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American Water Works Association. Journal; May 2007; 99, 5; ABI/INFORM Trade & Industry
pg. 127

Trihalomethanes (THMs) are contaminants of drinking water produced by the reaction between chlorine and natural organic matter. Determination of THM formation potential (THMFP) is a means of quantifying precursor abundance in waters from diverse sources. THMFP in river water entering and leaving Taylorsville Lake (Ky.) was measured to assess internal and external sources of THM precursors. THMFP in Taylorsville Lake was largely determined by watershed inputs. External inputs from tributary streams accounted for 80% of reservoir THMFP, and internal processes resulted in a net generation of 20%. Chlorophyll concentrations in the main tributary (Salt River) were comparable to those measured in Taylorsville Lake, suggesting that algal production in source waters may be important in regulating precursor supply to the reservoir. The highest THMFP was found in hypolimnetic samples, and peak export from the reservoir occurred during fall turnover, suggesting that decomposition of sedimenting organic matter both delayed and enhanced precursor release.

Internal and external sources of THM precursors in a midwestern reservoir

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More than 200 million people in the United States depend on disinfected drinking water, with chlorination used as one of the most common methods of disinfection (Clark & Sivaganesen, 1998). Water utilities are able to provide reliable, safe, and relatively inexpensive drinking water through chlorine treatment and maintenance of disinfection residuals in distribution systems. Although disinfection has clear benefits for safeguarding drinking water, chlorination poses potential threats to human health. More than 20 years ago, a study reported the presence of chloroform and other trihalomethanes (THMs) in chlorinated water (Rook, 1976). Subsequent research showed that these disinfection by-products (DBPs) were formed by the reaction between chlorine and natural organic matter and that some of these compounds were carcinogenic in laboratory animals (Gopal et al, 2007; Singer, 1999). Epidemiologic studies have linked DBPs with increased risk of bladder and rectal cancers in humans (Simpson & Hayes, 1998). DBP precursors constitute a small and variable fraction of the pool of natural organic matter, but little is known about their chemical characteristics (Kim & Yu, 2005; Richardson, 2002). Although there are no direct methods of quantifying precursor concentrations, standardized procedures for quantifying DBP formation potential (DBPFP) have been used in monitoring and experimental studies to identify factors regulating precursor abundance (Krasner et al, 2006).

The activities that occur along the shores of a water source—whether naturally occurring, such as erosion or collection of natural organic matter, or human-caused, such as logging or industrial discharge—can cause the water to carry elevated amounts of disinfection by-product precursors.

River impoundments are widely used as sources of drinking water. By virtue of their hydrogeomorphic position, these systems intercept drainage from large catchment areas, resulting in water quality conditions that are reflective of inflowing waters. Both internal (reservoir) and external (catchment and riverine) processes may be important in determining DBPFP within river impoundments. Internal production stems from the activities of photosynthetic organisms (macrophytes and planktonic or attached algae) that produce organic compounds which serve as DBP precursors (Palmstrom et al, 1988). Evidence in support of the importance of autochthonous sources include a variety of studies that correlate THM formation potential (THMFP) with measures of algal abundance in environmental or experimental settings (Jack et al, 2002; Graham et al, 1998; Schmidt et al, 1998). External sources of DBP precursors derive in part from organic materials that have been introduced into source waters from terrestrial production as well as from upstream (riverine) algal production. The fate of DBP precursors within reservoirs may be determined in part by subsequent biochemical transformations during microbial decomposition that enhance or diminish the reactivity of organic matter with disinfecting agents. Several studies have linked DBPFP to bulk properties of organic matter such as particulate and dissolved organic carbon concentrations (Jack et al, 2002; Lin et al, 2000; Singer, 1999; Clark & Sivaganesan, 1998).

New US Environmental Protection Agency regulations require water utilities to take steps to reduce regulated DBPs (Cooke & Kennedy, 2001). Compliance efforts have focused on engineering (i.e., within-plant) solutions to minimize DBP formation during treatment (e.g., Musikavong et al, 2005) and have not considered the underlying ecological mechanisms or anthropogenic influences that determine the production and fate of DBP precursors. Source waters typically are situated in proximity to population centers such that human activities influence internal and external processes regulating DBPFP. Watersheds experiencing agriculture, logging, or other activities that promote erosion may receive elevated loadings of DBP precursors because of inputs of dissolved organic carbon (DOC) and particulate organic carbon. Source waters proximal to urban and agricultural areas also receive elevated inputs of inorganic nutrients and experience excessive phytoplankton blooms that may promote internal generation of precursors. Scientific understanding of the links between watershed development and DBPs is poor in part because few studies have considered precursor issues in the context of ecosystem processes. Pending regulations increase the urgency to address the ultimate questions of why water sources vary widely in DBPFP and how source waters and their catchments can be managed to reduce DBPs.

This study quantified external inputs and internal production of THM using a mass balance approach for a river impoundment (Taylorsville Lake, Ky.). THMFP of inflowing and outflowing water was measured and used in combination with discharge data to derive fluxes into and out of the reservoir. The authors predicted that if algal production within the reservoir was the predominant source of THM precursors, then (1) THMFP export from the reservoir would be large in relation to inputs from the catchment and (2) the highest THMFP would be associated with summer epilimnetic samples. Alternatively, if THM precursors were derived from terrestrial sources or upstream (riverine) algal production, then inputs to the reservoir would be large and comparable to outputs. Laboratory experiments were performed to quantify the effects of algal growth and senescence on THMFP in river and reservoir samples. It was predicted that treatments favoring high algal growth rates would promote the largest increases in THMFP.

METHODS

Study area. Taylorsville Lake was created in 1983 as an impoundment of the Salt River for flood control, recreation, and wildlife conservation. The study area is located in north central Kentucky (Figure 1) and experiences a humid, continental climate with a mean annual temperature of 14°C and a mean annual precipitation of 122 cm. The principal tributary (Salt River) drains a watershed area of 917 km^2 that is predominantly agricultural, with 76% devoted to pasture and cropland; of the remainder, 20% of the land is devoted to silviculture and 4% to residential areas (KDOW, 2000). Additional smaller tributaries include Beech Creek, Little Beech Creek, and Crooked Creek. The reservoir is 30 km in length with an area of 1,234 ha (at summer pool) and a shore length of 120 km. Shoreline habitat is composed of banks (consisting of clay and rock) with flooded standing timber. Annual mean hydraulic residence time is 84 days, mean lake depth is 8.4 m, and maximum depth is 23 m. The lake is nutrient-rich and thermally stratified and exhibits an anoxic hypolimnia (Table 1). A strong and stable oxycline (at 5 m) is apparent by June and persists until fall turnover.

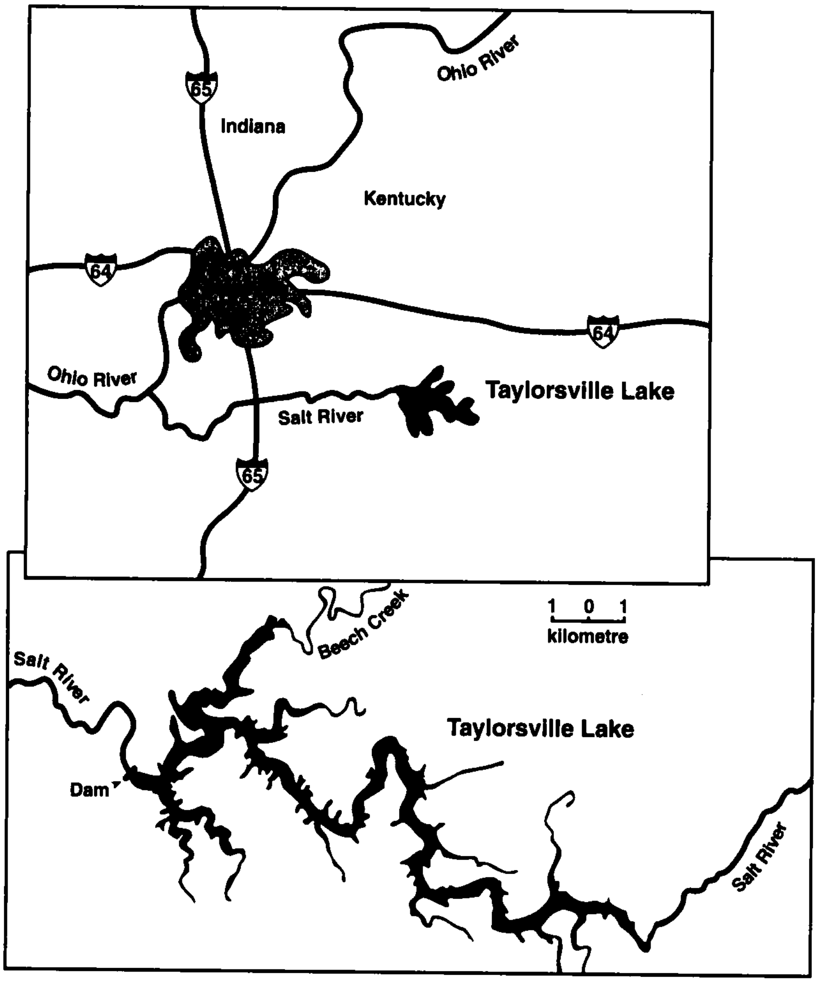
Sampling. Four sampling sites were selected to characterize inputs, outputs, and in-lake conditions with respect to THMFP, chlorophyll a, DOC, and ancillary variables. Inputs via the primary inflow (Salt River) were characterized on the basis of monthly samples and continuous discharge measurements obtained at a US Geological Survey station located 6 km upstream from the reservoir. The Salt River accounts for 49% of surficial inputs to the lake (USACE, 1992), with the remaining fraction contributed by numerous small tributaries. The largest of these—Beech Creek with 11% of inputs—was selected to represent inputs from small catchments that drain directly into Taylorsville Lake (Figure 1). Beech Creek was sampled monthly at a location 1 km above its confluence with the lake to ensure that the sample was representative of water originating in the subbasin. Outflowing water from Taylorsville Lake was sampled 200 m downstream of the dam. Inflow and outflow samples were collected by submerging two acid-washed 1-L plastic bottles[1] and one 1-L amber glass bottle (for THMFP) from as near to the midchannel as conditions permitted. All samples were immediately placed on ice in a dark container for transport to the laboratory. Inflow and outflow samples were collected from June 2000 through October 2001. Lake samples were collected monthly during the period of thermal stratification (June through October 2000 and April through October 2001). Samples were taken near the deepest part of the lake basin (300 m upstream of the dam) from the epilimnion (1 m) and hypolimnion (>12 m) using a 4-L van Dorn water sampler.

TABLE 1 Dissolved oxygen, pH, and nutrients in the inflow, epilimnion, hypolimnion, and outflow of Taylorsville Lake during the study period (June 2000 through October 2001)

Parameter	Inflow Mean (Range)	Epilimnion Mean (Range)	Hypolimnion Mean (Range)	Outflow Mean (Range)
DO—*mg/L*	9.0 (4.9–14.7)	8.6 (6.0–11.1)	0.3 (0.0–0.9)	9.2 (5.0–13.3)
pH	8.55 (6.35–9.82)	8.68 (5.68–9.39)	7.76 (7.23–8.34)	8.34 (5.09–9.14)
Nitrate—*µg/L*	1,289 (4–4,814)	82 (2–652)	396 (2–1,390)	338 (9–1,208)
Ammonia—*µg/L*	60 (23–115)	36 (18–107)	537 (27–1,199)	97 (25–337)
SRP—*µg/L*	210 (74–411)	4 (1–7)	79 (9–151)	29 (3–104)

DO—dissolved oxygen, SRP—soluble reactive phosphorus

FIGURE 1 Maps showing location of Taylorsville Lake in Kentucky (inset) and the primary (Salt River) and secondary (Beech Creek) inflows (larger map)



Analysis. Water samples were analyzed for chlorophyll a, nutrients, DOC, and THMFP. Samples for chlorophyll analyses were collected on 0.5-mm filters, extracted in acetone (12 h), and analyzed by fluorometry[2] with acid correction. Nutrient analyses followed standard methods (*Standard Methods,* 1998). Dissolved inorganic nitrogen and soluble reactive phosphorus were determined from filtered samples (0.45 µm) by automated techniques using cadmium reduction (for nitrate), phenate (for ammonia), and ascorbic acid (for soluble reactive phosphorus) methods. DOC was measured by high-temperature combustion on an automated total carbon analyzer[3] after sparging for 4 min to remove inorganic carbon.

THMFP incubations were started within 24 h of collection by buffering samples to pH 7.0 and chlorinating with an excess of free chlorine—approximately 1 mL of 5 mg Cl_2 per mL, in accordance with *Standard Methods* (1998). After the seven-day reaction period (at 25°C), concentrations of individual THMs (bromoform, bromodichloromethane, dibromochloromethane, and chloroform) were determined by the purge-and-trap gas chromatographic/mass spectrometric method. Total THMFP reported here is the sum of the four species. On average, 95% of THMFP formed chloroform, 4% was bromodichloromethane, and less than 1% was bromoform and chlorodibromomethane. Temperature, pH, and dissolved oxygen were measured with a minisonde.[4]

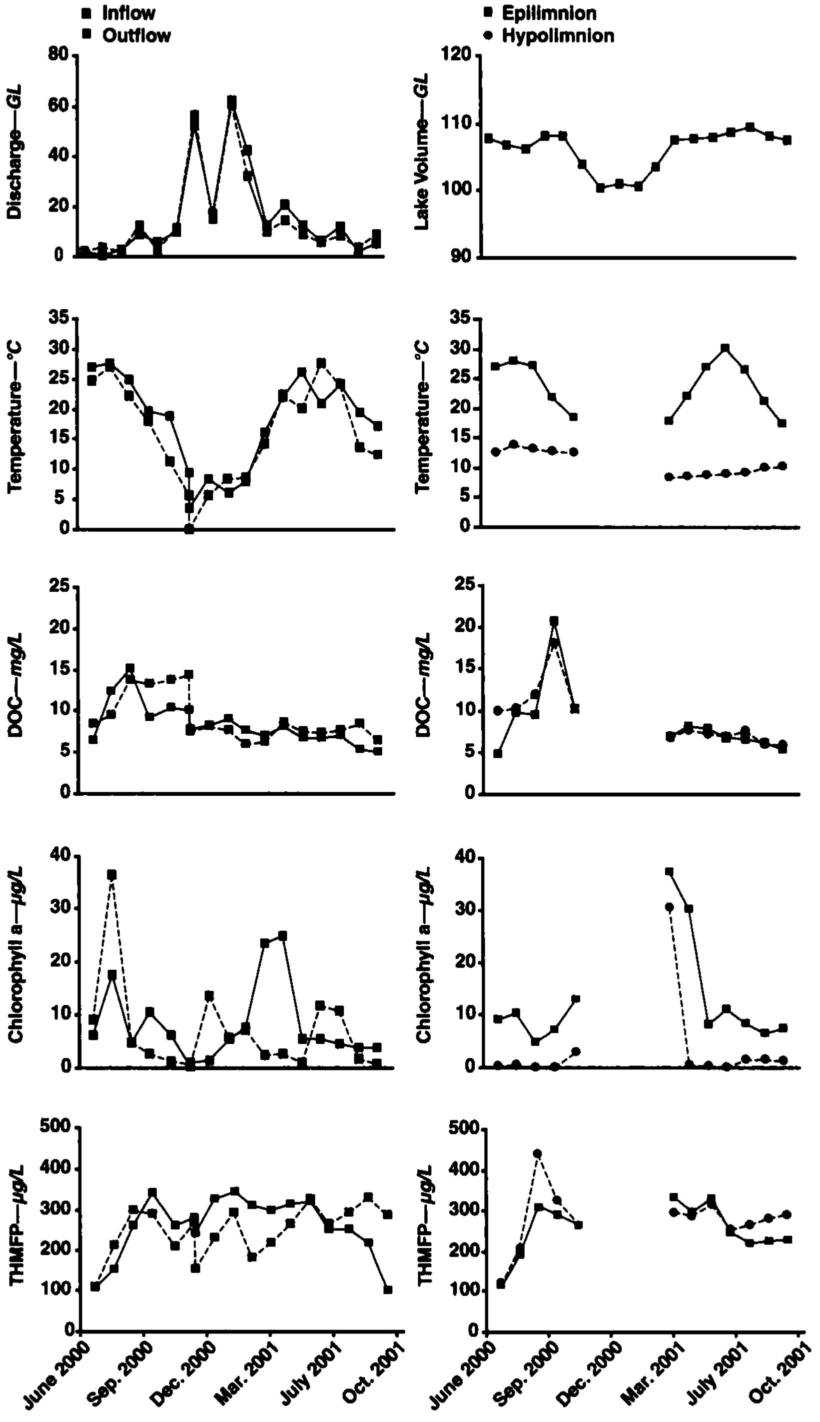
Input and output fluxes of DOC, chlorophyll a, and THMs were calculated as the product of concentration and discharge. Flux estimation for chlorophyll a and DOC is routine, whereas application of this approach to quantify THM precursor flux is new (Stepczuk et al, 1998a). Flux values arising from the product of discharge and THMFP concentrations can be viewed as the potential mass yield of THMs from a volume of water corresponding to the cumulative discharge during the period. Fluxes were calculated using average daily discharges for the primary inflow and the lake outflow, which were obtained from the US Geological Survey (USGS, 2002) and the US Army Corps of Engineers (USACE, 2002). The weighted average of solute concentrations for the two inflow sites (Salt River and Beech Creek) was used to represent surficial inputs to the lake. Because there was no relationship between discharge and concentrations of DOC, chlorophyll a, or THMFP, a linear interpolation was used to derive daily flux rates between sampling dates. To characterize seasonal variation in transport and retention, input–output budgets were developed for four index periods by adding daily flux values during summer (June through August 2000 and 2001), fall–winter (September 2000 through February 2001), and spring (March through May 2001). An overall mass balance was derived for the period from June 2000 through August 2001. Estimates of in-lake production or retention were corrected for changes in lake storage using daily pool elevation and hypsographic data provided by the Corps of Engineers (2002).

Experiments. In July and October 2001, laboratory experiments were performed to assess the effects of algal growth and senescence on THMFP using water (20 L) collected from the lake (epilimnion) and primary inflow. Two treatments were used in a factorial design with three replicates (n = 12) for each of the two source waters and experimental dates (total n = 48). The goal was to produce a range of algal growth responses using prefiltration and variable shading to manipulate algal standing stocks and growth rates. One treatment entailed prefiltration to reduce algal standing stocks at the outset of the experiment. A second treatment entailed covering the experimental vessels (Erlenmeyer flasks) to eliminate light penetration and promote algal senescence.

The authors expected that uncovered, nonfiltered cultures would yield the highest algal standing stocks and that uncovered, filtered cultures would show modest increases in algal abundance (measured as chlorophyll a). It was also predicted that covered, nonfiltered cultures would show the highest rates of algal decline and that covered, filtered cultures would show little change in chlorophyll.

All cultures were placed on a shaker table rotating at 100 rpm in an environmental chamber that simulated typical summer conditions (25°C, 16:8 light to dark). Light intensity approximated summer average daily irradiance at 1-m depth in Taylorsville Lake (~540 µE m^2/s) (Shostell & Bukaveckas, 2004). Cultures were incubated for five days. Samples taken at the outset and conclusion of the experiment were analyzed for THMFP, DOC, and chlorophyll a using the same analytical procedures as for inflow, outflow, and lake samples. Experimental data were analyzed by relating rates of change in THMFP (µg/L per day) to changes in chlorophyll (µg/L per day) and DOC (mg/L per day) during the five-day incubations.

FIGURE 2 Taylorsville Lake discharge, lake volume, temperature, DOC, chlorophyll, and THMFP for the inflow and outflow and the hypolimnion and epilimnion from June 2000 through October 2001



DOC—dissolved organic carbon, THMFP—trihalomethane formation potential

Epilimnetic and hypolimnetic data are for the period of thermal stratification only.

TABLE 2 Comparison of inputs and outputs of water, THM precursors, chlorophyll a, and DOC for Taylorsville Lake during four index periods and the entire period of study

	Summer	Fall/Winter	Spring	Summer	All
Index Period	**June–August 2000**	**September 2000–February 2001**	**March–May 2001**	**June–August 2001**	**June 2000–August 2001**
Water—*GL*					
Input	5.1	156.6	75.7	30.6	268.0
Output	7.9	159.4	56.4	22.9	246.7
Storage	1.7	7.6	–4.3	-1.5	3.4
Balance	1.1	–4.8	-15.0	–6.1	-24.7 (-9%)
THMFP—*kg*					
Input	1,157	35,341	14,097	9,793	60,388
Output	1,195	47,503	18,121	6,427	73,246
Storage	342	2,267	-1,337	–424	848
Balance	-304	9,895	5,361	-2,942	12,010 (+20%)
Chlorophyll a—*kg*					
Input	47	471	376	350	1,244
Output	88	551	830	118	1,588
Storage	14	31	–81	-14	-51
Balance	28	49	535	-218	395 (+32%)
DOC—*kg*					
Input	53,175	1,437,580	463,370	219,651	2,173,776
Output	90,479	1,370,909	431,710	157,743	2,050,841
Storage	13,427	68,968	-32,895	-10,961	38,540
Balance	23,877	-135,639	1,235	-50,947	-161,475 (–7%)

DOC—dissolved organic carbon, THMFP—trihalomethane formation potential

Balances are outputs minus inputs, corrected for changes in lake storage (also expressed as percent relative to inputs).

RESULTS

Lake inflows and outflows were highest in winter months with peak flows occurring in December (52 GL) and February (62 GL) (Figure 2). Cumulative inflows from December 2000 to March 2001 were 175 GL and exceeded lake volume 1.7-fold. In comparison, summer inflows (June through August) did not exceed 15 GL per month (<15 % of lake volume). Water temperatures of the primary inflow and outflow ranged from 5 to 30°C during the period of study. Inflow temperatures were similar to epilimnetic values, suggesting that tributary inputs were entrained in surface waters. The lake exhibited stable thermal stratification, with bottom temperatures not exceeding 15°C during the period from April to October.

DOC. DOC concentrations typically ranged between 6 and 10 mg/L (Figure 2). Differences in values for inflow, outflow, and lake (epilimnetic and hypolimnetic) were generally <1 mg/L. DOC did not show pronounced seasonal trends except for a period of somewhat higher inflow concentrations (~13 mg/L) in fall 2000 and an elevated lake concentration (~20 mg/L) in September 2000.

Chlorophyll a. Chlorophyll a concentrations of the primary inflow were comparable to those observed in the reservoir (Figure 2). The highest inflow chlorophyll concentrations (35 µg/L) occurred in July 2000; otherwise, inflow chlorophyll concentrations were <20 µg/L. The highest outflow chlorophyll concentrations (25 µg/L) were observed in April–May 2001 and coincided with a spring phytoplankton bloom during which lake concentrations were 30–40 µg/L.

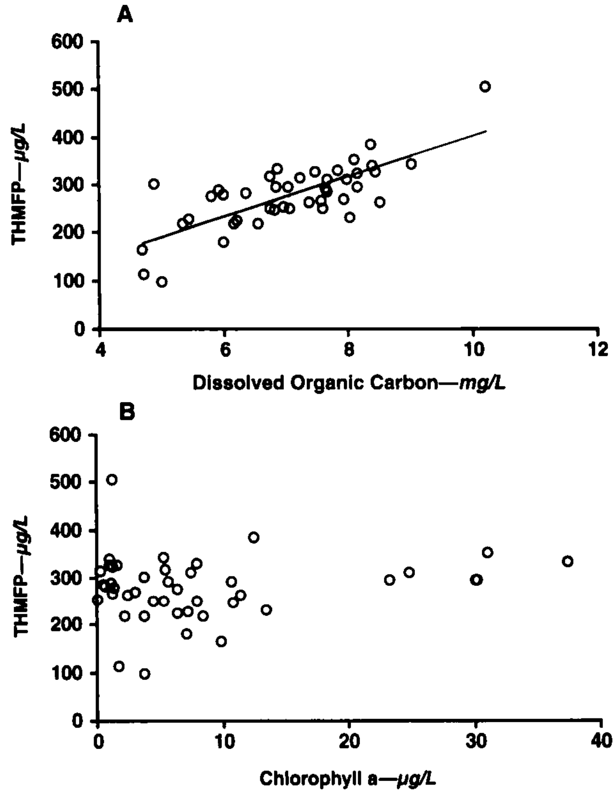
THMFP. Inflow and outflow THMFP concentrations varied considerably, with values ranging from 100 to 325 µg/L (Figure 2). From September 2000 through May 2001, outflow THMFP exceeded inflow concentrations in every month. Inflow values averaged 78% of outflow concentrations during this period (average difference = 67 µg/L). In summer months, inflow THMFP equaled or exceeded outflow values. Lake concentrations typically ranged from 225 to 350 µg/L. THMFP concentrations in the epilimnion and hypolimnion were comparable during the early stages of stratification, whereas hypolimnetic values exceeded epilimnetic values in the late stages of stratification. The highest THMFP recorded during this study (437 µg/L) was a hypolimnetic sample collected in August 2000. For the pooled data set of inflow, outflow, and lake samples, variation in THMFP was correlated with DOC concentrations ($R^2 = 0.56$, $p < 0.001$) (Figure 3, part A).

Regression models derived for site-specific subsets of these data were generally not significant. Chlorophyll a was not found to be a significant predictor of variation in THMFP either in the pooled data set or for individual sites (Figure 3, part B). A multivariate model that included both DOC and chlorophyll a as well as temperature, POC, and pH accounted for a somewhat greater proportion of the variation in THMFP ($R^2 = 0.72$, $p < 0.001$).

Water budgets showed good agreement, with inputs and outputs balancing to within 9% for the period of study (Table 2). A budget for fall and winter (September through February) agreed to within 3%, whereas budgets for periods of low to moderate discharge (summer and spring) were within 25% of agreement. Variation in inflow and outflow THMFP concentrations was smaller than the variation in inflow and outflow volume such that temporal dynamics in flux rates were driven largely by seasonal changes in discharge. The highest flux rates were observed in the fall and winter months (September through February). The reservoir acted as a net source of precursors during this period, with THM precursor flux outputs exceeding inputs by more than 20% in six of eight months. Peak outputs occurred in December 2000 and February 2001 and exceeded inputs by 33 and 22%, respectively. The potential mass yield of THMs in outflowing waters exceeded that in inflowing waters by 9,895 kg (28%) during the six-month period. In contrast, the lake was a net sink for THM precursors during summer months, with retention rates (relative to inputs) of 26% for the period June–August 2000 and 30% for June–August 2001. Overall, the lake was found to be a source of precursors, with the potential THM yield of outflowing waters exceeding that of inflows by 12,010 kg (20%) during the 15-month period. In addition, the lake was a net source of chlorophyll, with outputs exceeding inputs by 395 kg (32%) over the period of study. The excess of chlorophyll leaving the lake was largely attributable to a positive export balance in spring when outputs exceeded inputs more than twofold. DOC fluxes were approximately in equilibrium, with inputs and outputs balanced to within 7%.

Experimental results were analyzed using variation in rates of change for chlorophyll and DOC as predictors of changes in THMFP during the five-day incubation (Figure 4). Treatment effects (prefiltration and shading) were generally successful in producing a range of algal abundances. The highest rates of change were observed in river water cultures, which showed peak growth rates of 10 µg/L per day (July) and 1.5 µg/L per day (October). Cultures experiencing large increases in chlorophyll a also showed the largest increases in THMFP, whereas cultures showing decreases in chlorophyll a generally declined in THMFP. Variation in chlorophyll accounted for 49% ($p < 0.02$; July experiment) and 91% ($p < 0.001$; October experiment) of the variation in THMFP among cultures containing river water. Little variation in chlorophyll a or THMFP was observed in lake cultures during the July experiment, and chlorophyll was not a significant predictor of rates of change in THMFP. In October, changes in chlorophyll a among lake cultures ranged from −1.0 to +0.5 µg/L per day and accounted for 56% of the variation in changes in THMFP ($p < 0.01$). Changes in DOC during the five-day experiments were comparatively small (−0.35 to +0.30 mg/L), given the large background pool of DOC (6–7 mg/L). Changes in DOC were

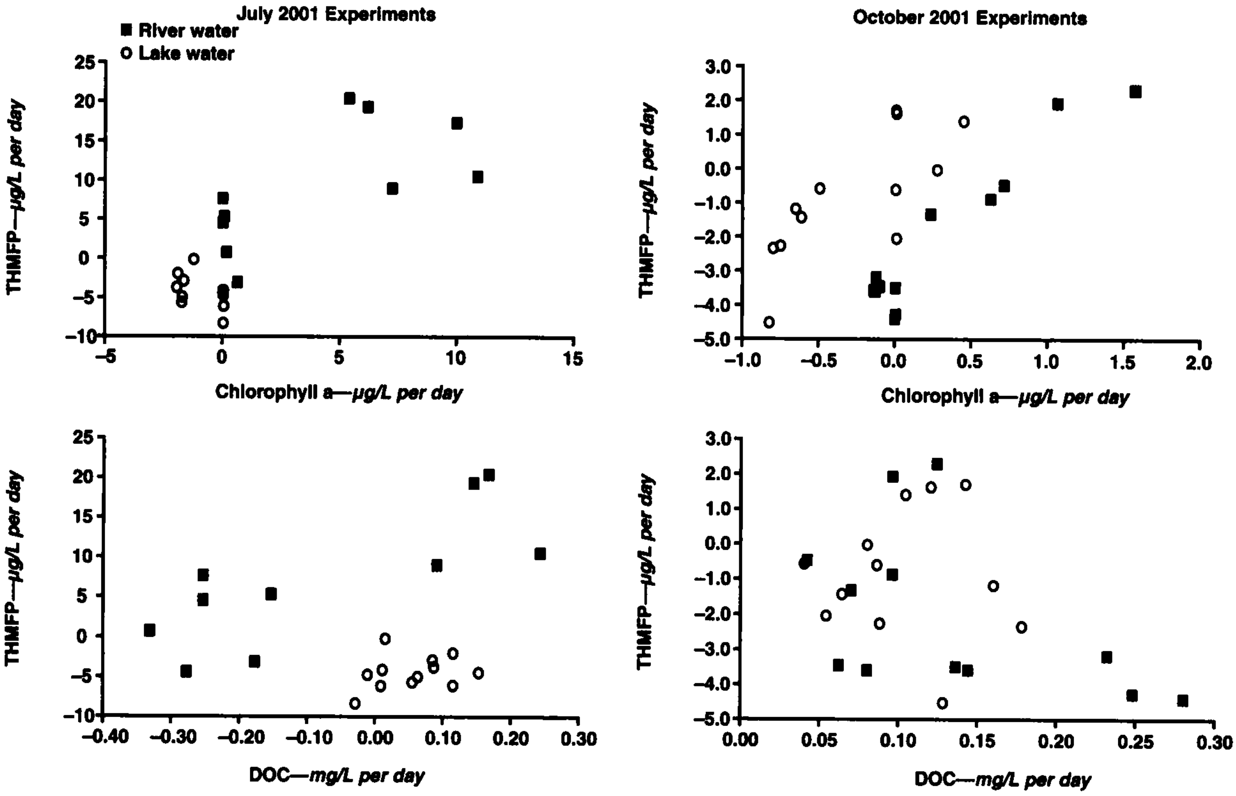
FIGURE 3 Dissolved organic carbon (A) and chlorophyll a (B) as predictors of variation in THMFP among samples collected from the inflow, outflow, hypolimnion, and epilimnion of Taylorsville Lake



THMFP—trihalomethane formation potential

Regression line in part A denotes statistically significant relationship between dissolved organic carbon and THMFP ($R^2 = 0.56$, p <0.001).

FIGURE 4 Rates of change in THMFP in relation to changes in chlorophyll and DOC during five-day incubations of river water and lake water in July and October 2001



DOC—dissolved organic carbon, THMFP—trihalomethane formation potential

River water samples were samples were collected from the primary inflow (Salt River), and lake water samples were obtained from the epilimnion.

generally not a significant predictor of changes in THMFP, with the exception of the river cultures during the July experiment ($R^2 = 0.62$, $p < 0.01$).

DISCUSSION

THMFP in two reservoirs. The mass balance analyses suggest that the THMFP of Taylorsville Lake is predominantly regulated by external processes. During a 15-month period that included two summers and intervening months, tributary inputs corresponded to 80% of exported THM precursor fluxes whereas internal processes resulted in a net generation of an additional 20%. These results contrast with those of prior research focusing on Cannonsville Reservoir (N.Y.) that partitioned THM loadings into internal and external sources (Stepczuk et al, 1998a; 1998b; 1998c) Stepczuk and colleagues reported that internal processes arising from epilimnetic phytoplankton production were the principal source of THM precursors accounting for two thirds of the cumulative input. The apparent discrepancy between that research and the study described here cannot be attributed to differences in hydrologic loading rates because the two reservoirs had comparable water residence times (Taylorsville Lake = 84 days, Cannonsville Reservoir = 125 days). The mass balance for Cannonsville Reservoir was based on the period from April to November when inflow discharge was generally low and epilimnetic primary production was maximal. Exclusion of winter months—when catchment inputs were likely higher and algal production minimal—would underestimate the importance of external sources in an annualized budget. In the current study, however, budgets for periods of similar conditions (June to August) showed that internal processes did not result in net generation of precursors; rather, Taylorsville Lake acted as a net sink retaining 26% of inputs in 2000 and 30% of inputs in 2001.

The alternative findings arising from the Taylorsville and Cannonsville studies may point to differences in watershed land use and geomorphology that are important to understanding sources of THM precursors. The principal tributary of Cannonsville Reservoir (west branch of the Delaware River) is situated in a predominantly forested region (70%) of varying topography. The principal tributary of Taylorsville Lake is a lowland river draining a relatively flat and agricultural (76%) watershed. High nutrient loadings and reduced flow velocities favor riverine algal production (Sellers & Bukaveckas, 2003) such that algal-derived precursors may account for a large fraction of external loading for THMFP. The results of the current study showed that external loadings are the principal source of THM precursors to Taylorsville Lake, but current methodologies do not allow for the partitioning of inputs according to their origin in terrestrial versus upstream (aquatic) environments. Chlorophyll a concentrations in the Salt River and Beech Creek were comparable to those measured in Taylorsville Lake. Cumulative inputs from the tributaries represented a large fraction (78%) of chlorophyll export from the lake. Net chlorophyll generation within the lake exceeded external inputs only during the spring phytoplankton bloom. Phytoplankton production in Taylorsville Lake is limited by low epilimnetic nutrient concentrations from midsummer through fall turnover (Table 1; Shostell & Bukaveckas, 2004). Upstream lotic environments are proximal to nutrient sources within the catchment and under favorable flow conditions may sustain high rates of phytoplankton production.

Experimental data in this study also supported the hypothesis that phytoplankton production in lotic environments is an important source of THM precursors. During both July and October experiments, river water cultures exhibited larger increases in chlorophyll a and THMFP than did lake water cultures. The experimental data were consistent with previous findings, indicating algal compounds may show high yields of THMFP relative to humic compounds (Plummer & Edzwald, 2001; Graham et al, 1998; Schmidt et al, 1998). Phytoplankton are an important source of THM precursors to Taylorsville Lake, but their production appears to be based largely in upstream lotic environments rather than in the reservoir itself.

Although disinfection has clear benefits for safeguarding drinking water, chlorination poses potential threats to human health.

In a previous study, chlorophyll concentrations were found to be a significant predictor of THMFP in rivers of the Ohio Valley (Jack et al, 2002). Increases in THMFP per unit increase in chlorophyll were found to be similar among rivers and in experimental mesocosms (2–3 µg THMFP per µg chlorophyll a). In the current study, THMFP was not correlated with chlorophyll a in either Taylorsville Lake or its inflows, although THMFP increases in river water cultures were similar to the value reported previously. Algal-derived organic matter appears to be an important source of THM precursors, but the relationship between THMFP and measures of phytoplankton abundance may depend on other factors, such as bacterial transformation of algal-derived compounds. The highest THMFP in Taylorsville Lake was found in hypolimnetic samples rather than in epilimnetic samples in which precursors derived directly from photosynthesis should be most abundant. Hypolimnetic concentrations increased progressively during summer stratification, and 2002 sampling (conducted subsequent to the study) showed persistent deepwater maxima THMFP at these depths through December at concentrations 40–80 µg/L greater than surface THMFP values (Bukaveckas & Jack, 2002). The reservoir was a net sink for THMFP during the summer production maxima but a net source in fall and winter when entrainment of hypolimnetic waters resulted in high export. The authors concluded that sedimentation of autochthonous and allochthonous organic matter both delays and enhances precursor release from the reservoir through storage and bacterial transformation in the hypolimnion.

Implications. The findings of this study have implications for water providers and reservoir managers that may be generally applicable to thermally stratified reservoirs situated in agricultural landscapes.

- First, THMFP was largely associated with the dissolved fraction, suggesting that filtration to remove particulates would have little influence on precursor concentrations.
- Second, hypolimnetic withdrawals are not recommended as a means of mitigating THMFP because of the presence of deepwater maxima arising from production of precursors through microbial decomposition of organic matter.
- Third, implementation of best management practices to mitigate nutrient loading likely would diminish THMFP by reducing algal abundance in tributaries and other source waters.

ACKNOWLEDGMENT

This project was funded by the US Environmental Protection Agency through the Region IV Technical Assistance Center for Water Quality at Western Kentucky University, Bowling Green, Ky. This article is a contribution to the Center for Watershed Research, which is affiliated with the Kentucky Institute for the Environment and Sustainable Development, Louisville, Ky.

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FOOTNOTES

[1] Nalge Nunc International, Rochester N.Y.
[2] 10-AU field fluorometer, Turner Designs, Sunnyvale, Calif.
[3] TOC-5050A, Shimadzu Scientific Instruments, Columbia, Md.
[4] Hydrolab Surveyor 4a, Hach Co., Loveland, Colo.

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Internal and external sources of THM precursors in a midwestern reservoir

Paul A. Bukaveckas, Dale McGaha, Joseph M. Shostell, Richard Schultz, and Jeffrey D. Jack

This research investigated the source of natural organic compounds that serve as precursors to disinfection by-product formation. Samples taken from a midwestern reservoir showed that inputs from tributary streams accounted for 80% of precursors leading to the formation of trihalomethanes (THMs) and that internal processes generated the remaining 20%. The highest THM formation potential (THMFP) was found in samples collected below the thermocline, suggesting that decomposition of sedimenting organic matter enhanced precursor production.

Study findings have implications for water providers managing thermally stratified reservoirs in agricultural landscapes. Because THMFP was largely found to be associated with the dissolved fraction, filtration to remove particulates would have little influence on precursor concentrations. Hypolimnetic withdrawals as a means of mitigating THMFP are not recommended because of deepwater THM concentrations arising from the production of precursors through microbial decomposition of natural organic matter. Implementation of best management practices in order to mitigate nutrient loading likely would diminish the formation potential of THMs by reducing algal abundance in tributaries and other source waters.—MPM

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Addressing problems with gas supersaturation at drinking water utilities

Marc Edwards and Paolo Scardina

Gas bubbles forming during conventional water treatment can be problematic for utilities, reducing operating efficiency and interfering with all aspects of treatment. Problems associated with bubble formation include floating floc during coagulation and sedimentation, head loss in media filters and upflow clarifiers, erratic particle counts, and erroneous turbidity measurements. This research found that these phenomena are fairly commonplace yet often unrecognized or overlooked by the drinking water industry. More significantly, engineers may not factor water supersaturation into treatment plant design, leading to consequences ranging from minor nuisances to complete failure of new full-scale facilities.

Dissolved gas supersaturation was investigated at several utilities. The case studies highlighted here and the analyses of bubble formation will help water providers in identifying, confirming, and mitigating the adverse effects of bubble formation. In addition, the authors suggest parameters that should be considered in the design of a new treatment plant or modification of an existing facility.—MPM

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Filter-to-waste optimization

William J. Soucie and Brett J. Sheen

The turbidity spike that occurs during filter ripening can be minimized without additional equipment or chemicals, simply by optimizing backwash steps. However, filter-to-waste (FTW) is still needed to achieve aggressive filter effluent turbidity targets.

A study was undertaken at the Central Lake County Joint Action Water Agency in Lake Bluff, Ill., to minimize water consumption and maximize filter service life. Filtration and water use were optimized using existing equipment and a method called extended terminal subfluidization wash, demonstrating that 10-year-old biologically active granular activated carbon is still viable. The FTW peak following backwash was reduced from an average of 0.13 to 0.08 ntu.

In addition, results suggest that FTW is not required in 96% of filter backwashes. Therefore, automatic FTW following backwash should be discontinued and, instead, FTW should only be used as needed.—SH