3. Review of Relevant Water Quality Data

The purpose of this chapter is to evaluate distribution system water quality data to answer the following questions:

- Is the orthophosphate treatment being implemented consistent with EPA's WQP goals?
- Has the orthophosphate treatment been successful at reducing lead in drinking water?
- Has the orthophosphate treatment had positive or negative impacts on bacteriological growth (with respect to both biofilm growth and nitrification) in DCWASA's distribution system?

Section 3.1 describes the water quality data obtained and reviewed for this report; Sections 3.2, 3.3, and 3.4 discuss the three questions above, respectively. This report reviews all available data (including non-compliance data) and, thus, does not attempt to confirm DCWASA's compliance with any Maximum Contaminant Level (MCL) or WQP defined by EPA. Conclusions based on the combined research findings for Chapter 2 and water quality data in this chapter are presented in Chapter 4 of this report.

3.1 Description of Dataset

Water quality data from January 2003 through December 2005 were obtained from EPA Region III and DCWASA. The data, originally organized in MS Excel files and summary reports, were uploaded into an MS Access database and organized by three main data types: "Monitoring Programs," "Sites," and "Sample Results." Each data type is described below. Once uploaded into the database, the files were checked to ensure no duplicate entries were created. Parameter names and units were standardized to facilitate ease of use in writing queries.

In addition to water quality data, we reviewed data from DCWASA's lead profiling program. All lead profiling data were obtained from DCWASA and organized in an MS Excel workbook. Section 3.3 provides a description of the lead profiling program and data types reviewed for this report.

Monitoring Programs

The data we received were generally associated with one of three DCWASA compliance monitoring programs:

- **Total Coliform Rule (TCR) monitoring**. DCWASA has approximately 65 TCR monitoring sites throughout District. It collects data from each site approximately once per week, usually generating between 250 and 300 samples per month, under an EPA approved monitoring plan;

- **Supplemental monitoring**. DCWASA used their hydraulic model to identify more than 25 supplemental monitoring sites, which are generally located in dead-end and low flow areas of the distribution system. The start of supplemental monitoring coincided with the start of orthophosphate treatment in August 2004. DCWASA monitored at supplemental sites per the monitoring plan submitted pursuant to the interim OCCT designation. They collect data at hydrants as well as inside tap locations (e.g., a restroom sink) at each site at least twice per month; and

- **LCR monitoring.** DCWASA has listed more than 100 tier 1 sites[1] in its EPA-approved LCR monitoring plan. LCR samples are collected by customers according to an instruction sheet provided by DCWASA. Customers collect a "first draw" sample from a cold water tap after at least a 6-hour stagnation period (either in the morning or after returning home from work). Then they collect a "second draw" sample after flushing the tap until the water becomes cold.

DCWASA and EPA also provided water quality data at alternative distribution system sites, which were often sampled in response to customer complaints, water quality problems, etc. These sites and samples were labeled "no program" in our database.

Sites

Site location is important in assessing the spatial (or locational) variability of water quality in the distribution system. The District of Columbia is divided into four geographic quadrants: Northwest (NW), Northeast (NE), Southwest (SW) and Southeast (SE), as shown in Exhibit 3.1.1. As described earlier in this report, DCWASA's distribution system consists of seven service areas, or pressure zones, based on elevation. These are the Low, 1st High, 2nd High, 3rd High, 4th High, (East and West), Anacostia 1st High, and Anacostia 2nd High. General correlations between quadrant and service area are as follows:

- NW, the most populated quadrant, is served primarily by the 1st, 2nd, and 3rd High pressure zones. The downtown portion of the quadrant is primarily served by the Low service area. NW contains the only 4th High lines, and shares the 2nd and 3rd High lines with NE;
- NE is served primarily by 1st High, 2nd High, and Low;
- SW is the smallest geographic area and is served primarily by the Low pressure lines; and
- SE is served primarily by Anacostia 1st High and Anacostia 2nd High.

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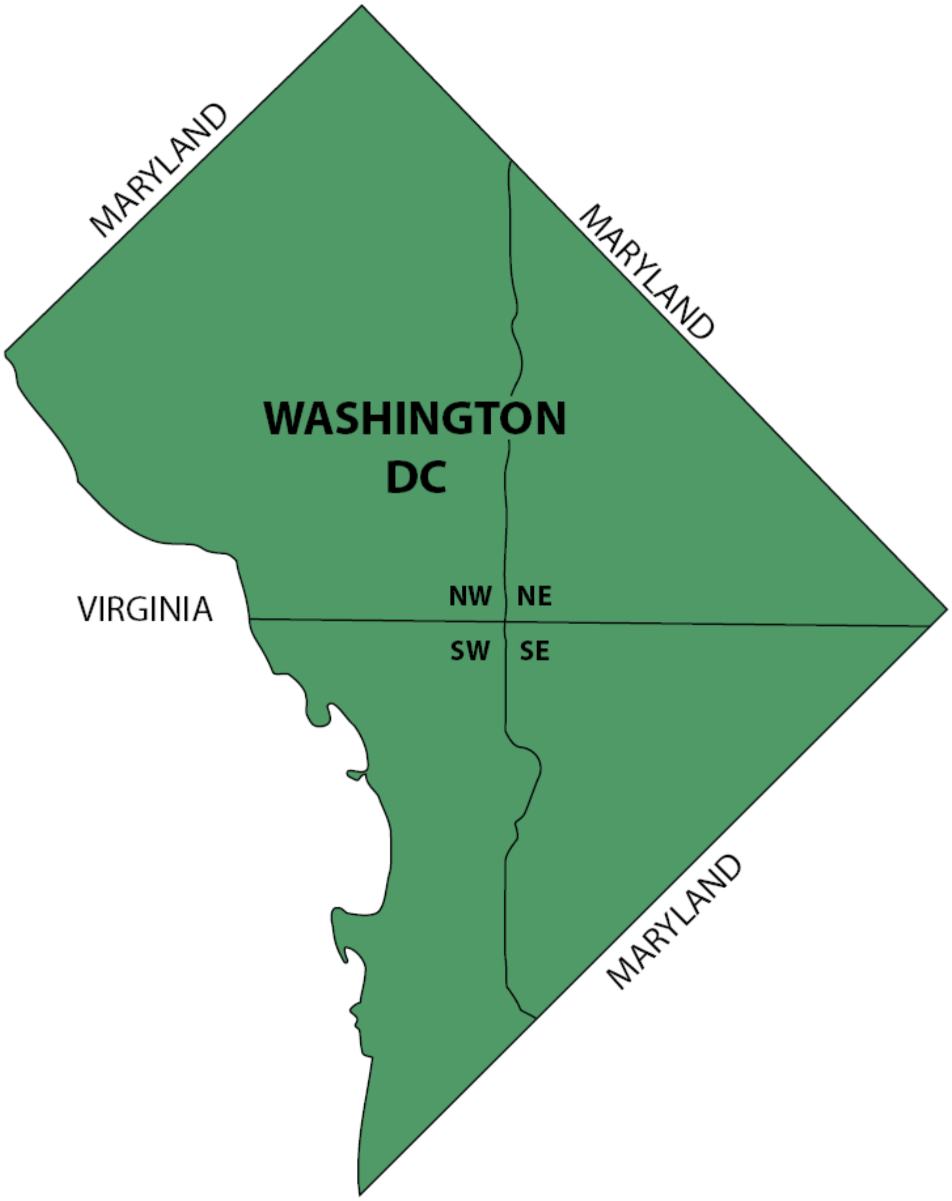
[1] Tier 1 sites are defined in the LCR as 1) single family homes containing copper pipes with lead solder that were installed after 1982 or single family homes containing lead pipes, and/or 2) homes that are served by an LSL.

Exhibit 3.1.1 Geographic Quadrants in D.C.



The primary information for all sample sites is the mailing address. In addition to address, both TCR and supplemental sites have unique ID numbers that begin with the service area designation (e.g., sites in the Low service area are designated "L-1," "L-2," and so on). Supplemental sites use the same numbering system as TCR sites except the ID number includes the acronym "BKJV." ("BKJV" is short for the name of the DCWASA contractor who selected these sites.) The LCR monitoring locations do not have ID numbers and thus do not include pressure zone information. Because service area information was not available for all sites, all spatial analyses of distribution system monitoring data were done according to city quadrant rather than service area.

Sample Results

Various WQPs were analyzed for each site. At supplemental and TCR sites, DCWASA generally collected total chlorine, pH, and temperature data on-site. The WA laboratory conducted analyses for coliforms (TCR sites only), HPCs, orthophosphate, free ammonia, nitrite, nitrate, and many other supplemental parameters required by EPA in their August 3, 2004 OCCT letter (see Appendix A).

If results exceeded an internal AL for a given WQP, DCWASA usually flushed and then re-sampled that same day until the parameter was below acceptable limits. When repeat samples occurred at a site on a single day, results were averaged to produce one value for that day.

For LCR compliance samples, the WA laboratory analyzed for total lead and total copper. Dissolved lead cannot be determined for these samples since the procedure requires immediate filtration.

3.2 Orthophosphate Treatment and WQP Monitoring

In August 2004, EPA approved the full-distribution-system application of orthophosphate in D.C., setting requirements for orthophosphate dose as well as other WQPs important to the maintenance of OCCT and monitoring of the distribution system for adverse effects, including pH, free ammonia nitrogen, and combined nitrite and nitrate nitrogen. Exhibit 3.2.1 summarizes WQP requirements and WQP optimal goals set by EPA for D.C.'s OCCT for both DCWASA and WA.[2] Under the interim OCCT designation, DCWASA is required to monitor for these parameters at identified TCR sites as well as at supplemental monitoring sites selected to represent the areas of the distribution system most likely to experience water quality problems.

Exhibit 3.2.1 WQPs and WQP Goals for DCWASA and WA

	DCWASA		**WA**	
	Interim WQPs	**WQP Goals**	**Interim WQPs**	**WQP Goals**
pH	7.7 ± 0.3	7.7 ± 0.1	7.8-7.9 ± 0.3	7.7 ± 0.1
Orthophosphate residual in tap samples	1.0-5.0 mg/L	3.0 mg/L	1.0-5.0 mg/L	3.0 mg/L*
Free Ammonia nitrogen	0.5 mg/L	0.2 mg/L		
Nitrate/ nitrite nitrogen	0.5 mg/L	< 0.1 mg/L		

* Dose needed to reach this residual in tap samples.
Source: EPA IOCCT Letter (Appendix A).

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[2] Virginia Department of Health set similar WQPs for Arlington County and Falls Church, VA.

The purpose of this section is to assess how well the corrosion control treatment is meeting the WQPs and WQP goals by reviewing DCWASA monitoring data. To gauge any temporal and/or geographic trends, all parameters are analyzed by month as well as by quadrant (NW, SW, SE, and NE). Charts comparing per-quadrant averages for ammonia, and nitrite/nitrate did not show significant spatial trends and are not included in this section.

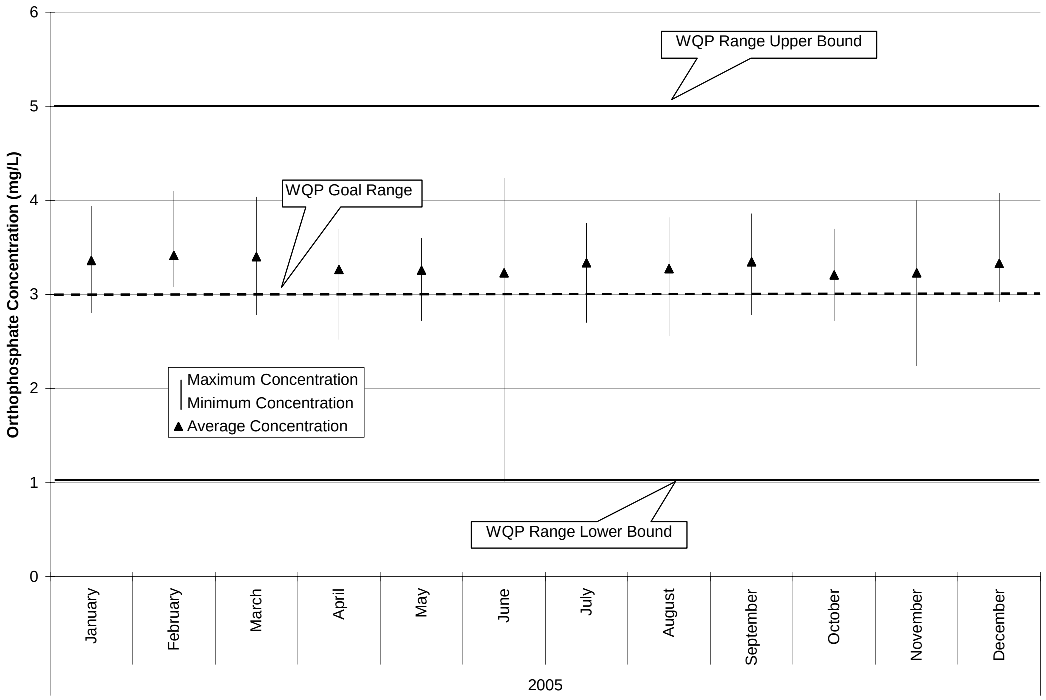
3.2.1 Orthophosphate Levels

Because WA made adjustments to the orthophosphate feed during the last several months of 2004, we evaluated orthophosphate levels for 2005 only. The dataset consists of more than 1,700 orthophosphate sample results from the distribution system during this time period, representing nearly 58 TCR and supplemental monitoring locations sampled once or twice per month at hydrants, taps, or both. Specifically, there were 30 TCR sites (all tap samples) and 28 supplemental monitoring sites (for most, samples were collected at both inside taps and hydrants). Only TCR sites (tap samples only) were subject to the interim OCCT WQPs.

Exhibit 3.2.2a shows monthly average, minimum, and maximum values for all geographic quadrants for TCR sites, tap samples only. Exhibit 3.2.2b shows monthly, maximum, and minimum orthophosphate values for taps and hydrant samples taken at both TCR and supplemental sites (supplemental sites are considered to be representative of the areas least likely to meet water quality goals). Exhibit 3.2.3 shows monthly averages by geographic quadrant. Exhibits 3.2.4 and 3.2.5 show average, minimum, and maximum levels by sample site for TCR and supplemental sites, respectively.

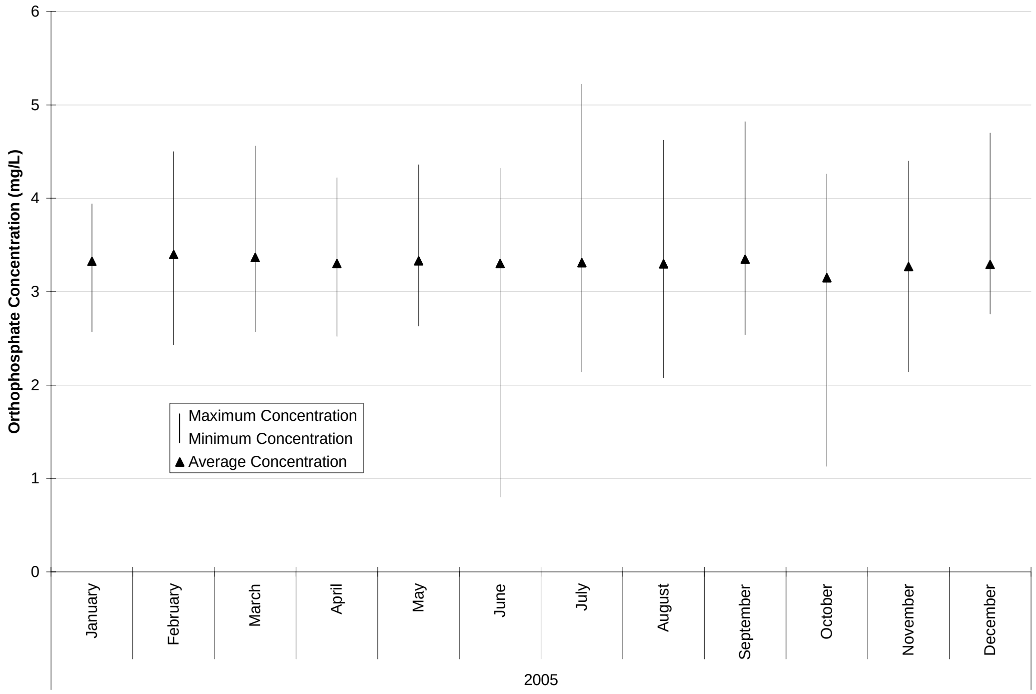
In general, the D.C. distribution system has consistently met the WQP goal for orthophosphate of 3.0 mg/L. Average orthophosphate levels for TCR sites were slightly above 3.0 mg/L for every month of 2005 and remained within the 1.0 – 5.0 mg/L range required by EPA's OCCT designation letter. Even when the "worst case" supplemental monitoring sites are considered along with TCR tap samples—as shown in Exhibit 3.2.2b—average orthophosphate levels remained consistently above 3.0 mg/L throughout 2005. D.C. experienced its lowest individual sample results for orthophosphate in June and October 2005 in the NW and SE quadrants of the city. This appears to be a result of a few isolated cases of very low orthophosphate readings, between 0.8 and 1.7 mg/L at two TCR and four supplemental sites. Exhibit 3.2.6 presents the lowest and second-lowest orthophosphate values for each of these sites. For all of these sites, the second lowest orthophosphate reading exceeded 2.5 mg/L, indicating that the chronic low orthophosphate levels were not a problem at these sites. For June 2005, repeat samples and samples taken at the same sites on the same day exhibited normal orthophosphate levels. For October 2005, other sites sampled on the same day reflected normal orthophosphate levels, while repeat samples at the same sites continually experienced low levels. These results could be caused by instrument or sampling error, but they also could represent a slug of water with low orthophosphate concentration.

Exhibit 3.2.2a Maximum, Minimum, and Average Orthophosphate Concentration by Month, TCR sites, Tap samples



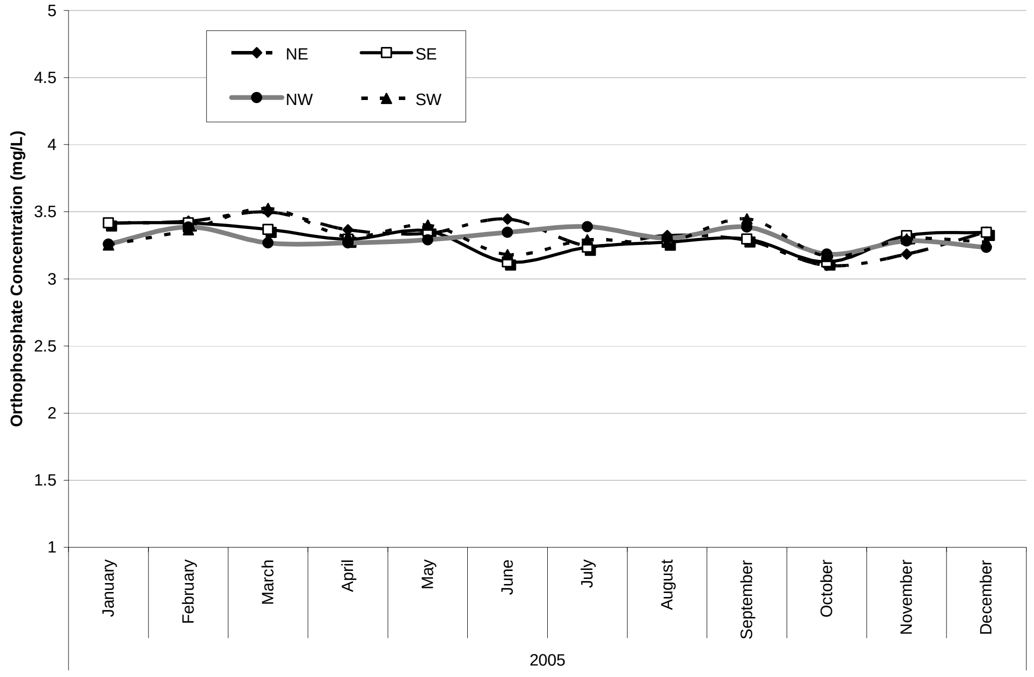
Source: TCR sites, tap samples only.

Exhibit 3.2.2b Maximum, Minimum, and Average Orthophosphate Concentration by Month, supplemental and TCR sites, tap and hydrant samples



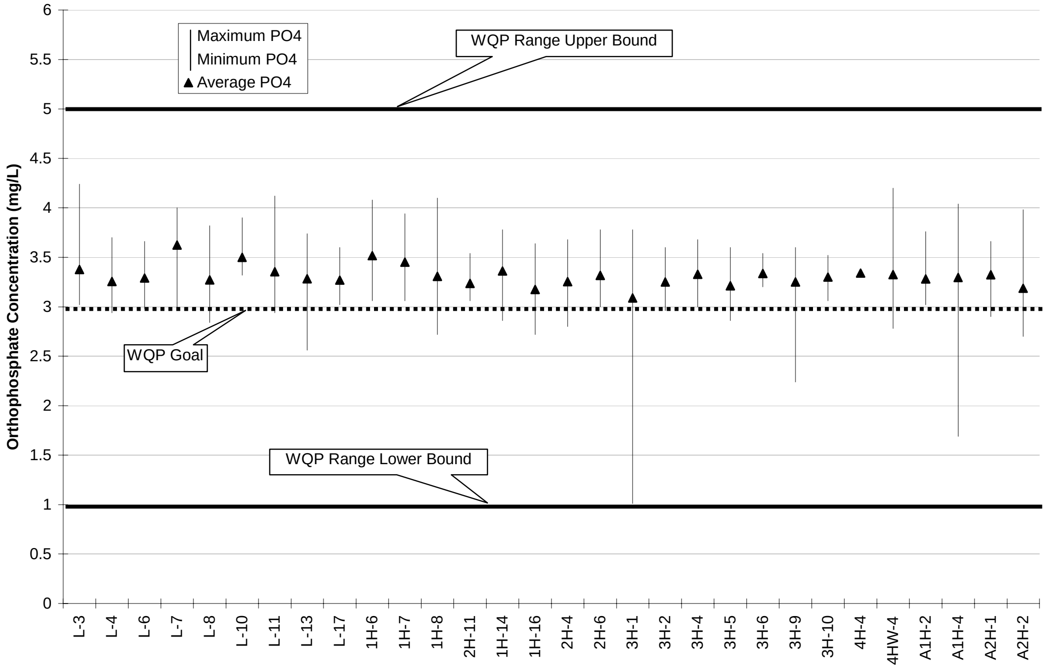
Source: Supplemental and TCR sites, taps and hydrants.

Exhibit 3.2.3 Monthly Average Orthophosphate Concentration by Quadrant



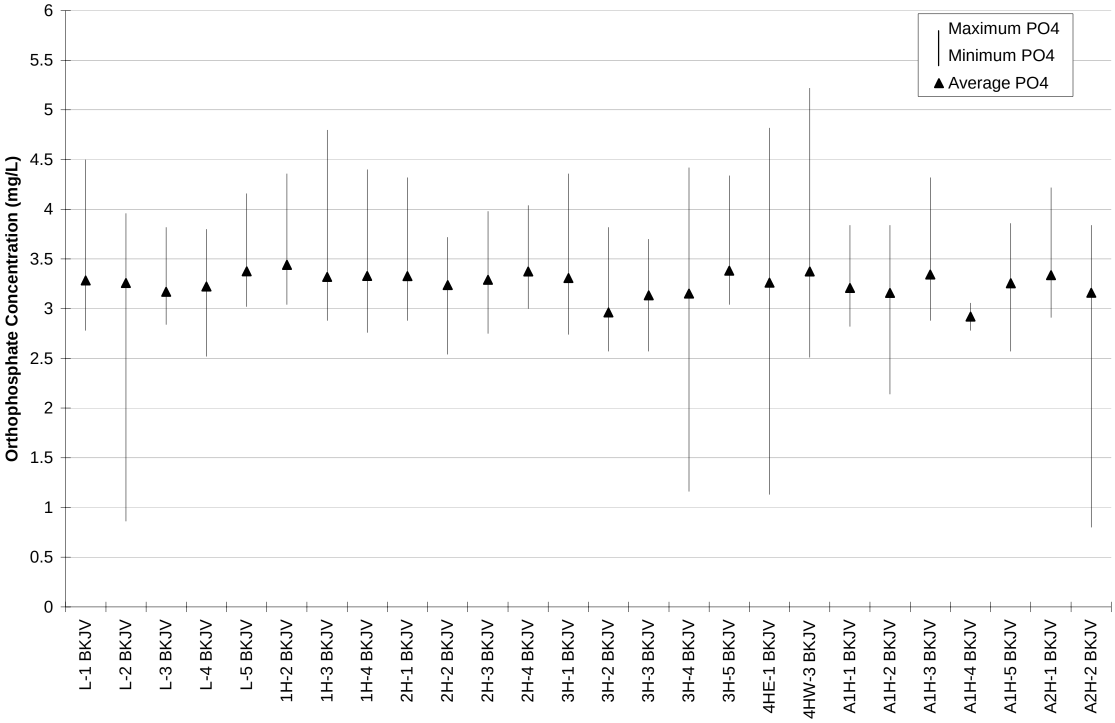
Source: Supplemental and TCR sites, hydrant and tap samples.

Exhibit 3.2.4 Maximum, Minimum, and Average Orthophosphate Concentrations by TCR Site (2005)



Source: TCR sites, tap samples.

Exhibit 3.2.5 Maximum, Minimum, and Average Orthophosphate Concentrations by Supplemental Site (2005)



Source: Supplemental monitoring sites, tap samples only.

Exhibit 3.2.6 Sites Experiencing the Lowest Orthophosphate Results for 2005

	Lowest	Date	Next Lowest	Date
A2H-2 BKJV	0.8	20-Jun	2.55	18-Jul
L-2 BKJV	0.86	20-Jun	2.63	17-Nov
3H-1	1.01	20-Jun	2.52	14-Jun
4HE-1 BKJV	1.13	24-Oct	2.54	2-Sep
3H-4 BKJV	1.16	24-Oct	2.69	21-Nov
A1H-4	1.69	15-Jun	2.9	22-Nov

Source: Supplemental and TCR monitoring sites, tap samples only.

3.2.2 pH Levels

Orthophosphate effectiveness depends on maintaining a fairly narrow pH operating window, which is reflected in the WQP goals established for DCWASA. Studies suggest that a sustained pH level substantially below 7.5 degrades the effectiveness of the inhibitor. Conversely, at pH levels substantially greater than 8.5 there is little evidence to suggest a meaningful benefit to orthophosphate addition (AWWA, Internal Corrosion in the Water Distribution System, 2nd edition, 1998).

DCWASA measures pH in the field at TCR and supplemental sites (both hydrant and inside tap sites). Our dataset consists of more than 4,000 pH readings taken between September 2004 and December 2005, with between 100 and 350 taken each month throughout the distribution system. Only tap samples at TCR sites are subject to WQPs (supplemental sites are meant to represent “worst case” conditions). The data presented in this analysis represent 59 TCR sites (2,750 tap samples and 11 hydrant samples) and 38 supplemental sites (608 tap samples and 576 hydrant samples).

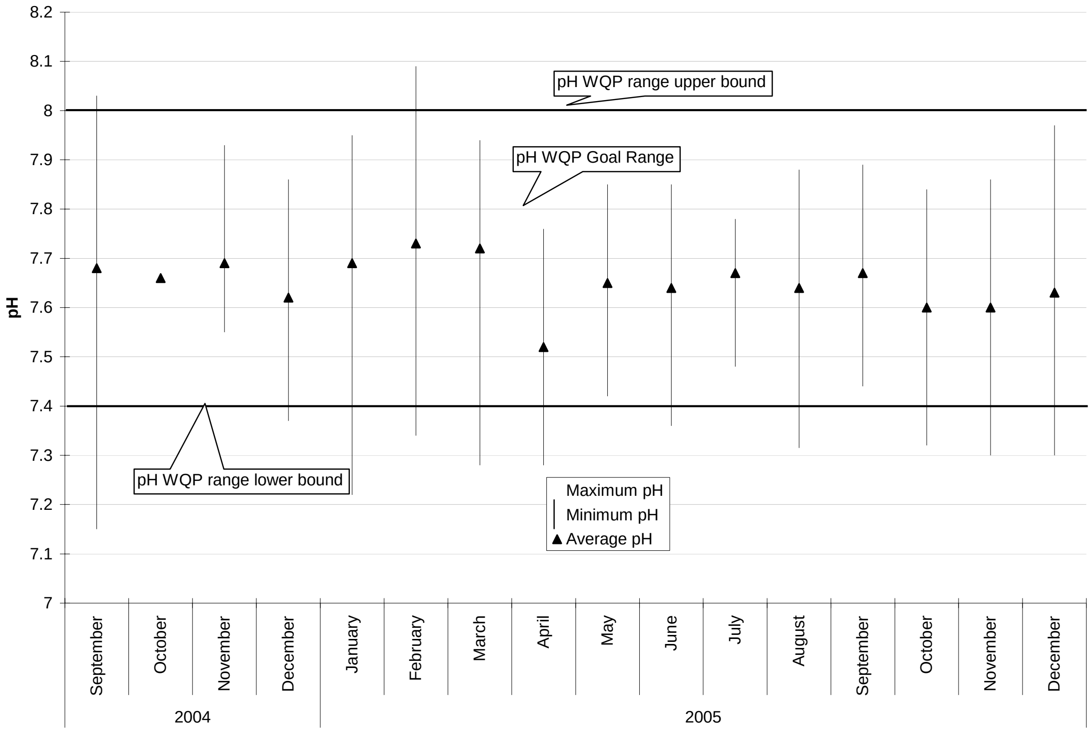
Exhibit 3.2.7a shows overall maximum, minimum, and median pH values per month for TCR sites, tap samples only. Exhibit 3.2.7b shows maximum, minimum, and median pH for TCR and supplemental sites, tap and hydrant samples. Exhibit 3.2.8 shows median pH for each month by geographic quadrant. April 2005 had the lowest median pH value. To further investigate these data, individual pH measurements for the month of April were plotted in Exhibit 3.2.9. Levels appear to be low throughout the system in April. A review of WA finished water by EPA Region III showed that finished water pH levels at both the Dalecarlia and McMillan plants were very stable, with an average pH of 7.7 and minimum values of 7.6 at both plants. The lower distribution system pH values in April could be related to a reduction in raw water alkalinity that is common for that time of year. Exhibits 3.2.7 and 3.2.8 show a very slight downward trend in pH over the time frame shown, particularly during the last three months of 2005.

Exhibits 3.2.10 and 3.2.11 show maximum, minimum, and median pH for TCR and supplemental monitoring sites, respectively. Data from all sites exhibit a fairly wide range of pH values, with average values for both TCR and supplemental sites remaining close to with average values for both TCR and supplemental sites. These exhibits do not reveal any identifiable pattern relative to pH spatial variation across the service area.

3.2.3 Nitrite, Nitrate, and Free Ammonia as Nitrogen

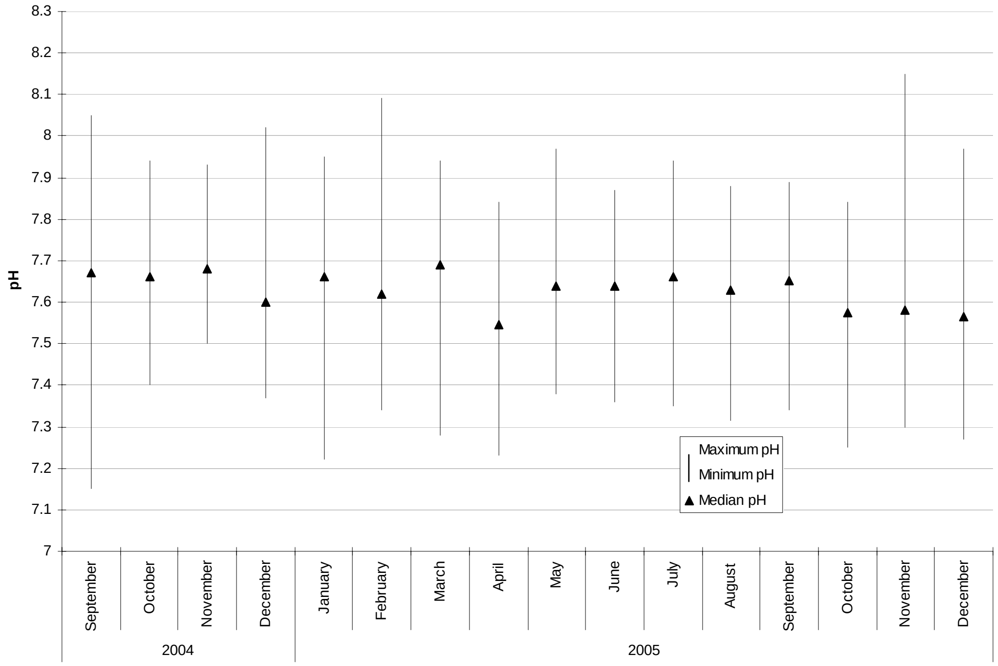
EPA’s WQPs include goals for free ammonia calculated as nitrogen, as well as the combination of nitrite and nitrate calculated as nitrogen. Exhibits 3.2.12 and 3.2.13 show the maximum, minimum, and average values by month for free ammonia as total nitrogen and nitrite/nitrate as total nitrogen, respectively. Note that nitrate was only measured if nitrite results for the site exceeded 0.1 mg/L or if free ammonia results either exceeded 0.4 mg/L or were below 0.2 mg/L. Average values were above the WQP goals every month except one for free ammonia, and most months for combined nitrate/nitrite. Further evaluation of ammonia, nitrite, and nitrate and their implications for nitrification are discussed in Section 3.5 of this report.

Exhibit 3.2.7a Maximum, Minimum, and Median pH Level by Month, TCR sites, Tap Samples Only



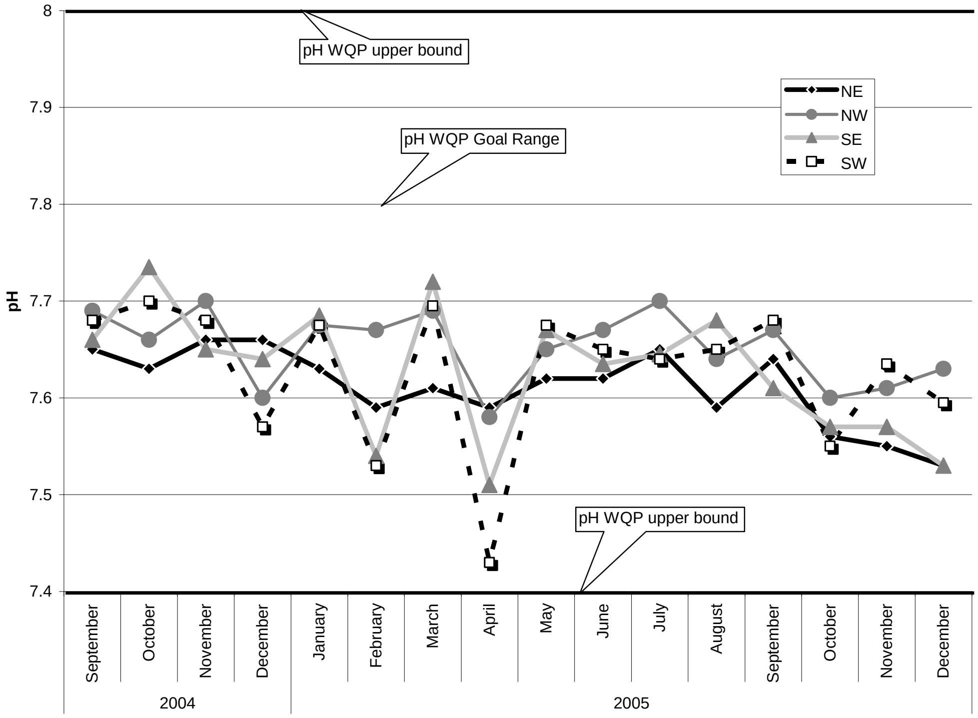
Source: TCR sites, tap samples only.

Exhibit 3.2.7b Maximum, Minimum, and Median pH Level by Month, Tap and Hydrants Samples, TCR and Supplemental Sites



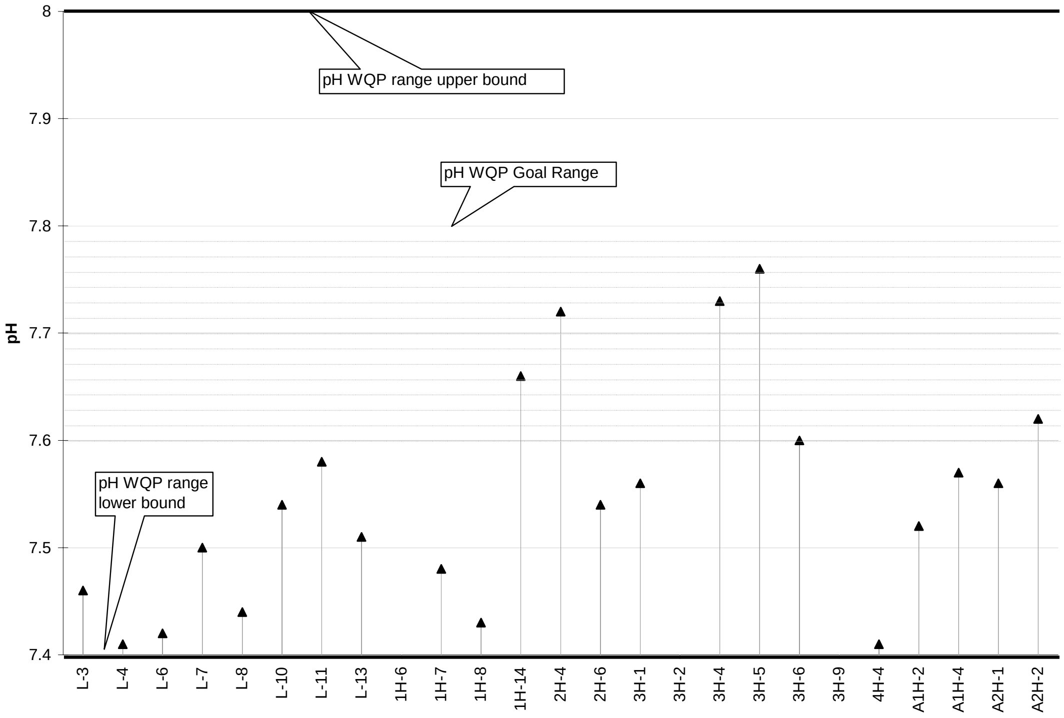
Source: TCR and supplemental sites, tap and hydrant samples.

Exhibit 3.2.8 Monthly Median pH Levels by Quadrant



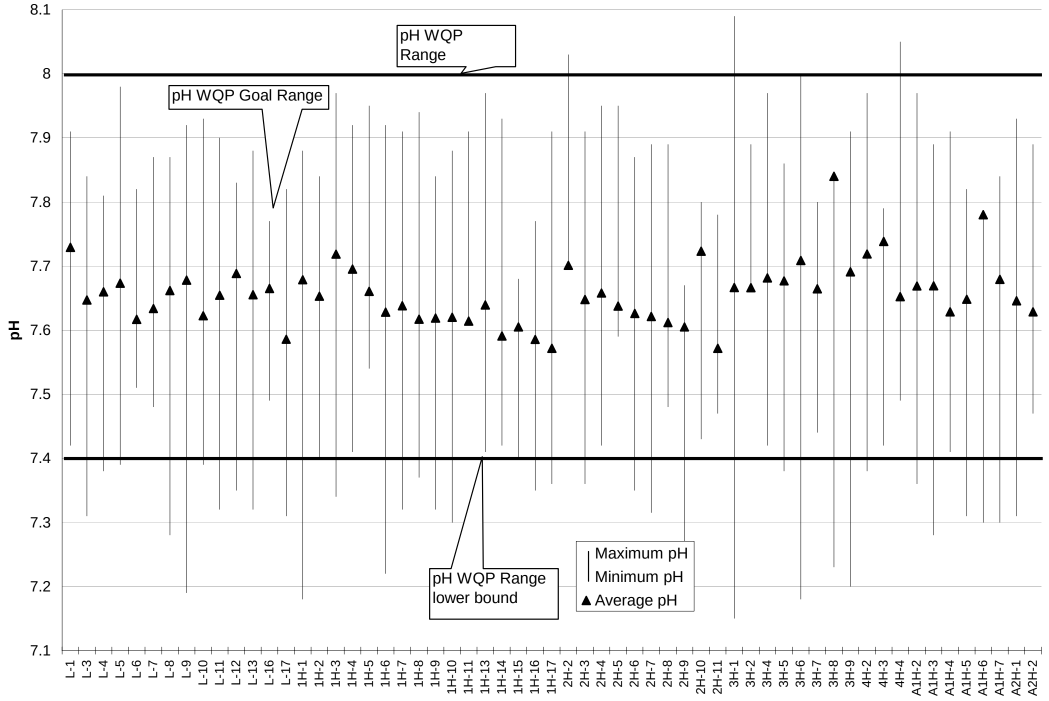
Source: TCR and supplemental sites, tap and hydrant samples.

Exhibit 3.2.9 pH Values by Site for the Month of April 2005 (Month Reporting the Lowest Median pH Value)



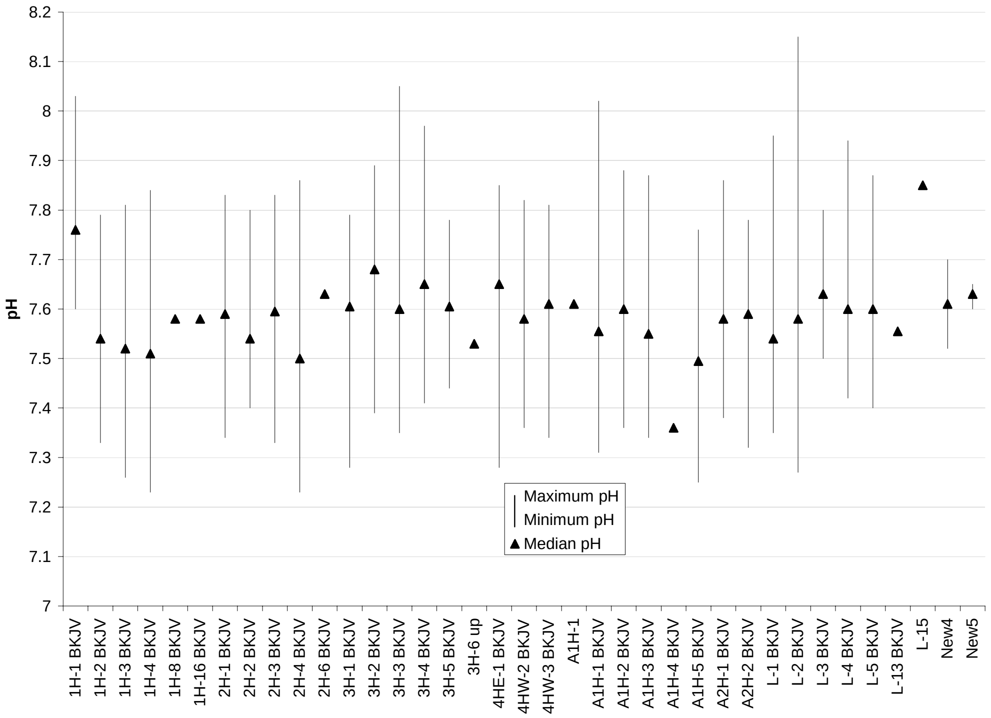
Source: TCR sites, tap samples only.

Exhibit 3.2.10 TCR Sites, pH Maximum, Minimum, and Median Values by Site ID (September 2004 to December 2005)



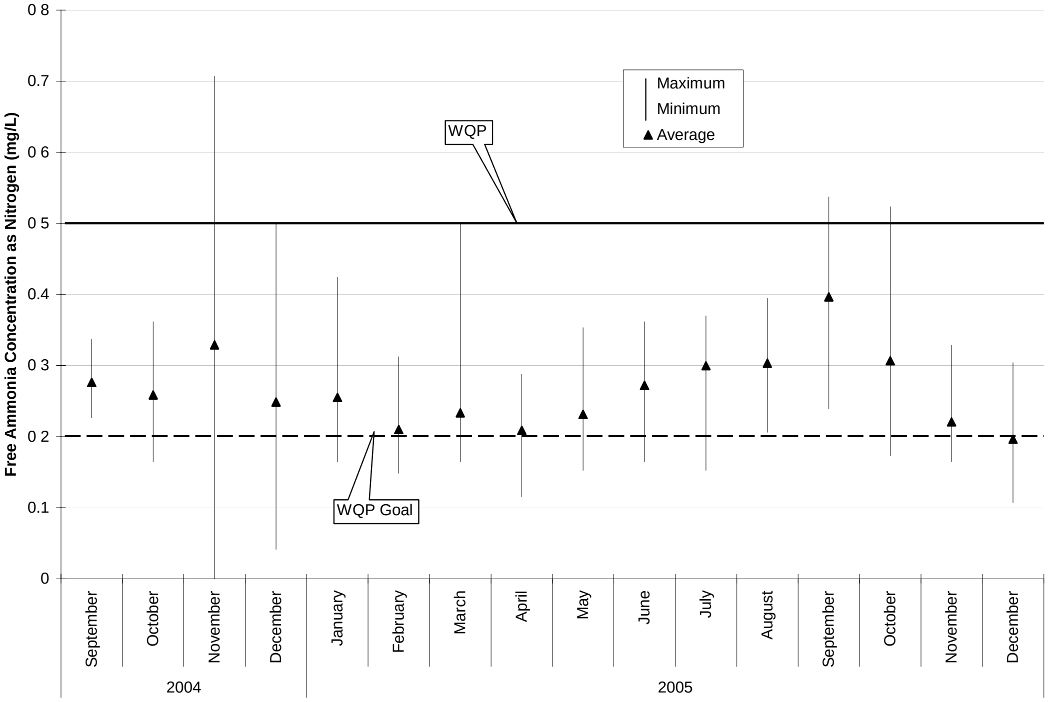
Source: TCR sites, tap samples only.

Exhibit 3.2.11 Supplemental Sites, pH Maximum, Minimum, and Median Values by Site ID (September 2004 to December 2005)



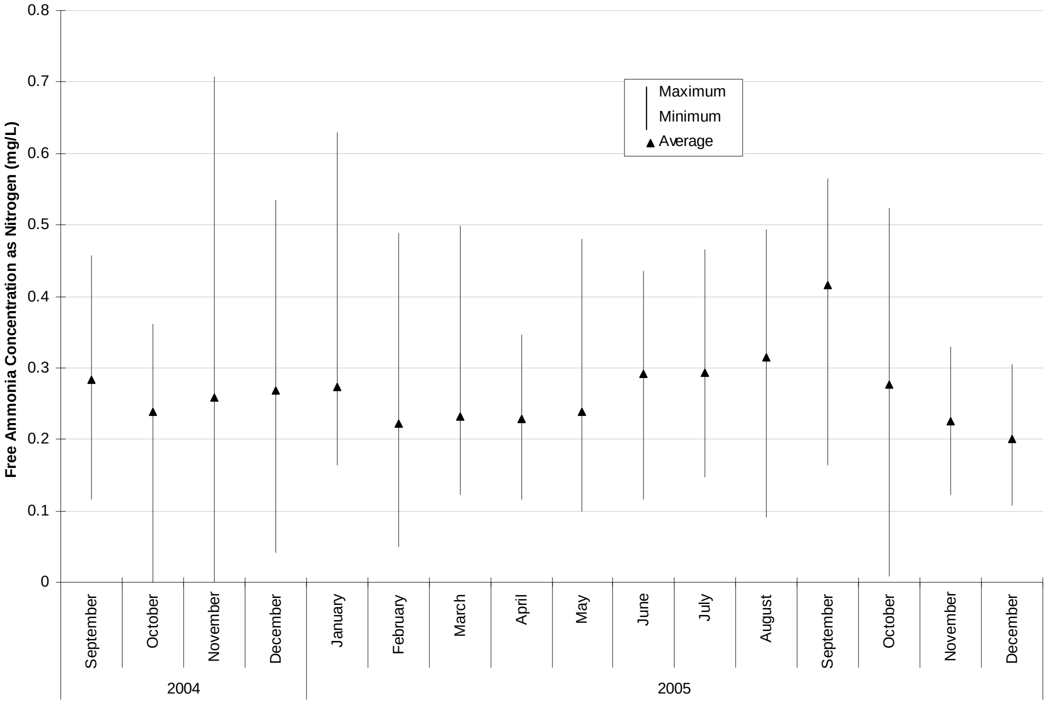
Source: Supplemental monitoring sites, tap and hydrant samples.

Exhibit 3.2.12a Maximum, Minimum, and Average Free Ammonia Concentration (as Nitrogen) by Month, TCR sites, Tap Samples Only



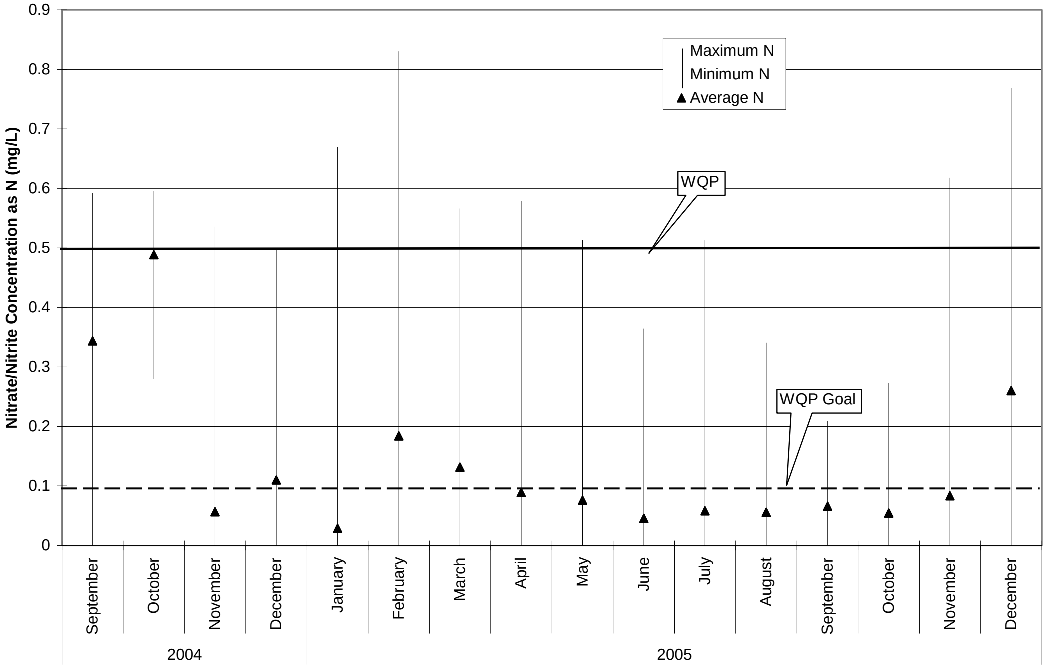
Source: TCR sites, tap samples only.

Exhibit 3.2.12b Maximum, Minimum, and Average Free Ammonia Concentration (as Nitrogen) by Month



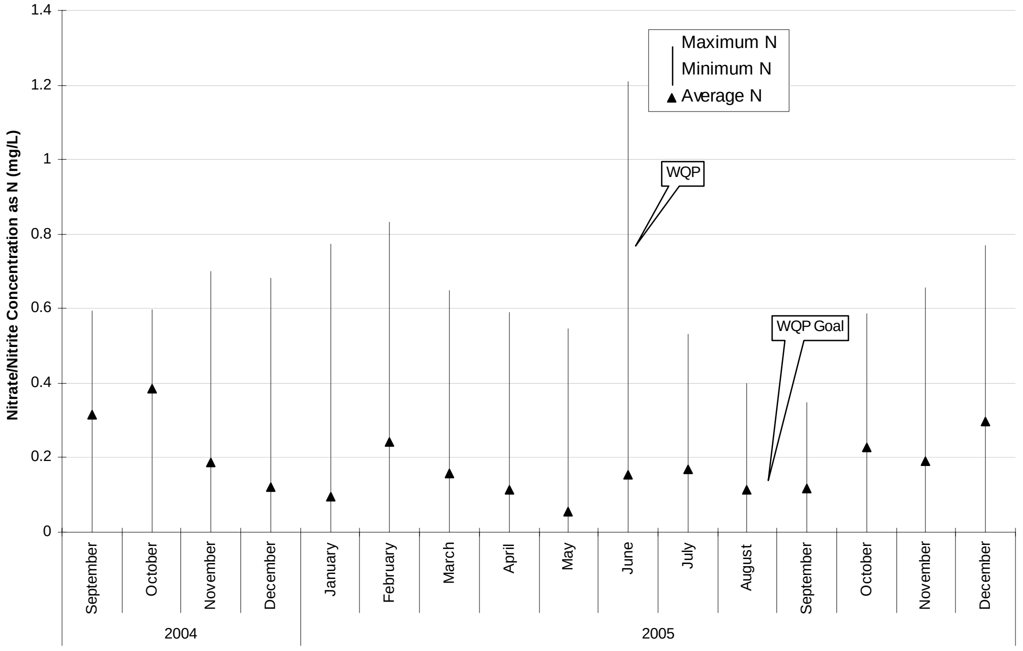
Source: TCR and supplemental sites, tap and hydrant samples.

Exhibit 3.2.13a Maximum, Minimum, and Average Total Nitrate/Nitrite Concentration as Nitrogen by Month, TCR sites, Tap Samples Only



Source: TCR sites, tap samples only.

Exhibit 3.2.13b Maximum, Minimum, and Average Total Nitrate/Nitrite as Nitrogen by Month, Supplemental and TCR sites, Hydrant and Tap Samples



Source: TCR and supplemental sites, tap and hydrant samples.

3.3 Results from Lead Profiling

3.3.1 Lead Profiling Procedure

DCWASA initiated lead profiling at customers' homes in late 2003, focusing on homes with LSLs. The primary goals of the program were to 1) identify the primary sources of lead in drinking water, i.e., was lead leaching from the service lines, household plumbing, brass faucet fixtures, etc., 2) examine the water for co-occurring constituents that might provide insight into why lead corrosion began increasing in 2002, and 3) determine if the elevated lead levels were in a particulate or dissolved form. Particulate forms may indicate that lead scale is detaching from the pipe wall, while dissolved lead may indicate dissolution through chemical or biochemical mechanisms (Giani et al 2004).

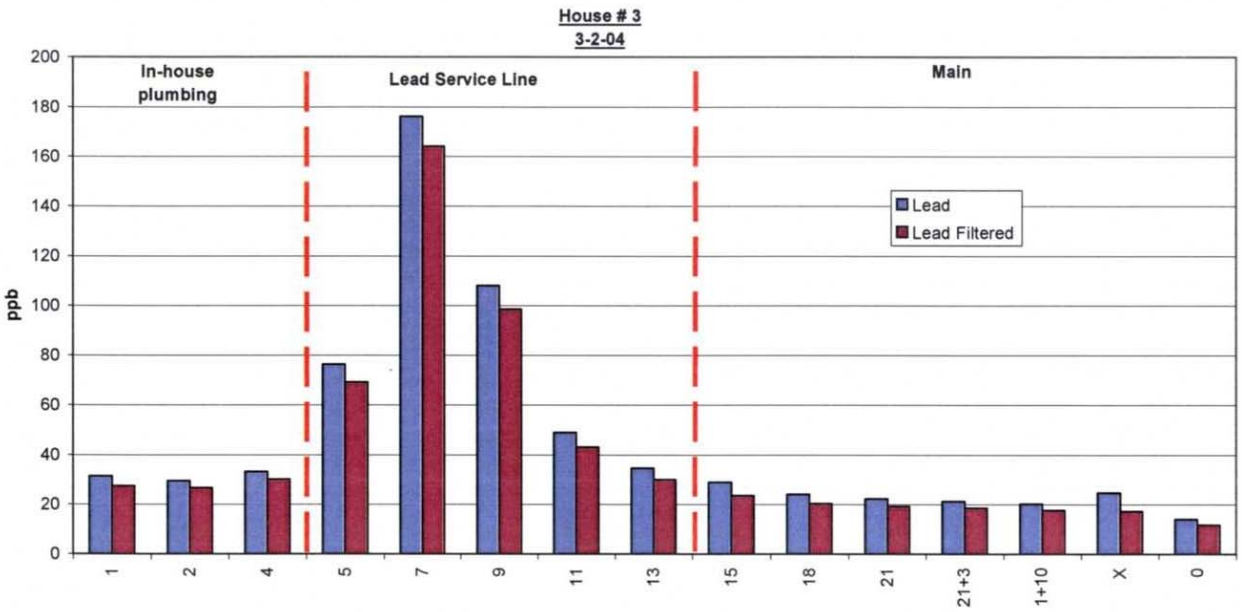
DCWASA also hoped to use this program to help track the performance of any new lead reduction treatment.

Lead profiling consists of seven main steps:

1. Document the material, diameter, and length of customer plumbing from the water main to the kitchen tap. Calculate the volume of water in each pipe section;
2. Collect a one-liter baseline sample after high water use (typically in the morning);
3. Stop all tap water use in the home for at least 6 hours;
4. Collect consecutive one-liter samples from the kitchen tap. The number of samples is based on the total volume of water in the customer plumbing from the water main to the kitchen tap;
5. Collect a water hammer sample by first fully opening and closing the faucet several times over a one-minute period, then running the faucet for 30 seconds prior to collecting a one-liter sample;
6. For each one-liter sample (including baseline and water hammer samples), filter 300 milliliters using a 0.45 micron filter, saving the filtrate for dissolved lead analysis in the laboratory; and
7. Analyze the remaining 700 milliliters for temperature, pH, free chlorine, and total chlorine for each sample on-site. Preserve and save a portion of the sample for laboratory analysis for lead (total and dissolved), iron, aluminum, zinc, copper, and HPC (Giani et al., 2004).

DCWASA created a standard graphic to represent lead profile results. They used a bar chart to plot total and dissolved lead for each profile, with lead concentration in ppb on the y-axis and liter of water on the x-axis. Using vertical dashed lines, they show which liters of water represent in-house plumbing, the LSL, and the water main. Exhibit 3.3.1 shows a typical lead profile graph developed by DCWASA. Information on how to interpret the graphs follows the exhibit. The next section presents and discusses results from the lead profiling program.

Exhibit 3.3.1 Typical Lead Profile Graph Developed by DCWASA



Interpreting Lead Profile Graphs:

The lightly shaded bar is total lead. The more darkly shaded bar is dissolved lead. Particulate lead can be derived by subtracting dissolved lead from total lead values. The x-axis lists the liter number that was collected from the tap. "1" represents the first liter drawn from the tap after the 6-hour stagnation period. Liter "2" represents the second liter taken, "18" represents liter 18, and so on. A number with a plus sign followed by a second number (e.g., 27 + 3) represents the liter number followed by the amount of minutes after the last sample was collected. For example, 27 + 3 would represent a sample collected 3 minutes after the 27th liter. "X" represents water hammering. In order to obtain "X", the faucet was open fully and closed rapidly several times over a one-minute period. Then the sample was allowed to run for 30 seconds prior to collection. "0" represents the baseline sample taken in the morning.

3.3.2 Lead Profiling Results

DCWASA conducted a total of 46 lead profiles between December 2003 and January 2006. Exhibit 3.3.2 lists each profile organized by date. Note that all except "Profile a" were taken at homes with LSLs. Appendix D contains lead profile graphs showing both total and dissolved lead per liter for all 46 profiles. The Appendix is organized chronologically and profiles are numbered sequentially for easy reference.

Most profiles were conducted in the NW quadrant of D.C. Repeat profiles were done for seven homes in the District, as indicated by a note in the last column of Exhibit 3.3.2. Repeat profiles were done at two homes before and after partial LSL replacement. WASA conducted lead profiling at 12 homes during its temporary conversion from chloramines to free chlorine for residual disinfection (or "chlorine burn" period) from April 2 through May 7, 2004. Many of these profiles were repeats of profiles conducted prior to the chlorine burn.

DCWASA lead profile data can be used to evaluate three different aspects of the lead corrosion problem in D.C. First, lead profiles provide critical information in assessing the effectiveness of the orthophosphate treatment. Second, profiles done before and after partial LSL replacements are useful in assessing the effectiveness of that program. Lastly, profiles done before and after the chlorine burn as well as profiles done at homes with and without LSLs support our understanding of the causes of elevated lead levels in D.C.

Findings Related to Cause of Lead Problem

Appendix D shows that prior to the orthophosphate treatment, peak total and dissolved lead almost always occurred in the LSLs. The profile for a home with a copper service line resulted in very low lead levels in the water (<4 ppb). Exhibit 3.3.3 compares a typical profile for a home with an LSL to the profile from the home with a copper service line. These two findings suggest that lead was leaching predominantly from the service lines.

Peaks in LSL samples were composed predominantly of dissolved lead, indicating that a chemical or biological reaction was most likely causing the lead to leach from the service lines, rather than a physical removal of scale material. Dissolved lead levels frequently exceeded 100 ppb in the service line portion of the profile prior to orthophosphate treatment.

As noted previously in this report, it was suspected that the November 2000 conversion from free chlorine to chloramines for secondary disinfection led to increased lead corrosion. Lead profiling conducted during the chlorine burn supports this theory. Profiles 15 through 26 all have fairly low total and dissolved lead levels, as shown in Appendix D. With the exception of a particulate lead spike in the first 1-liter sample in Profile No. 22, the peak total lead concentration was always below 80 ppb during the chlorine burn, and peaks continued to fall throughout the burn period.

Exhibit 3.3.2 Summary of Lead Profiles Conducted by DCWASA from December 2003 through January 2006

Profile No.	Date of profile	Profile Address	Profile Quadrant	Special Profile Conditions
a	7/7/2004	[redacted]	NE	No LSL
1	12/8/2003	[redacted]	NW	
2	12/15/2003	[redacted]	NW	
3	1/5/2004	[redacted]	NW	
4	1/13/2004	[redacted]	NW	Repeat of Profile 1 following partial LSL replacement
5	2/9/2004	[redacted]	NE	
6	2/24/2004	[redacted]	NW	Repeat of Profile 3 following partial LSL replacement
7	3/2/2004	[redacted]	NW	
8	3/9/2004	[redacted]	NW	
9	3/16/2004	[redacted]	NW	
10	3/24/2004	[redacted]	NW	
11	3/24/2004	[redacted]	SW	
12	3/30/2004	[redacted]	NW	
13	3/31/2004	[redacted]	NW	
14	4/1/2004	[redacted]	NW	
15	4/5/2004	[redacted]	NW	Affected by Cl Burn
16	4/6/2004	[redacted]	NW	Affected by Cl Burn
17	4/6/2004	[redacted]	NW	Affected by Cl Burn
18	4/13/2004	[redacted]	NW	Affected by Cl Burn
19	4/26/2004	[redacted]	NW	Second repeat of Profile 3 following partial LSL replacement; Affected by Cl Burn
20	4/27/2004	[redacted]	SE	Affected by Cl Burn
21	4/29/2004	[redacted]	NW	Second repeat of Profile 1 following partial LSL replacement; Affected by Cl Burn
22	4/30/2004	[redacted]	NW	Repeat of Profile 12; Affected by Cl Burn
23	5/3/2004	[redacted]	NW	Affected by Cl Burn
24	5/3/2004	[redacted]	NW	Affected by Cl Burn
25	5/7/2004	[redacted]	NW	Repeat of Profile 13; Affected by Cl Burn
26	5/18/2004	[redacted]	NE	Repeat of Profile 5; Affected by Cl Burn
27	6/28/2004	[redacted]	NW	
28	7/6/2004	[redacted]	NW	
29	7/16/2004	[redacted]	NW	Second repeat of Profile 13; Affected by Partial System Application
30	11/30/2004	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
31	12/6/2004	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
32	1/6/2005	[redacted]	NW	Repeat of Profile 11; Affected by System-Wide Orthophosphate TMT
33	1/25/2005	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
34	2/22/2005	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
35	3/30/2005	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
36	4/29/2005	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
37	5/16/2005	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
38	6/1/2005	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
39	6/7/2005	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
40	7/25/2005	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
41	9/28/2005	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
42	10/5/2005	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
43	11/29/2005	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
44	12/12/2005	[redacted]	NW	Affected by System-Wide Orthophosphate TMT
45	1/27/2006	[redacted]	NW	Affected by System-Wide Orthophosphate TMT

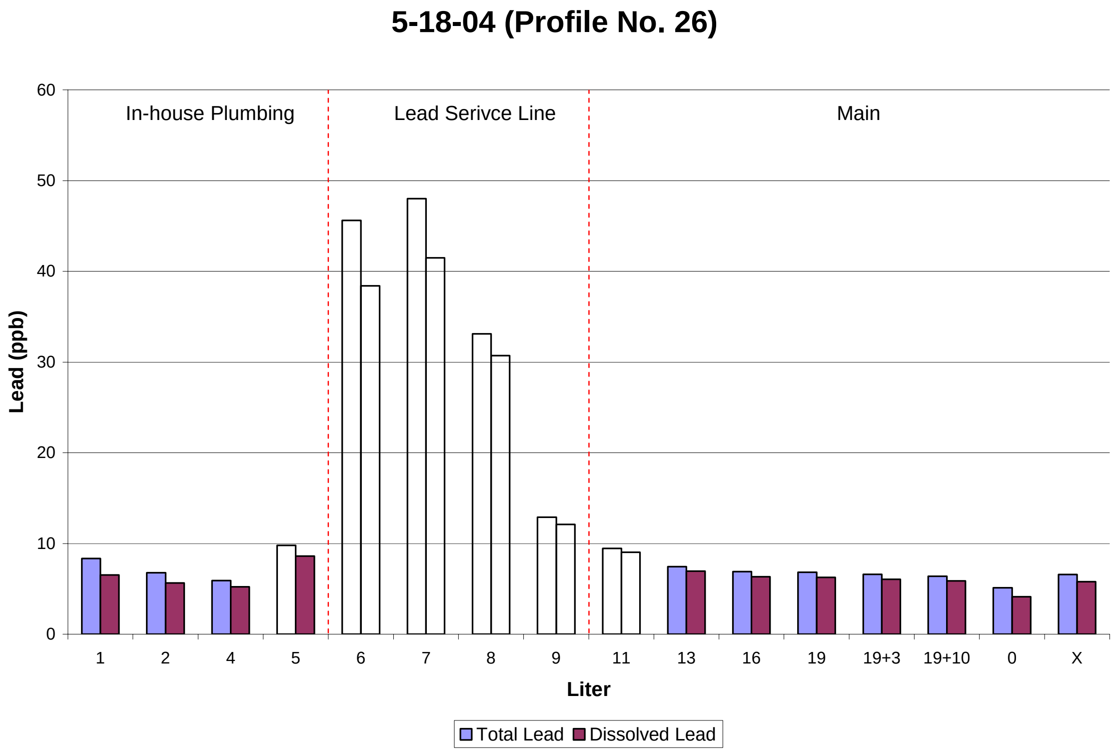
Notes:

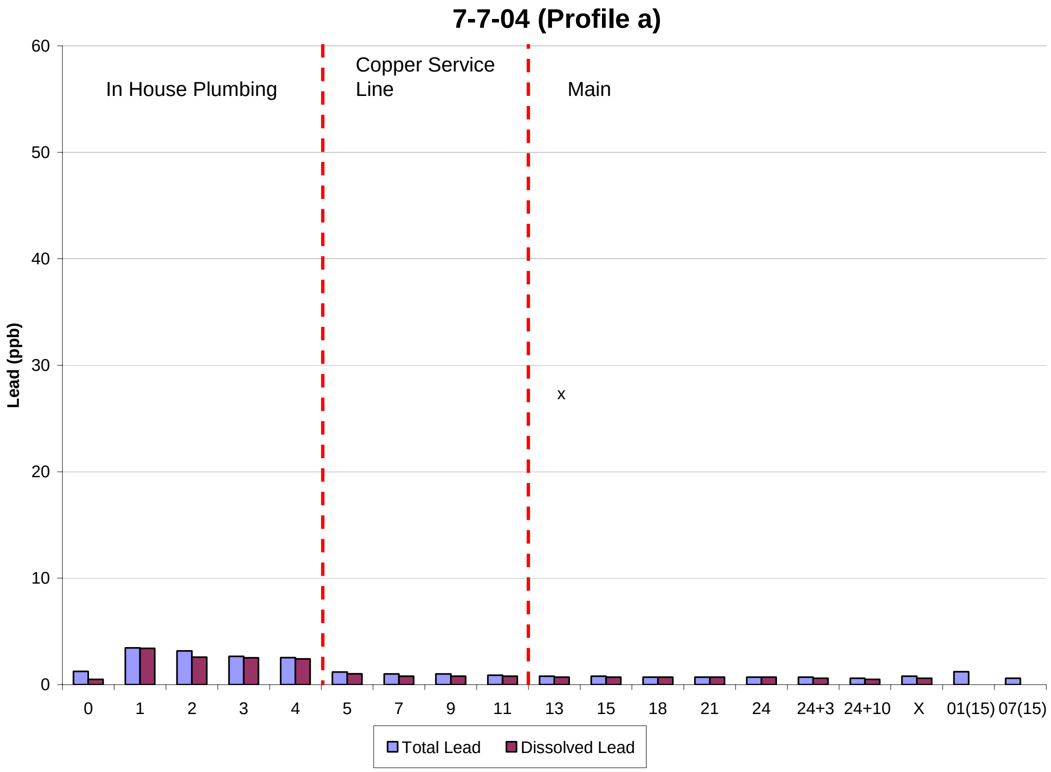
Chlorine burn was conducted from April 2, 2004 through May 7, 2004. Although the Profile 26 was conducted after the burn, lead leaching was likely still impacted by the change in oxidants.

Profile 29 was done approximately 7 weeks after start of partial system application in the 4th high service area.

Cl = chlorine; LSL = lead service line; TMT = treatment

Exhibit 3.3.3 Comparison of Lead Profiles for Homes with Lead and Copper Service Lines





During the chlorine burn period, DCWASA repeated profiles at three locations[3]. Exhibit 3.3.4 shows the peak total and dissolved lead in the LSLs prior to and during the chlorine burn period for comparison. Note that except for Profile No. 22, peak total and dissolved lead were substantially less during the chlorine burn period than during the regular chloramine conditions.

Exhibit 3.3.4 Comparison of Peak Lead Concentration Before and During the Chlorine Burn

Address of Profile	Lead Concentration (ppb) Prior to the Chlorine Burn			Lead Concentration (ppb) During the Chlorine Burn		
	Profile No. and Date	Peak Total Lead	Peak Dissolved Lead	Profile No. and Date	Peak Total Lead	Peak Dissolved Lead
Location 1	12. 3/30/04	27	11	22. 4/30/04	110[1]	3
Location 2	13. 3/31/04	110	101	25. 5/7/04	10	8
Location 3	5. 2/9/04	82	75	26. 5/18/04 [2]	48	38

Notes:

1. A lead peak of 110 ppb, predominantly particulate lead with almost no dissolved lead, occurred in the first liter sample. The next highest total lead peak during the profile was 6 ppb. This profile also showed elevated particulate lead in the water hammer sample (48 ppb). It is suspected that the peak of 110 ppb is either a sample error or potentially corrosion scale abrasion on the valve surfaces of the faucet.
2. This profile was done approximately 11 days after the chlorine burn ended on May 7, 2004. Because changes in lead scale can occur slowly, this profile may have still been impacted by the chlorine burn event.

Findings Related to PARTIAL LSL REPLACEMENT

Based on information provided by DCWASA, two locations in NW D.C. were profiled before and after an LSL replacement. The first home was profiled on December 8, 2003 (Profile No. 1). Approximately half of the lead service line was replaced with copper immediately after the profile was taken. This location was profiled a second time on January 13, 2004 (Profile No. 4). Lead levels in Profile No. 4 are about half as much as lead levels in Profile No. 1. Exhibit 3.3.5a shows these profiles on the same page for comparison.

The second home was profiled on January 5, 2004 (Profile No. 3) and again after replacement of all but 1 foot of the LSL on February’ 24, 2004 (Profile No. 6). Consistent with an almost complete reduction in LSL, the lead levels decreased from a peak of approximately 110 ppb (Profile No. 3) to less than 7 ppb in all samples (Profile No. 6). Exhibit 3.3.5b shows these graphs on the same page for comparison.

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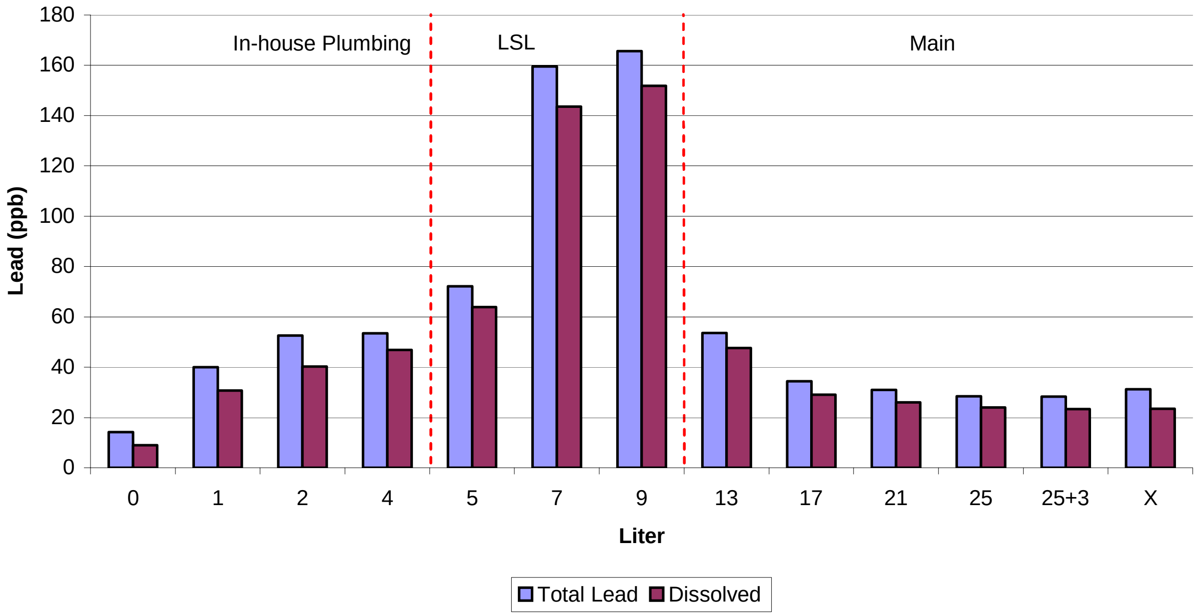
[3] Two additional sites were repeat profiled during the chlorine burn (see subsection titled *Findings Related to PARTIAL LSL REPLACEMENT*). However, DCWASA had already replaced a portion of the lead service lines at these sites prior to the chlorine burn so they were not included in the analysis.

Exhibit 3.3.5a Comparison of Profiles Done Before and After Partial LSL Replacement At the Same Residence

12-08-03 (Profile No. 1)



1-13-04 (Profile No. 4)

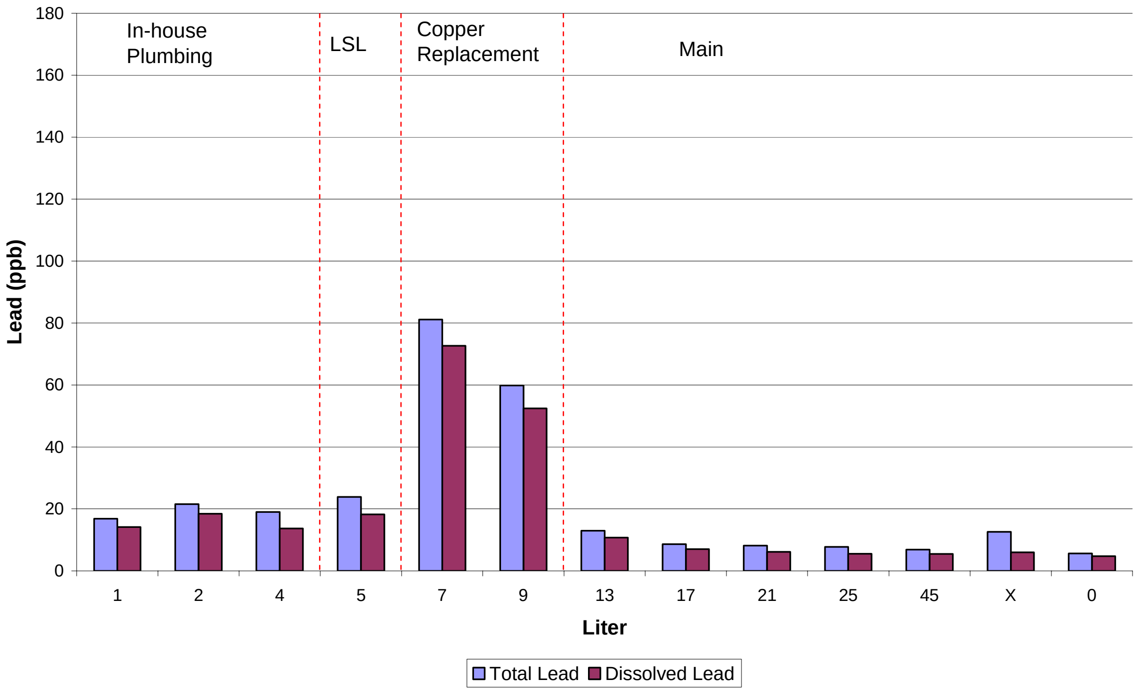
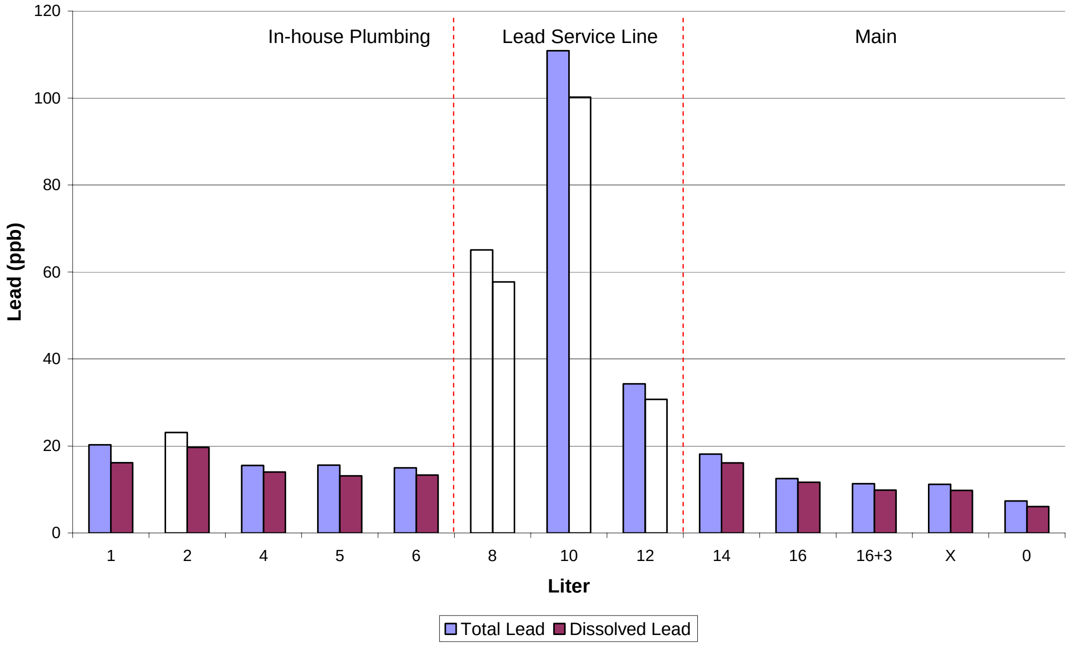
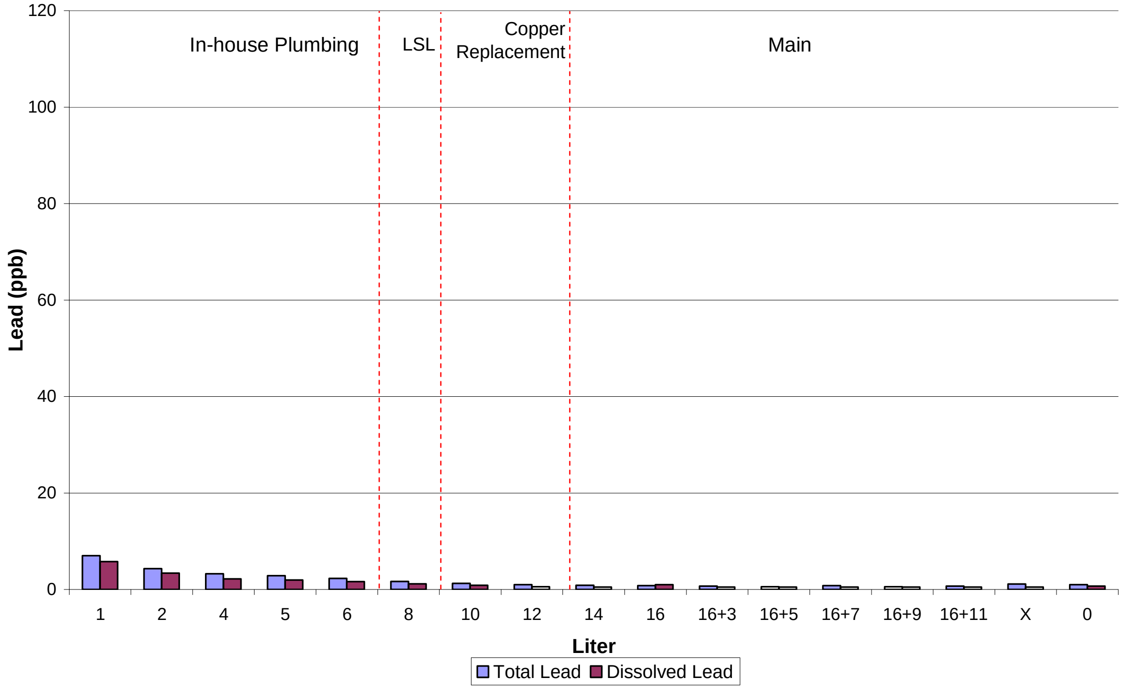


Exhibit 3.3.5b Comparison of Profiles Done Before and After Partial LSL Replacement At the Same Residence

1-5-04 (Profile No. 3)



2-24-04 (Profile No. 6)



Findings Related to the Effectiveness of the Orthophosphate Treatment

To assess the effectiveness of the orthophosphate treatment, we compared profiles done after the system-wide orthophosphate treatment began on August 23, 2004, to profiles conducted before that time. Comparisons of peak lead concentrations as measured in the service line or household plumbing samples and peak lead in water hammer sample provide useful information. As described in the previous section, LSL replacement also reduces lead levels in water. Hence, profiles conducted after LSL replacement (as indicated by a note in the fourth column in Exhibit 3.3.2) were removed so as not to influence the analysis of orthophosphate effectiveness.

Exhibit 3.3.6 shows peak total and dissolved lead concentrations in the service lines, averaged for those profiles conducted before and those profiles conducted after the initiation of orthophosphate treatment. Exhibit 3.3.7 shows similar statistics for water hammer samples. Exhibits 3.3.8 and 3.3.9 graphically depict the reduction in total and dissolved lead that occurred in profile samples after the start of orthophosphate treatment. One home was profiled both before and after the orthophosphate treatment. Exhibit 3.3.10 shows that the total and dissolved lead concentrations at this location decreased after orthophosphate treatment.

These exhibits collectively show the success of the orthophosphate treatment in reducing both total and dissolved lead concentrations in drinking water. The average total and dissolved lead in service lines or household plumbing for profiles conducted after the initiation of the orthophosphate treatment (15 ppb and 7 ppb, respectively) are much lower than averages for profiles conducted before the treatment (105 ppb and 94 ppb, respectively). While the average total lead in water hammer samples is not significantly different before and after the orthophosphate treatment, Exhibit 3.3.9 shows that the concentration of particulate lead in the water hammer samples is decreasing as the orthophosphate treatment progresses. This finding suggests that the orthophosphate treatment may be enhancing the physical stability of lead scales.

It is important to recognize that analyses in Exhibits 3.3.6 through 3.3.9 consider primarily different homes profiled before and after orthophosphate treatment. The magnitude of the change, particularly in Exhibit 3.3.8, however, is substantial and unlikely to be caused by differences in sample sites alone. As noted above, data exists for one home profiled before and after the orthophosphate treatment. Exhibit 3.3.10 shows a substantial decrease in total and dissolved lead in the profile done after the treatment, supporting findings in Exhibits 3.3.6 through 3.3.9.

Exhibit 3.3.6 Peak and Dissolved Lead Concentration in Service Lines or In-House Plumbing, Average for Profiles Done Before and After Orthophosphate Treatment

Profile Category	No. of Profiles	Average of Peaks in LSLs or Household Plumbing	
		Total Lead (ppb)	Dissolved Lead (ppb)
Prior to Orthophosphate Treatment	15	105	94
After Start of Orthophosphate Treatment	16	15	7
Total	31		

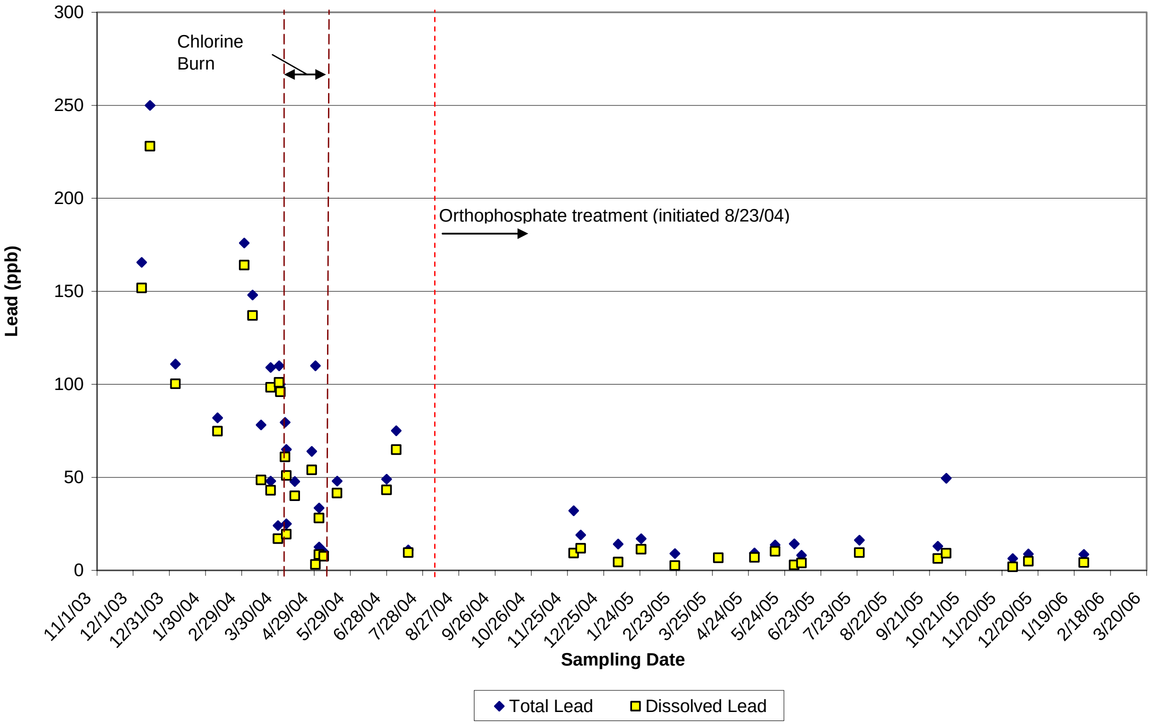
Notes: Does not include profiles conducted during the chlorine burn (4/2/04 - 5/7/04), after LSL replacement, or Profile No. 27, which was done after partial system application of orthophosphate in the 4th high service area.

Exhibit 3.3.7 Lead Concentrations in Water Hammer Samples, Average for Profiles done Before and After Orthophosphate Treatment

Profile Category	No. of Profiles	Average of Peaks in Water Hammer Samples	
		Total Lead (ppb)	Dissolved Lead (ppb)
Prior to Orthophosphate Treatment	15	19	12
After Start of Orthophosphate Treatment	16	22	2
Total	31		

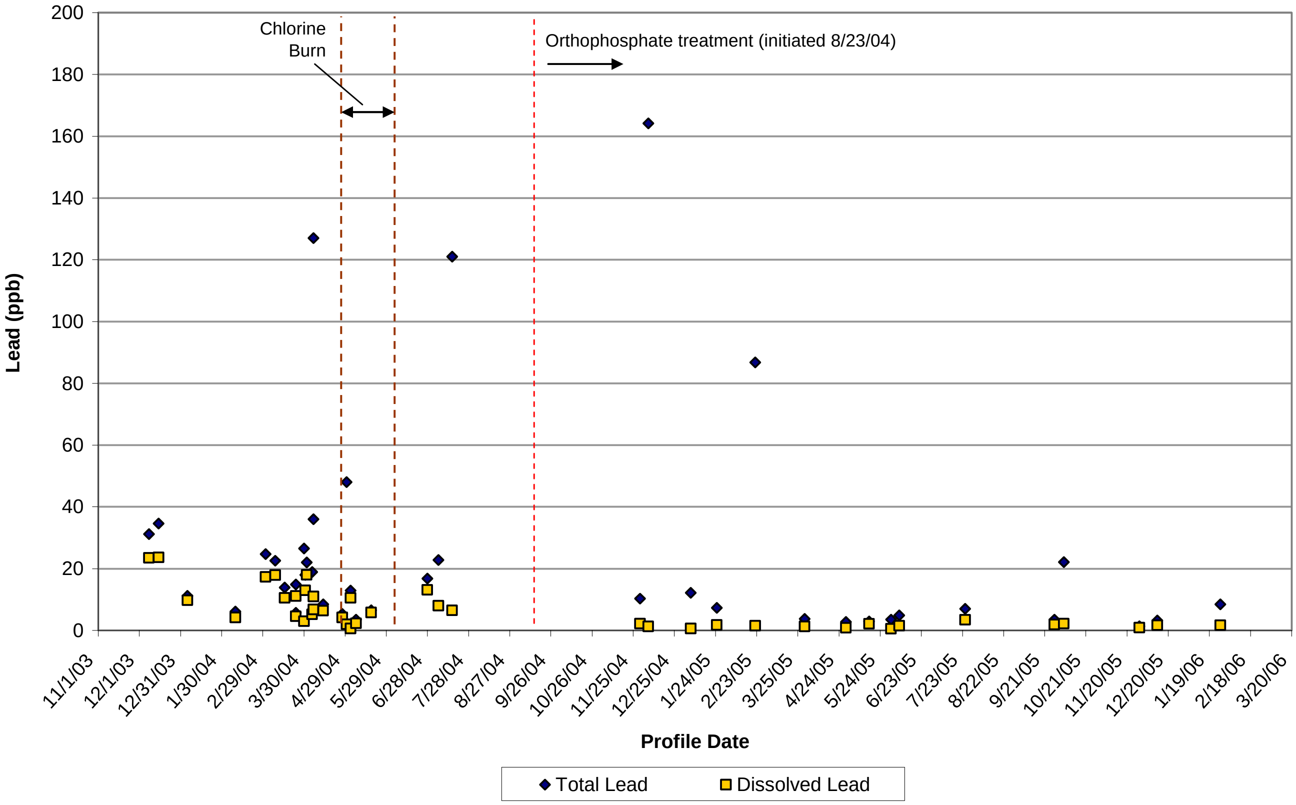
Notes: Does not include profiles conducted during the chlorine burn (4/2/04 - 5/7/04), after LSL replacement, or Profile No. 27, which was done after partial system application of orthophosphate in the 4th high service area.

Exhibit 3.3.8 Peak Lead Concentration in Service Lines or In-House Plumbing for Individual Profiles by Date



Note: Total of 41 profiles shown, see Exhibit 3.3.2 for listing. Excludes profiles done after LSL replacement (Profile Nos. 4, 6, 19, and 21).

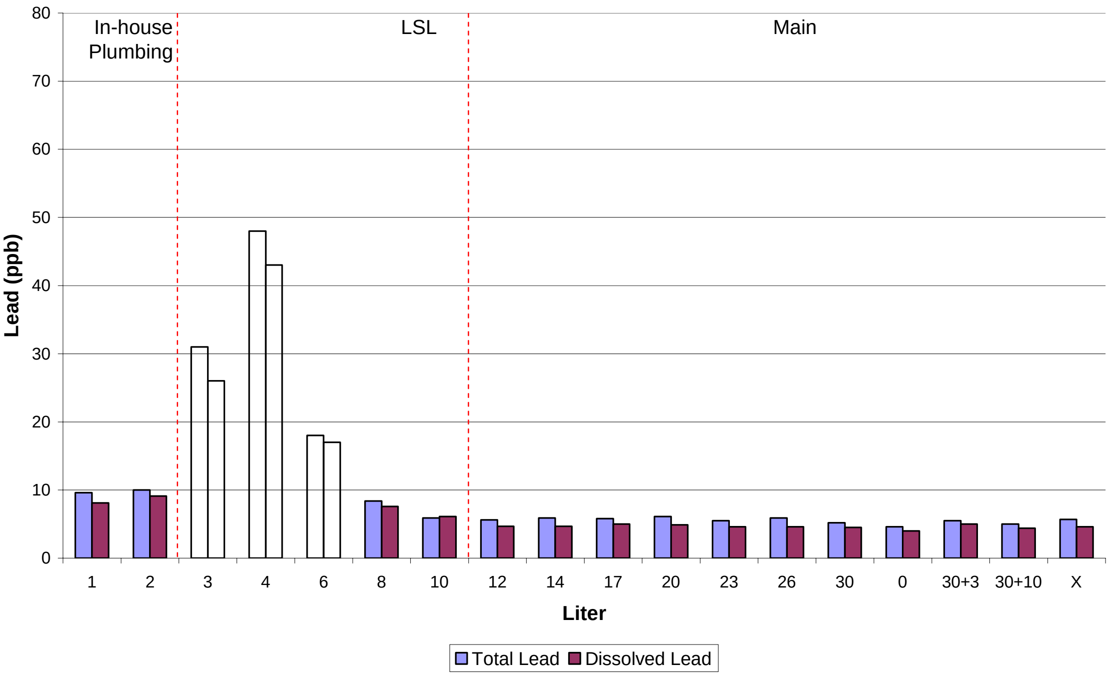
Exhibit 3.3.9 Lead Concentrations in Water Hammer Samples for Individual Profiles by Date



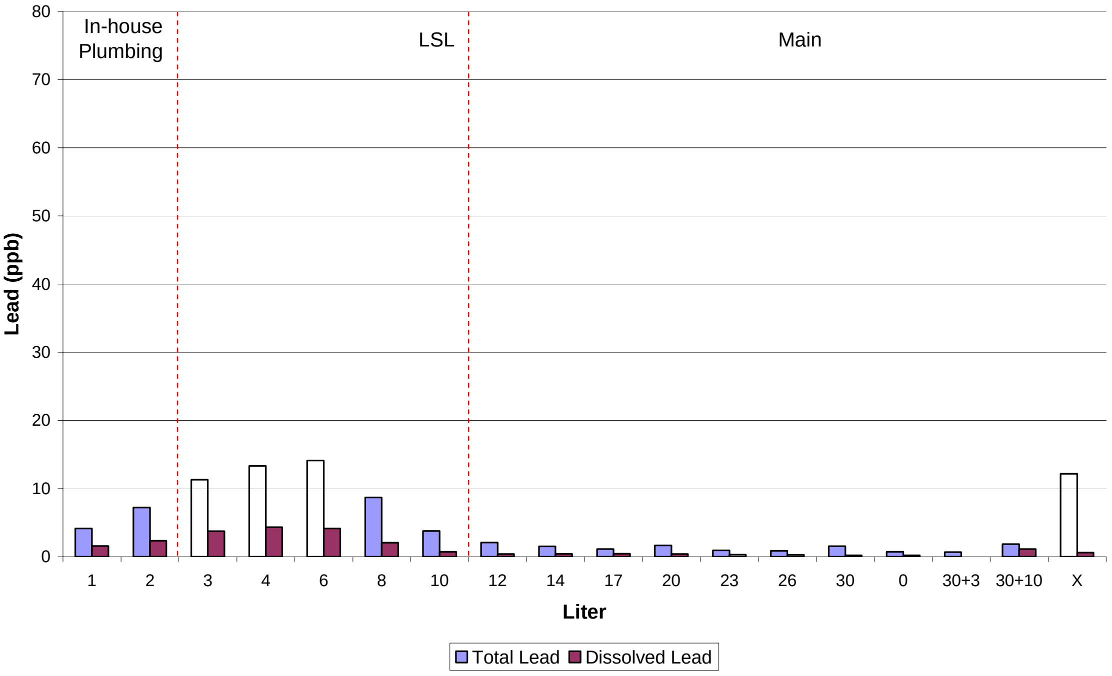
Note: Total of 41 profiles shown, see Exhibit 3.3.2 for listing. Excludes profiles done after LSL replacement (Profile Nos. 4, 6, 19, and 21).

Exhibit 3.3.10 Comparison of Profile Conducted Before and After Start of the Orthophosphate Treatment At the Same Residence

3-24-04 (Profile No. 10)



1-6-05 (Profile No. 32)



3.4 LCR Monitoring Data

3.4.1 Description of LCR Dataset

Lead data from January 2003 through December 2005 were evaluated to assess the effectiveness of the orthophosphate treatment and identify potential spatial and/or temporal trends in peak lead occurrences. Our dataset comprises a total of 1,662 lead samples taken during the three years: 833 first-draw and 829 second-draw samples. Data are for total lead only (assessing the dissolved fraction is difficult for the standard LCR compliance sample because it requires immediate filtration of the sample, which is problematic when done by residents). It is important to note that the data analyses in this report may include more samples than were approved by EPA for use in calculating the 90th percentile LCR compliance value.

Our dataset contains results for more than 450 homes in the District, most with full LSLs. DCWASA collected data from 100 to 281 homes per 6-month period, indicating that the sampled homes changed from one 6-month period to the next. Participants can request to be removed from the LCR program or are removed by DCWASA if they undergo a full LSL replacement.

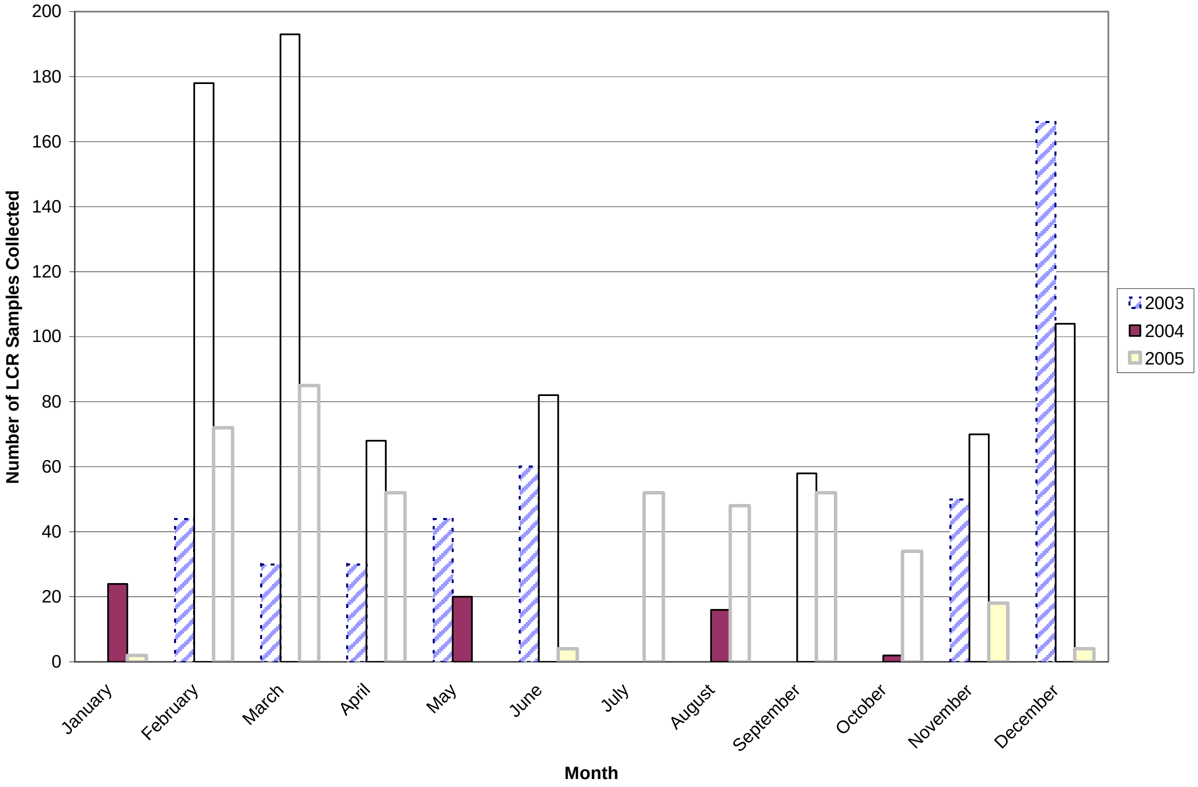
Service area information was not provided for the LCR sites; therefore, quadrant information was used as a proxy to evaluate spatial variability. The samples are not allocated evenly among the four quadrants, as illustrated in Exhibit 3.4.1. More than two-thirds of the samples were taken in NW, which is expected since this quadrant contains a disproportionate amount of the LSLs known to exist in D.C.

Sample collection dates are not spread evenly over a given year. Exhibit 3.4.2 shows the number of first-draw samples collected each month for 2003 through 2005. DCWASA collected a significantly higher number of LCR compliance samples in December 2003 and February and March 2004 compared to other months: these months represent an intense period of research on the D.C. lead issue. In 2005, samples were collected in the first several months of each 6-month period, with zero or very few samples collected in May, June, and December.

Exhibit 3.4.1 Number of LCR Samples in Dataset by Geographic Quadrant (January 2003 - December 2005)

Quadrant	First Draw	Second Draw	Total Samples	Percent of Total Samples
Northeast (NE)	145	145	290	17%
Northwest (NW)	576	572	1,148	69%
Southeast (SE)	107	107	214	13%
Southwest (SW)	5	5	10	1%
TOTAL	**833**	**829**	**1,662**	

Exhibit 3.4.2 Number of First Draw LCR Samples in Dataset by Month



Note: Total number of first draw samples from January 2003 – December 2005 = 833. Results for second draw samples are almost identical.

3.4.2 LCR Monitoring Results

Exhibits in this section are presented to demonstrate changes both in the ***magnitude*** and ***variability*** of lead concentrations before and after the orthophosphate treatment (initiated on August 23, 2004). The first set of exhibits track changes in all lead sample results (both first draw and second draw) from year to year. The last exhibit evaluates changes in the subset of homes that were sampled both before and after the orthophosphate treatment.

Analyses of all LCR data

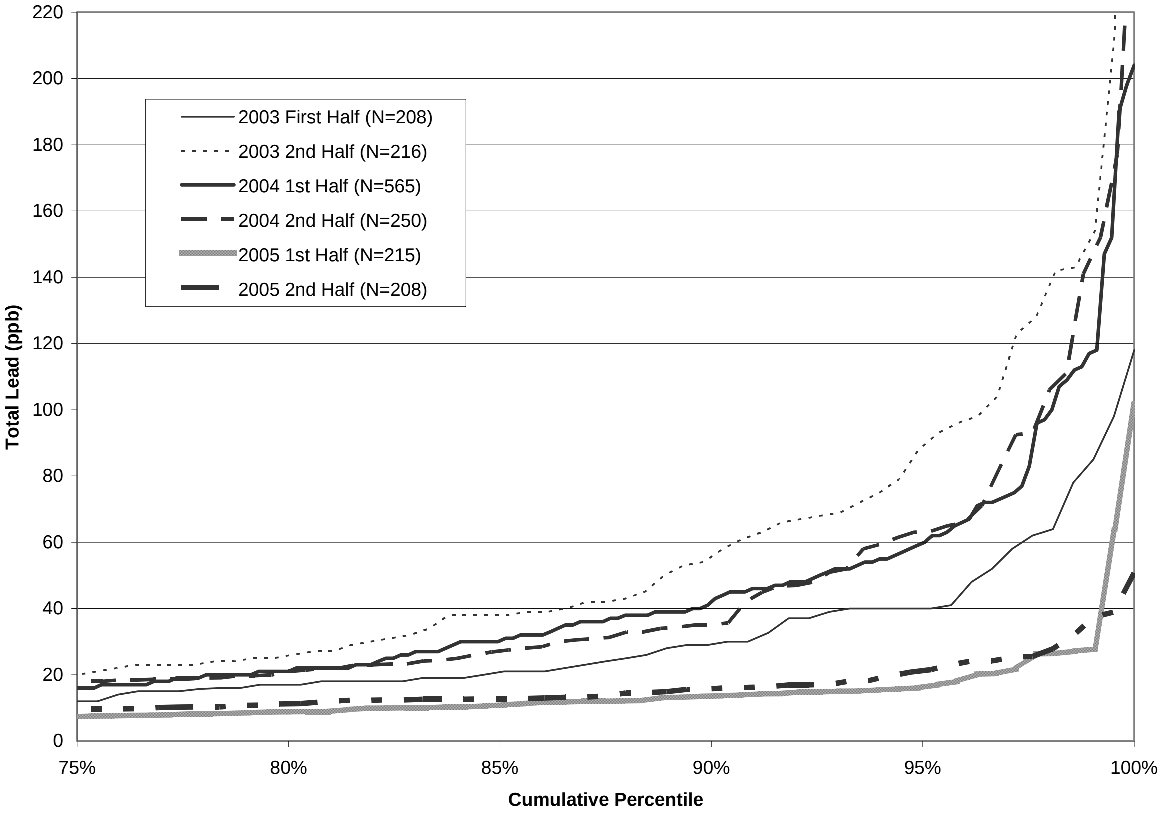
Exhibit 3.4.3 shows the cumulative graphical distribution of all lead results (from both first draw and second draw samples) for each six-month time period starting in 2003. The distribution of high lead levels is much lower for the first and second halves of 2005 as compared to 2003 and 2004. The graph also shows that peak values have decreased significantly in 2005 compared to prior years. The peak total lead concentrations in the first and second 6-months of 2005 were 51 ppb and 102 ppb, respectively. 2005 results can be compared to very high peak results of 364 ppb and 265 ppb in 2003 and 2004, respectively.

Similar trends are shown in Exhibit 3.4.4, which compares the percent of all LCR samples (considering both first and second draw samples) over total lead threshold levels of 15 ppb, 30 ppb, and 50 ppb for 2003, 2004, and 2005. The exhibit shows consistently and significantly lower percentages of samples above the threshold levels in 2005 compared to 2003 and 2004 in each category. The exhibit also shows a decrease in the overall average total lead concentration for all samples from 2003 (14.6 ppb) and 2004 (14.7 ppb) to 2005 (6.9 ppb).

Exhibits 3.4.5a through 3.4.5d expand on Exhibit 3.4.4 by showing the percent of samples over total lead threshold levels *per month* for 2003, 2004, and 2005. These graphs show that occurrence of high lead levels fluctuated more month-to-month prior to 2005. Since orthophosphate treatment began on August 23, 2004, the occurrence of peak lead concentrations in first and second draw samples has been generally lower for all threshold categories.

Exhibits 3.4.6a and 3.4.6b display the monthly averages and peak value for first draw samples, respectively, by each quadrant (data from SW was not considered when comparing the quadrants due to the low sample size). Second draw samples show similar results and thus, are not displayed here. The quadrant analysis was conducted to examine any spatial trends in lead levels. Prior to the orthophosphate treatment, the data show a slight trend of higher average and peak lead concentrations in NW compared to the NE quadrant. The highest averages in the fall of 2005 occurred primarily in NW, although this is likely due to its larger sample size. Overall, there does not appear to be any meaningful anomaly in the spatial distribution of LCR monitoring results.

Exhibit 3.4.3 Cumulative Percent of Total Lead in First and Second Draw Samples by Monitoring Period



Source: LCR Monitoring Data
Notes: Not shown on graph – 2003 Second Half (100% = 364 ppb); 2004 Second Half (100% = 265ppb)

Exhibit 3.4.4 Comparison of Lead Results for 2003, 2004, and 2005

Year	Total Number of LCR Samples (first and second draw)	Average Total Lead for all Samples (ppb)	Percent of Samples with Total Lead Greater Than			
			15 ppb	30 ppb	50 ppb	100 ppb
2003	424	14.6	26%	14%	8%	2%
2004	815	14.7	69%	38%	20%	5%
2005	423	6.5	13%	2%	1%	0%

Exhibit 3.4.5a Percent of Peak Lead Values Greater than 15 ppb Each Month for 2003, 2004, and 2005

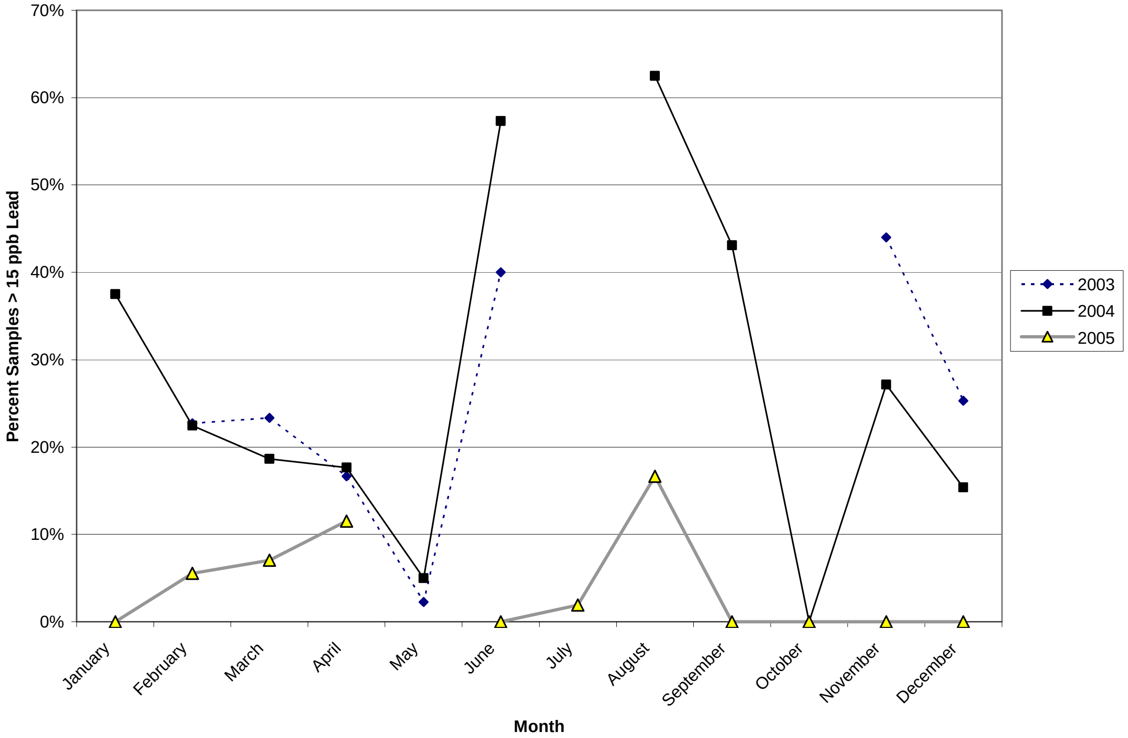


Exhibit 3.4.5b Percent of Peak Lead Values Greater than 30 ppb Each Month for 2003, 2004, and 2005

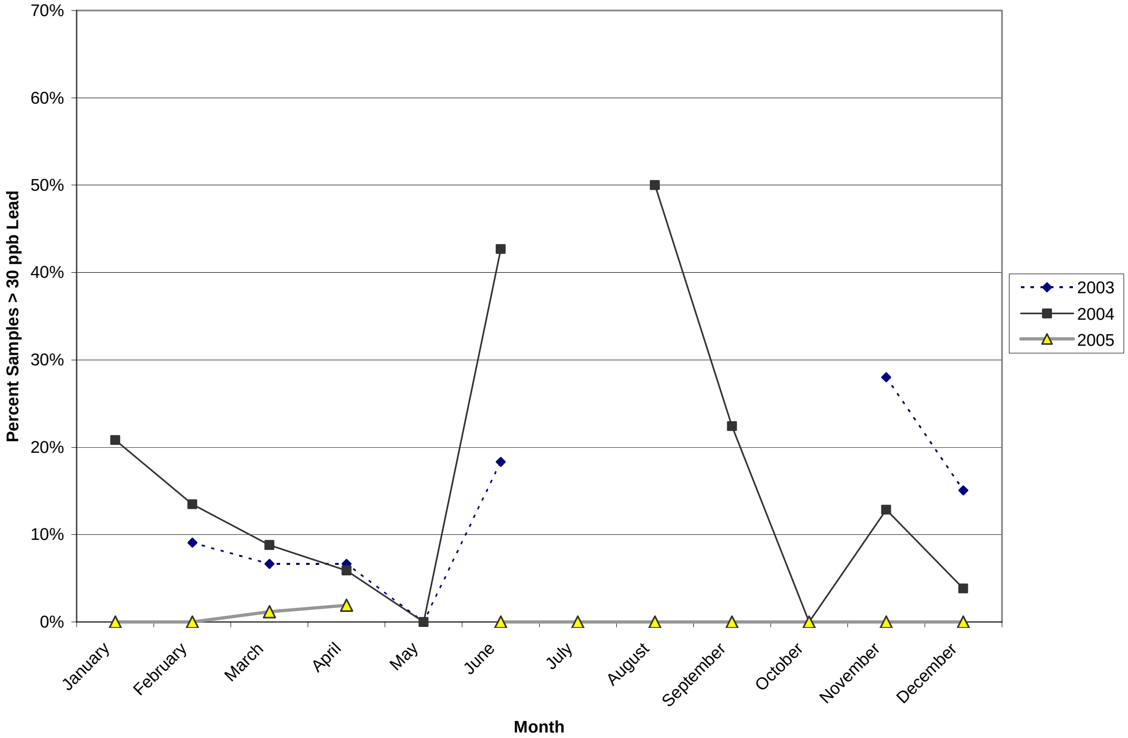


Exhibit 3.4.5c Percent of Peak Lead Values Greater than 50 ppb Each Month for 2003, 2004, and 2005

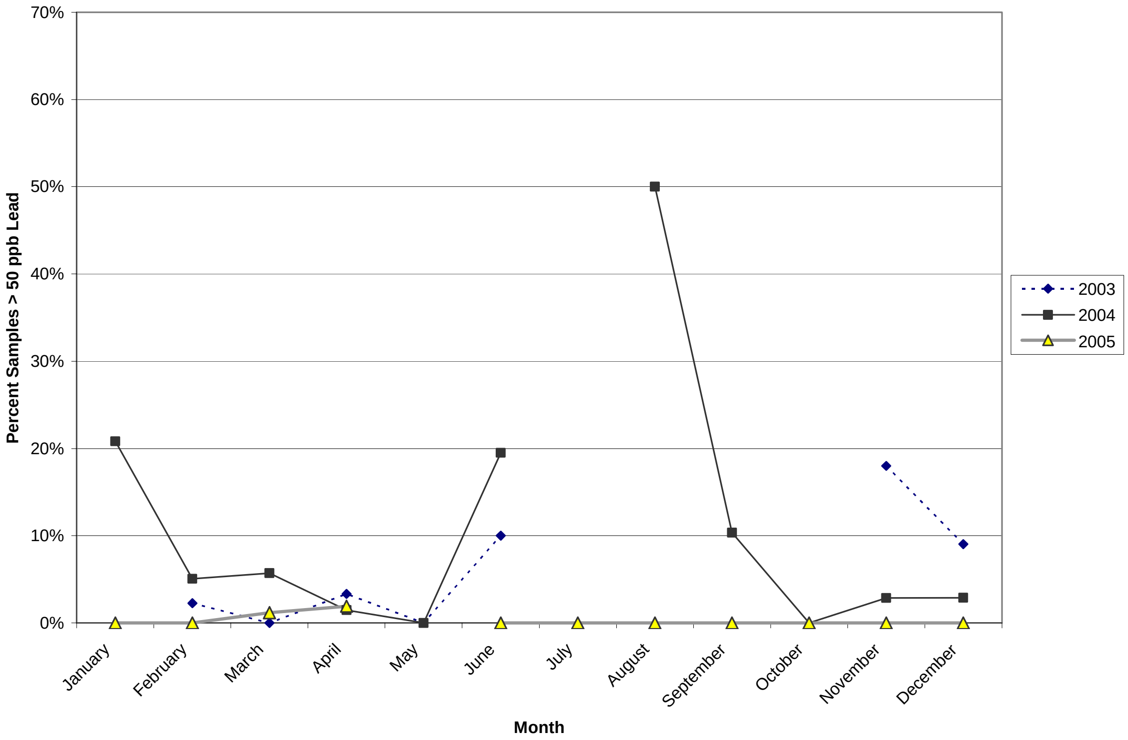


Exhibit 3.4.5d Percent of Peak Lead Values Greater than 100 ppb Each Month for 2003, 2004, and 2005

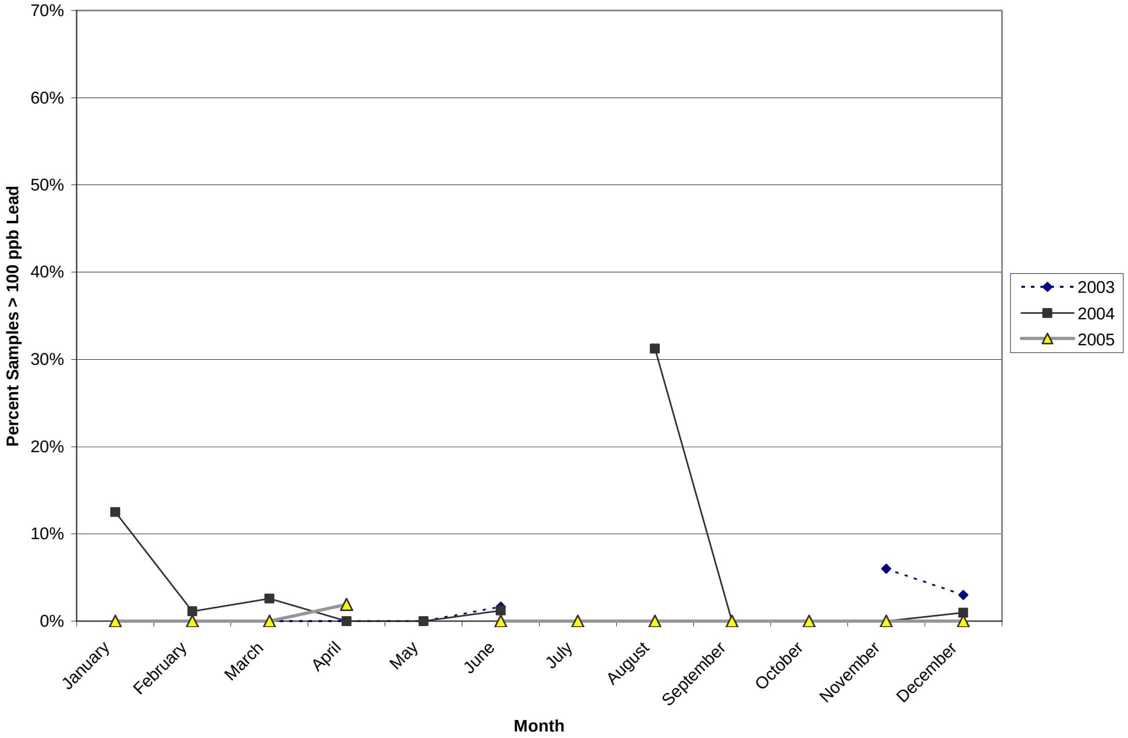


Exhibit 3.4.6a Monthly Average Total Lead Concentration in First Draw Samples by Geographic Quadrant (January 2003 – December 2005)

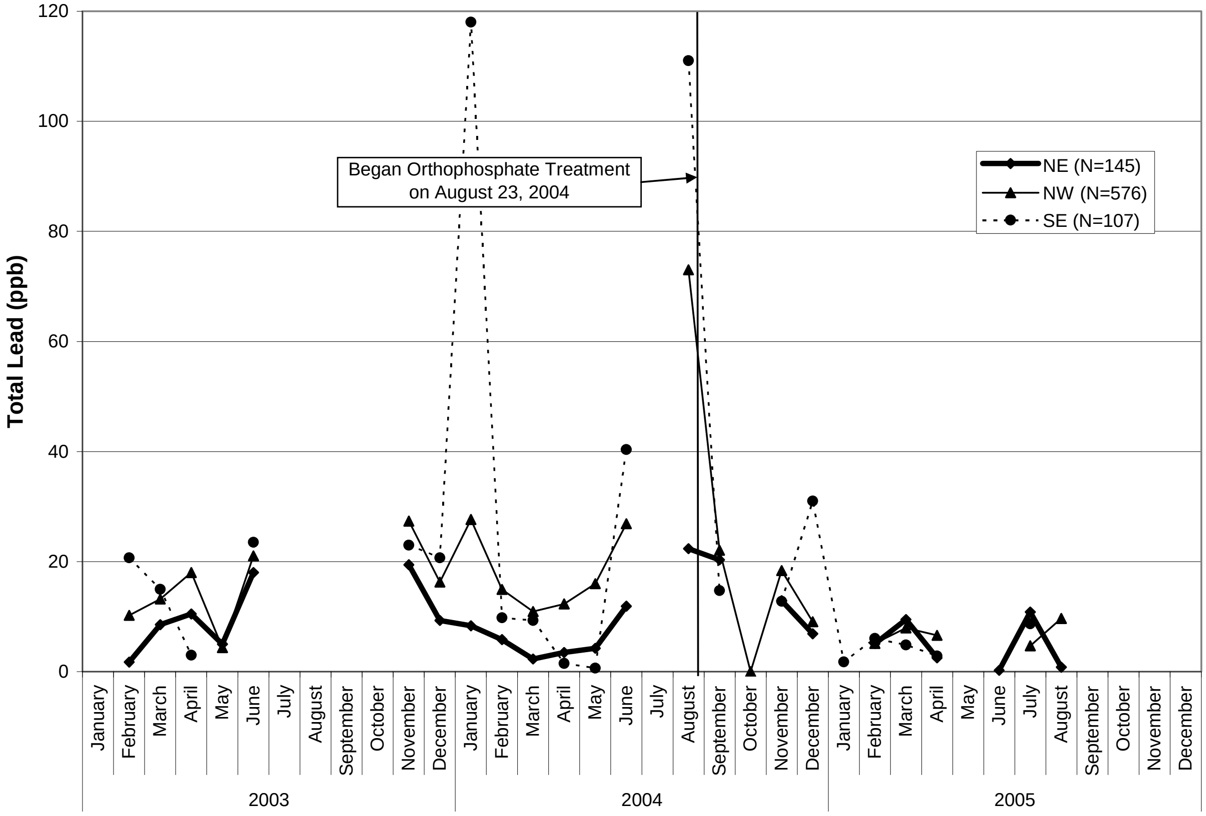
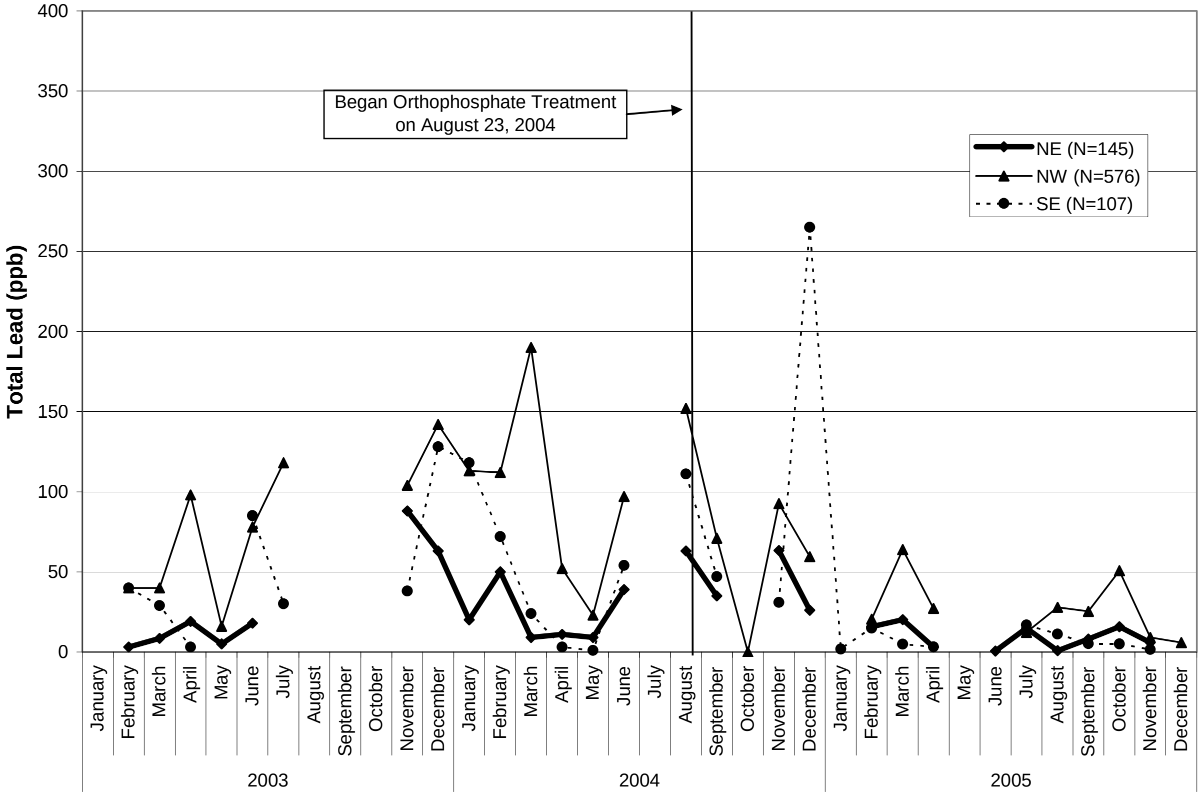


Exhibit 3.4.6b Monthly Maximum Total Lead Concentration in First Draw Samples by Geographic Quadrant (January 2003 – December 2005)



We assessed the magnitude of the elevated lead levels after orthophosphate treatment by reviewing individual results for those samples collected in 2005 with total lead concentration greater than 15 ppb. Exhibit 3.4.7 shows that most of the values are less than 30 ppb, with only two first draw samples greater than 30 ppb at 64 ppb and 51 ppb. Additional analysis revealed that approximately one half of the first draw results greater than 15 ppb are associated with a second draw sample result greater than 15 ppb. The rest of the samples were followed by second draw sample results of less than 15 ppb.

Exhibit 3.4.7 Results for Samples with Total Lead concentration > 15 ppb in 2005, Ranked High to Low

Sample Type	Total No. of Samples Taken in 2005	Total No. of Samples with Total Lead > 15 ppb	Concentration (ppb) for Samples >15 ppb, Ranked High to Low
First Draw	211	17	64 51 28 27 26 25 24 24 22 20 20 17 17 17 16 16 15
Second Draw	212	22	102 39 37 32 28 26 26 23 22 21 20 18 18 18 17 16 16 16 16 16 15 15

Analysis of LCR data for Homes Sampled Before and After Orthophosphate Treatment

Analyses of LCR monitoring data is complicated by the fact that different homes are sampled during different times of the year. Only a fairly small subset of the more than 450 homes in our dataset were sampled more than once from January 2003 through December 2005. Approximately 95 homes were sampled both before the start of the orthophosphate treatment on August 23, 2004 and after January 1, 2005 when the treatment process had stabilized.

Exhibit 3.4.8 compares results for homes sampled before and after the start of orthophosphate treatment. In all cases, the percent of samples with high total lead concentrations was significantly reduced following the implementation of the orthophosphate treatment.

Exhibit 3.4.8 Comparison of Lead Levels for Subset of Homes Sampled Before and After Start of Orthophosphate Treatment

Sampling Time Frame	Sample Type	Total Number of LCR Samples[2]	Average Total Lead for all Samples (ppb)	Percent of Samples with Total Lead Greater Than			
				15 ppb	30 ppb	50 ppb	100 ppb
Prior to Orthophosphate Treatment	**1st Draw**	127	27.8	63%	32%	14%	2%
	2nd Draw	127	27.9	55%	31%	15%	5%
After Orthophosphate Treatment[1]	**1st Draw**	148	7.1	9%	1%	1%	0%
	2nd Draw	149	6.4	10%	1%	1%	1%

[1] Because adjustments were still being made to the treatment process, we excluded data from August 24, 2004 through December 31, 2004 from this subset.

[2] All samples are from a total of 95 homes.

3.5 Analysis of Bacteriological Activities in the Distribution System

Although the primary goal of orthophosphate addition in D.C. is to reduce lead levels, orthophosphate treatment can have a beneficial impact on microbiological activity in the D.C. system. There was a concern that orthophosphate could increase bacteriological activity and exacerbate the nitrification problem, since phosphate acts as a nutrient for some microorganisms. However, phosphate-based corrosion inhibitors combined with appropriate disinfection have been shown to reduce biofilms growth.

A review performed by Dr. Anne Camper of past studies and of D.C. distribution system conditions suggests that orthophosphate indeed may help alleviate microbiological activity in the long term. (See Appendix E for a copy of Dr. Camper's review memo.) In systems with a considerable amount of unlined iron pipe—such as D.C.'s—biofilm activity is apt to be even greater when humic (organic) substances interact with corroded iron oxides. By reducing the corrosion of iron pipes, orthophosphate can help eliminate some of the favorable conditions for biofilm growth, thus improving the biological stability of drinking water. Initial reactions with pipe linings, however, may cause bacteria to slough off, resulting in a temporary spike in HPCs and total coliforms. As shown later in this section, D.C. did experience a peak in HPCs and total coliforms in September 2004, soon after the orthophosphate initiation. Flushing was recommended and implemented in response to HPC spikes in the distribution system.

Dr. Camper did not believe it was likely that phosphate would increase bacteriological activity, as phosphate was likely not the limiting nutrient to bacterial growth in this system. Rather, carbon is the limiting nutrient for biofilms in D.C.'s system.

Corrosion control treatment such as orthophosphate has been shown to reduce nitrification by allowing for increased chlorine residuals in areas of historically high water age. Because ammonia-oxidizing and nitrite-oxidizing bacteria (AOB and NOB, respectively) perform nitrification in drinking water systems, reduced microbial activity in distribution systems often has direct implications for nitrite and nitrate levels.

To assess the impact of the DCWASA orthophosphate treatment on microbiological activity in the distribution system, we evaluated the following data:

- Percent positive total coliform samples by month for 2003 – 2005;
- HPCs; and
- WQPs related to nitrification (nitrite, nitrate, free ammonia, and total chlorine).

WQPs were reviewed by date and by site to evaluate potential spatial and temporal trends. Tracking results by location can be particularly helpful because both nitrification and biofilm growth are highly localized water quality problems that depend on water age (disinfectant residual) and pipe composition. It is important to note that DCWASA revised its unidirectional flushing procedures in mid-2004, confounding potential conclusions regarding the impact of orthophosphate on bacteriological conditions

Exhibit 3.5.1 summarizes the water quality data assessed in this section of the report.

Exhibit 3.5.1 Number of Samples in the Dataset

	2004		2005		Total
	TCR	**Supplemental**	**TCR**	**Supplemental**	
HPC	2,146	155	285	847	3,433
Total Chlorine	2,556	183	2,363	479	5,581
Nitrite	95	215	305	943	1,558
Nitrate	58	94	67	399	618
Free Ammonia	87	220	305	922	1,534

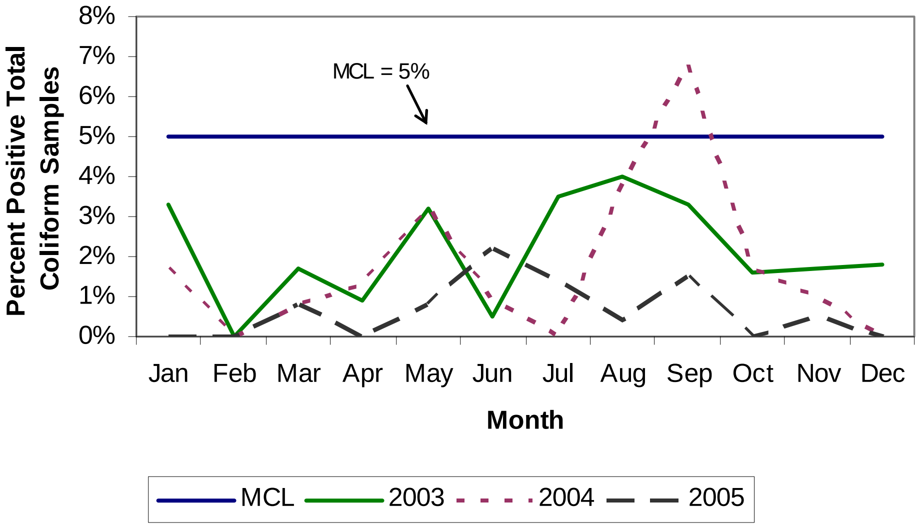
Notes: TCR = DCWASA’s TCR Compliance Monitoring Program sites.
Supplemental = DCWASA’s Supplemental Monitoring Program sites.

3.5.1 Total Coliforms

Historically, HPC and total coliform monitoring results for the D.C. distribution system follow a seasonal pattern, with the highest results occurring in the spring and summer. Serving a population of approximately 550,000, DCWASA is required to collect 210 TCR samples per month, although they routinely collect many more samples than this number.

Exhibit 3.5.2 depicts monthly results for positive total coliforms in 2003, 2004, and 2005. In 2003 and 2004, DCWASA recorded very similar results for total coliforms, in fairly similar patterns. During each of these years, the D.C. distribution system experienced the fewest positive total coliforms in February, and it experienced peaks in both May and in late summer months (August and September), separated by a drop positive total coliforms in early summer months (June and July). This drop may be attributed to the annual, spring-time conversion (in 2003 and 2004) of chloramines to free chlorine for residual disinfection (i.e., the chlorine burn).

Exhibit 3.5.2 Percent Positive TC Samples



In August of 2004, WA initiated the full-system application of orthophosphate. Soon after, for the month of September 2004, DCWASA experienced a total coliform peak in excess of the monthly limit of 5% positive total coliform samples. This resulted in a TCR violation, and was followed by aggressive flushing by DCWASA in problem areas. By October 2004, total coliform levels were in compliance and began a downward trend in keeping with seasonal patterns. Because orthophosphate has been known to loosen iron and biofilm deposits that accumulate along pipe walls (as pointed out in Dr. Anne Camper's memo in Appendix E), the initiation of this corrosion inhibitor is the suspected cause of the TCR violation.

Although the initiation of the orthophosphate corrosion inhibitor may have caused a spike in total coliform levels, orthophosphate may eventually reduce bacteria levels by eliminating distribution system conditions that facilitate biofilm growth. As shown in Exhibit 3.5.2, D.C. experienced generally lower positive total coliform results following the system-wide orthophosphate addition. As with previous years, total coliforms were lowest in February of 2005 and were highest in the spring and summer. Unlike previous years, 2005 results peaked in June, a month where the system typically observed a drop in positive total coliforms. To minimize interference with the orthophosphate application, WA skipped the annual chlorine burn in 2005, possibly explaining the total coliform peak in June. D.C. also experienced a lesser peak in September 2005, but, true to historical patterns, levels continued to decline into the fall and winter months.

3.5.2 Heterotrophic Plate Count (HPC) Results

Similar to total coliforms, HPC results reflect biological conditions throughout the distribution system. Unlike total coliforms, HPC results, measured in colony-forming units per mililiter (CFU/mL), include a wide range of bacteria types and, thus, are generally higher in distribution systems and better illustrate changes in bacterial quality.

DCWASA measured HPC at its TCR sites and supplemental sites. In 2004, DCWASA analyzed a total of 2,301tap and hydrant samples at these sites; DCWASA analyzed approximately 1,132 samples in 2005. Exhibit 3.5.3 depicts monthly average HPC results for all samples from January 2004 through December 2005. The number of samples taken per month ranged from 60 to 370. For this analysis, if multiple samples were taken at a site at the same location (hydrant or tap) on the same date, an average was taken to create a single value per site per location per day. Also, values found to be <1 or >5,700 were noted as 1 and 5,700, respectively.

Exhibit 3.5.4 compares average hydrant and tap results for 2004 and 2005. Note that hydrant and tap samples exhibited similar HPC results, with the exception of higher hydrant results for July 2005.

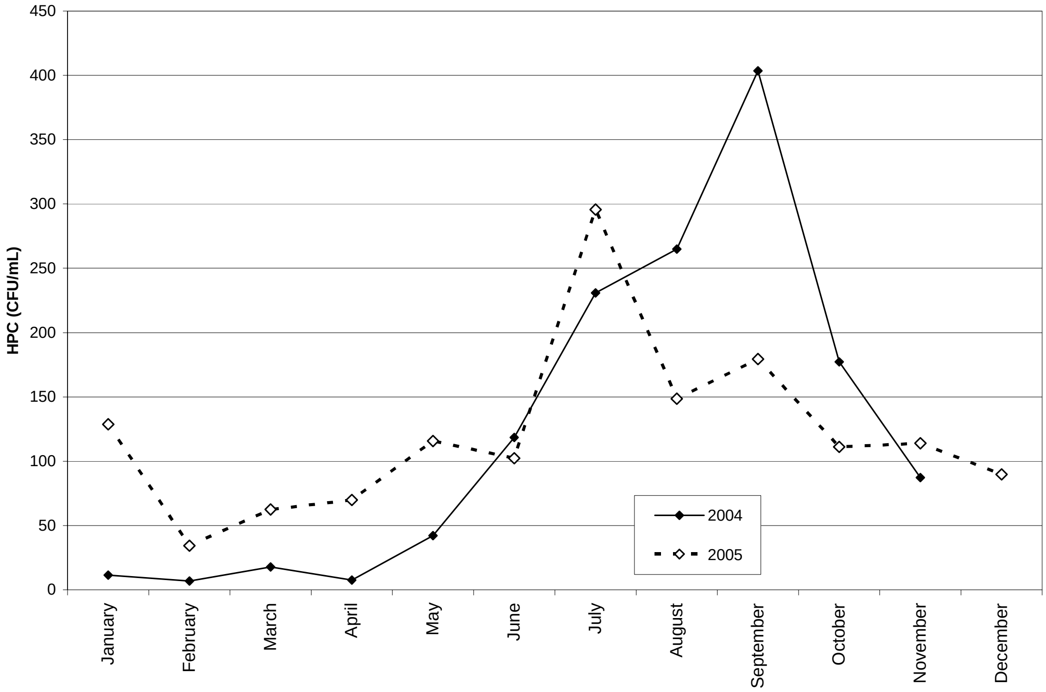
DCWASA's HPC counts—like its total coliform results—follow a seasonal pattern, with peaks in the warmer spring and summer months and lows in the fall and winter.

- The D.C. water system experienced its highest average HPC in September 2004 (404 CFU/mL), the same month that DCWASA exceeded the total coliform MCL;
- Average monthly HPCs for the first half of 2005 (ranging from 34 to 129 CFU/mL) were slightly higher than for the first half of 2004 (ranging from 7 to 119 CFU/mL); and
- Average monthly results for the second half of 2005 (90 to 296 CFL/mL) were lower than the same time period in 2004 (87 to 404 CFL/mL). The high results for early 2005 may be related to mild temperature conditions in the winter of 2005.

Slightly lower HPC results for spring and summer of 2005, compared to spring and summer 2004, may be evidence of the effect of orthophosphate in making system conditions less favorable to bacterial growth, although differences are not substantial enough to draw firm conclusions.

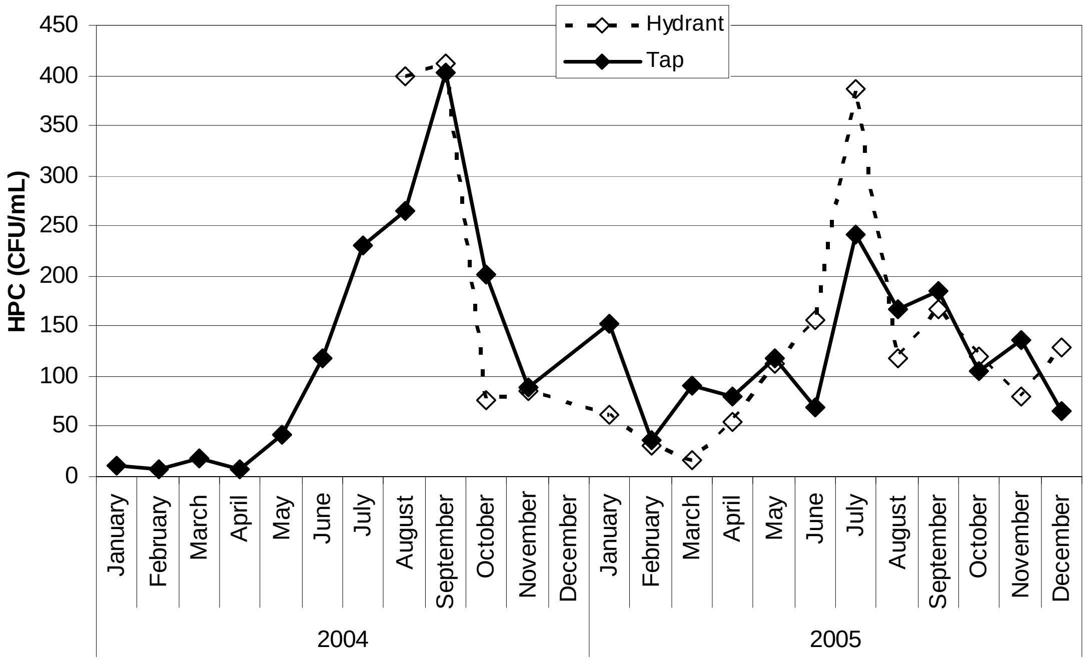
Because microbial activity in distribution systems is highly localized, HPC results for the D.C. system were also analyzed by site. Exhibits 3.5.5a and 3.5.5b show average HPC results for TCR sites and supplemental monitoring sites, respectively, for the period of September 2004 through December 2005. The HPC data do not appear to exhibit a strong pattern by site or by pressure zone. The sites with the highest results (>5,700 CFU/mL)—siteIDs L-5 BKJV, A1H-2 BKJV, and A1H-4 BKJV, all tap samples—experienced these peaks at different times throughout the September 2004 to December 2005 period of analysis, suggesting these were isolated events.

Exhibit 3.5.3 Average Monthly HPC Results for 2004 and 2005



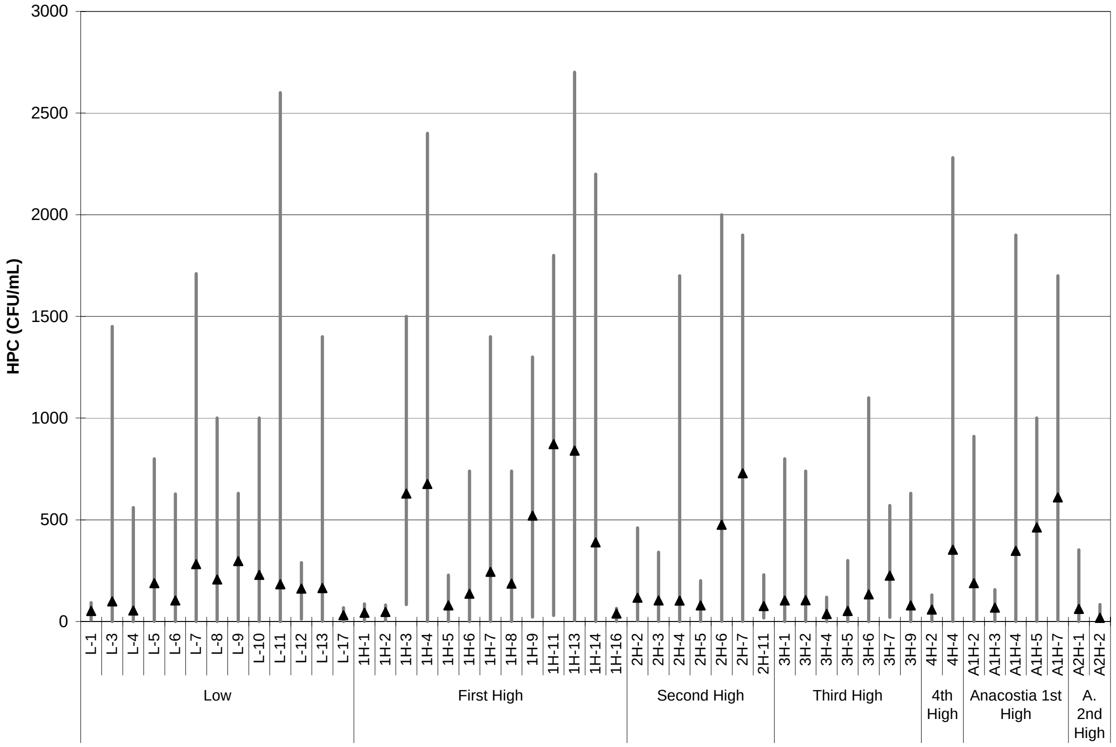
Source: TCR and supplemental monitoring sites, tap and hydrant samples, including downstream and upstream samples. Note that the number of samples taken per month varies.

Exhibit 3.5.4 Average Monthly HPC Results for Tap and Hydrant Samples (Jan. 2004- Dec. 2005)



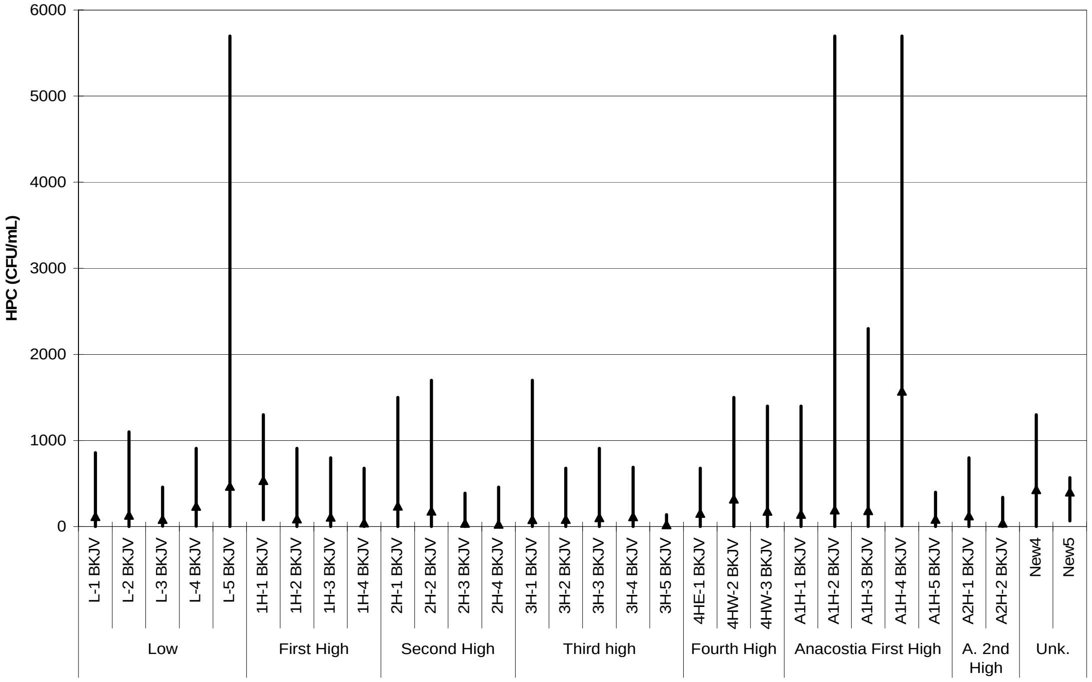
Source: TCR and supplemental monitoring sites, tap and hydrant samples**,** including downstream and upstream samples. Note that the number of samples taken per month varies.

Exhibit 3.5.5a Average HPC Results for TCR Sites (Sept. 2004- Dec. 2005)



Source: TCR Monitoring Sites, taps and hydrants, no upstream or downstream samples.
Note: The number of samples taken per site varies.

Exhibit 3.5.5b Average HPC Results for Supplemental Sites (Sept. 2004- Dec. 2005)



Source: Supplemental monitoring Sites, taps and hydrants, no upstream or downstream samples.
Note: The number of samples taken per site varies.

3.5.3 Nitrification Parameter Monitoring

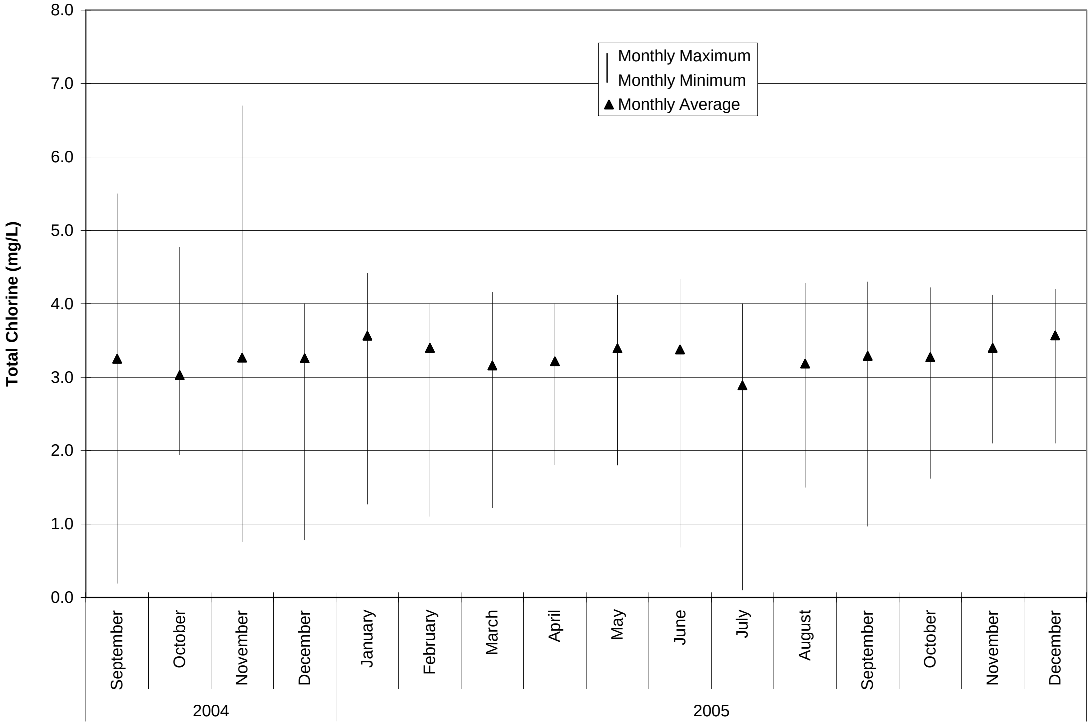
Nitrification is the biochemical process by which bacteria convert ammonia to nitrite and nitrate. EPA regulates both nitrite and nitrate in finished water (water entering the distribution system) because of their impacts on human health. Nitrite's MCL is 1 mg/L as nitrogen, while nitrate's MCL is 10 mg/L as nitrogen.

Nitrification most often occurs in low-flow and remote areas of distribution systems where disinfectant residuals are lower and bacteria counts are higher. It is a particularly vexing problem for chloraminated systems (such as D.C.'s) when excess ammonia accumulates and helps accelerate the nitrification process. With growing concentrations of nitrate and nitrite, nitrification decreases disinfectant (chloramine) residuals and thus leaves the water system more susceptible to increased microbial activity and contamination events.

According to the AwaaRF guide, *Optimizing Chloramine Treatment, 2nd Edition* (AwwaRF 2004**)**, nitrification is most easily observed by reviewing monitoring results for reduced disinfectant residual (total chlorine) and elevated nitrite. Nitrification is also associated with elevated nitrates, higher HPCs, and elevated free ammonia.

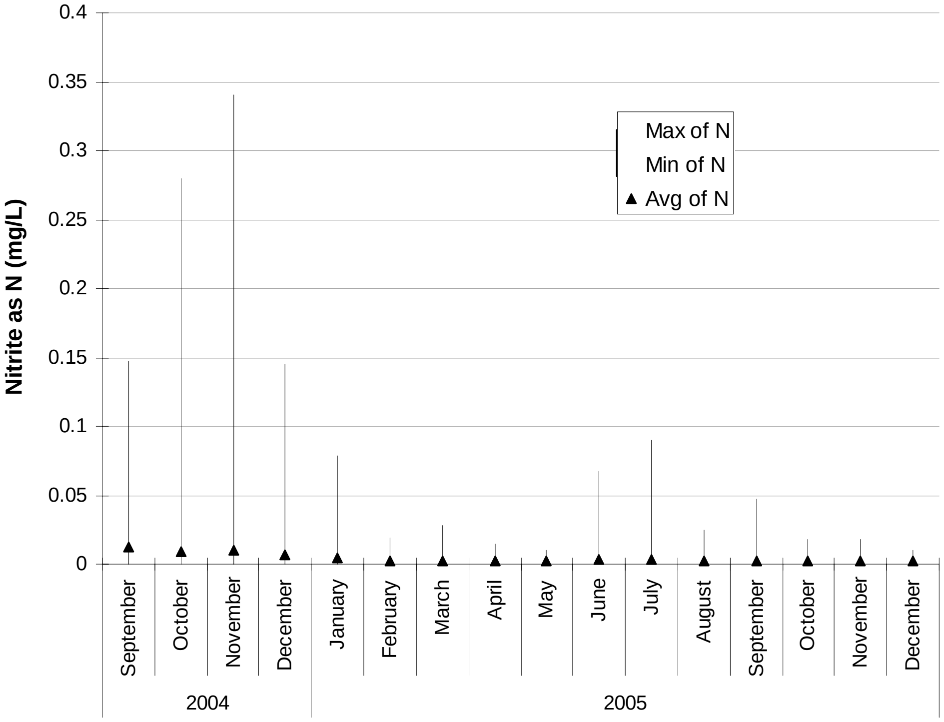
Since September of 2004, DCWASA has regularly monitored for nitrate, nitrite, and free ammonia at TCR and supplemental sites in the system. It should be noted that DCWASA only measured nitrate if nitrite results for a sample exceeded 0.1 mg/L or if free ammonia results either exceeded 0.4 mg/L or were below 0.2 mg/L. Our dataset contains more than 100 free ammonia results each month and nearly that many nitrite results each month. The sample size for nitrate is smaller, representing an average of 25-30 samples each month. In addition to these parameters, total chlorine is always recorded in the field using HACH brand test kits. Exhibits 3.5.6 through 3.5.9 show monthly maximum, minimum, and average values for total chlorine, nitrite, nitrate, and free ammonia from September 2004 to December 2005.

Exhibit 3.5.6 Total Chlorine Results by Month



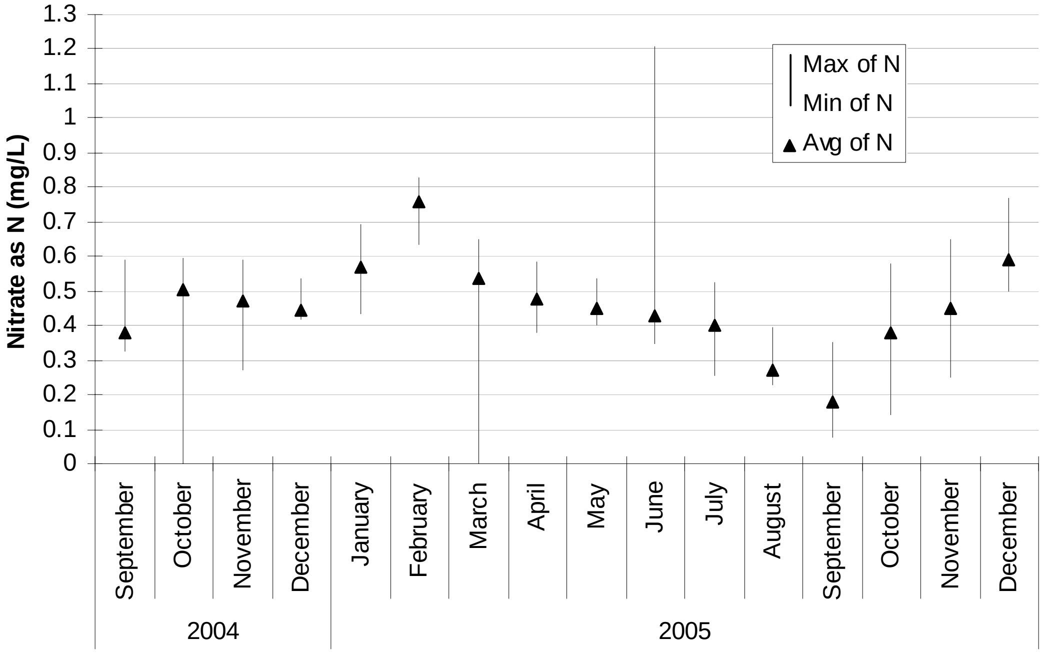
Source: TCR and Supplemental Monitoring Sites, taps and hydrants.

Exhibit 3.5.7 Nitrite as Nitrogen Monitoring Results by Month



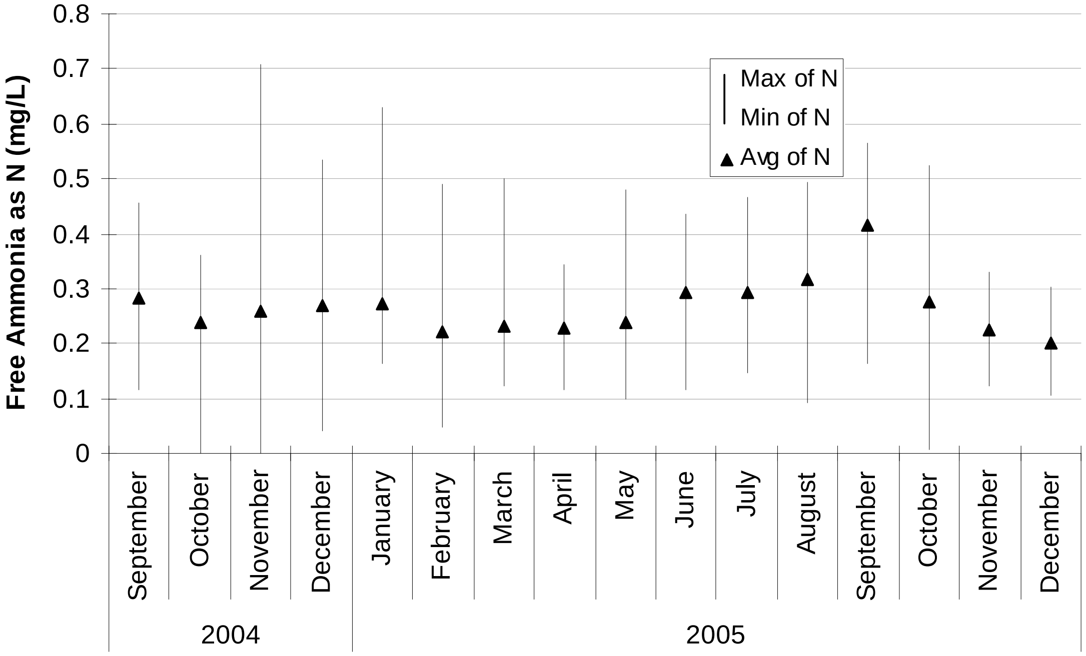
Source: TCR and supplemental Monitoring sites, tap and hydrant samples.

Exhibit 3.5.8 Nitrate as Nitrogen Monitoring Results by Month



Source: TCR and supplemental monitoring sites, taps and hydrants.

Exhibit 3.5.9 Free Ammonia as Nitrogen Monitoring Results by Month

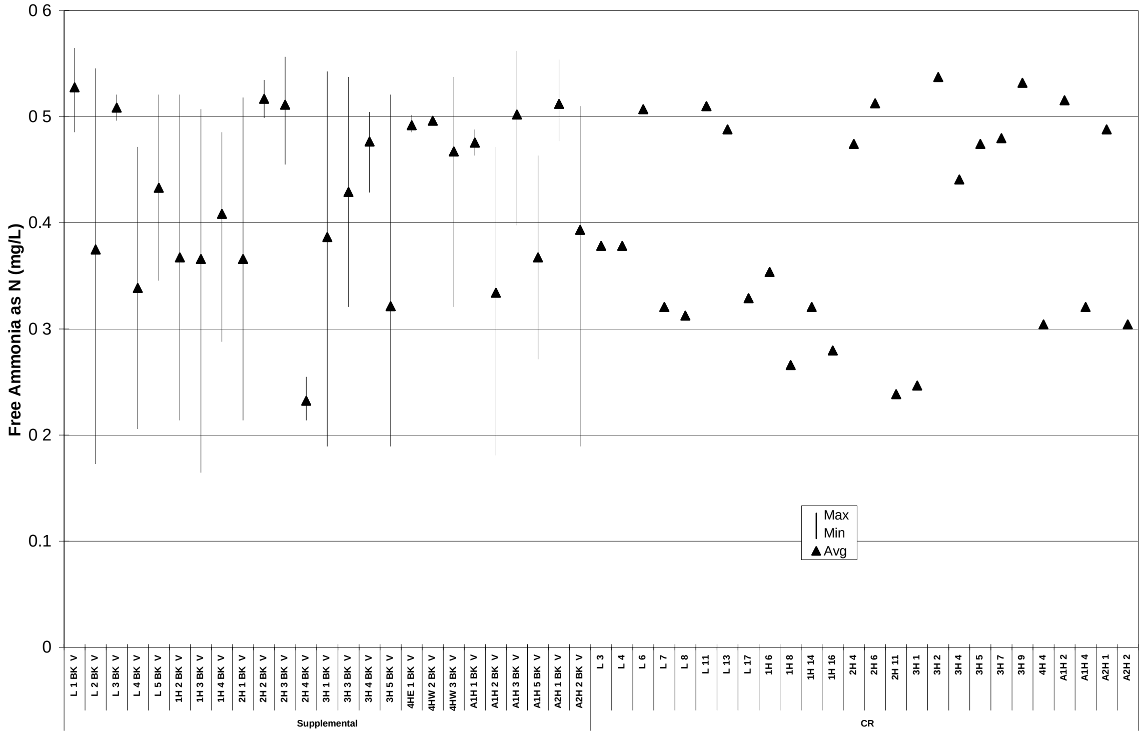


Source: TCR and supplemental monitoring Sites, taps and hydrants.

Overall, there does not appear to be a strong relationship among the four parameters (total chlorine, nitrite, nitrate, and free ammonia levels) since the start of orthophosphate application in August 2004. While nitrite and total chlorine do not exhibit a strong pattern in concentration over time, average nitrate levels were generally greatest in the winter months of both 2004 and 2005. Free ammonia levels remained, on average, steady over time. DCWASA observed a spike in average free ammonia in September 2005. Evaluation of average HPC counts did not reveal a related increase in bacteriological activity during this time frame or a relationship with nitrite or nitrate levels. To determine if this spike was localized or system-wide, we graphed free ammonia results by site for September 2005. Exhibit 3.5.10 shows average, maximum, and minimum free ammonia for each supplemental and TCR site for which data were available during this month. No patterns appear by site or pressure zone.

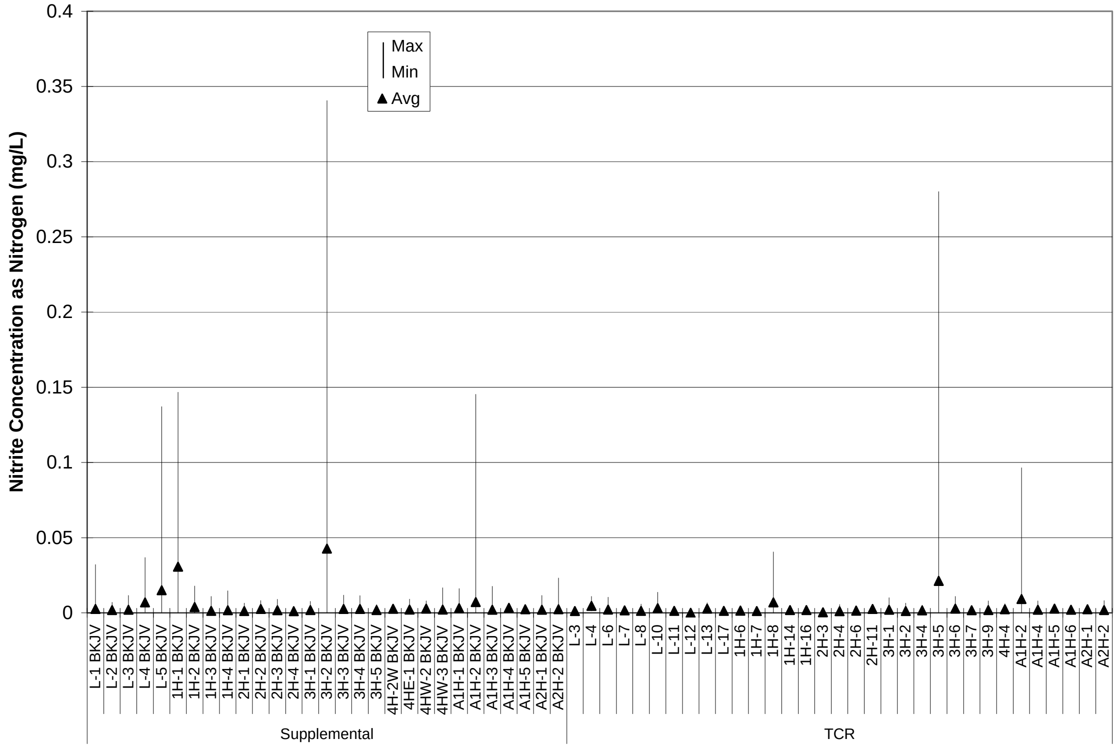
Exhibits 3.5.11 and 3.5.12 show nitrite and nitrate concentration by Site ID, respectively, for both TCR and supplemental monitoring sites. Exhibit 3.5.11 reveals high nitrite maxima only at a few specific sites; Exhibit 3.5.12 reveals a nitrate spike at one site (A2H-1 BKJV). The TCR site 3H-5 and the supplemental monitoring sites L-5 BKJV, 1H-1 BKJV, 3H-2 BKJV, and A1H-2 BKJV represent those locations with the highest nitrite results, all in excess of 0.1 mg/L. Elevated nitrite concentrations at these five sites—possibly indicative of localized nitrification events—are graphed over time in Exhibit 3.5.13. It appears that, while DCWASA experienced high nitrite levels for selected locations in late 2004, nitrite levels for these same sites declined over time. This is confirmed in Exhibits 3.5.14 through 3.5.18, which track total chlorine and nitrite level for each site over time. Note that the graphs of individual sites have different scales for nitrite and chlorine. In almost every graph, higher nitrite values are accompanied by lower total chlorine results, suggesting that, indeed, nitrification was occurring. DCWASA personnel reported that at at least one location, they discovered a cross connection which likely contributed to high nitrite levels.

Exhibit 3.5.10 Free Ammonia as Nitrogen Results by Site (September 2005)



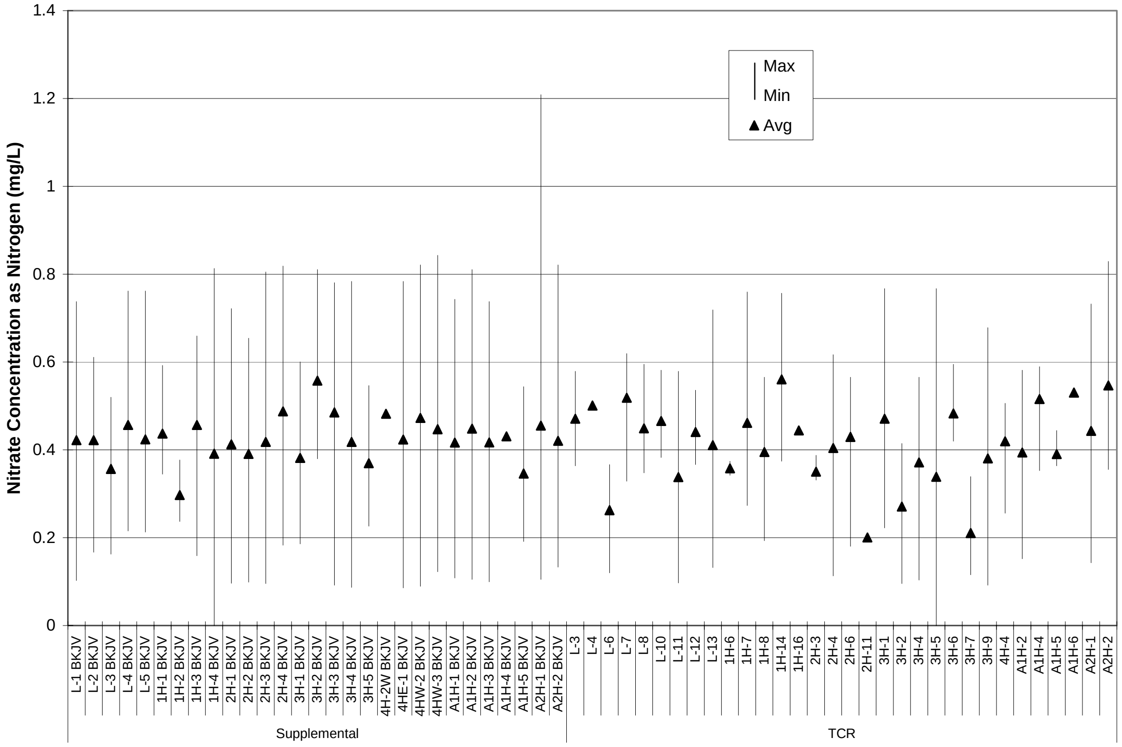
Source: TCR and supplemental monitoring sites, taps and hydrant data.

Exhibit 3.5.11 Nitrite as Nitrogen Results by Site (Sept. 2004 - Dec. 2005)



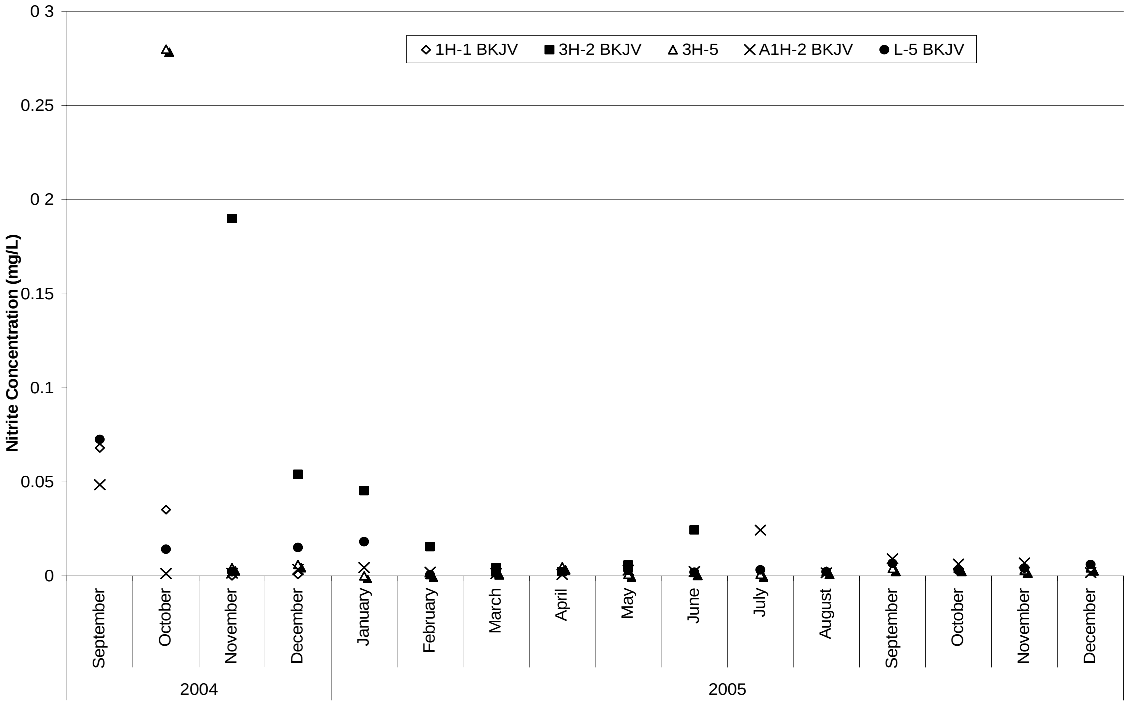
Source: TCR and Supplemental monitoring sites, taps and hydrants.

Exhibit 3.5.12 Nitrate as Nitrogen Results by Site (Sept. 2004 - Dec. 2005)



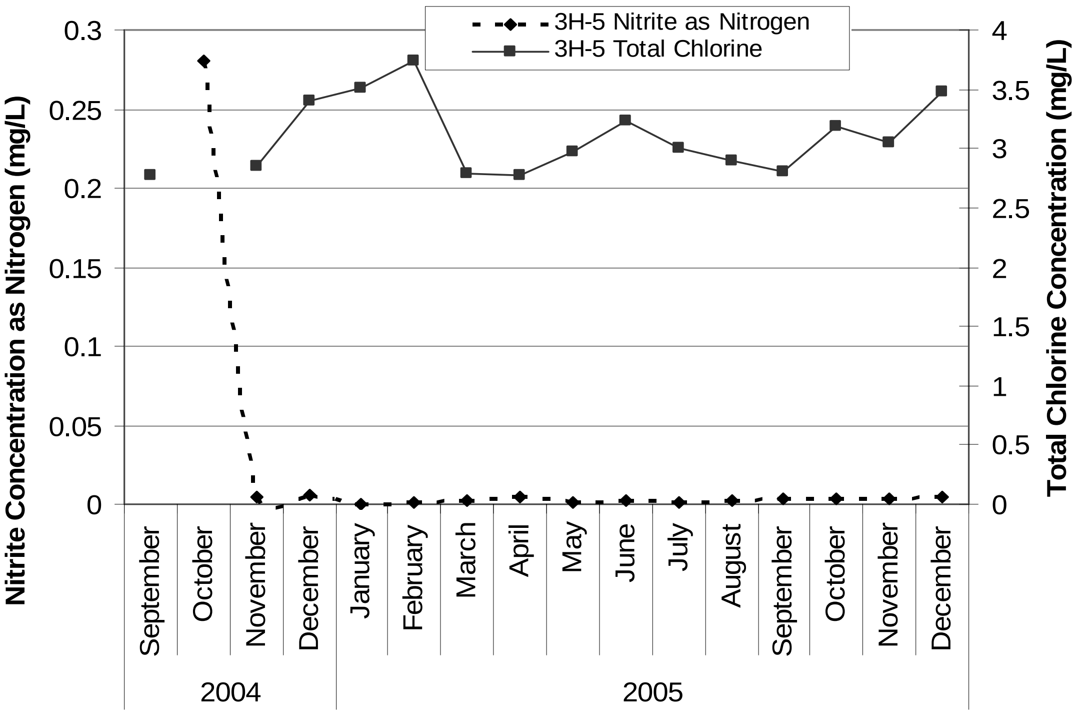
Source: TCR and Supplemental Monitoring Sites, taps and hydrants.

Exhibit 3.5.13 Maximum Nitrite Values as Nitrogen for Sites with High Nitrite Peaks



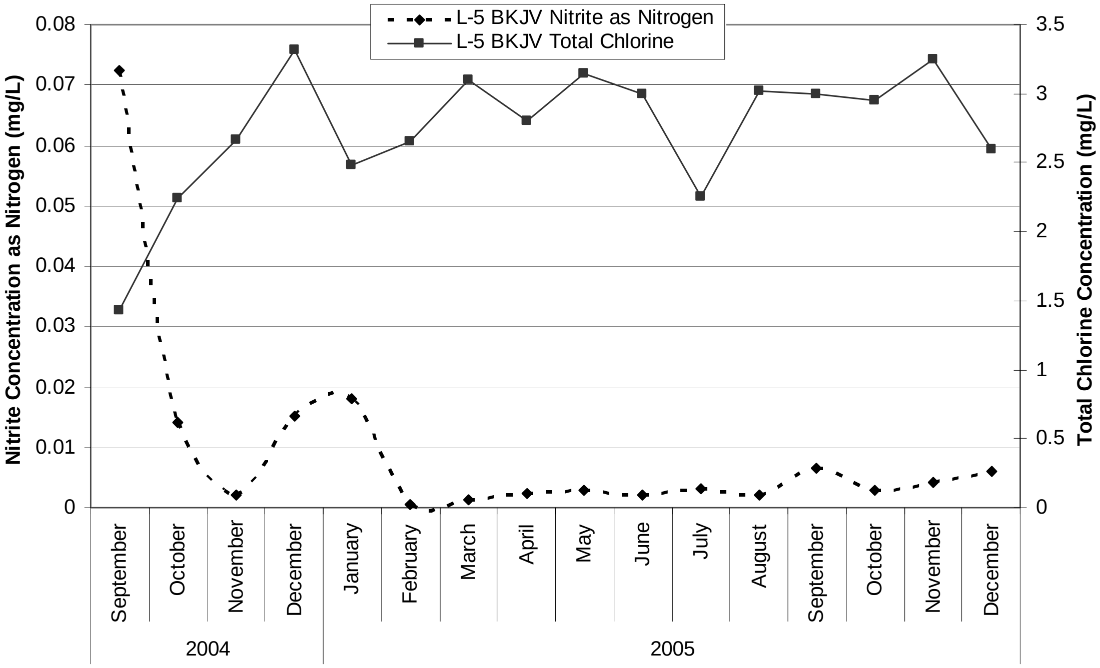
Source: TCR and Supplemental Monitoring Sites, taps & hydrants.

Exhibit 3.5.14 Monthly WQP Results for 3H-5



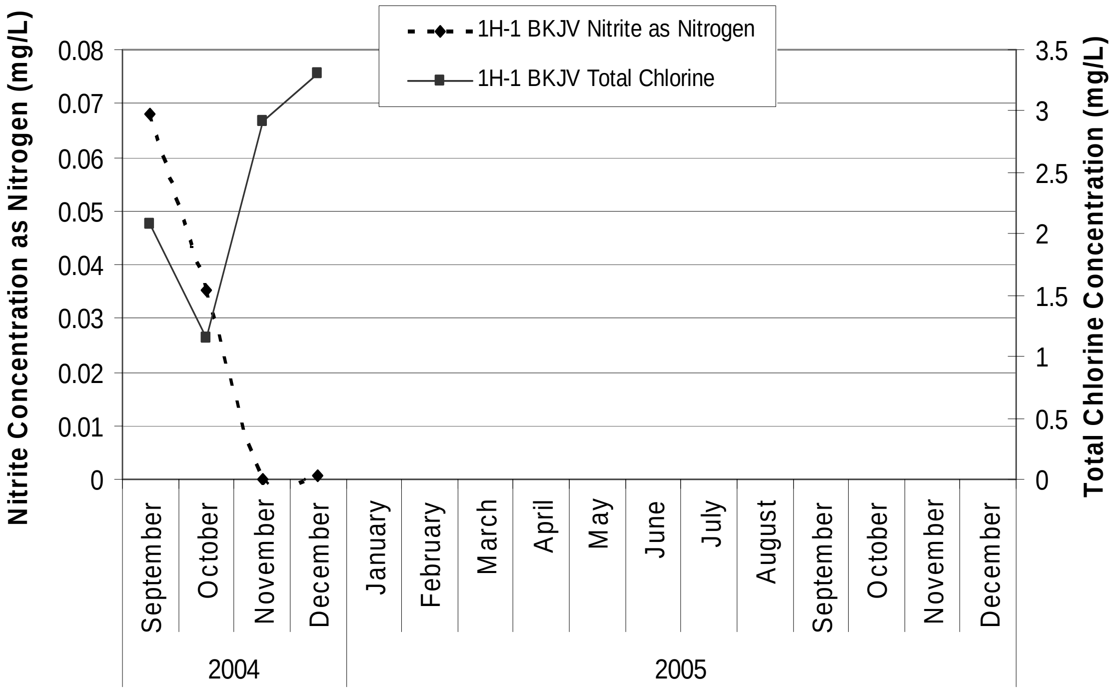
Source: Tap & hydrant samples.

Exhibit 3.5.15 Monthly WQP Results for L-5 BKJV



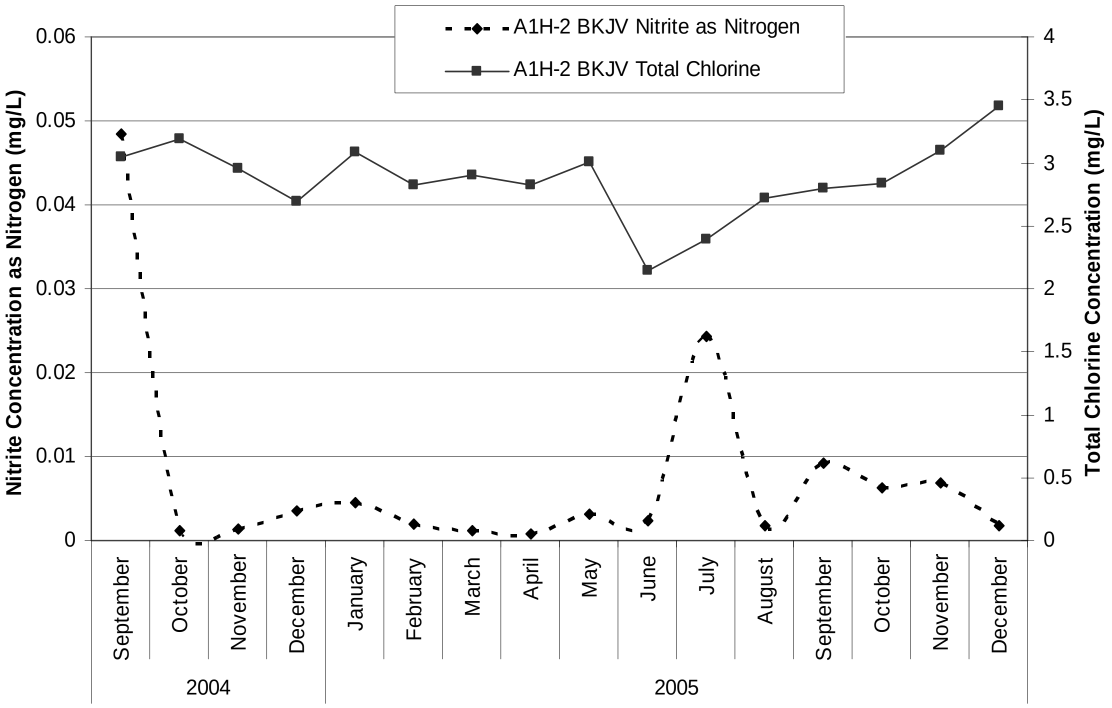
Source: Tap & hydrant samples.

Exhibit 3.5.16 Monthly WQP Results for 1H-1 BKJV



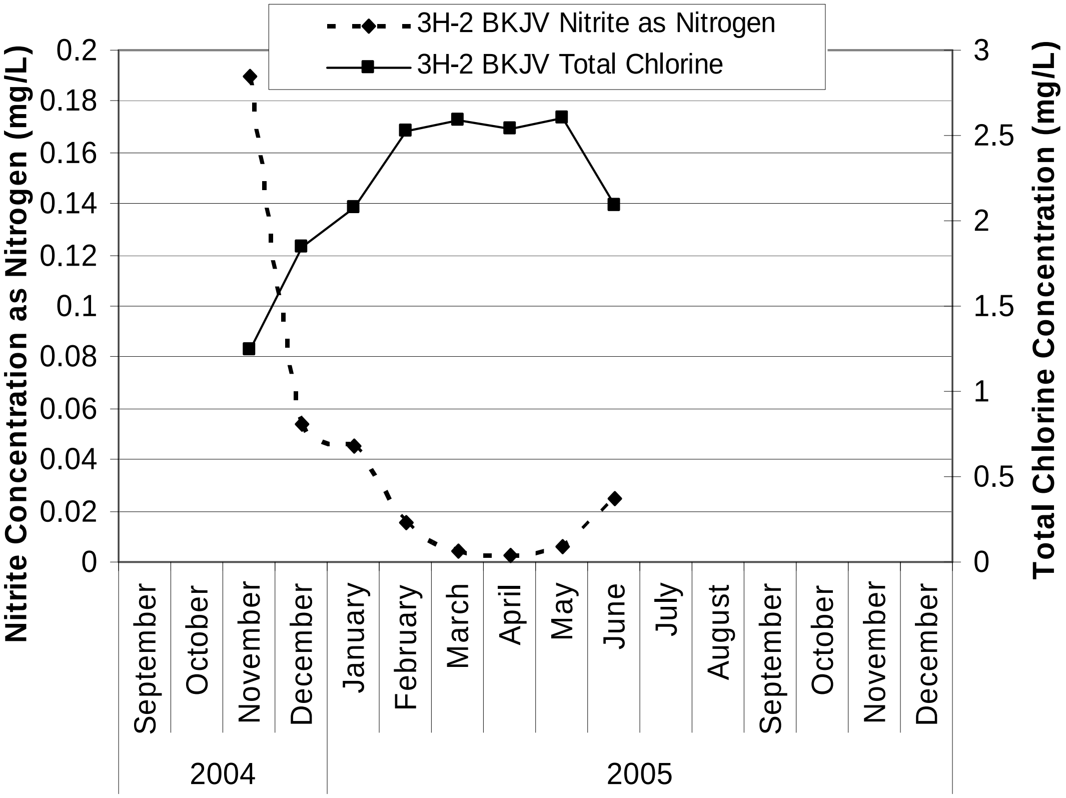
Source: Tap & hydrant samples

Exhibit 3.5.17 Monthly WQP Results for A1H-2 BKJV



Source: Tap & hydrant samples

Exhibit 3.5.18 Monthly WQP Results for 3H-2 BKJV



Source: Tap & hydrant samples.