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Reports from the Ohio Tributary Monitoring Program

Annual Unit Area Loads of Sediment, Nutrients, and Chloride

This report presents information on the total amount of water and five water quality constituents transported annually in seven of the largest rivers within the state of Ohio, which together constitute the Ohio Tributary Monitoring Program. In addition, comparable values are provided for three smaller rivers or streams in Ohio and for the River Raisin in Michigan. The report covers water years[1] 1996 to 2001.

Stations

Basic information about the stations is shown in Table 1. More detailed information about the location of the monitoring stations, the sampling approach, and the analysis of samples is provided in a companion report: Program Description.

Table 1. Characteristics of the seven major Ohio Tributary Monitoring Program stations, and four additional stations included in this report.

River	Drainage Area above Station (sq.mi.)	Land use above station, by percent*			
		Agri-culture**	Urban	Wooded	Other***
River Raisin at Monroe, MI USGS 04176500	1,042				
Maumee R. at Waterville USGS 04193500	6,330	89.9	1.2	7.3	1.6
Sandusky R. near Fremont USGS 04198000	1,253	84.1	0.9	13.0	2.0
Rock Creek at Tiffin USGS 04197170	34.6	82.0	0.9	16.1	1.0
Honey Creek at Melmore USGS 04197100	149	85.6	0.6	12.5	1.3
Vermilion R. at Mill Hollow USGS 04199500	262				
Cuyahoga R. at Independence USGS 04208000	708	30.4	9.6	50.1	9.9

Table 1. Characteristics of the stations, continued

River	Drainage Area above Station (sq.mi.)	Land use above station, by percent*			
		Agri-culture**	Urban	Wooded	Other***
Grand R. at Painesville USGS 04212100	686	40.0	0.9	45.2	13.1
Muskingum R. at McConnelsville USGS 03150000	7,420	52.0	1.7	43.4	2.9
Scioto R. at Chillicothe USGS 03231500	3,854	80.2	4.6	12.9	2.3
Great Miami R. below Miamisburg USGS 03271601	2,685	82.1	4.7	10.3	2.9

* Source: ODNR Division of Real Estate and Land Management
** Includes open urban/suburban areas such as lawns
*** Includes shrub/scrub lands, open water, non-forested wetlands, barren ground

Methods

Annual discharge was calculated by summing up mean daily flows determined by the U.S. Geological Survey. Annual loads were calculated using AutoBeale, a computer implementation of the Beale Ratio Estimator. Information about this approach to load calculation can be found in Richards et al. (1996). Because the stations on the Scioto and Great Miami rivers did not begin operation until part way through the 1996 water year, annual loads were calculated for these stations beginning with WY1997. Unit area loads are calculated by dividing the total annual load by the area of the watershed upstream from the monitoring station.

Results

The resulting loads are shown in Table 2 on the next page. Q represents discharge, SS is suspended solids (sediment), TP is total phosphorus, SRP is soluble reactive phosphorus. Nitrate is expressed in mg/L as nitrogen. Since unit area discharge has units of length it can be compared directly with annual rainfall.

Table 2. Unit area discharge and loads of sediment, nutrients, and chloride at eleven WQL tributary monitoring stations, Water Years 1996 through 2001. Unit area discharge is in centimeters; loads are in kilograms/hectare. One cm=0.394 inches, one kg/ha=0.89 lb/acre.

River and year		Q	SS	TP	SRP	Nitrate	Chloride
Raisin	1996	24.8	203	0.43	0.037	11.4	89
	1997	30.9	251	0.62	0.074	16.0	106
	1998	32.8	317	0.74	0.085	12.7	104
	1999	24.7	279	0.44	0.074	13.4	87
	2000	20.5	293	0.41	0.078	11.1	83
	2001	26.2	309	0.52	0.111	13.7	113
Maumee	1996	31.3	539	1.16	0.126	25.4	97
	1997	42.0	812	1.75	0.260	26.0	104
	1998	39.8	709	1.79	0.310	18.2	82
	1999	24.9	316	0.78	0.131	15.7	73
	2000	20.4	377	0.72	0.123	16.5	72
	2001	23.0	206	0.57	0.159	15.9	89
Sandusky	1996	35.6	873	1.52	0.096	23.7	100
	1997	44.6	1123	2.06	0.185	28.2	92
	1998	35.8	642	1.60	0.213	18.4	76
	1999	16.8	163	0.43	0.077	11.8	62
	2000	22.2	291	0.68	0.145	19.0	81
	2001	19.1	Station not in operation due to bridge repairs				
Honey Cr.	1996	34.7	545	1.32	0.135	23.7	85
	1997	43.5	1128	2.23	0.225	23.4	89
	1998	39.4	589	1.71	0.272	18.9	68
	1999	15.5	62	0.31	0.073	8.6	47
	2000	27.5	307	1.19	0.251	17.9	57
	2001	15.5	84	0.36	0.127	9.3	56
Rock Cr.	1996	34.4	1240	1.99	0.100	15.8	80
	1997	43.9	2021	2.79	0.123	17.2	75
	1998	44.6	986	1.86	0.201	11.7	82
	1999	14.5	121	0.38	0.078	5.6	46
	2000	24.7	465	1.27	0.201	11.4	59
	2001	16.0	161	0.45	0.123	5.7	55
Vermilion	2001	15.5	190	0.34	0.065	5.7	75

Table 2. Unit area discharge and loads of sediment, nutrients, and chloride, continued

Cuyahoga	1996	55.9	1391	1.60	0.153	10.3	713
	1997	63.0	1123	1.31	0.136	9.1	598
	1998	42.4	562	0.88	0.133	7.7	479
	1999	31.0	545	0.80	0.161	7.2	554
	2000	40.7	784	1.01	0.191	7.5	634
	2001	32.2	531	0.79	0.226	7.5	674
Grand	1996	64.5	913	0.85	0.047	4.9	211
	1997	70.7	772	0.87	0.046	2.6	155
	1998	38.2	335	0.40	0.025	1.9	117
	1999	26.3	342	0.30	0.014	2.6	123
	2000	39.7	458	0.52	0.066	2.5	133
	2001	31.2	278	0.32	0.043	2.5	183
Muskingum	1996	53.5	632	1.10	0.081	10.6	158
	1997	42.9	341	0.71	0.062	8.0	131
	1998	34.4	294	0.55	0.075	5.3	97
	1999	31.4	230	0.47	0.065	5.4	114
	1999*	31.4	230	0.44	0.066	5.4	115
	2000*	Not	251	0.55	0.124	5.3	113
	2001*	Available	251	0.55	0.124	5.3	113
Scioto	1996	53.0	—	—	—	—	—
	1997	40.9	637	1.46	0.378	16.7	133
	1998	33.8	355	1.03	0.334	14.0	109
	1999	23.8	214	0.74	0.277	10.0	121
	2000	25.5	283	0.89	0.348	13.6	133
	2001	25.9	274	0.83	0.368	12.3	134
Great Miami	1996	55.2	—	—	—	—	—
	1997	42.5	485	1.54	0.565	20.0	167
	1998	34.8	338	1.35	0.521	16.7	147
	1999	25.2	102	0.77	0.372	10.7	138
	2000	22.4	232	0.85	0.390	13.5	140
	2001	27.7	311	1.06	0.512	14.1	159

* Loads calculated by the program Integrator, because mean daily flow data needed for the Beale Ratio Estimator are not available for this station after 1999. Unit area loads for 1999 calculated by both programs are given to show that results are very similar.

Discussion

Unit area discharges are smallest in the Maumee, Sandusky, and Raisin Rivers and in Honey and Rock Creeks, intermediate in the Great Miami, Scioto, and Muskingum, and largest in the Cuyahoga and Grand watersheds. This finding is generally consistent with long-term average precipitation (Table 3), which increases from west to east and from north to south across the state.

Table 3. Long-term annual precipitation for the monitoring stations, based on NOAA climatological data for the regions which correspond most closely to the tributary watersheds.

River	NOAA Climatological Region and Region Number	Annual Precipitation (inches)
Maumee	Northwest (1)	33.44
Sandusky	North Central (2)	35.33
Cuyahoga	Northeast (3)	38.45
Grand	Northeast (3)	38.45
Great Miami	West Central (4)	37.24
Scioto	Central (5)	38.08
Muskingum	Central Hills (6), Northeast Hills (7), and Southeast (10), averaged	39.07

Long term weather records for the entire state indicate an average precipitation of 38 inches, of which 10 inches (26%) becomes runoff in the short term, and an additional 2 inches (5.4%) eventually runs off via ground-water recharge (Penrose et al.) Thus discharge should be about 31% of precipitation, though considerable fluctuations are to be expected from year to year. For the stations listed in Table 3 and the years of this report, the figures are somewhat higher. Annual discharge expressed as a percent of average annual rainfall ranges from 19 to 72 percent, with a median of 36% and a mean of 39%. Annual discharge expressed as a percent of annual rainfall in the same year ranges from 20 to 77%, with a median of 36% and a mean of 37%. The highest percentages are from 1997, a year of low precipitation and high discharge. The two highest percentages are associated with the Cuyahoga and Grand Rivers, and are atypically high in comparison with the rest of the data.

Unit area loads of sediment are the largest, followed by loads of chloride, nitrate, total phosphorus, and soluble phosphorus in decreasing order. Very roughly, the unit area loads of these constituents are in the ratio SS : CL : NO3 : TP : SRP = 2600 : 800 : 90 : 6 : 1, based on the median values when all stations are considered together.

The most conspicuous detail in Table 2 is the very high chloride unit area loads at the Cuyahoga station. These loads are at least three times as large as those at the other stations, and presumably reflect the use of road salt in this more urbanized watershed. The Cuyahoga also tends to have higher sediment loads than the other stations, with the Sandusky and its tributaries close behind. The Sandusky and its tribs, Maumee, and Great Miami tend to have the highest total phosphorus loads, while the Grand, Muskingum, and Raisin have the lowest. The Great Miami and Scioto tend to have the highest soluble reactive phosphorus loads, and the Grand, Muskingum, and Raisin the lowest. The soluble reactive phosphorus load constitutes about 30-40% of the total phosphorus load in the Great Miami and Scioto Rivers, as compared to about 10-20% in the other watersheds, and 5-15% in the Grand River. This presumably reflects an urban influence due to point source loadings from sewage treatment plants in Dayton and Columbus. The Cuyahoga has lower soluble reactive phosphorus because of the phosphorus removal programs which were instituted in the Lake Erie basin in the 1970's. Relatively high nitrate loads are associated with the Maumee and Sandusky Rivers and Honey Creek; comparitively low unit area loads are found in the Grand River.

Particulate phosphorus (i.e. the phosphorus load carried by the sediment) was estimated as the difference between total phosphorus and soluble reactive phosphorus, and particulate phosphorus loads were calculated for each river and year. These loads are overestimates, because soluble reactive phosphorus underestimates total dissolved phosphorus. It is interesting to observe that the Cuyahoga and Grand stations are distinctly different from the others, with about 1 gram of phosphorus per kilogram of sediment as compared to 1.5 to 3 grams of phosphorus per kilogram of sediment at the other stations. This probably reflects a difference in the grain size and mineralogy of the sediment particles in each watershed. In the case of the Cuyahoga, at least, much of the sediment is eroded from the long steep slopes of the Cuyahoga River valley, is of glacial origin, and has not been exposed to anthropogenic sources of phosphorus.

Comparison with other watersheds

It is instructive to compare these unit area loads with results from other regions of agricultural land use. In Figure 1, unit area loads for phosphorus and sediment are plotted as a function of the percent of the basin which is in agricultural land use. Data for other watersheds are taken from values published in the literature and from values contributed by other researchers in response to an email request for information; this set of data is undoubtedly far from complete. In some cases, ranges of values were given; for these, the data are represented by the geometric mean of the maximum and minimum values of load and/or land use provided.

While many sources of uncertainty confound this exercise, it is clear that the tributaries in the Ohio Monitoring Program have higher unit area loads of sediment and total phosphorus than most other locations. This is true in spite of successful efforts to reduce these loads in the Lake Erie basin over the last 20+ years. In part, at least, these high loads reflect the fine-grained nature of Lake Erie basin soils, which allow particles to remain in suspension longer, leading to higher suspended sediment loads. Also, fine particles can carry much more phosphorus than an equivalent weight of coarser-grained sediment.

Unit area loads of of soluble reactive phosphorus and nitrate are broadly comparable to those elsewhere, though there is not much SRP data from elsewhere upon which to make

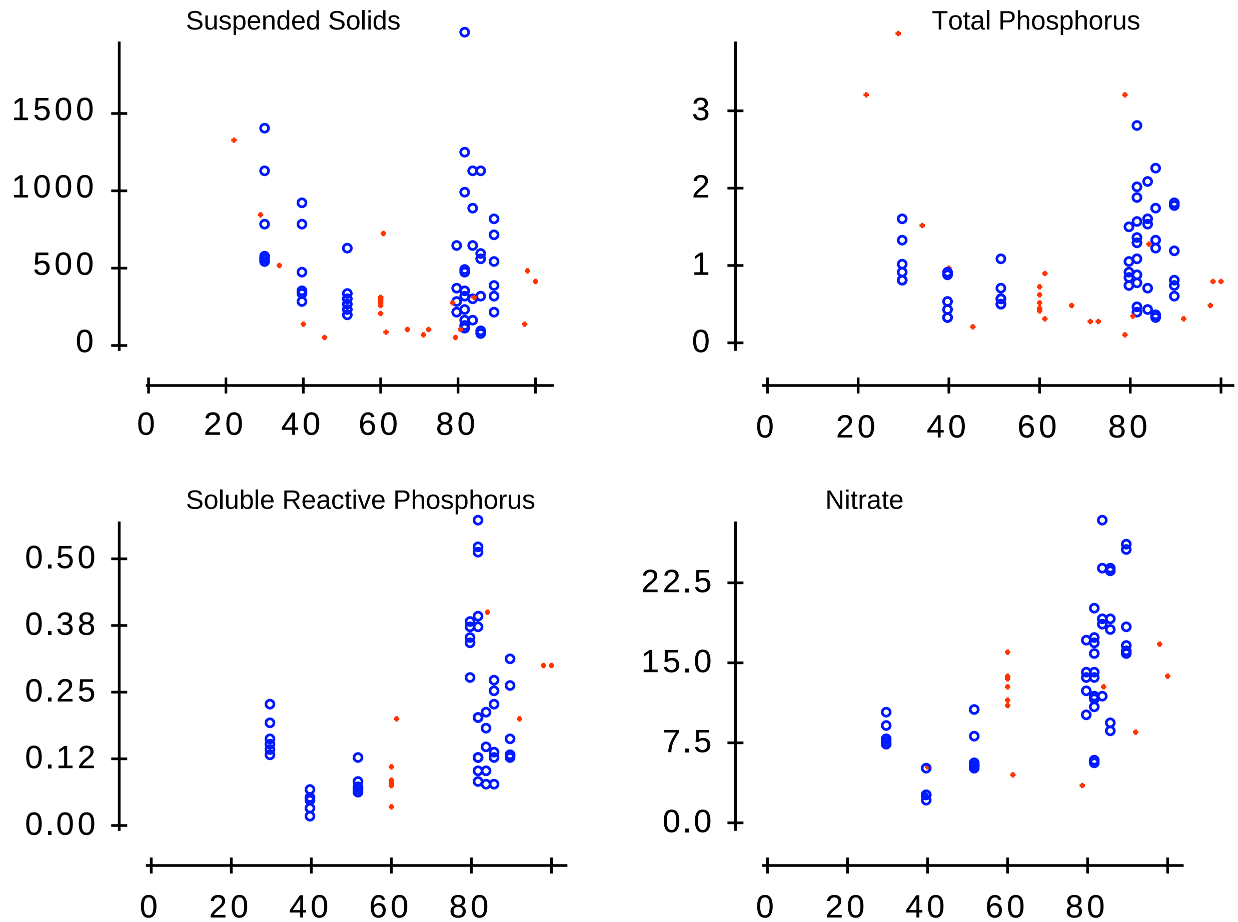

Figure 1. Unit area loads as a function of agricultural land use. Loads are expressed as metric tons per year, and land use as a percent. Ohio Tributary Monitoring Program data are shown as blue circles, and data from other watersheds are shown as red dots.

this comparison. The three highest points among the Ohio SRP data are unit area loads for the Great Miami and Scioto, discussed above.

The Cuyahoga River is a high outlier in these plots, given the trend of the rest of the Ohio data, with more soluble reactive phosphorus and more nitrate than would be expected from 30% agricultural land use. This reflects the urban influence, probably primarily from point sources. The Scioto and Great Miami are also influenced by point sources in Columbus and Dayton, but because of their high percentage of agricultural land use, the urban effect is somewhat masked.

References

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[1] A water year runs from October 1 of one year to September 30 of the following year. The water year 1996, for example, extends from October 1, 1995 to September 30, 1996. Water years are used for water quality analyses because the late summer is usually a dry time with low flow, and this provides a natural break point for summing up annual flows and loads.