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Reduced River Phosphorus Following Implementation of a Lawn Fertilizer Ordinance

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Abstract––Statistical comparisons of 2008 surface water quality data with a historical data set at weekly and sub-weekly resolution has 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. Non-target 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 ca. 25% in monthly mean value were predicted to require weekly samples during the summer for only 1 or 2 years for TP, and statistically significant reductions measured after 1 year averaged 28%, or about 5 kg P per day. The lawn fertilizer ordinance was only one component of broader efforts to reduce non-point source loading of P, however, so the magnitude of its role in the measured changes remains uncertain.

Growing numbers of municipalities and state governments have adopted or are considering the adoption of restrictions on the residential use of P-containing fertilizers. The actions are based on awareness that 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 (NJ 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, there has unfortunately been little evidence yet 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 prohibits use of phosphorus lawn fertilizer except in prescribed instances. The prohibition went into effect in 2004 in the Twin Cities metropolitan area and statewide in 2005. 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 data sets. Vlach et al. (2008) report reductions in phosphorus 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, based on analysis of more than 500 data points. The study involved pair-wise comparisons of six sub-watersheds in the municipalities of Plymouth and Maple Grove, MN. The sites differed in their regimens of fertilizer use, with the Plymouth sites using only phosphorus free fertilizer, and Maple Grove sites serving as controls, using P-containing fertilizer. Concentrations of total P in runoff were virtually identical between the two 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 TMDL (Total Maximum Daily Load) that called for a 50% reduction in phosphorus discharges to the Huron River, the city of Ann Arbor in southeast Michigan enacted an ordinance that went into effect in 2007 (Ann Arbor 2006) to limit phosphorus application to lawns. Compliance with the lawn fertilizer ordinance depends on point-of-sale restrictions and monitored compliance by lawn care services. The estimated effect of full compliance was a 22% reduction in phosphorus 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 one or two years of 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. This paper reports the test of the *a priori* predictions after one year.

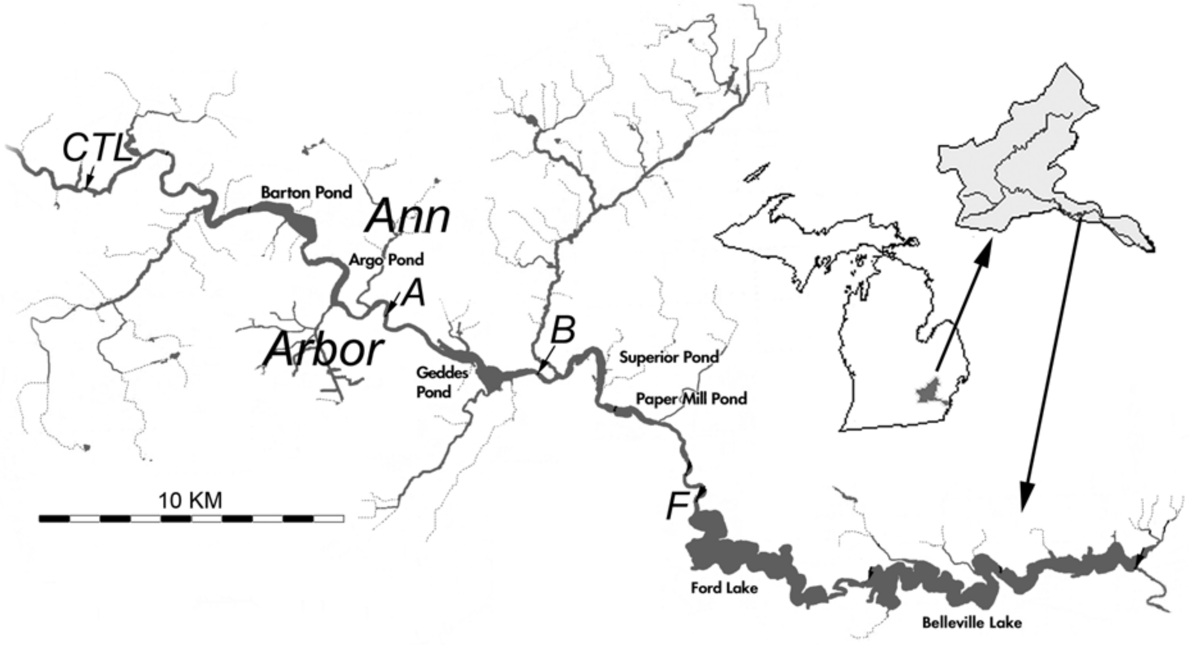

Figure 1. Study site, with sampling stations identified.

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 sub-weekly 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 km^2 of catchment attributable to Ann Arbor, and station B has about 94 km^2. A fourth station, designated 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 four years (2003 to 2006) prior to implementation of Ann Arbor's fertilizer ordinance.

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

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

Field sampling––Water was collected at weekly intervals from May to Sep 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 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) 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, three replicates were measured at each site. For DP, two 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 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 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. We had no *a priori* expectations regarding the non-target variables, and so we applied two-tailed tests to them and set $\alpha = 0.1$ 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 Based on previous work we expected values from the different sampling stations to differ and that there would be significant differences in mean monthly concentrations. In order 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 three factors proved statistically significant ($P< 0.02$ for both SRP and DP, and $P< 0.0001$ for TP). We subsequently explored the data with attention to detailed response by station, particularly control vs 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).

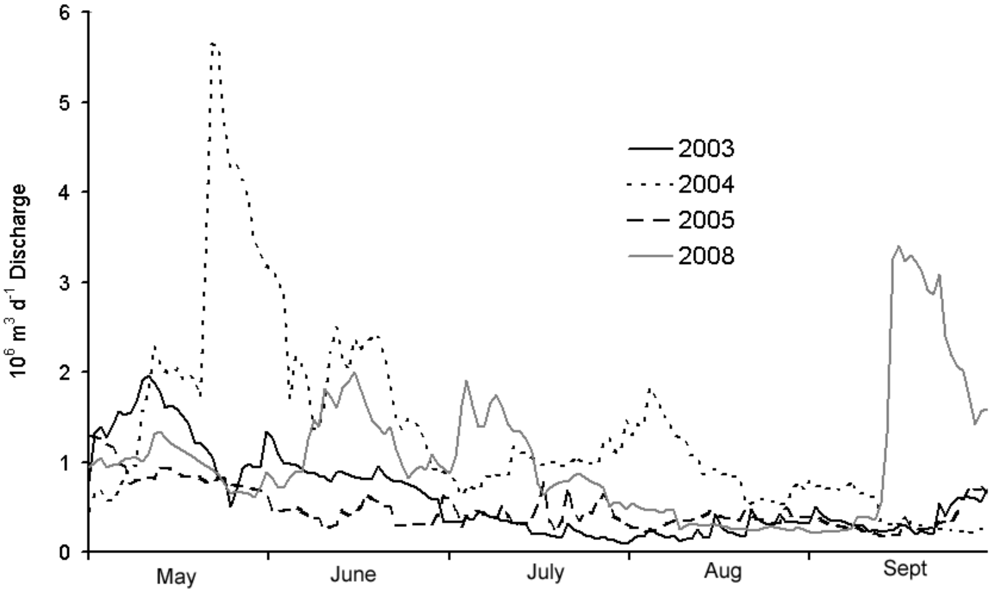

Figure 2. Fluvial discharge of the Huron River at Ann Arbor (USGS 04174500) from May to September for three reference years (2003 to 2005) and the post-ordinance test year 2008.

Non-target 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 ($P = 0.49$).

CDOM, on the other hand, 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 Jul and Aug, 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 Sep in 2008 were significantly lower than reference values at any site other than station F in Aug. For DP, there was a trend of decreasing mean concentrations at the experimental stations, particularly stations B and F (Fig. 3). TP concentrations, however, 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 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 five 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 one 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 Sep (Fig. 3). Moreover, there is a trend of reduced (mean) TP concentrations 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%.
- For DP, reductions in concentration were rarely significant at 90% confidence level at the experimental sites (Fig. 3), although there is a trend of reduced monthly mean concentrations 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, are 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 non-point source loading.

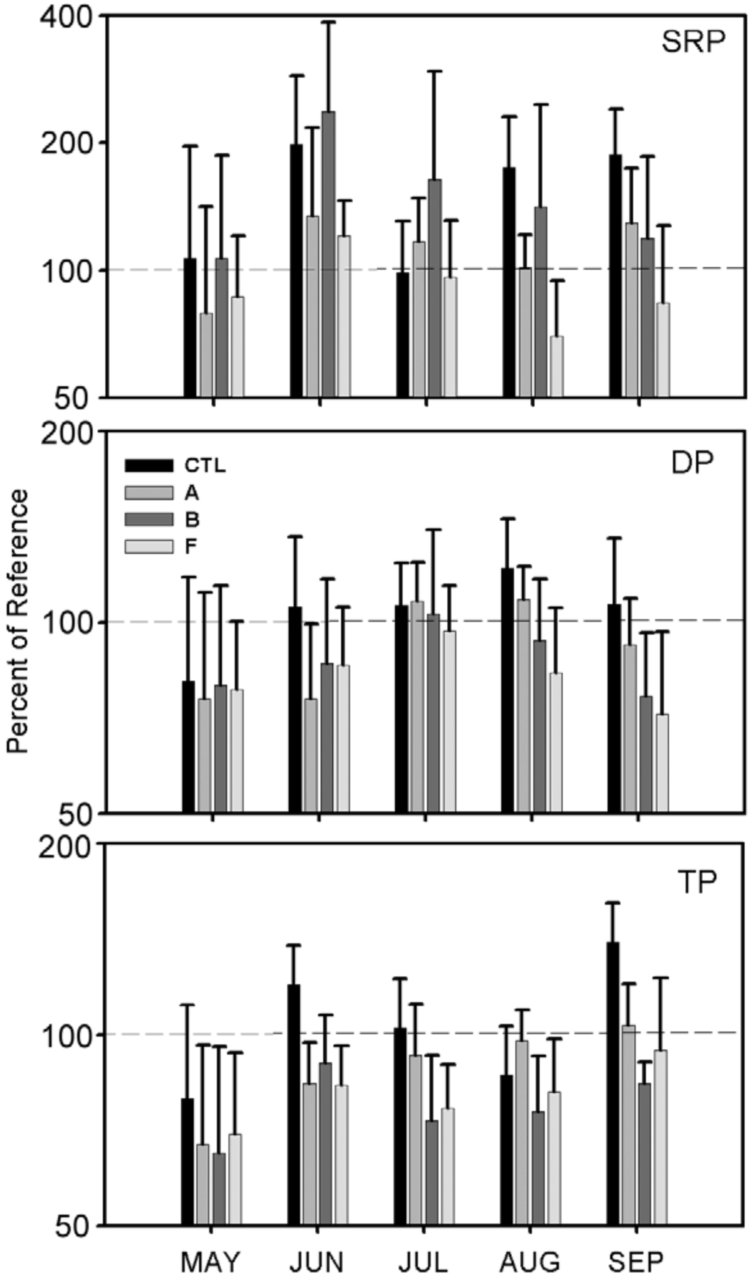

Figure 3. Concentration anomalies of SRP, DP, and TP at control and experimental sites in 2008 expressed as percent of reference values. Error bars represent upper 90% confidence intervals of the means.

- The upstream site CTL appeared to function well as a control site, in that no reductions in SRP, DP or TP were noted there.
- The non-target 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 to 2005 (data from Ferris and Lehman 2008), the magnitude of the load reduction is about 5 kg P per day.

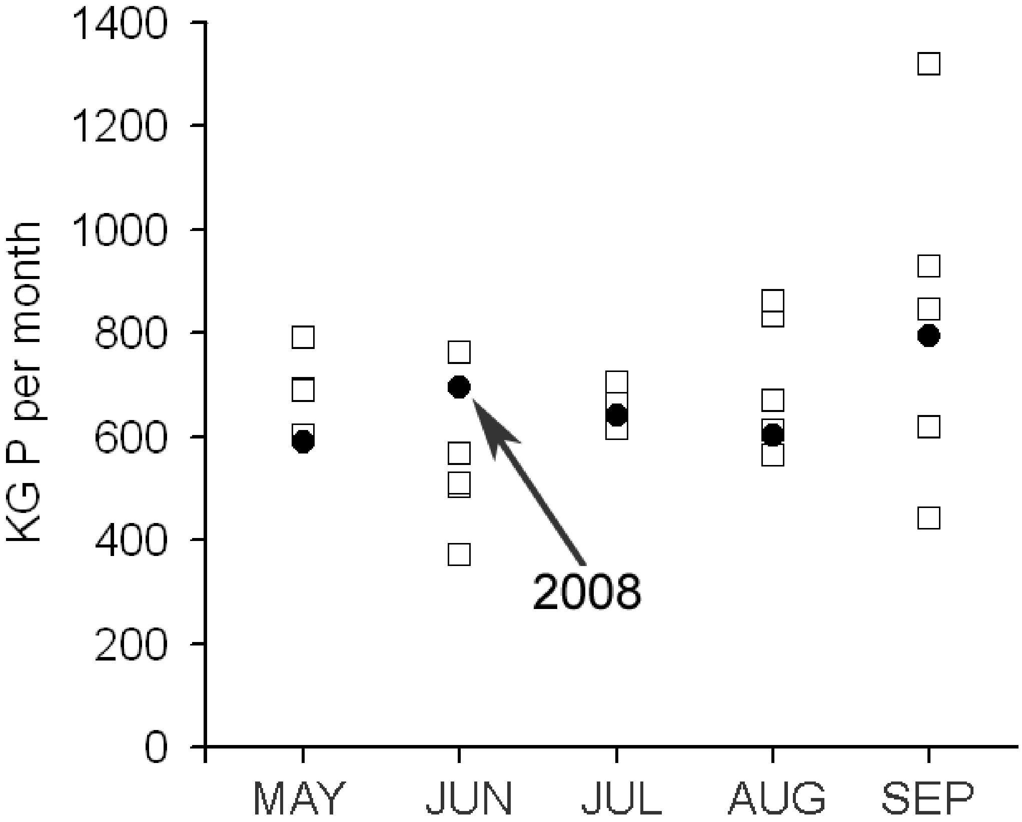

Figure 3. Monthly discharge of TP from the Ann Arbor wastewater treatment facility from 2003 to 2008. □ = 2003 to 2007; • = 2008.

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 Sep. Percentage reductions are of the magnitude that was predicted to be detectable at the applied level of sampling effort. We can state objectively within the context of our statistical model that phosphorus concentrations were lower in 2008 compared with the reference period (2003 to 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 two are highly correlated and traceable to non-point 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, nor 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 indeed 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.

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