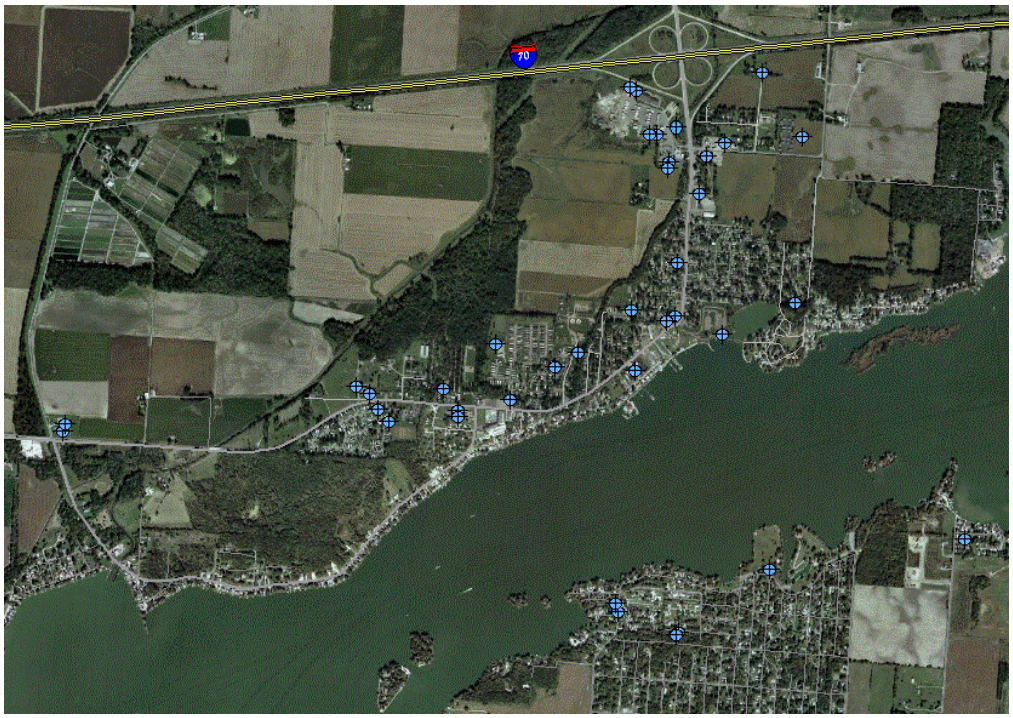
State of Ohio
Environmental Protection Agency

Division of Drinking and Ground Waters

Investigation of Bacteria in Public Water System Compliance Monitoring Samples

Village of Buckeye Lake
Licking County, Ohio



April 2008

Ted Strickland, Governor
Chris Korleski, Director

Executive Summary

Some Public Water Systems (PWSs) in the Village of Buckeye Lake, Licking County, Ohio, have a long history of bacteriological problems. Examination of Ohio EPA compliance monitoring data since 2000 indicates that 8 of the 23 public water systems in the Village of Buckeye Lake have had 10% or more of their bacteriological samples identified as positive for total coliform. The PWS wells are completed in the South Fork Licking Buried Valley Aquifer at depths ranging from 78 to 190 feet and overlain by more than 60 feet of clay. This isolation and confined nature of the aquifer suggest the aquifer is not sensitive to surficial pathogen contamination. The purpose of the current study was to determine the cause or source of positive bacteria detections in the public water system wells.

Twelve (12) PWSs in the Village of Buckeye Lake were selected for this special sampling study (eight had historic total coliform problems, four had little to no occurrences of positive total coliforms). Distribution and raw (untreated) water were sampled – if a raw water tap was available – for inorganic parameters, iron bacteria, and total coliform (using both MMO-MUG and Membrane Filtration methods for comparison). If total coliform was present, the sample was analyzed for *E. coli* and the species of bacteria were identified. Field parameters (temperature, oxidation-reduction potential [ORP], pH, TDS, and conductivity) were also collected at each sampling location. Sites were sampled in February, April, and August, 2007.

The total coliform positive results for all three sampling events are shown in Table 1. Only four of the eight PWSs that historically had 10% or more of their bacteriological samples positive for total coliform resulted in a positive total coliform during this study. For all samples that were total coliform positive using the MMO-MUG method and negative using the Membrane Filtration method, the bacteria species present was non-coliform. The presence of iron bacteria did not correlate to a positive total coliform result. Although there are some potential contaminant sources (or rapid pathways) for bacteria present in the Village (i.e. abandoned or wells, a sewage lift station and sanitary sewers, and flood waters), the thick confining layer which exists over the study area appears to protect the aquifer from detrimental water quality impacts associated with land use or waste management practices. The sanitary sewer line near Lakeshore Court MHP and Louie's Corner House may be an exception.

Table 1. Total Coliform Positive results for the samples collected at Buckeye Lake during the February, April and August 2007 sampling events. "P" indicates that bacteria were positively detected and "N" indicates that no bacteria were detected.

Location		Sample Date	TC (MMOMUG)	TC (MF)	*E. Coli*	Fe Bacteria	Bacteria Speciation
Citgo	Treated	8/14/2007	P	P	N	P	***Enterobacter cloacae*** [1]
Head Start	Raw	8/14/2007	P	N	N	P	*Aeromonas hydrophila*
KOA	Raw - DUP A	4/17/2007	P	P	N	P	***Enterobacter cloacae*** [1]
	Raw - DUP B	4/17/2007	P	N	N	P	*Enterobacter agglomerans*
	Treated	4/17/2007	P	N	N	P	*Enterobacter agglomerans*
Louie's	Raw	4/18/2007	P	P	N	P	***Enterobacter cloacae*** [1]
	Raw	8/15/2007	P	P	N	P	***Citrobacter freundii*** [1]

[1] Bacteria identified by Benchmark Labs as true coliform bacteria

The ground water at Buckeye Lake is geochemically reduced as indicated by the negative oxidation-reduction potential (ORP), the elevated iron and arsenic, and the presence of ammonia. The presence of reduced water was expected because the depth of the wells and the thick clay confining layer over the aquifer limit the amount of oxygen-rich local precipitation that recharges the aquifer. Arsenic was consistently present above the MCL (10 µg/L) in the raw water of most wells that were sampled.

The ammonia concentrations detected in four of the wells sampled are generally higher than typically found in reduced ground water, which may point to a nearby source of ammonia. The source of the elevated ammonia may be from the sanitary sewer line that runs adjacent to Lakeshore Court MHP, Louie's Corner House, and Buckeye Lake Head Start. Lakeshore Court MHP and Louie's Corner House contained the highest raw water ammonia concentrations of the sampled wells (5.29 mg/L and 3.81 mg/L, respectively).

No conclusive source for the cause of the historical total coliform positives at many of the public water systems in the Buckeye Lake area has been identified based on the results of this study. The historic total coliform positive results could be from: selection of poor sampling locations; improper sample collection methods; modifications to the distribution system to correct problems; or actual bacteriological sources. The bacteriological sampling results suggest that the sensitivity of the MMO-MUG method may produce false positive results (compared to membrane filtration) due to presence of non-coliform bacteria.

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INTRODUCTION

The Village of Buckeye Lake is located in Licking County at the Fairfield County border, approximately 40 miles east of Columbus. Many Public Water Systems (PWSs) in the Village have a history of positive total coliform in their compliance monitoring samples. The purpose of this study was to determine the cause or source of positive bacteria detections in the public water system wells.

Background

The Public Water Systems in the Village of Buckeye Lake have a long history of bacteriological problems. Ohio EPA compliance monitoring data examined since 2000 indicate that 8 of the 23 public water systems in the Village of Buckeye Lake have had 10% or more of their bacteriological samples positive for total coliform (Table 1). Four of these systems have also been *E. coli* positive on at least one occasion. PWSs that have a positive total coliform result are immediately required to collect four repeat samples. A plan of study was developed and approved in January 2007.

Project Location

The Village of Buckeye Lake covers an area of approximately three square miles, and is located in southern Licking County on State Route 79, south of Interstate 70, approximately 40 miles east of Columbus. The population of Buckeye Lake is roughly 3,000. Twenty-three (23) public water systems exist in the village's municipal boundaries (Figure 1). Residents are supplied water by private wells. The Village of Buckeye Lake has been served by public sewer (Buckeye Lake Sewer District #1) since 1956.

Geology

All of the PWS wells are completed in the South Fork Licking Buried Valley Aquifer. The well depths are 78 feet to 190 feet. Depth to bedrock exceeds 300 feet. In most cases, the aquifer is covered by a thick layer of clay (50 feet to over 100 feet thick), believed to provide significant contamination protection from land uses. In general, the wells are cased through this confining layer (casing lengths > 70 feet). Depth to water ranges from approximately 15 feet to more than 60 feet; in most wells this is above the bottom of the protective clay layer, indicating that the aquifer is confined and under pressure.

Data Collection

Selection of Public Water Systems to Sample

Eight PWSs in the Village of Buckeye Lake with 10% or more of their bacteriological compliance samples positive for total coliform (Table 1) since 2000 were selected for this special sampling study. Four PWSs that have had minimal to no positive detections of total coliform were also chosen to investigate possible differences in water treatment, geology, aquifer media, well construction, well maintenance, distribution system, and location.

Table 1 - Buckeye Lake Public Water Systems

PWS ID	PWS NAME	PWS Type	Bacteriological Results[1]				Treatment			Well Construction					Avg As (ug/L)	Avg Fe (ug/L)
			# TC+	# TC-	% TC+	# EC+	Disin-fection	Fe Removal	Soften-ing	Well Depth (ft)	Clay Thick (ft)	Casing Length (ft)	DTW (ft)	Year Drilled		
4538112	Beechridge Lounge	TNC	2	15	11.8	0	Y	Y	Y		85-90		30-50			
4505112	Blue Heron Manor	COMM	0	91	0.0	0	Y	Y	Y	100	65	88	45	1987	6.2	168.8
4559912	Buckeye Lake Duke Station	TNC	79	85	48.2	2			Y	152	>100	~136	41	1968		
4500012	Buckeye Lake Estates MHP	COMM	2	99	2.0	0	Y		Y	93	83	~83	50	1962	5.8	100
4557212	Buckeye Lake Head Start[2]	NTNC	7	63	10.0	0	Y	Y	Y	125	100	121	50	2006	12.9	632.5
4538612	Buckeye Lake KOA Kampground	TNC	6	35	14.6	0			Y	85	>70	~78	78	1969		
4556812	Buckeye Lake Truck Stop	NTNC	4	233	1.7	0	Y		Y	109-167	98	~100	40	1989	13.8	110
4562612	Catfish Charley's Pizza PWS	TNC	0	5	0.0	0		Y	Y	156	>100	~150	56	2000		
4557312	Citgo Buckeye Lake PWS	TNC	44	139	24.0	0	Y		Y	135	129	~129	129	1959		
4533012	Fraternal Order of Eagles	TNC	11	71	13.4	0		Y	Y	100	>40		2			
4558512	Harmony Hall	TNC	1	29	3.3	0	Y		Y	91	87	~87	49	1993		
4500212	Lakeshore Court Mobile Home	COMM	0	79	0.0	0	Y	Y		78	65	~70	30	2000	6.5	
4505512	Leisure Village MHP 2 PWS	COMM	0	79	0.0	0	Y	Y	Y	146	125	~127	37	1997	4.8	56.7
4502112	Leisure Village MHP PWS	COMM	2	93	2.1	0	Y		Y	78-160	70-100	78, ~155	27-43	1999, 1990	7.7	1703
4553712	Louie's Corner House	TNC	18	44	29.0	2	Y		Y	153	0		75	1999		
4543512	McDonalds Restaurant #4326	TNC	3	185	1.6	0	Y	Y	Y	142	133	136	33	2004		
4503612	North Pointe Cove	COMM	3	100	2.9	0	Y		Y	87	80	~81	35	1997	6	586.7
4557712	ODNR-Buckeye Lake North	TNC	3	66	4.3	1	Y	Y		95	85	~88	31	1991		
4535812	Our Lady of Mt. Carmel Church	TNC	1	28	3.4	0			Y	190	100		50			
4532512	Super 8 Motel PWS	TNC	0	51	0.0	0	Y		Y		79		79			
4542612	Taco Bell-Buckeye Lake[3]	TNC	27	78	25.7	0			Y	103	88	98	35	2005		
4502412	Walnut Ridge Tow nhomes	COMM	6	149	3.9	1	Y	Y	Y	93	80	88, 89	23	2001, 2002	4.4	2460
4553312	Wendys - Buckeye Lake	TNC	0	80	0.0	0	Y	Y	Y	149	141	~141	38	1984		

[1] Based on review of bacteriological results submitted to Ohio EPA from 2000-2006 for compliance purposes.

[2] Buckeye Lake Head Start has a state-of-the-art arsenic removal system in place since 2006, as part of a USEPA pilot project. The TC positives are associated w ith the old w ell, w hich now serves a small library.

[3] Taco Bell has an iron removal filter in place for the beverage lines only.

HIGHLIGHTED = Systems w ith percentage of positive total coliform results greater than or equal to 10%

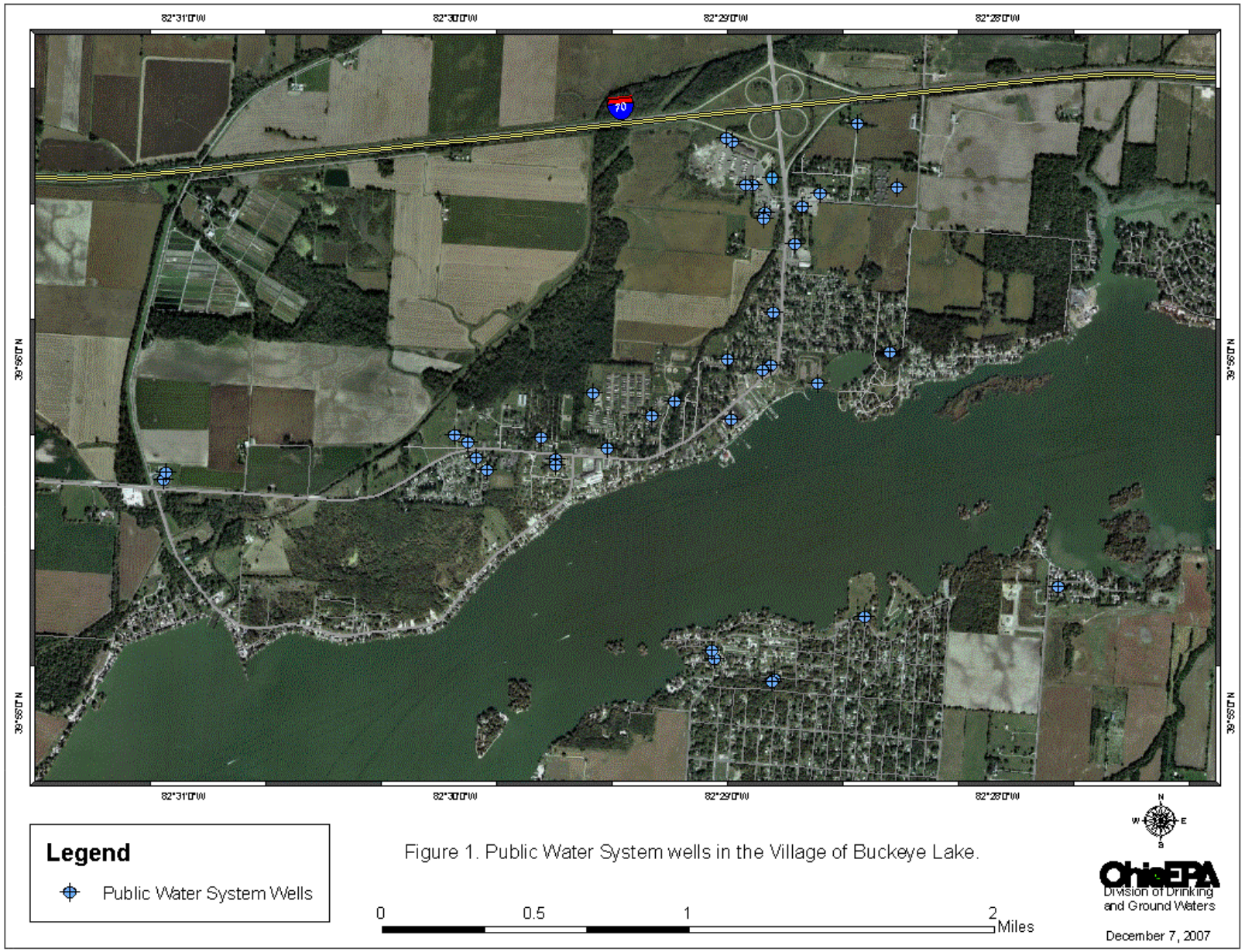

Figure 1. Public Water System wells in the Village of Buckeye Lake.

Distribution (treated) water was collected from all 12 PWSs in this study (Figure 2). Raw (untreated) water was also collected from those systems that had a raw water tap available. Only three PWSs (Beechridge Lounge, Citgo Buckeye Lake, and Our Lady of Mount Carmel Church) did not have an available raw water tap.

The PWSs that were sampled can be grouped into four separate categories based on the percentage of total coliform detections and if the PWS disinfects, as shown in Table 2.

Table 2. Matrix of PWSs chosen for sampling.

	PWS Disinfects	**PWS does not Disinfect**
Total Coliform positive detections in >10% of the samples since 2000	Citgo Buckeye Lake Beechridge Lounge Louie's Corner House Buckeye Lake Head Start†	Buckeye Lake Duke Station Taco Bell - Buckeye Lake Fraternal Order of Eagles KOA Kampground
Total Coliform positive detections in <10% of the samples since 2000	Lakeshore Court MHP McDonalds	Our Lady of Mt. Carmel Catfish Charlie's

† It is possible that the old well for Buckeye Lake Head Start (now supplying water to a small library) did not have disinfection, explaining the historical TC problems. The new well (which has disinfection) has not had a positive total coliform compliance sample since it was activated in summer of 2006.

Sample Collection Protocol

Samples for total coliform were collected using the methods outlined in Ohio Administrative Code rule 3745-81-27. Inorganic samples were collected using the procedures outlined in the Ambient Ground Water Monitoring Network's Operating Procedures Document (2002). After collection, all samples (bacteriological and inorganic) were put on ice and kept at 4°C until arriving at the lab. The exception to this is for a select group of bacteriological samples collected in August 2007 that were allowed to warm up in the hot vehicle to study the effect of ambient temperature on the growth of bacteria.

Parameter Selection

The raw and treated water at the PWSs were sampled for the following inorganic parameters during the first sampling event in February, 2007: **nitrate-N, nitrite-N, ammonia, total Kjeldahl nitrogen (TKN), iron, arsenic, manganese, chloride, sulfate, total phosphorus, total organic carbon (TOC), and total dissolved solids (TDS)[1].** Field parameters (**temperature, oxidation-reduction potential [ORP], pH, TDS, and conductivity**) were collected at each site and proved to be critical to supplement the water chemistry. The waters were also sampled for **iron bacteria and total coliform** (using both MMO-MUG and Membrane Filter methods for comparison). If total coliform was present using either method, the sample was analyzed for *E. coli* and the species of bacteria were identified.

[1] The April and August sampling events analyzed for the full suite of inorganic parameters.

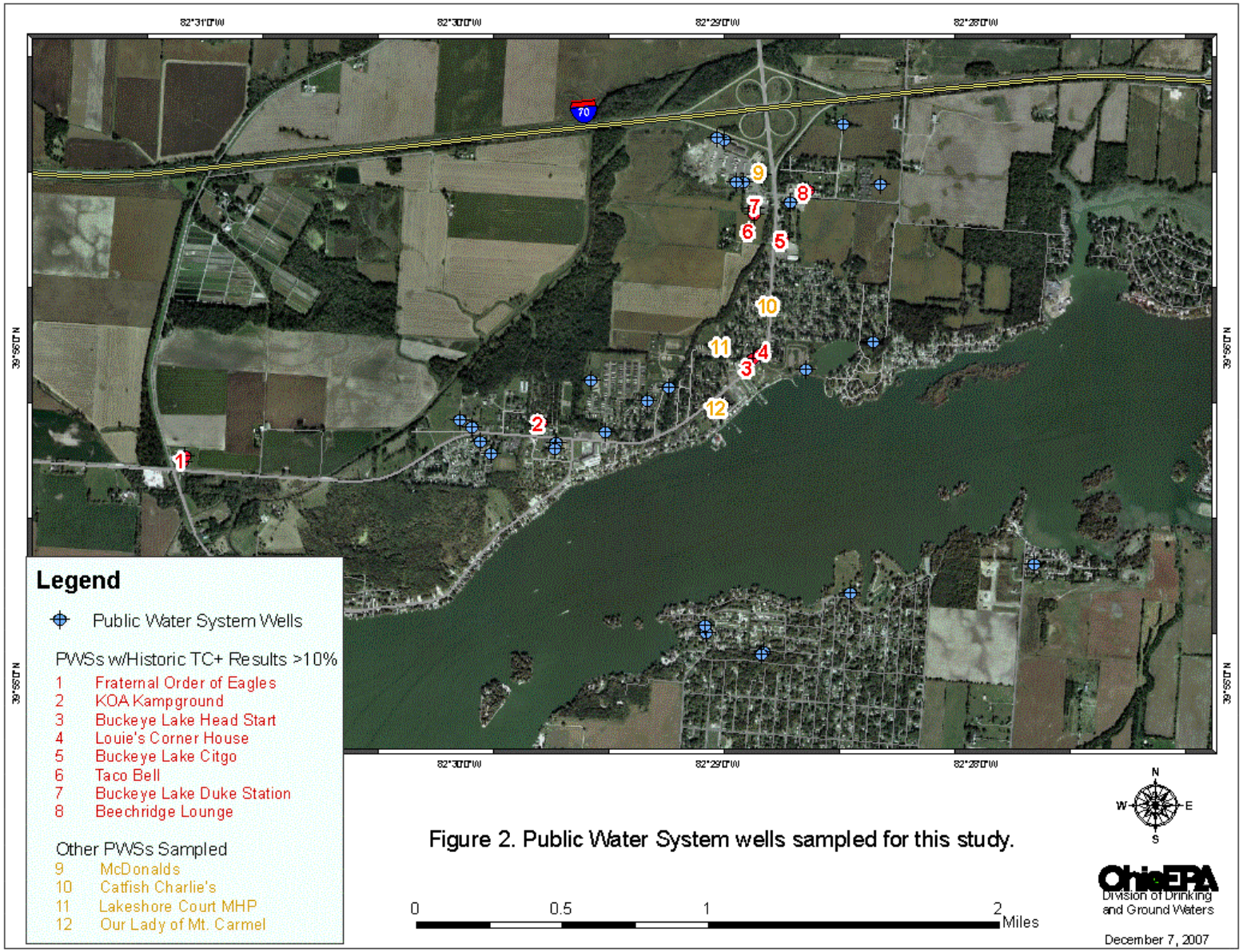

Figure 2. Public Water System wells sampled for this study.

The inorganic parameters were analyzed at Ohio EPAs Division of Environmental Services (DES) Lab. Since DES was not set up to speciate bacteria or analyze for total coliform using the Membrane Filtration method, the bacteriological parameters were analyzed at Benchmark Labs in Columbus, Ohio[2].

Sampling Schedule

The original sampling plan proposed two rounds of sampling: one in February and one in August. Because the first round of samples unexpectedly produced no positive bacteria results, a follow-up set of samples was collected in April. A summary of the results from the February, April and August sampling events are shown in Table 3.

[2] A select group of bacteriological samples were sent to DES for the second round to compare MMO-MUG results to Benchmark Labs.

Table 3. Summary of results from the February, April and August 2007 sampling events.

	FEBRUARY 21-22, 2007		APRIL 17-18, 2007		AUGUST 14-15, 2007	
	Raw	Treated	Raw	Treated	Raw	Treated
Total Samples	9	12	9	12	10	11
Average ORP	-67.9	199.3	-79.1	196.3	-56.2	54.4
Average Temp (°C)	11.4	13.2	12.9	14.1	15.4	17.9
Average Ammonia (mg/L)	1.9	1.6	1.7	0.5	1.7	0.8
Average Arsenic (µg/L)	12.1	6.2	11	6.9	13	6
Average Iron (µg/L)	2743	253	2434	254	2560	627
# Positive Iron Bacteria Samples	6	8	8	12	9	10
# Total Coliform Positive Samples (MMO-MUG)	0	0	3†	1	2	1
# Total Coliform Positive Samples (Membrane Filter)	0	0	2	0	1	1
The following climate data were obtained from NOAA National Weather Service, observed in Columbus, Ohio.						
MONTHLY Average Minimum Air Temp (°F)	13.8		41.3		67.7	
MONTHLY Average Maximum Air Temp (°F)	28.5		60		87.9	
MONTHLY Total Rainfall/Snowmelt (inches)	2.06		2.31		4.73	
MONTHLY Total Snowfall (inches)	13.1		0		0	

† One positive MMO-MUG is from a duplicate sample.

BACTERIOLOGICAL RESULTS

The purpose of this study was to determine the cause of the positive total coliform samples from public water systems in the Buckeye Lake area. Eight PWSs were identified as having frequent (>10%) total coliform positive water samples from 2000-2006. Raw and treated water samples were collected from these eight PWSs, along with four additional PWSs that did not have historic bacteria issues, in February, April and August of 2007. Our results did not duplicate the historic results.

Total Chlorine Residual

The presence of residual chlorine, from either disinfection of the distribution water or shock chlorination of the well, should remove any bacteria that may be present in the raw or distribution water. To insure that the raw water was chlorine-free (which would provide the most representative sample), the raw and treated water was analyzed for total chlorine using the DR/890 Hach Colorimeter in the field prior to collecting a sample for bacterial analysis. The procedure used to test for total chlorine is outlined in Appendix B. Hach indicates that the estimated detection limit (EDL) for the total chlorine test using the DR/890 colorimeter is 0.02 mg/L, with a standard deviation of ±0.01 mg/L (Hach, 2000). The EDL is the lowest concentration where there is a 99% confidence that the result is not zero. Therefore, any concentration below 0.02 mg/L is assumed to be zero. Table 4 shows the total chlorine results.

Table 4. Total Chlorine Residuals prior to collecting a sample, in mg/L.

	February 2007		April 2007		August 2007	
	Raw	Tap	Raw	Tap	Raw	Tap
Beechridge Lounge	--	0	--	0	--	--
Catfish Charley's	0.27	0.13	0.01	0	0	0
Citgo Station	--	0	--	0	--	0
Duke Station	0	0.25	0	0	0	0
Fraternal Order of Eagles	0	0.12	0	0.02	0	0
Head Start	0.35	0.02	0	1.46	0	0.13
KOA Kampground	--	--	0.12	0.01	0	0
Lakeshore Court MHP	0.28	0	0.07	>2.2	0.07	>2.2
Louie's Corner House	0.18	>2.2	0	0.20	0	0
McDonald's	0	0	0	0.01	0	0.05
Our Lady of Mt. Carmel	--	0.01	--	0	--	0
Taco Bell	0.03	0	0.08	0	0	0.04

There were significantly more detections of residual chlorine during the February sampling event. Since chlorine was detected in the distribution water of PWSs that do not disinfect (Duke and Fraternal Order of Eagles, for example), it is thought that some of the detections were due to operator error of the colorimeter. It was the first time the meter was used by a few of the staff. Results of chlorine residuals in April and August appeared more reasonable.

In April, KOA Kampground, Lakeshore Court MHP, and Taco Bell had elevated chlorine residual in their raw water prior to sampling. The well sampled at KOA Kampground was installed two

weeks prior, so most likely the chlorine was residual from the well installation. A Taco Bell employee stated that they shock chlorinate the well every two weeks or so (this has not been substantiated), and it is unknown when the well was last shocked relative to the April sampling event. Lakeshore Court MHP has consistently had elevated chlorine residuals in both the raw and treated water. It is possible that there is a problem with the distribution system, such as backflow of the chlorine. Also, because we had to inform the operator that we were coming to sample to gain access to the pump house, it is possible that the wells were shock chlorinated before we arrived.

Total Coliform Detections

The February sampling event produced no positive total coliform results. It was initially thought that the cold weather in the days and weeks prior to sampling may have affected the bacteria, but the lack of positive bacteria results during the April and August sampling events do not substantiate this. Table 5 summarizes the PWSs that tested positive for total coliform during the February, April, and August 2007 sampling events (shown on Figure 3).

Table 5. Total Coliform Positive results for the samples collected at Buckeye Lake during the February, April and August 2007 sampling events. "P" indicates that bacteria were positively detected and "N" indicates that no bacteria were detected.

Location		Sample Date	TC (MMOMUG)	TC (MF)	*E. Coli*	Fe Bacteria	Bacteria Speciation
Citgo	Treated	8/14/2007	P	P	N	P	*Enterobacter cloacae* [1]
	Treated-Not Iced	8/14/2007	P	P	N	P	*Enterobacter cloacae* [1]
Head Start	Raw	8/14/2007	P	N	N	P	*Aeromonas hydrophila*
KOA	Raw - DUP A	4/17/2007	P	P	N	P	*Enterobacter cloacae* [1]
	Raw - DUP B	4/17/2007	P	N	N	P	*Enterobacter agglomerans*
	Treated	4/17/2007	P	N	N	P	*Enterobacter agglomerans*
Louie's	Raw	4/18/2007	P	P	N	P	*Enterobacter cloacae* [1]
	Raw	8/15/2007	P	P	N	P	*Citrobacter freundii* [1]
	Raw-Not Iced	8/15/2007	P	P	N	P	*Citrobacter freundii* [1]

[1] Bacteria identified by Benchmark Labs as true coliform bacteria

KOA Kampground: The April sampling resulted in positive total coliform in the raw, treated and duplicate samples. Two weeks prior to our sampling, the KOA had a new well drilled because they could not get water out of their old well. Central District Office staff collected a raw and treated sample one week after our April sampling which produced negative results. It is possible that the bacteria were a remnant of the drilling process.

Buckeye Lake Citgo (now Valero): The Citgo station was negative for total coliform until the August sampling event. During February and April, we sampled the small sink behind the counter. In August we discovered that the water that supplies this sink was disconnected. Our choices of places to sample were a utility sink, where the faucet was very loose and almost falling off, or the bathroom sink, which was very dirty. We selected the bathroom sink, and it's possible that the sample was total coliform positive because it was a poor sampling location. Compliance sampling typically took place at either the bathroom sink or utility sink. .

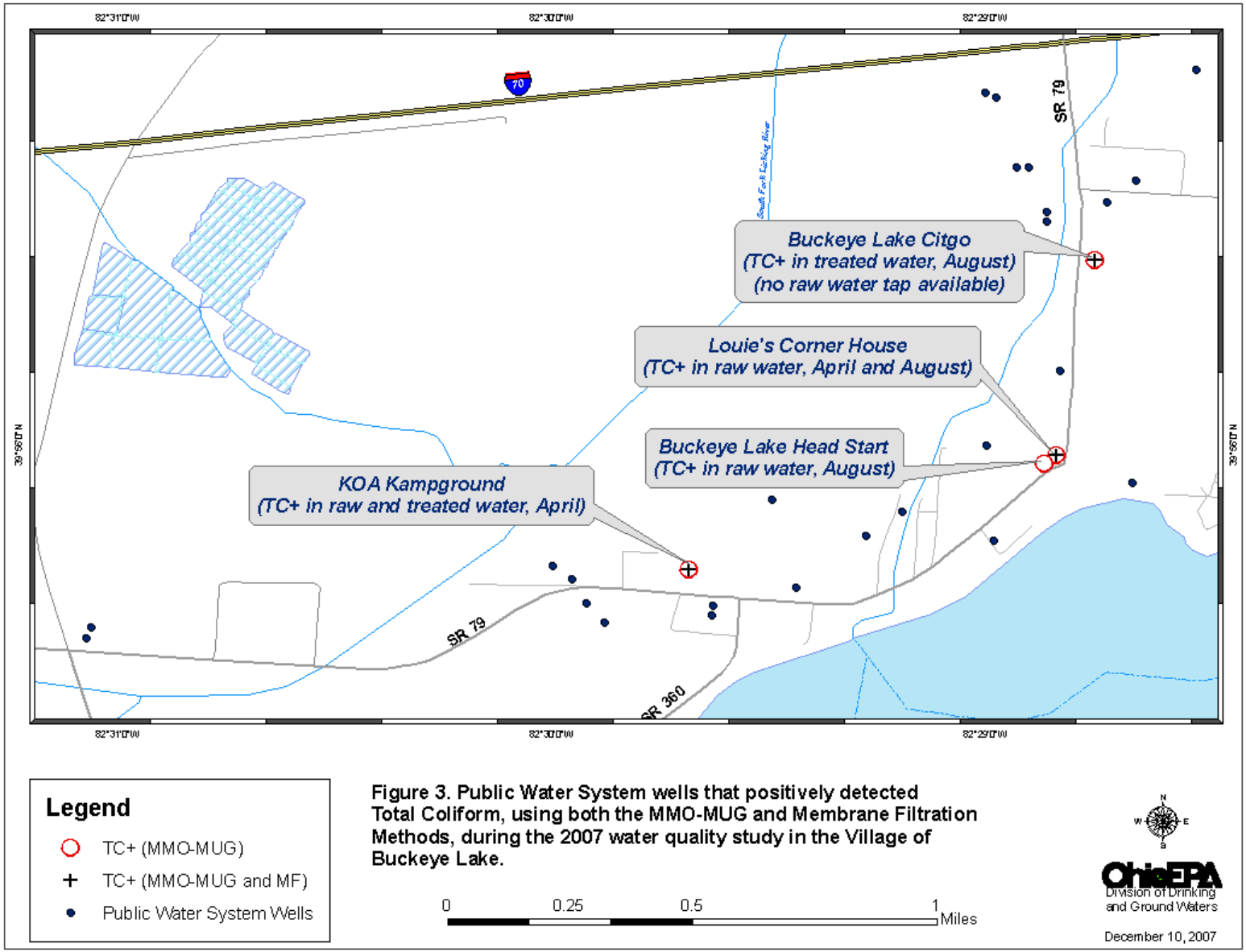

Figure 3. Public Water System wells that positively detected Total Coliform, using both the MMO-MUG and Membrane Filtration Methods, during the 2007 water quality study in the Village of Buckeye Lake.

Louie's Corner House: The raw tap at Louie's Corner House may have had positive total coliform in April and August because of not being able to properly disinfect the sampling point (Figure 4). It is also possible that the coliform is coming from the sanitary sewer that runs near the well (Figure 5).

Buckeye Lake Head Start: The Head Start had a positive total coliform (for MMO-MUG only) in the August sample. The bacteria present was a non-coliform bacteria, possibly resulting in a false positive MMO-MUG result (MF was negative). This well is also near the sanitary sewer.

Figure 4. Raw water tap at Louie's Corner House.

Possible Causes for the Historical Positive Total Coliforms

The bacteriological results of this study did not substantiate the frequent historic detections of total coliform at many of the PWSs at Buckeye Lake. Possible reasons for this discrepancy were evaluated.

Potential sources of bacteria in the Buckeye Lake area:

a) The Village of Buckeye Lake has been served by public sewer (Buckeye Lake Sewer District #1) since 1956. However, a few septic systems still exist within the Village limits. A wastewater treatment facility is located immediately east of Lakeshore Court MHP and is subject to flooding from the South Fork Licking River. A 24" gravity-fed sanitary sewer line runs adjacent to the wells at Lakeshore Court MHP, Louie's Corner House, and Buckeye Lake Head Start (Figure 5).

b) Hundreds of private drinking water wells exist in the Village. The older wells (and poorly constructed wells) may provide a pathway for contaminants to enter the aquifer.

c) During heavy rains, the South Fork Licking River overflows its banks and floods some of the western portions of the Village. Flood waters can distribute contamination that is present on the ground surface to other parts of the Village. The water may infiltrate the subsurface by flowing along the casing of open or poorly constructed wells. However, the flooding does not typically extend to State Route 79.

Legend

- Public Water System Wells
- Lift Station
- Force Main
- 24" Gravity Sewer

Figure 5. Portion of the Buckeye Lake Sanitary Sewer System, showing the Wastewater Treatment Plant. Note the proximity of the sanitary sewer lines to Lakeshore Court MHP, Louie's Corner House, and Buckeye Lake Head Start. Location of Sanitary Sewers courtesy of Licking County Water and Wastewater.

0 250 500 1,000 Feet

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d) There are wells in the study area that are no longer used (Figure 6) and should be properly abandoned to eliminate these potential contaminant pathways.

Although some potential sources of bacteria exist in the Village, the confined nature of the aquifer generally limits contaminant transport to artificial pathways along improperly constructed and maintained, used and unused wells.

Figure 6. Unused and unmaintained well at the Buckeye Lake-Citgo (now Valero) station.

Iron bacteria:

An initial hypothesis was that the presence of iron bacteria could result in more false positives using the MMO-MUG method. Iron bacteria are gram-negative and should not trigger the MMO-MUG method, but it was thought that its presence could cause interference and produce a positive result. The vast majority (84%) of the samples during all three events were positive for iron bacteria (Tables A7-A9). Only nine out of the 65 samples that were positive for iron bacteria (14%) were also total coliform positive (using the MMO-MUG method); therefore, this hypothesis was not substantiated.

Analysis methods (MMO-MUG versus Membrane Filtration):

The vast majority of PWSs have their compliance samples analyzed using the MMO-MUG method, an enzyme-based method that produces a color change in the sample. The reasons for using this method vary for each system, but some advantages are:

- The results are usually conveyed to the PWS within 24 hours, giving them a quick heads-up if there is a problem.
- The test is relatively inexpensive.
- Most labs are certified to analyze for total coliform using the MMO-MUG method.

The other common total coliform testing method is Membrane Filtration (MF). This method is slightly more expensive ($5 to $15 more, depending on the lab), and can take up to 48 hours for the results. However, it tends to trigger less false positive total coliforms and the cost savings in fewer repeat samples may quickly outweigh the increase in analysis cost (Dr. Michael Burns, Benchmark Labs, verbal communication, 2006 and 2007; Jeremy Olstadt, Wisconsin State Laboratory of Hygiene, e-mail communication, 2007; Olstadt et al., 2007). Often, Ohio EPA drinking water inspectors recommend this method to PWSs that are having a problem with frequent total coliform positives.

An analysis of PWS compliance monitoring data suggests that the MMO-MUG method may have a higher seasonal total coliform positive rate (Figure 7) in the summer months than the Membrane Filtration method (Figure 8). We cannot distinguish between sample methods earlier than 2000 because the bacteriological compliance database did not include a field for sample method for pre-2000 data. Possible reasons membrane filtration (MF) results are producing a flatter curve than the MMO-MUG results are:

- There are an insufficient number of MF samples to produce a statistically valid graph for comparison;
- Most of the PWS using the MF method have had significant historic total coliform positive results; it's possible that an increase in temperature does not influence positive results;
- The MMO-MUG is more sensitive than the MF test (the enzyme used in the MMO-MUG method will result in a color change with as little as one bacterium present whether it is viable or not, whereas the MF method requires 10 colonies to be present);
- The MF method is less likely to be positive if the bacteria is non-coliform;
- The sensitivity of the enzyme-based MMO-MUG method may be identifying a single total coliform bacterium that is alive but not healthy enough to reproduce, and thus would not be recorded as present in the MF method;
- The colorless substrate in the enzyme based MMO-MUG method may be cleaved by non-coliform bacteria leading to a true false positive compared to MF methods.

Figure 7 was broken down further by the type of PWS. Table 6 summarizes the results.

Table 6. Summary of total coliform results from Ohio EPA compliance monitoring, 2000-2007.

	Community	NTNC	TNC	All Types
TC+	2,189	3,230	10,821	16,240
TC-	134,589	31,835	70,057	236,481
Total	136,778	35,065	80,878	252,721
% TC+	1.6%	10.1%	15.4%	6.9%

A main concern using the MMO-MUG method is that it susceptible to false positive results (Dr. Michael Burns, Benchmark Labs, verbal communication, 2006 and 2007; Jeremy Olstadt, Wisconsin State Laboratory of Hygiene, e-mail communication, 2007; Olstadt et al., 2007). It is possible that some of the total coliform positives are a result of non-coliform bacteria present in the plumbing, either because of the warmer weather or because of the long residence time in the transient systems (water is not flushed through the plumbing as often, especially during the winter months). For the samples that were MMO-MUG positive-MF negative, the bacteria present was a non-coliform bacteria (Table 5, page 9). Ohio EPAs Division of Environmental Services (DES) lab was contacted to discuss this issue but could not comment, possibly because DES only analyzes water samples using the MMO-MUG method and does not have the information to compare the methods.

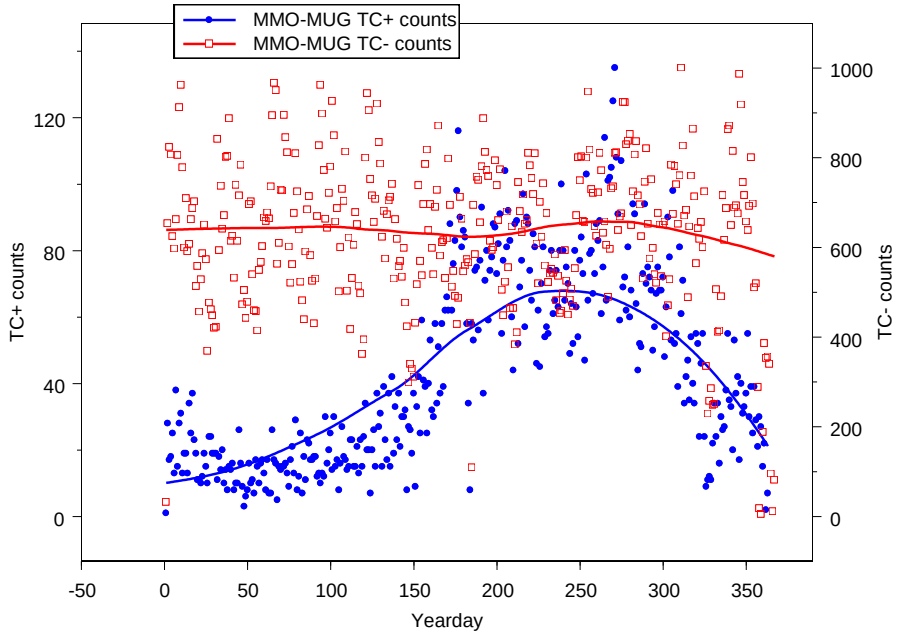


Figure 7. Distribution of Ohio EPA compliance samples for total coliform for all PWS types analyzed using the MMO-MUG method since 2000.

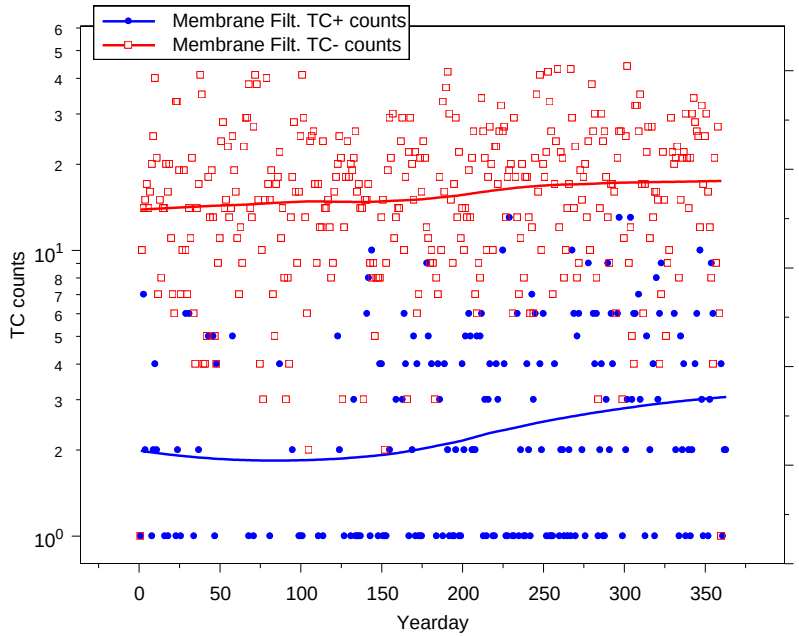


Figure 8. Distribution of total coliform positive Ohio EPA compliance samples analyzed using the Membrane Filtration method since 2000.

Labs used for sampling and/or analysis:

In general, the Buckeye Lake PWSs hire labs or certified operators to collect their compliance samples. Only a small number collect their own. There was no correlation between the lab or sampler to the total coliform positive results.

The April bacteriological samples were duplicated and analyzed at both DES and Benchmark Labs in Columbus, Ohio. DES is only set-up to analyze for total coliform using the MMO-MUG method for drinking water samples, whereas Benchmark can analyze using the MMO-MUG and MF methods, as well as speciate for the type of bacteria present. The results show that samples anlalyzed using the MMO-MUG method by both DES and Benchmark were consistent (Table A8).

Elevated temperature (both air and sample temperature) promoting bacteria growth:

Temperature (both air and sample) has a direct impact on the presence or absence of bacteria in the water sample. In climates where water temperatures are warm, bacterial growth may be very rapid (LeChevallier, 2003). Figure 9 shows the occurrence of coliform bacteria is significantly higher when water temperatures are above 15°C. These data shown in Figure 9 were obtained from a study of more than 90 public water systems throughout the United States.

Ohio EPA compliance data shows a very similar relationship. Figure 10 shows a count of total coliform positive samples plotted against the day of the year it was collected. The data consists of approximately 250,000 compliance samples collected since 2000. The occurrence of total coliform positive results start to dramatically increase around day 110 (April 20), corresponding to the beginning of consistently warmer air temperatures and the start-up season for many transient PWSs. The positives reach a peak at around day 235 (August 23), and then begin to steadily drop off. Negative total coliforms occur at a fairly constant rate throughout the year. Figure 10 also shows how this trend correlates to the average air temperature taken at Port Columbus Airport from 1971-2000. Note the significant lag between increased air temperature and total coliform results.

Compliance samples collected at the Buckeye Lake PWSs show a very similar pattern (Figure 11), albeit with a little more scatter. The *E. Coli* and fecal coliform detections primarily occurred during the summer months.

The rise in air temperature usually means a rise in temperature in the pump house or in the distribution system. The public and private water systems at Buckeye Lake all use ground water as their drinking water source. Because the ground water is relatively deep, the water temperature coming out of the ground should not change significantly throughout the year; therefore, the temperature changes are occurring at the surface. The rise in both air and distribution system temperatures increase the possibility of the water sample being total coliform positive.

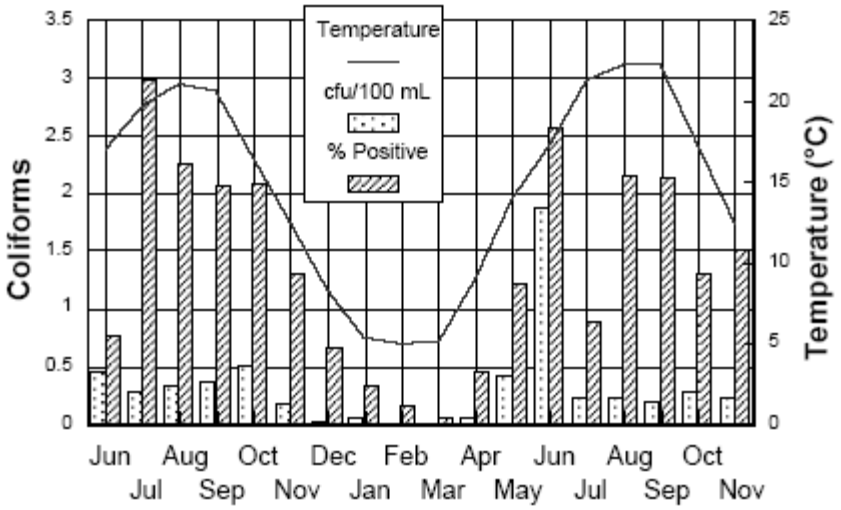


Figure 9. Relationship between monthly average water temperature and coliform occurrence from more than 90 water systems (LeChevallier, 2003).

Sample temperature can also be a factor in producing a positive total coliform for the same reasons as air temperature. Ohio EPA and US EPA guidance documents on bacteriological water sampling do not <u>require</u> the sample to be stored at 4°C, they merely <u>recommend</u> it. However, studies document (LeChevallier, 2003; Olstadt et al., 2007) that temperature greatly affects bacterial growth. If a sample is refrigerated or put on ice immediately after collection, the bacteria in the sample essentially stay dormant until the sample is analyzed. This means that the results should be representative of the water that was collected. However, if the sample is allowed to warm up (which easily happens in the summer months), the bacteria colonies change (some die off while others grow) and the results may not be representative of the water at the time and place of collection.

This theory was tested during the August sampling event. A duplicate bacteriological sample was collected at eight PWSs (Table A9), but instead of storing the sample in a cooler, it was placed in the sun on the dashboard for the remainder of the trip (2 to 6 hours, depending on when the sample was collected). Although it was expected that total coliforms would be found in all of the warm samples, this was not the case. The results were consistent with the samples that were put in a cooler and stored at 4°C. Although these results were unexpected, it does not refute the evidence that temperature in general affects the growth of bacteria. Bacteria live at very small, distinct, and varied temperature ranges. Different types of bacteria have different criteria for growth. Our study did not measure the temperature that was reached inside the truck or the temperature of the sample itself. It is possible that the temperature was sufficiently high enough to kill off the existing bacteria instead of allowing the bacteria to grow.

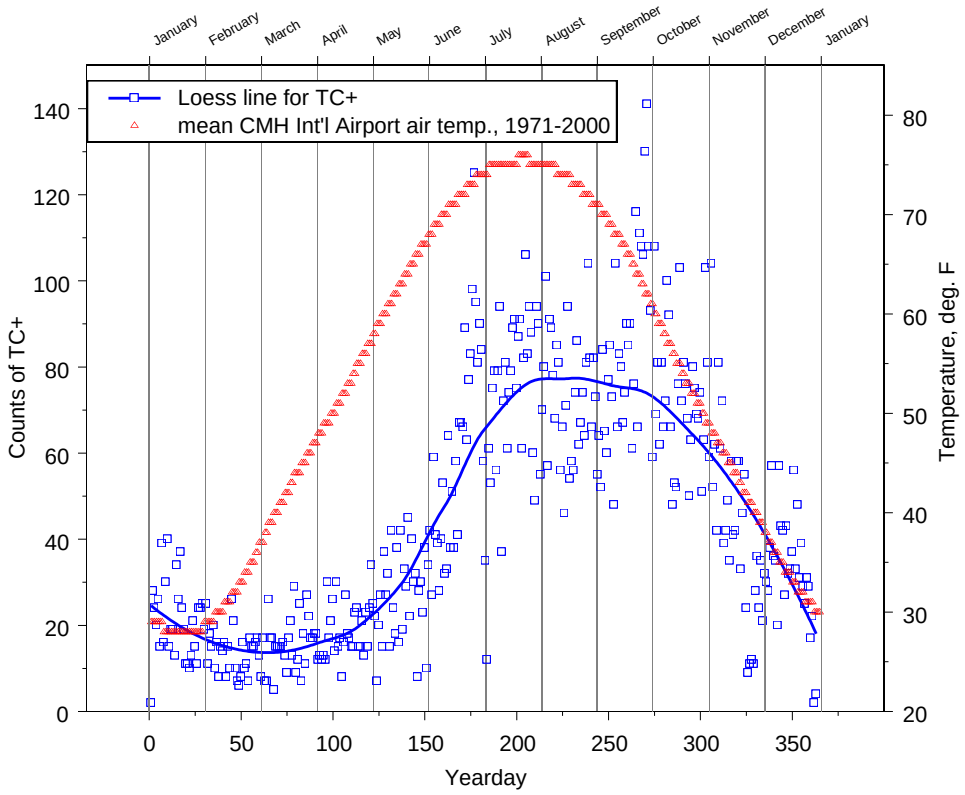


Figure 10. Total coliform positive results for all PWSs in relation to the average air temperature taken at Port Columbus Airport from 1971-2000.

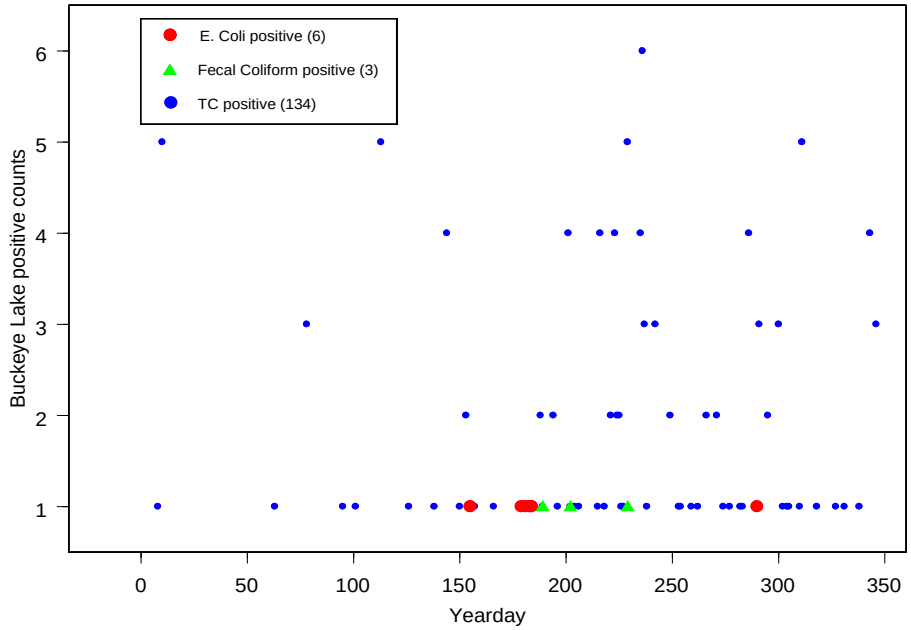


Figure 11. Seasonal distribution of total coliform, E.coli, and fecal coliform positive results for compliance monitoring since 2000 at the Buckeye Lake PWSs.

Sampling inconsistencies or improper sampling locations:

Incorrect sampling methods can account for some of the positive total coliform results. If the sampling location is not appropriate (i.e., swivel faucets, Figure 12), or if it hasn't been disinfected adequately, positive results may occur.

Discussions with some PWS owners during this study indicated that sometimes when a laboratory hires new staff to sample, they may not be trained very well. Consequently, the water may not run long enough or the tap may not be disinfected properly, if at all, prior to sampling. This may also be the case if the samplers are rushed to collect all of their samples and get them back to the lab by a certain time.

Figure 12. Swivel faucet on the utility sink at the Duke Station. This is the sampling point for their compliance sample.

PWS Compliance Sampling - 2007

Despite the historical bacteriological issues at eight of the public water systems in the Buckeye Lake area, only two systems had a positive total coliform in 2007 (through October 26) in the samples they submitted for Ohio EPA compliance:

- **McDonalds:** McDonalds is a new system (came online in 2004), and until July 2007 has never had a positive total coliform. Around this time, the owner of McDonalds decided to start collecting their own compliance samples instead of using their long-time operator. McDonalds is again utilizing the services of their former operator, and since July 2007 has not had a positive total coliform (our sampling in August resulted in total coliform being negative).

- **Citgo:** Citgo has had many bacteriological problems in the past (24% of their compliance samples have been total coliform positive). In 2007, they were in compliance for total coliform until July and again in October. During the August sampling event, we noticed that the faucet on the utility sink (where the compliance samples are collected) was extremely loose and almost falling off. We chose to collect a sample from the rest room sink, which was dirty but had a tight, non-swivel faucet (our sampling also produced a positive total coliform). It is possible that if the faucets were replaced and kept somewhat more sanitary, Citgo would be more likely to be in compliance for total coliform.

INORGANIC RESULTS

Comparisons between the three sampling events show very little differences in the inorganic chemistry (Table 3, page 7). There is also very little difference between the PWSs that had historic total coliform positives and those that did not. The raw water is generally geochemically-reduced as indicated by the negative oxidation-reduction potential (ORP), the elevated iron and arsenic, and the presence of ammonia. The presence of reduced water was expected because the depth of the wells (all > 75 feet) and the thick clay confining layer (all > 60 feet) over the aquifer isolate the aquifer from the atmosphere. This isolation and confined nature of the aquifer suggest the aquifer is not sensitive.

A piper diagram[3] (Figure 13) was developed using data from the April and August sampling events. Data from the February sampling event could not be included in the piper diagram because all of the major inorganic ions were not analyzed at the time.

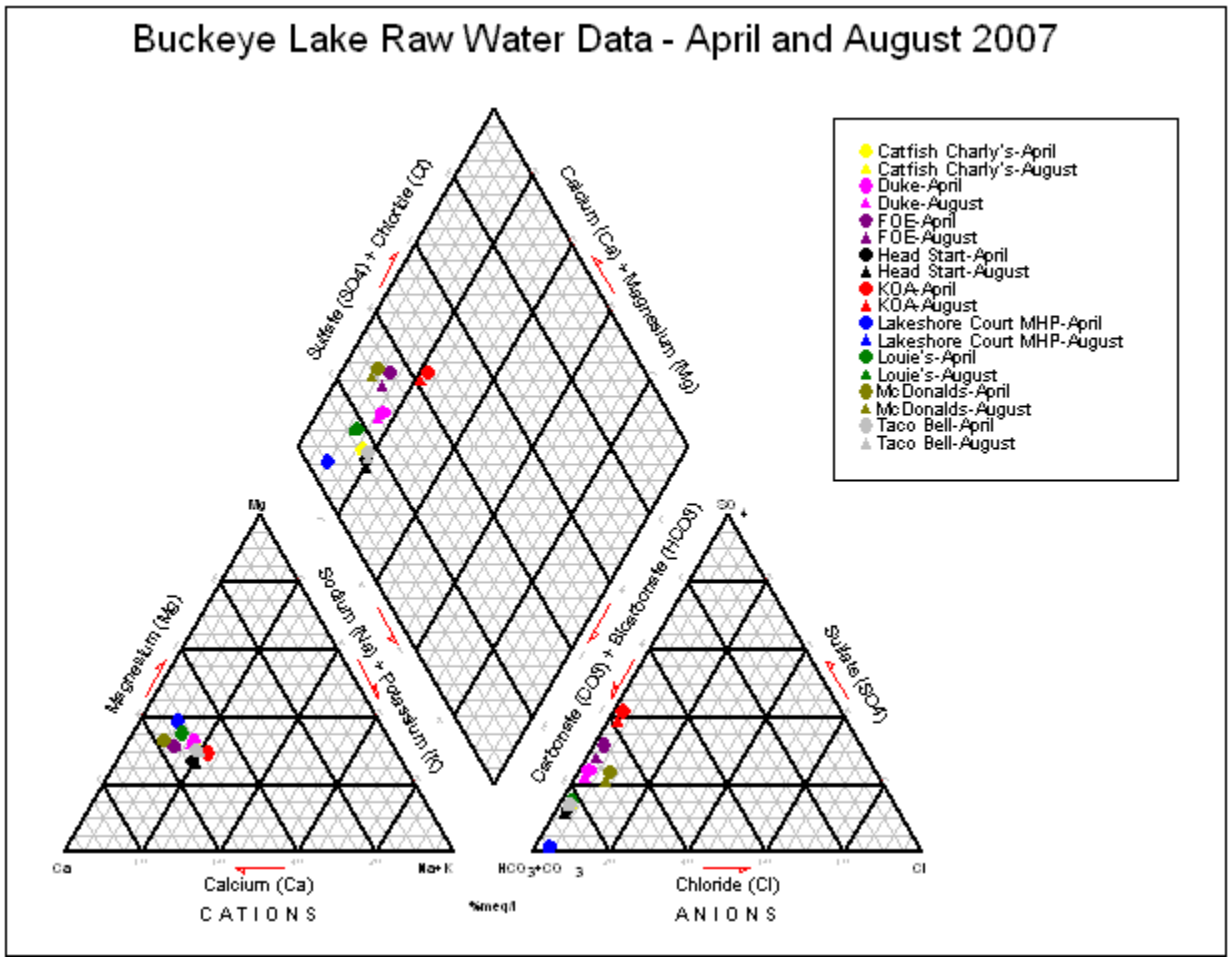


Figure 13. Piper diagram developed from the wells used in the Buckeye Lake study.

[3] A piper diagram plots the major ions as percentages of milliequivalents in two base triangles. The main purpose of a piper diagram is to show clustering of data points to indicate samples that have similar compositions.

In general, the piper diagram shows that there is very little difference in the major ions between April and August. There is a bit of variability in the carbonate and sulfate anions (lower right triangle). A comparison of the PWSs in the order they appear on the anion triangle (lower, right triangle) is shown in Table 7. Nothing stands out to explain the position in the anion triangle; that is, why the geochemistry varies between the sites. The aquifer geochemistry is very site-specific, and it is probable that the source of the aquifer material is from sandstone and carbonate debris with some gypsum present and low chloride concentrations.

Cation Reduction - Raw to Treated Water

Tables A3 through A6 show the water quality results for the PWSs sampled during April and August. In general, the cations that have a +2 ion (barium, calcium, magnesium, and strontium), as well as Hardness, are greatly reduced from the raw water sample to the treated water sample. This is most likely due to the water being softened, which removes the cations that have a +2 charge. All of the PWSs sampled during this study have a water softener, with the exception of Lakeshore Court MHP. The cations do not change significantly from raw to treated water at Lakeshore Court MHP, supporting the conclusion that the water softeners are removing the cations at the PWSs that have this treatment.

Arsenic and Iron: In general, the aquifer that supplies drinking water to the PWSs at Buckeye Lake has elevated arsenic (Figure 14). Average raw water arsenic for all sampling events is 12 µg/L, with a maximum concentration of 26.2 µg/L (Fraternal Order of Eagles). The maximum contaminant level (MCL) for arsenic is 10 µg/L.

The geochemically-reduced nature of the aquifer favors the presence of elevated iron and arsenic. Five of the twelve PWSs sampled at Buckeye Lake have an iron removal system in place (Beechridge Lounge, Catfish Charlie's, Lakeshore Court MHP, Fraternal Order of Eagles, and McDonald's). One PWS (Buckeye Lake Head Start) has an arsenic removal system that was installed as part of a USEPA pilot project. The results of this study indicate that treatment removed more than 90% of the iron and 40-90% of the arsenic (Figure 15). Although arsenic geochemistry is similar to iron, Figure 15 illustrates that arsenic was not removed very effectively in many of the PWSs sampled for this study. This is probably related to the intensity of the oxidation/disinfection occurring at individual PWSs. Strong oxidation is required to oxidize As^{+3} to As^{+5}, the first step for effective arsenic removal. ORP is an indicator of the reduction/oxidation (redox) state of water, with positive values indicating oxidized water. The maximum arsenic concentration decreases as ORP increases (Figure 16).

Table 7. Comparison of public water systems from anion triangle of Piper diagram (Figure 12). Average concentrations are from raw (untreated) water samples.

	Public Water System	Well Depth (ft)	Casing Length (ft)	Clay Thickness (ft)	Year Drilled	Avg ORP	Avg Arsenic (µg/L)	Avg Sulfate (mg/L)	Avg Chloride (mg/L)	Avg Sodium (mg/L)	Avg Alkalinity (mg/L)	Avg TDS (mg/L)	Avg Conductivity (µmhos/cm^2)
High SO_4^{-2}, Cl^- Low HCO_3	KOA	86	82	77	2007	-101	4.0	125	<5.0	37	220	448	768
	FOE	100	?	?	?	-98	25.8	101	6.1	23	290	502	757
	Duke	152	136	>100	1968	-120	10.2	73	<5.0	28	295	425	696
	McDonalds	142	136	133	2004	-86	17.0	78	20.6	16	314	493	774
	Louie's	153	?	?	1999	-151	2.7	46	<5.0	20	320	409	684
	Taco Bell	103	98	88	2005	-51	8.6	41	<5.0	31	307	407	668
	Catfish	156	150	>100	2000	-87	11.6	37	<5.0	26	287	378	664
Low SO_4^{-2}, Cl^- High HCO_3	Head Start	125	121	100	2006	-49	14.1	34	<5.0	32	300	375	633
	Lakeshore	78	70	65	2000	+169	14.9	<5	6.6	13	323	334	521

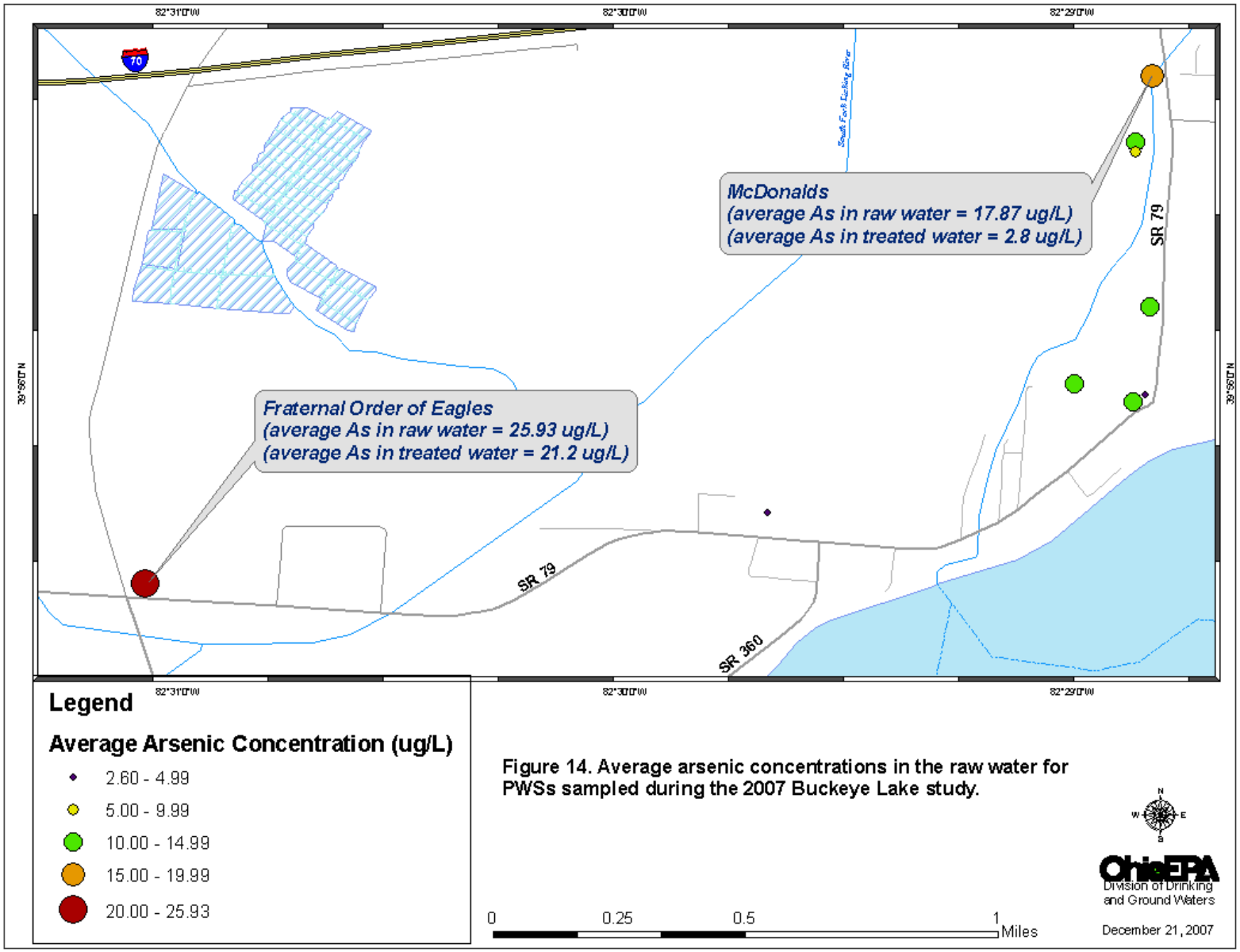


Figure 14. Average arsenic concentrations in the raw water for PWSs sampled during the 2007 Buckeye Lake study.

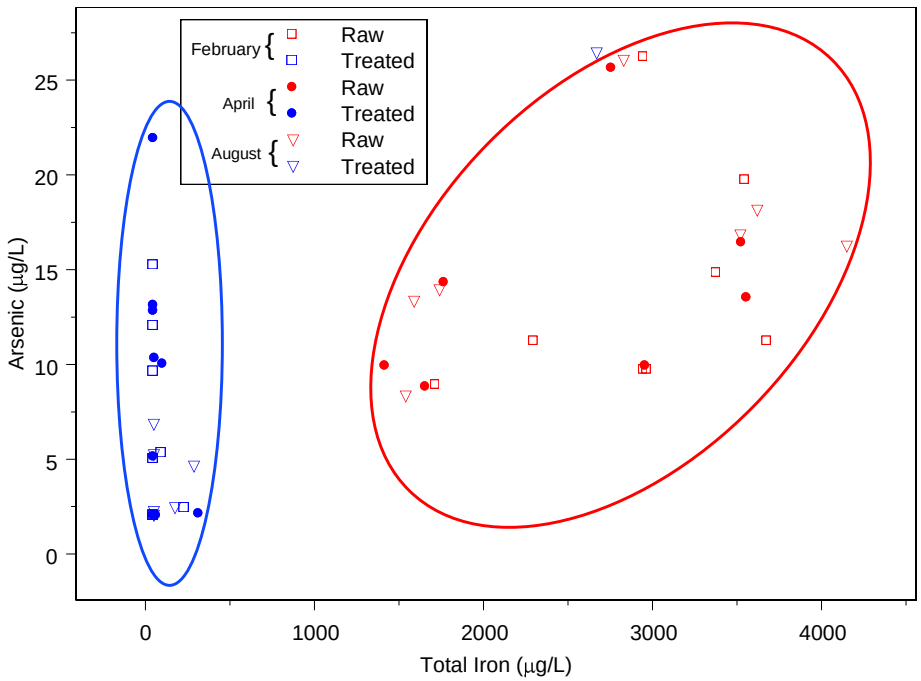


Figure 15. Graph showing the relationship between arsenic and iron in public water systems at Buckeye Lake. PWSs that do not treat for iron or arsenic have been excluded from this figure.

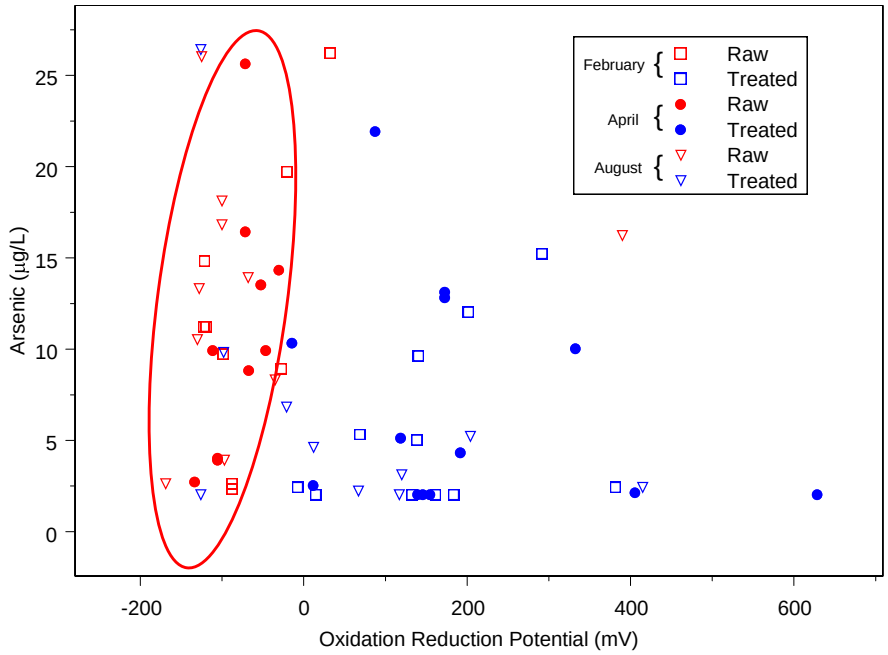


Figure 16. Graph showing the relationship between arsenic and ORP in PWS wells at Buckeye Lake. The highest arsenic concentrations occur at low ORPs.

Nitrogen components: The nitrogen constituents analyzed were nitrate, nitrite, ammonia, and total Kjeldahl nitrogen (TKN). Nitrate and nitrite were consistently less than detection in both the raw and treated water, which was expected given the lack of oxygen in the ground water. Ammonia and TKN were present at approximately the same elevated levels (Figure 17). TKN consists of organic nitrogen plus ammonia. The similar concentrations suggest that very little organic nitrogen is present.

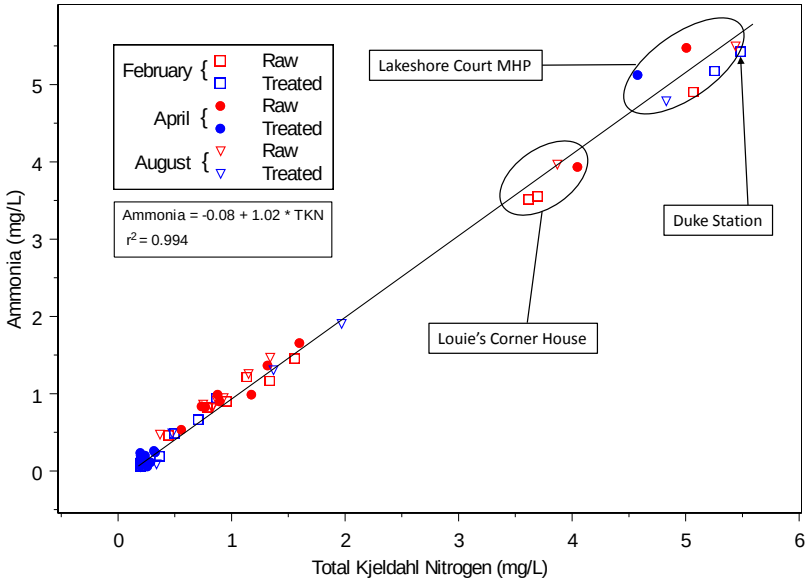
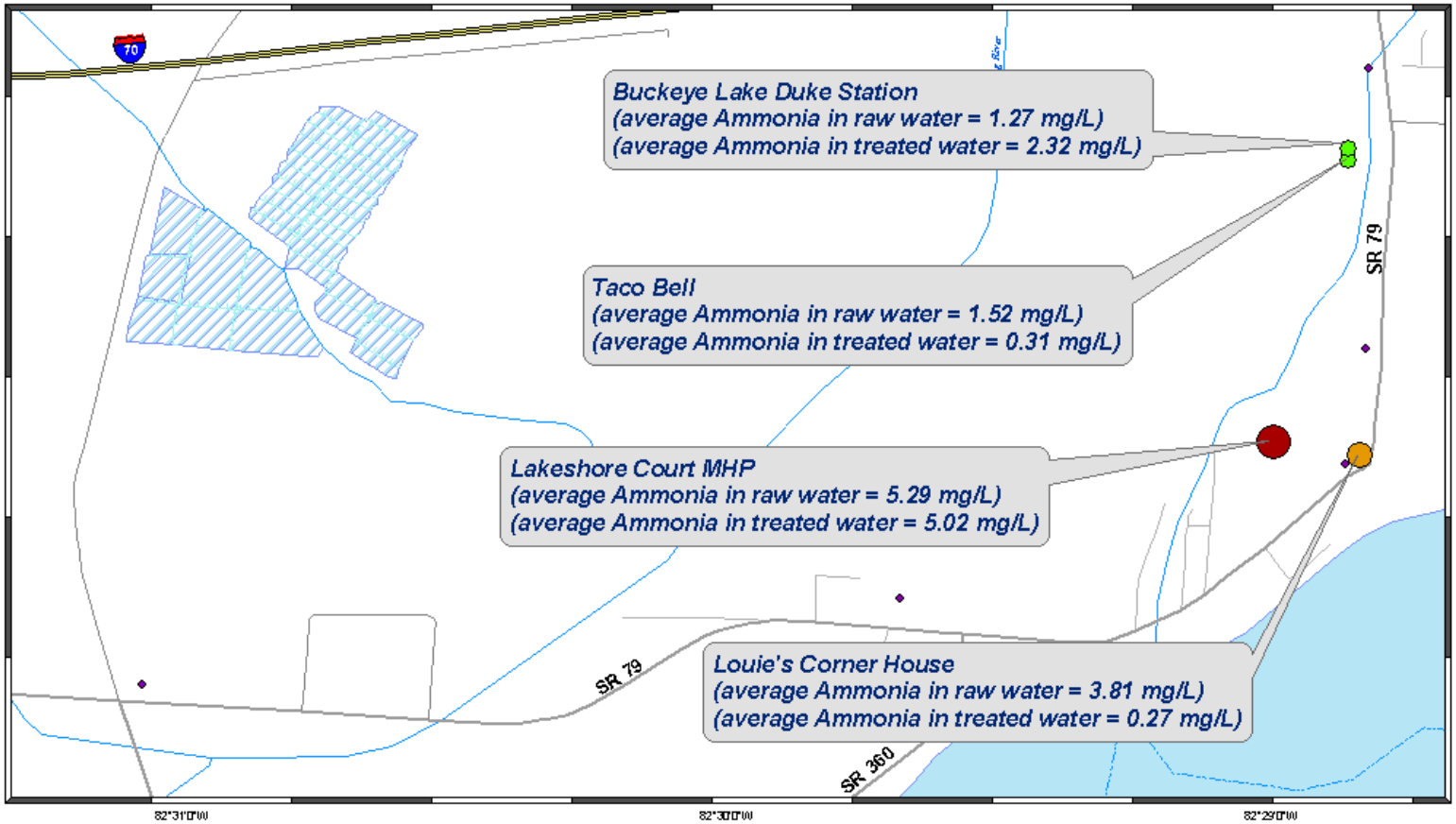


Figure 17. Graph showing the relationship between ammonia and TKN in PWS wells at Buckeye Lake. The similar concentrations suggest that very little organic nitrogen is present.

The ammonia concentrations found in four of the wells sampled at Buckeye Lake (Figure 18) are generally higher than typically found in reduced ground water. For example, only 4% of Ambient Ground Water Monitoring (AGWM) raw water samples exceed ammonia concentrations of 1 mg/L (Ohio EPA, 2006). It is possible that the source of the elevated ammonia is a 24" gravity-fed sanitary sewer line that runs adjacent to Lakeshore Court MHP, Louie's Corner House, and Buckeye Lake Head Start (Figure 5, page 12). The sanitary sewer line is approximately 50 years old. Lakeshore Court MHP and Louie's Corner House contained the highest raw water ammonia concentrations of the sampled wells (Figure 18). Lakeshore Court MHP has approximately the same ammonia concentration in both the raw and treated water. Ammonia is typically reduced after chlorination (chlorination oxidizes the water), and it is unknown why this did not occur at Lakeshore Court MHP.

Ammonia exhibits a strong relationship to ORP (Figure 19). The waters with negative ORPs (geochemically-reduced environment) typically had elevated ammonia concentrations. The raw water has more ammonia and more negative ORPs than the treated water, indicating that the reduced water contains less oxygen and favors the formation of ammonia.



Legend

Average Ammonia Concentration (mg/L)

- 0.48 - 0.99
- 1.00 - 2.99
- 3.00 - 4.99
- 5.00 - 5.29

Figure 18. Average ammonia concentrations in the raw water for PWSs sampled during the 2007 Buckeye Lake study.

0 0.25 0.5 1 Miles

Ohio EPA
Division of Drinking and Ground Waters

December 21, 2007

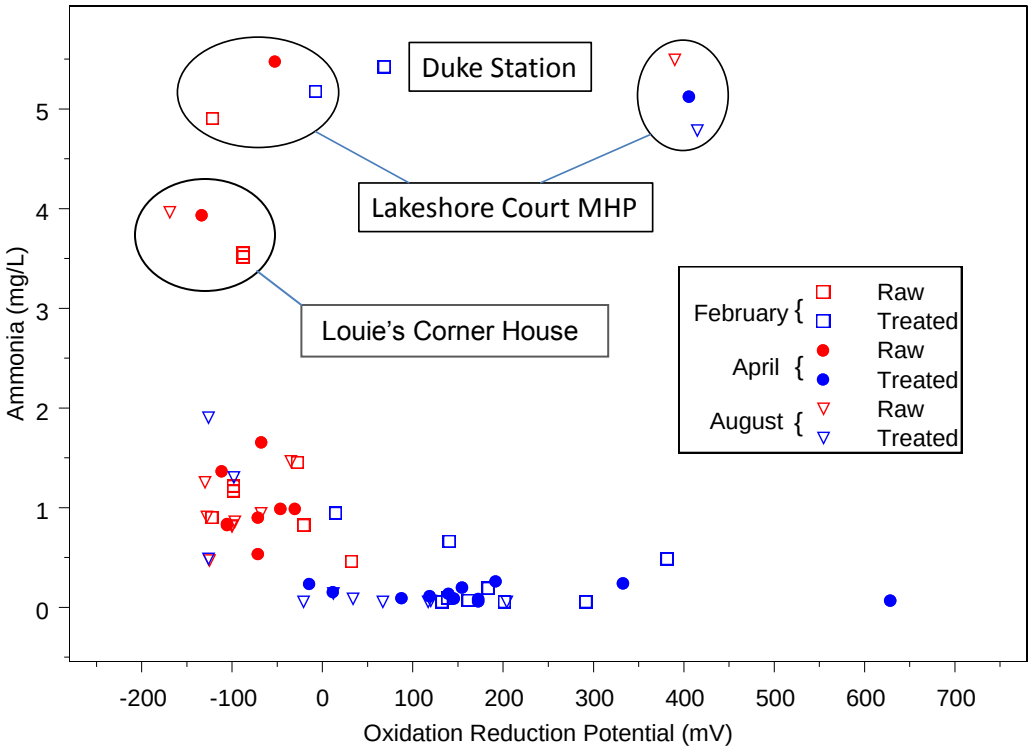


Figure 19. Graph showing the relationship between ammonia and ORP in PWS wells at Buckeye Lake. Ammonia is inversely related to the amount of oxygen present.

CONCLUSIONS

No conclusive source for the cause of the historical total coliform positives at many of the public water systems in the Buckeye Lake area has been identified based on the results of this study. The historic total coliform positive results could be from the selection of poor sampling locations, improper sample collection methods, modifications to the distribution system to correct problems, or from actual bacteriological sources. In some cases the sensitivity of the MMO-MUG method may produce false positive results. Since this study lacked many positive results for total coliform, it is not possible to conclude a general cause for the historic results.

Bacteriological Results

- Although there are some potential contaminant sources for bacteria present in the Village (such as used and unused wells, a sewage lift station and sanitary sewers, and flood waters), the thick confining layer appears to protect the aquifer from impacts associated with land use. The sanitary sewer line near Lakeshore Court MHP and Louie's Corner House may be an exception.
- Temperature (both air and sample) has been shown to correlate with the presence or absence of bacteria in a water sample. However, when this theory was tested at Buckeye Lake, no difference was found in results between the samples immediately put on ice and those that were left to warm up in the hot vehicle.
- The positive total coliforms that were encountered in our study can be explained by either a poor sampling location or a false positive result from the MMO-MUG method.
- For all samples that were total coliform positive using the MMO-MUG method and negative using the membrane filtration, the bacteria species present was non-coliform.
- The presence of iron bacteria did not result in a positive total coliform
- It is possible that the public water systems at Buckeye Lake are no longer having problems because the PWSs have taken efforts to properly collect compliance monitoring bacteriological samples (with the exception of Citgo).
- In general, the bacteria found in the compliance and special study samples collected at Buckeye Lake do not appear to be present in the ground water source.

Inorganic Results

- Arsenic is consistently present above the MCL (10 µg/L) in the raw water of the wells sampled at Buckeye Lake. Public Water Systems (PWSs) that treat for iron tend to also reduce the arsenic concentrations. Arsenic was found to be below the MCL in the treated (tap) water at all PWSs except at the Fraternal Order of Eagles.
- The geochemistry (such as elevated arsenic and iron, negative ORPs, the presence of ammonia and the lack of nitrate) indicates that the aquifer exhibits reducing conditions caused by the lack of oxygen. This was expected because of the depth of the aquifer (in most cases, greater than 100 feet), and the thick clay confining layer (> 60 feet) that limited the amount of precipitation that recharged the aquifer.
- The source of the elevated ammonia is possibly from the sanitary sewer line that runs adjacent to Lakeshore Court MHP, Louie's Corner House, and Buckeye Lake Head Start. Lakeshore Court MHP and Louie's Corner House contained the highest raw water ammonia concentrations of the sampled wells (5.29 mg/L and 3.81 mg/L, respectively).

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APPENDIX A

Water Quality Sampling Results

Table A1. Water quality results of samples collected on February 21, 2007, Buckeye Lake.
Results in RED are above the MCL.

Location	McDonalds		Duke			Head Start-R		Taco Bell-R		Library		Mt Carmel	Beechridge
	Raw	Tap	Raw (dup A)	Raw (dup B)	Tap	Raw	Tap	Raw	Tap	Raw	Tap	Tap	Tap
Temp (Field, °C)	10	12.2	11.2	11.2	13.8	13.5	18.4	10.7	11.9	14.5	18.7	18.1	14.2
pH (Field)	7.36	7.36	7.47	7.47	7.47	7.6	7.69	7.43	7.76	7.53	7.68	8.63	7.49
ORP (Field)	-20	15.1	-98	-98	69	-122	133	-27	141	-1	680	139	202
Cond (Field)	789	820	687	687	742	636	160	659	1492	630	710	617	761
TDS (Field, mg/L)	554	576	479	479	517	442	467	461	1090	437	484	425	531
Cl, tot (Field,mg/L)	0	0	0	0	0.25	0.35	0.02	0.03	0	0	2.2	0.01	0
TDS (mg/L)	440	484	346	360	416	292	388	370	412	342	420	352	460
TOC (mg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	2.2	<2.0
As (µg/L)[1]	**19.7**	<2.0	9.7	9.7	5.3	**11.2**	<2.0	8.9	9.6	**16.6**	**14**	5	**12**
Fe (µg/L)	3550	<50	2950	2970	98	3680	<50	1720	<50	2270	<50	<50	<50
Mn (µg/L)	344	34	41	41	<10	136	<10	192	<10	14	<10	<10	<10
Alkalinity (mg/L)	299	300	275	272	273	288	290	295	305	284	291	297	302
Ammonia (mg/L)	0.819	0.941	1.21	1.16	5.42	0.896	<0.050	1.45	0.658	1.41	<0.050	0.089	<0.050
Chloride (mg/L)	19.9	19.7	<5.0	<5.0	<5.0	<5.0	8.7	<5.0	<5.0	<5.0	11.2	<5.0	8
Nitrate (mg/L)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Nitrite(mg/L)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Sulfate (mg/L)	87.2	81.3	75.6	75.1	81.3	35.5	37.5	44.6	44.6	41.3	42.4	<5.0	69
TKN (mg/L)	0.79	0.87	1.14	1.34	5.49	0.96	<0.20	1.56	0.71	1.57	<0.20	<0.20	<0.20
Total Phos (mg/L)	0.051	0.031	0.035	0.025	0.014	0.036	<0.010	0.043	0.074	0.027	0.251	0.049	0.024

[1] Maximum Contaminant Level (MCL) for Arsenic is 10 µg/L.

Table A2. Water quality results of samples collected on February 22, 2007, Buckeye Lake.
Results in RED are above the MCL.

Location	Catfish Charlies		Lakeshore Court MHP		FOE		Louie's Corner House			Citgo
	Raw	Tap	Raw	Tap	Raw	Tap	Raw (dup A)	Raw (dup B)	Tap	Tap
Temp (Field, °C)	12.4	8.6	12.1	12.5	10.1	11.6	9.8	9.8	8.9	9.7
pH (Field)	7.62	7.43	7.68	7.67	7.23	8.16	7.54	7.54	7.94	7.59
ORP (Field)	-119	184	-121	-7	33	292	-87	-87	382	162
Cond (Field)	629	642	630	620	753	879	697	697	753	645
TDS (Field, mg/L)	438	447	437	431	529	636	486	486	532	451
Cl, tot (Field,mg/L)	0.27	0.13	0.28	0	0	0.12	0.18	0.18	>2.2	0
TDS (mg/L)	320	382	306	306	412	522	362	340	408	378
TOC (mg/L)	N/A	<2.0	3.4	3.4	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
As (µg/L)[1]	**11.2**	<2.0	**14.8**	2.4	**26.2**	**15.2**	2.6	2.3	2.4	<2.0
Fe (µg/L)	2300	<50	3380	234	2950	<50	2200	2200	2050	<50
Mn (µg/L)	132	<10	12	425	24	<10	72	75	<10	<10
Alkalinity (mg/L)	278	285	316	311	284	306	308	310	315	318
Ammonia (mg/L)	N/A	0.186	4.9	5.17	0.456	<0.050	3.55	3.51	0.483	0.064
Chloride (mg/L)	<5.0	<5.0	6.8	6.9	6.3	6.7	<5.0	<5.0	16.3	<5.0
Nitrate (mg/L)	N/A	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Nitrite(mg/L)	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Sulfate (mg/L)	34.9	39.3	<5.0	<5.0	112	113	48.3	47.9	59.1	6.3
TKN (mg/L)	N/A	0.37	5.07	5.26	0.45	<0.20	3.7	3.62	0.5	<0.20
Total Phos (mg/L)	N/A	0.038	0.032	0.071	0.026	0.013	0.221	0.191	2.52	0.082

[1] Maximum Contaminant Level (MCL) for Arsenic is 10 µg/L.

Table A3. Water quality results of samples collected on April 17, 2007, Buckeye Lake. Results in RED are above the MCL.

Location	KOA			Lakeshore Court MHP		Head Start		Louie's Corner House		Duke		Citgo
	Raw (dup A)	Raw (dup B)	Tap	Raw	Tap	Raw	Tap	Raw	Tap	Raw	Tap	Tap
Temp (Field, °C)	12.8	12.8	12.2	12.9	12.8	13.6	16.3	12.5	10.3	13.4	16.1	14.7
pH (Field)	7.56	7.56	7.82	7.59	7.6	7.37	7.39	7.7	8.04	7.52	7.78	7.56
ORP (Field)	-105	-105	12	-52	406	-30	629	-133	192	-111	-14	140
Cond (Field)	668	668	716	618	681	634	689	681	834	696	735	638
TDS (Field, mg/L)	464	464	500	429	510	440	474	476	578	483	509	441
Cl, tot (Field,mg/L)	0.12	0.12	0.01	0.07	>2.2	0	1.46	0	0.2	0	0	0
TDS (mg/L)	432	436	464	332	342	378	422	400	524	424	470	414
TOC (mg/L)	<2.0	<2.0	<2.0	3.3	3.2	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
As (µg/L)[1]	4	3.9	2.5	**13.5**	2.1	**14.3**	<2.0	2.7	4.3	9.9	**10.3**	<2.0
Cd (µg/L)	0.21	<0.20	0.21	0.25	0.23	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Pb (µg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Se (µg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Al (µg/L)	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200
Ba (µg/L)	41	41	<15	1750	1530	288	<15	988	81	209	<15	<15
Ca (mg/L)	73	73	<2	70	68	78	<2	80	<2	80	<2	<2
Cr (µg/L)	<30	<30	<30	<30	<30	<30	45	<30	<30	<30	<30	<30
Cu (µg/L)	<10	<10	<10	<10	<10	<10	43	<10	<10	<10	<10	<10
Hardness (mg/L)	293	293	<10	306	302	294	<10	336	<10	332	<10	<10
Fe (µg/L)	2430	2100	<50	3560	317	1770	<50	2150	2360	2960	57	<50
Mg (mg/L)	27	27	<1	32	32	24	<1	33	<1	32	<1	<1
Mn (µg/L)	21	15	<10	16	221	85	<10	75	10	37	<10	<10
Ni (µg/L)	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40
K (mg/L)	2	2	<2	3	4	2	<2	3	<2	2	<2	<2
Na (mg/L)	37	37	172	13	19	31	166	20	213	29	181	164
Sr (µg/L)	8440	8600	48	3390	3330	3000	37	5970	103	9190	<30	80
Zn (µg/L)	45	24	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Alkalinity (mg/L)	213	215	214	313	306	284	289	301	321	281	282	318
Ammonia (mg/L)	0.83	0.822	0.148	5.47	5.12	0.984	0.063	3.93	0.255	1.36	0.228	0.13
COD (mg/L)	<10	<10	10	<10	<10	<10	116	<10	<10	<10	<10	<10
Chloride (mg/L)	<5.0	<5.0	<5.0	6.4	15.6	<5.0	12.5	<5.0	27.1	<5.0	<5.0	<5.0
Fluoride (mg/L)	1.72	1.76	1.76	1.07	1.11	1.22	1.23	1.06	1.1	1.71	1.7	1.62
Nitrate (mg/L)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Sulfate (mg/L)	125	128	127	<5.0	<5.0	34.4	34.8	44.1	<5.0	73.5	74.4	6.8
TKN (mg/L)	0.74	0.77	<0.20	5.01	4.58	1.18	<0.20	4.05	0.32	1.32	<0.20	<0.20
Total Phos (mg/L)	<0.010	<0.010	<0.010	0.013	<0.010	<0.010	0.023	0.301	7.21	0.012	0.015	0.042

[1] Maximum Contaminant Level (MCL) for Arsenic is 10 µg/L.

Table A4. Water quality results of samples collected on April 18, 2007, Buckeye Lake. Results in RED are above the MCL.

Location	FOE		Taco Bell		Catfish Charlies		McDonalds		Mt Carmel	Beechridge Lounge	
	Raw	Tap	Raw	Tap	Raw	Tap	Raw	Tap	Tap	Tap (dup A)	Tap (dup B)
Temp (Field, °C)	12.8	15.8	12.7	13.6	13	12.1	12.6	13.8	16.5	14.4	14.4
pH (Field)	7.24	7.46	7.54	7.74	7.42	7.49	7.26	7.3	8.22	7.36	7.36
ORP (Field)	-71	88	-67	333	-46	146	-71	155	119	173	173
Cond (Field)	760	832	671	689	711	802	771	815	578	760	760
TDS (Field, mg/L)	535	579	459	478	494	562	540	570	398	529	529
Cl, tot (Field,mg/L)	0	0.02	0.08	0	0.01	0	0	0.01	0	0	0
TDS (mg/L)	516	564	424	460	386	430	500	538	382	508	502
TOC (mg/L)	<2.0	<2.0	<2.0	2.7	<2.0	<2.0	<2.0	<2.0	2	<2.0	<2.0
As (µg/L)[1]	**25.6**	**21.9**	8.8	10	9.9	<2.0	**16.4**	<2.0	5.1	**13.1**	**12.8**
Cd (µg/L)	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Pb (µg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Se (µg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Al (µg/L)	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200
Ba (µg/L)	56	<15	290	<15	385	<15	388	<15	<15	<15	<15
Ca (mg/L)	96	<2	75	2	71	<2	100	<2	<2	<2	<2
Cr (µg/L)	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Cu (µg/L)	<10	<10	<10	<10	<10	<10	<10	11	<10	<10	<10
Hardness (mg/L)	376	<10	298	<10	292	<10	394	<10	<10	<10	<10
Fe (µg/L)	2760	<50	1660	105	1420	<50	3530	67	<50	<50	<50
Mg (mg/L)	33	<1	27	1	28	<1	35	<1	<1	<1	<1
Mn (µg/L)	22	<10	193	<10	118	<10	342	<10	<10	<10	<10
Ni (µg/L)	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40
K (mg/L)	2	2	2	<2	2	<2	2	<2	<2	<2	<2
Na (mg/L)	23	198	30	165	26	157	16	190	142	183	186
Sr (µg/L)	5980	<30	7630	224	4190	<30	5420	36	<30	<30	<30
Zn (µg/L)	<10	<10	22	<10	<10	<10	<10	<10	<10	<10	<10
Alkalinity (mg/L)	277	303	290	296	275	279	294	297	286	305	301
Ammonia (mg/L)	0.529	0.087	1.65	0.235	0.982	0.084	0.895	0.194	0.108	0.054	0.08
COD (mg/L)	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Chloride (mg/L)	6.1	5.9	<5.0	<5.0	<5.0	<5.0	20.2	20	<5.0	7.9	8
Fluoride (mg/L)	0.92	0.92	1.63	1.6	1.24	1.2	0.99	1.01	1.46	1.26	1.32
Nitrate (mg/L)	<0.10	<0.10	<0.10	0.21	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Sulfate (mg/L)	106	106	39.8	39.8	35.2	37.1	80.5	80.4	<5.0	65.5	64.6
TKN (mg/L)	0.56	<0.20	1.6	0.33	0.88	<0.20	0.9	0.24	0.29	0.26	<0.20
Total Phos (mg/L)	<0.010	0.029	<0.010	0.026	<0.010	<0.010	0.014	<0.010	<0.010	<0.010	<0.010

[1] Maximum Contaminant Level (MCL) for Arsenic is 10 µg/L.

Table A5. Inorganic water quality results of samples collected on August 14, 2007, Buckeye Lake. Results in RED are above the MCL.

Location	Duke		KOA		Lakeshore Court		Taco Bell		Citgo	Head Start	
	Raw	Tap	Raw	Tap	Raw	Tap	Raw	Tap	Tap	Raw	Tap
Temp (Field, °C)	19.3	19.4	14.4	13.9	14.7	15.4	14.7	15	19.1	15.8	18.2
pH (Field)	7.56	7.39	7.43	7.42	7.59	7.6	7.57	7.6	7.55	7.42	7.54
ORP (Field)	-130	-98	-97	120	390	415	-35	204	-126	-68	117
Cond (Field)	696	695	987	784	613	702	664	709	644	632	627
TDS (Field, mg/L)	480	479	867	543	425	641	461	510	444	464	434
Cl, tot (Field,mg/L)	0	0	0	0	0.07	>2.20	0	0.04	0	0	0.13
TDS (mg/L)	426	416	476	510	336	356	390	444	374	372	384
TOC (mg/L)	<2.0	<2.0	<2.0	<2.0	3.6	3.5	<2.0	<2.0	<2.0	2	<2.0
As (µg/L)[1]	**10.5**	9.8	3.9	3.1	**16.2**	2.4	8.3	5.2	<2.0	**13.9**	<2.0
Cd (µg/L)	<0.20	<0.20	<0.20	<0.20	0.21	0.2	<0.20	<0.20	<0.20	<0.20	<0.20
Pb (µg/L)	<2.0	<2.0	<2.0	<2.0	10.7	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Se (µg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Al (µg/L)	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200
Ba (µg/L)	200	130	44	<15	1720	1560	290	<15	192	283	<15
Ca (mg/L)	78	79	77	<2	68	67	75	<2	72	76	<2
Cr (µg/L)	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Cu (µg/L)	<10	<10	<10	<10	10	<10	<10	<10	<10	<10	<10
Hardness (mg/L)	318	321	312	<10	302	295	298	<10	291	284	<10
Fe (µg/L)	2490	2030	2060	53	4150	175	1540	<50	1360	1740	<50
Mg (mg/L)	30	30	29	<1	32	31	27	<1	27	23	<1
Mn (µg/L)	28	23	13	<10	344	396	194	<10	70	86	<10
Ni (µg/L)	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40
K (mg/L)	2	2	2	<2	3	4	2	<2	2	2	<2
Na (mg/L)	27	27	38	186	12	22	32	175	29	32	155
Sr (µg/L)	8870	7920	8850	82	3370	3290	7730	<30	7010	2970	39
Zn (µg/L)	<10	<10	29	<10	<10	<10	25	<10	<10	<10	<10
Alkalinity (mg/L)	308	307	233	237	333	331	324	320	338	315	285
Ammonia (mg/L)	1.25	1.3	0.854	0.06	5.49	4.78	1.46	<0.050	1.9	0.939	<0.050
COD (mg/L)	<10	<10	<10	<10	13	10	<10	<10	<10	<10	<10
Chloride (mg/L)	<5.0	<5.0	<5.0	<5.0	6.7	21.5	<5.0	<5.0	<5.0	<5.0	18.4
Fluoride (mg/L)	1.74	1.74	1.68	1.73	1.05	1.09	1.59	1.71	1.52	1.16	1.21
Nitrate (mg/L)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Sulfate (mg/L)	72.4	73.1	122	136	<5.0	<5.0	42.5	43.3	11.6	34	25.7
TKN (mg/L)	1.15	1.37	0.75	<0.20	5.44	4.83	1.34	<0.20	1.97	0.93	<0.20
Total Phos (mg/L)	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.067	<0.010	<0.010

[1] Maximum Contaminant Level (MCL) for Arsenic is 10 µg/L.

Table A6. Inorganic water quality results of samples collected on August 15, 2007, Buckeye Lake. Results in RED are above the MCL.

Location	McDonalds			Catfish Charlies		FOE		Louie's		Mt. Carmel
	Raw Dup A	Raw Dup B	Tap	Raw	Tap	Raw	Tap	Raw	Tap	Tap
Temp (Field, °C)	14.3	14.3	16.8	15.3	22.3	17.3	20.7	13.8	18.8	16.9
pH (Field)	7.43	7.43	7.79	7.61	7.57	7.33	7.31	7.75	7.67	8.06
ORP (Field)	-100	-100	12	-128	67	-125	-126	-169	34	-21
Cond (Field)	777	777	586	617	643	754	760	687	728	569
TDS (Field, mg/L)	543	543	838	428	441	524	525	478	504	393
Cl, tot (Field,mg/L)	0	0	0.05	0	0	0	0	0	0	0
TDS (mg/L)	492	486	540	370	406	488	482	418	466	378
TOC (mg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	2	2	2.5
As (µg/L)[1]	**18.1**	**16.8**	4.6	**13.3**	2.2	**26**	**26.4**	2.6	<2.0	6.8
Cd (µg/L)	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.21
Pb (µg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Se (µg/L)	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Al (µg/L)	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200
Ba (µg/L)	394	399	<15	385	<15	55	50	981	<15	<15
Ca (mg/L)	102	104	<2	70	<2	96	96	80	<2	<2
Cr (µg/L)	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Cu (µg/L)	<10	<10	16	<10	<10	<10	<10	<10	<10	<10
Hardness (mg/L)	403	412	<10	290	<10	376	376	336	<10	<10
Fe (µg/L)	3620	3520	288	1590	<50	2830	2670	2060	123	<50
Mg (mg/L)	36	37	<1	28	<1	33	33	33	<1	<1
Mn (µg/L)	351	356	<10	124	<10	22	19	73	<10	<10
Ni (µg/L)	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40
K (mg/L)	2	2	<2	2	<2	2	2	3	<2	<2
Na (mg/L)	16	16	197	26	156	23	23	19	182	147
Sr (µg/L)	5430	5650	41	4190	<30	5730	4640	5720	<30	<30
Zn (µg/L)	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Alkalinity (mg/L)	323	324	331	298	294	303	331	338	332	312
Ammonia (mg/L)	0.807	0.817	0.136	0.904	<0.050	0.466	0.482	3.96	0.082	<0.050
COD (mg/L)	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Chloride (mg/L)	20.5	21	26.7	<5.0	<5.0	6.1	6.2	<5.0	8.4	<5.0
Fluoride (mg/L)	0.87	0.86	0.9	1.13	1.11	0.8	0.82	0.9	0.92	1.35
Nitrate (mg/L)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Sulfate (mg/L)	77.9	76.8	81.5	38.8	38.4	95.7	101	47.2	50.2	<5.0
TKN (mg/L)	0.83	0.83	<0.20	0.87	<0.20	0.37	0.48	3.87	0.34	<0.20
Total Phos (mg/L)	<0.010	<0.010	0.013	<0.010	<0.010	<0.010	0.024	0.123	0.477	<0.010

[1] Maximum Contaminant Level (MCL) for Arsenic is 10 µg/L.

Table A7. Bacteriological water quality results of samples collected on February 21-22, 2007. "P" indicates that bacteria were positively detected and "N" indicates that no bacteria were present.

Location		Sample Date	TC (MMOMUG)	TC (MF)	*E. Coli*	Fe Bacteria	Bacteria Speciation
Duke	Raw-DUP	2/21/2007	N	N	N/A	P	
	Raw-DUP	2/21/2007	N	N	N/A	P	
	Treated	2/21/2007	N	N	N/A	P	
Citgo	Treated	2/22/2007	N	N	N/A	N	
Lakeshore Court	Raw	2/22/2007	N	N	N/A	N	
	Treated	2/22/2007	N	N	N/A	P	
Head Start	Raw	2/21/2007	N	N	N/A	P	
	Treated	2/21/2007	N	N	N/A	P	
Library	Raw	2/21/2007	N	N	N/A	P	
	Treated	2/21/2007	N	N	N/A	N	
Louie's	Raw-DUP	2/22/2007	N	N	N/A	P	
	Raw-DUP	2/22/2007	N	N	N/A	P	
	Treated	2/22/2007	N	N	N/A	N	
Taco Bell	Raw	2/21/2007	N	N	N/A	P	
	Treated	2/21/2007	N	N	N/A	P	
McDonalds	Raw	2/21/2007	N	N	N/A	P	
	Treated	2/21/2007	N	N	N/A	P	
Catfish Charlies	Raw	2/22/2007	N	N	N/A	N	
	Treated	2/22/2007	N	N	N/A	P	
Beechridge Lounge	Treated	2/21/2007	N	N	N/A	P	
FOE	Raw	2/22/2007	N	N	N/A	N	
	Treated	2/22/2007	N	N	N/A	N	
Mt. Carmel	Treated	2/21/2007	N	N	N/A	P	

N/A = Not analyzed, since no total coliform were present.

Table A8. Bacteriological water quality results of samples collected on April 17-18, 2007. "P" indicates that bacteria were positively detected and "N" indicates that no bacteria were present.

Location		Sample Date	TC (MMOMUG) - DES -	TC (MMOMUG) - Benchmark -	TC (MF) - Benchmark -	*E. Coli*	Fe Bacteria	Bacteria Speciation
Duke	Raw	4/17/2007	N	N	N	N/A	P	
	Treated	4/17/2007	N	N	N	N/A	P	
Citgo	Treated	4/17/2007	N	N	N	N/A	P	
KOA	Raw - DUP A	4/17/2007	P	P	P	N	P	*Enterobacter cloacae* [1]
	Raw - DUP B	4/17/2007	P	P	N	N	P	*Enterobacter agglomerans*
	Treated	4/17/2007	P	P	N	N	P	*Enterobacter agglomerans*
Lakeshore Court	Raw	4/17/2007	N	N	N	N/A	P	
	Treated	4/17/2007	N	N	N	N/A	P	
Head Start	Raw	4/17/2007	N	N	N	N/A	P	
	Treated	4/17/2007	N	N	N	N/A	P	
Louie's	Raw	4/18/2007	P	P	P	N	P	*Enterobacter cloacae* [1]
	Treated	4/18/2007	N	N	N	N/A	P	
Taco Bell	Raw	4/18/2007	N	N	N	N/A	P	
	Treated	4/18/2007	N	N	N	N/A	P	
McDonalds	Raw	4/18/2007	N	N	N	N/A	P	
	Treated-DUP A	4/18/2007	N	N	N	N/A	P	
	Treated-DUP B	4/18/2007	N	N	N	N/A	P	
Catfish Charlies	Raw	4/18/2007	N	N	N	N/A	P	
	Treated	4/18/2007	N	N	N	N/A	P	
Beechridge Lounge	Treated-DUP A	4/18/2007	N	N	N	N/A	P	
	Treated-DUP B	4/18/2007	N	N	N	N/A	P	
FOE	Raw	4/18/2007	N	N	N	N/A	N	
	Treated	4/18/2007	N	N	N	N/A	P	
Mt. Carmel	Treated	4/18/2007	N	N	N	N/A	P	

[1] Bacteria identified by Benchmark Labs as true coliform bacteria

N/A = Not analyzed, since no total coliform were present.

Table A9. Bacteriological water quality results of samples collected on August 14-15, 2007. "P" indicates that bacteria were positively detected and "N" indicates that no bacteria were present.

Location		Sample Date	TC (MMOMUG)	TC (MF)	*E. Coli*	Fe Bacteria	Bacteria Speciation
Duke	Raw	8/14/2007	N	N	N/A	P	
	Treated	8/14/2007	N	N	N/A	P	
	Treated-Not Iced	8/14/2007	N	N	N/A	P	
Citgo	Treated	8/14/2007	P	P	N	P	*Enterobacter cloacae* [1]
	Treated-Not Iced	8/14/2007	P	P	N	P	*Enterobacter cloacae* [1]
KOA	Raw	8/14/2007	N	N	N/A	P	
	Raw-Not Iced	8/14/2007	N	N	N/A	P	
	Treated	8/14/2007	N	N	N/A	P	
	Treated-Not Iced	8/14/2007	N	N	N/A	P	
Lakeshore Court	Raw	8/14/2007	N	N	N/A	P	
	Treated	8/14/2007	N	N	N/A	N	
Taco Bell	Raw	8/14/2007	N	N	N/A	P	
	Treated	8/14/2007	N	N	N/A	P	
	Treated-Not Iced	8/14/2007	N	N	N/A	N	
Head Start	Raw	8/14/2007	P	N	N	P	*Aeromonas hydrophila*
	Treated	8/14/2007	N	N	N/A	P	
McDonalds	Raw	8/15/2007	N	N	N/A	P	
	Treated-DUP A	8/15/2007	N	N	N/A	P	
	Treated-DUP B	8/15/2007	N	N	N/A	P	
	Treated-Not Iced	8/15/2007	N	N	N/A	P	
Catfish Charlies	Raw	8/15/2007	N	N	N/A	P	
	Treated	8/15/2007	N	N	N/A	P	
FOE	Raw	8/15/2007	N	N	N/A	N	
	Treated	8/15/2007	N	N	N/A	P	
	Treated-Not Iced	8/15/2007	N	N	N/A	N	
Louie's	Raw	8/15/2007	P	P	N	P	*Citrobacter freundii* [1]
	Raw-Not Iced	8/15/2007	P	P	N	P	*Citrobacter freundii* [1]
	Treated	8/15/2007	N	N	N/A	P	
	Treated-Not Iced	8/15/2007	N	N	N/A	P	
Mt. Carmel	Treated	8/15/2007	N	N	N/A	P	

[1] Bacteria identified by Benchmark Labs as true coliform bacteria

N/A = Not analyzed, since no total coliform were present.

APPENDIX B

Procedure for Collecting a Total Chlorine Residual from a Water Sample Using a Hach DR/890 Colorimeter

The Hach DR/890 colorimeter is a microprocessor-controlled, LED-sourced photometer suitable for colorimetric testing in the field. The instrument is pre-calibrated. The procedure to analyze for free chlorine residual using the colorimeter is equivalent to USEPA method 330.5 for wastewater and Standard Method 4500-Cl G for drinking water.
The procedure to collect the sample was as follows:

1. Water was purged from the sampling point for a minimum of three minutes before collecting a sample.
2. The glass sampling vial was rinsed several times with water from the sampling point.
3. The glass vial was filled to the 10 mL mark, and immediately analyzed using the following procedure.

This procedure for analyzing the water sample was taken from the Hach DR/890 Datalogging Colorimeter Handbook.

Method 8021

CHLORINE, FREE (0 to 2.00 mg/L) **For water, wastewater, and seawater**

DPD Method (Powder Pillows or AccuVac Ampuls)
USEPA accepted for reporting wastewater and drinking water analyses*

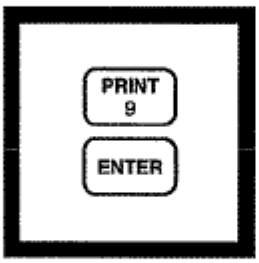
Using Powder Pillows

1. Enter the stored program number for free and total chlorine (Cl_2) powder pillows.

Press: **PRGM**

The display will show:

PRGM ?

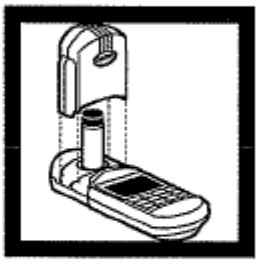


2. Press: **9 ENTER**

The display will show **mg/L, Cl2** and the **ZERO** icon.

3. Fill a sample cell with 10 mL of sample (the blank).

Note: Samples must be analyzed immediately and cannot be preserved for later analysis.



4. Place the blank into the cell holder. Tightly cover the sample cell with the instrument cap.

5. Press: **ZERO**

The cursor will move to the right, then the display will show:

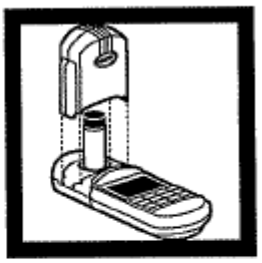
0.00 mg/L Cl2

Note: *If Reagent Blank Correction is on, the display may flash "limit". See Section 1.*

6. Fill another cell with 10 mL of sample.

7. Add the contents of one DPD Free Chlorine Powder Pillow to the sample cell (the prepared sample). Cap the cell and swirl vigorously to dissolve the powder.

Note: *A pink color will develop if free chlorine is present.*



8. Immediately place the prepared sample into the cell holder. Tightly cover the sample cell with the instrument cap.

Note: *Perform Step 9 within one minute of reagent addition.*

9. Press: **READ**

The cursor will move to the right, then the result in mg/L chlorine will be displayed.

Note: *Standard Adjust may be performed using a prepared standard (see Section 1).*

Note: *If the sample temporarily turns yellow after reagent addition, or the display flashes "limit", it is due to high chlorine levels. Dilute a fresh sample and repeat the test. A slight loss of chlorine may occur during dilution. Multiply the result by the dilution factor; see Section 1. Or, use the High Range Free Chlorine test, program #8.*

Method Performance

Precision

In a single laboratory using a standard solution of 1.00 mg/L chlorine and two representative lots of reagents with the instrument, a single operator obtained a standard deviation of ±0.01 mg/L chlorine.

In a single laboratory using a standard solution of 1.00 mg/L chlorine and two representative lots of AccuVac Ampuls with the instrument, a single operator obtained a standard deviation of ±0.01 mg/L chlorine.

Estimated Detection Limit (EDL)

The estimated detection limit for programs 9 and 11 is 0.02 mg/L Cl_2. For more information on derivation and use of Hach's estimated detection limit, see *Section 1*.

Pollution Prevention and Waste Management

Samples treated with sodium arsenite for manganese or chromium interferences will be hazardous wastes as regulated by Federal RCRA for arsenic (D004). See *Section 3* for more information on proper disposal of these materials.