A Preliminary Study of Runoff of Selected Contaminants from Rural Maine Highways

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 97-4041

Prepared in cooperation with the

MAINE DEPARTMENT OF TRANSPORTATION

MAINE DEPARTMENT OF ENVIRONMENTAL PROTECTION

UNIVERSITY OF MAINE WATER RESEARCH INSTITUTE

Augusta, Maine
1997

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CONVERSION FACTORS

Multiply	*By*	*To obtain*
foot (ft)	0.3048	meter
inch (in.)	2.54	centimeter
kilogram (kg)	2.205	pound
pound per acre per year (lb/acre-yr)	1.12	kilogram per hectare per year
cubic yard (yd^3)	0.765	cubic meter

To convert temperature in degrees Celsius (°C) to degrees Fahrenheit (°F), use the following equation:

$$°F = (1.8 \times °C) + 32$$

ABBREVIATIONS

ADT	Average Daily Traffic
EPDM	Ethylene Propylene Diene Monomer
kg	Kilograms
KPR	Kimball Pond Road
lb/acre-yr	Pounds per acre per year
MDEP	Maine Department of Environmental Protection
MDOT	Maine Department of Transportation
mg	Milligrams
NaOH	Sodium Hydroxide
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic Atmospheric Administration
NWS	National Weather Service
RT2	Route 2
RT27	Route 27
SECL	Sawyer Environmental Chemistry Laboratory
SEE	Standard Error of Estimate
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
µm	Micrometers
µS/cm	Microsiemens per centimeter

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ABSTRACT

The loads of phosphorus and total sediment in runoff from three rural highways in west-central Maine were estimated for the period September 1992 through August 1993. The estimates were made on the basis of water-quality and other hydrologic data collected at two paved highways (Routes 2 and 27) and at an unpaved roadway (Kimball Pond Road in New Sharon). The estimated loads of total sediment exported from the three study sites ranged from 36,500 to 148,000 lbs/acre (pounds per acre). Estimated total phosphorus loads ranged from 8 to 33 lbs/acre, and estimated loads of biologically-available phosphorus sites ranged from 0.9 to 2 lbs/acre.

Biologically-available phosphorus loads are highest for the unpaved study site, although this site yielded the lowest total sediment load. Analysis of sediment samples indicate a higher percentage of the biologically-available phosphorus in the smallest size frations is present at the unpaved site than at the paved site on Route 27 or at the Maine Department of Transportation sanding piles at Mercer. This suggests a large portion of the biologically-available phosphorus in road sediment at the unpaved study site has a greater potential for transport in runoff than at the paved study sites.

INTRODUCTION

Maine lakes are an important natural resource and they are considered less affected by human activities when compared with lakes nationwide. Because phosphorus is the limiting nutrient in most Maine lakes, small increases in the phosphorus loads to the lakes could result in decreased water-quality and contribute to eutrophication. The Maine Department of Environmental Protection (MDEP) has identified highways as a potential major contributor of phosphorus to streams and lakes. The Maine Department of Transportation (MDOT) has addressed the problem of sedimentation during and after road construction by implementing erosion control and site stabilization; however, the long-term problem of controlling contaminants associated with highway runoff still needs to be addressed.

Studies from other areas of the country that measured phosphorus loads from highway runoff may be inappropriate for use in Maine and New England. The Federal Highway Administration funded a study of pollutant loading and impacts of highway runoff (Driscoll and others, 1990); however, the study was conducted primarily along interstate highways in urban settings with milder climates.

The method currently being used to estimate phosphorus loads from highway runoff in Maine is heavily weighted towards urban environments and does not reflect the climate, environment, or the rural character of most of the state. In an effort to provide estimates of phosphorus loadings in runoff from rural highways in Maine, the U.S. Geological Survey (USGS), in cooperation with the Maine Department of Transportation (MDOT), the Maine Department of Environmental Protection (MDEP), and the University of Maine Water Research Institute, conducted a hydrologic study during 1992 and 1993 at three highway sites in west-central Maine. The study sites were in the Town of New Sharon, Franklin County, and the Town of Rome, Kennebec County. Two of the sites were on paved highways and the third was on an unpaved road; the two paved highway sites have distinctly different traffic volumes and the unpaved road has seasonal traffic serving several residences and a large number of summer cottages.

SITE DESCRIPTIONS

Two study sites were located in the Town of New Sharon, and one in the Town of Rome, in west-central Maine (fig. 1). The physiography of this rural region is gently rolling. Agriculture and logging are common in this region and define much of the land use and a substantial portion of the roadway use. The climate of the study area is typified by cold winters and mild summers. The average annual temperature in the study area is 41.0 degrees Fahrenheit and the mean annual precipitation is 46.25 inches (National Oceanic and Atmospheric Administration, 1993, and Thomas Hawley, National Weather Service, written comm., 1996).

The first study site, Route 2 (RT2), is located 0.5 miles west of the village of New Sharon (intersection of U.S. Route 2 and State Route 134) along U.S. Route 2. Runoff collected at the RT2 site was entirely from the highway's surface, encompassing an area from the curb to the centerline crown of the roadway and from the data-collection point to the drainage divide on the eastbound lane of the highway. Drainage area of the study site is 9,410 square feet (ft^2) and the data-collection site has an elevation of approximately 350 feet above the National Geodetic Vertical Datum of 1929 (NGVD of 1929). U.S. Route 2 is a major east-west artery in central Maine and has the most traffic of the three selected study sites. The MDOT reported an Average Daily Traffic (ADT) volume of 6,540 vehicles for this section of Route 2 in 1991 (Christine Olson, Maine Department of Transportation, oral comm., 1992). It should be noted that the entire section of the highway represented by the RT2 site was repaved between April 30, 1993 and June 9, 1993, during the period of this study.

The second site, Kimball Pond Road (KPR), is located in New Sharon, 1.3 miles south along the Kimball Pond Road from it's intersection with State Route 134. The KPR site's drainage area is 13,200 ft^2 and consists of the western half of the roadway, a ditch along the west side of the road, and a four- to six-foot-high berm along the west side of the ditch. Measurement of drainage area for this study site is not as precise as for the RT2 site because the road is constructed with gravel.

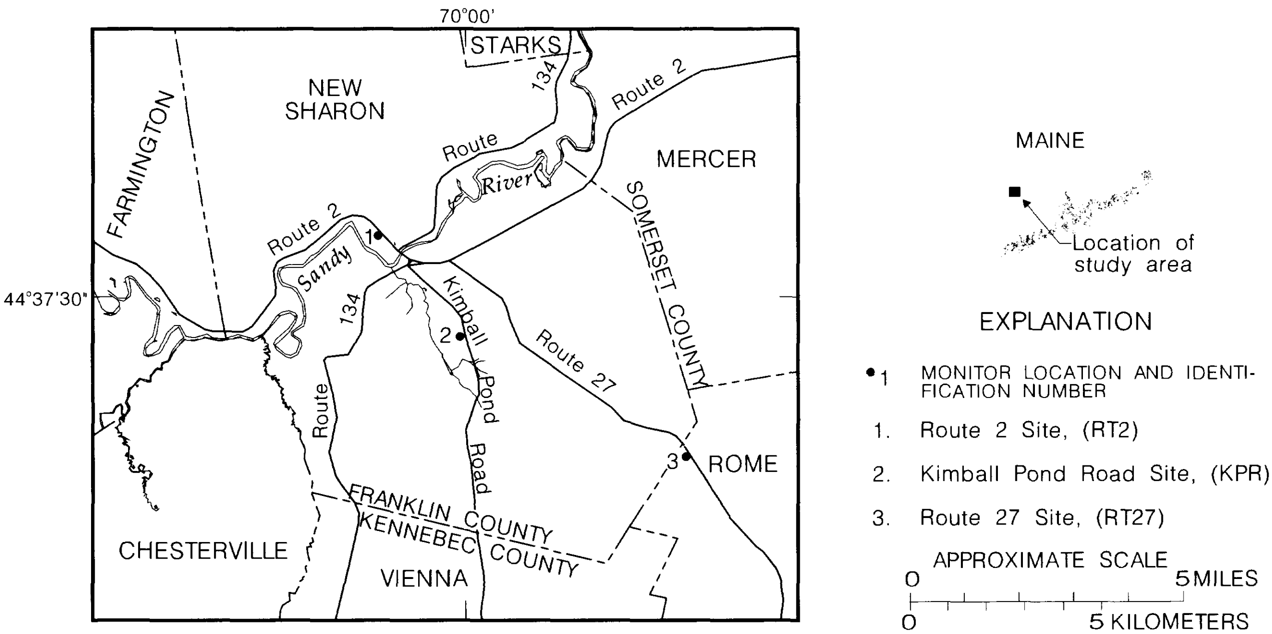

Figure 1. Location of the highway-runoff study sites in west-central Maine.

For instance, the location of the crown of the roadway changes over time due to wear and grading of the road surface. Furthermore, wheel ruts in the spring would route some of the runoff past the data-collection site, or increase contribution from other areas. The elevation of the data-collection site is approximately 540 ft. NGVD. Four hundred feet of ditch at the study site was lined with an Ethylene Propylene Diene Monomer (EPDM) membrane to prevent runoff in the ditch from infiltrating into the ground prior to reaching the gaging and sampling site.

The third site, Route 27 (RT27), is located in Rome, 0.1 miles south of the New Sharon-Rome town line along State Highway 27. The runoff collected at the RT27 site was entirely from the highway's surface, encompassing an area from the curb to the centerline crown of the roadway and from the collection point to the drainage divide on the southbound lane of the highway. The drainage area of this site is 9,160 ft^2. The elevation of the data-collection site is approximately 670 feet NGVD. The MDOT determined the average daily traffic volume to be 1,690 vehicles for this section of Route 27 in 1988 (Christine Olson, oral comm., 1992).

DATA COLLECTION

Water-quality and hydrologic data used in this investigation were obtained from measurements of dissolved orthophosphate, total phosphorus, total sediment concentrations, specific conductance, pH, rainfall, and runoff values. The sediment parameter was called *total sediment* instead of *total suspended sediment* due to the characteristics of the material collected. Some of the material in the sampled runoff consisted of particles as large as one to two millimeters. Although the particles were transported by the runoff from the roads, they would settle out quickly in water samples and therefore could not truly be considered suspended material. Data were collected over the one year period from September 1, 1992 to August 31, 1993. The physical and chemical nature of sediment collected from the shoulders of the study sites and from several MDOT winter sanding piles was also determined. All data collected during the study are available from the U. S. Geological Survey (USGS) Maine District Office in paper and electronic form.

At all three study sites, automated runoff collection-sampler units were configured identically. A sketch of the RT27 study site (fig. 2) illustrates the overall collection setup. Runoff from the highway surface was guided into a PVC intake pipe by an asphalt berm. The PVC pipe entered a wooden shelter housing the flow-measuring and sampling equipment, and drained into a debris basin. A drain in the PVC pipe allowed water and sediment to enter the sampler. The runoff then spilled into a second basin with a V-notch weir, which in turn drained into a final basin that funneled the runoff to the outlet pipe of the collection system. Water level, or stage, in relation to the V-notch weir was monitored by a nitrogen gas bubble system and pressure transducer. A data logger recorded the stage data and computed the discharge and the volume of the runoff passing the V-notch weir on one-minute intervals. The storm-water sampler pumped runoff subsamples into a single 9-liter glass jar at specified volume intervals. When the runoff event ended, the jar was removed and the flow data retrieved. Thus, a flow-weighted composite sample was collected for each sampled event at the three study sites.

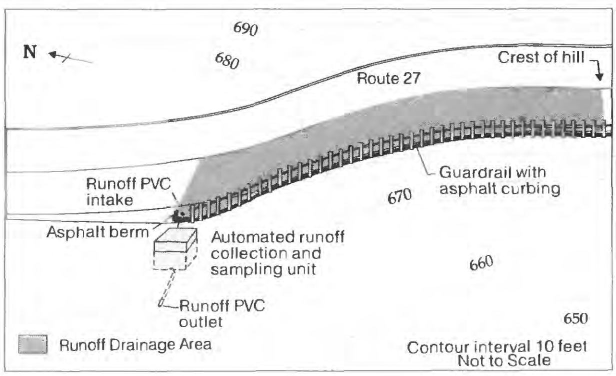

Figure 2. Highway runoff collection and sampling scheme for the Route 27 site in Rome, Maine.

Composite samples were collected by field personnel after each runoff event and split into triplicate samples using a USGS churn splitter. Triplicate samples were collected for analysis of total phosphorus, dissolved orthophosphate, and total sediment. The total sediment samples were filtered with a 1.2 µm filter, and the sediment remaining on the filter was dried and weighed. Triplicates were analyzed by University of Maine Water Research Institute (WRI) in Orono, Maine. Median values from the replicate data were used for data analysis and calculations of loads. Field analyses of specific conductance and pH were performed by USGS personnel.

In addition to the composite samples, discrete samples were collected for supplemental data at each site. The subsampling scheme used the same equivalent volume interval as the composite sampling, but each subsample was put in an individual bottle. These samples also were analyzed by WRI. To compute the load for the discretely sampled events, the "subdivided day, mid-interval method" was applied (Porterfield, 1972).

Rain gages were installed at the RT2 and RT27 sites. The KPR site was not suitable for a rainfall gage. The rainfall gage at the RT27 site was read by USGS personnel during site visits. The rainfall gage near the RT2 site was read by a local observer on a daily schedule. Rainfall data from the RT2 rainfall gage was used as the primary record for the KPR site. Rainfall data from a National Weather Service observer in New Sharon was used to check and supplement recorded rainfall data.

Samples of roadway sediment material collected from the shoulders of each of the sites, as well as samples from several MDOT winter sanding piles, also were analyzed for phosphorus content. These samples were collected by USGS and MDOT personnel and analyzed by WRI.

PHYSICAL CHARACTERISTICS OF HIGHWAY RUNOFF

Table 1 shows normal precipitation and snowfall amounts computed for the National Weather Service (NWS) station in New Sharon, Maine. Table 1 also includes precipitation and snowfall values recorded during the period of the study, September 1992 through August 1993. Study period precipitation was 77 percent of normal and snowfall was 134 percent of normal.

Table 1. Precipitation and snowfall data for New Sharon, Maine.

[Data in inches, furnished by the National Weather Service]

			September 1992-August 1993	
Month	Normal precipitation	Normal snowfall	Precipitation	Snowfall
January	3.91	22.2	1.94	11.0
February	2.66	16.1	4.31	48.3
March	4.13	14.4	4.25	39.7
April	4.10	5.8	6.29	8.5
May	3.75	0.0	1.49	0.0
June	4.05	0.0	3.55	0.0
July	3.36	0.0	1.35	0.0
August	4.06	0.0	1.78	0.0
September	3.59	0.0	3.19	0.0
October	4.29	0.3	2.68	0.0
November	4.75	5.4	3.47	1.5
December	3.60	17.3	1.17	0.5
Total Year	46.25	81.5	35.47	109.5

During the study period at the RT2 site, 25.2 inches (in.) of rain fell. Snowfall was not measured or recorded at the study site. Most of the snowfall did not contribute to measured runoff from the RT2 site because the snow was plowed beyond the guardrail and out of the runoff collection area. On the basis of average sand application data for the winter of 1992-1993, approximately 6 cubic yards (yd^3) of sand-salt mix were applied to the drainage area of this site during the study period. It is important to note that 6 yd^3 is derived from an application value averaged over 41.0 lane miles (mi.) of Route 2, from Skowhegan to Farmington Falls. The amount of sand-salt mix that was actually applied at the site is expected to be higher than 6 yd^3 because the RT2 runoff site is situated at the bottom of an incline and sand-salt mix is applied in heavier amounts on inclines (Jon Whitten, Maine Department of Transportation, oral and written comm., 1993, 1996). A total of 17,204 cubic feet (ft^3) of runoff was measured at the RT2 site. During repaving at this site, the curb was temporarily removed. Thus, for three rainfall events, June 12, 19, and 22, 1993, no curbing was in place to collect the runoff from an estimated total of 0.6 in. of rain. Partial curbing was in place for four other events, June 23, 29, July 4, and 9, 1993, during which estimated total rainfall was 0.4 in.

During the study period, 26.4 inches of rain fell at the RT27 site. Snowfall was not measured or recorded at the study site. As with RT2, much of the snowfall was plowed from the roadway before runoff occurred. Approximately 12 yd^3 of sand-salt mix were applied to the drainage area of this site during the study period. The RT27 site sand-salt estimate is expected to be closer to the actual amount applied than the RT2 estimate because it is derived from an application value averaged over only 13.6 lane mi. compared to 41.0 lane mi. for the RT2 site. (Jon Whitten, oral and written comm., 1993, 1996). The actual sand-salt application rate may be somewhat higher than the estimate because the RT27 site is located on a hill. Runoff measured at the RT27 site totalled 11,068 ft^3. The RT27 site had numerous cracks and breaks in the pavement in the area of sample collection, which could have resulted in the loss of some runoff due to infiltration.

During the study period, 24.3 in. of rain fell at the KPR site. Runoff measured during the data collection period totalled 28,554 ft^3. Of this total, about 23,400 ft^3 was from snowmelt during the spring of 1993. The amounts of sand and salt application at this site are unknown. Unlike the highway sites, the snow plowing operations on the Kimball Pond Road could not remove the snow from the drainage basin of the KPR site. The snow was plowed into the ditch and against the berm. Eighty-four percent of the runoff recorded at the KPR site was from snowmelt; this large amount may be due to the limited infiltration during periods when the ground was frozen compared to infiltration during other periods.

Total sediment concentrations in the runoff were determined for each of the sites. The total sediment concentrations in runoff at the KPR site were consistently lower than the total sediment concentrations in the runoff of the two paved highway sites. In addition, total sediment concentrations at the RT2 site were relatively low during the summer months compared to the other paved site (RT27). The repaving at RT2 in the spring could be a factor. During the repaving, all salt-sand deposits which had remained along the edge of the highway in the catchment area were removed.

Specific conductance and pH in the highway runoff was also measured. Although formal seasonal tests were not done, it is probable that the specific conductance was elevated during the winter when sand and salt were being applied to the roads. Values for pH appear to increase with increasing concentration of total sediment and total phosphorus at all three sites. Overall, the pH of the runoff at the KPR site was lower than at the two paved highway sites and was less variable. A summary of total sediment, specific conductance, and pH data at each site is shown in table 2.

Table 2. Summary of total sediment, specific conductance, and pH data, by site.
[mg/l, milligrams per liter; μS/cm, microsiemens per centimeter at 25 degrees Celsius]

Site and Physical Characteristic	Minimum	Maximum	Median	Number of samples
RT2, Total sediment (mg/l)	18	129,000	6,920	35
RT2, Specific Conductance (μS/cm)	13	6,950	33	31
RT2, pH	4.5	7.5	6.2	18
RT27, Total sediment (mg/l)	92	114,000	20,800	27
RT27, Specific Conductance (μS/cm)	7	8,640	28	29
RT27, pH	4.5	6.9	6.3	15
KPR, Total sediment (mg/l)	32	25,000	777	23
KPR, Specific Conductance (μS/cm)	11	838	34	25
KPR, pH	2.7	6.1	5.4	16

CHEMICAL CHARACTERISTICS OF HIGHWAY RUNOFF

Runoff samples were analyzed for total phosphorus, dissolved orthophosphate, and total and dissolved copper, zinc, lead, chromium, and nickel. A summary of phosphorus data for the three runoff sites is shown in table 3. Median concentrations of total phosphorus for the RT2 site and the RT27 site were similar and averaged 67 percent higher than that for the KPR site. As with physical properties, seasonal variability of chemical constituents were not evaluated.

The concentrations of all of the dissolved metals except zinc were below U.S. Environmental Protection Agency (USEPA) chronic limits for freshwater. Zinc exceeded the acute concentration of 120 micrograms per liter, based on a water hardness reference of 100 milligrams per liter of calcium carbonate, at the RT2 and RT27 sites (U.S. Environmental Protection Agency, 1991), in 6 out of 12 samples at the RT2 site, and 3 out of 9 samples at the RT27 site. Acute concentrations are higher than chronic limits.

Table 3. Summary of phosphorus concentration data, by site.
[μg/l, micrograms per liter]

	Dissolved Orthophosphate				Total phosphorus			
Site	Minimum	Maximum	Median	Number of samples	Minimum	Maximum	Median	Number of samples
	(Micrograms per liter)				(Micrograms per liter)			
RT2	< 1	98	16	24	37	17,900	1,780	41
RT27	< 1	15	4	24	70	22,400	1,760	31
KPR	1	81	6	19	27	45,500	1,060	25

Total Phosphorus and Biologically-Available Phosphorus

Total phosphorus comprises dissolved and particulate forms of inorganic and organic phosphorus (Sonzogni and others, 1982). Dissolved inorganic phosphate is the form of phosphorus that is immediately available to biota. Other forms of phosphorus become biologically-available through conversion to the dissolved, inorganic phosphate form. This conversion, which can be bacterially mediated, depends on the geochemical condition of the source water, the existing concentration of dissolved, inorganic phosphate in the water, and the rate of phosphate removal, or uptake, by algae and other biota (Cole, 1983).

The primary source of total phosphorus in the road runoff samples from this study is the particulate material or road sand. The relation between sediment contained in the runoff samples and the associated total phosphorus concentration, is shown in figure 3. The largest fraction of phosphorus in the road sand exists as inorganic phosphate-containing minerals, including apatite. Sand used on Maine roads is commonly a granitic sand, and a typical Maine granite can contain several tenths of a percent apatite. The presence of apatite in the sanding material applied to the paved study sites was confirmed using a heavy liquid magnetic separation to physically isolate apatite crystals from a sample of sand collected from the MDOT Mercer storage facility. The non-apatite forms of inorganic phosphorus that are potentially biologically-available include phosphorus adsorbed to iron and aluminum oxides, and iron and aluminum phosphate minerals. These forms of inorganic phosphates are thought to be readily converted into biologically-available phosphorus.

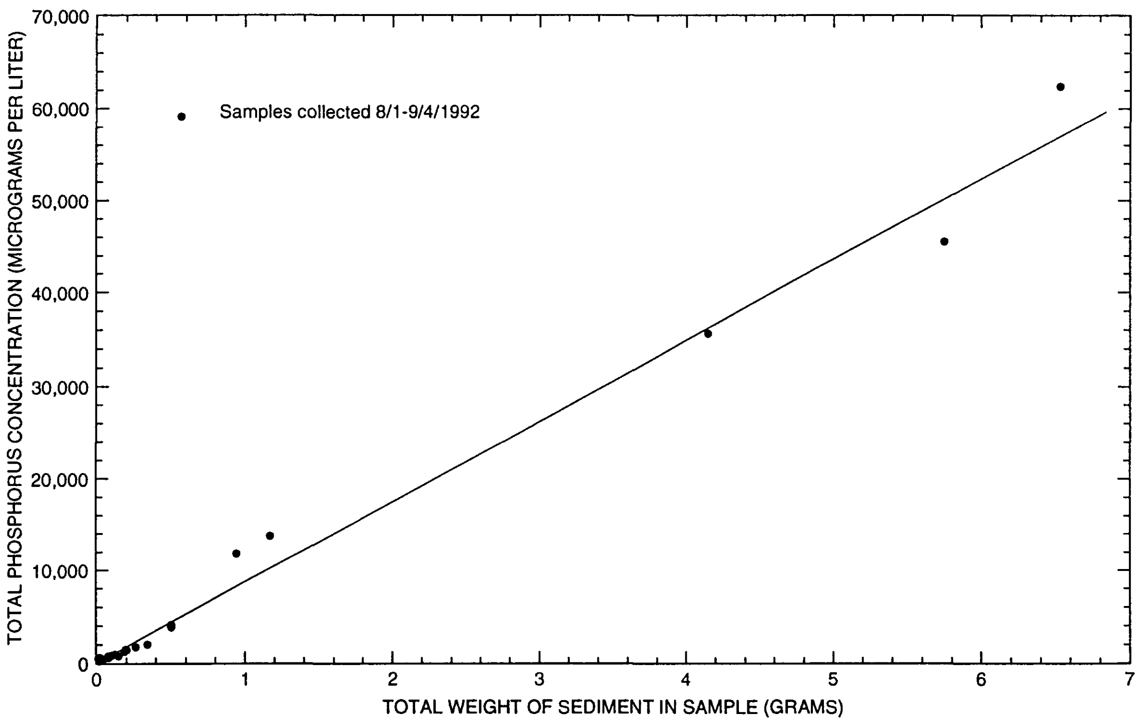

Figure 3. Relation between total phosphorus concentration and sediment weight in highway stormwater runoff samples.

Total phosphorus concentrations in runoff samples from this investigation were determined using a H_2SO_4 persulfate digestion. Apatite is soluble in a persulfate total phosphorus digestion (Chang and Jackson, 1957), but is not generally biologically-available because it is only slightly soluble in most natural waters. Though the resulting total phosphorus data set does not accurately reflect phosphorus that is typically biologically-available to algae in the short term, it does indicate a maximum total phosphorus loading. Additional sampling was done at all three sites and total phosphorus and biologically-available phosphorus were determined using the persulfate and the sodium hydroxide (NaOH) extraction methods. The non-apatite forms of inorganic phosphorus that are potentially biologically-available are thought to be readily converted into biologically-available phosphorus and are selectively extracted by a NaOH extraction (Sonzogni and others, 1982). Data obtained from the comparative extraction tests were used in concert with results of sediment analyses to develop estimates of biologically-available phosphorus loading from the year-long total phosphorus data set.

Sediment Fractionation

Phosphorus concentrations in size-fractionated samples of road shoulder and MDOT sand pile materials were determined using both persulfate and NaOH extractions to identify the relative amounts of phosphorus that are available for biological uptake compared to the total phosphorus concentrations. Three sediment samples were fractionated by size at the MDOT materials laboratory and the size fractions subsequently tested for phosphorus. A sample of the source of road sanding material for the paved runoff sites was taken from the MDOT lot in Mercer. Samples were also collected from the shoulders of the KPR and RT27 sites during the project. Sediment samples were not taken at the RT2 site because the road was repaved a few days before sediment sampling and, consequently, there was no sediment on the shoulder. The samples were dried in an oven, weighed, and split using five sieves ranging from 63 to 2,000 micrometers in mesh size to produce six sample fractions for testing (tables 4-6). The sediment size fractions were weighed, put into suspension, and analyzed for phosphorus using both the persulfate and NaOH extractions for comparison.

Table 4. Fractionation and phosphorus concentrations for a sediment sample collected May 20, 1993 from the ditch of Kimball Pond Road runoff site, New Sharon, Maine.
[µm, micrometers; mg/kg, milligrams per kilogram of sediment; --, not applicable]

Sieve mesh sizes (µm)	Sediment weight fraction (percent)	Persulfate extracted total phosphorus (mg/kg)	NaOH extractable phosphorus (mg/kg)	Persulfate extracted total phosphorus by fraction (percent)	NaOH extractable phosphorus by fraction (percent)	NaOH extractable phosphorus (percent of total P)
2000	18.6	90	29	6	5	32
425	35.5	370	69	42	23	19
250	16.0	300	100	16	16	33
150	10.8	230	130	8	14	56
63	11.1	330	170	12	18	52
PAN	8.0	600	310	16	24	52
Total sample	--	300	100	--	--	33

Table 5. Fractionation and phosphorus concentrations for a sediment sample collected May 20, 1993 from the shoulder of Route 27 runoff site, Rome, Maine.
[µm, micrometers; mg/kg, milligrams per kilogram of sediment; --, not applicable]

Sieve mesh sizes (µm)	Sediment weight fraction (percent)	Persulfate extracted total phosphorus (mg/kg)	NaOH extractable phosphorus (mg/kg)	Persulfate extracted total phosphorus by fraction (percent)[a]	NaOH extractable phosphorus by fraction (percent)[a]	NaOH extractable phosphorus (percent of total P)
2000	5.6	140	12	2	4	9
425	51.3	340	14	50	36	4
250	26.4	340	18	25	25	5
150	9.7	330	22	9	11	7
63	4.4	510	32	6	7	6
PAN	2.6	970	120	7	16	12
Total sample	--	350	19	--	--	5

Table 6. Fractionation and phosphorus concentrations for a sediment sample collected May 20, 1993 from the sanding pile at the Maine Department of Transportation lot, Mercer, Maine.
[µm, micrometers; mg/kg, milligrams per kilogram of sediment; --, not applicable]

Sieve mesh sizes (µm)	Sediment weight fraction (percent)	Persulfate extracted total phosphorus (mg/kg)	NaOH extractable phosphorus (mg/kg)	Persulfate extracted total phosphorus by fraction (percent)	NaOH extractable phosphorus by fraction (percent)[a]	NaOH extractable phosphorus (percent of total P)
2000	4.6	180	6	3	2	3
425	49.0	310	13	49	43	4
250	29.3	280	14	27	29	5
150	11.2	300	18	11	14	6
63	4.3	400	25	6	7	6
PAN	1.6	850	50	4	6	6
Total sample	--	310	15	--	--	5

a. Does not add to 100 percent due to rounding

The phosphorus data in tables 4-6 indicate that the sanding material from the MDOT lot at Mercer is similar in composition and phosphorus content to the sample from RT27. Total phosphorus appears to be related to fraction size with relatively constant concentrations in the intermediate size fractions, low in the coarse fractions, and highest concentrations in the PAN fractions for all three sites. Biologically-available phosphorus also appears to be related to grain-size fraction at all three sites, with lowest concentrations in the largest grain-size fractions, increasing in concentration with decreasing fraction size, to highest concentrations in the PAN fractions. Biologically-available phosphorus occurs in higher concentrations in all size fractions in the KPR samples than in the RT27 and Mercer sand pile samples. The KPR sediment data also indicate a higher percentage of the biologically-available phosphorus is present in the smaller fractions than in the RT27 or Mercer samples. About 42 percent of the total biologically-available phosphorus occurs in the sediment fractions less than 150 μm at the KPR study site. This suggests a large portion of the biologically-available phosphorus in road sediment at the KPR site has a high potential for transport in runoff.

LOAD COMPUTATIONS

The loads of dissolved orthophosphate, total phosphorus, and total sediment were computed for all sampled runoff, and estimated for all unsampled runoff. The number of events and total runoff volume represented by samples at each site are listed in table 7. The relatively low sampled volume at the KPR site is due to difficulty in measuring spring snowmelt at this site. Melting snow in the KPR ditch provided almost constant runoff, which continually exceeded the capacity of the composite sampling jar.

Flow-weighted mean-concentration values for dissolved orthophosphate, total phosphorus, and total sediment were used to compute a load based on the total runoff volume of each sampled event. To estimate loads for unsampled runoff, regression analyses were performed on the existing phosphorus and total sediment data using time of year, total runoff volume, runoff event duration, and mean and peak discharges as explanatory variables. The regression models explain part, but not all of the variability in the loads of the sampled runoff events. The limited number of explanatory variables and load data prevent more complete explanation of the variability in the data using regression models. A measure of this unexplained variability is the standard error of estimate (SEE). A regression model that explains most of the variability in the data will have a low SEE value. On average, about two-thirds of the measured load data is within one standard error of the regression line fitted to that data. The standard error of estimate for each of the regression models are listed in table 8 by site and constituent. For example, the value of 310 percent for the KPR total phosphorus model means that, on average, two-thirds of the measured load values used to define the regression line fall within plus or minus 310 percent of the line. The regression model used to estimate total phosphorus loads for unsampled runoff events at the KPR site is plotted as an example in figure 4.

Table 7. Number of events and total runoff sampled, by site, during study.
[ft^3, cubic feet]

Site	Total runoff volume (ft^3)	Sampled runoff volume (ft^3)	Total number of runoff events	Number of sampled runoff events
Route 2	17,204	11,506	71	44
Route 27	11,068	6,458	63	37
Kimball Pond Road	28,554	6,939	57	32

Table 8. Standard error of estimates for load-estimating regression models by site and constituent.

Site	Standard error (percent)		
	Dissolved orthophosphate	Total phosphorus	Total sediment
Route 2	103	180	396
Route 27	81	565	266
Kimball Pond Road	149	310	1,240

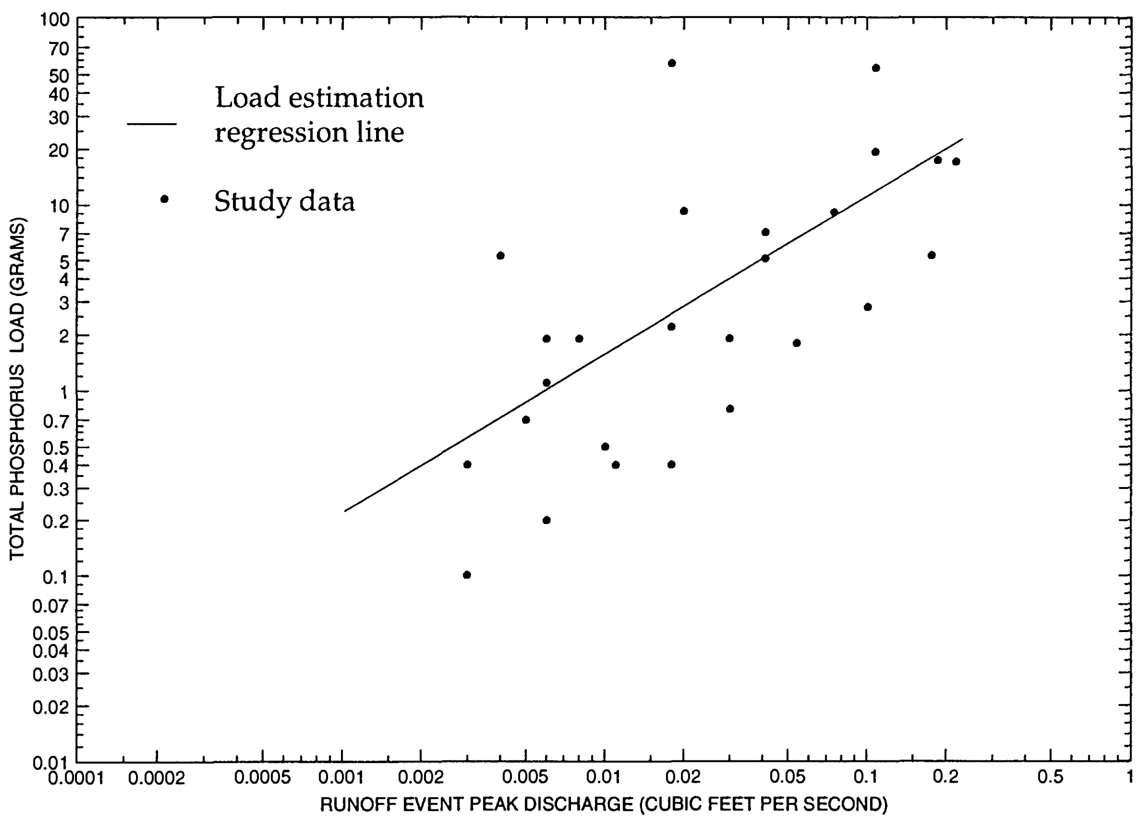

Figure 4. Regression function for estimating total phosphorus load, as a function of peak discharge, for unsampled runoff at the Kimball Pond Road site, New Sharon, Maine.

Sediment samples taken from the surfaces of the three runoff sites and MDOT sand pile storage facilities throughout the state were analyzed for total phosphorus and biologically-available phosphorus. Phosphorus data obtained from these analyses are listed in table 9.

Table 9. Total and biologically-available phosphorus data for sediment samples taken from the highway runoff sites and Maine Department of Transportation sanding piles.
[mg/kg, milligrams per kilogram]

Sample ID	Persulfate extracted total phosphorus (mg/kg)	NaOH extractable biologically-available phosphorus (mg/kg)	NaOH extractable phosphorus fraction of total phosphorus (percent)
	Highway runoff sites		
KPRS-50	270	60	22.2
KPRS-100	277	62	22.3
KPR-15	254	39	15.4
KPR-70	351	96	27.4
KPR-100	281	58	20.6
RT27-10	348	9.3	2.7
RT27-50	472	13.5	2.9
RT27-100	326	9.6	2.9
RT27-150	323	10.8	3.3
RT27-200	429	10.9	2.5
RT27-A	290	13.4	4.6
RT27-B	323	11.8	3.7
RT2-10	298	16.9	5.7
RT2-50	382	14.1	3.7
RT2-100	374	11.1	3.0
RT2-150	323	15.0	4.6
RT2-200	322	13.4	4.2
RT2-A	249	7.5	3.0
RT2-B	369	16	4.3

Table 9. Total and biologically-available phosphorus data for sediment samples taken from the highway runoff sites and Maine Department of Transportation sanding piles. --Continued
[mg/kg, milligrams per kilogram]

Sample ID	Persulfate extracted total phosphorus (mg/kg)	NaOH extractable biologically-available phosphorus (mg/kg)	NaOH extractable phosphorus fraction of total phosphorus (percent)
MDOT Sand Pile Sites			
MERCER-A	324	14.0	4.3
MERCER-B	359	9.7	2.7
MERCER-C	350	12.6	3.6
MERCER	219	15.6	7.1
Alton-51741	300	10.9	3.6
West Enfield-51472	287	7.0	2.4
Washington-51476	436	28.7	6.6
North Berwick-51473	480	39.3	8.1

These data were used to estimate the load of biologically-available phosphorus from the total phosphorus load at each site, using calculated percents of NaOH extractable phosphorus. A correction factor of 4.07 percent was obtained for the RT2 and RT27 sites by averaging the percent values for all samples listed in table 9 for those sites and the MDOT sand pile sites. These sites were combined because the composition of the sanding material at the RT27 and RT2 sites is similar to the MDOT sanding pile sediment (tables 5-6). The correction factor of 21.6 percent for the KPR site was calculated using only KPR sediment data in table 9 because particle fractionation data (tables 4-6) indicated it differed greatly from the MDOT sanding material and sediment at RT27. This correction factor method for estimating the load of biologically-available phosphorus from total phosphorus assumes sediment was transported in runoff in the same sediment particle-size proportions as it was sampled from the runoff surfaces and sanding piles.

A series of storm runoff samples collected in the spring and summer of 1995 were analyzed using both the persulfate digestion and NaOH extraction techniques to provide a second estimate of the export of biologically-available phosphorus. The resulting paired phosphorus data were used to develop site-specific relations between total and biologically-available phosphorus concentrations at each site.

Total phosphorus concentration data collected in 1992-1993 were used as input for the site-specific estimation functions to yield mean biologically-available phosphorus concentrations for each event which were then converted to loads. However, the range of the total phosphorus concentration values from the paired phosphorus samples collected in 1995 define only a small part of the range of total phosphorus concentrations seen during the study in 1992-1993. Higher total phosphorus concentrations observed in the 1992-1993 study data are not represented by the estimation functions. For this reason, the concentration of NaOH extractable phosphorus at high total phosphorus concentrations cannot be estimated with great accuracy. Estimation of biologically-available phosphorus for those high total phosphorus events was made using an extrapolation of the defined linear relationships derived from the low phosphorus concentrations sampled in 1995. Figure 5 illustrates the extrapolated linear regression estimate for the KPR site.

ANNUAL EXPORT ESTIMATES OF PHOSPHORUS AND TOTAL SEDIMENT

Estimates of the export of dissolved orthophosphate, total phosphorus, biologically-available phosphorus, and total sediment for the one year period from September 1992 through August 1993 were determined for each site by summing the individual runoff event load estimates over the study period. Export estimates for the study period are tabulated by site in table 10.

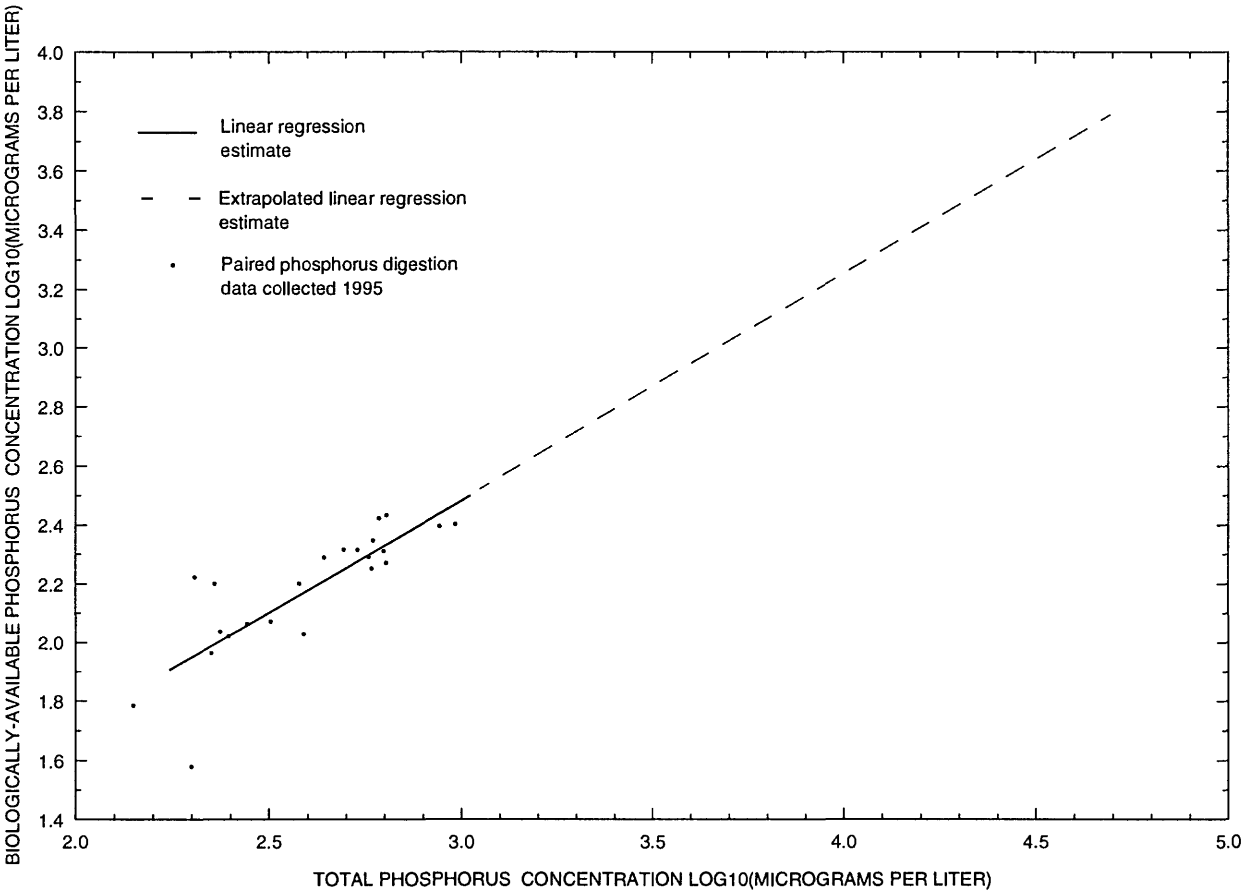

Figure 5. Paired phosphorus digestion data for 1995, illustrating the extrapolated function used for estimating biologically-available phosphorus from total phosphorus record. Kimball Pond Road site, New Sharon, Maine.

Table 10. Export estimates for dissolved orthophosphate, total phosphorus[a], biologically-available phosphorus[b], and total sediment at three highway sites in west-central Maine, September 1992 through August 1993.
[lb/acre/yr, pounds per acre per year; P, phosphorus]

Site	Dissolved orthophosphate (lb/acre/yr)	Total phosphorus (lb/acre/yr)	Biologically-available P fraction of total P (percent)	Biologically-available P (correction factor estimate) (lb/acre/yr)	Biologically-available P (regression estimate) (lb/acre/yr)	Total sediment (lb/acre/yr)
RT2	0.19	22	4.07	0.9	1	148,000
RT27	0.02	33	4.07	1.3	1	121,000
KPR	0.04	8	21.6	1.7	2	36,500

a. All phosphorus present regardless of form. This includes all types of organic and inorganic phosphorus, most of which is **not** biologically-available. This type of phosphorus is analyzed by a persulfate digestion.
b. Forms of phosphorus that are readily available for biota uptake, including P adsorbed to Fe and Al oxides and Fe and Al phosphate minerals. This type of phosphorus is analyzed by a NaOH extraction.

The MDOT currently uses a total phosphorus export value of 3.5 lb/acre/yr for road surface runoff. This value is based on data from a study that was conducted primarily along interstate highways in urban settings with milder climates than Maine (Driscoll, Shelly, and Strecker, 1990). To determine how much of the total phosphorus export will be available for algal production, the MDEP recommends an adjustment coefficient of 0.5 yielding 3.5 x 0.5 = 1.75 lb/acre/yr. (Noel, Dennis, Dennis, and Kuhns, 1992).

Results from this study indicated that for the period September 1992 through August 1993, total phosphorus loads ranged from 8 to 33 lb/acre and total sediment loads ranged from 36,500 to 148,000 lb/acre. Estimates of biologically-available phosphorus loads ranged from 0.9 to 2 lb/acre. The biologically-available phosphorus loads for each of the three sites were estimated using two different methods. The similarity between the two estimates for each of the three sites lends a measure of confidence to the techniques used.

The KPR site yielded the lowest total phosphorus load of the three sites due to runoff of total sediment that was 25-30 percent that of the paved sites. The low total sediment load at KPR is expected to be a result of infiltration of runoff into the road surface and changing runoff conditions. Sediment fractionation data indicate a higher percentage of the biologically-available phosphorus is present in the smaller fractions at the KPR site than in the sediment found at the paved sites or MDOT sanding piles. This suggests a large portion of the biologically-available phosphorus in the KPR road sediment has a greater potential for transport in runoff than at the paved sites, resulting in a higher annual load at the KPR site. These results indicate that phosphorus loadings from gravel roads is worthy of further investigation, including examination of roadway material source and particle-size composition.

LIMITATIONS OF THE STUDY

The purpose of this study was to quantify the export of phosphorus and total sediment at three highway runoff sampling sites in west-central Maine. The study period export estimates, summarized in table 10, were determined by summing measured runoff event loads and loads that were estimated using regression models.

A number of important confounding factors affecting this investigation warrant consideration for the data collected during this study and future studies of this kind:

Total phosphorus concentrations in runoff samples from this investigation were determined by using persulfate digestions. The persulfate digestion method includes all forms of phosphorus, including apatite, and yields very high phosphorus concentration values not indicative of biologically-available phosphorus. Though the resulting total phosphorus data does not accurately reflect phosphorus that is typically biologically-available to algae in the short term, it does indicate a maximum total phosphorus loading.

Snow plowing operations presented a significant problem. An unknown portion of the sand and salt applied to the drainage areas of the study sites during the winter was plowed over the guard rails at the paved sites. Because of this, the total sediment and phosphorus export estimates at the paved sites are likely to be low. At the dirt road site, snow is simply piled into the ditch and it is possible that snow from outside the drainage area contributed to runoff measured at the site.

Uncertainties in sand and salt application rates at the sites prevented normalization of the total sediment data to the amount of sand applied.

Many runoff events were unsampled or only partially sampled. Sampling units were difficult to operate 24 hours a day in extreme environmental conditions. Another problem was that runoff dynamics often exceeded programmed sampling parameters. Many events, such as drizzle or brief summer showers, were too small to be sampled or provide enough samples. Other runoff events, such as the snow melt in the ditch at the KPR site, were large enough to exceed the capacity of composite sampling jar. Multiple samplers programmed for a variety of storm scenarios and/or the use of a local observer during most runoff events could have minimized these equipment problems.

The repaving at the Route 2 site affected loads and runoff volumes during the construction period by altering the size of the catchment area. The complete effects of this construction on the Route 2 data are unknown.

SUMMARY

The effect of runoff from rural highways on the quality of water of Maine's lakes and streams is an important environmental factor in watershed planning and highway engineering design. The export of phosphorus and sediment in runoff at three highway sites in west central Maine was studied during 1992-93. Two of the sites were on paved highways and third site was on an unpaved road. The paved sites were on State Routes 2 and 27 and designated RT2 and RT27; the unpaved site was on Kimball Pond Road in New Sharon and designated KPR.

Water-quality and hydrologic data used in this investigation were obtained from measurements of dissolved orthophosphate, total phosphorus, total sediment concentrations, specific conductance, pH, rainfall, and runoff volume. Data were collected from September 1, 1992 through August 31, 1993. The physical and chemical characteristics of material collected from the shoulders of the roads and from several MDOT winter sanding piles were also determined. Analyses of the data collected for this investigation yielded estimates of loadings of phosphorus and total sediment for the three study sites during the study period.

The total sediment concentration in runoff at the unpaved KPR site was consistently lower than the total sediment in the runoff at the two paved highway sites. In addition, median total sediment concentration data at the RT2 site were lower than those for the RT27 site. The repaving at the RT2 site in the spring of 1993 could have been a factor. During the repaving, all salt-sand deposits which had remained along the edge of the highway in the catchment area were removed.

Specific conductance was elevated during the winter when roads were being maintained with sand and salt. pH increased with increasing total

sediment and total phosphorus concentrations at all three sites. Overall, pH of the runoff at the KPR site was lower than at the two paved highway sites and was less variable.

Total phosphorus concentrations in runoff samples from this investigation were determined by using the persulfate digestion method. The persulfate digestion method includes all forms of phosphorus, including apatite, and yields very high phosphorus concentration values not indicative of biologically-available phosphorus. Though the resulting total phosphorus data do not accurately reflect phosphorus that is typically biologically-available to algae in the short term, they do indicate a maximum total phosphorus loading. Data obtained from comparative extraction tests and sediment analyses were used to develop a method for the estimation of biologically-available phosphorus loading from the year-long total phosphorus data set.

The sediment analysis data indicate that the sanding material from the MDOT lot at Mercer is similar in composition and phosphorus content to the shoulder sediment sample from RT27. Total phosphorus appears to be related to fraction size with relatively constant concentrations in the intermediate size fractions, low in the coarse fractions, and highest concentrations in the smallest fractions for the RT27, KPR, and Mercer MDOT lot sites. Biologically-available phosphorus also appears to be fraction size related at all three sites with lowest concentrations in the largest fractions, increasing in concentration with decreasing fraction size, to highest concentrations in the smallest fractions. Biologically-available phosphorus occurs in higher concentrations for all fractions at the KPR site compared to the RT27 and Mercer samples. The KPR sediment data also indicate a higher percentage of the biologically-available phosphorus is present in the smaller fractions than the RT27 or Mercer samples. This suggests a large portion of the biologically-available phosphorus in road sediment at the KPR site has a high potential for transport in runoff.

Runoff samples were also analyzed for total and dissolved copper, zinc, lead, chromium, and nickel. All of the dissolved metals data were below chronic Environmental Protection Agency (EPA) limits for freshwater, except zinc which exceeded both the chronic and acute concentrations at the RT2 and RT27 sites. The higher acute concentration limit of 120 micrograms per liter, based on a water hardness reference of 100 milligrams per liter of calcium carbonate, (USEPA, 1991) for zinc was exceeded in 6 out of 12 samples at the RT2 site and in 3 out of 9 samples at the RT27 site.

Phosphorus and total sediment loads were computed for all sampled runoff, and estimated for all unsampled runoff. Flow-weighted mean-concentration values for dissolved orthophosphate, total phosphorus, and total sediment were used to compute a load based on the storm volume of each sampled event. To estimate loads for unsampled runoff, regression analyses were performed on the existing phosphorus and total sediment data using time of year, total runoff volume, runoff event duration, and mean and peak discharges as explanatory variables. The regression models explain part, but not all of the variability in the loads of the sampled runoff events. The limited number of explanatory variables and load data prevent full explanation of the variability in the data using regression models. Biologically-available phosphorus loads were estimated based on sediment analyses and paired phosphorus data. Annual loads for phosphorus and total sediment were determined for each site by summing all of the runoff event load estimates over the annual study period.

The estimated total sediment loads exported from the three study sites during the one-year study period ranged from 36,500 to 148,000 lbs/acre. Study period total phosphorus loads ranged from 8 to 33 lbs/acre. Study period estimates for biologically-available phosphorus loads for the sites ranged from 0.9 to 2 lbs/acre. For watershed planning, the MDOT currently uses a biologically-available phosphorus estimate of 1.75 lb/acre/year for road surface runoff.

Load estimates from this study indicate that phosphorus loadings from gravel roads is worthy of further investigation, including examination of roadway material source and particle-size composition.

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