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DISTRIBUTION OF PHOSPHORUS IN BED SEDIMENTS OF THE WINOOSKI RIVER WATERSHED, VERMONT, 1997

Amounts of phosphorus in Lake Champlain must be reduced in order to improve the health and recreational value of the Lake. An understanding of how phosphorus is distributed in the Lake Champlain watershed is necessary to develop effective policies to reduce phosphorus. The U.S. Geological Survey collaborated with university and State agency staffs in Vermont to study the distribution of phosphorus in bed sediments.

IMPORTANT FINDINGS

- Concentrations of phosphorus in bed sediment generally increased from the headwaters of the Winooski River to the watershed outlet.
- Average concentrations of phosphorus in bed sediments were 20 percent higher in urban and agricultural areas than in forested areas.
- Fine-grained bed sediment (silt and clay) had 60 percent higher concentrations of phosphorus, on average, than coarse-grained bed sediment (sand).
- Flow regime strongly influenced sediment grain size. Bed sediment in impoundments consisted of fine sand, silt, and clay, whereas sediment in depositional zones in free-flowing reaches of streams consisted of medium and fine sands.

BACKGROUND

Phosphorus is an essential element of all living organisms and is often the limiting nutrient for plant growth in fresh waters. An estimated four-fold increase in phosphorus loadings to Lake Champlain since the early 19th century has resulted in accelerated algal and plant growth in the Lake (Smeltzer and Quinn, 1996). Human activities are responsible for elevated phosphorus levels in Lake Champlain. Anthropogenic sources of phosphorus include municipal and industrial wastewater discharges, and urban and agricultural runoff. Since implementation of the Clean Water Act of 1972, a ban on phosphate detergents, controls on agricultural runoff, and the construction of phosphorus-removal facilities at municipal and industrial treatment plants have helped control phosphorus inputs to

A typical dairy farm along the banks of the Winooski River, Middlesex, Vermont.

the Lake. Despite the reductions, Lake Champlain continues to have nuisance levels of algal growth. Recent lake water-quality standards endorsed by the States of Vermont and New York, and by the province of Quebec, in the 1993 Lake Champlain Water-Quality Agreement, require additional reductions in phosphorus loadings to Lake Champlain (Smeltzer and Quinn, 1996).

An understanding of the cycling, storage, and transport of phosphorus in the Lake Champlain watershed is necessary to evaluate the effectiveness of phosphorus-reduction policies. The University of Vermont (UVM), School of Natural Resources, and the Vermont office of the Natural Resources Conservation Service (NRCS) are using dynamic simulation and mass-balance modeling techniques to evaluate the dynamics of phosphorus in tributary watersheds of Lake Champlain (Cassell and others, 1997). The initial focus of the modeling effort is on the Winooski River watershed. The 2,828-square kilometer Winooski River watershed is the largest tributary basin to Lake Champlain, has the greatest population (Henson and Gruendling, 1977), and contributes the second largest total

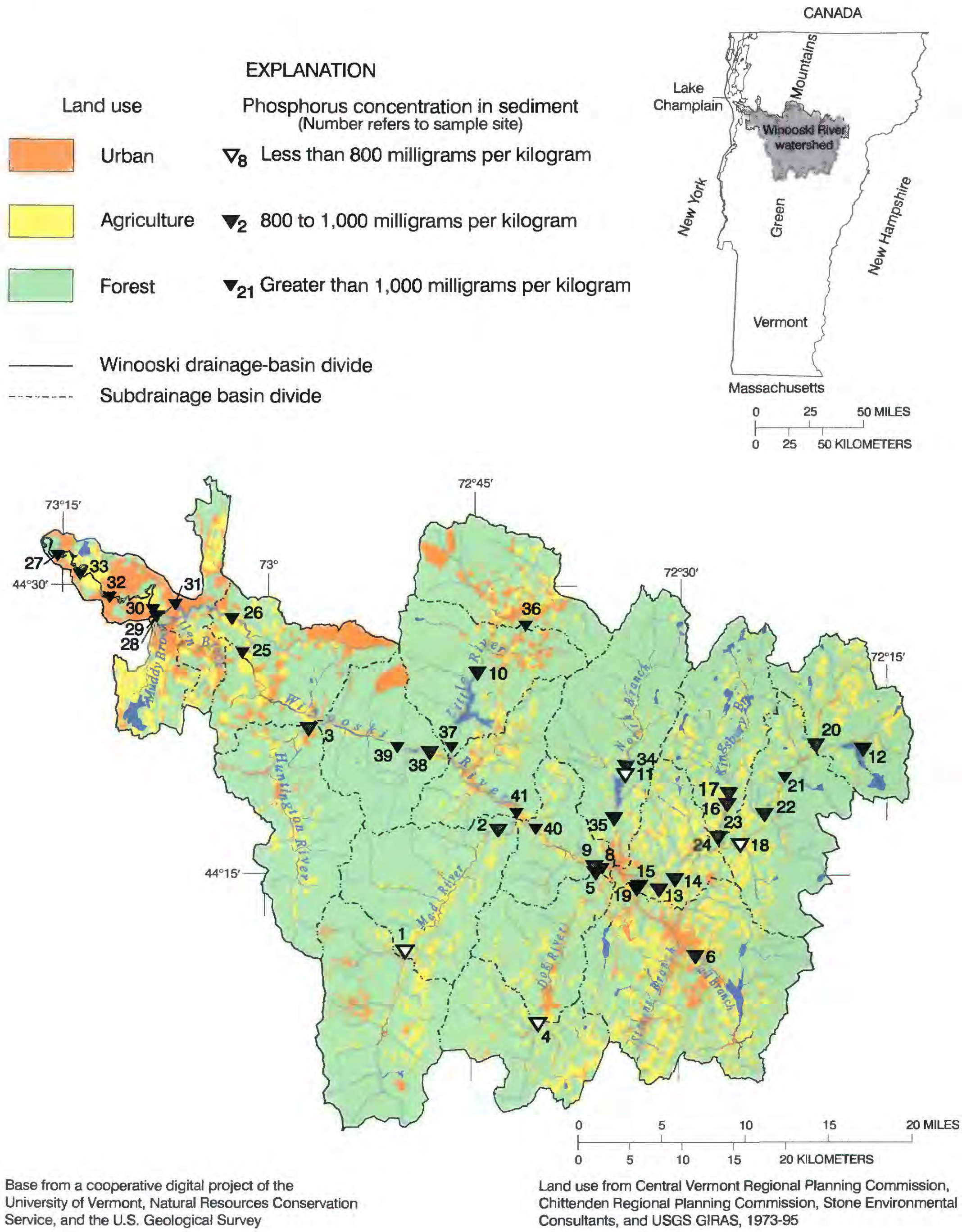

Figure 1. Land use, sampling sites, and phosphorus concentration in sediment in the Winooski River watershed.

phosphorus (TP) load of any watershed entering Lake Champlain (Smeltzer and Quinn, 1996). The U.S. Geological Survey (USGS) in collaboration with UVM and NRCS, has undertaken a study to collect the data needed for dynamic-simulation modeling of phosphorus in streambed sediments in the Winooski River watershed.

Previous studies have analyzed TP in fine-grained bed sediment at the mouths of tributaries to Lake Champlain (Colman and Clark, 1992) and in the Connecticut, Housatonic, and Thames River watersheds (Harris, 1997). Concentrations of TP in bed sediment measured by Colman and Clark (1992) ranged from 800 to 1,800 milligrams per kilogram (mg/kg), except at two sites on Mill Brook in New York, where concentrations were 3,300 and 3,500 mg/kg. Samples of bed sediments near the mouth of the Winooski River contained 1,100 and 1,200 mg/kg TP. Harris (1997) found TP concentrations in fine-grained bed sediment ranging from 1,100 mg/kg in Vermont to 5,100 mg/kg near Hartford, Conn. Sites that drained areas from 62 to 97 percent urban and agricultural land had a median TP concentration of 2,200 mg/kg compared to a median concentration of 1,600 mg/kg for sites that drained areas of 83 to 91 percent forested land.

This report describes the distribution of total phosphorus in streambed sediment and identifies some factors controlling total phosphorus distribution in the Winooski River watershed.

OBJECTIVES

The principal objectives of the study described here were to:

1. Assess the distribution of TP in bed sediment in the Winooski River watershed.
2. Determine the extent of TP in fine- and coarse-grained bed sediment.
3. Determine the relation(s) between concentrations of TP in sediment and watershed features such as land use, soil drainage class, basin slope, and streamflow regime.

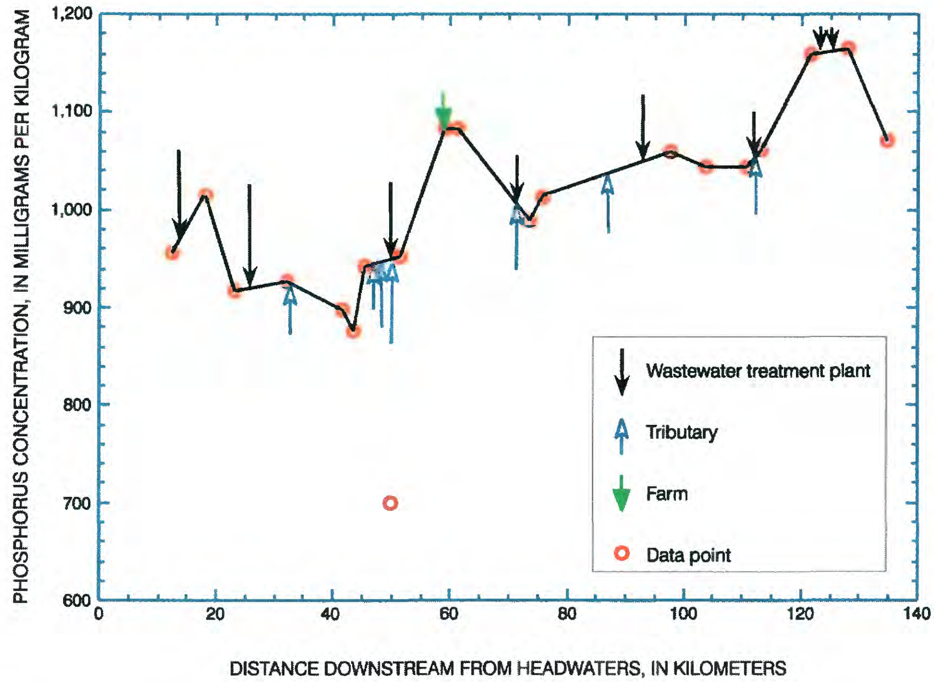

Figure 2. Concentration of phosphorus in fine-grained-bed sediment in the Winooski River,

WATERSHED CHARACTERIZATION AND SAMPLING SITE SELECTION

The Winooski River watershed was classified with respect to land use, soil type, basin slope, and flow regime with available Geographic Information System (GIS) data. Land-use data consisted of percentages of forested, agricultural, and urban land; soil drainage class specified either poorly to very poorly drained, or somewhat poorly drained to excessively drained; and basin slopes were designated as either 0-5 percent or greater than 5 percent. The classification of flow regime referred to whether the site was impounded or free flowing. Land-use data were a compilation of three land-use data sets from Washington, Chittenden, and Lamoille Counties, merged with a 1:250,000 scale 1973-76 USGS Geographic Information Retrieval Analysis System data set (Cassell and others, 1997). Forested, agricultural, and urban land uses comprise 77, 13.5, and 7.6 percent of the watershed area, respectively. Most of the urban development, and much of the agricultural land, is located along the flood plains of the Winooski River and its major tributaries (fig. 1). Slope information was generated from a USGS Digital Elevation Model (DEM) for Lake Champlain at a scale of 1:250,000 (accessed on June 20, 1997 at http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html). Seventy-two percent of the watershed had slopes of 0 to 5 percent. Most of the areas with slopes greater than 5-percent were in the middle of the watershed, which is dominated by the Green Mountains. Soils data came from NRCS soil surveys that were digitized by NRCS for the Vermont Center for Geographic Information (1997). Eleven percent of the watershed had poorly to very poorly drained soils. The poorly drained soils were primarily in the headwaters and near the watershed outlet.

Forty sampling sites were selected to represent a range of watershed characteristics (fig. 1). The land-use classification assigned to each site was based on the primary land use in the river corridor or flood plain directly upstream from the site, not that of the entire hydrologic subbasin of the site. Soil drainage and slope classification for each site is based on the soil and slope data for the hydrologic subbasin of the site (Vermont Center for Geographic Information, 1997).

Table 1. Characterization and total phosphorus concentrations of bed-sediment sites in the Winooski River watershed, Vermont

Bed-sediment site number	Bed-sediment site name	Site characteristics				Total phosphorus in fine bed sediment (milligrams per kilogram)
		Land use	Percent of subbasin with poorly drained soils	Percent of subbasin with less than 5 percent slope	Flow regime	
20	Winooski River above Mollys Brook near Marshfield	Agriculture	26	88	River	957
12	Mollys Falls Pond at Mollys Brook inlet near Cabot	Forest	26	88	Impoundment	888
21	Winooski River above Beaver Meadow Brook near Marshfield	Agriculture	24	86	River	1,016
22	Winooski River above Nasmith Brook near Plainfield	Agriculture	24	86	River	917
18	Great Brook at mouth at Plainfield	Agriculture and forest	24	86	River	711
23	Winooski River above Kingsbury Branch near Plainfield	Agriculture	24	86	River	928
17	Kingsbury Branch above North Montpelier Pond near North Montpelier	Agriculture	12	91	River	871
16	North Montpelier Pond at Kingsbury Branch inlet at North Montpelier	Forest	12	91	Impoundment	952 split 963
24	Kingsbury Branch at mouth near Plainfield	Agriculture	12	91	River	872
14	Winooski River above Levesque Dam Pool near East Montpelier	Agriculture	20	96	River	899
13	Winooski River at Levesque Dam near East Montpelier	Forest	20	96	Impoundment	877
15	Winooski River below Levesque Dam Pool near Montpelier	Urban	20	96	River	942
6	Jail Branch near Websterville	Forest	20	88	River	864
19	Stevens Branch at mouth near Montpelier	Urban	19	90	River	1,087
34	North Branch Winooski River near Worcester	Agriculture	6	70	River	860
11	Wrightsville Detention Reservoir at North Branch inlet near Worcester	Forest	6	70	Impoundment	772
35	North Branch Winooski River at Wrightsville	Forest	6	70	River	829
8	Winooski River at Montpelier	Urban	3	71	River	697
4	Dog River below Bull Run near Northfield	Agriculture and forest	8	70	River	652
5	Dog River upstream of Waste Water Treatment Plant near Montpelier	Agriculture and forest	3	64	River	978
9	Winooski River below Dog River near Montpelier	Urban	3	71	River	952
40	Winooski River above Middlesex Dam near Waterbury	Agriculture	3	71	Impoundment	1,180 replicate 985
1	Mad River at Waitsfield	Forest	6	50	River	794
2	Mad River hydro pool near Moretown	Forest	5	63	Impoundment	804
41	Winooski River below Mad River near Waterbury	Agriculture and forest	4	65	River	1,083
36	Little River below West Branch at Stowe	Urban	2	65	River	1,123
10	Waterbury Reservoir at Little River inlet near Stowe	Forest	3	52	Impoundment	898
37	Little River near mouth near Waterbury	Forest	3	52	River	1,023
38	Winooski River above Bolton Falls near Waterbury	Agriculture	2	40	Impoundment	989 split 989
39	Winooski River below Bolton Falls near Bolton	Forest	2	40	River	1,012
3	Huntington River near mouth at Jonesville	Forest	5	49	River	970
25	Winooski River above Railroad Bridge near Williston	Agriculture	11	79	River	1,059
26	Winooski River above North Williston Road Bridge near Williston	Agriculture	11	79	River	1,045
31	Winooski River at Essex 19 Dam Pool at Essex Junction	Urban	23	100	Impoundment	1,058 replicate1,032
29	Allen Brook at mouth near Essex Junction	Agriculture	23	100	River	1,067
28	Muddy Brook at mouth near Essex Junction	Agriculture	24	97	River	1,116
30	Winooski River near Essex Junction	Agriculture	24	100	River	1,062
32	Winooski River below Chase Mill at Burlington	Urban	24	100	River	1,159
33	Winooski River at Ethan Allen Homestead near Burlington	Agriculture	24	100	River	1,165
27	Winooski River at Highway 127 Bridge near Colchester	Agriculture and forest	24	100	River	1,071

DATA COLLECTION AND ANALYSIS

Samples of bed sediments were collected using USGS National Water-Quality Assessment Program protocols (Shelton and Capel, 1994) during low flow in the summer of 1997. Samples were collected in zones of sediment deposition because fine-grained sediment and organic matter are natural accumulators of phosphorus. Homogenized composite samples were sieved to collect a fine-grained sample (sediment that passed through a 62-micron-sieve diameter). At selected sites, a coarse-grained sample (sediment that passed through a 2-millimeter-sieve diameter but did not pass through a 62-micron-sieve diameter) and a sample for grain-size analysis (sediment that passed through a 2-millimeters-sieve diameter) were also collected. Grain-size distribution was analyzed by the USGS Louisiana District Sediment Laboratory. Samples were dried, crushed, and analyzed for TP by acid persulfate digestion and phosphomolybdate determination of phosphorus concentration at the National Water Quality Laboratory in Arvada, Colo. (Fishman and Friedman, 1989).

DISTRIBUTION OF PHOSPHORUS IN THE WATERSHED

The median concentration of total phosphorus in fine bed sediment in the Winooski River watershed was 957 mg/kg. The concentrations ranged from 652 to 1,180 mg/kg TP (table 1), which corresponded to TP concentrations found in bed sediment in similar locations in other studies (Colman and Clark, 1992; Harris, 1997). In the main stem of the Winooski River, concentrations of TP generally increased from the headwaters to the watershed outlet (fig. 2). The downstream increase in concentration is probably the result of a cumulative effect of runoff from agricultural and urban land, and discharge from wastewater treatment plants. The highest concentration of phosphorus (1,180 mg/kg) was detected in a sediment sample from the Winooski River adjacent to a dairy farm where cows were standing in the river. Samples with the next highest concentrations (1,159 and 1,165 mg/kg) were collected in large urban areas near the watershed outlet, and downstream from several large wastewater treatment plants. Bed sediments in tributaries generally had similar or lower concentrations of TP than sediments in the main stem, with the exception of the Stevens Branch, which flows through a large urban area (table 1).

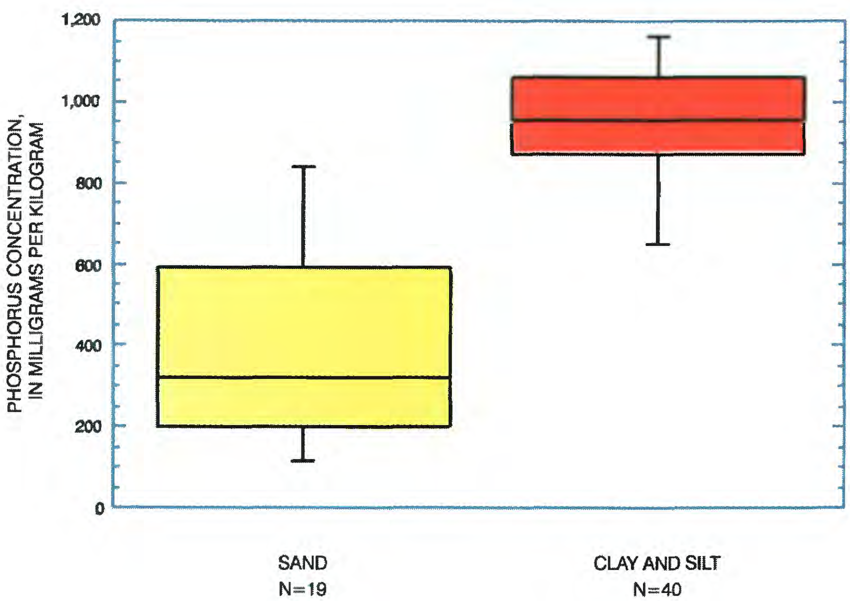

Figure 3. Phosphorus concentration as a function of grain size in bed sediment in the Winooski River watershed, Vermont. (N equals number of samples collected and analyzed to construct the box plots.)

Sites classified as urban had a median TP concentration of 1,045 mg/kg, whereas those classified as agricultural and forested had median concentrations of 1,002 mg/kg and 882 mg/kg, respectively. The relation between TP concentration in bed sediment and land use was most apparent in the small tributary watersheds with the least amount of mixed land use. Bed sediment in tributaries in heavily urbanized and agricultural areas had a median bed-sediment TP concentration of 1,087mg/kg, whereas sediment in tributaries in predominantly forested areas had a median concentration of 829 mg/kg. No relation was apparent between TP concentration in fine-grained bed sediment and soil drainage class, basin slope, or flow regime. Median concentrations of TP were 986 mg/kg for sites with poorly drained soils and 952 mg/kg for sites with well drained soils. Median concentrations of TP were 957 mg/kg for areas with slopes primarily less than 5 percent and 978 mg/kg for areas with slopes predominantly greater than 5 percent. Median TP concentrations at impounded and free-flowing sampling sites were 898 mg/kg and 970 mg/kg, respectively.

RELATION OF GRAIN SIZE TO PHOSPHORUS CONCENTRATION AND FLOW REGIME

Grain-size distribution data for bed sediment collected in depositional areas in streams and impoundments in the Winooski River watershed were analyzed to determine the relation of grain size to concentrations of TP and flow regime. A complete listing of grain-size analysis, TP concentrations, and field data is available in Coakley and others (1998). The median concentration of 957 mg/kg TP in fine-grained sediment (silt and clays) was nearly three times greater than the median TP concentration of 323 mg/kg found in coarse-grained sediment (sands) (fig. 3). Median grain-size distributions for free-flowing sites were 6 percent coarse sand, 46 percent medium sand, 48 percent fine sand, and 2 percent silt/clay. Median grain-size distributions for the impounded sites were 2 percent coarse and medium sand, 75 percent fine sand, and 13 percent silt/clay.

SUMMARY AND CONCLUSIONS

The concentration of total phosphorus in the fine-grained bed sediment of the Winooski River watershed showed a general increase downstream from the headwaters to the watershed outlet. This increase is probably the cumulative effect of the additions of phosphorus in runoff from agricultural and urban land and discharge from wastewater treatment plants. Land use appeared to be the dominant factor influencing TP distribution in sediment. Concentrations of TP were higher in bed sediment in heavily urbanized and agricultural areas than in sediments in forested areas. Concentrations of TP in bed sediment in the Winooski River watershed appear to be related to grain size; silt and clays had much higher concentrations than sands. The flow regime in the Winooski River watershed strongly influences grain-size distribution of bed sediments. Sediments in impoundments consist almost entirely of deposits of fine sand, silt and clay, whereas sediments in depositional zones in free flowing reaches of streams consist of medium and fine sands. The high percentage of silt and clay in impoundments, combined with high concentrations of TP in silt and clay, suggests that there is a significant potential for storage of phosphorus in impoundments that could be an important factor in predicting the dynamics of TP loads in the watershed.

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