

# **MODIFICATIONS FOR IMPROVED WATER QUALITY IN ARLINGTON, TEXAS**

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## **Abstract**

The City of Arlington began experiencing atypical water quality problems beginning in 1999 with the implementation of Ozonation and Biofiltration. These problems included high chloramine residual decay rates, system nitrification and manganese in the finished water that were linked to water produced at the Pierce-Burch South Water Treatment facility. As a result of a review of existing data and literature; pilot plant and “bottle” testing, it was determined that improvements could be made to the water quality through treatment plant modifications. These modifications include both design and process changes including:

- Process changes to how plant filters are taken in and out of service
- Modifications of the filter backwash to non-chloraminated water
- Modifications to the chemical feed points

The results of these changes have led to significant water quality improvements.

## **KEY WORDS**

Ozone; Ozonation; Biofiltration; Chloramine; Nitrification; Water Quality; Manganese; Contact time; pH; Mixing energy; Biomass

## **Introduction**

The City of Arlington owns and operates two potable water treatment facilities: Pierce-Burch (PB) and John Kubala (JK). In 1999, coincident with the startup of the ozone and biofiltration processes, atypical water quality problems became evident including high chloramine residual decay rates, nitrification in the distribution system and elevated levels of manganese in the finished water. An investigation of these issues was undertaken by the water treatment staff beginning in the fall of 2003 beginning with a review of the City's existing data from the period of October 2001 until September 2003.

The Pierce-Burch South (PBS) plant has a capacity of 75 MGD. The last major modification to the plant was in 1999 when ozonation and biofiltration were added to the conventional processes. These processes were not added to PBN. The ozonation process includes both pre and intermediate ozonation. The biofiltration process is accomplished using granular activated carbon (40 inches) along with a layer of sand (6 inches). Chlorine, sodium hydroxide, fluoride and ammonia are all added post-filtration.

The JK plant has a capacity of 65 MGD. In 1999, ozonation and biofiltration processes were added to the plant at the same time as PBS. The JK and PBS plants use almost identical treatment processes although the process units have some physical differences. One example of this is that the biofiltration process at JK is accomplished using a total of 56 inches of media; 48 inches of granular activated carbon along with 8 inches of sand. No additional chemicals are used for taste and odor treatment at PBS or JK because of the effectiveness of the ozonation processes.

The raw water is supplied to the PB plants using a pump station located on Lake Arlington. The Lake Arlington source water is from natural runoff that is heavily supplemented by water from the Tarrant Regional Water District system (TRWD). The TRWD system pumps water from Richland Chambers, Cedar Creek and Benbrook which are all man-made surface reservoirs. The JK plant receives water directly from the TRWD pipelines. The water qualities from all of these reservoirs are very similar.

The City of Arlington water distribution system is divided into two major pressure planes, the upper (UPP) and the lower (LPP). Generally, the LPP is served by the PB plants and the UPP by the JK plant. There is mixing of the water using a booster pump station (PB to the UPP) and by the use of transfer valves (JK to the LPP). JK generally operates at a near maximum production rate as water production costs are significantly less at JK. After the 2002 expansion of JK increased its capacity to 65 MGD, the practice of shutting down the PBS plant during the low demand winter months was implemented. During these months, JK provides 100 percent of the City's supply.

Studies by Wilczak et al (2003) show that the fastest chloramine formation occurs at pH of 8.3 and that the slowest decomposition occurs above pH 8.0. Longer contact times with free chlorine (45 minutes versus 1 minute) are stabilizing to the chloramine residual, (Wilczak et al, 2003). The time required for the reaction between chlorine and ammonia is a treatment variable strongly affected by pH and temperature. While the optimum pH for the formation of monochloramine is 8.3, at pH values on either side of 8.3, the rate of reaction falls off dramatically, (Kirmeyer et al, 2004). Other studies show that mixing affects chloramine formation. Mixing can be accomplished with physical or mechanical mixers however; a chlorine solution will be completely mixed within 10 diameters of pipe length without any mechanical mixers provided certain design criteria are followed, (White, 1999).

Research indicates that the current PB filter practices (chloraminated backwashing and randomly taking filters in and out of service) are harmful to the filter biomass. A study by Ahmad et al (1998) demonstrates that using chlorinated backwash water is detrimental to biofilter performance and will impair the removal of AOC and nonpurgeable organic carbon by the biofilters, (Ahmad et al, 1998). During shutdown (of the biological filters), even if the filters remain submerged, the decreasing amount of nutrients in the surrounding stagnant water may compromise the biomass as well as the removal of biodegradable organic matter and nitrification. After filter shutdown, the dissolved oxygen concentrations in the filters can decrease to 2 mg/L within a few hours eventually creating anaerobic conditions, (Niquette et al, 1998).

It has been shown that Iron (Fe) and manganese (Mn) can be removed using biological means. The abilities of certain types of bacteria to absorb/adsorb dissolved Fe and Mn, reducing them using enzymatic/catalytic action, has long been known. The biological treatment process can encourage the growth and maintenance of large colonies of these bacteria, where they can act on the dissolved Fe and Mn. The bacterial action oxidizes the Fe and Mn, and the resulting precipitates are trapped within the surrounding filter medium. Success (of this process) depends on creating the right environmental conditions within the filter to permit the most beneficial bacteria to develop and maintain strong colonies. The filters must not be exposed to disruptive amounts of compounds toxic to the biomass including chlorine compounds, hydrogen sulfide, heavy metals, ammonia nitrogen, phosphates, organics and hydrocarbons. (It has also been shown that) the startup of a new biological Mn removal plant may take 2-8 weeks to develop sufficient numbers of organisms (for successful Mn removal), (Sommerfeld, 1999).

As was previously mentioned, the JK and PBS plants have physical design differences including the layouts of the filter effluent channels and where the post-filtration chemicals are added. Table 1 illustrates the free chlorine contact times for the PBS and JK plants and shows that the JK contact time is about 6 times greater than PBS.

**Table 1.** Chlorine to Ammonia detention times

MGD flow	Detention time in minutes		
	PBS*	JK	Difference
15	1.07	6.00	4.93
20	0.80	4.50	3.70
30	0.53	3.00	2.47
40	0.40	2.25	1.85
50	0.32	1.80	1.48
60	0.27	1.50	1.25
PBS	X	5.6	= JK
*PBS Cl2 feed point is for filters 1- 4 only. Filters 5-20 have reduced detention times			

Also mentioned, is the fact that these plants use almost identical treatment processes. One major process difference between the plants is the source water used for the filter backwash process. Backwashing of the filters at PB is accomplished using the finished water containing all the post filtration chemicals (chloraminated). JK uses backwash water that has been filtered and does not contain any of the post filtration chemicals (nonchloraminated). Another difference is that the PBS filters are frequently placed in and out of service due to the production rate fluctuations while the constant high production rates at JK require that all filters remain in service. The practice of shutting down PB for the winter months also magnifies this effect on the PBS filters.

## **METHODS AND MATERIALS**

### **Chloramine decay rates**

Decay rate analyses were performed by placing a 4 liter sample into amber screw cap bottles that had been washed and baked at 180 °C. Finished samples were collected at the entrance to the plant clearwells (where potable water is stored before being pumped into the distribution system). Other samples were taken throughout the plant processes and treatment chemicals were added as required. Adjustment of pH, when needed, was accomplished using a sodium hydroxide solution and was executed before the chloramination process. Chloramination was achieved using known solutions of sodium hypochlorite and ammonium chloride. The free chlorine contact time during this process before adding the ammonia solution was a minimum of one minute and all bottles were gently inverted 6 times after all chemical additions. Samples were kept in a continuous flow water bath using plant finished water to simulate the actual plant water temperatures. Additional mixing energy was provided by inverting the sample bottles additional times. Aliquots were taken from the bottle throughout the test after mixing by inverting the bottle six times and then pouring out

a sample. Total chlorine was measured using a Hach Chlorine Pocket Colorimeter II. Measurement of pH was performed using a standard pH electrode and meter.

*Note: Two analyses were performed to test the effects of removing the aliquots from a single 4 liter bottle versus using individual bottles for each aliquot. The first analysis performed during the May 10, 2004 series demonstrated that there was 0.2 mg/L greater loss in the bottle used for the aliquots versus the unopened duplicate bottle at 88 hours. The second analysis performed during the September 10, 2004 series resulted in 0.1 mg/L greater loss in the unopened duplicate sample bottles over the bottles being used to remove aliquots at 92 hours. These results indicate that use of individual samples bottles did not significantly improve test accuracy.*

### **Manganese analyses**

Samples for manganese analyses were collected in plastic bottles which were washed specifically for metals analyses. Samples were then preserved (hydrochloric acid) and set up using EPA method 200.2. For the initial filter survey, two Atomic Absorption Spectrophotometric methods were used: (Standard Methods, 18<sup>th</sup> edition, method 3111 B for sample concentrations above 25 µg/L and EPA method 200.9 for sample concentrations below 25 µg/L) by the City of Arlington Water Utilities Laboratory. After the initial survey, method 3111 B was used exclusively for analyses. The reporting limit for this method is 50 ug/L however, for purposes of this study, samples with less than this level were recorded as long as the absorbance exceeded 0.004 absorbance units.

### **Pilot Plant Testing**

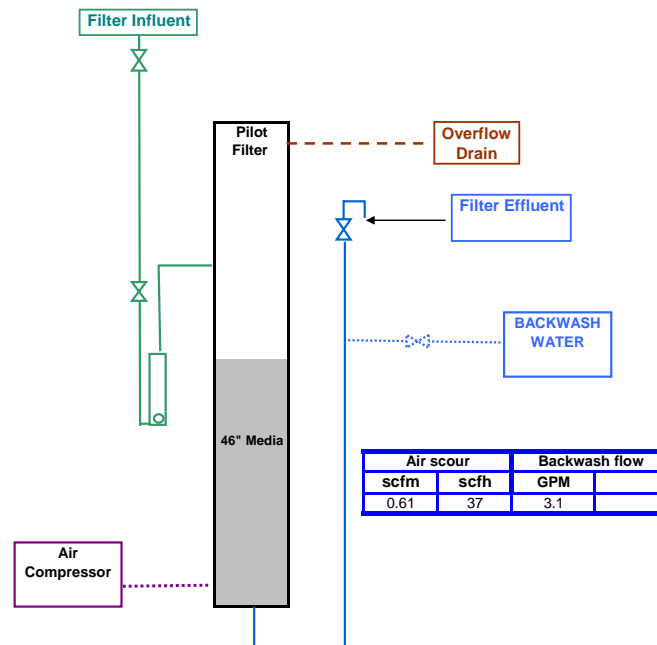
A pilot plant was constructed by staff using three 5.25 inch diameter Plexiglas tubes. (Figures 1-2) These filters were fitted with Leopold Type “S” filter bottoms identical to what was installed in the PBS and JK filters in 1999. Just prior to the pilot plant startup, the three filters were loaded with media (40 inches GAC, 6 inches sand to emulate the PBS filters). Filter #1 was loaded with GAC taken directly from an active JK filter. To harvest the GAC from the JK filter, a coring device was used to insure that the biomass obtained was representative (top to bottom). Filters #2 and #3 were loaded with GAC taken from a PB filter (top 24 inches) that had been out of service and “dry” for approximately seven (7) months. A small air compressor was installed for the air scour process during backwash. Filters #1 and #2 were water backwashed using the PBS filter effluent (no post filtration chemicals, i.e. nonchloraminated). A small pump was used to provide the needed pressure for the backwash. Filter #3 was backwashed using PBS finished water under normal system pressure (chloraminated). The influent flow of the pilot plant filters was adjusted so that the biomass received a steady flow of nutrients and oxygen. As a result, a minimal flow rate was used and in using this strategy, it was only necessary to backwash the filters once daily. The backwash process first used air scour for four minutes and then water for five minutes.

Flows of air and water were regulated to provide a bed expansion of approximately 25 percent. After backwashing, the filters were returned to service and shrouded to keep light from reaching the media through the sides of the Plexiglas filters. The pilot plant was designed so that Filter #1 would simulate treating PBS water with the JK biofilter processes; Filter #2 would simulate a PBS filter that was backwashed with non-chloraminated water; Filter #3 would simulate the “normal” PBS filter backwashing processes. The plant was in operation from July 13 until September 3, 2004.

### Full Scale Non-chloraminated backwash

The normal supply of filter backwash water for PBS comes from the PBS clearwells (chloraminated finished water). Based on the positive pilot plant results, and after discussions with the Texas Commission on Environmental Quality, implementation of full-scale non-chloraminated backwashing of the PBS filters using filtered water was implemented on August 26, 2004.

**Figure 1.** PBS Pilot Plant Diagram



**Figure 2.** PBS Pilot Plant Photo



## **RESULTS**

### **Review of Existing Data**

The results of this review indicated that the majority of decay, nitrification and manganese problems could be linked to water produced by the PBS Water Treatment Plant. Results from this data included:

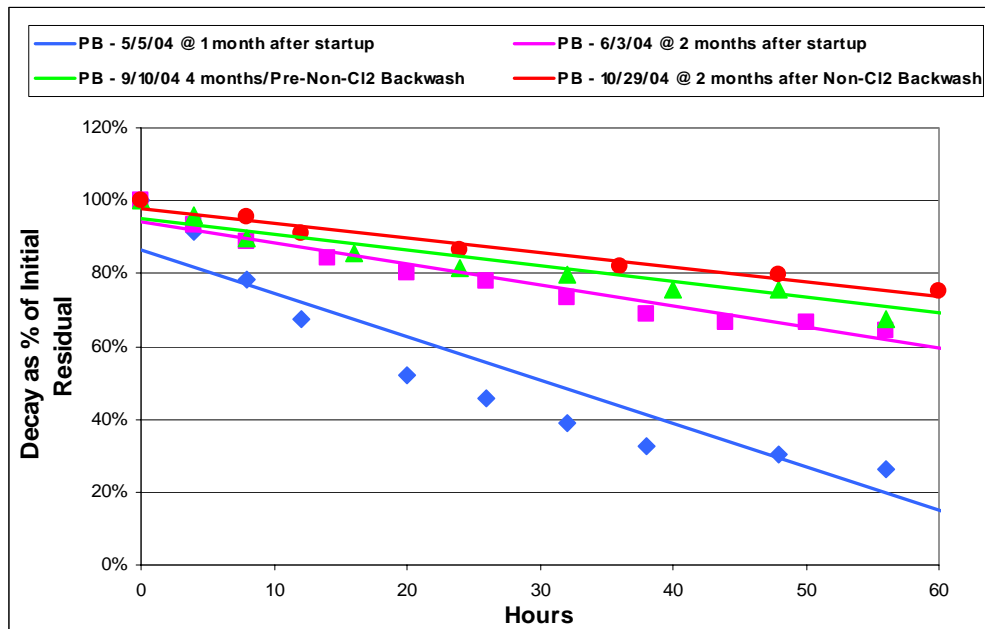
1. Abnormally low total chlorine residuals and data indicative of nitrification were discovered in only the Lower Pressure Plane (LPP) sites and elevated tanks when the majority of the supply was PBS water.
2. The total chlorine decay rate in the LPP was an average of 100 percent greater than the Upper Pressure Plane (UPP) decay rate when majority of the supply was PBS water. This rate was determined by comparing the monthly averages of the residuals from the finished water at the plants versus distribution system sample residuals in each pressure plane.
3. During the period of October 2003 through August 25, 2004, approximately 25 percent of the PBS finished water samples had detectable amounts of manganese. In comparison, the JK finished water had no samples with detectable amounts for the same time period.

## Chloramine Decay Models

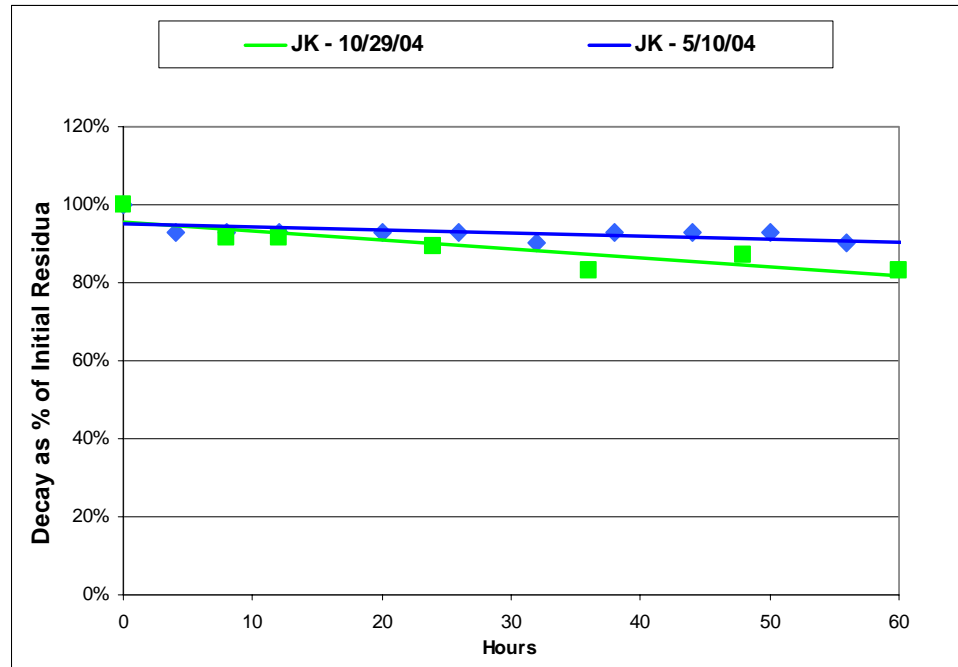
### ***PBS and JK Finished Water***

The PBS plant was started on April 4, 2004 after a 4 month winter shutdown. The PBS filters remained dry during this period and were backwashed several times to prepare them for the startup. On May 5, an initial chloramine decay analysis was performed on the PBS finished water. The results showed a residual loss of 85% after 60 hours. The June 3 sample showed that the residual decay had reduced to a 40% loss. This is indicative of improved biofilter performance even using chloraminated backwash water. The September 10 sample showed the residual decay had reduced to a 30% loss. At this point, non-chloraminated filter backwash was implemented at PBS based on the pilot plant results which showed the potential to improve the chloramine stability and prevent manganese breakthrough. The October 29 sample showed the residual decay had been reduced by an additional 5% to a total loss of 25%. Similar chloramine decay analyses were run on JK finished water. On May 10, the residual loss was 10% for the 60 hour time interval. The October 29 analysis showed the loss to be 17%. (Figures 3-4). The additional losses were most likely the result of the decline in free chlorine contact time (-61%) due to increased plant flow rates and the increase in plant water temperature (+5%).

**Figure 3.** PBS finished water chloramine decay comparison



**Figure 4.** JK finished water chloramine decay comparison



(Table 2) illustrates chloramine decay versus free chlorine contact time. These are solely a function of the changing plant flow rates. These results indicate that as free chlorine contact time increased (flow rate decreased), the chloramine decay rate decreased. At PBS, it is assumed that much of this improvement was a function of the maturation of the biomass as well as the improved free chlorine contact times. No biomass measurements were performed during this study.

**Table 2.** Chloramine decay versus free chlorine contact time

Site/Date	Plant flow rate (MGD)	Free Cl <sub>2</sub> contact time (min.)	% Cl <sub>2</sub> Decay @ 60 hrs	Total Cl <sub>2</sub> residual left @ 60 hrs (%)	Water Temp (F)
PBS 5/5/04	28	0.57	85	15	74
PBS 6/3/04	15	1.07	40	60	80
PBS 9/10/04	14	1.14	30	70	82
PBS 10/29/04	12	1.34	25	75	78
JK 10/29/04	49	1.84	17	83	76
JK 5/10/04	19	4.74	10	90	72

**PBS chloramine decay simulation: Series 1 (27 May 04)**

The sample results indicate that the plant processes and not the raw water are the cause of the higher chloramination decay rates. Results also indicate that adjustment of the

pH to nearer the target of 8.3 and increasing the free chlorine contact time from 1 to 10 minutes lessened the decay rate. (Table 3).

**Table 3.** Series 1 (27-May-04 @ 28 hours)

Sample	Raw	Filter #7	Finished	Filter #5	Filter #5	Filter #7
pH	8.0	8.5	8.1	7.7	7.7	7.7
Free Cl <sub>2</sub> contact time (minutes)	1	1	N/A	10	1	1
Chloramine decay (mg/L)	-0.4	-0.9	-1.0	-1.4	-1.6	-1.9

**PBS chloramine decay simulation: Series 2 (3 June 04)**

Samples in this series again indicate that pH adjustment and longer free chlorine contact times lessened the decay rate. In this simulation, the 10 minute and 4 hour contact time samples indicate no difference in decay rate. Some samples were also analyzed for total trihalomethanes (TTHM). (Table 4).

**Table 4.** Series 2 (3-Jun-04 @ 92 hours)

Sample	Filter #5	Filter #5	Filter #5	Filter #5
pH	8.1	8.1	8.1	7.7
Free Cl <sub>2</sub> contact time (minutes)	10	240	1	1
Chloramine decay (mg/L)	-1.3	-1.3	-1.7	-2.9
TTHM (ug/L)	N/A	48.0	7.0	N/A

**PBS chloramine decay simulation: Series 3 (8 June 04)**

Samples in this series again compare results of different contact times for pH adjusted samples. The samples continue to indicate improvement as contact time increases although, the 5 and 10 minute results were similar. (Table 5).

**Table 5.** Series 3 (8-Jun-04 @ 84 hours)

Sample	Filter #7	Finished	Filter #7	Filter #7	Filter #7	Filter #7
pH	7.9	8.1	8.0	7.9	8.0	7.9
Free Cl <sub>2</sub> contact time (minutes)	60	N/A	10	5	2	1
Chloramine decay (mg/L)	-1.2	-2.1	-2.2	-2.2	-2.5	-2.9

**PBS chloramine decay Simulation Series 4 (22 June 04)**

Samples in this series compare contact times and mixing energies between samples. In this simulation, there was no improvement trend as a result of increased mixing energy. This may indicate that the standard mixing by inversion 6 times is sufficient energy for this reaction. (Table 6).

**Table 6.** Series 4 (22-Jun-04 @ 72 hours)

Sample	Filter #7	Filter #7	Filter #7	Filter #7	Filter #7	Filter #7	Filter #7
pH	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Free Cl <sub>2</sub> contact time (minutes)	2	5	2	2	1	1	1
Mix by inversion (times)	6	24	12	24	6	24	12
Chloramine decay (mg/L)	-2.4	-2.5	-2.6	-2.6	-2.8	-2.8	-2.9

## PBS Pilot Plant

### Series 1 (July 14, 2004)

Chloramine decay analyses were performed after the plant had been in service for approximately 30 hours. The results clearly indicate that the JK media in Filter #1 had the best performance with an average residual loss of 0.6 mg/L (16%) over a 92 hour time period. The PB media in Filters #2 and #3 averaged losses of 2.6 mg/L (70%). All samples were pH adjusted in an attempt to reach the 8.3 target. Some interesting data indicated that the Filter #1 effluent sample pH was 7.1 while filter #2 and #3 effluent sample pHs were lower at 6.7 and 6.8 respectively. In all cases, the 5 minute free chlorine contact time improved the stability over the 1 minute contact time. The PBS filter #11 treating the same water had a decay of 1.7 mg/L. (Table 7).

**Table 7.** Pilot Plant Series 1 (14-Jul-2004 @ 92 hours)

Sample	Filt. #1	Filt. #1	Filt. #2	Filt. #2	Filt. #3	Filt. #3	PBS #11
pH	8.8	8.8	7.4	7.4	8.5	8.5	8.9
Free Cl <sub>2</sub> contact time (minutes)	1.0	5.0	1.0	5.0	1.0	5.0	1.0
Chloramine decay (mg/L)	-0.7	-0.5	-3.1	-2.1	-3.3	-1.9	-1.7

### Series 2 (July 28, 2004)

This series was performed after the pilot plant had been in service for 15 days. In this series, Filter #1 continued to have the best results with an average loss of 0.55 mg/L (15%). Filter #2 was much improved with an average loss of 0.95 mg/L (21%). The filter #3 average loss was 2.6 mg/L (68%), similar to the first series. Again, all samples were pH adjusted to near the 8.3 target. The pilot filter effluent pH of all three filters measured approximately 7.4. Also, in this series, only the filter #3 sample indicated improvement with the additional free chlorine contact time. The PBS finished sample indicated a decay of 2.2 mg/L (49%). The estimated free contact time on this sample was less than 40 seconds. (Table 8).

**Table 8.** Pilot Plant Series 2 (28-Jul-2004 @ 92 hours)

Sample	Filt. #1	Filt. #1	Filt. #2	Filt. #2	Filt. #3	Filt. #3	Finished
pH	8.2	8.2	8.2	8.2	8.2	8.2	N/A
Free Cl <sub>2</sub> contact time (minutes)	1.0	5.0	1.0	5.0	1.0	5.0	0.7
Chloramine decay (mg/L)	-0.4	-0.7	-0.8	-1.1	-2.8	-2.4	-2.2

### Series 3 (August 4, 2004)

This series was performed after the pilot plant had been in service for 22 days. In this series, Filter #1 average loss was 1.85 mg/L (33%). Filter #2 average loss was 2.05 mg/L (39%). Filter #3 average loss was 4.2 mg/L (70%), again the same as the first series. All samples were pH adjusted to near the 8.3 target. In this series, all 5 minute free chlorine contact time chloramines were more stable than the 1 minute contact samples. The PBS finished water indicated a decay of 2.2 mg/L (40%). The estimated free contact time on this sample was less than 55 seconds. A probable explanation for the higher pilot filter decay rates seen in this series was that Lake Arlington water quality was affected by heavy rains that occurred on July 28-29, 2004. The raw water turbidity was 70 nephelometric turbidity units (NTUs) on August 4, 2004. The average raw turbidity is normally less than 10 NTUs. (Table 9).

**Table 9.** Pilot Plant Series 3 (4-Aug-04 @ 92 hours)

Sample	Filt. #1	Filt.#1	Filt. #2	Filt. #2	Filt. #3	Filt. #3	Finished
pH	8.2	8.2	8.2	8.2	8.2	8.2	N/A
Free Cl <sub>2</sub> contact time (minutes)	1.0	5.0	1.0	5.0	1.0	5.0	0.9
Chloramine decay (mg/L)	-2.1	-1.6	-2.8	-1.3	-5.1	-3.3	-2.2

### Series 4 (August 10, 2004)

This series was performed after the pilot plant had been in service for 28 days. In this series, Filter #1 average loss was 1.05 mg/L (19%). Filter #2 average loss was 1.65 mg/L (28%). Filter #3 average loss was 2.6 mg/L (46%). All samples were pH adjusted to near the 8.3 target. In this series, the 5 minute free chlorine contact time samples were more stable than the 1 minute contact samples except for Filter #1. The PBS finished water sample indicated a decay of 2.4 mg/L (51%). The estimated free contact time on this sample was less than 40 seconds. Again a probable explanation for the higher pilot filter decay rates seen in this series was that the raw water turbidity was over 60 NTUs at the time of testing. (Table 10).

**Table 10.** Pilot Plant Series 4 (10-Aug-04 @ 93 hours)

Sample	Filt. #1	Filt. #1	Filt. #2	Filt. #2	Filt. #3	Filt. #3	Finished
pH	8.2	8.2	8.2	8.2	8.2	8.2	N/A
Free Cl <sub>2</sub> contact time (minutes)	1.0	5.0	1.0	5.0	1.0	5.0	0.7
Chloramine decay (mg/L)	-0.9	-1.2	-1.7	-1.6	-2.7	-2.5	-2.4

**Series 5 (August 26, 2004)**

This series was performed after the pilot plant had been in service for 43 days. In this series, Filter #1 loss was 0.5 mg/L (10%). The filter #2 loss was 0.7 mg/L (15%). The filter #3 loss was 1.1 mg/L (22%). The results from this series were taken at 69 hours instead of the 92 hour target time period used in the previous 3 series. All samples were pH adjusted to near the 8.3 target. In this series, all samples were run using only the 1 minute free chlorine contact time. The PBS finished water sample indicated a decay of 1.4 mg/L (28%). The estimated free contact time for this sample was less than 70 seconds. (Table 11).

**Table 11.** Pilot Plant Series 5 (26-Aug-06 @ 69 hours)

Sample	Filt. #1	Filt. #2	Filt. #3	Finished
pH	8.2	8.2	8.2	N/A
Free Cl <sub>2</sub> contact time (minutes)	1.0	1.0	1.0	1.2
Chloramine decay (mg/L)	-0.5	-0.7	-1.1	-1.4

**Manganese**

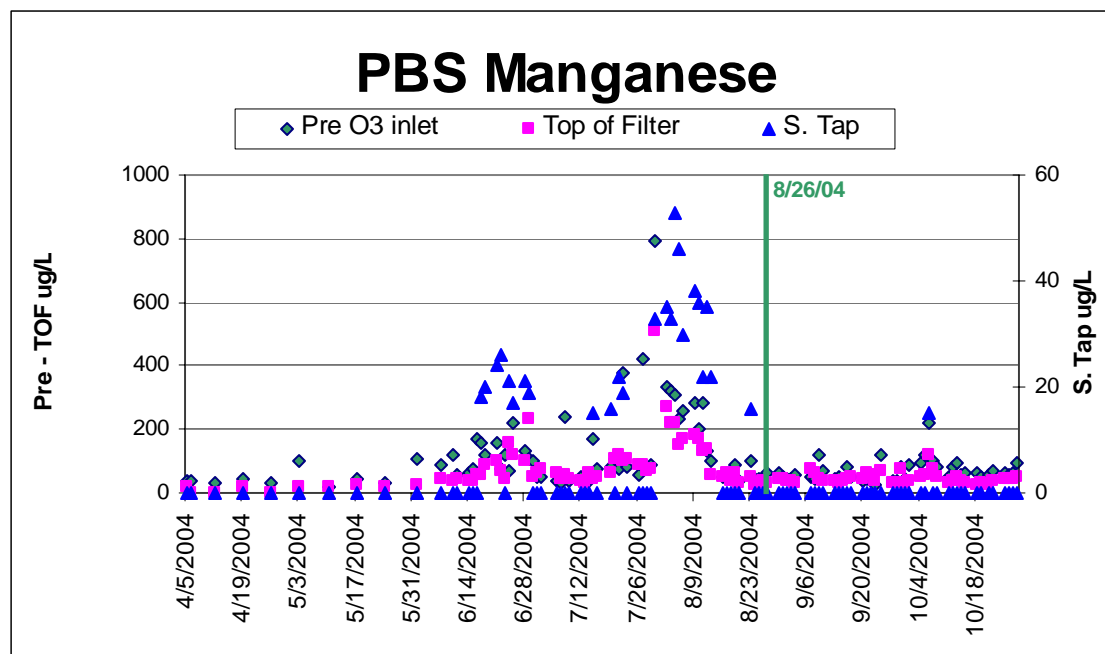
Results of the filter effluent samples from day one (July 14, 2004) of running the pilot plant demonstrate that Filter #1 removed the Manganese (Mn) while Filters #2 and #3 did not. After backwashing with non-chloraminated water for 9 days (July 22, 2004), samples from Filters #1 and #2 indicate no Mn detected while Filter #3 continues to allow Mn breakthrough. Day 23 (August 5, 2004) show similar results. Day 35 (August 17, 2004) indicate no Mn detected on any of the filters. It is unknown if this was the result of the low levels of Mn in the filter influent or the age of the filters providing enough biomass for removal. (Table 12) Based on the pilot filter results, the

process of using of non-chlorinated backwash water at PBS was initiated on August 26, 2004. From this date until the PBS winter shutdown (October 29, 2004), only 1 of 43 finished water samples had detectable manganese (2%). (Figure 5).

**TABLE 12.** Pilot Plant Filter Manganese Results (ug/L)

Sample	07/14/04	07/22/04	08/05/04	08/17/04
Raw	32	380	230	330
Top of Filter	61	100	150	60
Filter #1	ND	ND	ND	ND
Filter #2	20	ND	ND	ND
Filter #3	23	20	30	ND
<b>ND = None Detected</b>				

**FIGURE 5.** PBS Manganese (ug/L)



## **DISCUSSION**

Retrofitting an existing treatment plant with ozone and biofiltration should not be implemented without review of the potential water quality issues associated with these processes. Based on the available literature and the results from this study, improved water qualities are possible by incorporating the following recommendations:

1. Modification of the procedures for taking filters in and out of service. Ideally, biofilters should remain in service at all times. If this is not possible, investigate methods of pre-conditioning the filter biomass before filters are placed into service.
2. Modification of the chemical feed points to provide increased free chlorine contact times. Water quality results from the JK plant and almost every series that was run during this study demonstrated that increased free chlorine contact time produces more stable chloramines. These increased times must be balanced against the potential to increase disinfection by-products. The order in which chemicals are fed is important as they should provide adequate free chlorine contact time and a stable pH near the target of 8.3 at the ammonia addition point.
3. Modification of the backwash system to allow backwash with non-chloraminated water. The referenced literature as well as the JK finished water, the pilot plant and the plant scale non-chloraminated backwash results demonstrate the potential for improved chloramine stability as well as manganese control when the proper plant conditions are in place.

## **CONCLUSION**

The implementation of the ozonation and biofiltration processes to the Arlington water treatment facilities has had both positive and negative impacts on water quality. The addition of these processes resulted in many benefits including:

- The elimination of taste and odor complaints
- The reduction in total trihalomethane levels from an average of 50 ug/l to less than 10 ug/L.
- The reduction in haloacetic acid levels from an average of approximately 30 ug/L to less than 10 ug/L.

While the existing processes at the JK plant were amenable to the addition of these processes, the existing design and processes at the PBS plant resulted in some unforeseen negative impacts. Existing data, literature, and the analyses performed during this investigation demonstrate that solutions are available. A determination of

the exact mechanisms of these solutions was not within the scope of this study due to limited resources and the complexity of the chemical and biological processes utilized in the water treatment process. It is our belief that others may benefit from the methods utilized (especially the chloramine decay methods) in this study to understand and improve similar water quality challenges. It is also our hope that others may expand on this research to gain additional understanding of the impacted processes.

## **ACKNOWLEDGEMENT**

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