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LOADS OF NITRATE, PHOSPHORUS, AND TOTAL SUSPENDED SOLIDS FROM INDIANA WATERSHEDS

Aubrey R. Bunch[1]: USGS Indiana-Kentucky Water Science Center, 5957 Lakeside Blvd., Indianapolis, IN 46278 USA

ABSTRACT. Transport of excess nutrients and total suspended solids (TSS) such as sediment by freshwater systems has led to degradation of aquatic ecosystems around the world. Nutrient and TSS loads from Midwestern states to the Mississippi River are a major contributor to the Gulf of Mexico Hypoxic Zone, an area of very low dissolved oxygen concentration in the Gulf of Mexico. To better understand Indiana's contribution of nutrients and TSS to the Mississippi River, annual loads of nitrate plus nitrite as nitrogen, total phosphorus, and TSS were calculated for nine selected watersheds in Indiana using the load estimation model, S-LOADEST. Discrete water-quality samples collected monthly by the Indiana Department of Environmental Management's Fixed Stations Monitoring Program from 2000–2010 and concurrent discharge data from the U. S. Geological Survey streamflow gages were used to create load models. Annual nutrient and TSS loads varied across Indiana by watershed and hydrologic condition. Understanding the loads from large river sites in Indiana is important for assessing contributions of nutrients and TSS to the Mississippi River Basin and in determining the effectiveness of best management practices in the state. Additionally, evaluation of loads from smaller upstream watersheds is important to characterize improvements at the local level and to identify priorities for reduction.

Keywords: Nutrient loads, mass transport, Indiana, nitrate, phosphorus, suspended solids

INTRODUCTION

Many factors can influence the concentration of nutrients and total suspended solids (TSS) in streams including climate, basin size, land use, and hydrological management practices (Meybeck et al. 2003; Domagalski et al. 2008). Excess nutrients (primarily nitrogen and phosphorus) can lead to eutrophication which degrades the structure and function of aquatic food chains (Dodds & Welch 2000). Excessive TSS, such as sediment, can also alter aquatic habitats through sedimentation (Bilotta & Brazier 2008). Eutrophication and sedimentation can lead to economic losses in recreational water usage and waterfront real estate, as well as increased spending on recovery and drinking water treatment (Carpenter et al. 1998; Bilotta & Brazier 2008; Dodds et al. 2009). The impacts of excessive nutrient and TSS loading in streams may not just be local; they can lead to degradation of water quality and habitat in waterbodies far downstream, and can contribute to large scale ecological effects in coastal areas (Diaz & Rosenberg 2008). The world's second largest hypoxia zone is located in the Gulf of Mexico in the shallow waters of the Louisiana shelf (Rabalais et al. 2002). Transport of dissolved nutrients and nutrients bound to suspended solids from Midwestern states to the Mississippi River has been identified as one of the main contributors to this hypoxia (Alexander et al. 2008, Robertson & Saad 2013, Robertson et al. 2014).

The Mississippi River drains all or portions of 31 states. The U.S. Geological Survey's Spatially Referenced Regressions On Watershed attributes (SPARROW) model (based on data from 1992 to 2002 and detrended to 2002) was used to estimate that of those 31 states, nine states (including Indiana) contributed 75% of the total nitrogen and total phosphorus delivery to the Gulf of Mexico (Alexander et al. 2008). Those nine states, however, constitute only 33% of the drainage area. The model identified corn/soybean row crop as the main contributor of total nitrogen loads, while phosphorus loads were linked to non-recoverable manure from pasture/rangelands. The SPARROW model results indicated that Indiana contributed 10–17% of the nitrogen and 5–10% of the phosphorus mass transported to the Gulf of Mexico from 1999 to 2002. A recently updated SPARROW model indicated that watersheds in Indiana contribute the third highest amount of nitrogen and the seventh highest amount of phosphorus to the Gulf of Mexico in comparison to other Midwest states (Robertson

[1] *Corresponding author:* Aubrey R. Bunch, 317-600-2783 (phone), 317-290-3313 (fax), aurbunch@usgs.gov.

Table 1.—Sites used for loads analysis and their associated USGS stream gages. Map ID for Figure 1. All sites are in Indiana.

Map ID number	Site name	Watershed	Drainage area (km^2)	USGS gage number
1	Wabash River at Montezuma	Lower Wabash	28,775	03340500
2	Wabash River at Lafayette	Middle Wabash	19,384	03335500
3	Wabash River at Peru	Upper Wabash	6,952	03327500
4	White River at Petersburg	White	28,796	03374000
5	West Fork White River near Centerton	West Fork White	6,436	03354000
6	East Fork White River at Seymour	East Fork White	6,056	03365500
7	Kankakee River at Shelby	Kankakee	4,604	05518000
8	Iroquois River near Foresman	Iroquois	1,404	05524500
9	Patoka River near Winslow	Patoka	1,682	03376300

et. al. 2014). Robertson et al. (2014) estimated that Indiana contributed 155,742,615 kg/yr of nitrogen and 6,767,868 kg/yr of phosphorus to the Gulf of Mexico, based on model applications with data from 1971 to 2006 with results made applicable to 2002. When loads were divided by watershed area to compute yields for each state, Indiana had the highest yield (kg/km^2) of nitrogen, 1,804 kg/km^2, and the seventh highest yield of phosphorus, 78.4 kg/km^2.

Evaluation of nutrient loads from select individual watersheds within Indiana may provide insight about the overall contribution of nutrients to the Mississippi River. Within Indiana, the Indiana Department of Environmental Management (IDEM) has collected monthly stream-water samples as part of their Fixed Station Monitoring Program (FSMP) since 1957 and the U.S. Geological Survey (USGS) has operated a network of stream gages that provides continuous stream discharge records for many sites and streams since the 1930's (Jian et al. 2012). The objective of this study was to use these two long-term data sets to calculate loads of nitrate, phosphorus, and TSS for select Indiana watersheds for the period 2000 to 2010; and compare loads to previously modeled contributions from Indiana.

METHODS

Site selection.—Nine sites from the IDEM FSMP and their associated USGS stream gages were selected and used to estimate loads of nitrate plus nitrite as nitrogen (referred to as nitrate in this paper), total phosphorus (referred to as phosphorus in this paper), and total suspended solids (referred to as TSS in this paper) from Indiana (Table 1, Fig. 1). There are 163 sites across the state in IDEM's FSMP (as of 2012). The nine IDEM FSMP sites chosen for load calculations were those located on the furthest downstream reaches of large watersheds within Indiana that drain to the Mississippi River system. For the two largest Indiana watersheds, the Wabash River and White River, two additional sites located upstream were also chosen to further examine

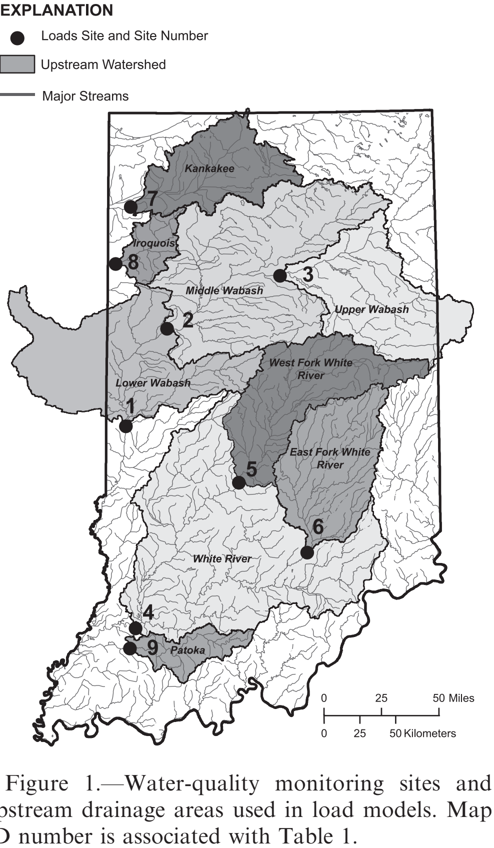

Figure 1.—Water-quality monitoring sites and upstream drainage areas used in load models. Map ID number is associated with Table 1.

Table 2.—Load model number and equations for predefined models ranked for model fit used in S-LOADEST to estimate loads for Indiana watersheds from 2000-2010. [a_0, intercept; $a_{\#}$, coefficient; ln, natural log; ln*Q*, ln(discharge) - median of ln(discharge); *dtime*, decimal time - decimal time adjustment; sin, sine; cos, cosine]

Model number	Regression model equation
1	$a_0+a_1\ln Q$
2	$a_0+a_1\ln Q+a_2\ln Q^2$
3	$a_0+a_1\ln Q+a_2 dtime$
4	$a_0+a_1\ln Q+a_2\sin(2\pi dtime)+a_3\cos(2\pi \mathrm{dtime})$
5	$a_0+a_1\ln Q+a_2\ln Q^2+a_3 dtime$
6	$a_0+a_1\ln Q+a_2\ln Q^2+a_3\sin(2\pi dtime)+a_4\cos(2\pi dtime)$
7	$a_0+a_1\ln Q+a_2\sin(2\pi dtime)+a_3\cos(2\pi dtime)+a_4 dtime$
8	$a_0+a_1\ln Q+a_2\ln Q^2+a_3\sin(2\pi dtime)+a_4\cos(2\pi dtime)+a_5 dtime$
9	$a_0+a_1\ln Q+a_2\ln Q^2+a_3\sin(2\pi dtime)+a_4\cos(2\pi dtime)+a_5 dtime+a_6 dtime^2$

loads within those larger watersheds. These sites had a complete water-quality record of monthly samples from 2000–2010 and were co-located at or within a reasonable distance from a USGS streamflow gage with a complete record of discharge data from 2000–2010. ArcGIS 10.1 geographic information system (ESRI 2012) was used to identify USGS stream gages that were co-located or on the same stream reach as a FSMP site. All sites had a drainage basin difference of less than 7% between the water-quality site and the USGS streamflow gage, except the Iroquois River at Foresman, IN which had an 18% difference.

Water-quality and streamflow data.—Data for monthly water-quality samples analyzed for nitrate, phosphorus, and TSS were obtained from IDEM's Assessment Information Management System (IDEM 2013) database. Laboratories and analysis procedures changed and reporting limits for phosphorus and TSS changed over time so the highest reporting limit was used to determine censored values. Nitrate had no censored values. Streamflow data for USGS gages associated with FSMP sites were obtained from the USGS National Water Information System (NWIS) (U.S. Geological Survey 2013a-i) database for each site from 2000–2010. The program waterData (Ryberg & Vecchia 2012) was used to screen and standardize zero and missing values and to mathematically assign probable streamflow values for missing values.

Load models.—Loads were calculated for nitrate, phosphorus, and TSS with the program S-LOADEST, an adaptation of LOADEST developed by Runkel et al. (2004). S-LOADEST was written for S-Plus statistical software (TIBCO 2008, any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government). This program calibrates load models using time-series streamflow and constituent concentration data. The regression models relate the concentration of nitrate, phosphorus, or TSS from monthly water-quality samples to the daily mean discharge on the day of sampling. In addition to streamflow and concentration, the program considers various functions of discharge, seasonality, and time over the 11 year period to calibrate models.

The S-LOADEST program has three methods that can estimate coefficients of the dependent variables in load models: Adjusted Maximum Likelihood Estimation (AMLE), Maximum Likelihood Estimation (MLE), and Least Absolute Deviation (LAD) (Runkel et al. 2004). The AMLE and MLE methods are most appropriate when data are normally distributed. LAD can be used when data are not normally distributed; however, it cannot be used with censored data. The AMLE method can be used with censored data; if the AMLE method is selected and no censored data are present, the method converts to MLE (Dempster et al. 1977; Wolynetz 1979; Cohn 1988; Cohn 2005). Because censored data were present, AMLE was used for estimating loads for this study. The AMLE method corrects for transformation bias in the regression-model coefficients.

Using the AMLE method, S-LOADEST software ranked nine predefined models (Table 2) for each site and constituent. Models were ranked and the best defined model was identified on the basis of Akaike Information Criterion

Table 3.—Annual loads, standard error of prediction and annual yields of nitrate plus nitrite as nitrogen, total phosphorus, and total suspended solids for Indiana watersheds.

Wabash River at Montezuma, IN

	Nitrate plus Nitrite as Nitrogen			Total phosphorus			Total suspended solids		
Year	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)
2000	24,127	7.58	838	1,082	0.25	38	377,684	189	13,125
2001	73,970	22.31	2,571	2,614	0.53	91	706,642	263	24,557
2002	78,513	23.18	2,729	2,548	0.47	89	841,810	309	29,255
2003	61,407	15.46	2,134	3,037	0.65	106	990,941	426	34,438
2004	64,812	15.45	2,252	2,529	0.45	88	744,401	260	25,870
2005	61,517	18.65	2,138	2,656	0.70	92	541,988	215	18,835
2006	61,815	14.11	2,148	2,228	0.34	77	638,479	181	22,189
2007	65,577	18.27	2,279	2,576	0.46	90	664,677	211	23,099
2008	67,578	20.52	2,348	3,397	0.70	118	1,021,398	370	35,496
2009	58,372	17.81	2,029	3,114	0.63	108	1,051,483	403	36,542
2010	37,329	11.83	1,297	2,382	0.61	83	981,318	495	34,103

Wabash River at Lafayette, IN

	Nitrate plus Nitrite as Nitrogen			Total phosphorus			Total suspended solids		
Year	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)
2000	15,816	3.97	816	815	0.08	42	271,770	121	14,020
2001	38,959	9.63	2,010	1,895	0.24	98	597,620	234	30,831
2002	36,594	9.04	1,888	1,615	0.21	83	551,351	212	28,444
2003	36,438	8.04	1,880	2,672	0.52	138	1,476,687	871	76,181
2004	32,821	6.45	1,693	1,882	0.25	97	678,319	291	34,994
2005	37,181	9.65	1,918	2,152	0.41	111	503,475	209	25,974
2006	35,745	6.79	1,844	1,884	0.22	97	499,412	148	25,764
2007	40,530	9.83	2,091	2,262	0.33	117	552,029	193	28,479
2008	43,058	11.41	2,221	2,600	0.44	134	683,567	253	35,264
2009	35,724	9.76	1,843	2,214	0.34	114	621,995	255	32,088
2010	23,760	6.19	1,226	1,518	0.18	78	475,807	216	24,546

Table 3.—Continued.

Wabash River at Peru, IN

Year	Nitrate plus Nitrite as Nitrogen: Annual load (Metric Tons)	Nitrate plus Nitrite as Nitrogen: Standard error of prediction (Metric Tons)	Nitrate plus Nitrite as Nitrogen: Annual yield (kg/km^2)	Total phosphorus: Annual load (Metric Tons)	Total phosphorus: Standard error of prediction (Metric Tons)	Total phosphorus: Annual yield (kg/km^2)	Total suspended solids: Annual load (Metric Tons)	Total suspended solids: Standard error of prediction (Metric Tons)	Total suspended solids: Annual yield (kg/km^2)
2000	9,787	3.60	1,408	408	0.08	59	93,302	28	13,421
2001	14,932	4.34	2,148	923	0.18	133	214,769	61	30,893
2002	12,664	3.33	1,822	681	0.13	98	186,179	59	26,781
2003	16,431	4.20	2,363	1,508	0.30	217	484,582	189	69,704
2004	9,713	2.26	1,397	743	0.12	107	194,793	56	28,020
2005	11,966	3.42	1,721	1,080	0.22	155	292,131	108	42,021
2006	11,095	2.54	1,596	905	0.14	130	236,182	66	33,973
2007	13,015	3.50	1,872	1,158	0.23	167	339,607	113	48,850
2008	12,915	3.51	1,858	1,038	0.21	149	333,655	113	47,994
2009	11,496	3.25	1,654	796	0.16	114	259,939	85	37,391
2010	9,826	3.33	1,413	619	0.12	89	204,445	62	29,408

White River at Petersburg, IN

Year	Nitrate plus Nitrite as Nitrogen: Annual load (Metric Tons)	Nitrate plus Nitrite as Nitrogen: Standard error of prediction (Metric Tons)	Nitrate plus Nitrite as Nitrogen: Annual yield (kg/km^2)	Total phosphorus: Annual load (Metric Tons)	Total phosphorus: Standard error of prediction (Metric Tons)	Total phosphorus: Annual yield (kg/km^2)	Total suspended solids: Annual load (Metric Tons)	Total suspended solids: Standard error of prediction (Metric Tons)	Total suspended solids: Annual yield (kg/km^2)
2000	22,656	7.26	787	1,803	0.32	63	915,881	198	31,806
2001	28,929	8.74	1,005	2,491	0.48	87	1,131,904	310	39,308
2002	34,660	11.39	1,204	3,204	0.59	111	2,346,413	834	81,484
2003	30,946	6.78	1,075	3,115	0.45	108	1,769,853	456	61,462
2004	27,073	6.92	940	2,725	0.40	95	1,376,605	352	47,805
2005	29,746	12.29	1,033	3,192	0.63	111	1,541,229	531	53,522
2006	39,781	11.64	1,381	4,263	0.70	148	2,153,985	590	74,802
2007	31,153	10.29	1,082	2,918	0.53	101	1,366,626	399	47,459
2008	41,105	16.15	1,427	4,674	0.96	162	3,159,257	1113	109,712
2009	32,272	8.82	1,121	3,452	0.62	120	1,870,784	494	64,967
2010	23,987	8.00	833	2,280	0.43	79	1,255,475	336	43,599

Table 3.—Continued.

West Fork White River near Centerton, IN									
	Nitrate plus Nitrite as Nitrogen			Total phosphorus			Total suspended solids		
Year	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)
2000	4,302	0.36	668	433	0.06	67	57,316	17	8,906
2001	7,380	0.84	1,147	756	0.11	117	220,484	113	34,258
2002	7,866	0.99	1,222	906	0.19	141	655,117	778	101,789
2003	10,083	1.51	1,567	1,423	0.45	221	1,951,766	3140	303,258
2004	7,229	0.79	1,123	800	0.11	124	315,372	236	49,001
2005	9,062	1.36	1,408	1,246	0.39	194	828,691	1197	128,759
2006	9,993	1.30	1,553	1,047	0.14	163	335,683	174	52,157
2007	8,449	1.19	1,313	981	0.20	152	434,467	370	67,506
2008	9,963	1.44	1,548	1,198	0.28	186	1,003,170	1176	155,869
2009	7,626	0.88	1,185	764	0.11	119	311,435	189	48,390
2010	6,486	0.71	1,008	651	0.12	101	397,036	383	61,690

East Fork White River at Seymour, IN									
	Nitrate plus Nitrite as Nitrogen			Total phosphorus			Total suspended solids		
Year	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)
2000	10,471	2.41	173	414	0.13	7	204,070	137	3,370
2001	11,407	2.39	188	679	0.32	11	269,804	240	4,455
2002	12,459	3.03	206	1,127	0.72	19	736,552	1003	12,162
2003	11,691	1.94	193	611	0.18	10	334,247	248	5,519
2004	7,976	1.43	132	704	0.49	12	270,774	328	4,471
2005	10,341	2.62	171	1,380	1.11	23	466,598	706	7,705
2006	13,358	2.78	221	1,113	0.55	18	469,714	433	7,756
2007	8,855	2.26	146	803	0.45	13	266,720	279	4,404
2008	12,437	3.66	205	2,208	1.93	36	1,525,883	3038	25,196
2009	10,510	2.15	174	1,107	0.76	18	858,391	1408	14,174
2010	9,353	2.27	154	761	0.39	13	610,067	703	10,074

Table 3.—Continued.

	Kankakee River at Shelby, IN								
	Nitrate plus Nitrite as Nitrogen			Total phosphorus			Total suspended solids		
Year	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)
2000	1,875	0.42	407	94	0.01	20	27,841	7	6,047
2001	3,761	0.69	817	137	0.02	30	33,466	7	7,269
2002	3,528	0.59	766	137	0.02	30	38,686	10	8,403
2003	2,333	0.31	507	105	0.01	23	29,844	7	6,482
2004	3,055	0.43	664	124	0.01	27	32,385	7	7,034
2005	3,358	0.60	729	115	0.01	25	25,881	5	5,621
2006	2,825	0.39	614	120	0.01	26	29,602	6	6,430
2007	4,090	0.59	888	173	0.02	38	43,910	11	9,537
2008	5,163	0.92	1,121	232	0.03	50	58,748	16	12,760
2009	3,980	0.75	864	204	0.03	44	54,372	14	11,810
2010	1,925	0.40	418	128	0.02	28	36,239	9	7,871

	Iroquois River near Foresman, IN								
	Nitrate plus Nitrite as Nitrogen			Total phosphorus			Total suspended solids		
Year	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)
2000	1,347	0.33	959	21	0.005	15	5,452	1.7	3,883
2001	3,929	0.91	2,798	55	0.013	39	10,008	3.2	7,128
2002	3,710	0.88	2,642	55	0.014	39	12,105	5.1	8,622
2003	2,988	0.71	2,128	130	0.051	93	22,755	16.0	16,207
2004	3,296	0.61	2,348	56	0.013	40	12,348	4.7	8,795
2005	2,365	0.56	1,684	38	0.011	27	6,707	2.5	4,777
2006	3,571	0.62	2,543	53	0.009	38	12,137	3.6	8,645
2007	3,249	0.72	2,314	54	0.012	38	10,962	4.0	7,808
2008	3,656	0.86	2,604	111	0.034	79	16,679	7.3	11,880
2009	2,858	0.72	2,036	80	0.025	57	14,278	6.9	10,170
2010	1,840	0.45	1,311	43	0.012	31	10,025	3.5	7,140

Table 3.—Continued.

	Patoka River near Winslow, IN								
	Nitrate plus Nitrite as Nitrogen			Total phosphorus			Total suspended solids		
Year	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)	Annual load (Metric Tons)	Standard error of prediction (Metric Tons)	Annual yield (kg/km^2)
2000	1,176	0.33	699	145	0.03	86	52,446	16	31,181
2001	1,064	0.32	633	133	0.03	79	39,043	15	23,212
2002	1,475	0.42	877	194	0.04	115	100,068	50	59,493
2003	1,188	0.27	706	124	0.02	74	49,108	13	29,196
2004	1,309	0.30	778	155	0.02	92	61,212	19	36,392
2005	1,031	0.29	613	110	0.02	65	35,263	11	20,965
2006	1,935	0.58	1,150	291	0.05	173	111,725	41	66,424
2007	1,202	0.35	715	124	0.02	74	38,319	11	22,782
2008	1,611	0.60	958	229	0.05	136	110,809	57	65,879
2009	1,517	0.34	902	202	0.04	120	80,652	22	47,950
2010	1,072	0.24	637	106	0.02	63	39,318	9	23,376

(AIC). The model with the lowest AIC score for each site and constituent was further evaluated with diagnostic plots for each model factor and residual plots to determine if residuals had equal statistical variance and were evenly distributed.

Once the best model was determined, USGS daily mean discharge data from associated stream gages for the period 1 January 2000 to 31 December 2010 were used with the regression model to estimate daily loads of nitrate, total phosphorus, and TSS for each site. Annual loads were estimated as the sum of the daily loads for each year. For each watershed, mean and median annual load for each constituent were calculated for the 11 year period.

Yields.—To compare loads for sites with varying drainage basin sizes, yields were calculated by dividing the load at each site by the watershed area. This allowed the comparisons between sites in units of tons per square kilometer per year.

RESULTS

Annual loads for nitrate, phosphorus, and TSS varied by year for each site (Table 3). For most sites and constituents, the lowest annual load values occurred in 2000 (Table 3). In general, standard error of prediction seen in the models was higher in years where the load was higher. For median annual loads for the 11 year period, sites with larger drainage areas (Lower Wabash, White River) tended to have higher loads than those with smaller drainage basins (Table 4, Figs. 2A-C). For yields, the values were more similar and in some instances sites with smaller watersheds had higher yields than those with larger watersheds (Table 4, Figs. 2D-F). Most notably the Iroquois River near Foresman, the site with the smallest watershed area, had the highest median annual yield for nitrate.

Nitrate.—Median annual nitrate loads for 2000–2010 vary across the state (Fig. 3). Median annual nitrate loads range from 1,202 metric tons per year at the Patoka River near Winslow, IN to 61,815 metric tons per year at the Wabash River at Montezuma, IN (Table 4, Fig. 2A). The Iroquois River near Foresman, IN had the largest median annual nitrate yield at 2,314 kg/km^2 per year, and the Patoka River near Winslow, IN had the lowest nitrate yield at 715 kg/km^2 per year (Table 4, Fig. 2D).

Phosphorus.—Median annual phosphorus loads for 2000–2010 vary across the state of Indiana (Fig. 4). Median annual phosphorus

Table 4.—Median annual loads and yields from 2000 to 2010 for Indiana watersheds. Bold number indicates highest value. All site are in Indiana.

Site Name	Watershed	Drainage area (km^2)	Median annual load (Metric Tons)	Median annual yield (kg/km^2)
			Nitrate plus Nitrite as Nitrogen	
Wabash River at Montezuma	Lower Wabash	28,775	**61,815**	2,148
Wabash River at Lafayette	Middle Wabash	19,384	36,438	1,880
Wabash River at Peru	Upper Wabash	6,952	11,966	1,721
White River at Petersburg	White	28,796	30,946	1,075
West Fork White River near Centerton	West Fork White	6,436	7,866	1,222
East Fork White River at Seymour	East Fork White	6,056	10,510	1,735
Kankakee River at Shelby	Kankakee	4,604	3,358	729
Iroquois River near Foresman	Iroquois	1,404	3,249	**2,314**
Patoka River near Winslow	Patoka	1,682	1,202	715
			Total Phosphorus	
Wabash River at Montezuma	Lower Wabash	28,775	2,576	90
Wabash River at Lafayette	Middle Wabash	19,384	1,895	98
Wabash River at Peru	Upper Wabash	6,952	905	130
White River at Petersburg	White	28,796	**3,115**	108
West Fork White River near Centerton	West Fork White	6,436	906	**141**
East Fork White River at Seymour	East Fork White	6,056	803	133
Kankakee River at Shelby	Kankakee	4,604	128	28
Iroquois River near Foresman	Iroquois	1,404	55	39
Patoka River near Winslow	Patoka	1,682	145	86
			Total Suspended Solids	
Wabash River at Montezuma	Lower Wabash	28,775	744,401	25,870
Wabash River at Lafayette	Middle Wabash	19,384	552,029	28,479
Wabash River at Peru	Upper Wabash	6,952	236,182	33,973
White River at Petersburg	White	28,796	**1,541,229**	53,522
West Fork White River near Centerton	West Fork White	6,436	397,036	61,690
East Fork White River at Seymour	East Fork White	6,056	466,598	**77,046**
Kankakee River at Shelby	Kankakee	4,604	33,466	7,269
Iroquois River near Foresman	Iroquois	1,404	12,105	8,622
Patoka River near Winslow	Patoka	1,682	52,446	31,181

loads ranged from 55 metric tons per year at the Iroquois River near Foresman, IN to 3,115 metric tons per year at the White River at Petersburg, IN (Table 4, Fig. 2B). The West Fork White River near Centerton, IN had the largest median annual phosphorus yield at 141 kg/km^2 per year, and the Kankakee River at Shelby, IN had the lowest phosphorus yield at 28 kg/km^2 per year (Table 4, Fig. 2E).

TSS.—Median annual TSS loads for 2000–2010 vary across the state of Indiana (Table 4, Fig. 5). Median annual TSS loads ranged from 12,105 metric tons at the Iroquois River near Foresman, IN to 1,541,229 metric tons per year at the White River at Petersburg, IN (Table 4, Fig. 2C). The East Fork White River at Seymour, IN had the largest median annual TSS yield at 77,046 kg/km^2 per year, and the Kankakee River at Shelby, IN had the lowest TSS yield at 7,269 kg/km^2 per year (Fig. 2F).

DISCUSSION

Stream loads are influenced by transport of the constituents to the stream and instream processes. Excess precipitation and associated runoff can increase the transport of constituents to streams

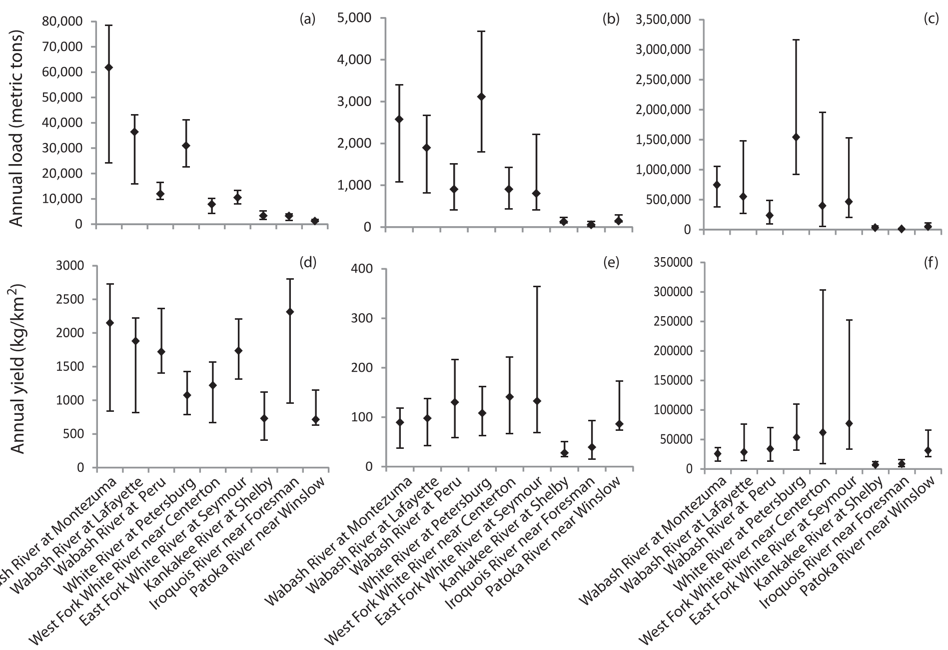

Figure 2.—Median annual loads for a) nitrate plus nitrite as nitrogen, b) total phosphorus, and c) total suspended solids, and annual yields for d) nitrate plus nitrite as nitrogen, e) total phosphorus, and f) total suspended solids. Diamond represents the mean annual load from 2000–2010. Whiskers represent the range of values for annual load (min and max) for each of the nine Indiana watersheds.

as well as increase the amount of water flowing in a stream. In addition, high stream flows can increase stream constituent transport levels through resuspension of constituents that may have settled to the stream bed or bank during periods of low discharge. On the other hand, prolonged time periods of little precipitation and runoff will lead to lower stream loads of constituents because of reduced flow and transport. During 2000, Indiana precipitation accumulation totals were below normal causing a moderate-to-severe drought through mid-June. The drought led to very low stream discharge at sites around the state (Stewart et al. 2001). Consequently, during the study period, six of the nine sites had their lowest annual load for nitrate, and eight of the nine sites had their lowest annual load for phosphorus and TSS in 2000.

Annual loads for TSS and phosphorus were correlated ($R^2 = 0.77$, Root mean-squared error (RMS) = 548; Fig. 6A); when TSS load was high, phosphorus load tended to be high and when TSS load was low, phosphorus load tended to be low. Annual nitrate loads were not as strongly correlated to annual loads of TSS ($R^2 = 0.30$, RMS = 16,400; Fig. 6B). Phosphorus binds to suspended sediment particles that are included in the TSS measurements. Though measurements of TSS can under estimate sediment concentrations, especially when sand-sized material exceeds 25% of the sediment mass (Gray et al. 2000), the correlation between phosphorus and TSS is still apparent. Nitrate did not follow this pattern because it is soluble in water and not influenced by the presence of sediment (Baker 1980).

Median annual yields for phosphorus and TSS were the lowest at Kankakee River at Shelby, IN and the Iroquois River near Foresman, IN. The northwestern part of Indiana, which includes the Iroquois and Kankakee River basins, is dominated by sandy soils, whereas the rest of the state has soils dominated by silt and clay (Clark & Larrison 1980). When sand concentrations are high in water, measurements of TSS are biased low (Gray et al. 2000). Also, sand particles have a lower surface area to mass ratio than silt and clay, reducing the area for phosphorus binding (Kaiserli et al. 2002). The high quantity of sand in soils in northwestern Indiana may help explain why the yield for both TSS and total phosphorus in the Iroquois and Kankakee River basins were lower than in streams elsewhere in the state.

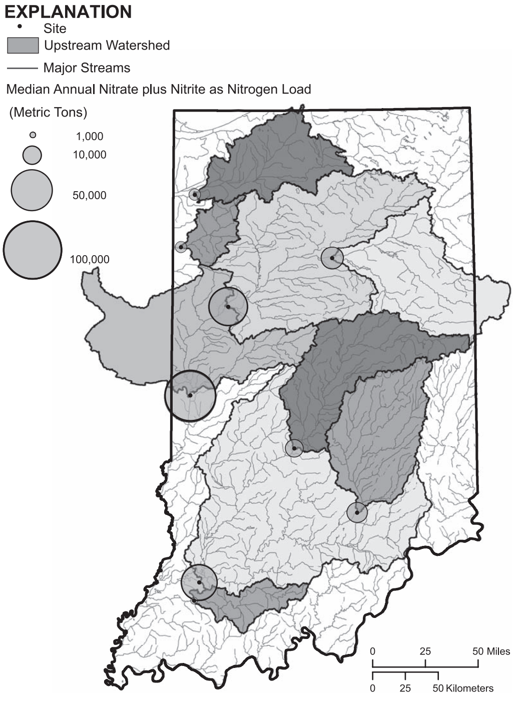

Figure 3.—Median annual loads of nitrate plus nitrite as nitrogen in metric tons per year in Indiana watersheds for the period 2000–2010. Size of circle is proportional to the load.

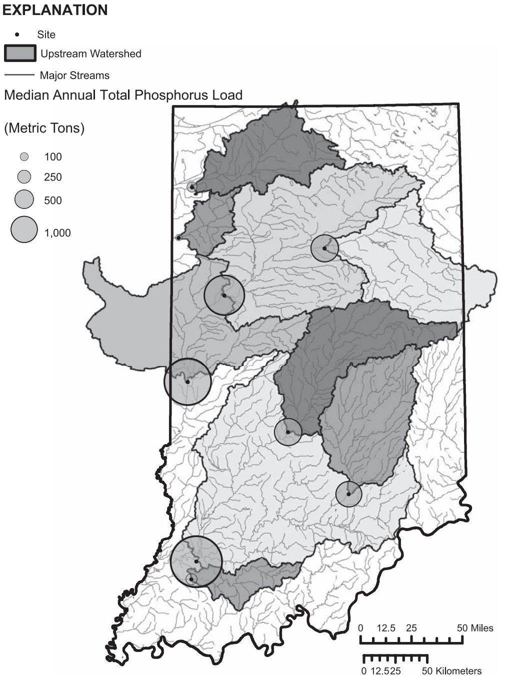

Figure 4.—Median annual loads of total phosphorus in tons per year in Indiana watersheds for the period 2000–2010. Size of circle is proportional to the load.

Instream dynamics, such as resuspension, storage, or nutrient uptake, make it difficult to pin-point the source of nutrients and TSS loads in streams. When a load is measured at a site it does not mean that that watershed contributes that full amount to the Gulf of Mexico; it only means that flux is moving past that point in the basin at the given time. Alexander et al. (2000, 2008) found that the proximity of a source to a large stream or river is strongly correlated with the fraction of its nitrogen or phosphorus load that is delivered to the Gulf of Mexico. Delivery was found to increase with stream size; however, reservoirs tended to reduce the amount of phosphorus delivered downstream due to sediment trapping. Loads estimated at smaller upstream sites, though important in understanding the dynamics of the smaller watershed, may not give much insight into the load that ultimately reaches an estuary system.

During 2003, the annual load of TSS at sites in the West Fork White River basin and the Upper Wabash River basin were higher than the annual loads at the downstream sites, i.e., the White River at Petersburg and the Wabash River at Montezuma. During this year, there were severe isolated rainstorms in both July and September in northern Indiana that resulted in floods in the West Fork White River basin and in the Upper Wabash River basin. The flooding in these upstream basins caused the daily discharge values above the 99th percentile seen for the period of record at these sites (U.S. Geological Survey 2004). Flood events can cause large amounts of TSS to be transported due to increases in erosion (Charlton 2008). Large amounts of constituents were moving through the upstream sites (West Fork White River basin and Upper Wabash River), but the lower portion of these watersheds (White River at Petersburg and the Wabash River at Montezuma) did not experience the high runoff and constituents likely settled out along the course of the water moving downstream as stream flow energy decreased. This illustrates that the loads measured at smaller upstream watersheds may not indicate what is delivered to the Gulf; however, they are important for measuring improvements or identifying priorities for reduction at a local level.

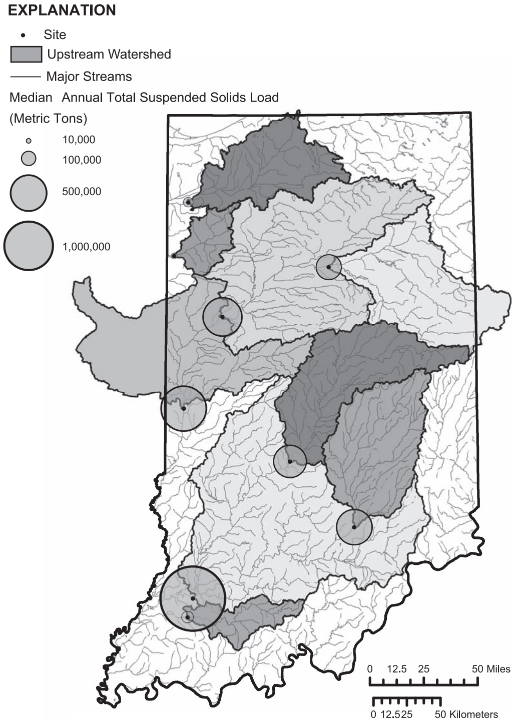

Figure 5.—Median annual loads of total suspended solids in tons per year in Indiana watersheds for the period 2000–2010. Size of circle is proportional to the load.

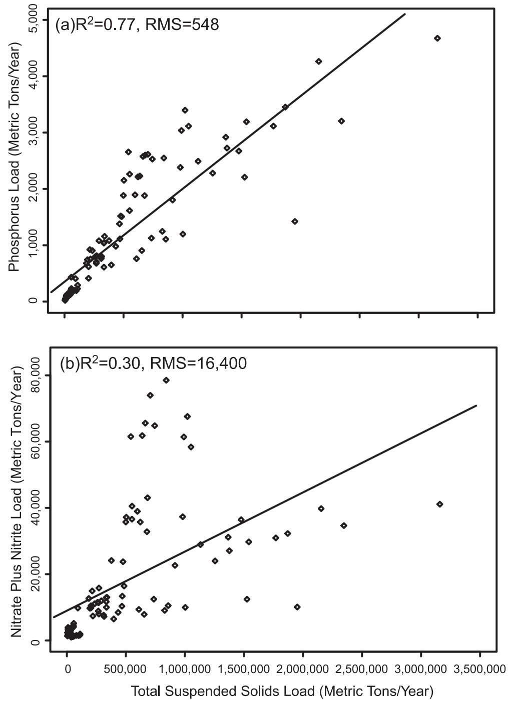

Figure 6.—Comparison of estimated annual loads for 10 years (2000–2010) at nine stations in Indiana for a) total phosphorus and total suspended solids and b) nitrate plus nitrite as nitrogen and total suspended solids, with R^2 and root-mean-square error (RMS). Line represents the regression for each graph.

There are multiple ways to estimate mass transport in rivers and streams. A simple one-to-one comparison of loads or yields calculated from differing methods and models may be inappropriate because of differences in assumptions, time scales, and target watersheds. However, simple comparisons of the general results between the different methods may be useful in evaluating qualitatively the results of the models. This study uses a simple qualitative comparisons between the results from using LOADEST (based upon discrete sampling and discharge data from 2000–2010) and the results from previous SPARROW applications (based upon long-term mean-annual loads (made applicable to 2002)). The median annual loads from the two most downstream sites (Lower Wabash at Montezuma, IN and White River at Petersburg, IN) were combined to estimate a "total" annual load delivered from Indiana. The Robertson et al. (2014) SPARROW model predicted 155,744 MT/yr of total nitrogen was delivered to the Gulf of Mexico from Indiana, the "total" annual load delivered of nitrate delivered from Indiana in this study was 92,761 MT/yr. The two models had similar yields, the SPARROW model estimated a total nitrogen yield of 1,800 kg/km^2 and the LOADEST model from this study estimated a nitrate yield of 1,600 kg/km^2. Even though this study uses nitrate concentrations and SPARROW models use total nitrogen, these results are comparable since in streams draining to the Gulf of Mexico it has been shown that the majority of total nitrogen is in the form of nitrate (Goolsby et al. 2001). Total phosphorus loads from Indiana to the Gulf of Mexico estimated from SPARROW models were 6,768 MT/yr, and the "total" annual load delivered for phosphorus from this study was 5,691 MT/yr. The phosphorus yields were estimated to be 78 kg/km^2 by the SPARROW model and 90 kg/km^2 for this study. Robertson et al. (2014) used all watersheds draining into the Mississippi to make their model (86,337 km^2); while this study only evaluated loads from the two largest river basins in Indiana, the Wabash and the White (57,570 km^2), to estimate loads. The similarities in delivered loads and yields from the Robertson et al (2014) SPARROW models and those calculated in this study illustrate that the Wabash and White River are likely the main sources for nutrients to the Gulf of Mexico from Indiana. Monitoring loads at these sites is important for assessing how Indiana is influencing Mississippi River loads and to determine if management practices are helping to reduce loads from the state.

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