



**Western Kentucky University  
Technical Assistance Center for Water Quality  
Center for Water Resource Studies**

**“Supporting Small Water Systems in  
Meeting the Goal of Public Health Protection”**

<http://water.wku.edu>  
(270) 745-8895

Grant Number X83123601

**Quarterly Report  
for the period  
July 1, 2006 – September 30, 2006**

Submitted to:  
**U.S. Environmental Protection Agency  
Office of Water  
October 31, 2006**

## **Introduction**

The Technical Assistance Center for Water Quality at Western Kentucky University (TACWQ WKU) serves to support capacity development of small drinking water systems through the Utility Management Institute, a circuit rider, source water protection activities, and information technology. The goal of the center is to help small systems meet the requirements of the Safe Drinking Water Act (SDWA) and ensure public health. While focused on solving local problems that can serve as national models, the TACWQ is impacting small systems throughout the country.

## **Activities and Outcomes**

### ***Utility Management Institute***

The Utility Management Institute (UMI) was created to provide utility managers, and other utility personnel, with the opportunity to gain valuable knowledge and earn a university-based, professional designation in the field of management. These goals can be accomplished through the successful completion of six modern, practical management courses, specifically developed for public water and wastewater utility personnel.

The UMI offers training to managers—and those interested in becoming managers—through a set of courses designed to be practical and applicable to water and wastewater utilities, regardless of size. Courses include Utility Management 101; Utility Organization, Regulation and Law; Utility Finance and Administration; Human Resource Management for Utilities; Public Relations in Utility Management; and Modern Technology and Utility Management.

During the quarter, the course entitled “Human Resource Management for Utilities” was presented in Dawson Springs, Kentucky on July 26-27, 2006 at Pennyryle Forest State Resort Park. There were thirty-five (35) students participating in this course. “Modern Technology & Utility Management” was presented in Carrollton, Kentucky on August 9, 2006 at General Butler State Resort Park. There were thirty-four (34) students participating in this course. “Public Relations in Utility Management” was presented in Bowling Green, Kentucky on September 13, 2006 at Carroll Knicely Conference Center. There were thirty-two (32) students participating in this course. Course assessments continue to show a high level of satisfaction with the training. Eighty-four (84) of the eighty-six (86) assessors rated the session at the two highest levels, very beneficial or beneficial. Course assessments for all three courses are available upon request.

The Utility Management Institute now claims a total of two hundred fifty-four (254) students. One hundred eighteen (118) of our students have now completed all six of the courses in the UMI Series and have been awarded the Utility Management Professional designation. New UMI brochures were mailed during the quarter to promote the program and advertise the UMI class schedule for 2007.

An Alumni Appreciation event and Train-the-Trainer conference are scheduled for October 11-12, 2006 in Bowling Green, Kentucky. These events are planned to honor the UMP designees and to share the UMI concept with technical assistance providers from other states.

### ***Small System Circuit Rider***

The "Circuit Rider" approach to providing a combination of on-site technical assistance and training is nationally recognized as the most effective method of assisting small public water systems to comply with state and federal environmental regulations. The Circuit Rider program works in partnership with Kentucky Division of Water (DOW) to target the public water systems serving populations under 3,300, with particular emphasis on systems serving less than 500 people. Our "Circuit Rider" approach works to target those small systems experiencing profound difficulties in complying with SDWA provisions in order to enhance protection of public health.

During the 4<sup>th</sup> Quarter, the Circuit Rider position logged 468.25 hours. Of that time 23% of the total time was spent directly assisting systems or their personnel including 106.5 hours on-site working with systems, 34.5 hours receiving training in the areas of GIS and Source Water Protection, 33.25 hours providing formal training, and 62.5 hours working with agencies and conducting program outreach.

The majority of time this quarter was spent assisting systems with GPS/GIS demonstration and implementation. Activities for technical assistance included GPS-GIS mapping, leak detection, and wellhead protection. Compliance assistance included public notification, DBP monitoring plans and Groundwater Protection Plans. Management/financial assistance included system development charges, project financing and cost of service.

#### **Significant Contacts:**

**City of Marion** – Located in Crittenden County, Kentucky; 1,700 water connections.

The City of Marion is a small agricultural community in western Kentucky served by surface water. The water superintendent contacted the Circuit Rider for assistance with evaluating problems with their intake structure. A suspected blockage or collapse within the intake had reduced flow from the reservoir to the point that the city had rented a pump to transfer water to the treatment plant. The pump was costing the city \$1,000/week to rent. Prior to requesting assistance from the Circuit Rider the city officials had discussed installing a pumping station to replace the current gravity intake at the cost of nearly \$500,000. The superintendent suggested evaluating the problem and the integrity of the raw water line before proceeding with a pump station. The Circuit Rider arrived with a pipeline inspection camera to find that the system personnel had plugged the intake in the reservoir, cut the raw water line, and were pumping the last of the water from the pit. The segment of line inspected was 278 feet of 14 inch ductile iron before reaching the elbow leading up to the intake structure. The raw water line was in good condition with consistent but minimal tuberculation of the pipe wall and no blockages. The pipe joints were in very good condition with no signs of leakage. A watertight seal at the intake was unable to be made; therefore water was cascading down the pipe and obscuring the view of the

video camera. The consensus of the group was that divers should inspect and repair the intake riser with the possibility of installing valves to create a multi level intake to improve raw water quality. This addition of valves would require engineering services and approval by the Division of Water. The repair itself would not require prior approval so long as the original design was not altered.

**System Savings:** estimated \$1,500.

**City of Campton** – Located in Wolfe County, Kentucky; 1,860 water connections.

The City of Campton is a small mining community in eastern Kentucky. They operate a surface water treatment plant supplied by a small reservoir. The reservoir is drought vulnerable and has dropped to critical levels over the past few summers. The water treatment plant superintendent contacted KRWA and the KY Geological Survey (KGS) for assistance in developing a supplemental groundwater supply. The city drilled two test wells and has two other wells from a previous water plant when the city was supplied by groundwater. The Circuit Rider was asked to assist with water level monitoring of the two new wells and the lake along with monitoring rainfall. The monitoring equipment was installed in September to determine the correlation of rainfall to the reservoir and groundwater levels. After the pumps are removed from the old wells the Circuit Rider will collaborate with the KGS on additional monitoring and perform a pumping test along with water quality monitoring. The KGS will provide the pumping test analysis and make recommendations for further developing a groundwater supply.

**System Savings:** \$2,340

### ***Linking Aquatic Ecosystem Metabolism to the Formation of Drinking Water Contaminants: Implications for River and Reservoir Management***

A preliminary model of the DBP predictive management tool was presented at the Water Quality Gordon Conference in New York in August (Bukaveckas, P.; Jack, J.D. and T.W. Sellers: Internal and external sources of trihalomethane (THM) precursors in a Midwest reservoir and the Ohio River). A paper titled “Reduction in Trihalomethane Formation Potential through Air Oxidation” was presented at the International Society for Environmental Information Sciences (ISEIS) annual conference in Bowling Green, Kentucky in August (see Appendix A). Included in the presentation was an explanation on how ecological ‘bulk parameters’ can provide useful information to plant managers. This paper was also published electronically in the ISEIS 2006 Environmental Archives. Springfield Water Company has been presented with the findings of the study, and has been given asset management options based on the studies and model development.

### ***Web-Based GIS***

The Center for Water Resource Studies (CWRS) and Spatial Data Integrations (SDI) have developed a prototype system to determine the effectiveness of a web based GIS solution for

small water utilities. The ability to host an entire GIS solution in one central location not only allows these utilities to share the cost involved in the creation of a GIS, it also reduces the amount of maintenance and manpower required by each individual utility. We believe that this new approach to GIS will prove to be a viable option for the small water systems in the U.S.

Access to the site can be obtained by navigating to <http://12.180.241.9/water> and using admin for the username and 1g2e3o for the password. You must use Internet Explorer and have all pop-up blockers turned off for the site to function correctly.

Upon successful login, you will find the Table of Contents located on the left hand side of the window where each layer can be turned on or off by clicking in the checkbox next to the layer name. A navigation toolbar is located above the system map. The tools available are: Zoom In, Zoom Out, Pan, Go to Full Extent, Previous Extent, Last Extent and Identify. An additional editor toolbar can be turned on by selecting View>Toolbars>SDI Tools>Editor Toolbar from the file menu. This toolbar enables the user to create new data through the web-based system. First click the start editing button, located at the far left, then select Create New Feature from the Task drop-down, and select the feature you would like to create from the Target Layer drop-down. Clicking on the map will subsequently add the new feature to the map. This process can be repeated for as many features as the user would like to add to their system infrastructure.

Additional tools that were added include:

- A digital rolodex to add and return contact information for Vendors, Manufacturers, and Contractors.
- A means to add and remove material types for both pipes and materials.
- A measurement tool that allows the user to take point-to-point measurements on-line without having to go out into the field.
- A customized selection tool that quickly allows the user to query data from the database. This tool can be accessed by selecting Selection>Selection Crafter from the file menu.

During this quarter SDI also successfully implemented the Web-based version of SDImaps with the data from 10 rural water systems (9 in Kentucky and 1 in Southern Indiana). Each system was asked to thoroughly beta test the application and fill out a short questionnaire regarding their overall satisfaction with the application and current infrastructure. Out of the 10 systems implemented, all tried out the application and five (5) completed the questionnaire. Items to note from the received questionnaires and personal contact are:

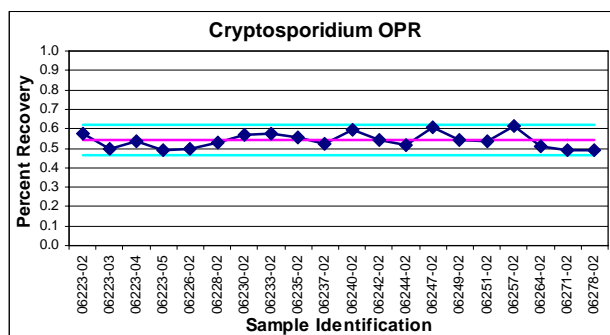
- 4 out of 5 have Broadband Internet Access (1 had dial-up)
- 4 out of 5 thought this technology would be beneficial to small utilities. (1 listed possible)
- 4 out of 5 thought the application was easy or very easy. One required assistance, which turned out to be an additional pop-up blocker that had been downloaded.
- The average age of computer equipment was 1 – 3 years of age.
- Many of the utilities that had an existing GIS expressed interest in this technology for the purpose of off-site backups and inter-office access to GIS data through the web browser instead of having to purchase additional software licensed for each user.

## ***Small Systems Partnership for Compliance Monitoring***

During the quarter, WATERS provided microbiological analytical services to nine (9) public water systems in Kentucky with populations less than 10,000. Six (6) of these systems have populations less than 3,300. A new microbiological analyst attended a one-week training course in Morehead, KY during the first week of August and obtained State certification for drinking water analysis.

## ***Source Water Assessment Analytical Method Development***

Two analysts attended an EPA Method 1623 Workshop in Cincinnati, OH, in July. After the workshop, IPR and OPR data was generated using spiking suspensions from Wisconsin State Laboratory of Hygiene and Waterborne Aqua-Glo G/C Direct FL antibody stain. Techniques learned at the workshop were integrated into WATERS Lab SOP for Cryptosporidium & Giardia Testing. The following results were submitted to EPA in September:



EPA notified the WATERS Laboratory on October 18, 2006 that the data was found to be acceptable, and that the laboratory was approved for Cryptosporidium analysis using Method 1623.

A slide presentation was developed on the topic of the Long Term 2 Enhanced Surface Water Treatment Rule (LT2 Rule) and presented at KRWA's Training Seminar in Somerset, KY in September. There were 56 water plant operators that attended the training. The discussion includes the following topics:

- What is Cryptosporidium & Giardia
- Introduction to LT2ESWTR
- LT2ESWTR in Kentucky
- Where to Collect Samples
- Monitoring Plan to the EPA
- Sample Collection Paperwork
- E. coli Sampling
- Cryptosporidium Sampling
- Sample Shipping
- Current Laboratory Information
- Laboratory Procedures
- IPMC and DCTS

## ***Procedures for Assessing Source Water Vulnerability to Suspended Sediment and Prioritizing Implementation of Best Management Practices in Karst Environments***

The goal of this project is to develop procedures for small water systems in karst regions to:

- a) assess source water vulnerability to suspended sediment and sediment-associated contaminants, and
- b) prioritize the implementation of best management practices (BMPs) for reducing the load of suspended solids to source waters.

During the quarter, analysis of USPED soil erosion model output of the Greensburg source area below Green River Lake was completed. Maps of erosion risk and estimated sediment loading to channels were developed, including loadings based on fixed-width riparian corridors of 50 to 350 meters. For upland areas, erosion risk is driven primarily by topography and land use model inputs, particularly at land use type boundaries where predicted sediment flux increases. The riparian corridor analysis suggests net deposition occurring in riparian zones, though the model does not resolve small scale features (gullies) that can efficiently transmit fine sediment across flat riparian areas to streams. Thus, model estimates should be viewed as conservative.

Increasing corridor width eventually produces estimates of net erosion, depending on valley width and local topography. Final results are summarized in the MS thesis of Narcisa Pricope, "Modeling Soil Erosion in the Upper Green River, KY". These results will be transferred to the Greensburg Water Department for use in assessing priorities for erosion and sediment control efforts. Collaboration with the Greensburg Water Department in addressing sediment-related water quality issues on the Upper Green River will continue, including analysis of raw water turbidity records for use in BMP assessment.

## ***Source Water Protection Education and Outreach***

A Decision Support System (DSS) web site which consolidates drinking water information and tools from multiple locations to allow the user to go to one location when making a decision regarding their water supply has been developed. The DSS can be found at <http://water.wku.edu/dss/> and incorporates pages that can be added to and edited by rural water districts. Spatially linked data is also available for query and addition. Water districts can add information about publications, GIS data, Conferences, and additional events and information of need to rural water districts.

## ***Laboratory Data Exchange System***

Large volumes of laboratory data from different sources have made data exchange between different applications very difficult. This project involves the development of a software system that consists of a set of tools to facilitate data exchange. Small water utilities will benefit from this system by being able to share information easily with reporting agencies and move data from

one information management tool to another without the time and expense of data conversion. This will facilitate the sharing and reporting of data for purposes such as tracking trends in water quality.

The legacy document converter program and an XML storage system have been developed, which allows for the storage of legacy water quality data into a database. A poster presentation regarding the project was given at the ISEIS conference in August. An article is in the process of being written for publication.

### ***Web Page Hosting***

Many small water systems do not have the financial or technical resources to develop and host their own websites. A template has been developed that allows small water systems to customize a site with pertinent information, such as CCRs, business hours, fee schedules, and contact information. The template can be viewed at: <http://water.wku.edu/hosting.htm>. Currently seven small water system websites are being hosted by CWRS. Three additional systems are gathering information to populate the template, and one system is presenting the proposal of a website to their board.

Mailings were sent to 28 water districts who had expressed interest in a website through a previous survey. Follow up phone calls have been used to also assess interest. Updates to each website will be provided by CWRS upon request by the systems.

### ***Technology Training***

As the use of technology develops, the need for technology training increases. A workshop for water districts was developed to help demystify the technology tools available to them. A class was held in conjunction with a KRWA training session in Carrollton, Kentucky with 35 Drinking Water utility representatives in attendance. CDs were provided to all attendees that included: tools available at no cost to water districts, including an open source GIS program, office templates, a water loss calculator and a CCR reporter. A copy of the web site template was also included.

### ***Center Coordination***

The CWRS hosted the 5<sup>th</sup> annual International Conference on Environmental Informatics (ISEIS) in Bowling Green, Kentucky on August 1-3. An exhibit booth promoting the Center's offerings was displayed. The TACWQ's annual Advisory Board meeting was held on August 1, in conjunction with the ISEIS conference, in order to ensure that the activities of the TACWQ accurately reflect the needs of its constituents.

Two CWRS representatives attended the KRWA annual conference in Owensboro, Kentucky on August 21-23, where an exhibit booth was displayed. Andrew Ernest attended the National Rural Water Association (NRWA) annual conference in Dallas, Texas on September 25-29, where he assisted with the TACNet booth. Presentations to system operators on proper sample

collection and transportation techniques were given at KRWA training sessions in Owensboro, KY on July 12 and in Somerset, KY on September 20. The operators obtained continuing education credit for the training.

Dr. Ernest is a member of several state and local government boards and councils, including the Barren River Area Development District (BRADD) Water Management Council, the Environmental Quality Commission (EQC), and the Statewide Watershed Steering Committee. Dr. Ernest attended these meetings throughout the quarter. Jana Fattic attended two River Basin Team meetings during the quarter.

## **Appendix A. THM Report**

## **Reduction in Trihalomethane Formation Potential through Air Oxidation Report to the Springfield Water Company Springfield, Kentucky**

R. S. Pirkle<sup>(1)</sup>, J.D. Jack<sup>(1)\*</sup>, and P.A. Bukaveckas<sup>(2)</sup>

<sup>(1)</sup> University of Louisville, Center for Environmental Science, Biology Department, 139 Life Sciences Building, Louisville, KY, 40292, USA

<sup>(2)</sup> Department of Biology, Center for Environmental Studies, Virginia Commonwealth University, 1000 W. Cary St., Richmond, VA, 23284, USA

**Abstract.** Trihalomethanes (THMs) are disinfection byproducts that have come under increasing scrutiny during the past 10 years due to a tightening of regulations by the United States Environmental Protection Agency. Current methods for reducing THM precursors in drinking water involve strong oxidizers (i.e. ozone and various forms of permanganate) which pose a number of safety issues for plant operators and for the general public. In a bench-scale experiment, we assessed the efficacy of a weaker oxidizing agent, bubbled air, in the reduction of THMFP. Hypolimnetic samples taken from two drinking water reservoirs in central Kentucky (USA) and finished drinking water from the water plant were used in this experiment. Results indicate that THMFP in finished water was reduced by 20 – 50% following air oxidation while source water samples showed inconsistent and non-significant results. These results indicate that air oxidation may help reduce the formation of THMs in the distribution system by removing precursors but would not be an effective strategy for reducing THMFP in source waters.

*Keywords:* Trihalomethane, THM, THMFP, Disinfection Byproducts, Water Quality

### **1. Introduction**

Water chlorination is used by many water companies to ensure potable drinking water. This process, however, can lead to the production of disinfection byproducts (DBPs) when chlorine reacts with natural organic matter. The production of trihalomethanes (THMs) such as chloroform and bromoform as a byproduct of water chlorination has come under increased scrutiny as THMs are known to be carcinogens in laboratory animals (Singer 1999) and have also been tied to higher incidence of rectal and bladder cancer in humans (Simpson and Hayes 1998). Recent regulations (2004) by the United States Environmental Protection Agency (USEPA) have reduced the allowable amount of THMs in finished water from 100 µg/L to 80 µg/L. This reduction has required some water companies to aggressively treat source waters in an effort to remove THM precursors before chlorination.

Two methods are commonly used to reduce THM formation potential (THMFP) in drinking water plants. Coagulation with subsequent flocculation of natural organic matter is effective and acts to reduce the amount of precursors in water prior to chlorination. Water treatment plants may choose to pre-oxidize source water with potassium permanganate or other strong oxidizers (see Jiang and Lloyd 2002 for a list of commonly used oxidizers) before treating with a flocculant such as ferric chloride. This process is effective in many cases in reducing THMFP, but in source waters with high levels of humic substances (Singer 1999), coagulation and flocculation may not reduce precursor amounts to levels below the USEPA standards. In addition, oxidizers can be hazardous and need to be handled with great care. Ozonation is an alternative disinfection process in which ozone is used to inactivate microbial contaminants in source water (Elovitz et al. 2000). This process results in little production of halogenated DPBs, but leads to the production of bromate (in bromine rich waters) which is also a hazardous DBP. Ozone is also an environmental hazard and improper handling of this oxidizer could result in unsafe conditions for employees at water treatment facilities.

The relative importance of various forms of THM precursors is thought to be influenced by site-dependent factors that include watershed characteristics (soils, land-use) and source water conditions (e.g. Jack et al. 2002). Therefore there is not likely to be a general treatment protocol which will be effective for all water companies. In addition, some water companies may find that even the current methods are insufficient to address their THMFP problems. In this paper, we examine a particular system in central Kentucky (USA) that has high organic loads in source waters which have led to levels of DBPs, especially THMs, above current USEPA standards. The THM violations tended to occur during times when the source water reservoirs were stratified and anoxic in the lower layers. The highly reducing conditions present during this period may enhance the production of THM precursors. THM levels also tend to be higher in the distribution system than in the plant, which suggests that precursors are not being

sufficiently degraded by the processes currently used by the plant operators. We hypothesized that air oxidation of the source waters, which does not require the use of harsh chemical oxidizers and poses little risk to the environment and water treatment plant employees, might prove effective in reducing THMFP in the source waters. This reduction could then allow the plant operators to successfully manage the THM levels by conventional methods and avoid water quality violations.

## 2. Methods

Our study sites were the reservoirs and treatment plant of a small central Kentucky water district which services approximately 4000 residences and businesses. The plant is an in-line direct filtration plant which utilizes pre-oxidation (via potassium permanganate), coagulation and flocculation (with acidified alum and cation polymers, respectively), and slow sand filtration. The primary source of water is a monomictic, man-made impoundment (Lake One; surface area = 53 ha). The impoundment is on average 2.5 meters deep with a maximum depth of about 15 meters at full pool. Between 4540 and 4920 liters/min are removed through the inlet of which approximately 4350 L/min are received at the treatment plant. Around 3785 L/min are processed for drinking water 20 hours/day with the remaining water during that time period and for the other 4 hours/day being shunted into a second smaller impoundment (Lake Two). Lake Two acts as a secondary water source and receives no other inputs except through rainfall. Lake Two exhibits characteristics similar to Lake One but is much smaller in size (approximately 6 ha).

From July 2005 through October 2005, we took weekly water samples near the intakes used by the water company. At each site, temperature, DO content, DO%, pH, and specific conductivity was recorded at one meter increments using a Hydrolab Minisonde 4a and Hydrolab Surveyor 4a. From August 2004 until the lakes became isothermal (approximately in October), samples of the water were taken at the surface, at two intermediate depths, and just above the bottom of the lake (total of four grab samples) using a translucent 10-liter Van Dorn. Care was taken with the bottom sample to not disturb the benthos and any grab sample that contained a large amount of sediments was released and another grab sample was taken. After the lake became isothermal only the surface and bottom samples were taken at monthly intervals. The water samples were transferred to a gallon water jug and a liter bottle and brought back to the lab, on ice, for processing. Beginning in May 2005, a finished water sample (post-processed and chlorinated) was concurrently collected from a water tap in the treatment plant. Hydrolab parameters were not gathered from the finished water samples.

Samples were prepared for analysis within 8 hours of collection. For each collected depth, whole water samples were subsampled for nutrient analysis. Four 500-mL bottles were filled (three of which were preserved with concentrated H<sub>2</sub>SO<sub>4</sub>, the other kept cold) and sent the next day to the WATERS Laboratory at Western Kentucky University for analysis of ammonia, total nitrogen, nitrate/nitrite, total phosphorous, soluble reactive phosphorous, chloride, and silicon dioxide levels by standard methods (APHA 1998). THMFP for each depth collected was determined using Standard Method 5710B (APHA 1998). To summarize, a one liter dark amber glass bottle was filled with water from each depth and lake sampled. The water was then quenched with chlorine and incubated for 7 days upon which it was analyzed by purge and trap gas chromatographic – mass spectrometric method (Standard Method 6232C; APHA 1998). Results were reported as the four major components of THMFP (chloroform, bromodichloromethane, chlorodibromomethane, and bromoform). THMFP was assumed to be the sum of these four haloforms. A portion of the remaining water was filtered through an ashed glass fiber filter (47 mm, Pall Type A/E) in order to ascertain particulate organic carbon levels. The filtered water was collected and sent to WKU for analysis of dissolved organic carbon. The final subsample of water was filtered through MCE (mixture of cellulose acetate and cellulose nitrate) filters (Fisherbrand, pore size of 0.45 µm). Chlorophyll a levels (acid corrected for pheo pigments) were determined by fluorometric methods on a Turner Designs Model 10-AU Fluorometer.

The remaining water from the lake and plant samples was then prepared for the air oxidation experiment. All samples were allowed to warm to room temperature (approximately 22°C). Redox potential was measured at the outset and at the conclusion of the aeration period to ensure that air oxidization was occurring. Redox potential was determined using an Orion Redox Probe (Model 967800) and an Orion pH Meter (Model 420A). The bottle tops were removed from the four replicate water samples and the initial redox potential was determined. One sample was then resealed and used as a reference sample. The remaining samples were aerated at a controlled air velocity for approximately 16 hours. Final redox potential was recorded for the aerated samples which were then prepared for incubations to determine THMFP along with the previously sealed reference sample. THMFP was quantified using a standardized method that mimics processes occurring during water treatment (APHA, 1998). Samples were buffered to pH 7.0; chlorine demand was quenched with excess chlorine and incubated at 25°C for 7 days. Upon

completion of the incubation period, THM concentrations were determined using the purge and trap gas chromatographic-mass spectrometric method described above.

Data was analyzed using SAS Version 9.1.3. Two-way (site and treatment) ANOVA with interactions were used where applicable and Bonferroni correction was used to correct for multiple testing errors.

### 3. Results

The water quality data was consistent with that found in other mesoeutrophic/eutrophic reservoirs in Kentucky (Bukaveckas et al, in review.) Average water temperature and dissolved organic carbon (DOC) were similar for Lakes One and Two (16.9°C and 17.7°C, respectively for temperature and 5.2 mg/L and 5.4 mg/L, respectively for DOC) but average surface chlorophyll a levels in Lake Two was more than double that of Lake One (48.3 µg/L versus 20.3 µg/L, respectively). Nitrate and soluble reactive phosphorus were below detection limits for most of the lake samples in the hypolimnion; ammonia was present but in very low concentrations (<0.36 µg/L.) Figure 1 shows average hypolimnetic (bottom) temperature and dissolved oxygen levels for these two reservoirs over the summer when THMFP problems occur in these systems. As expected, oxygen levels were very low in bottoms of both of these lakes leading to a highly reduced physiochemical environment.

Oxidation occurred in all aerated samples as indicated by a change in redox potential after 16 hours of aeration (Tables 1-3). The change in redox potentials (measured as final redox potential – initial redox potential [mV]) varied greatly within site and between sites. Lake Two, for example, averaged a redox potential change of -17.13 mV, but the range of redox potential change was from -88.7 to +0.2 mV. Lake One showed similar variability (average change in redox potential = -14.90 mV, maximum = -98.4 mV, minimum = 0.0 mV). Finished water samples were the most consistent; the average redox potential change for finished water was -127.9 mV with a maximum change of -188.7 mV and minimum change of -87.0 mV.

The THMFP for unaerated reference samples were significantly different between sites (Figure 2). Unaerated finished water averaged 146.13 µg/L THMFP and was significantly higher than both hypolimnetic samples from Lake One (78.96 µg/L) and Lake Two (65.93 µg/L;  $p=0.0127$  and  $p=0.0013$ , respectively) while there was no significant difference between hypolimnion samples ( $p=1.000$ ). After aeration, Lake Two THMFP (49.1 µg/L) was significantly lower than finished water (92.4 µg/L) and Lake One (95.8 µg/L; samples ( $p=0.0033$  and  $p=0.0011$ , respectively) with no difference between the latter sample sites ( $p=1.000$ ).

The proportion of THMFP left after air oxidation (THMFP-aerated/THMFP-unaerated) was also determined. After aeration, the THMFP proportion for finished water from the treatment plant averaged 0.63 which indicates an overall reduction in the THMFP by approximately 37%. This was significantly different ( $p<0.0001$ ) than the average THMFP proportion for Lake One which was 1.58 (an average increase of 58%), but not significantly different than Lake Two ( $p=0.0826$ ) which had an average THMFP proportion of 1.03.

### 4. Conclusions

In this treatment facility, the amounts of natural organic matter and the particular constituents of the THM precursor pool pose a significant management challenge for the operators. Current protocols at the plant do not reduce THMFP enough to produce finished water which meets USEPA guidelines for THMs and may actually be promoting precursor formation. However, in our bench-top scale experiments, 16 hours of aeration was able to reduce the amount of THMFP precursors in 1-liter of finished drinking water by as much 52%. We believe that this change occurs by the process of air oxidation which is known to degrade organic based materials (Denney 1971). The degradation occurs through the formation of a free radical on the carbon molecule leading to the oxidation of that molecule. Oxidation of THM precursors may “inactivate” them such that they would not add to the THMFP. This suggests that aggressive aeration of the water before it enters the distribution system may help reduce the formation of THMs as the water passes from the plant to the customers.

While we did not fully characterize the constituents of the finished water, the levels of dissolved organic carbon (DOC) measured concurrently with these samplings indicates that the processes used at the treatment plant may not effectively remove important small organic molecules that contribute to THMFP. Levels of DOC in raw water averaged 5.16 mg/L (SE = 0.08 mg/L) during the sampling period while DOC levels in processed finished water were only reduced to an average of 2.86 mg/L (SE = 0.05 mg/L) (unpublished data). DOC levels were not available from sources within the distribution system, so we can not assess how levels of DOC changed as they left the plant. Alternative treatments which could further reduce DOC levels should be considered as part of the plants strategy for addressing THM formation, particularly in their distribution system.

While our analysis has thus far focused on “in-system” solutions to the THM problems faced by this plant, the ultimate source of the THMFP in any water system is the watershed of the source waters. One of the interesting trends is the large decline in THMFP following aeration of the source water in Lake 2 in the fall. This time period coincides with the beginning of winter turnover and may be indicative of changing redox state conditions in the hypolimnion. The change in redox conditions could lead to a varied microbial community structure which other studies indicate the importance of microbes, in particular decomposers, to the formation of THM precursors (Bukaveckas et al., in review). During winter turnover, dissolved oxygen levels in the hypolimnion increased which would lead in a shift of the microbial community from predominately anaerobic decomposers to one that would contain the energetically favored aerobic microbes. Water companies may be able to further study the microbial community structure in order to exploit possible pre-chlorination engineering solutions (perhaps pre-chlorination aeration in basins similar to current flocculation basins) that will assist in reducing the initial THM precursor load. Modest reductions in THMFP could be expected with the appropriate treatment as THMFP for Lake Two showed a reduction of 75 and 50% for the September and October 2005 samples, respectively. It is important to note the apparent “production” of THM precursors during the disinfection/chlorination process. THMFP is consistently higher in finished water than source water throughout the sampling period (see Figure 2). Plant processes may significantly increase precursor formation through promoting anaerobic conditions that might encourage the generation of labile carbon that is unusable due to the very conditions that generated them. The production of these THM precursors may be the portion that are consistently removed through aeration and would be indicative of a need for water companies to re-evaluate the particular process they use in order to minimize anaerobic processes during water processing.

**Acknowledgements.** We would like to thank the Region Four Technical Assistance Center for Water Quality at Western Kentucky University and USEPA for funding this project. We appreciate the cooperation of the staff at the water plant site.

#### References

- American Public Health Association (APHA). (1998). Standard Methods for the Examination of Water and Wastewater, 20<sup>th</sup> ed. APHA.
- Bukaveckas, P. A., D. McGaha, J. Shostell, and J. D. Jack. In review. Internal and external sources of trihalomethane (THM) precursors in a mid-western reservoir. *Journal of the American Water Works Association*.
- Elovitz, M.S., Von Gunten, U. and Kaiser H.-P. (2000) Hydroxyl radical/ozone ratios during ozonation process. *Science and Engineering*. 22(2), 123-150.
- Denney, D.B. (1971). Chemical oxidation of organic compounds. In Faust, S. J. and Hunter, J.V. (Eds). *Organic Compounds in Aquatic Environments*. 377-385. Marcel Dekker, Inc.
- Jack, J. J., Sellers, T., and Bukaveckas, P.A. (2002). Algal production and trihalomethane formation potential: an experimental assessment and inter-river comparison. *Canadian Journal of Fisheries and Aquatic Sciences*. 59, 1482-1491.
- Jiang, J. and Lloyd B. (2002). Progress in the development and use of ferrate(VI) salt as an oxidant and coagulant for water and wastewater treatment. *Water Research*. 36, 1397-1408.
- Simpson, K.L. and Hayes, K.P. (1998). Drinking water disinfection by-products: an Australian perspective. *Water Research*. 32, 1522-1528.
- Singer, P.C. (1999). Humic substances as precursors for potentially harmful disinfection by products. *Water Science Technology*. 40, 25-30.

Table 1. Average, Maximum and Minimum THMFP ( $\mu\text{g/L}$ ) for Aerated vs. Un-aerated Waters

Site	Average THMFP	Standard Error	Maximum	Minimum
Un-aerated				
Lake Two	65.93	19.42	154.6	21.9
Lake One	78.96	16.09	129.7	11.6
Finished Water	146.13	7.50	183.4	132.7
Aerated				
Lake Two	49.10	24.98	81.0	4.9
Lake One	95.84	52.28	169.1	17.1
Finished Water	92.44	17.37	128.1	66.0

Table 2. Redox data.  $\Delta$  Redox Potential is measured in mV and is equal to redox potential of after aeration – redox potential before aeration.

Site	$\Delta$ Redox Potential	Standard Error	Maximum $\Delta$	Minimum $\Delta$
Lake Two	-17.13	10.30	-88.7	0.20
Lake One	-14.90	9.99	-98.4	0.0
Finished Water	-127.87	6.14	-188.7	-87.0

Table 3. Proportion of THMFP-aerated / THMFP-un-aerated

Site	Average Proportion	Standard Error	Maximum	Minimum
Lake Two	1.03	0.16	2.47	0.20
Lake One	1.58	0.22	4.37	0.23
Finished Water	0.63	0.02	0.77	0.48

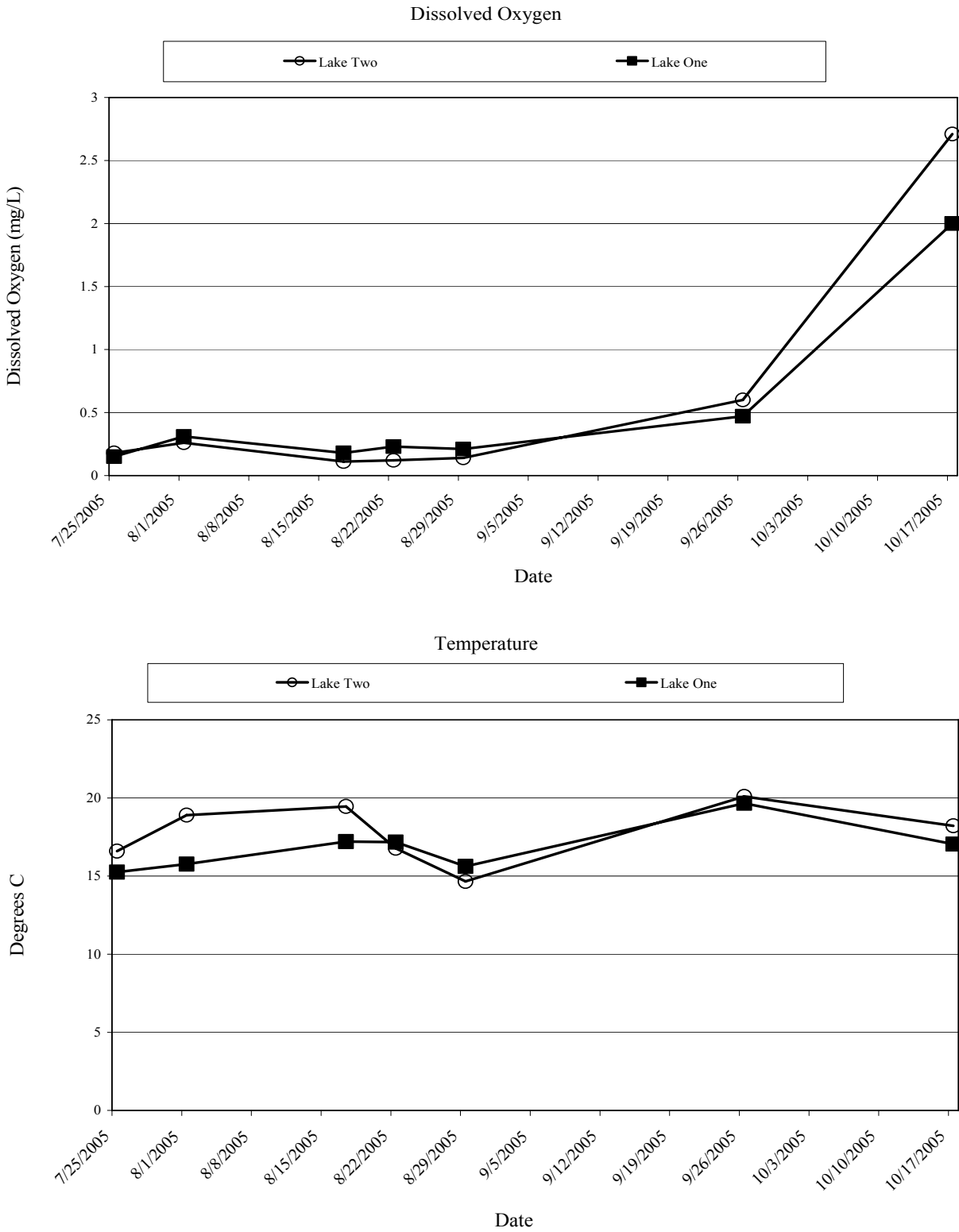
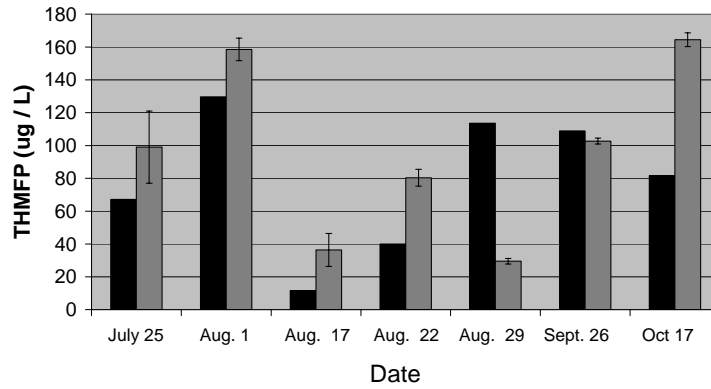
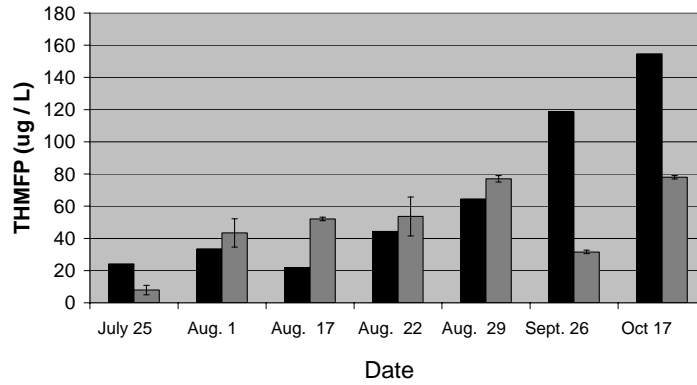


Figure 1. Dissolved oxygen content and temperature data for the hypolimnion of Lakes One and Two from July to October 2005. Levels were similar between the two lakes during the sampling period.

A



B



C

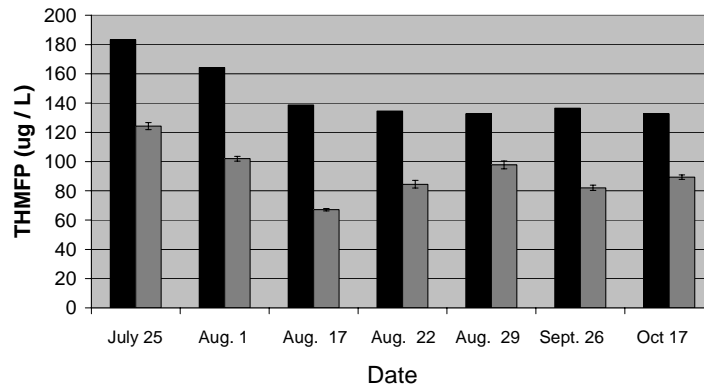


Figure 2. THMFP responses to aeration in Lake One (a), Lake Two (b) and the treatment plant. The dark bars show THMFP in unaerated (control) bottles for each sampling day, the paired light bars show THMFP in aerated bottles. Error bars show standard errors.