United States Environmental Protection Agency
Research and Development

Environmental Research Laboratory
Athens GA 30613

EPA-600/S3-83-054 Jan. 1984

EPA

Project Summary

Fluvial Transport and Processing of Sediments and Nutrients in Large Agricultural River Basins

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Rivers and streams draining watersheds in northwestern Ohio were sampled in a 3- to 5-year study to describe the transport of nutrients and sediments in large agricultural basins. Land use in the watersheds, which ranged in size from 171 to 16,395 km^2, was dominated by row crop agriculture on generally fine textured and poorly drained soils. Automatic samplers were used to collect at least four samples per day at 12 U.S. Geological Survey gauging stations. During storm events all samples were analyzed, whereas during non-event periods one sample per day was analyzed.

For these rivers the concentrations of suspende olids, total phosphorus, nitrate plus nitrite nitrogen and total Kjeldahl nitrogen increased with increasing stream flow. Storms with similar peak discharges had widely varying flux weighted concentrations of both sediments and nutrients. Large seasonal and annual variations in flux weighted concentrations were also observed. The ratio of particulate phosphorus to sediments varied greatly among samples, with lower ratios generally associated with higher suspended solids concentrations.

The unit area yields of nutrients were considered to be in the high range for agricultural watersheds. Sediment delivery ratios ranged from 6.2% to 11.9%. There was no correlation between sediment delivery ratio and basin size. Furthermore, there was no correlation between gross erosion rates and unit area nonpoint phosphorus yields.

Phosphorus entering streams from point sources was rapidly processed by the stream system. Subsequent transport of this phosphorus to the lake depended on resuspension of particulate phosphorus during storm events. The soluble reactive phosphorus exported during storm events was largely derived from nonpoint sources. Upon delivery to Lake Erie, phosphorus from nonpoint sources had a higher percentage availability than phosphorus derived from point sources and processed by the stream system.

The data illustrate many patterns of nutrient and sediment transport in river systems. Many of these patterns need to be taken into account in establishing water quality monitoring programs. These data should also be useful in evaluating the effectiveness of conservation tillage in controlling agricultural nonpoint source pollution.

This Project Summary was developed by EPA's Environmental Research Laboratory, Athens, GA, to announce key findings of the research project that is fully documented in a separate report (see Project Report ordering information at back).

Background

Studies of nonpoint pollution in the Great Lakes Basin indicate that the rivers of northwestern Ohio, which drain into the western and central basins of Lake Erie, carry the largest loads of agriculturally derived nutrients and sediments entering the entire Great Lakes system. These loads are a product of intensive, row-crop agriculture on fine textured soils in the relatively large river basins of this region. Because these loads comprise a large portion of the phosphorus entering Lake

Erie, the transport and processing of sediments and nutrients in the major rivers of this region have received detailed study. The objectives of these studies have been to document and characterize the existing pollutant loads, to identify critical subwatersheds, to compare the transport and fate of pollutants derived from point and nonpoint sources, and to develop baseline data to evaluate water quality benefits of nonpoint control programs.

Modeling studies of the phosphorus balance for Lake Erie indicate that reductions in phosphorus loading from agricultural sources will be necessary to achieve the desired reductions in eutrophication. Concurrently with the river transport studies, the U.S. Army Corps of Engineers conducted detailed studies to determine the applicability of various agricultural best management practices for reducing nutrient and sediment losses from cropland in these river basins. These studies concluded that a variety of conservation tillage practices, including no-till, could significantly and economically reduce phosphorus loading to Lake Erie.

A major tillage demonstration project was initiated in the Honey Creek Watershed of the Sandusky Basin with support from the U.S. Army Corps of Engineers and the Agricultural Stabilization and Conservation Service. The results of the Honey Creek Project, and other tillage demonstration projects in the area, confirm that many of the area's soils are suitable for conservation tillage management and that these methods, when properly implemented, offer economic advantages to farmers. The Great Lakes National Program Office of the U.S. EPA has supported a conservation tillage implementation program in 20 agricultural counties within the Lake Erie Basin.

Studies of nutrient and sediment transport in northwestern Ohio rivers have been supported by grants and contracts from several different agencies and organizations. These include: 1) research grants from the U.S. EPA for studies of flow augmentation and river transport; 2) contracts with the Toledo Metropolitan Area Council of Governments as part of their 208 Planning Study; 3) contracts with the U.S. Army Corps of Engineers for data collection in support of the Lake Erie Wastewater Management Study; 4) contracts with the Ohio Department of Natural Resources for reservoir management studies; 5) grants from the Rockefeller Foundation and the Soap and Detergent Association for studies of agricultural nonpoint pollution; 6) grants from the cities of Tiffin, Bucyrus, and Upper Sandusky for evaluating instream benefits of phosphorus removal programs; and 7) support from Heidelberg College for matching funds and data collection during interim periods between external funding sources. A selected list of related reports is included at the end of this summary.

The results of this study have been used extensively for the development of recommendations contained in the Final Report of the Lake Erie Wastewater Management Study. The data have also been used in calibrations of several nonpoint source models. A detailed river transport model was developed by the U.S. Army Corps of Engineers using Sandusky Basin data. A generalized version of the U.S. Army Corps river transport model is presented in the Appendix to the complete report.

Study Area

The study area, which contains 12 U.S. Geological Survey stream gauging stations, is located in northwestern Ohio. The stations included river mouth stations on the Maumee, Portage, Sandusky and Huron rivers where data on tributary loading to Lake Erie were obtained. In addition, stations were operated on five major tributaries to the Sandusky River and three additional Sandusky River sites to identify critical watersheds and to study the transport and processing of nutrients and sediments as they move through stream systems.

Study Methods

Automatic samplers were used to collect a minimum of four samples per day at each sampling station. During periods of high flow and/or high turbidity, each sample was analyzed. Under low flow conditions, only a single sample per day was analyzed. Analyses routinely included suspended solids (SS), total phosphorus (TP), soluble reactive phosphorus (SRP), nitrate plus nitrite nitrogen, ammonia, conductivity, and chloride. The U.S. Geological Survey provided stage data for the times of sample collection and stage-discharge rating tables for each station.

This report focuses on data collected through the 1979 water year. At that time from three to five years of data were available at each station. Since 1979, studies have continued at several of the transport stations, and pesticide analyses have been added. All data have been placed in the STORET system.

Results

Flux-weighted and time-weighted mean concentrations were developed for major parameters at each sampling station. These are shown in Table 1. Parameters whose concentrations tend to increase with increasing stream flow — SS, TP, and nitrates — have higher flux-weighted than time-weighted concentrations. The Bucyrus station is located a short distance downstream from the municipal sewage treatment plant. At that site, the time-weighted concentration of TP exceeded the flux-weighted concentration. Conductivity always decreased with increasing flow, whereas the time-weighted concentrations of SRP were higher than the flux-weighted concentrations at stations below significant point source inputs.

In Figure 1, a typical hydrograph, chemograph and sediment graph pattern for northwestern Ohio rivers is shown. The peak concentrations of SS and TP occur in advance of the peak discharge whereas peak nitrate concentrations trail the peak discharge. Concentrations of TP (not shown) parallel the SS concentrations. Often SRP concentrations increase in parallel with the TP concentrations. The minimum conductivity generally corresponds with the peak discharge.

The trailing nitrate peaks are associated with the delayed arrival at the stations of nitrate-laden tile effluents relative to the arrival of surface runoff with its high SS and TP concentrations. Sediment resuspension during the rising stage of the hydrograph also helps to account for the advance sediment and phosphorus peaks.

At each of the sampling stations, the flux-weighted concentrations of sediments and nutrients showed large variations between individual storms, seasons and years. At the Upper Sandusky station, the flux-weighted concentrations were calculated for 52 individual storms. In Figure 2 these concentrations for TP are plotted in relation to the peak flow for the storm. Storms with similar peak flows have widely varying concentrations of both TP and sediments over the entire range of peak flows. Although some of the variability is associated with differences between snow melt and rainfall induced events, much of it is related to variations in rainfall intensity and amount, pre-existing soil moisture and ground cover. This large variability in phosphorus and sediment concentrations for storms with similar peak flows illustrates the complexity associated with calibrating runoff models for large watersheds.

There are large annual variations in discharge, load and flux-weighted mean concentrations of sediments and nutrients at the stations. The concentrations depend

Table 1. *Comparison of Flux Weighted and Time Weighted Mean Concentrations of Suspended Solids and Nutrients in Northwestern Ohio River Basins*

Location	*N*	*Weighted Concentration*	*Suspended Sediment, mg/L*	*Total P, mg/L*	*Soluble Reactive P, mg/L*	*NO_3-NO_2 Nitrogen, mg/L*	*Conductivity µmhos*
Maumee	1769	Flux	242	0.516	0.116	4.92	517
		Time	106	0.340	0.116	3.91	652
Portage	1842	Flux	164	0.402	0.119	5.89	554
		Time	62	0.360	0.191	3.80	854
Huron	2027	Flux	220	0.362	0.104	3.61	540
		Time	69.6	0.343	0.201	2.50	685
Sandusky	2237	Flux	217	0.453	0.093	4.61	487
		Time	83.1	0.244	0.073	3.09	716
Mexico	1578	Flux	239	0.428	0.070	3.50	624
		Time	85.8	0.250	0.069	3.49	750
Upper Sandusky	2729	Flux	235	0.518	0.134	3.90	478
		Time	105	0.482	0.234	2.60	709
Bucyrus	2299	Flux	173	0.573	0.219	3.42	460
		Time	49.6	1.13	0.837	3.11	702
Tymochtee Cr.	2631	Flux	205	0.419	0.069	5.12	397
		Time	68.7	0.181	0.040	3.48	751
Honey Cr.	2115	Flux	180	0.403	0.101	4.85	397
		Time	57.8	0.195	0.102	3.74	587
Broken Sword Cr.	1766	Flux	244	0.401	0.061	4.87	428
		Time	78.3	0.157	0.042	3.11	637
Wolf, East	1654	Flux	181	0.416	0.118	4.71	578
		Time	42.4	0.161	0.063	2.92	764
Wolf, West	1699	Flux	183	0.394	0.100	6.14	464
		Time	40.8	0.232	0.133	3.45	747

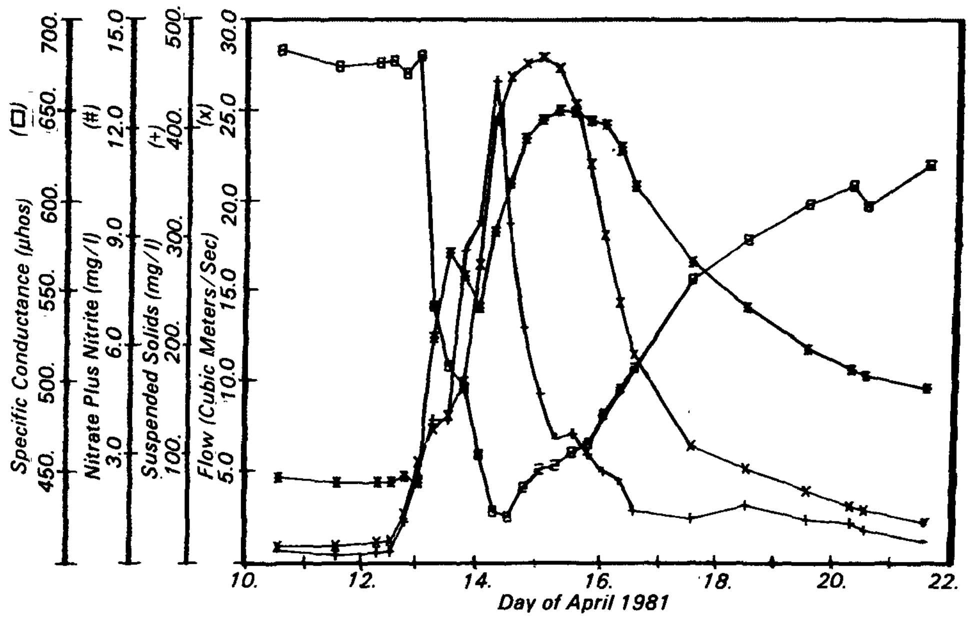

Figure 1. *Typical patterns of changing concentrations of suspended sediments, nitrates and conductivity during a runoff event at the Melmore gaging station on Honey Creek.*

more on the proportion of winter-to-summer runoff than on the total amount of runoff for the year.

Calculated particulate phosphorus (PP) to sediment ratios show that because there are substantial variations in annual flux-weighted concentrations of SS, there are also large annual variations in phosphorus/sediment ratios. Models that estimate PP export based on sediment yields should take into account the effects of sediment concentrations on PP/SS ratios.

Mean annual loads of nutrients and sediments at each station were estimated using two methods. Either flux-weighted concentrations were multiplied by mean annual discharge based on long term hydrological records for each station or flow duration tables were used in combination with flux-weighted concentrations for each flow interval. The two methods gave very similar results. The resulting mean annual unit area yields are shown in Table 2. These yields are considered to be in the high range for agricultural regions that have been studied, especially considering the large size of the drainage areas.

As part of a related study, gross erosion rates were calculated for each of the study watersheds. These erosion rates coupled with the unit area sediment yields allow direct calculation of sediment delivery ratios. Both the erosion rates and sediment delivery ratios are also shown in Table 2.

The sediment delivery ratios ranged from 6.2% to 11.9%. The general tendency of delivery ratios to decrease with increasing basin area, however, was not evident for these streams. These basins were much larger than those in which previous measurements of sediment delivery have been made. Sediment delivery ratios were inversely correlated with gross erosion rates for the study watersheds.

Concentration exceedency calculations for nitrates, for example, indicate that Ohio's drinking water standard (10 mg/L nitrate-N) was exceeded from 2% to 5% of the time at the transport stations (see Table 3). Concentrations of 7 mg/L are exceeded more than 10% of the time at all of the stations. Widespread adoption of conservation tillage in this region could increase the duration of time when nitrate standards are exceeded by increasing tile flow in relation to surface runoff.

Flux exceedency calculations confirm the dominant role of periods of high flux in total stream transport of sediments and nutrients. For the Maumee station the 5% of the time with the highest fluxes accounted for the following percentages of total stream transport: SS, 70%; TP, 57%; SRP, 39%; dissolved solids, 30.3%; and water 39.2%. For the Honey Creek station the corresponding figures were: SS, 79%; TP, 65%; SRP, 50%; dissolved solids, 30%; and water 44.4%. In general, as the watersheds become smaller, greater percentages of the total transport are accounted for by short periods of high flux.

The nonpoint phosphorus yields from each basin were calculated by subtracting the upstream point source inputs. The resulting unit area nonpoint phosphorus yields are shown also in Table 2. This calculation assumes 100% delivery of point source inputs through the stream system. It is recognized that for stations with substantial point source inputs, such as Bucyrus and Portage, the resulting unit area nonpoint phosphorus yields are unrealistically low. These same stations have sediment yields similar to adjacent basins. One would expect similar nonpoint phosphorus-to-sediment ratios regardless of the presence or absence of point sources in the basins. These data suggest that the delivery of point source phosphorus through stream systems is substantially less than 100%.

Much of the phosphorus that enters stream systems from point sources is quickly removed from the flowing water. In the Sandusky Basin, the point source phosphorus loading rate upstream from the Fremont station was 5.3 kg/hr. At this station the phosphorus flux was less than 5.3 kg/hr 55% of the time while during this time the average flux was only 1.8 kg/hr. Although these periods of low phosphorus flux are associated with low stream flows, most of the flow is derived from base flow in the watershed rather than point source inputs. Given the low flow phosphorus concentrations in water-

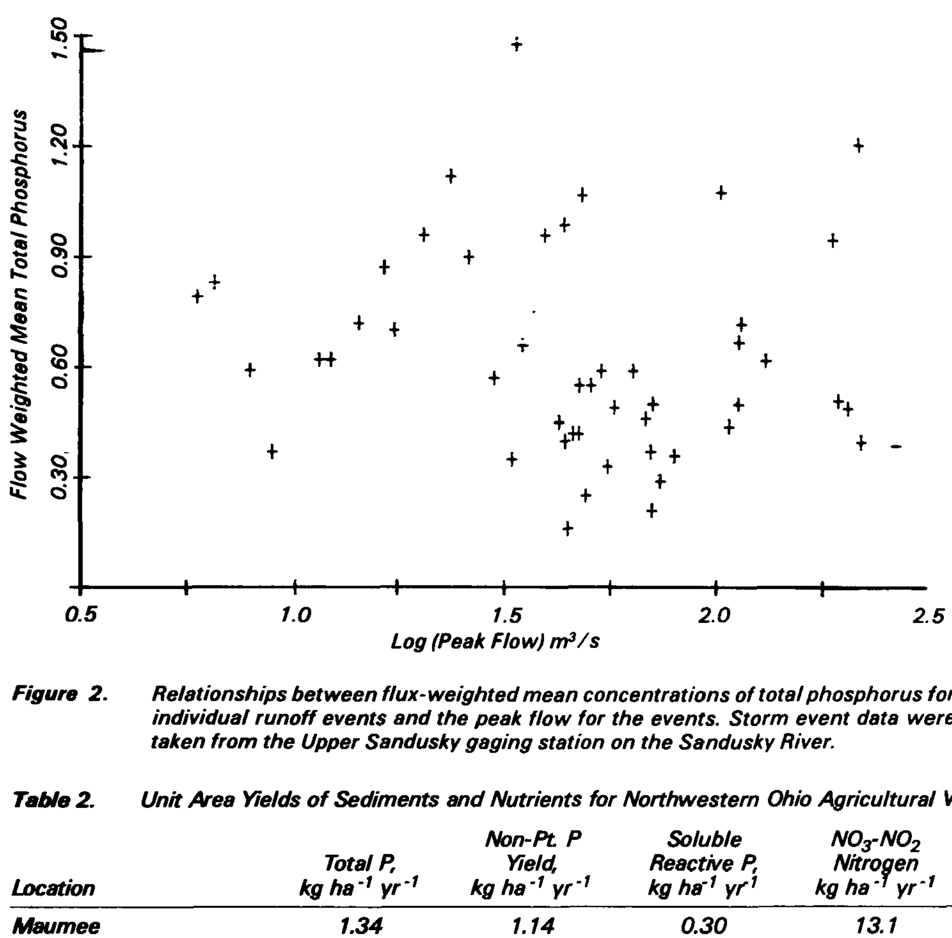

Figure 2. *Relationships between flux-weighted mean concentrations of total phosphorus for individual runoff events and the peak flow for the events. Storm event data were taken from the Upper Sandusky gaging station on the Sandusky River.*

Table 2. *Unit Area Yields of Sediments and Nutrients for Northwestern Ohio Agricultural Watersheds*

Location	*Total P, kg ha^{-1} yr^{-1}*	*Non-Pt. P Yield, kg ha^{-1} yr^{-1}*	*Soluble Reactive P, kg ha^{-1} yr^{-1}*	*NO_3-NO_2 Nitrogen kg ha^{-1} yr^{-1}*	*Suspended Sediment, ton ha^{-1} yr^{-1}*	*Gross Erosion ton ha^{-1} yr^{-1}*	*Delivery Ratio, %*
Maumee	1.34	1.14	0.30	13.1	0.63	6.84	9.2
Portage	0.97	0.61	0.30	15.1	0.40	5.00	8.0
Huron	1.02	0.57	0.29	10.2	0.59	7.51	7.9
Sandusky	1.10	0.96	0.24	12.5	0.52	8.25	6.3
Mexico	1.17	0.98	0.21	12.2	0.65	9.37	6.9
Upper Sandusky	1.45	1.04	0.39	11.4	0.63	9.35	6.8
Bucyrus	1.85	0.68	0.74	11.5	0.54	7.85	6.9
Tymochtee Cr.	1.06	1.06	0.18	13.4	0.52	8.41	6.2
Honey Cr.	1.09	1.01	0.27	13.1	0.49	6.86	7.1
Broken Sword Cr.	1.43	1.43	0.22	17.3	0.87	9.39	9.2
Wolf, East	1.40	1.40	0.39	15.8	0.61	5.11	11.9
Wolf, West	1.02	1.03	0.26	16.0	0.48	4.19	11.5

sheds lacking point sources, most of the low flow phosphorus flux must be derived from nonpoint sources. Phosphorus concentration profiles in stream reaches below point source inputs confirm the rapid deposition of point source derived phosphorus. Data described above suggest that some of this point source derived phosphorus is not resuspended and exported from the stream system.

Although point source phosphorus enters streams largely as bioavailable SRP, this phosphorus is rather quickly assimilated into the stream bed. Its subsequent export is apparently in the form of PP that is resuspended during storm events. Comparison of the bioavailability of PP, as measured by traditional extraction techniques, at sites downstream from large point source inputs with the bioavailability of PP exported from watersheds lacking major point sources, shows no differences. Apparently, point source SRP has undergone similar chemical transformations as fertilizer SRP by the time it is exported from the watersheds.

During runoff events, much more SRP is exported from these rivers than can be accounted for by upstream point source inputs entering the streams during the storm events. Watersheds lacking point source inputs have similar SRP export as those containing point sources. Consequently, most of the SRP exported during storm events must be derived from nonpoint sources. This SRP exported during storm events may be an important source of bioavailable phosphorus entering the open water of Lake Erie. Its rapid passage through estuaries and bays would make it much less subject to estuarine or nearshore processing than SRP derived from point sources emptying directly into estuaries or the nearshore zone of the lake. Because of the extensive export of nonpoint-derived SRP during runoff events, the overall bioavailability of nonpoint-derived phosphorus is greater than the bioavailability of point source-derived phosphorus at the time of its export from the river basins.

Conclusions

1. A combination of both detailed and long-term studies is necessary to accurately characterize the export of nutrients and sediments from large agricultural watersheds such as those of northwestern Ohio. Most of the material export occurs during runoff events. During individual events the concentrations of various components change rapidly and in characteristic patterns. The flux-weighted mean concentrations for runoff events of the same size, however, can show large variations from storm-to-storm over a wide range of storm sizes. Only part of this variability can be explained on the basis of seasonal effects. Large annual variations in flux-weighted means are also present. Ratios of phosphorus-to-sediment export vary from year to year. Attempts to characterize the export of nutrients and sediments based on short term studies, no matter how detailed they might be, could give very misleading results. An appreciation of the patterns of variability observed in these studies could be useful in designing and interpreting monitoring studies in other areas.
2. The large variability in nutrient and sediment loads for storms of equal size suggests that material export is not limited by the transport capacity of the rivers but rather by the movement of materials from the land surface to the stream system. Thus, reductions in river export should accompany nonpoint control programs that reduce material transport from the land surface to the stream systems. Possible increases in stream bed or stream bank erosion associated with the sediment carrying capacity of the stream will not prevent the effectiveness of land management control programs.
3. The sediment delivery ratios in the study watersheds range from 6.2 to 11.9%, whereas average gross erosion rates vary from 4.2 ton to 9.4 ton/ha/yr. The delivery ratios are not correlated with the size of the watershed but are inversely correlated with the gross erosion rate. There is no correlation between gross erosion rates and unit area nonpoint phosphorus yields. These observations raise doubts about the concept of "critical areas" and the use of gross erosion rates in their identification. The sediment and phosphorus yields from these large watersheds may be more related to the amount of clay entrained by rain drop impact and subsequent surface runoff. Tillage practices that increase cover and/or decrease runoff could reduce sediment and phosphorus yields from areas of both high and low gross erosion.

Table 3. *Percentage of Time the Indicated Concentrations of Nitrate-Nitrogen (mg/l) were Exceeded at Representative Gaging Stations*

Exceedency	*Maumee*	*Portage*	*Tindall*	*Melmore*	*Wolf West*	*Nevada*
99%	.01 mg/l	.02 mg/l	.02 mg/l	.480 mg/l	.040 mg/l	.059 mg/l
98%	.03	.06	.03	.770	.070	.070
95%	.13	.21	.09	.970	.110	.130
90%	.44	.47	.240	1.260	.240	.240
80%	1.45	1.07	.510	1.670	.500	.500
70%	2.01	1.70	1.190	2.020	.900	.800
60%	2.57	2.21	1.800	2.340	1.55	1.620
50%	3.20	2.93	2.560	2.820	2.66	2.230
40%	4.30	3.79	3.140	3.330	3.61	2.870
30%	5.32	4.80	4.100	3.990	4.54	3.800
20%	6.53	6.43	5.410	4.990	6.16	5.000
10%	8.02	8.69	7.200	7.380	8.21	7.200
5%	9.10	10.00	8.800	9.360	9.70	9.440
2%	10.60	11.89	10.900	13.300	11.30	13.00
1%	12.30	13.10	13.820	16.110	14.60	16.00
0.5%	13.00	14.10	16.460	18.520	16.39	18.80
Watershed area Km²	16,395	1,109	3,240	386	171.5	271
Gross Erosion m.t./ha/yr.	6.84	5.00	8.25	6.86	4.19	9.31

4. Both concentration profiles and flux exceedency data indicate that point source phosphorus, most of which is in the form of soluble reactive phosphorus when it enters streams, is rapidly processed by the stream sediments. There is indirect evidence that less than 100% of the point source derived phosphorus is subsequently delivered out of the stream system. Limited data suggest that the bioavailability of particulate phosphorus exported during storms is no greater from watersheds containing large point source phosphorus inputs than from watersheds lacking point sources. Apparently, the bioavailability of point source derived particulate phosphorus is no greater than that of nonpoint source derived particulate phosphorus. Most of the soluble reactive phosphorus exported during storm events is derived from nonpoint sources. The short retention time of storm flows in the lower portions of rivers or in estuaries, bays and the nearshore zone may result in high deliveries of nonpoint derived soluble phosphorus through these zones to the open lake. In contrast, point source phosphorus entering these zones may be subject to deposition and transformation to less bioavailable forms.
5. The data sets on nutrient and sediment transport in northwestern Ohio rivers provide baseline data upon which the regional water quality benefits of conservation tillage can be assessed. Accelerated conservation tillage implementation programs are underway throughout the region.

Related Reports

Cahill, Thomas H., R. W. Pierson, Jr., and B. R. Cohen. 1979. Nonpoint Source Model Calibration in Honey Creek Watershed. U.S. EPA. Athens, Georgia. EPA-600/3-79-054. 134 pp.

U.S. Army Corps of Engineers, Buffalo District. 1982. Lake Erie Wastewater Management Study. Final Report. 223pp.

Verhoff, Frank H. and David B. Baker. 1981. Moment Methods for Analyzing River Models With Application to Point Source Phosphorus. *Water Research,* 15:493-501.

Verhoff, Frank H., David A. Melfi and David B. Baker. 1978. Phosphorus Transport in Rivers. Lake Erie Wastewater Management Study, U.S. Army Corps of Engineers, Buffalo District, Buffalo, New York. 88 pp.

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The complete report, entitled "Fluvial Transport and Processing of Sediments and Nutrients in Large Agricultural River Basins," (Order No. AD A111894; Cost: $17.50, subject to change) will be available only from:
National Technical Information Service
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