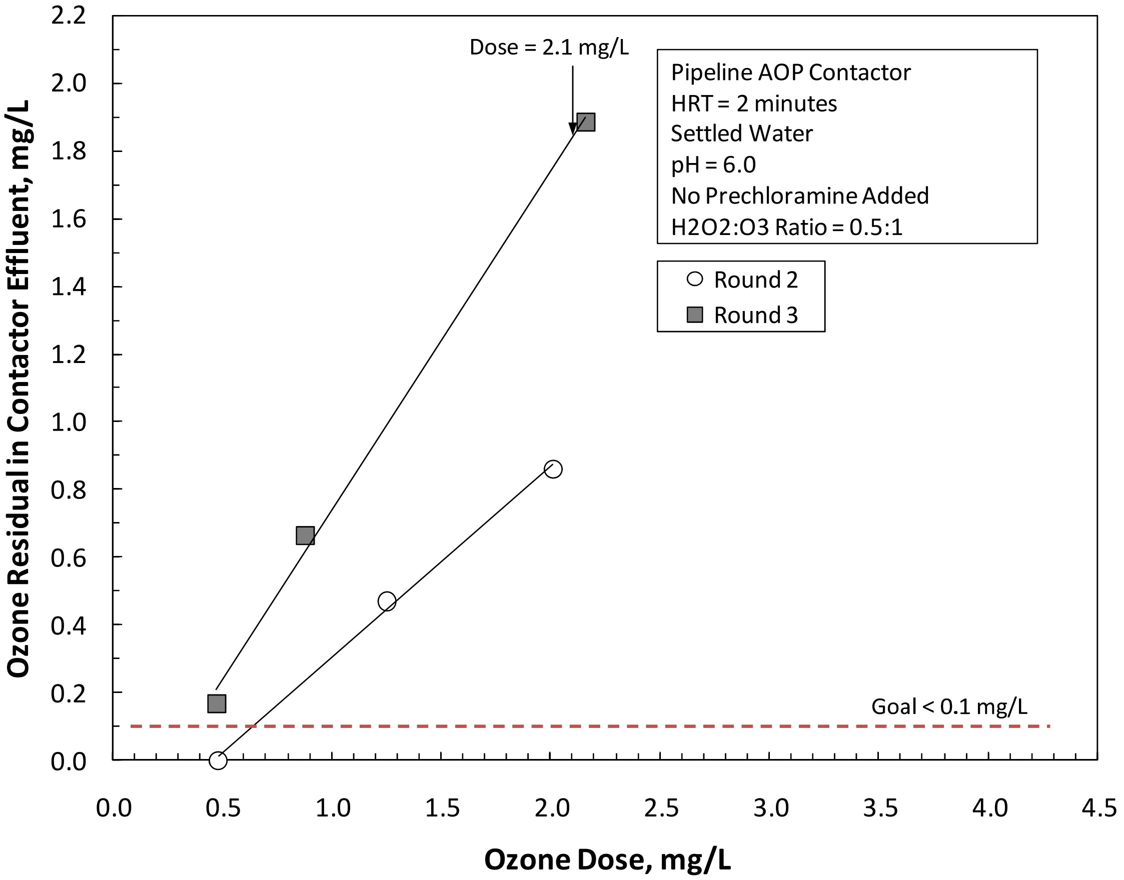


Conventional Contactor
HRT = 10 minutes
Settled Water
pH = 6.0
No Prechloramine Added
▲ Round 1
○ Round 2
Dose = 4.0 mg/L (?)
Goal < 0.1 mg/L
Ozone Residual in Contactor Effluent, mg/L
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
Ozone Dose, mg/L
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5


Percent MIB Destruction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Dose = 2.1 mg/L
Goal > 71%
Pipeline AOP Contactor
HRT = 2 minutes
SettledWater
pH = 6.0
No Prechloramine Added
○ Round 2 (MIB = 33 ng/L)
■ Round 3 (MIB = 44 ng/L)


Percent Geosmin Destruction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L
Dose = 1.5 mg/L
Goal > 73%
Dose = 1.8 mg/L
Pipeline AOP Contactor
HRT = 2 minutes
SettledWater
pH = 6.0
No Prechloramine Added
○ Round 2 (Geosmin = 27 ng/L)
■ Round 3 (Geosmin = 43 ng/L)


Pipeline AOP Contactor
HRT = 2 minutes
Settled Water
pH = 6.0
No Prechloramine Added
H2O2:O3 Ratio = 0.5:1
○ Round 2 (Bromide = 531 µg/L)
■ Round 3 (Bromide = 436 µg/L)
Dose = 2.1 mg/L
BrO3 = 28 µg/L
BrO3 = 18 µg/L
Goal < 8 µg/L
Bromate Formed, µg/L
90
80
70
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L


Dose = 2.1 mg/L
Pipeline AOP Contactor
HRT = 2 minutes
Settled Water
pH = 6.0
No Prechloramine Added
H2O2:O3 Ratio = 0.5:1
○ Round 2
■ Round 3
Goal < 0.1 mg/L
Ozone Residual in Contactor Effluent, mg/L
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Ozone Dose, mg/L

APPENDIX C
EMERGING DBPs SAMPLING PROTOCOL

Protocol for setting up and collecting samples to be analyzed for DBPs at Clemson

Background: A total of 20 samples will be collected from the pilot plant and sent to Clemson University for analysis of non-regulated DBPs (I-THMs and HNMs). Samples will be shipped from Zone 7's Del Valle WTP on Tuesday, October 7 for arrival at Clemson on Wednesday October 8th. For each process (i.e., ozone vs. ozone/peroxide), there will be 10 samples collected and shipped. Various conditions will be established to examine the effects of different parameters such as chemical doses and pH values consistent with expected plant operation.

Materials needed:

Ice chest	Blue ice
DBP Sample bottles (60-mL pre-cleaned amber glass vials), total of 40	Labels
1-L clean amber glass bottles, total of seven	Caustic solution for adjusting pH
Sodium hypochlorite solution (1 mg/mL)	Ammonia solution (1 mg/mL as N)
1-L glass graduated cylinder	Pipettes

Sample Description: The 20 samples will be as follows (CC means Conventional Contactor – ozone only, and PC means Pipeline Contactor – ozone + peroxide):

1-RW	Raw water		
2-CC	Raw water dosed with 0.75 mg/L chloramine	2-PC	Raw water dosed with 0.75 mg/L chloramine
3-CC	Raw water that has been pre-chloraminated and then ozonated	3-PC	Raw water that has been pre-chloraminated and then peroxone treated
4-CC	Raw water that has been pre-chloramination, ozonated, and then dosed with chlorine for 10 minutes, followed by ammonia to form chloramine. This sample will be stored at room temperature for 24 hrs before shipping.	4-PC	Raw water that has been pre-chloramination, peroxone treated, and then dosed with chlorine for 10 minutes, followed by ammonia to form chloramine. This sample will be stored at room temperature for 24 hrs before shipping.
5-CC	Raw water with pH depressed to 7.0 and ozonated	5-PC	Raw water with pH depressed to 7.0 and peroxone treated
6-CC	Raw water with pH depressed to 7.0, ozonated, then pH raised back to 8.0, dosed with chlorine for 10 minutes, and followed by ammonia to form chloramine. The sample will be stored at room temperature for 24 hrs before shipping.	6-PC	Raw water with pH depressed to 7.0, peroxone treated, then pH raised back to 8.0, dosed with chlorine for 10 minutes, and followed by ammonia to form chloramine. The sample will be stored at room temperature for 24 hrs before shipping.
7-SW	Settled water		
8-CC	Settled water dosed with 0.75 mg/L chloramine	8-PC	Settled water dosed with 0.75 mg/L chloramine
9-CC	Settled water dosed with chloramine, then ozonated	9-PC	Settled water dosed with chloramine, then peroxone treated
10-CC	Settled water dosed with chloramine, ozonated, then pH adjusted to pH 8.0, dosed with chlorine for 10 minutes, and followed by ammonia to form chloramine. This sample will be stored at room temperature for 24 hrs before shipping.	10-PC	Settled water dosed with chloramine, peroxone treated, then pH adjusted to pH 8.0, dosed with chlorine for 10 minutes, and followed by ammonia to form chloramine. This sample will be stored at room temperature for 24 hrs before shipping.
11-DV	Del Valle Plant Effluent		
12-SW	Settled water, pH adjusted to 8, dosed with chlorine for 10 minutes, and followed by ammonia to form chloramine. This sample will be stored at room temperature for 24 hrs before shipping.		

Instructions:

Day 1 (Monday, October 6th)

1. Start up both trains of pilot plant with raw water, adding chloramine to each train. Establish the following conditions:
    a. CC flow = 6.5 gpm, PC flow = 3.5 gpm
    b. Chlorine dose = 0.75 mg/L to inlet of both contactors
    c. Ammonia dose = 0.19 mg/L to inlet of both contactors
2. Allow to stabilize for 10 minutes
3. Collect the following samples
    a. 1-RW from pilot plant influent tap
    b. 2-CC from effluent of first cell (CC-1)
    c. 2-PC from mid-point of pipeline contactor (PC-3)
4. Start ozone feed to both contactors. Use an ozone dose of 2 mg/L for both contactors
5. Start peroxide feed to pipeline contactor at a dose of 1 mg/L
6. Allow to stabilize for 20 minutes
7. Collect the following samples
    a. 3-CC from the effluent of the conventional contactor (CC-5)
    b. 3-PC from the effluent of the pipeline contactor (PC-6)
    c. Fill two 1-L amber bottles, one from the effluent of each contactor (collect exactly one liter in each bottle). These will be used for 4-CC and 4-PC; set aside
8. Turn chlorine and ammonia feed off to both contactors
9. Start acid feed to source tank, adjusting until pH reaches 7.0
10. Allow to stabilize for 30 minutes (three HRT through contactor)
11. Collect the following samples
    a. 5-CC from effluent of conventional contactor (CC-5)
    b. 5-PC from effluent of pipeline contactor (PC-6)
    c. Fill two 1-L amber bottles, once from the effluent of each contactor (collect exactly one liter in each bottle). These will be used for 6-CC and 6-PC; set aside
12. Switch source water to pilot plant from raw to settled water
13. Collect sample 7-SW from source water tank. At the same time, collect exactly 1-L of settled water into a 1-L amber glass bottle, this will be used for 12-SW
14. Start up chlorine and ammonia feeds to each contactor
    a. Chlorine dose = 0.75 mg/L
    b. Ammonia dose = 0.19 mg/L
15. Allow to stabilize for 10 minutes
16. Collect the following samples
    a. 8-CC from effluent of first chamber (CC-1)
    b. 8-PC from mid-point of pipeline contactor (PC-3)
17. Start ozone feed to both contactors at 1.0 mg/L
18. Start peroxide feed to pipeline contactor at 0.5 mg/L
19. Allow to stabilize for 20 minutes
20. Collect the following samples
    a. 9-CC from effluent of conventional contactor (CC-5)
    b. 9-PC from effluent of pipeline contactor (PC-6)

    c. Fill two 1-L amber glass bottles, one from each contactor (collect exactly one liter in each bottle). These will be used for 10-CC and 10-PC; set aside

21. Collect sample 11-DV from plant effluent tap into DBP bottle
22. Shut down both contactors and all chemical feeds
23. Take the seven 1-L bottles (4-CC, 4-PC, 6-CC, 6-PC, 10-CC, 10-PC, and 12-SW) to the lab
24. Place the 13 filled 60-mL DBP samples in the refrigerator (those starting with 1, 2, 3, 5, 7, 8, 9, 11)
25. For bottles 6-CC, 6-PC, 10-CC, 10-PC, and 12-SW perform the following steps:
    a. Place bottle on magnetic stirrer, add stir bar and mix
    b. Make sure pH probe is clean, place pH probe in bottle
    c. Slowly add caustic solution and measure pH. Continue adding caustic solution until pH reaches 8.0 ± 0.2
    d. Continue mixing for 5 more minutes, ensure that pH is stable at 8.0 ± 0.2
    e. Measure and record pH of each bottle

Sample ID	**pH after caustic addition**
6-CC	8.06
6-PC	8.04
10-CC	8.01
10-PC	7.98
12-SW	7.96

26. For all seven samples in amber bottles, perform the following steps:
    a. Add 2.5 mg of hypochlorite, gently stir
    b. Wait 10-minutes
    c. Add 0.63 mg of ammonia, gently stir
    d. Cap bottle and store at room temperature overnight
27. Make sure there is sufficient frozen blue ice in freezer, add more if needed

Day 2 (Tuesday, October 7th)

1. Twenty-four hours after completion of step 26, measure and record the following from each amber glass bottle: pH, temperature, total chlorine residual

Sample ID	**temperature**	**pH**	**Total chlorine, mg/L**
4-CC	20.7	2.01	1.01
4-PC	20.6	7.61	0.53
6-CC	20.6	7.86	0.82
6-PC	20.6	7.87	0.12
10-CC	20.6	7.77	0.75
10-PC	20.6	7.73	0.30
12-SW	20.6	7.65	1.10

2. Pour samples from each of the 1-L bottles into the corresponding 60-mL DBP bottles
3. Pack all 20 60-mL sample bottles in ice chest and add frozen blue ice
4. Ship ice chest via overnight carrier to Clemson University

APPENDIX D
DATA FROM SIMULATED DISTRIBUTION SYSTEM DBP TESTS

Simulated Distribution System Testing Results

						Chlorine Dose, mg/L			1-hr free Chlorine Residual, mg/L			24-hr total Chlorine Residual, mg/L			N Concentration, mg/L			THMs Formed, ug/L			HAA5 Formed, ug/L		
Date	source	pH	Conventional Contactor Ozone Dose, mg/L	Pipeline Contactor Ozone Dose, mg/L	Pipeline AOP Contactor H2O2 Dose, mg/L	Source Water	Conventional Contactor Effluent	Pipeline AOP Contactor Effluent	Source Water	Conventional Contactor Effluent	Pipeline AOP Contactor Effluent	Source Water	Conventional Contactor Effluent	Pipeline AOP Contactor Effluent	Source Water	Conventional Contactor Effluent	Pipeline AOP Contactor Effluent	Source Water	Conventional Contactor Effluent	Pipeline AOP Contactor Effluent	Source Water	Conventional Contactor Effluent	Pipeline AOP Contactor Effluent
6/4/2008	raw	7.8	1.8	2.5	2	5.0	5.0	5.0	0.95	2.06	1.72	3.89	3.53	3.09	0.02	0.15	0.00	99.8	71.7	82.6	42.2	31.1	37.9
6/10/2008	raw	8.1	4	4	0.8	3.5	3.5	3.5	0.98	0.96	0.96	0.93	0.94	0.34	0.17	0.10	0.07	98.0	74.7	82.9	29.0	21.9	22.3
7/11/2008	raw	7.7	2.5	2.5	1.3	2.4	2.4	2.4	0.55	0.51	0.49	0.51	0.34	0.42	0.09	0.07	0.03	68.2	62.1	63.9	23.0	18.9	17.2
7/22/2008	raw	7.9	2.5	2.5	1.3	3.0	3.0	3.0	1.67	1.66	1.62	1.67	1.51	1.79	0.11	0.14	0.03	67.3	42.0	44.2	25.5	19.9	21.2
8/5/2008	settled	6.6	1.5	1.5	0.75	3.0	3.0	3.0	2.16	2.46	2.64	1.07	1.06	1.42	0.15	0.22	0.25	37.8	19.7	19.9	10.1	7.9	8.0
9/3/2008	settled	6.7	3	3	3	2.2	2.2	2.2	1.36	1.78	0.03	0.46	0.82	0.07	0.29	0.41	0.00	60.7	43.1	6.4	11.1	10.9	4.2
9/16/2008	settled	6.8	2	2	2	3.4	3.4	3.4	1.86	2.32	0.07	1.57	1.59	0.19	0.12	0.16	0.04	71.3	46.1	12.2	13.6	10.3	1.1
9/30/2008	settled	6.7	1.5	1.5	0.75	3.6	3.6	3.6	1.06	2.62	1.15	0.14	1.73	0.83	0.00	0.28	0.13	97.1	36.4	56.3	10.6	9.3	9.7
10/28/2008	raw	7.8	3	3	1.5	3.5	3.5	3.5	0.97	0.95	0.94	0.94	0.93	0.78	0.12	0.18	0.21	102.0	86.4	81.2	23.4	17.7	19.1