LAND USE EFFECTS
ON HUDSON RIVER TRIBUTARIES

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by

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ABSTRACT

Thirteen tributaries of the Hudson River were studied to quantify the effects of land use on water quality. Water samples were taken from these streams biweekly from June to September 1991. Nitrate, phosphate, chloride, sulfate, temperature and total suspended solid (TSS) levels were analyzed. For each of the thirteen watersheds land use information was obtained, and expressed as percentages of urban, agricultural and forest land use. The effect of land use on the water chemistry parameters was determined by regression analysis.

Nitrate, chloride and sulfate concentrations and temperature all increased with increasing urbanization. Sulfate and TSS concentrations increased with the amount of agriculture in the watershed. Phosphate concentrations showed no effects of either land use.

The regression results suggested small increases in urbanization in previously forested watersheds can produce disproportionately large changes in stream water quality. This information can be used by local and regional planners to help assess the potential effects of urban development.

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INTRODUCTION

Natural waters in populated areas are influenced by human activities in many ways. This influence is a topic that is demanding the attention of environmental and urban planners. In the 1970's and 1980's, resolution of point source pollution has been the primary focus of water quality protection efforts. In recent years, the topic of nonpoint source pollution, which can increase sediment and nutrient loads in surface waters, has received more attention. This study was primarily concerned with nonpoint land use effects on Hudson River tributaries.

Studies have shown that significant modification of stream water occurs due to deforestation and land use practices (Likens and Bormann, 1975 ; Howells and Merriman, 1986 ; Jordan et al., 1986 ; Perry and McIntyre, 1986). Paved streets and roads constitute a large percentage of urban area, reducing the surface area of exposed soil and decreasing the land's capacity to absorb water, nutrients, pollutants, and other chemicals. The materials that are present in roadway runoff arise from a variety of sources which include road-surface degradation, vehicle exhaust emissions, vehicle load loss, and road-surface cleaning and de-icing compounds (Perry and McIntyre, 1986). Quarries and gravel pits increase the amount of suspended solids in waterways increasing the amount of sediment deposition

(Hammerton, 1986). Sediment deposition makes the water system shallower and wider, raising the temperature and changing the foraging and spawning habitat for the fish (Smith, 1966). The sedimentation itself may directly harm the eggs and young of spring spawning trout (Brewer, 1988). Eutrophication can result from poorly maintained septic systems, fertilizers applied to lawns, gardens and croplands, and pet wastes and manures.

This study concerns land use in Hudson Valley watersheds and how it affects certain parameters of water chemistry in Hudson River tributaries. Studies investigating the Hudson River's tributaries are important in determining the health of the river itself. Limburg and Schmidt (1990) showed that the Hudson River alewife population is sensitive to processes within the tributary watersheds, including urbanization. Their data demonstrate an effect of urbanization on anadromous fish spawning success. The land-use parameter explained a significant amount of the variability in fish egg and larval densities.

I chose this topic because land use is changing rapidly in the Hudson Valley and because there is little literature on this subject. To examine the effects of land use, I used a cross watershed comparative analysis examining streams with a range of different land uses (urban, forested and agricultural) within their watersheds.

I hypothesized that land use would affect stream water

quality in several ways. Relative to streams in forested watersheds, agricultural streams were expected to have higher concentrations of nitrate and phosphate due to fertilizer inputs and increased suspended solids resulting from erosion. In addition, temperature in agricultural streams was expected to be higher due to the lack of canopy cover over the stream channel as well as the widening and shallowing of the stream as a result of increased sedimentation. Streams draining urbanized watersheds were expected to have higher concentrations of nitrate, phosphate, chloride and sulfate and higher temperatures than agricultural streams, for several reasons. 1) Roads, pavement, and other impervious surfaces decrease the surface area of the soil so that natural inputs of nutrients and other chemicals run off directly into the streams. The higher road density also increases the amount of chloride and sediments in the streams due to salting and de-icing compounds used on the roads. 2) Septic systems in populated areas often affect water systems, by causing elevated chloride, sulfate, nutrient pollution, and suspended sediments. 3) Coal combustion results in sulfur dioxide (SO_2) emissions, which raise sulfate (SO_4^{2-}) concentrations in rain and potentially in surface waters. However, coal combustion is not a ubiquitous characteristic of urbanized watersheds, and "acid rain" can be deposited in watersheds far from the source of pollutants. 4) The reduction of canopy over streams in urban settings can raise the temperature of the stream water.

The purpose of this research was to determine how the chemistry of Hudson River tributaries is affected by land use within their watersheds. This information is important for environmental protection and planning in the Hudson Valley and for helping to assess the health of and to manage the resources of the Hudson River.

METHODS

Thirteen tributaries of the Hudson River estuary were studied (Figure 1). Fifteen tributaries were sampled during the summer of 1991 and stream water quality data exists for all, but two (Stony Creek and Saw Kill) are lacking land use data and will not be considered in this report. The streams studied are all on the east side of the river, ranging from Tarrytown (Westchester County) to mid-Columbia County. These streams were chosen by three main criteria: 1) land use, to get a good range in land use types among the tributaries 2) size, such that the streams were small enough to sample easily but were perennial, and 3) accessibility. Each of the 13 streams were sampled biweekly under baseflow conditions for a total of 5 samples during summer 1990. Stormflow was also sampled. Only 4 of the 13 streams were sampled during storm events because of the time constraint of sampling the streams at approximate peak discharge times during the storm.

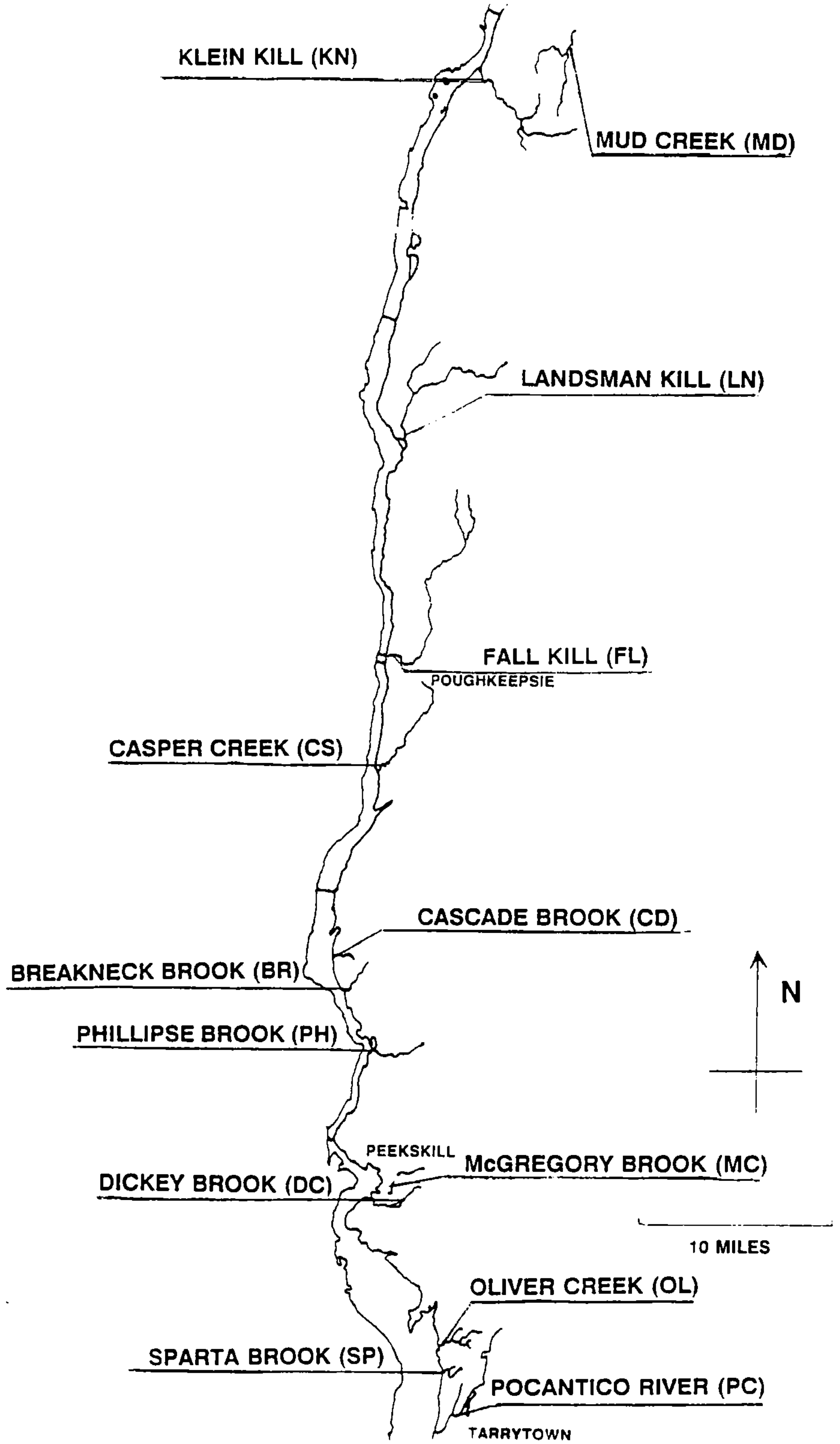

Figure 1. The Hudson River and the tributaries that were studied. The codes that will be used to identify the streams in future graphs are shown in parentheses.

Due to lack of rain, only two storm events were processed during the sampling period; consequently this paper will focus on the baseflow data. For more information on the effect that storms have on the concentrations of solutes and particulate material in discharge see the extensive study carried out on the East Branch of Wappinger Creek, New York by Ma (1990).

Water samples were collected manually and returned to the laboratory for analysis. The parameters of water quality that were measured were nitrate (NO_3^-), phosphate (PO_4^{3-}), chloride (Cl^-), sulfate (SO_4^{2-}), total suspended solids (TSS) and temperature. The temperature was measured on site, as was stream discharge. Depth measurements were made at 0.1 - 1 meter intervals across the stream, depending on the stream width. Stream widths varied from 0.40 - 14.0 meters at the sampling sites, and the intervals ranged from 5.3 to 25 percent of the stream width. Cross-sectional area of each interval was calculated from the depth and the interval width using a trapezoid approximation. Flow velocity was measured in each interval at 1/6 the depth using a Marsh/McBirney 201m electronic current meter. Discharge was calculated from the flow and the cross-sectional area. Discharge for all stream intervals were summed to calculate the discharge for the entire stream.

Concentrations of nitrate, chloride, and sulfate were

measured using a Dionex 2000i ion chromatograph with an AS4 column. Phosphate concentrations were measured using the phosphomolybdenum blue technique on a Technicon autoanalyzer (EPA, 1987). Total suspended solids were measured by filtering a known volume of a sample through a preweighed Gelman A/E glass fiber filter. These filters were then dried and reweighed to determine the total weight of the seston. Filtering of the samples took place within 48 hours of collection, and the filtrate was stored at 4°C until chemical analysis could be completed (usually within one week). All stored samples were preserved using two to three drops of chloroform.

The watersheds of the 13 streams fell within 4 different counties. The land use information was drawn from various sources in the different counties. For the most part, land use information was mapped from aerial photographs provided by county planning departments. The aerial photographs ranged in scale from 1 inch:200 feet to 1 inch:1000 feet and were taken between 1983 and 1990. Maps were made by overlaying tracing paper on the photographs and coding the different land use types within the watersheds. Watershed boundaries were designated either from existing watershed maps or standard U.S.G.S. topographic maps.

The watersheds of these tributaries were divided into three basic land uses: forest, urban, and agriculture.

Norvell et al. (1979) showed that using six land use categories (very low, low, and medium to high density urban areas, wooded areas, water surface, and agricultural land) instead of three categories did not improve the prediction of phosphorus concentrations in lakes. I included both forested areas and uncultivated meadows in the forest category. Row crops, orchards, hay fields and pasture lands came under the agricultural land use category. Urban land use contained all residential areas, commercial areas, institutional land and all major roads.

The traced watershed maps were photocopied to standardize their weights. Each of the photocopied maps were then cut into pieces corresponding to land use units, and the pieces were weighed to determine the area of each land use in the watershed.

The land use data for the streams in Westchester County were gathered from a combination of aerial photographs and the County's Geographic Information System (GIS). The GIS gave the bulk of the needed data, and the aerial photographs were used to map areas that were ambiguously classified in the GIS.

RESULTS

The percentage of each land use type was calculated for each of the 13 watersheds (Figure 2). Cascade and Breakneck Brooks (CD and BR) are the least urbanized

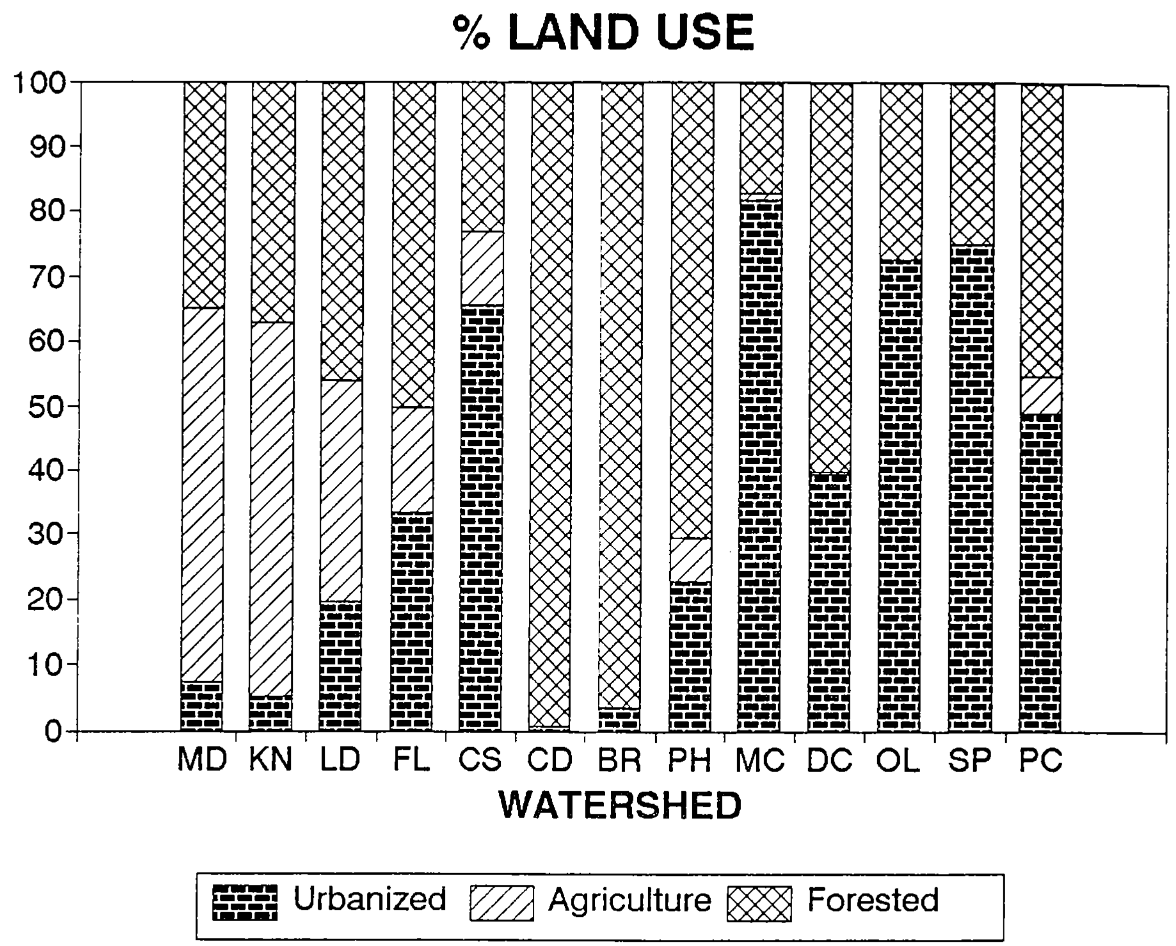

Figure 2. Percentages of agricultural, urbanized and forested land use in each watershed. See Figure 1 for watershed codes.

watersheds; they are almost completely forested. Because the natural vegetation of this region is forest, I use these watersheds to represent relatively undisturbed stream water chemistry. Klein (KN) and Mud (MD) Creeks also have a low amount of urbanization in their watersheds, but they are primarily agricultural watersheds so their characteristics are quite different. Among the more urbanized watersheds, Casper Creek (CS) runs through Poughkeepsie, Oliver Creek (OL) goes through the city of Ossining, McGregory Brook (MC) is a small stream that runs through Peekskill, and Sparta Brook (SP) is another small stream that goes through southern Ossining. Dickey Brook (DC), runs through part of Peekskill, but a large portion of the watershed is in the undeveloped Blue Mountain Reservation in southern Peekskill. The other watersheds have a more even distribution of land uses.

Table 1. Results of regressions of each parameter measured versus percent urbanization for the ten non-agricultural streams. The independent variables in the regressions were the mean concentration (mg/L) or mean temperature (°C) of the five baseflow samples for each stream. The P value represents the significance of the overall regression. Results are generally considered significant if $P<0.05$.

Parameter	R^2 (%)	Slope	P
NO_3^-	54.2	0.0364	0.0151
PO_4^{3-}	23.7	0.00128	0.154
Cl^-	42.5	0.708	0.0412
SO_4^{2-}	41.9	0.212	0.0429
TSS	9.47	0.00307	0.387
Temp.	50.5	0.0265	0.0213

The effect of urbanization was evaluated by regressing the streamwater parameters against percent urbanization in the watersheds. To show the effect of urbanization without accounting for agriculture, watersheds with more than 20% agriculture were not included in this initial regression analysis. The results of these regressions are summarized in Table 1. The regression lines in the graphs that follow Table 1 reflect these analyses. Figure 3 shows the mean baseflow concentration of NO_3^- versus the percent urbanization in the in each of the watersheds. A trend of increasing NO_3^- with increasing urbanization is reflected on the regression statistics of Table 1. Figure 4, Cl^- versus urbanization, also shows this trend. The Fall Kill (FL) stands out in Figure 4 because of its high Cl^- concentrations but relatively low urbanization. This stream runs through the

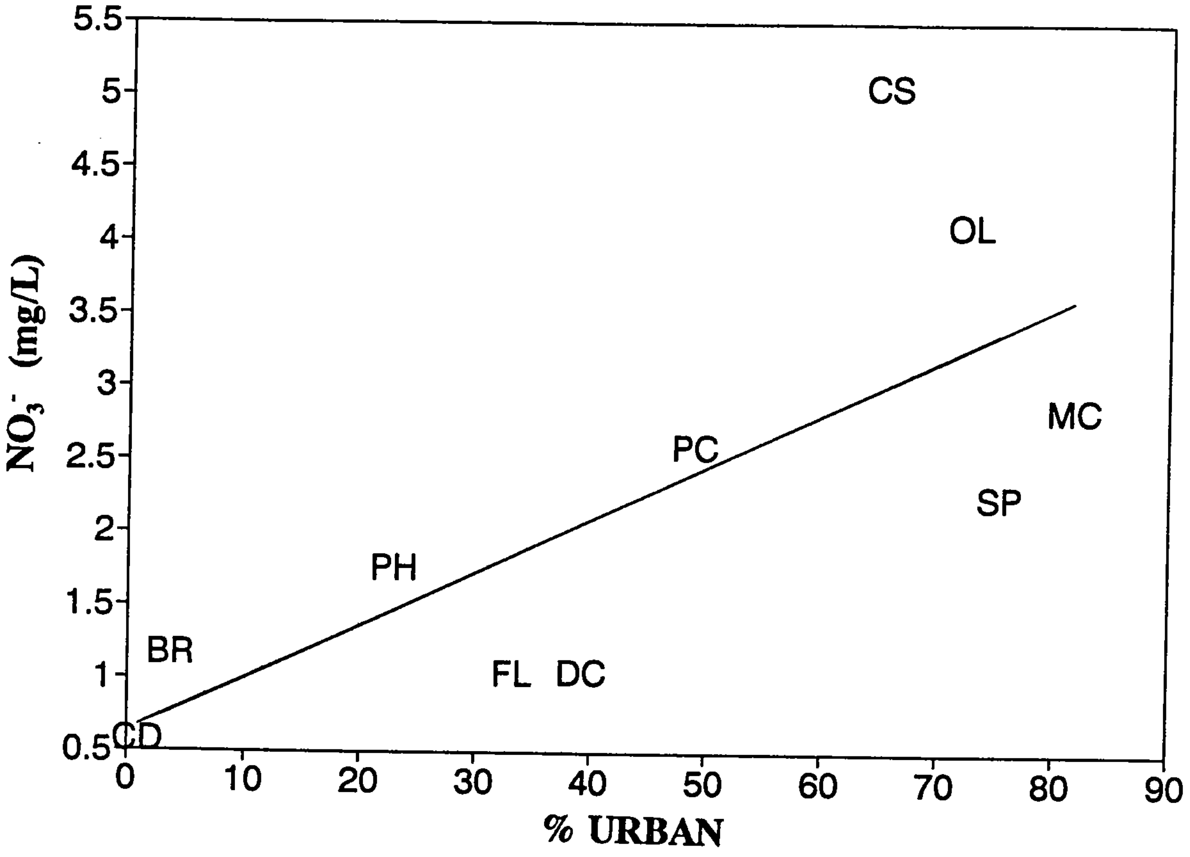

Figure 3. Graph of the average baseflow nitrate concentration versus the percent urbanization in the watersheds. For a key to the tributary code names, see Figure 1.

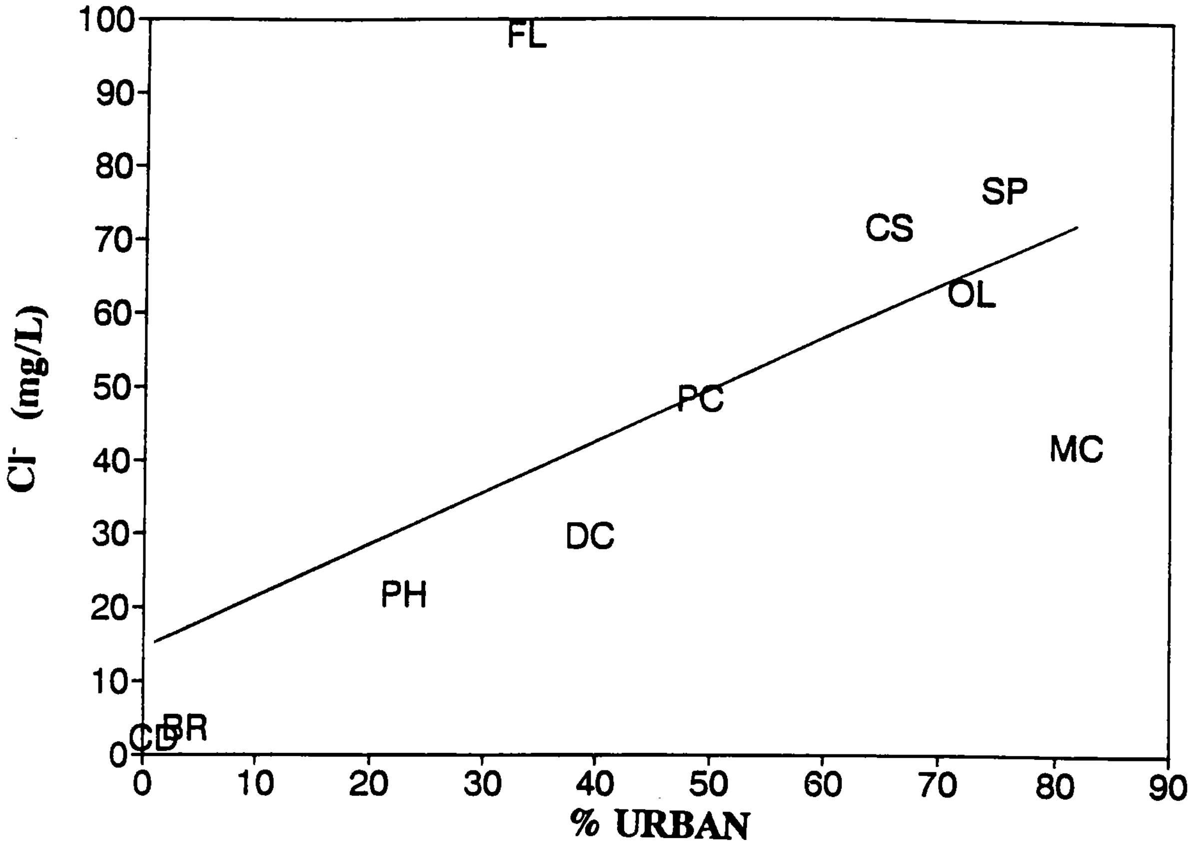

Figure 4. Graph of the average baseflow chloride concentration versus the amount of urbanization in the tributary watershed.

middle of Poughkeepsie and Hyde Park and has a high road density near the sampling site. This fact or some industrial process near the stream might account for this anomaly. Temperature also showed a significant correlation to increasing urbanization (Figure 5; Table 1). At the point Dickey Brook (DK) was sampled it had gone through a portion of the Blue Mountain Reservation, and this forested area may have cooled the stream. Sparta Kill (SP) also had a somewhat low temperature given its urbanization, perhaps because it flows underground for part of its route through the city of Ossining.

Urbanization had a significant effect on nitrate, chloride, and sulfate concentrations as well as temperature (Table 1). Although these results are statistically significant, urbanization only explained approximately 50% of the variance in these parameters.

To evaluate the combined effects of urbanization and agriculture, multiple regressions were performed using all 13 watersheds (Table 2). These data are not particularly powerful for examining agricultural effects because I sampled only three watersheds with substantial percentages of agricultural land use. Of the parameters tested, only SO_4^{2-} and TSS showed a significant effect of agriculture. TSS varied significantly with the amount of agriculture in the watershed, but not with the amount of urbanization. The

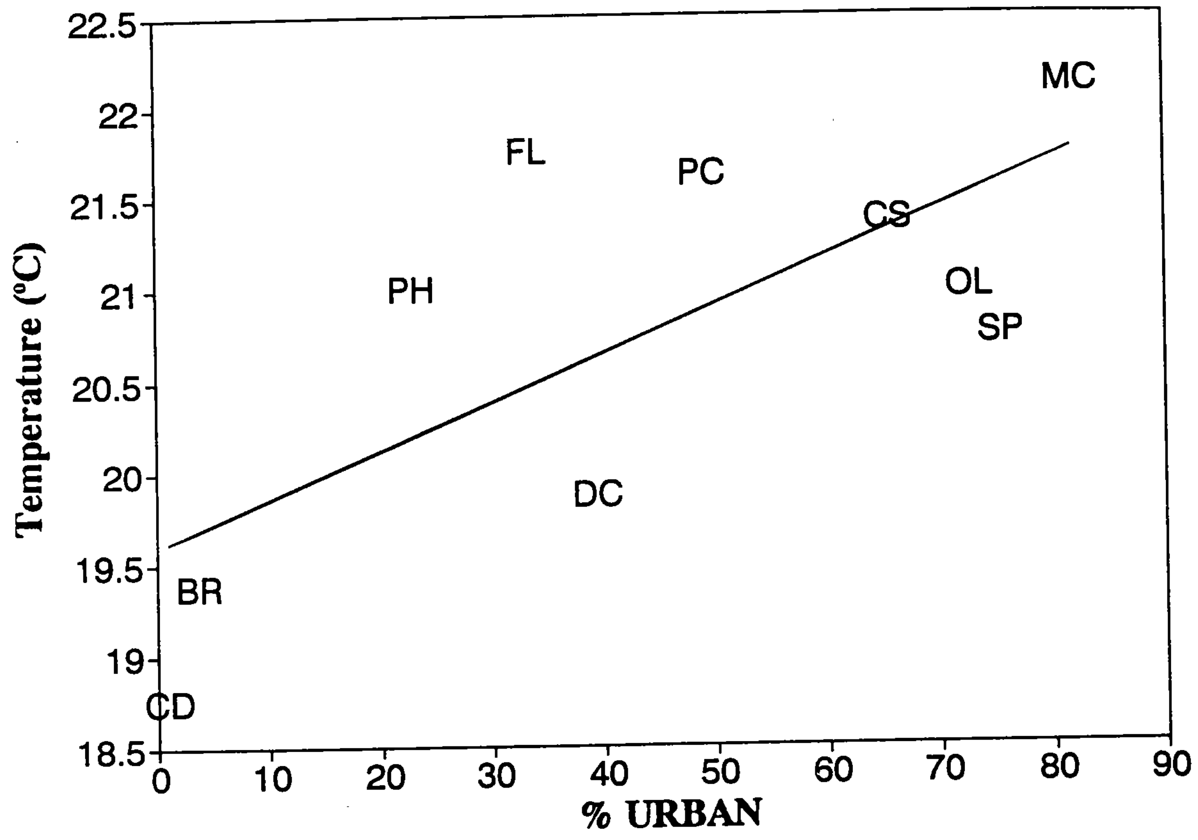

Figure 5. Graph of the mean temperature of the tributaries during baseflow versus the amount of urbanization in the watershed.

Table 2. Results of multiple regression of each parameter measured versus increase in urbanization and agriculture. Results include all 13 streams and represent the mean concentration for the baseflow data.

Parameter	R^2 (%)	slope (urb)	slope (ag)	P (overall)	P (urb)	P (ag)
NO_3^-	53.9	0.0376	0.0156	0.0208	0.0075	0.339
PO_4^{3-}	27.1	0.00137	0.000737	0.206	0.0851	0.475
Cl^-	50.9	0.791	0.262	0.029	0.0116	0.476
SO_4^{2-}	51.8	0.228	0.308	0.0259	0.0166	0.0186
TSS	43.0	0.00304	0.0114	0.0603	0.339	0.0217
Temp.	36.7	0.0126	0.0301	0.102	0.0456	0.102

concentration of SO_4^{2-} in the watershed was affected significantly by both the amount of urbanization and agriculture in the watershed. The graph of SO_4^{2-} versus the percent urbanization in the watershed is shown in Figure 6. Klein (KN), Landsman (LD) and Mud (MD) Creeks have highly agricultural watersheds. They all had high SO_4^{2-} concentrations and low urbanization. McGregory Brook (MC) is

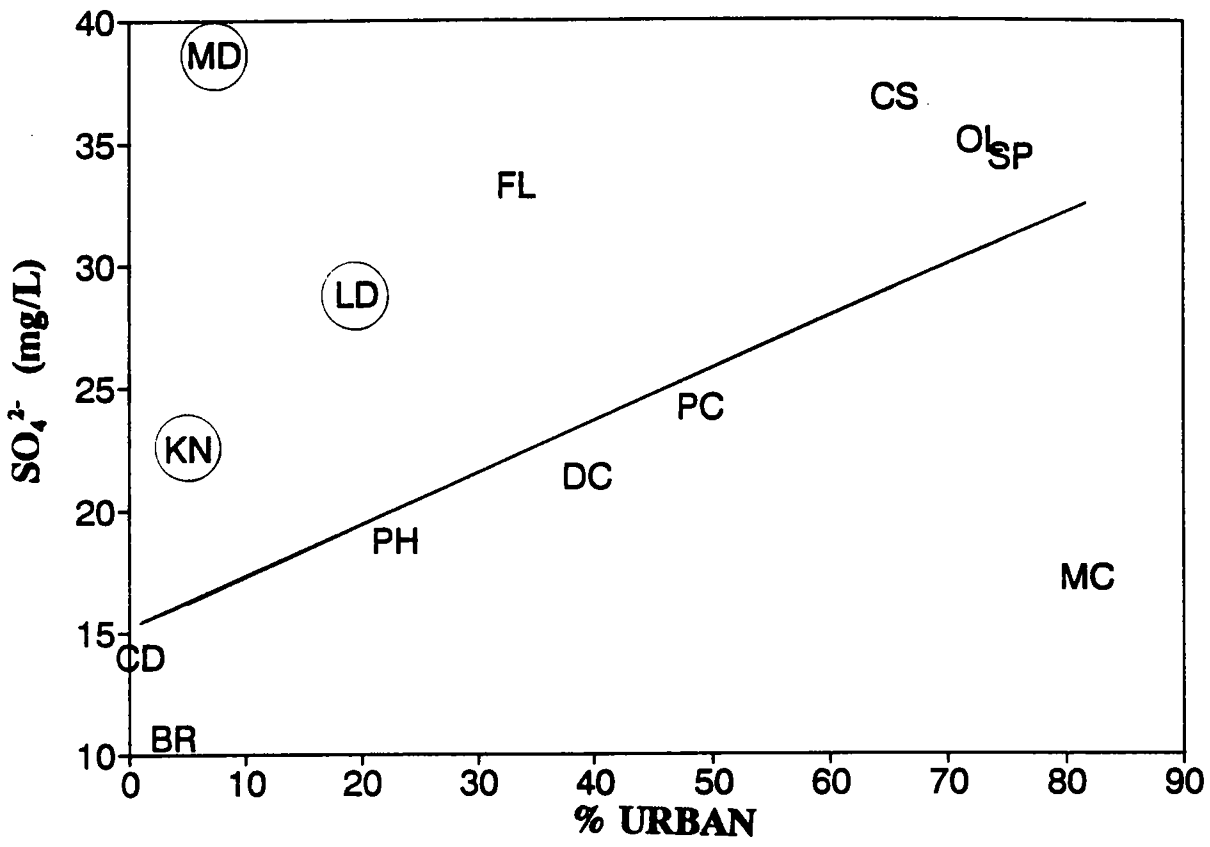

Figure 6. Graph of mean baseflow concentration of sulfate versus the amount of urbanization in the watershed. Regression line reflects the simple regression analysis from Table 1. The three highly agricultural watersheds (circled) are not included in this regression analysis.

the watershed with the highest percentage of urbanization but it had one of the lowest SO_4^{2-} concentrations, for reasons unclear to me. Surprisingly, phosphate did not vary significantly with either urbanization or agriculture in the watershed. Adding the agricultural streams into the analysis and using agriculture as an independent variable increased the R^2 more than 5% for Cl^-, SO_4^{2-}, and TSS, but decreased the R^2 for temperature.

DISCUSSION

The effect of urban development in large river systems is complex. Direct responses to urbanization are superimposed on responses to the natural environment. As a result, a natural pattern, such as variation in stream chemistry in response to bedrock type, may be either amplified or obscured by urbanization. None the less, studies on the urbanization of watersheds have important implications for both improved management of human dominated landscapes and for improving understanding of ecological phenomena (Limburg and Schmidt, 1990).

Nitrate levels in the streams that I studied were affected by urbanization in the watershed and not by the amount of agriculture. An increase in the nitrate levels with agriculture had been hypothesized before the study began, mainly from consideration of row crop agriculture

where fertilization and plowing are common. Young (1986) found the effect of plowing established grass in normal farming systems was to release between 200 and 400 kg of N/ha/yr that leaches into groundwater.

It has been shown by Peierls et al. (1991) that human population density in a watershed is a good predictor of river nitrate concentrations and export for large rivers of the world. Human influences on river nitrate range from sewage loading and atmospheric deposition, to agriculture and deforestation. Peierls et al. (1991) found the sewage loading in the watersheds of the rivers they studied to be roughly the same magnitude as the nitrate exported from the rivers. A significant relationship was also found in this same study between atmospheric nitrate deposition and river nitrate concentration.

In this study concentrations of chloride also showed significant increase in response to urbanization. This could be due to de-icing compounds used on roads (Perry and McIntyre, 1986), landfill leachate (Parsons, 1986), sewage or possibly water softeners. Sulfate is also present in leachate from landfills (Parsons, 1986) and in sewage. Sulfate levels in this study increased in both urban and agricultural areas. The increase in sulfate in the agricultural areas could have been due to the same factors mentioned above that are associated with urban growth. However, sulfur is sometimes applied as a fertilizer, but I do not know if it was being used in the watersheds I studied. Sulfur can also be released during weathering of certain types of rocks, but the watersheds we sampled included both metamorphic (Westchester and Putnam Counties) and sedimentary (Dutchess and Columbia Counties) rocks. The patterns in sulfate concentrations do not appear to reflect bedrock type.

Total suspended solids were shown in this study to increase significantly in response to increases in agriculture, but not to urbanization. The agricultural effect may be due to erosion from plowed fields. Quarries in watersheds also increase sediments in the watersheds (Hammerton, 1986). In Mud Creek, one of the agricultural watersheds, a small portion of the watershed included part of a gravel quarry.

Concentrations of phosphate showed no significant effect of either urbanization or agriculture, despite the fact that past studies have shown such effects. Dillon and Kirchner (1975) showed that forested watersheds export an average of 4.8 $mg/m^2/yr$ of total phosphorus and watersheds with forests and pastureland export 11.0 $mg/m^2/yr$. They also showed that geology affects total phosphorus levels in that forested watersheds on igneous rock exported 2.5-7.7 $mg/m^2/yr$ while those on sedimentary rock exported 6.7-12.2 $mg/m^2/yr$. The similar magnitude in these numbers illustrated that a change from forest to mixed forest and pasture in a watershed of

igneous bedrock had a similar effect on the total phosphorus export as a change from igneous forested to sedimentary forested watersheds. Intensive agriculture was also shown by Dillon and Kirchner (1975) to increase phosphorus export from watersheds. An agricultural watershed on sedimentary rock had a total phosphorus export of 46 $mg/m^2/yr$, double the export of forest/pasture watersheds on sedimentary rock. In other agricultural watersheds Jaworski et al. (1969) found that 32-80 $mg/m^2/yr$ of PO_4^{3-}-P was exported. Owen and Johnson (1966) measured total phosphorus export of 17-35 $mg/m^2/yr$ in sedimentary rock watersheds that were used mostly for agriculture, while watersheds of similar rock type but with urban land use exported 1370-1660 $mg/m^2/yr$.

In urban areas a significant amount of phosphorus in streams is from sewage. D'Ermilio (1985) showed that phosphorus inputs from the Millbrook Municipal Sewage Treatment plant effluent cause a significant increase in the levels of total phosphorus in the stream. The capacity of a stream to buffer the effects of nutrient inputs and to protect the river downstream is determined by many factors such as the amount of previous inputs, the health and size of the plant and microbial communities near or in the stream, and the type of stream bed (McColl, 1974). Other factors that affect phosphorus levels are human population density, which would raise the concentration of phosphorus, and the presence of lakes and wetlands along the stream, which can act as nutrient traps, decreasing the export of phosphorus (U.S. Congress, 1984). Although PO_4^{3-} concentrations did not vary significantly with either urbanization or agriculture in this study, we noted the stream with the highest concentration of PO_4^{3-} was a highly urbanized watershed (CS). In general the urbanized watersheds had higher concentrations of PO_4^{3-} than the agricultural watersheds, and certainly have higher concentrations than the forested watersheds (Figure 7).

The regression coefficients in Table 1 permit a rough quantitative prediction of the effects of urbanization on stream chemistry. For example, the regression equation indicates that a 10% rise in urbanization in a forested watershed would lead to a 0.36 mg/L rise in NO_3^- levels in the stream. Cascade Brook, the least urbanized watershed, has a mean NO_3^- concentration of 0.57 mg/L. If only 10% of this watershed was urbanized the regression results predict that the concentration would go up to 0.93 mg/L, a 60% increase. Similar predictions could be made for other variables in Table 1. It must be remembered, however, that many factors control stream water chemistry, and only 50% of the variance is explained by these regressions.

Why are these changes in streamwater quality important? First, although I sampled small streams to facilitate

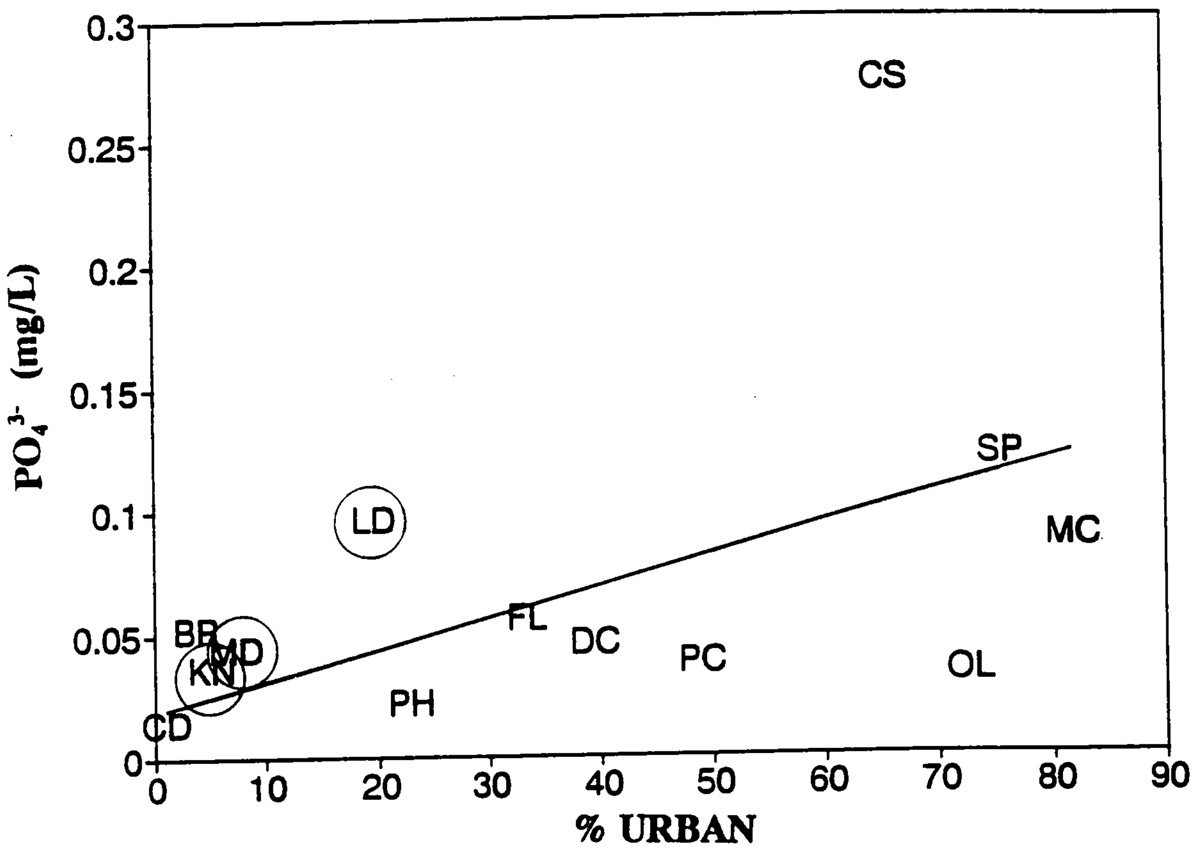

Figure 7. Graph showing the mean baseflow concentrations of phosphate versus the percent urbanization in the watersheds. Regression line reflects the simple regression analysis of Table 1 (P = 0.154). The three highly agricultural watersheds (circled) are not included in this regression analysis.

classifying the watersheds, I presume that the same general effects would be manifested in larger streams which may serve as municipal water supplies or sport fishing resources. Pollution of these streams could therefore directly affect human activities. Addition of nutrients like NO_3^- and PO_4^{3-} promote algal growth in the streams and alter existing food webs. Sediment pollution can alter fish habitat and spawning success (Smith, 1966).

The impact of these results on the Hudson River itself is less clear and deserves further study. Export of sediments and other pollutants to the Hudson probably occurs mainly during stormflow events and this study is primarily concerned with baseflow. However, it seems reasonable to hypothesize that the effects seen here will be evident, and perhaps even amplified, in stormflow conditions. In this case, if we consider the small watersheds to be representative of the whole, land use in the watershed will have a major impact on the quality of water in the Hudson River.

CONCLUSIONS/RECOMMENDATIONS

The results of this study show that human influences in watersheds can be great, whether they be urban development or agricultural activity. Nitrate, chloride, sulfate and temperature in the streams all show a positive correlation

with urbanization in the watershed. Suspended solids (TSS) and sulfate within streams increase as the amount of agriculture in the watershed increases. No relationship was found between the phosphate level and agriculture or urbanization although this effect has been shown in other studies.

This study could be refined and expanded by: 1) including more agricultural streams in the data set to distinguish more clearly the effects of agricultural and urban areas on streamwater NO_3^- concentrations in the Hudson Valley; 2) considering human population density in watersheds, not just urbanization for its effect on NO_3^-; 3) studying the effects of road density and road salt application on Cl^- and TSS levels in streamwater; and 4) examining point sources of pollution and comparing their effects with those of nonpoint sources. To help regional planners manage human impact in the Hudson Valley, more research needs to be focused on how changes in the landscape affect the Hudson River and its tributaries.

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