Reduced River Phosphorus Following Implementation of a Lawn Fertilizer Ordinance: Year 2 Results

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***Abstract––*A**nalysis of 2009 surface water quality data agrees with findings from 2008 by showing 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. Non-target analytes including nitrate, silica, colored dissolved organic matter, specific conductance, and pH did not change systematically as did P. The data were compared with a multi-year historical data set at weekly and sub-weekly resolution that preceded the ordinance. The average reduction in TP from May to September was 17 percent.

In response to a state-imposed phosphorus TMDL (Total Maximum Daily Load) that called for a 50% reduction in phosphorus discharges to the Huron River, the city of Ann Arbor, Michigan enacted an ordinance that went into effect in 2007 (Ann Arbor 2006) to limit phosphorus application to lawns. The projected effect of full compliance was a 22% reduction in phosphorus entering the river. The prediction was made by measuring the lawn fertilizer runoff from a creekshed within the city and extrapolating that result to all other creeksheds. Statistical modeling (Ferris and Lehman 2008) indicated that reductions of that specified magnitude for total P (TP) could be detectable using an existing historical set of Huron River water quality data within two years by sampling four times per month. Similar percentage reductions in dissolved P (DP) would likely take two or three years, and for soluble reactive P (SRP), the time could be as long as 8 years. After just one year, 2008, Lehman et al. (2009) were able to report a statistically significant reduction in TP and a trend of decreasing concentration for DP. This report summarizes the results of our Year 2 (2009) sampling season.

Study site––Our field site (Fig. 1) is a portion of the Huron River catchment in southeastern Michigan (United States Geological Survey, USGS Cataloging Unit 04090005). Four stations were established on the basis of an existing historical data set at weekly and sub-weekly intervals (Ferris and Lehman 2008). The station designated Control (CTL) corresponds to station 1 of Ferris and Lehman (2008). It is upstream from Ann Arbor and outside the jurisdiction affected by the city ordinance. Stations A and B correspond with Ferris and Lehman's stations 5 and 6. Station A represents about 29 km^2 of catchment attributable to Ann Arbor, and station B has about 94 km^2. A fourth station, designated F, is downstream at the site where the Huron River discharges into Ford Lake, a eutrophic impoundment. Station F is downstream from the outfall of the wastewater treatment facility that serves Ann Arbor (AAWWTP); stations A and B are upstream of the outfall. Water quality data at station F have been reported by Ferris and Lehman (2007), and include four years (2003 to 2006) prior to implementation of Ann Arbor's fertilizer ordinance.

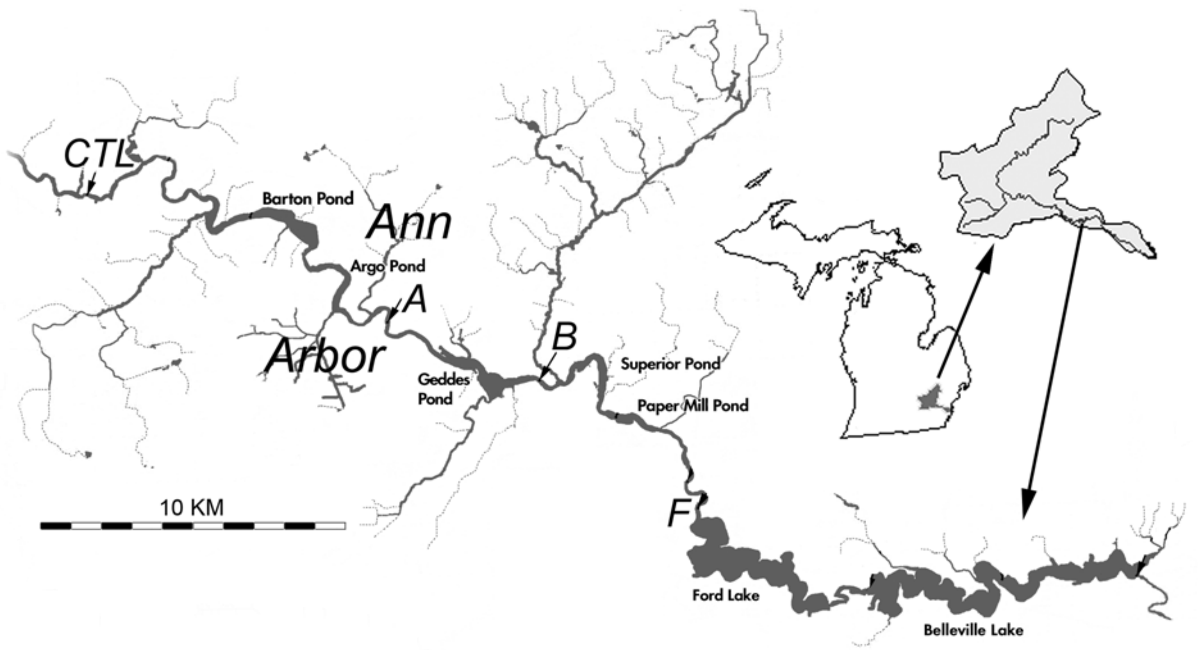

Figure 1. Study site, with sampling stations identified.

Field sampling––Water was collected at weekly intervals from May to Sep of 2008 and 2009. 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 soluble reactive phosphorus (SRP), dissolved phosphorus (DP), total phosphorus (TP), soluble reactive Si (SRSi), pH, and nitrate (NO_3). SRP was measured as molybdate-reactive phosphate in filtrate. DP and TP were measured as 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) demonstrated 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, three replicates were measured at each site; two replicates were measured for DP. 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 non-target or quasi-control 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 objective was to hold type I error reasonably low while seeking a credible level of power to detect environmental changes if they indeed occur. Our *a priori* expectation was that P concentrations would decrease, so we applied one-tailed tests to the P data. We had no *a priori* expectations regarding the non-target variables; therefore, two-tailed tests were applied and α was set at 0.1 in order to mimic the threshold probability applied to P variables.

SRP, DP, TP, NO_3, SRSi and CDOM were log-transformed prior to statistical comparison. K_{25} and pH were used in statistical tests without transformation. For ease of presentation we summarized the results in graphical form. For each month at each sampling site, the mean analyte concentrations from the reference period were regarded as benchmark values of 100 percent. Mean monthly concentrations measured in 2008 and 2009 were portrayed as percent of reference using vertical bar graphs with error bars indicating the 90 percent confidence interval for each mean. Confidence intervals were calculated with respect to the combined standard error of the reference and post-ordinance data sets:

$$SE_{joint} = [(var_{ref}(n_{ref} - 1) + var_{post}(n_{post} - 1))/(n_{ref} + n_{post} - 2) \bullet (1/n_{ref} + 1/n_{post})]^{1/2} \qquad (1)$$

where var_x and n_x represent the variances and sample sizes of the reference and post-ordinance data sets, respectively.

Significant reductions in P were recognized as cases where both the mean and its one-tailed confidence bar were less than 100 percent. Mean values for non-target variables were likewise portrayed as bar graphs, but the error bars represented two-tailed 90 percent confidence intervals. Significant differences from reference conditions were recognized as cases where the mean plus or minus the confidence interval differed from 100 percent.

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

Hydrology––Monthly mean fluvial discharge of the Huron River at Ann Arbor (USGS 04174500) over the 25 years from 1985 to 2009 was used to rank the years 2003 to 2006 (reference) and 2008 to 2009 (Table 1). Collectively, the reference period seems to have slightly lower flows than the post-ordinance period, but statistical significance is marginal (two-tailed t-test, $P = 0.052$).

Non-target variables–Numerous departures from reference conditions were observed for non-target variables (Figs 2 and 3), but in almost all cases the differences were present at the CTL station, upstream from the experimental area, and propagated downstream. The only exceptions were with respect to nitrate (Fig. 2): station A nitrate levels were significantly higher than reference in July and station F nitrate levels were significantly lower than reference in June, July, and September.

Table 1. Rank order of Huron River fluvial discharge by month in the 25-year period from 1985 to 2009. Lowest flow = 1; highest flow = 25.

Year	May	June	July	August	September
2003	9	9	2	1	6
2004	23	22	20	22	8
2005	3	3	8	5	4
2006	24	13	12	9	16
2008	4	16	23	3	25
2009	25	24	19	18	14

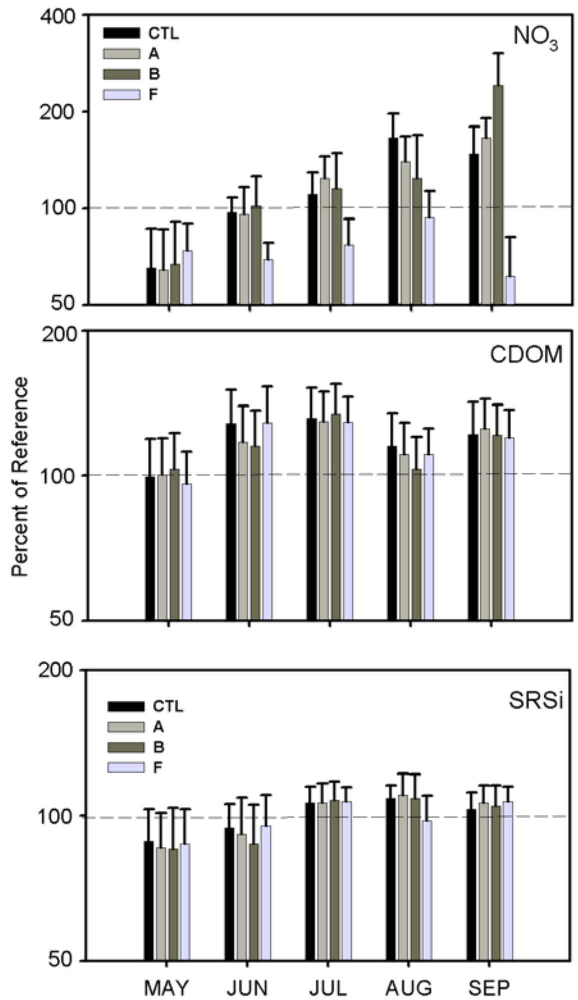

Figure 2. Concentration anomalies for nitrate, colored dissolved organic matter (CDOM), and SRSi from May to September of 2008 and 2009 expressed as percent of reference conditions at four sites. Error bars represent two-tailed 90% confidence intervals.

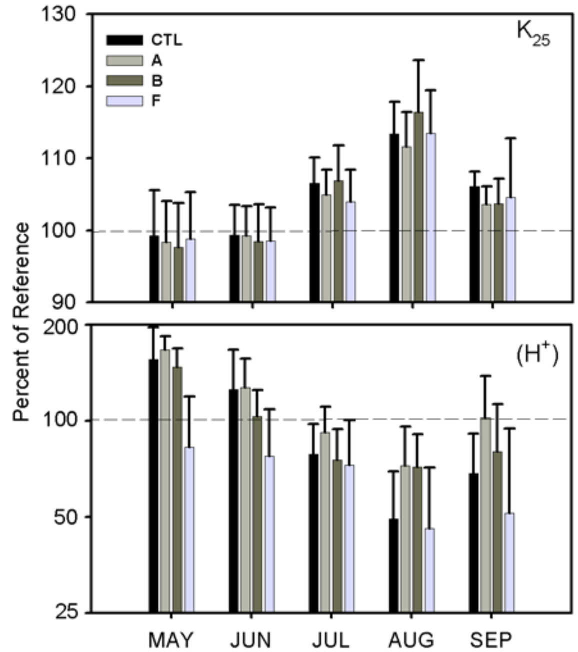

Figure 3. Anomalies for specific conductance (K_{25}) and hydrogen ion activity (H^+) in 2008 and 2009 compared to reference conditions. Error bars represent two-tailed 90% confidence intervals.

Phosphorus variables––Consistent with past sampling experience, SRP was more variable than DP or TP (Fig. 4) and there was no indication that concentrations were significantly lower than reference values at any site other than station F from July to September. In fact, it appears that SRP concentrations may have been somewhat elevated with respect to reference at the CTL site in some cases. For DP, concentrations were lower than reference from June to September at station F and from July to September at station B. TP concentrations were consistently below reference levels at station B as well as at station F from May to August notwithstanding some exceptional releases of P from the AAWWTP in May (Fig. 5). Mean concentrations of DP and TP at station A show a downward trend, but the results were not statistically significant in most cases. The mean reductions recorded at B and F from May to September were 17% at both sites.

Discussion––After two years of post-fertilizer ordinance data collection, concentrations of TP in the Huron River measured at stations B and F are 17% lower than pre-ordinance reference levels. The *a priori* prediction for full compliance with the ordinance had been 22% reduction (Ferris and Lehman 2008). DP levels were likewise reduced on average, by 14% at station B and by 20% at station F, but the changes achieved statistical significance at those sites only from July to September. Variability associated with SRP measurements is double that of DP and TP, with the consequence that no consistent pattern has emerged at the experimental sites. A summary of key findings from two years of investigation follows:

- Decreasing concentrations of TP were evident at all experimental sites (A, B and F) from May to Sep (Fig. 4). Reductions at station B, just upstream from the AAWWTP outfall, were consistently statistically significant. 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 at station B was 17%.

- For DP, a pattern of decreasing mean concentration at all experimental sites was also evident, although differences achieved statistical significance in only 8 cases out of 15 possible, mainly from July to September.

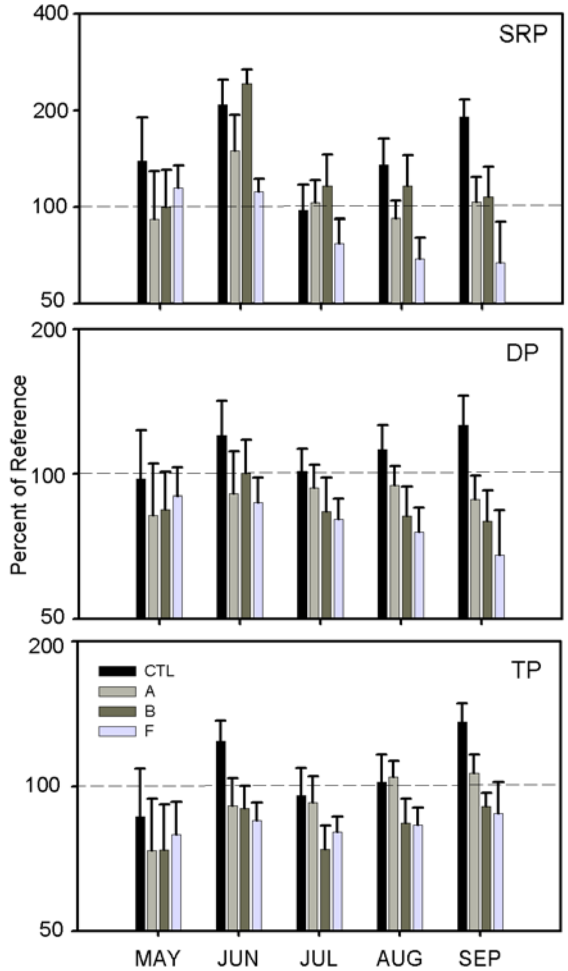

Figure 4. Concentration anomalies of SRP, DP, and TP at control and experimental sites in 2008 and 2009 expressed as percent of reference values. Error bars represent one-tailed 90% confidence intervals of the means.

- Absence of any systematic trend in point source discharge of TP (Fig. 5) suggests that the detectable effects trace to non-point source loading.
- The upstream site CTL appeared to function well as a control site, in that no reductions in SRP, DP or TP were detected there.
- The non-target variables showed no evidence of the station-specific response seen for phosphorus variables. Consistent changes in nutrient concentrations only within the experimental unit were confined to P. Departures from historical conditions, when they occurred, generally appeared to originate upstream of the experimental unit, thus affecting the control site and propagating downstream. An exception seems to be nitrate at station F. The AAWWTP is known to be a significant nitrate source to the river, but

nitrate discharge is not one of the variables measured by facility staff, so we cannot compare pre- and post-ordinance loading as for TP (Fig. 5).

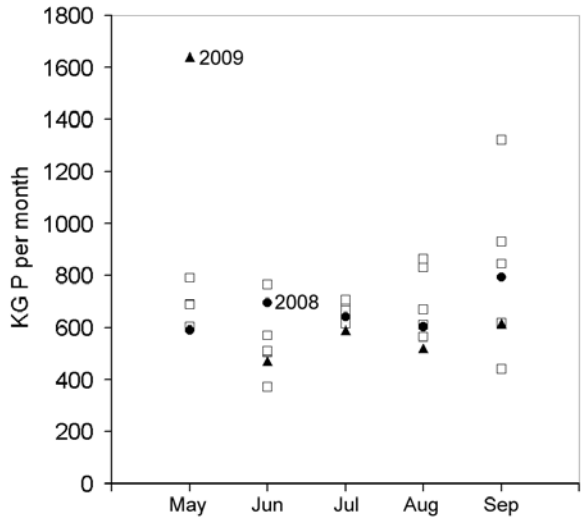

Figure 5. Monthly discharge of TP from the Ann Arbor wastewater treatment facility. □ = 2003 to 2007.

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