

Reduced river phosphorus following implementation of a lawn fertilizer ordinance

John T. Lehman*, Douglas W. Bell and Kahli E. McDonald
Department of Ecology and Evolutionary Biology, Natural Science Building,
University of Michigan, Ann Arbor, MI 48109-1048, USA

Abstract

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Statistical comparisons of 2008 surface water quality data with a historical data set at weekly and subweekly resolution revealed statistically significant reductions in total phosphorus (TP) and a trend of reduction in dissolved phosphorus following implementation of a municipal ordinance limiting the application of lawn fertilizers containing phosphorus. No reductions were seen at an upstream control river site not affected by the ordinance. Nontarget analytes including nitrate, silica and colored dissolved organic matter did not change systematically as did P. The data were analyzed in the context of a statistical model that characterized historical temporal variability and predicted the sampling effort needed to detect changes of specified magnitude. Expected changes of about 25% in monthly mean value were predicted to require weekly samples during the summer for only 1 or 2 years for TP; statistically significant reductions measured after 1 year averaged 28%, or about 5 kg P/day. The lawn fertilizer ordinance was only one component of broader efforts to reduce nonpoint source loading of P, however, so the magnitude of its role in the measured changes remains uncertain.

Key words: eutrophication, sampling requirements, temporal variation, watershed

Growing numbers of municipalities and state governments have adopted or are considering the adoption of restrictions on residential use of phosphorus-containing fertilizers. The actions are based on awareness that phosphorus (P) is often not a growth-limiting nutrient in many terrestrial soils, and that excessive application of the element leads to runoff and eutrophication of surface waters (e.g., Carpenter *et al.* 1998). Examples include the state of New Jersey, with over 100 municipalities affected (New Jersey 2007); Sarasota County, Florida (Sierra Club 2007); the state of Maine (Maine 2008); and Dane County in Wisconsin (Dane County 2007).

Aside from the environmental consciousness of the actions, little evidence exists that the bans are having a salutary effect. For example, the state of Minnesota enacted a law to regulate the use of phosphorus lawn fertilizer with the intent of reducing unnecessary phosphorus fertilizer use. The law, which went into effect in 2004 in the Twin Cities metropolitan area and statewide in 2005, prohibits use of phosphorus

lawn fertilizer except in prescribed instances. However, field studies to examine the efficacy of the ban for improving surface water quality were inconclusive (MDA 2007), a fact attributed to excessive variability in runoff data. The problem may indeed be the statistical power of available datasets. Vlach *et al.* (2008) analyzed more than 500 data points and reported reductions in P runoff from sub-watersheds in Minnesota, where the use of fertilizer containing P was restricted in 1999, compared to other sub-watersheds where the ban was not imposed until 2004. The study involved pair-wise comparisons of 6 subwatersheds in the municipalities of Plymouth and Maple Grove, Minnesota. The sites differed in their regimens of fertilizer use, with the Plymouth sites using only P-free fertilizer, and Maple Grove sites serving as controls using P-containing fertilizer. Concentrations of total P in runoff were virtually identical between the 2 treatments, but soluble reactive P concentrations in runoff were 17% lower at the P-free sites.

As part of its efforts to comply with a state-imposed phosphorus total maximum daily load (TMDL) that called for a 50% reduction in P discharges to the Huron River, the city of Ann Arbor in southeast Michigan enacted an ordinance

*Corresponding author: jtlehman@umich.edu

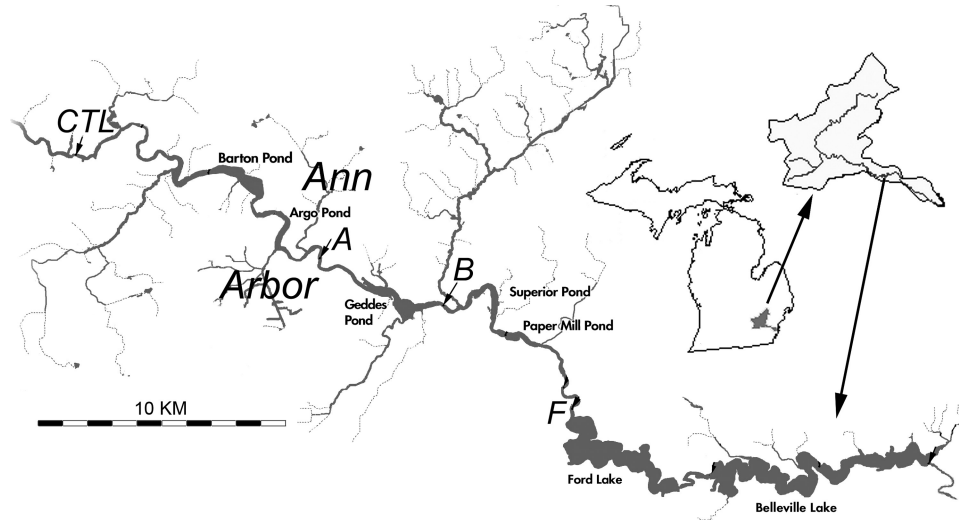


Figure 1.-- Study site, with sampling stations identified.

that went into effect in 2007 (Ann Arbor 2006) to limit phosphorus application to lawns. Compliance with the lawn fertilizer ordinance depends on restriction of phosphorus fertilizer application by homeowners and lawn care services unless they have a soil test demonstrating need. The estimated effect of full compliance was a 22% reduction in P entering the river. The prediction was obtained by estimating the lawn fertilizer runoff from a creekshed within the city and extrapolating that result to all other creeksheds. Ferris and Lehman (2008) used their historical set of Huron River water quality data to predict the sampling effort that could detect changes of roughly 25%. They concluded that a 25% reduction in total P (TP) would be detectable after 1 or 2 years of sampling 4 times per month. Similar percentage reductions in dissolved P (DP) would likely take 2 or 3 years, and for soluble reactive P (SRP), the time could be as long as 8 years. This paper reports the test of the *a priori* predictions after 1 year.

Study site

Our field site (Fig. 1) was a portion of the Huron River catchment in southeastern Michigan (United States Geological Survey, USGS Cataloging Unit 04090005). Four stations were established (Table 1) on the basis of an existing historical data set at weekly and subweekly intervals (Ferris and Lehman 2008). The station designated Control (CTL) corresponded to station 1 of Ferris and Lehman (2008). It was upstream from Ann Arbor and outside the jurisdiction affected by the city ordinance. Stations A and B corresponded with Ferris and Lehman’s stations 5 and 6. Station A represents about 29 km² of catchment attributable to Ann Arbor, and station B represents about 94 km². A fourth station,

F, was downstream at the site where the Huron River discharges into Ford Lake, a eutrophic impoundment. Station F was downstream from the outfall of the wastewater treatment facility that serves Ann Arbor (AAWWTP); stations A and B were upstream of the outfall. Water quality data at station F have been reported by Ferris and Lehman (2007), and include 4 years (2003–2006) prior to implementation of Ann Arbor’s fertilizer ordinance.

Field sampling

Water was collected at weekly intervals from May to September 2008. Raw water was filtered on site for nutrient analysis using Millipore™ disposable filter capsules of nominal 0.45 μm pore size.

Nutrient analyses

Analyses included SRP, DP, TP, soluble reactive Si (SRSi), pH, and nitrate (NO₃). The SRP was measured as molybdate-reactive phosphate in filtrate; DP and TP were measured as

Table 1.-Locations and approximate catchment areas of 4 Huron River stations that are attributable to Ann Arbor. Coordinates are specified as eastings and northings for UTM Zone 17.

Station	Catchment area attributable to Ann Arbor (km ²)		
	E	N	
CTL	262796	4691655	0
A	275285	4685262	29
B	279744	4683268	94
F	284834	4679126	94 + AAWWTP outfall

SRP after first oxidizing filtrate (DP) or unfiltered water (TP) with potassium persulfate at 105 C for 1 h. Specific conductance at 25 C (K_{25} , μS) was measured with samples at 25 C in a water bath. Colored dissolved organic matter (CDOM) was measured as UV absorbance at 254 nm. Ferris and Lehman (2008) showed that CDOM correlates strongly with both dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) in the Huron River. All nutrient analyses were performed according to Ferris and Lehman (2007). For SRP and TP, 3 replicates were measured at each site. For DP, 2 replicates were measured at CTL and station A, and 3 replicates were measured at stations B and F. Sample means and standard error of the mean (SE) were calculated for each determination and additional replicates were added if the ratio of SE to mean exceeded 0.05.

Daily volumetric discharge and mean daily TP concentrations in the effluent of the AAWWTP were supplied by the city of Ann Arbor from the operator's logs.

Statistical methods

The primary response variables of interest were SRP, DP and TP; however, NO_3 , CDOM, SRSi, pH and K_{25} were included as nontarget or quasicontrol variables because we reasoned that they should be unaffected by a nutrient reduction strategy specifically targeted at P. We adopted the statistical model developed by Ferris and Lehman (2008) with the aim of testing the efficacy of the new ordinance; it balanced type I error against type II error such that $\alpha = 0.1$ and $\beta = 0.75$. The object was to hold type I error reasonably low while seeking a credible level of power to detect environmental changes if they indeed occur. Because we wished to test the model predictions, we set $\alpha = 0.1$ for significance testing. Our *a priori* expectation was that P concentrations would decrease, and so we applied one-tailed tests to the P data. Because we had no *a priori* expectations regarding the nontarget variables, we applied two-tailed tests and set $\alpha = 0.1$ to mimic the threshold probability applied to P variables.

We log-transformed SRP, DP, TP, NO_3 , SRSi and CDOM prior to statistical comparison and used K_{25} and pH in statistical tests without transformation. Based on previous work we expected that values from the different sampling stations would differ and that there would be significant differences in mean monthly concentrations. To partition variability contributed by these factors while testing differences between the control and treatment sites and between the pre-ordinance and post-ordinance years, a MANOVA (SAS) was used to assess overall changes in concentrations of the three P variables simultaneously, using station, month and year (reference period vs. 2008) as categorical factors. All 3 factors proved statistically significant ($P < 0.02$ for both SRP and DP; $P < 0.0001$ for TP). We subsequently explored the

data with attention to detailed response by station, particularly control versus experimental as well as the direction of change.

All original data used in these analyses are archived for public access at <http://www.umich.edu/~hrstudy/dataarchive.htm>.

Hydrology

Fluvial discharge of the Huron River at Ann Arbor (USGS 04174500) during 2008 was qualitatively similar to discharges recorded during the reference years, with the exceptions of unusually high discharges during late May 2004 and late Sep 2008 (Fig. 2).

Nontarget variables

Analysis of variance (AOV, SYSTAT version 10) revealed that SRSi concentrations varied significantly by month ($P < 0.0001$) but not by station or year ($P > 0.19$). Nitrate varied significantly by station and month ($P < 0.0001$) but not by year ($P = 0.49$). In comparison, CDOM varied by month ($P < 0.0001$) and by year ($P = 0.007$) but not by station ($P > 0.6$). Across all stations, including CTL, CDOM was on average about 8% higher in 2008 compared with the reference period, suggesting that DON or DOC levels were elevated. Specific conductance was similarly on average about 9% higher in 2008 than the reference period across all stations including CTL ($P < 0.0001$), and pH was significantly higher by about 0.1 unit ($P < 0.0001$). Temporal patterns in CDOM, specific conductance and pH seemed to correspond with the seasonal pattern of river flow variation in 2008. As flow slackened in July and August, these properties increased at all stations, including CTL.

Phosphorus variables

As anticipated from past sampling experience, SRP was more variable than DP or TP (Fig. 3) and there was no indication that concentrations for the months of May to September in 2008 were significantly lower than reference values at any site other than station F in August. For DP, a trend of decreasing mean concentrations was observed at the experimental stations, particularly B and F (Fig. 3); however, TP concentrations were repeatedly lower than reference at the 90% probability level, particularly at stations B and F (Fig. 3).

The magnitude of the concentration decreases observed at station F downstream of the AAWWTP outfall were indistinguishable from the decreases observed at upstream station B. Paired t-tests of the concentration differences by month

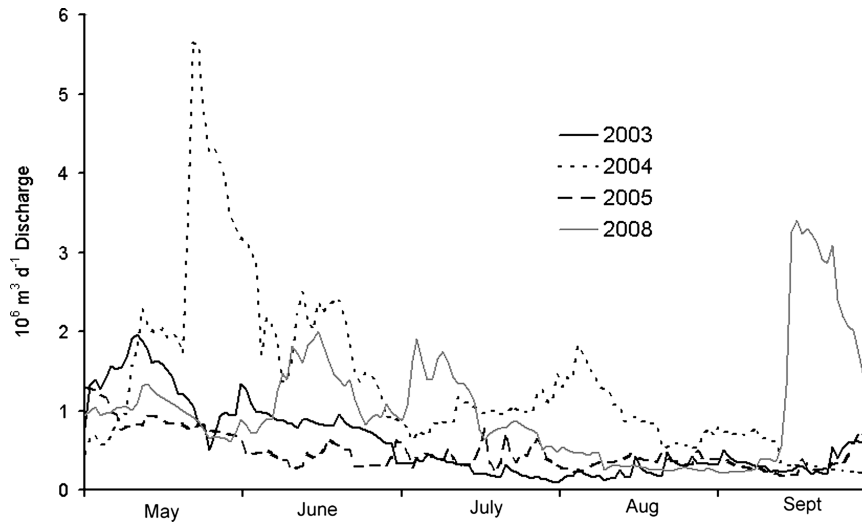


Figure 2.—Fluvial discharge of the Huron River at Ann Arbor (USGS 04174500) from May to September for 3 reference years (2003–2005) and the post-ordinance test year 2008.

for 2008 compared to the reference period differed neither for TP ($P = 0.83$) nor for DP ($P = 0.13$). Analysis of TP discharge records for the AAWWTP (Fig. 4) revealed that 2008 discharge levels were within the range observed during the previous 5 years.

Discussion

Ferris and Lehman's (2008) median estimate of the effort needed to detect a 25% change was 8 years of weekly samples for SRP but only 2 years for TP and 3 years for DP. The results of this study after 1 year are consistent with those predictions. A reduction in SRP was detected at only one site on one date, whereas reductions were detected for both DP and TP at experimental sites with greater regularity. A summary of key findings follows:

- Decreases in TP concentration at 90% confidence were noted in 10 cases out of 15 at the experimental sites (A, B and F) during the main growing period from May to September (Fig. 3). Moreover, a trend of reduced (mean) TP concentrations was observed at the experimental sites in 14 cases out of 15. Reductions at station B, just upstream from the AAWWTP outfall, were more regular than at station A. Station B receives considerably more cumulative drainage from Ann Arbor than does station A and may therefore be more responsive. The average reduction in concentration for the 10 statistically significant cases was 28%.
- Reductions in concentration of DP were rarely significant at 90% confidence level at the experimental sites (Fig. 3), although a trend of reduced monthly mean concentrations

was observed at the experimental stations, with the mean reduction being 13% overall.

- The magnitudes of the DP and TP reductions at station F, downstream from the AAWWTP outfall, were indistinguishable from DP and TP reductions measured at station B, upstream of the outfall. Combined with absence of any systematic trend in point source discharge of TP (Fig. 4), this suggests that the detectable effect traces to nonpoint source loading.
- The upstream site CTL appeared to function well as a control site, in that no reductions in SRP, DP or TP were noted.
- The nontarget variables showed no evidence of the station-specific response seen in TP and to a lesser degree in DP. Departures of specific conductance, pH and CDOM from historical conditions appeared to originate upstream of the experimental unit because they were in evidence at the control site. Consistent changes in nutrient concentrations only within the experimental unit were confined to P.
- Based on the median daily TP load carried by the Huron River at station B during May to September 2003–2005 (data from Ferris and Lehman 2008), the magnitude of the load reduction is about 5 kg P/day.

After the first year of data collection and analysis, detectable reductions have been documented for TP and, to some degree, for DP for every month from May to September. Percentage reductions are of the magnitude predicted to be detectable at the applied level of sampling effort. We can state objectively within the context of our statistical model that P concentrations were lower in 2008 compared with the

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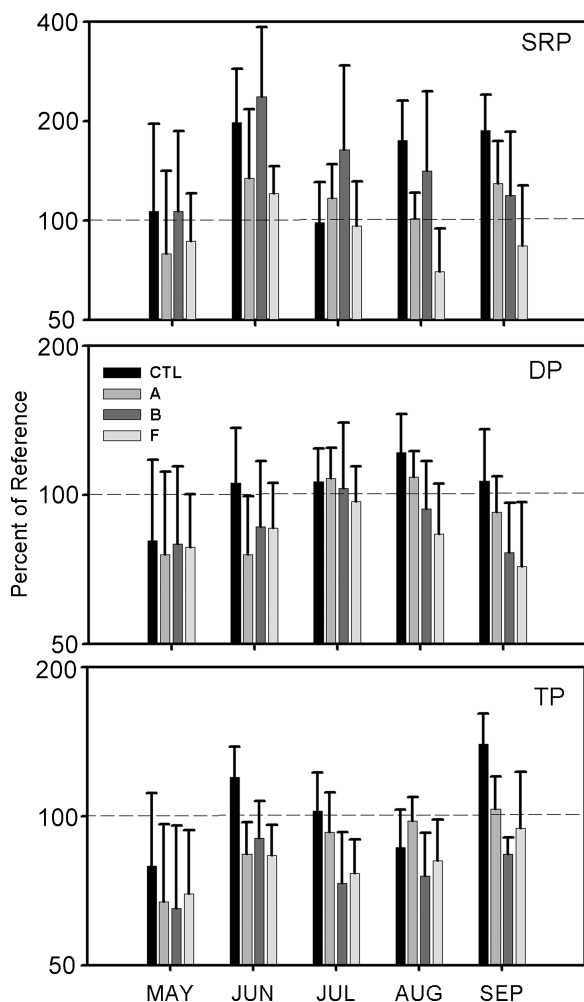


Figure 3.—Concentration anomalies of SRP, DP and TP at control and experimental sites in 2008 expressed as percent of reference values. Error bars represent upper 90% confidence intervals of the means.

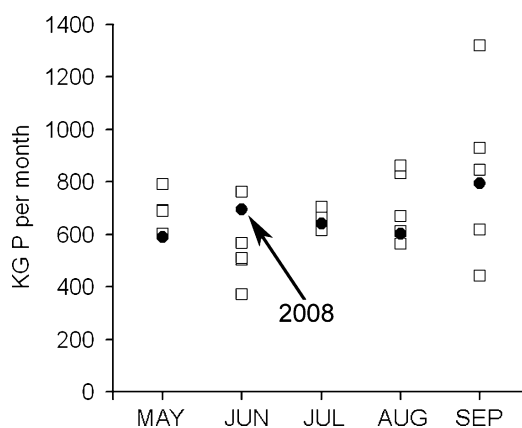


Figure 4.—Monthly discharge of TP from the Ann Arbor wastewater treatment facility from 2003 to 2008.

reference period (2003–2005) at experimental sites upstream from the AAWWTP outfall and therefore independent from treatment or discharge practices. These reductions were coincident with a city ordinance restricting use of lawn fertilizers containing phosphorus. In fact, the magnitudes of DP and TP reductions downstream of the outfall are not statistically different from those measured upstream, meaning that the 2 are highly correlated and traceable to nonpoint source loading.

The magnitudes of the TP reductions are generally greater than DP reductions, even though DP accounted for 56% (SE = 3%) of TP at all sites during the reference period and 60% (SE = 3%) of TP in 2008. This suggests that the main effect has been reduction in the particulate P load of the river. We have not tried to determine the relative contributions of biogenic or mineral particles to the total, or whether phosphate in particulate matter is biologically absorbed or physically adsorbed.

It would be tempting to conclude that the phosphorus reductions were caused by implementation of the ordinance, and that may be the case; however, the ordinance was enacted in the context of public education efforts that encourage citizens to be more mindful of yard waste discharges into storm drains, to exert more diligence regarding buffer strips of vegetation along stream banks and to exhibit more environmental awareness in general. These multi-faceted efforts make it difficult to isolate a single cause for the changes, but the changes appear to be real and of the predicted magnitude and direction. Continued measurements are certainly in order in this watershed as well as others, but the initial results suggest that with good baseline data even relatively modest (25%) changes in nutrient load can be detected against background variation on time scales fast enough to help inform policy decisions.

Acknowledgments

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