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DISCUSSION[1]

"Nutrient Inputs to the Laurentian Great Lakes by Source and Watershed Estimated Using SPARROW Watershed Models" by Dale M. Robertson and David A. Saad[2]

R. Peter Richards, Ibrahim Alameddine, J. David Allan, David B. Baker, Nathan S. Bosch, Remegio Confesor, Joseph V. DePinto, David M. Dolan, Jeffrey M. Reutter, and Donald Scavia[3]

ABSTRACT: Results from the Upper Midwest Major River Basin (MRB3) SPARROW model and underlying Fluxmaster load estimates were compared with detailed data available in the Lake Erie and Ohio River watersheds. Fluxmaster and SPARROW estimates of tributary loads tend to be biased low for total phosphorus and high for total nitrogen. These and other limitations of the application led to an overestimation of the relative contribution of point sources *vs.* nonpoint sources of phosphorus to eutrophication conditions in Lake Erie, when compared with direct estimates for data-rich Ohio tributaries. These limitations include the use of a decade-old reference point (2002), lack of modeling of dissolved phosphorus, lack of inclusion of inputs from the Canadian Lake Erie watersheds and from Lake Huron, and the choice to summarize results for the entire United States Lake Erie watershed, as opposed to the key Western and Central Basin watersheds that drive Lake Erie's eutrophication processes. Although the MRB3 SPARROW model helps to meet a critical need by modeling unmonitored watersheds and ranking rivers by their estimated relative contributions, we recommend caution in use of the MRB3 SPARRROW model for Lake Erie management, and argue that the management of agricultural nonpoint sources should continue to be the primary focus for the Western and Central Basins of Lake Erie.

(KEY TERMS: water quality; agriculture; modeling; nonpoint-source pollution; point-source pollution; nutrients; watershed management; monitoring.)

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INTRODUCTION

The Spatially Referenced Regressions on Watersheds (SPARROW) model for Upper Midwest Major River Basin (MRB3) (Robertson and Saad, 2011a), which includes the Great Lakes, is a major work that reports the application of the SPARROW model to a large body of GIS-based and other sets of data on water quality, land use, and land attributes. The

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greatest promise of the SPARROW model lies in its ability to estimate constituent loadings (in this case, total phosphorus [TP] and total nitrogen [TN]) for places where there are no water-quality data, including unmonitored watersheds and portions of watersheds upstream or downstream of monitoring locations. As such, it is potentially a powerful tool for large-scale land use planning and land management in the absence of detailed monitoring information. We are fortunate in the Lake Erie watershed, in that, because of longstanding concerns over eutrophication, highly detailed monitoring has been underway on the major tributaries for more than 30 years (Baker, 1982; Richards and Baker, 2002; Richards, 2007; Jarvie *et al.*, 2011), along with well-established approaches for combining these observations with point-source inventories and other sources of information to arrive at whole-lake loads and loads to each Lake Erie subbasin (IJC, 1978; Dolan and McGunagle, 2005). Because phosphorus is the nutrient of choice to limit the productivity of Lake Erie (Vallentyne, 1974; Schindler, 1977; IJC, 1978), particular attention has been paid to tracking phosphorus loads. Similarly, detailed monitoring results are also available for some major Ohio tributaries to the Ohio River, which are also included in MRB3. This extensive and data-rich history offers an excellent opportunity for an independent evaluation of the SPARROW results.

Previous work, based on these extensive data sets, has demonstrated that nonpoint sources of nutrient loading came to dominate total loading to Lake Erie by the early 1980s (e.g., Baker and Richards, 2002; Dolan and McGunagle, 2005; Dolan and Richards, 2007; IJC, 1987; Richards and Baker, 1993), and that agricultural sources now dominate nonpoint loads to the Western and Central Basins (Richards, 2007). This assessment is based primarily on land use, which for the Western Basin (Maumee, Portage, Ottawa, and Raisin watersheds) in 2001 was 76% agricultural, 12% urban, 7% forest, and 4% other land uses (computed from 2001 National Land Cover Database [http://www.mrlc.gov] layer by Confesor in 2012). A similar conclusion was reached by the Ohio Lake Erie Phosphorus Taskforce, and recent management efforts have been focused on reducing phosphorus export from agricultural lands (OLEPTF, 2010).

Contrary to these assessments, Robertson and Saad's (2011a) SPARROW results indicate that, for the entire United States (U.S.) Lake Erie basin (US-LEB), point-source loads are roughly equal in magnitude to agricultural loads. We suggest that this finding is misleading and, taken out of context, could be inappropriately applied to weaken efforts to reduce agricultural loadings and to attribute too much responsibility for Lake Erie's eutrophication problems to urban sources and sewage treatment plants. We also find that the tributary loads used in the SPARROW model and computed from our data differ systematically from our calculations using the same data: Robertson and Saad's TP loads are generally smaller and their TN loads are generally larger.

The purpose of this commentary is twofold. First, we offer detailed comparisons between our findings and the SPARROW findings to show where biases appear to exist in the SPARROW results. Second, we consider the SPARROW results in the context of Lake Erie, its water-quality issues, and management efforts to address those issues. Given the intense interest generated by recent extensive harmful algal blooms and the resurgence of large regions of low oxygen in the Central Basin, it is imperative that the scientific perspective be clearly and accurately communicated to the management community and the general public.

SPARROW is a general model (Schwarz *et al.*, 2006) that can be and has been implemented in different geographic areas and for different parameters. In what follows, our discussion applies specifically to the implementation of SPARROW for the Upper Midwest (Great Lakes and Upper Mississippi, Ohio, and Red River basins [MRB3]) reported by Robertson and Saad (2011a), and should not be construed to apply to the SPARROW modeling platform in general.

After a brief description of our methods, we compare our load estimates for several rivers with loads reported by Robertson and Saad (2011a), or with loads computed using their methodology. We consider TP first, then TN. Within each section, we assess loads from point sources and nonpoint sources separately. Finally, we discuss Robertson and Saad's SPARROW results in the broader context of the ecological issues confronting Lake Erie managers.

METHODS

The National Center for Water Quality Research (NCWQR) at Heidelberg University operates refrigerated automatic samplers at or near USGS gaging stations at a number of locations in Ohio and Michigan. Three samples per day are collected year-round. During periods of storm runoff or high turbidity, all samples are analyzed for suspended solids; nutrients including total and dissolved reactive phosphorus and nitrate, nitrite, and total Kjeldahl nitrogen; and major ions. Analytical methodology closely parallels standard EPA methods. TN is calculated as the sum of nitrate, nitrite, and total Kjeldahl nitrogen. For station locations and more detailed methods descriptions, see Richards and Baker (2002). Typically, 400-500 samples are analyzed per year at each station. Data are available at http://www.heidelberg.edu/academiclife/distinctive/ncwqr/data.

For tributary load calculations, daily flow-weighted average concentrations are computed for days with more than one sample. Daily loads are computed as the product of concentrations, mean daily discharge from USGS, and time (1 day), and the factor 0.002447 for converting units from mg/L * ft^3/s * day to megagrams (Mg) or metric tons. Annual loads are computed on a water year basis (October 1 to September 30) using the stratified Beale Ratio Estimator (Beale, 1962; Tin, 1965; Richards, 1998) to estimate daily loads for days without samples. Since most days are represented by samples, the loads computed in this way are generally very similar to the simple sums of the daily loads. Annual loads (for periods of record through 2006 ranging from 10 to 31 years) were adjusted to 2002 conditions by detrending the data to 2002 levels.

Whole lake loads from all sources, and loads to each of the lake's three major basins, are derived by combining tributary nonpoint-source loads, with adjustments for unmonitored areas; point-source loads; and estimates of direct atmospheric deposition onto the lake and inputs from Lake Huron. The approach has been in use by the International Joint Commission for more than 30 years. The methodology is described in Dolan and McGunagle (2005).

Fluxmaster (Schwarz *et al.*, 2006), the load estimation program used to provide tributary loads for input to SPARROW, uses a regression approach that predicts concentrations as a function of flow, time, and season. The regression model, as used in the work of Robertson and Saad (2011a), is (Dale M. Robertson, USGS, 2008, personal communication):

$$\begin{aligned}\ln(c) = b_1 * \ln(q) + b_2 * \mathrm{dy} + b_3 * \sin(2 * \pi * \mathrm{dy}) \\ + b_4 * \cos(2 * \pi * \mathrm{dy}) + b_5 + \varepsilon,\end{aligned} \tag{1}$$

where c is the daily concentration, q is the daily mean flow, dy is the decimal year, b_1 to b_5 are regression coefficients, and ε is a normally distributed error term with mean of 0 and variance of σ^2, where σ is the standard error of the model. Additional terms, including $\ln(q)^2$, dy^2, and sine and cosine terms of $4*\pi*\mathrm{dy}$ or $6*\pi*\mathrm{dy}$ are sometimes used to improve the model fit to the data, but were not used by Robertson and Saad (2011a).

Predicted daily concentrations, adjusted to 2002 (see Robertson and Saad, 2011a), are back-transformed, and retransformation bias is corrected using the parametric correction factor (half the variance of the residuals), or the nonparametric smearing estimate. Predicted concentrations are converted into daily loads by multiplying by the mean daily flow and the units conversion factor. For this comparison, it is important to note that the observations used to establish the regression model are replaced by model predictions, and are not used in the calculation of the loads.

RESULTS AND COMPARISONS

Total Phosphorus Loads

Robertson and Saad (2011a) estimate a total U.S. load to Lake Erie (excluding loads from the atmosphere and from Lake Huron) for 2002 of 4,610 metric tons or Mg of TP, of which 1,941 Mg are from point sources, and 2,669 Mg are from all nonpoint sources. Dolan and McGunagle (2005) estimated a total load (the U.S. and Canada, including loads from Lake Huron and the atmosphere) for 2002 of 9,733 Mg: 1,992 from point sources, 5,967 from nonpoint sources, 694 Mg from atmospheric deposition, and 1,080 Mg from Lake Huron via the connecting channel. Robertson and Saad's (2011a) load estimate is therefore only 47% of Dolan and McGunagle's whole-lake estimate, with the majority of the difference entering the ecologically vulnerable Western Basin. However, even without the Canadian and Lake Huron inputs and atmospheric contributions, Dolan and McGunagle's estimate would be 6,730 Mg: 1,785 from point sources and 4,945 from nonpoint sources. These figures are, respectively, 146, 92, and 185% of Robertson and Saad's SPARROW estimates. It is important to note that Robertson and Saad's estimates are not loads for 2002 *per se*, but rather are longer-term average loads "normalized" to 2002 conditions. This is discussed further in the section below on nonpoint load estimates.

Tributary Load Estimates. Robertson and Saad (2011b), in their supporting documents, provide tributary load estimates for their reference year 2002 (table S2_TP), as annual average loads computed by Fluxmaster and normalized to 2002, and as estimated by SPARROW. Eight of the tributaries reported in these tables have been intensively monitored by the NCWQR for between 11 and 35 years, with 300 to >500 samples per year per station. Five of these are in the Lake Erie watershed; the other three flow into the Ohio River. Robertson and Saad (2011a) used the NCWQR data in their load calculations, and possibly some other data as well.

Because of the completeness and detail of the NCWQR data, one would expect very good agreement between loads calculated by NCWQR and those calculated by Robertson and Saad, even though different approaches to load calculation are used. However, the Fluxmaster TP loads are in most cases low compared with the NCWQR loads (Table 1). Generally, the TP SPARROW loads for these rivers are even lower than the Fluxmaster loads. This is particularly true for the Raisin, Maumee, Sandusky, and Great Miami rivers.

To try to place the load estimates on the most equivalent basis possible, we calculated *daily* loads for these rivers over their period of record using three methods:

1. Direct calculation of daily loads using observed daily concentrations and flows. We take these to be the true values of the daily loads – the values that Fluxmaster should be reproducing.
2. Use of the same five-parameter regression model as was used with Fluxmaster, with bias correction using the parametric correction factor (half the variance of the residuals), and conversion into daily loads by multiplying by the mean daily flow.
3. Same regression-based approach but using the smearing estimate of Duan (1983) for bias correction.

These calculations were made using the actual dates of the samples – that is, they were not detrended.

Results for TP are summarized in Table 2. Because some daily observations were missing, the results are given in terms of daily loads, not annual loads, and only days with observations were used in calculating the summary statistics. In general, the Fluxmaster calculations using the two different bias correction approaches are similar and tend to underestimate the mean load, the standard deviation, and the upper percentiles, whereas overestimating the median and the interquartile range. Results for the Sandusky are comparable for all three methods.

Figure 1 displays the flow and TP concentration data used for the Maumee and the Great Miami calculations. In each plot, the straight line represents the linear relationship assumed by Fluxmaster, and the curved line is a LOWESS fit (20% bin width) that more accurately characterizes the trend. Figures 1A and 1B display the natural logarithm of concentration (henceforth ln *C*) plotted against the natural logarithm of flow (henceforth ln *Q*), and do not represent the complete Fluxmaster model, which also includes temporal and seasonal factors. Figures 1C and 1D plot ln *C* after it has been adjusted for these factors by taking the residuals of a regression of ln *C* against these factors and adding them to the mean of ln *C*. It is evident that adjusting for the additional variables does not materially change the flow/concentration relationship.

By inspection (Figure 1), the Fluxmaster model, as used by Robertson and Saad, underestimates concentrations at high and low flows, and overestimates them in a relatively narrow range at intermediate flows. Errors in estimation under low-flow conditions do not affect overall load estimates very much, but systematic errors in estimation under high-flow conditions have a large impact on loads, resulting in the low bias shown in Table 2. At least some of this bias could have been eliminated by including higher order terms, especially ln Q^2, in the model.

In contrast, the relationship between ln *C* and ln *Q* for the Sandusky River is linear, and for this river, the Fluxmaster loads are very similar to those calculated from the data by Method 1. The relationship for the Muskingum River deviates only slightly from linearity, and the agreement between the loads is better than for most of the other rivers.

The relationship for the Scioto River is highly nonlinear, although not as much as that for the Great Miami River. However, there is essentially no first-order relationship between ln *C* and ln *Q* – the regression explains only 0.2% of the total variance.

TABLE 1. USGS and NCWQR TP Loads for Intensively Sampled Lake Erie Tributaries, Referenced to 2002.

River	USGS Station Number	Period of Record Through 2006 (years)	Fluxmaster Load Adjusted to 2002 (Mg)	SPARROW Load (Mg)	NCWQR Load Adjusted to 2002 (Mg)	Fluxmaster as % of NCWQR	SPARROW as % of NCWQR
River Raisin	04176500	25	111	96.5	134	82.8	72.0
Maumee River	04193500	29	1,482	1,107	2,093	70.8	52.9
Sandusky River	04198000	31	360	234	420	85.7	55.7
Cuyahoga River	04208000	25	186	182	265	70.2	68.7
Grand River	04212100	17	91	101	128	71.1	78.9
Great Miami River	03271601	10	925	759	1,077	85.9	70.5
Scioto River	03231500	10	1,097	979	1,192	92.0	82.1
Muskingum River	03150000	12	1,342	1,429	1,347	99.6	106.1
Total	-	-	5,594	4,888	6,656	82.4	75.0

Note: USGS results from Robertson and Saad (2011b, table S2_TP).

TABLE 2. Comparison of Daily TP Loads Computed Directly from the Data and Using the Regression Model of Fluxmaster.

River	Method	*n*	Mean (Mg)	Mean as % of Direct Calculation	Median (Mg)	SD	Interquartile Range	10th Percentile	90th Percentile
Raisin	Direct	8,972	0.372	(100)[1]	0.099	0.944	0.205	0.026	0.912
	Parametric	8,972	0.330	88.7	0.119	0.650	0.255	0.031	0.803
	Smearing	8,972	0.334	89.8	0.121	0.659	0.258	0.031	0.814
Maumee	Direct	10,296	5.954	(100)	0.971	16.89	3.356	0.151	15.24
	Parametric	10,296	5.056	84.9	1.184	11.38	3.932	0.152	13.53
	Smearing	10,296	5.083	85.4	1.190	11.44	3.953	0.153	13.61
Sandusky	Direct	10,272	1.302	(100)	0.102	4.134	0.491	0.010	3.065
	Parametric	10,272	1.305	100	0.130	4.337	0.523	0.010	2.904
	Smearing	10,272	1.309	101	0.131	4.351	0.523	0.011	2.913
Cuyahoga	Direct	9,906	0.755	(100)	0.272	1.937	0.445	0.097	1.509
	Parametric	9,906	0.653	86.5	0.328	1.008	0.531	0.115	1.488
	Smearing	9,906	0.664	87.9	0.333	1.026	0.540	0.117	1.513
Grand	Direct	5,601	0.417	(100)	0.050	2.169	0.221	0.004	0.901
	Parametric	5,601	0.284	68.1	0.076	0.583	0.273	0.004	0.759
	Smearing	5,601	0.296	71.0	0.079	0.607	0.285	0.004	0.791
G. Miami	Direct	5,220	3.244	(100)	1.119	6.389	1.508	0.637	7.795
	Parametric	5,220	2.785	85.9	1.399	3.780	2.084	0.601	6.555
	Smearing	5,220	2.796	86.2	1.404	3.795	2.093	0.603	6.581
Scioto	Direct	3,419	3.397	(100)	1.285	5.539	2.450	0.516	9.044
	Parametric	3,419	3.160	93.0	1.529	4.052	2.761	0.522	8.507
	Smearing	3,419	3.169	93.3	1.534	4.065	2.770	0.523	8.533
Muskingum	Direct	4,705	3.772	(100)	1.539	6.373	3.148	0.433	9.592
	Parametric	4,705	3.425	90.8	1.847	3.915	3.642	0.461	9.237
	Smearing	4,705	3.432	91.0	1.850	3.923	3.650	0.462	9.257

[1] In cells with percentages enclosed by parentheses, the mean load is being compared with itself, so the result is trivially 100%.

Consequently, the loads predicted from the regression differ only slightly from loads estimated by multiplying the daily flow by the overall average concentration. Indeed, the Pearson correlation between Fluxmaster loads and those obtained using the average concentration is 0.99.

In Figure 2, the natural logarithm of the TP concentrations predicted by Fluxmaster for the Great Miami River is plotted as a function of the natural logarithm of the observed TP concentrations. There is a highly significant statistical relationship between the two, but it only explains 25% of the variance. Even after adjustment for the other explanatory variables, the explained variance improves only marginally (<1%), indicating a rather weak predictive relationship, which results from failure to appropriately characterize the relationship between concentration and flow.

The data for these rivers show that the relationship between TP concentrations and flow tends to be nonlinear in log-scale and concave up. As a consequence, the Fluxmaster loads for such rivers tend to be biased low. To the extent that the concave shape is characteristic of TP elsewhere in MRB3, Fluxmaster loads for other rivers are likely to be biased low as well. SPARROW estimates tend to be even lower than the Fluxmaster estimates, although the reasons for this remain unknown.

Point-Source Load Estimates. Robertson and Saad's (2011a) 2002 point-source load is similar to that reported by Dolan and McGunagle (2005). Close agreement would be expected because both studies used the same sources of information to derive their load estimates, although the estimates developed for SPARROW used "typical pollutant concentrations" (Maupin and Ivahnenko, 2011) in some cases rather than actual reported concentrations, and Dolan and McGunagle used only reported concentrations. The discrepancy between the two point-source load estimates appears to be due to the fact that the MRB3 SPARROW model adjusts the computed point-source loads by a factor of 1.068.

Distribution Among Agricultural Nonpoint Sources. The SPARROW model estimates yields from agricultural sources in terms of the percent of a particular component (fertilizer and manure from confined or unconfined animals) delivered to the watershed outlet, and as such it includes a number of factors that field-scale source accounting does not. This hampers direct comparison with other estimates of agricultural sources. Nonetheless, the SPARROW results for the Maumee indicate that 58.2% of the agricultural load comes from fertilizers and 41.8% from manure. Estimates of field-scale phosphorus inputs (Richards *et al.*, 2002; OLEPTF, 2010) indicate that

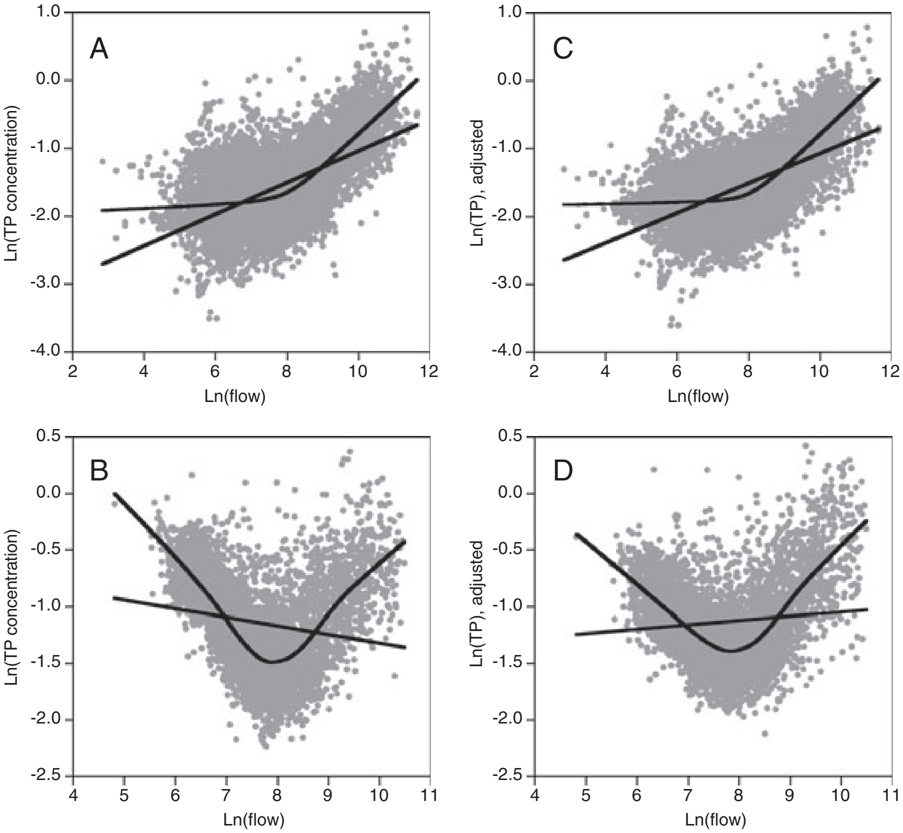

FIGURE 1. Natural Log of Total Phosphorus (TP) Concentration as a Function of the Natural Log of Flow, Maumee River (top) and Great Miami River (bottom). Left graphs are based on the natural logs of concentrations and flows. Right graphs have concentrations adjusted for the other Fluxmaster variables (see text for details). The straight lines indicate the relationship assumed by the Fluxmaster regression model as used by Robertson and Saad (2011a); the curved lines are LOWESS fits that more adequately capture the structure of the data.

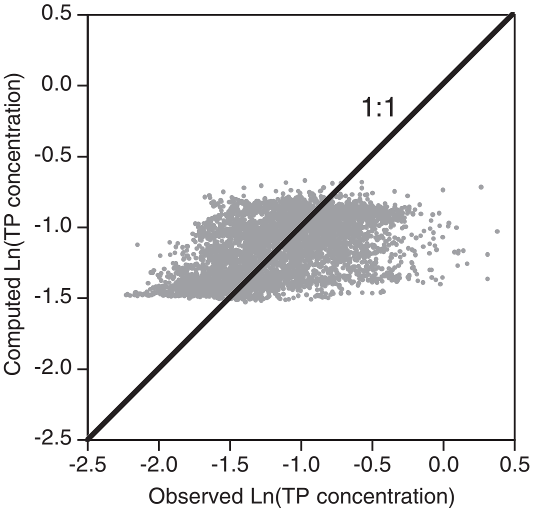

FIGURE 2. Observed Daily Total Phosphorus Concentrations in the Great Miami River and Those Computed Using the Five-Parameter Model Assumed by Robertson and Saad (2011a), Plotted After Log-Transformation. The 1:1 line represents the expected relationship for a perfect model.

fertilizer represents 71-74% of the applied nutrients, and manure accounts for 26-29%. NRCS (2009) found that manure produced within the Maumee watershed can only supply one-sixth of the phosphorus removed with crops, based on typical yields (8 lb/acre applied as manure, 48 lb/acre removed with crop harvest). The difference between these field-scale results and the SPARROW results must be attributed to the differential delivery of phosphorus from manure from confined animals (9%) and phosphorus from fertilizer (3%). However, in order to rectify these results, the delivery of phosphorus from all manure (not just that from confined animals) must be nearly four times as large as the delivery of phosphorus from commercial fertilizer for these results to agree with the results reported in Richards *et al.* (2002). The delivery would have to be nearly seven times as great when compared with the NRCS figures. These comparisons suggest that the SPARROW distribution of the agricultural load is probably incorrect. In the Lake Erie watersheds, the contribution of commercial fertilizers is more important, and the contribution of manure less important, than what the SPARROW results indicate.

Total Nitrogen

The approach described above for TP was also used to compare TN loads computed by direct calculation and by the Fluxmaster regression model. Results for TN are summarized in Tables 3 and 4. In general, the Fluxmaster calculations using the two different bias correction approaches give very similar results. For the agricultural Lake Erie tributaries Raisin, Maumee, and Sandusky, the regression approach tends to overestimate the mean load, the standard deviation, and the upper and lower 10th percentile values. For the Cuyahoga and Grand rivers, the regression approach underestimates the mean and standard deviation, though the results are not greatly different. For the Great Miami, Scioto, and Muskingum, all results are comparable. SPARROW loads often (but not always) deviate by a greater amount than Fluxmaster loads from loads by direct calculation.

For the agricultural tributaries, the Fluxmaster model overestimates concentrations at high and low flows, and underestimates them in a relatively narrow range at intermediate flows (i.e., the relationship is concave down). For the Grand and Cuyahoga rivers, the reverse is true; they show the same kind of concave-up relationship as Figure 1. When the relationship between $\ln C$ and $\ln Q$ is concave upward, the regression model of Fluxmaster generally

TABLE 3. USGS and NCWQR TN Loads for Intensively Sampled Lake Erie Tributaries, Referenced to 2002.

River	USGS Station Number	Fluxmaster Load Adjusted to 2002 (Mg)	SPARROW Load (Mg)	NCWQR Load Adjusted to 2002 (Mg)	Fluxmaster as % of NCWQR	SPARROW as % of NCWQR
River Raisin	04176500	5,210	5,018	4,084	127.6	122.9
Maumee River	04193500	52,272	67,826	38,418	136.1	176.6
Sandusky River	04198000	14,119	13,977	7,490	188.5	186.6
Cuyahoga River	04208000	2,372	2,366	2,507	94.6	94.4
Grand River	04212100	1,220	1,860	1,289	94.6	144.3
Great Miami River	03271601	16,861	16,404	15,415	109.4	106.4
Scioto River	03231500	20,089	28,576	18,526	108.4	154.3
Muskingum River	03150000	19,796	18,203	18,369	107.8	99.1
Total	-	131,939	154,230	106,098	124.4	145.4

Note: USGS results from Robertson and Saad (2011b).

TABLE 4. Comparison of Daily TN Loads Computed Directly from the Data and Using the Regression Model of Fluxmaster.

River	Method	*n*	Mean (Mg)	Mean as % of Direct Calculation	Median (Mg)	SD	Interquartile Range	10th Percentile	90th Percentile
Raisin	Direct	9,067	11.4	(100)[1]	3.93	18.6	11.5	0.51	32.3
	Parametric	9,067	13.0	114	3.93	28.0	10.8	0.63	33.4
	Smearing	9,067	13.0	114	3.95	28.1	10.8	0.63	33.5
Maumee	Direct	9,372	109	(100)	31.4	197	105	1.8	317
	Parametric	9,372	136	125	31.1	308	107	2.7	370
	Smearing	9,372	136	125	31.1	308	107	2.7	371
Sandusky	Direct	8,575	22.4	(100)	4.95	47.1	17.8	0.14	63.5
	Parametric	8,575	34.4	153	4.71	99.3	17.8	0.25	83.4
	Smearing	8,575	34.5	154	4.72	99.5	17.8	0.25	83.6
Cuyahoga	Direct	9,872	7.01	(100)	4.82	7.79	4.19	2.64	12.6
	Parametric	9,872	6.73	96	5.19	4.94	4.86	2.68	12.8
	Smearing	9,872	6.75	96	5.21	4.95	4.87	2.68	12.8
Grand	Direct	5,118	3.86	(100)	1.01	10.3	3.70	0.049	9.99
	Parametric	5,118	3.59	93	1.14	6.21	4.02	0.054	10.3
	Smearing	5,118	3.61	94	1.14	6.21	4.05	0.054	10.3
G. Miami	Direct	5,148	44.0	(100)	18.5	67.6	36.4	5.85	116
	Parametric	5,148	43.1	98	20.5	63.2	36.2	5.91	106
	Smearing	5,148	43.1	98	20.5	63.3	36.3	5.91	107
Scioto	Direct	3,389	51.8	(100)	23.0	72.0	49.2	6.09	146
	Parametric	3,389	52.1	101	23.8	70.8	48.6	6.26	147
	Smearing	3,389	52.2	101	23.9	70.9	48.6	6.27	147
Muskingum	Direct	4,705	51.5	(100)	28.0	59.4	55.0	6.45	136
	Parametric	4,705	51.6	100	29.7	56.8	55.3	6.98	136
	Smearing	4,705	51.6	100	29.7	56.8	55.3	6.98	136

[1] In cells with percentages enclosed by parentheses, the mean load is being compared with itself, so the result is trivially 100%.

underestimates loads, and when the relationship is concave downwards, it overestimates loads.

SPARROW and Land Management. In addition to issues related to the bias in Fluxmaster/SPARROW load calculations, a number of other factors cloud the use of the current model for today's management decisions for Lake Erie. Some of them follow. We emphasize the management implications of the SPARROW model estimates because of the intense current focus on reducing eutrophication symptoms in western and central Lake Erie.

The MRB3 SPARROW model references its results to the year 2002. This is 10 years ago and many important changes have occurred since then. These include changes in land use and agricultural practices (OLEPTF, 2010), increasing separation of storm and sanitary sewers in cities and towns (e.g., SEMCOG, 2008; http://www.neorsd.org/projectcleanlake.php), decreases in particulate phosphorus loads and concentrations (Richards *et al.*, 2009) but increases in dissolved phosphorus (Richards, 2007), increases in discharge in the major Lake Erie tributaries (Richards *et al.*, 2009; Baker, 2010), and changes in the timing of greatest phosphorus loading from spring to winter (Richards, unpublished). In recent years, Lake Erie has experienced substantial increases in the extent of hypoxia and the severity of cyanobacterial blooms (L.E. LaMP, 2011). Although there is value in the generalized loading picture that SPARROW gives for 2002, it is less relevant to management decisions being made in 2012.

SPARROW produces load estimates for a year of typical hydrology. From a management perspective, however, the extreme loads are what is most important, especially if they occur close together in time. In northwest Ohio, three of the four highest years for discharge and TP loading (out of 34 years of record) have occurred in the last five years (NCWQR data).

The MRB3 SPARROW model assumes that source coefficients are invariable geographically within the area being modeled. This assumption is probably not valid for a region as large and varied as the entire MRB3 watershed, and may lead to erroneous conclusions about smaller areas such as the Lake Erie watershed. By contrast, Hoos and McMahon (2009) allowed nutrient delivery to vary with Ecoregion in their Southeast TN SPARROW model, and found that doing so improved their model fit and removed some of the spatial patterns in their residuals.

Implications for Management Issues in the Lake Erie Basin

Lake Erie managers are challenged at present to address two main water-quality concerns: algal blooms in the Western Basin and hypoxia in the Central Basin. Both have worsened in the last decade, and both have been attributed to phosphorus inputs, particularly dissolved reactive phosphorus from the tributaries (OLEPTF, 2010). Agricultural sources have been identified as the largest contributor. The current SPARROW model results suggest that point sources and agricultural sources are approximately equal in importance to Lake Erie TP loads. We believe this conclusion is misleading for several reasons:

- The SPARROW model addresses the U.S. side of the Lake Erie watershed only. As such, it fails to include inputs, primarily to the Western and Central Basins, from Canada. These Canadian watersheds contribute minimal point-source phosphorus but substantial nonpoint-source phosphorus, mainly of agricultural origin. Dolan's estimates for 2002 are that these tributaries loaded 857 Mg to the Western Basin and 986 Mg to the Central Basin. If these are added to the SPARROW results for Lake Erie, the agricultural contribution would nearly double.
- The apparent tendency of SPARROW to underestimate tributary loads but more correctly characterize point-source loads adds to the bias in favor of point sources.
- The SPARROW model is for the entire USLEB, but the most critical current management issue (algal blooms) is basically a Western Basin issue. By including the whole U.S. basin, point sources in Cleveland, Ohio; Erie, Pennsylvania; and to some extent Buffalo, New York come into the calculations. The relatively small eastern Central Basin and Eastern Basin watersheds are more predominantly forested and urban. Thus, the picture for the entire basin emphasizes point sources more and agricultural sources less. By comparison, the summary of SPARROW results for the Maumee River alone (from the web mapper at wim.usgs.gov/Sparrow/SparrowMapper.html#) indicates that 27.6% of the TP load comes from point sources, 62.3% from agricultural sources, and 10.1% from other nonpoint sources. Our results for annual loads for 1995-2005 are 89.9% from nonpoint sources and 10.1% from point sources. Using the relative contributions from various nonpoint sources estimated by SPARROW, 77.4% of the total load would come from agriculture and 12.5% from other nonpoint sources. Both our estimates and those of SPARROW include extrapolations for unmonitored areas downstream of the sampling station at Waterville and point-source inputs from Toledo, Ohio. Although this comparison indicates that SPARROW overestimates the portion of the Maumee TP load that comes from point sources,

nonpoint sources dominate the loading to a greater extent than is suggested by the proportions reported for the USLEB as a whole.

- Finally, the current SPARROW model treats TP (and TN) only, but gives no information about the various environmental compartments of phosphorus, notably particulate phosphorus and dissolved phosphorus. Because of great differences in bioavailability of particulate and dissolved phosphorus (DePinto *et al.*, 1981; Young and DePinto, 1982; Sharpley, 1992; Auer *et al.*, 1998; Baker, 2010), models that predict in-lake ecological responses on the basis of bioavailable phosphorus are increasingly important and those that fail to do so are of less utility to managers dealing with eutrophication problems (DePinto *et al.*, 1986).

Toward a Better SPARROW Model for Lake Erie

Many of the issues that we have raised can be addressed possibly with less effort than was required to build the current model. Indeed, we understand that some steps are already underway to improve the model (Dale M. Robertson, USGS, 2008, personal communication). Improvements that we think would be particularly valuable for Lake Erie include the following:

- The accuracy of the tributary load estimates should be improved by a more refined use of Fluxmaster, incorporating where appropriate the higher-order terms for time trend, flow, and seasonality that are available in Fluxmaster, to obtain a better fit between the data and the regression model. This would need to be done on a station-by-station basis, with careful evaluation of diagnostics such as residuals plots, to make sure that inclusion of these terms actually improved the model.
- The model should be extended to include the Canadian watershed if at all possible.
- A more up-to-date model adjusted to the year 2012 will be possible in the near future when the 2009 Cropland Data Layer (http://www.nass.usda.gov/research/Cropland/SARS1a.htm), the 2011 land cover database (http://pubs.usgs.gov/fs/2012/3020/fs2012-3020.pdf), and the 2012 agricultural census data (http://www.agcensus.usda.gov/Newsroom/2012/02_10_2012.php) become available. This updated model will better reflect contemporary conditions.
- Although we recognize the challenges posed by data limitations, a model that addresses dissolved or bioavailable phosphorus in addition to TP would be a substantial improvement.

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