NUTRIENT AND SEDIMENT YIELD IN THE SAW KILL WATERSHED:

PARTITIONING THE IMPACT OF MULTIPLE LAND USES

Jennifer Pitt

Polgar Fellow

Yale University
School of Forestry and Environmental Studies
New Haven, Connecticut

Project Advisor:

Paul K. Barten, Ph.D.
Associate Professor of Water Resources
Yale University

ABSTRACT

The hydrological regime and biogeochemical cycling in relatively small, homogeneous watersheds has been studied intensively for the past thirty years. As a result, the structure and function of these elemental watersheds has been well characterized. Similar studies of larger heterogeneous watersheds have been much less common. Monitoring and research in these more complex systems is needed to improve the design and effectiveness of environmental management. This paper describes the initiation of a study to characterize the relationship between land use and surface water quality in the Saw Kill watershed in Dutchess County, New York. A Geographic Information System (GIS) was used to identify subwatersheds with relatively homogeneous land uses. Because of the extraordinarily dry weather during the 1993 field season the opportunity for experimental verification of sediment and nitrate loading in the Saw Kill surface waters was limited. The surface waters of the subwatersheds were sampled during three storm events for suspended particulate matter (SPM) and nitrate (NO_3^-) concentration. Water quality monitoring by the staff of the Hudson River National Estuarine Research Reserve has continued at the sampling sites identified by this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Sediment and nutrient concentrations in surface waters reflect the basic features of watersheds (topography, soils, geologic setting) as well as the cumulative impact of land use. As non-point source pollutants, sediment and nutrients can have a significant influence on aquatic ecosystems. Biological productivity is directly affected by changes in nutrient availability and the changes in the stream channel substrate caused by sediment deposition (Berner and Berner 1987; Dunne and Leopold 1978).

Non-point source pollution is widely considered to be a principal and pervasive cause of environmental degradation. However, spatial and temporal variation at the landscape scale has made controlled field research difficult to implement and sustain. Few studies have quantified the impacts of various land uses on stream water constituents. Until interaction of land use and water quality is more clearly quantified, policy makers and practitioners will have limited opportunities to identify, prioritize, then manage the multiple causes and effects of non-point source pollution.

Different land uses may have effects on surface waters disproportionate to their areal representation in the landscape. For example, a single hectare of corn field might contribute more sediments and nutrients to local streams than a much larger area used for low density housing. In addition to the confounding effect of spatial variation, devising a sampling scheme that captures temporal variation continues to challenge researchers and managers. Many water quality studies are based upon samples collected at regular intervals of a week or month (e.g., Parsons and Lovett

1991; Ponce 1980; Stednick 1991). However, sediment and nutrients are largely mobilized during storm events as water flows overland into stream channels. Sampling at widely separated fixed intervals is unlikely to capture the pulse of sediments and nutrients that enter surface waters during storm events. Therefore, a sampling strategy should attempt to represent both the episodic (stormflow) and systematic (baseflow) variations in loading and transport. This hydrological response typically varies in relation to soil properties, slope, bedrock geology, vegetation, and the amount of impervious surface in a given area (Beaulac and Reckhow 1982; Brooks *et al.* 1991; Fetter 1980). Site selection for water quality sampling should actively consider these sources of variation.

This study builds on the previous work by Reichheld and Barten (1991), who characterized land use and made estimates of annual soil loss for the Saw Kill watershed, and Norwood (1993), who proposed the use of subwatersheds for segregating the effects of different land cover conditions. It also was linked to the on-going water quality monitoring program of the Hudson River National Estuarine Research Reserve (Nieder *et al.* unpublished data).

OBJECTIVES

The primary objectives of this study are summarized below:

1) Identify sampling sites appropriate for subwatersheds of the Saw Kill that differ indominant land use. Digitize the boundaries of these subwatersheds on the IDRISI Geographic Information System (GIS) and ensure compatibility with maps prepared by Reichheld and Barten (1991).

2) Define the characteristics of the subwatersheds, including data on land use and soil loss estimates, using the Saw Kill GIS.

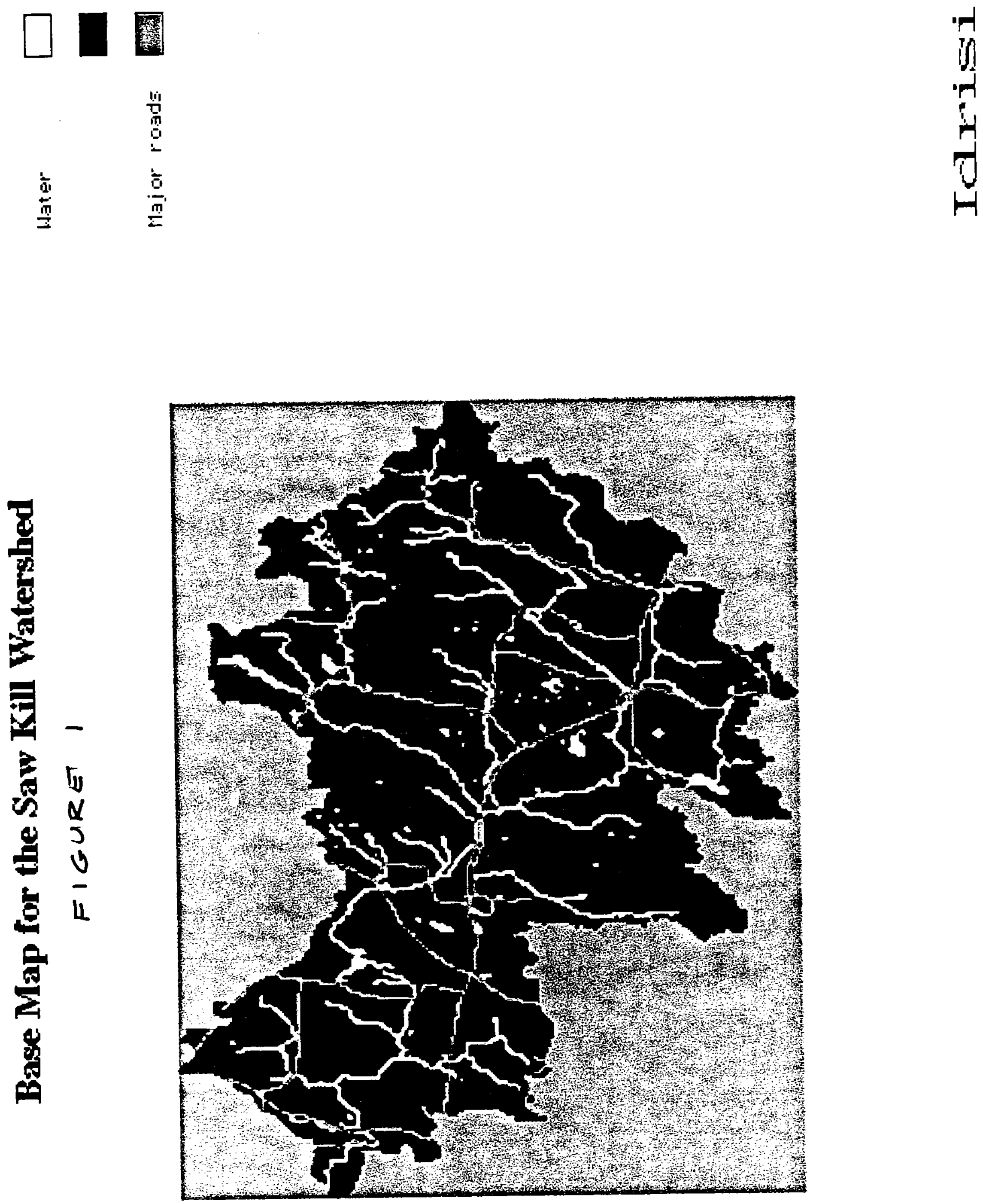
3) Collect water samples from subwatersheds and conduct analysis for suspended particulate matter (SPM) and nitrate (NO_3^-) concentration.

4) Describe sediment and nutrient loading into streams over time during storm events.

SITE DESCRIPTION

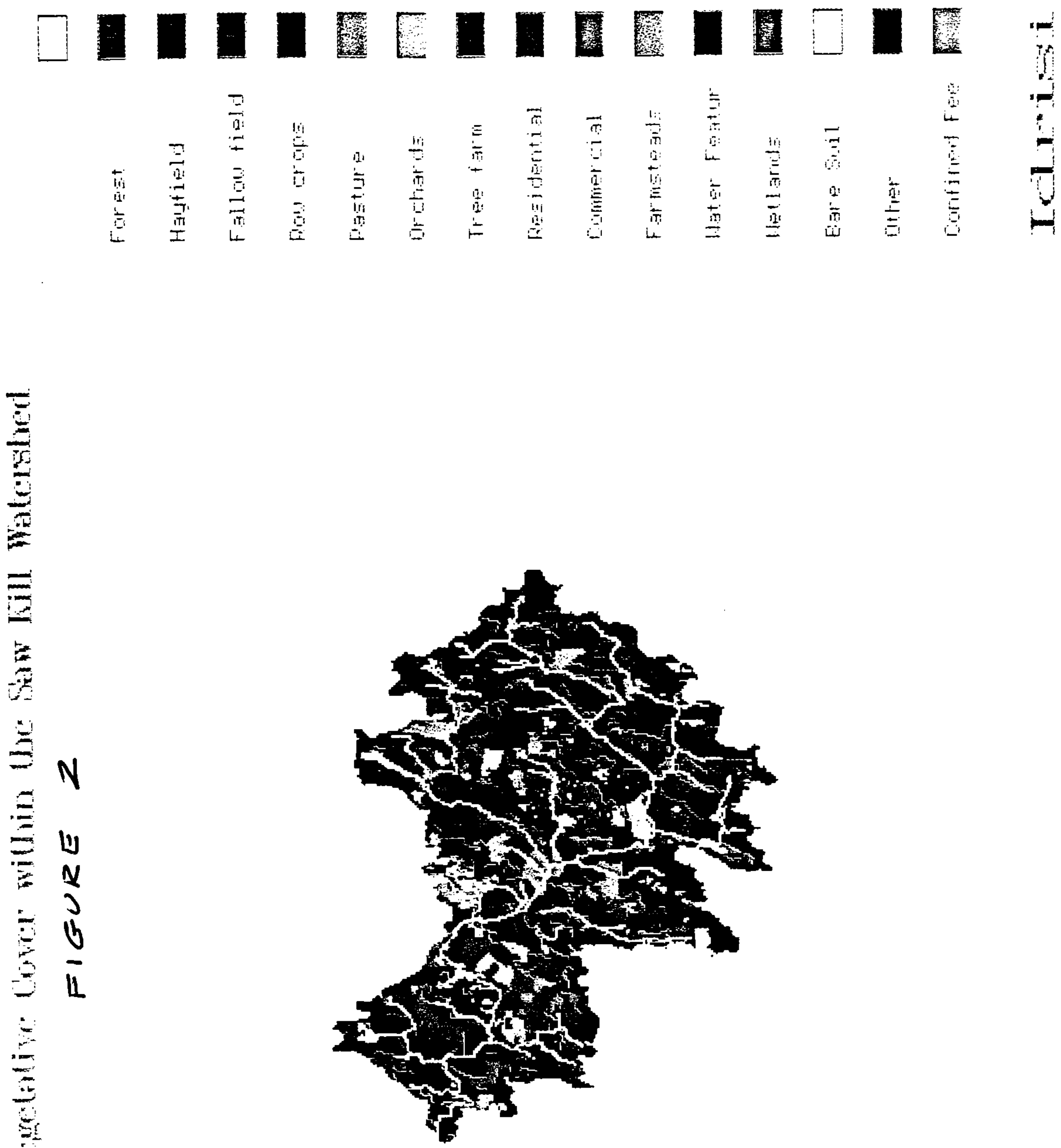
The Saw Kill watershed is located in the northwest corner of Dutchess County, NY, one hundred river miles north of New York City on the east bank of the Hudson River. The Saw Kill [Kill is the Dutch word for creek] is the principal upland tributary to Tivoli South Bay, a shallow embayment along the east shore of the Hudson River. The Tivoli Bays, and three other sites along the tidally influenced section of the river, are protected and managed by the Hudson River National Estuarine Research Reserve (HRNERR). The Tivoli Bays have been, and continue to be, the focus of a number of ecological studies.

The Saw Kill watershed encompasses 6886.5 hectares (26.6 square miles), and includes portions of the Townships of Milan, Red Hook, and Tivoli (Figure 1). Fifty-one percent of the Saw Kill watershed is forested. It is mostly second growth, and consists of both deciduous, coniferous, and mixed species stands. Since the Saw Kill watershed would be virtually all forest land in the absence of human settlement, this vegetative cover is considered to be the control, or background condition, for this study. Agriculture occupies nearly 25 percent of the total area (Reichheld and Barten 1991). Low and medium density residential areas are interspersed with working farms. The Village of Red Hook (in the western section of the watershed) and Bard College (located just above Tivoli South Bay on the Hudson River escarpment) contain high density residential land use. The patchwork of land uses also includes, commercial enterprises and a landfill (Figure 2).



Base Map for the Saw Kill Watershed

FIGURE 1



Land Use/Vegetative Cover within the Saw Kill Watershed

FIGURE 2

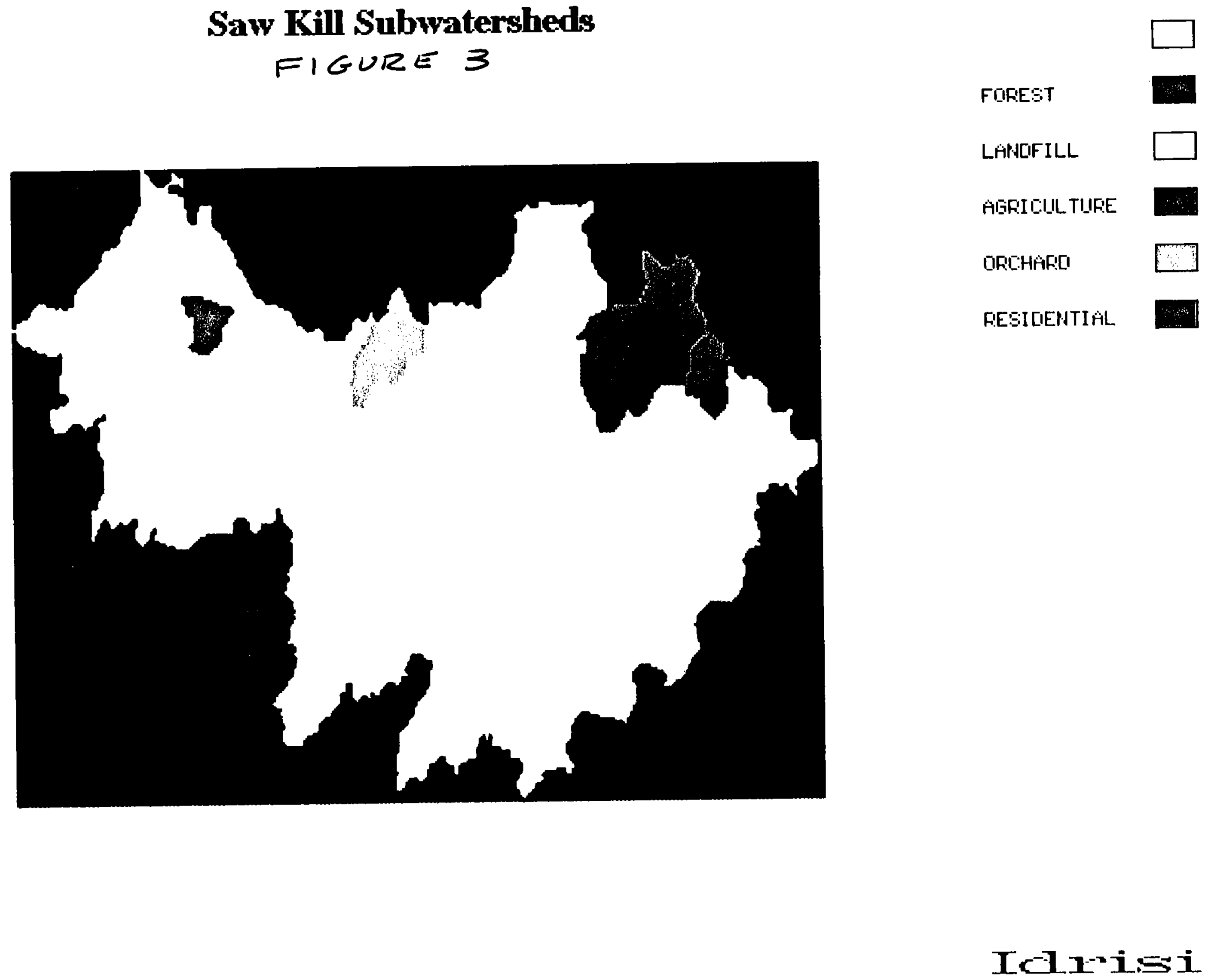
METHODS

Five subwatersheds of the Saw Kill system that represent land uses of interest were delineated in the GIS (Figure 3). Primary and secondary layers had been prepared by Reichheld and Barten (1991), including: a base map of roads and streams, land use and vegetative cover, topography, slope, soil type, and soil physical properties. The GIS database is comprised of 50 by 50 meter (0.25 hectare) grid cells. In addition, Reichheld and Barten (1991) prepared a map of estimated annual soil loss for the Saw Kill watershed using the Modified Soil Loss Equation (MSLE). This includes data on rainfall erosivity, soil erodibility, slope length, slope gradient, land use, and vegetative cover. Figure 4 shows the estimated soil loss for the five subwatersheds.

The range and frequency distribution of slopes and soil types, quantified with the GIS, were very similar in the five subwatersheds. Therefore, it was not necessary to alter site selection with these criteria. An additional consideration was the need for ready access. Therefore, the downstream point of each subwatershed is located at a point where the stream intersects a public road. The subwatersheds include the following land uses: 1-*forest* (68.25 ha), 2-*landfill* (96.5 ha), 3-*mixed agriculture* (371.5 ha), 4-*orchards* (117.5), 5-*residential* (49.25 ha). No more than 15 percent of each watershed is occupied by land uses other than the major category or forests. Because the rate of sediment and nutrient export from forests is minimal, the presence of small areas should not bias estimates of impacts from other land uses. The boundaries of the five subwatersheds were digitized for the GIS then used to isolate base layer and soil loss data.

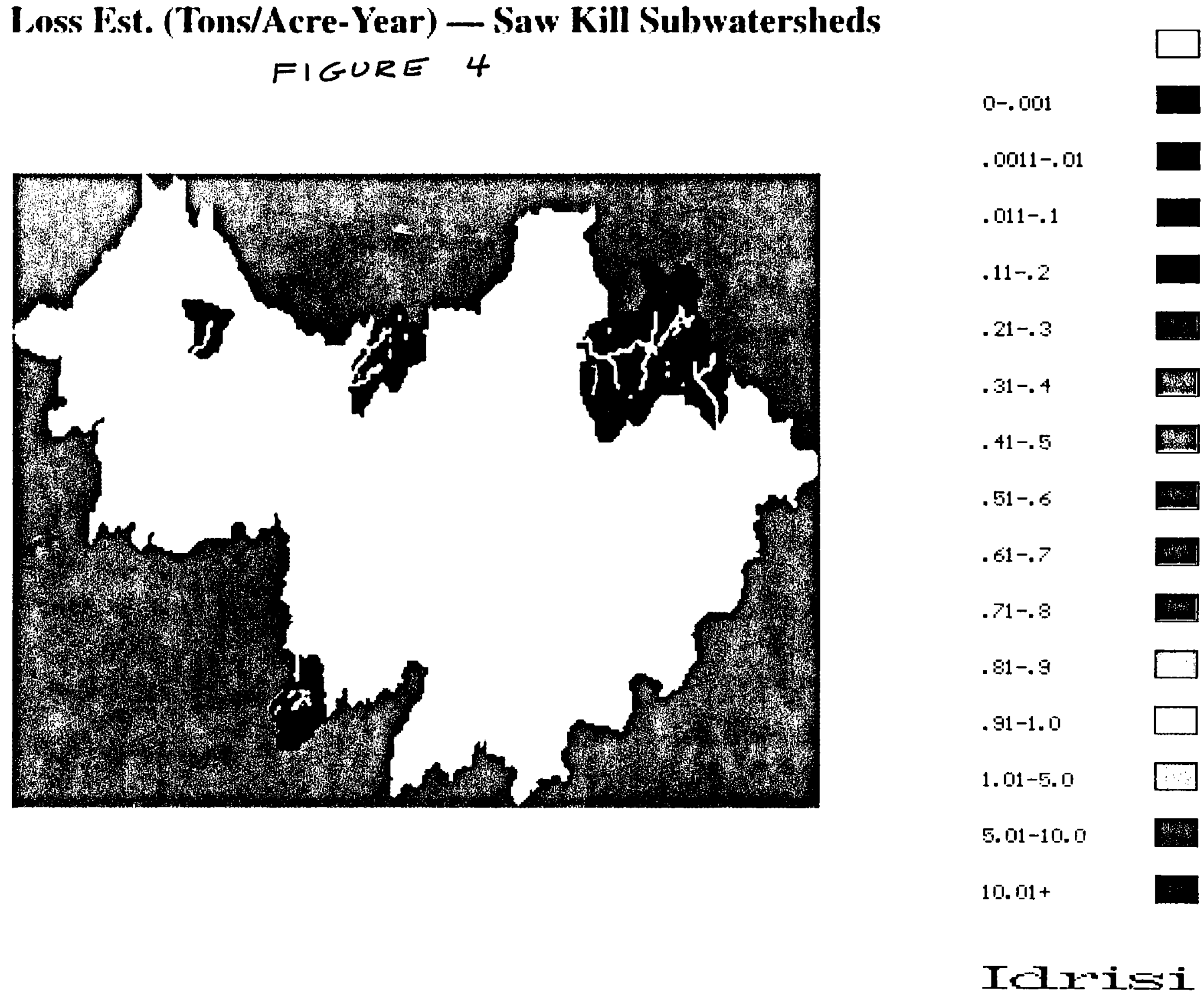
Saw Kill Subwatersheds

FIGURE 3



Soil Loss Est. (Tons/Acre-Year) — Saw Kill Subwatersheds

FIGURE 4



Water Quality Sampling

Samples were collected in 500 ml plastic bottles washed in phosphate-free antibacterial detergent, and rinsed three times in de-ionized distilled water. Each bottle was rinsed with stream water three times before the sample was collected. Samples were stored in an ice chest at 0 °C immediately after collection for transportation back to the laboratory. Millipore membranes (0.45 micron pore diameter) were rinsed in a dilute acid solution, dried in a desiccator for 24 hours, then weighed. Within 10 hours of collection, each sample was filtered through a membrane. The membranes were again dried and weighed to determine the spm value for each sample. The liquid (including suspended and dissolved material less then 0.45 microns) that passed through the membrane was acidified to pH 2.5 and stored for no longer than 24 hours. The nitrate (NO_3^-) concentration of each sample was measured for on a spectrophotometer (Tecator 5023) with NaOH added to neutralize the samples. The detection limit of this method is 8 micromoles/liter.

RESULTS AND DISCUSSION

The results of the GIS characterization of the five subwatersheds are presented below.

Subwatershed 1: Forest (Figure 5)

The sampling point for the forested subwatershed is located where a tributary of the Saw Kill crosses through a culvert under Milan Hill Road, approximately 0.2 kilometers (0.12 miles) west of its intersection with Willow Glen Road. The subwatershed encompasses 68.25 hectares (168.6 acres), 95 percent of which is forest or wetland. The remaining 5 percent of the watershed is hayfield. Since this area is not near the stream, it is unlikely to have a significant effect on streamflow quantity or quality. A majority (78%) of the soils in the forested subwatershed are well drained. The balance (22%) is very poorly drained with little or no slope (centered on the wetland). Slopes in the forested subwatershed do not exceed 18 percent, and the majority are under 12 percent.

Subwatershed 2: Landfill (Figure 6)

The sampling point for subwatershed 2 is located where a tributary to the Saw Kill crosses under Oriole Mills Road, just east of the intersection with Stone Church Road and Norton Road. The stream at that point drains 96.5 hectares (238.3 acres). The majority of the subwatershed is forested (70%), and 9 percent is wetland. The remainder (21%) is bare soil, on which the landfill is located. The majority of subwatershed 2 soils are deep and well drained, although 20 percent is poorly drained. Four hectares (4.4%) of the landfill is located on soils classified as poorly drained. The landfill subwatershed slopes range up to 20 percent; most are below 10 percent.

Subwatershed 3: Mixed Agriculture (Figure 7)

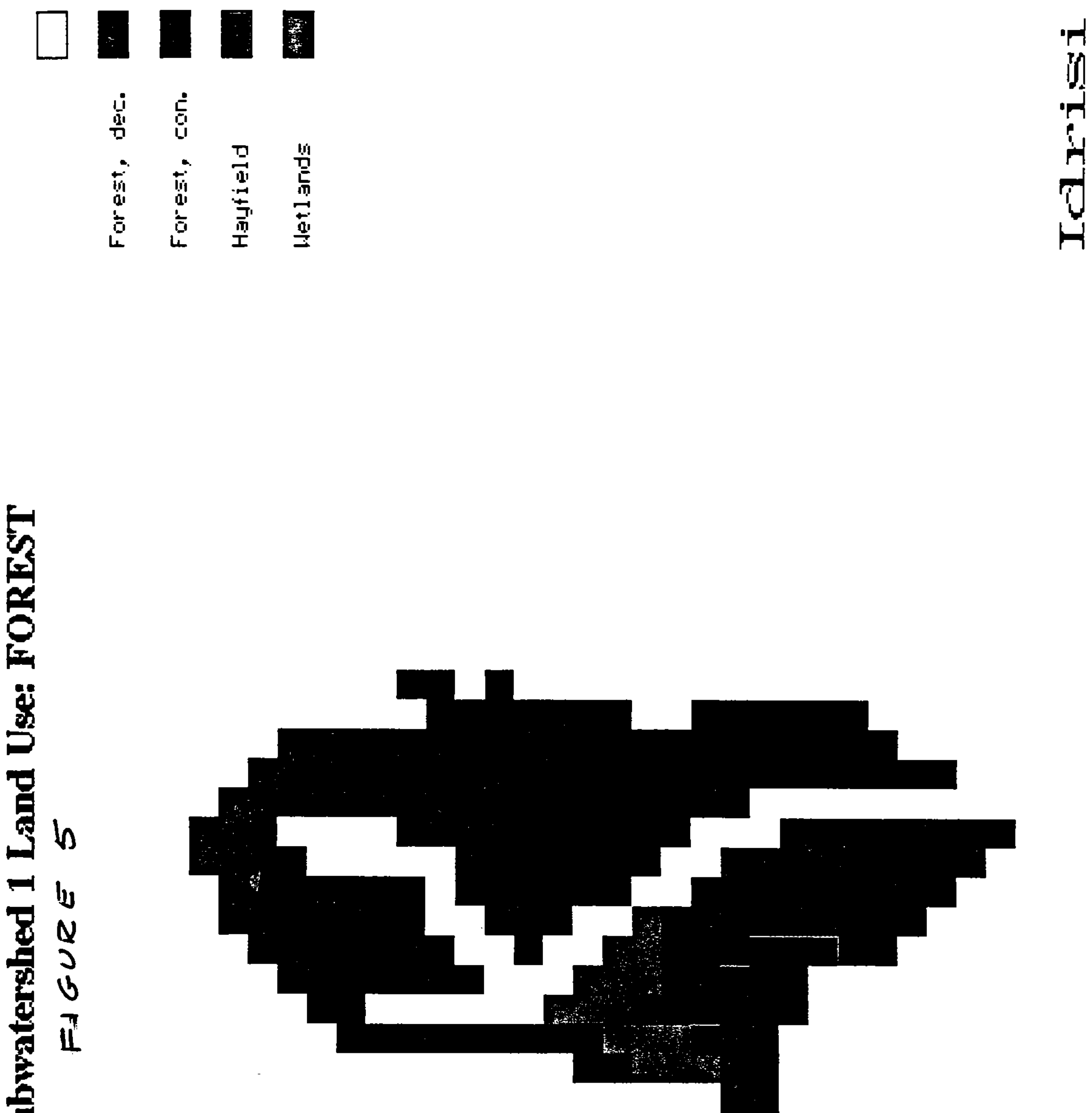
The sampling point for subwatershed 3 is located on Hapeman Hill Road at the intersection with Salisbury Road. Subwatershed 3 encompasses 371.5 hectares (917.6 acres), and includes several types of land use classified as agricultural, including hayfields (12%), row crops (4%), and pasture (9%). The subwatershed also includes low-density residential housing (3%), and the balance is forested (72%). Most soils in the agricultural subwatershed are well drained and only slightly erodible. Subwatershed 3 slopes range to 24 percent.

Subwatershed 4: Orchards (Figure 8)

The sampling point for the orchard subwatershed is on Echo Valley Road, just south of the intersection with Fraleighs Road. The subwatershed encompasses 117.5 hectares (281.6 acres), of which 42 percent is orchard, 15 percent hayfield, 28 percent forest and 8 percent wetland. Additionally, farmsteads are nearly 7 percent of the subwatershed, and residential and commercial cover the balance of the area. The orchard subwatershed soils are well drained and only slightly erodible, slopes range to 10 percent.

Subwatershed 5: Residential (Figure 9)

The sampling point for the residential subwatershed is located north of the Village of Red Hook, west of Route 79 on Aspinwall Road. Samples are collected on the north side of a pond maintained by the Red Hook Department of Public Works. The subwatershed encompasses 49.25 hectares (121.6 acres), and consists of 20 percent forest, 5 percent agricultural, and 75 percent residential land. The residential subwatershed soils are nearly all well drained and only slightly erodible. Only 5% are classified as erodible. The maximum slope is only 9 percent.

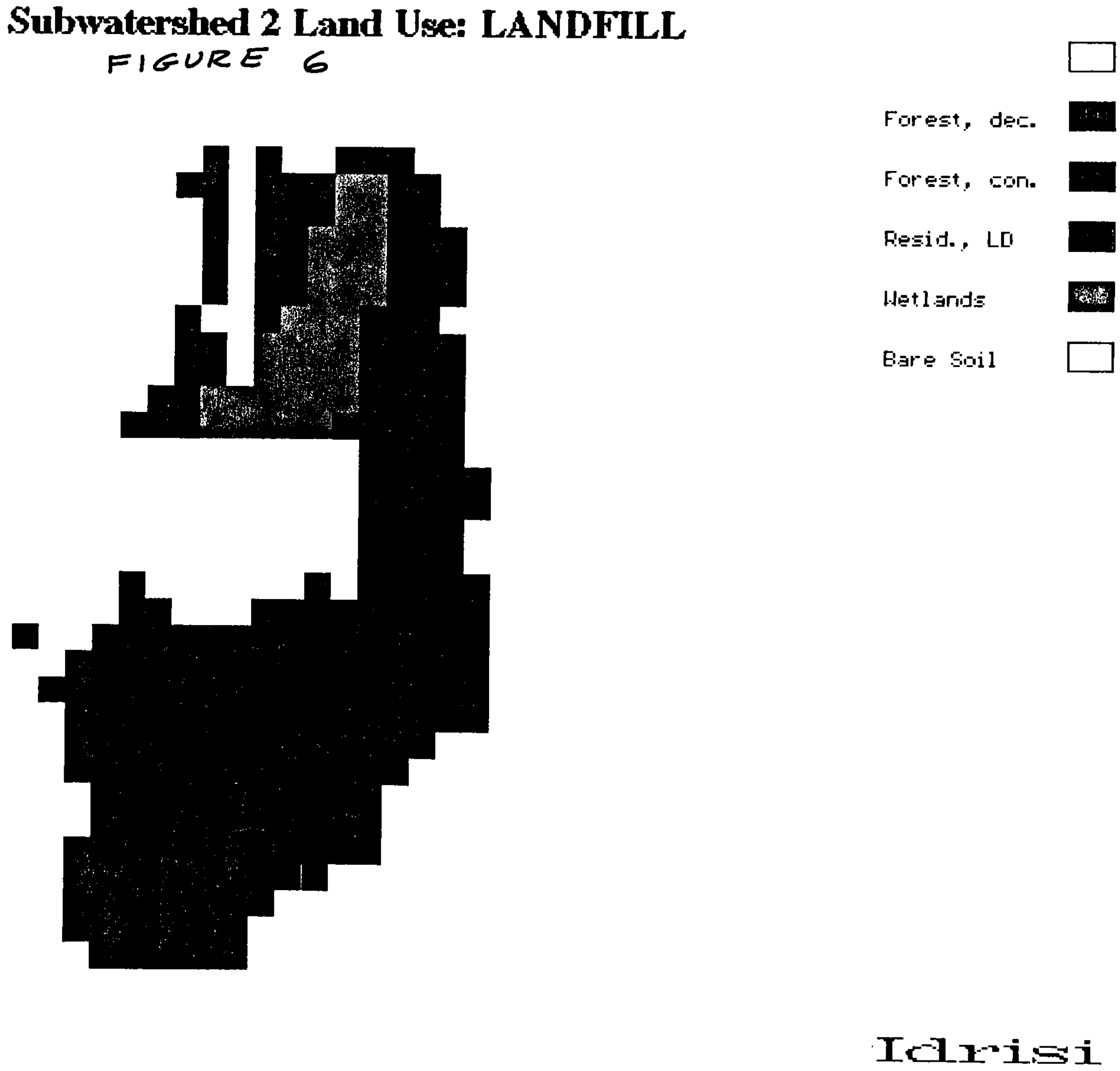


Saw Kill Subwatershed 1 Land Use: FOREST

FIGURE 5

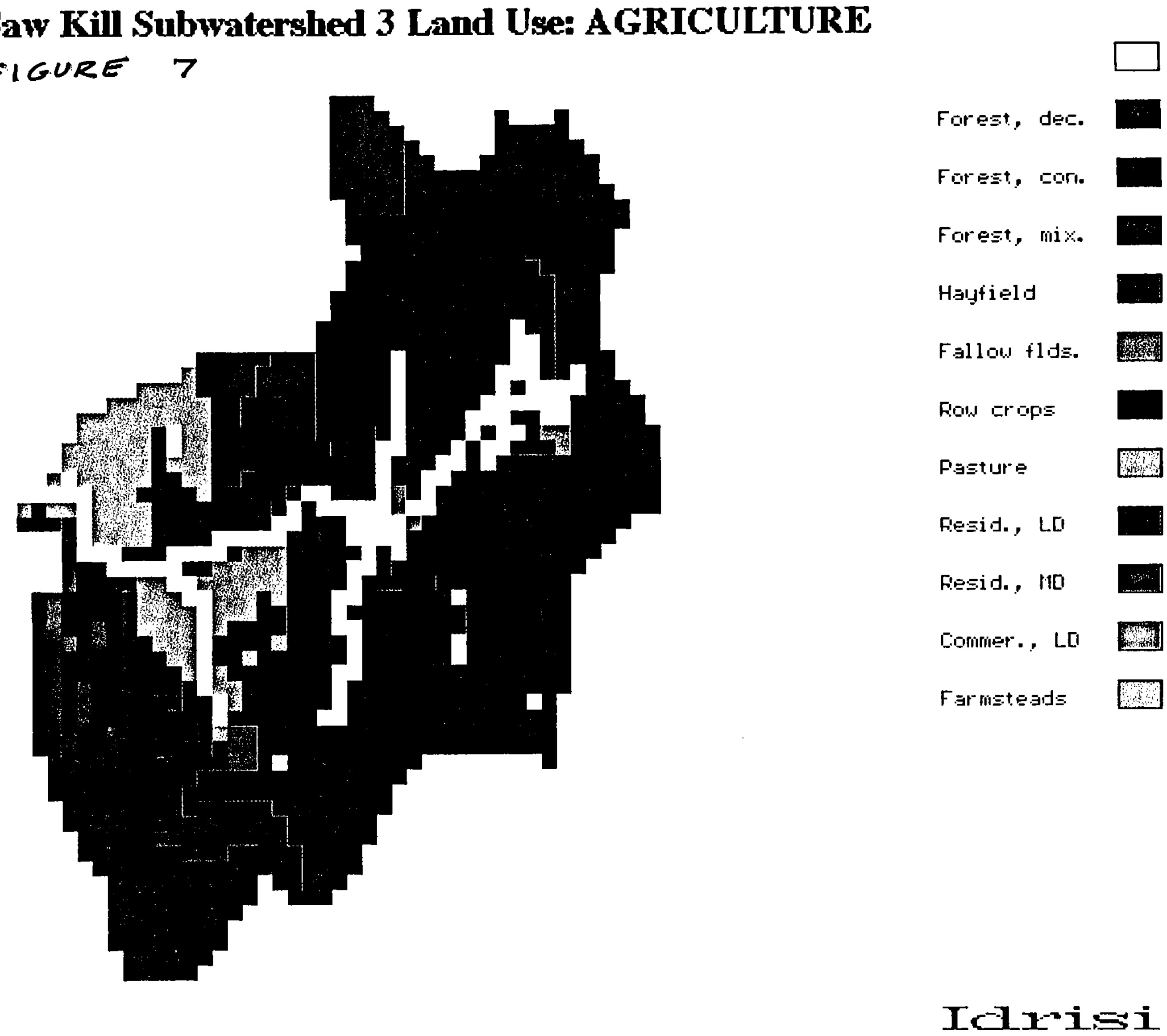
Saw Kill Subwatershed 2 Land Use: LANDFILL

FIGURE 6



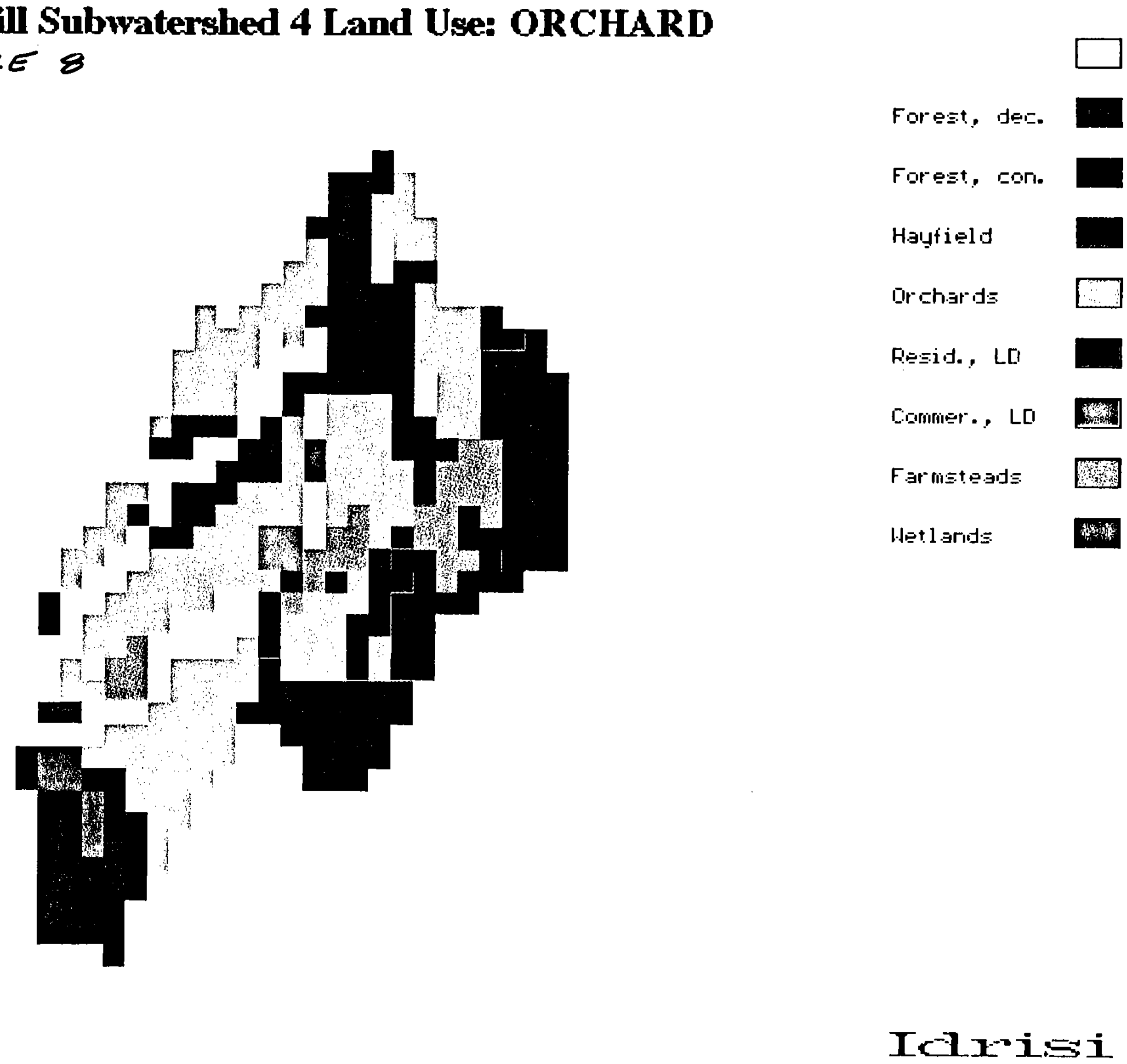
Saw Kill Subwatershed 3 Land Use: AGRICULTURE

FIGURE 7



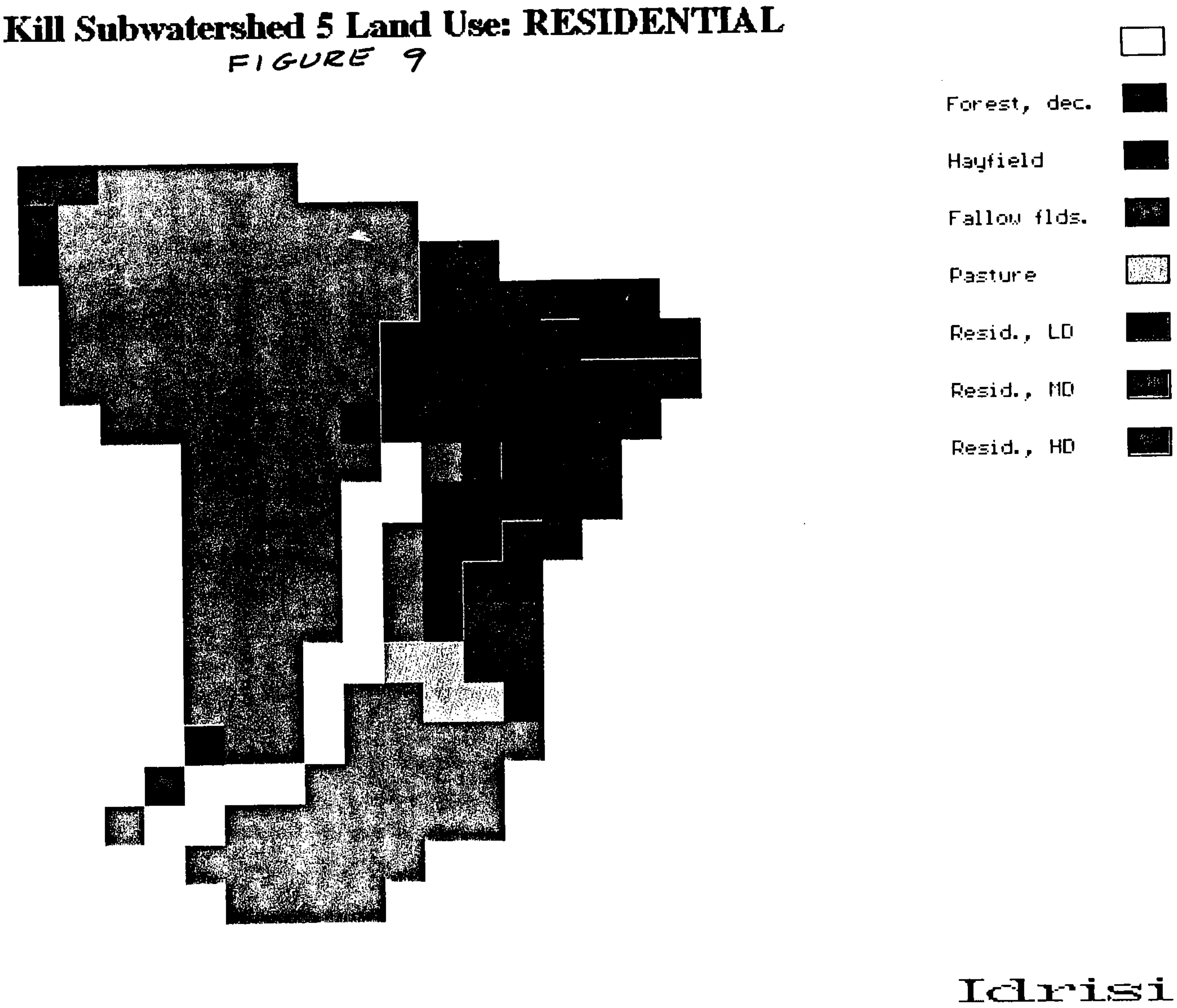
Saw Kill Subwatershed 4 Land Use: ORCHARD

FIGURE 8



Saw Kill Subwatershed 5 Land Use: RESIDENTIAL

FIGURE 9



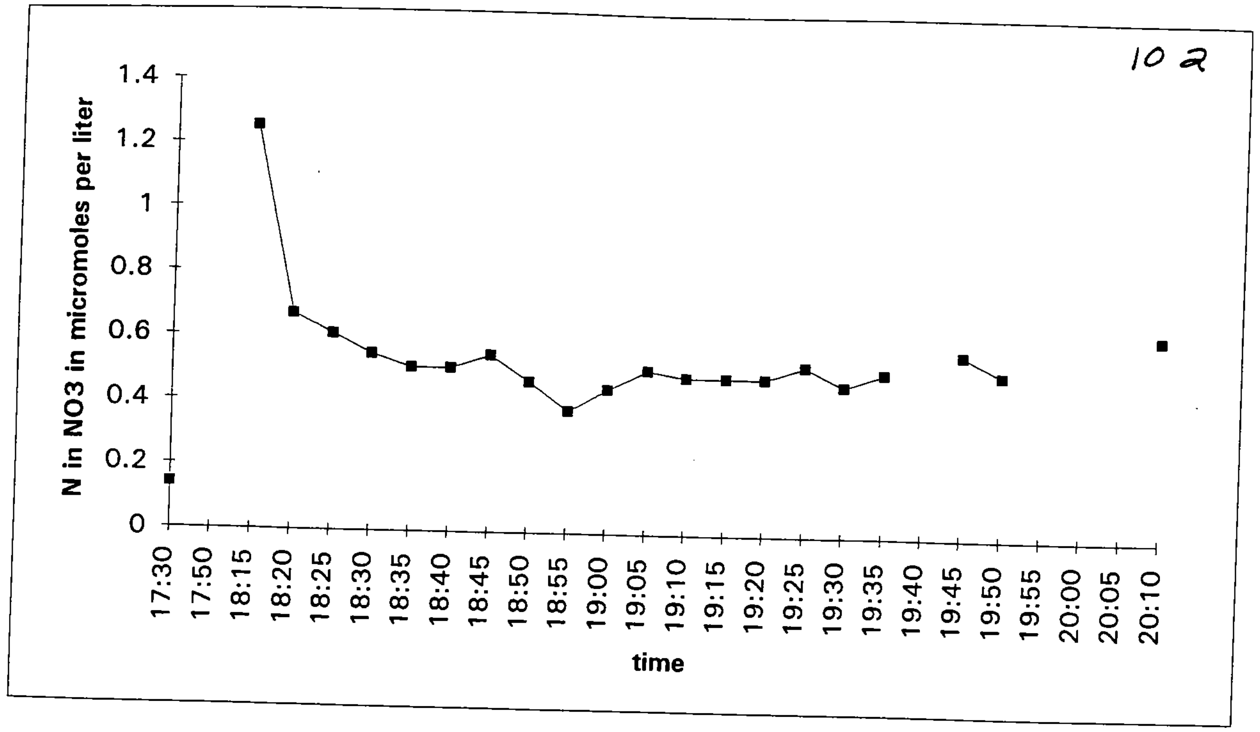
The results of soil loss calculations for each subwatershed are presented in Table 1. The wide range in the predicted soil loss per unit area estimates illustrates the combined effect of land use, soils, and slopes. Since soils and slopes are relatively uniform across the five subwatersheds, most of the variation in predicted soil loss can be attributed to differences in land use.

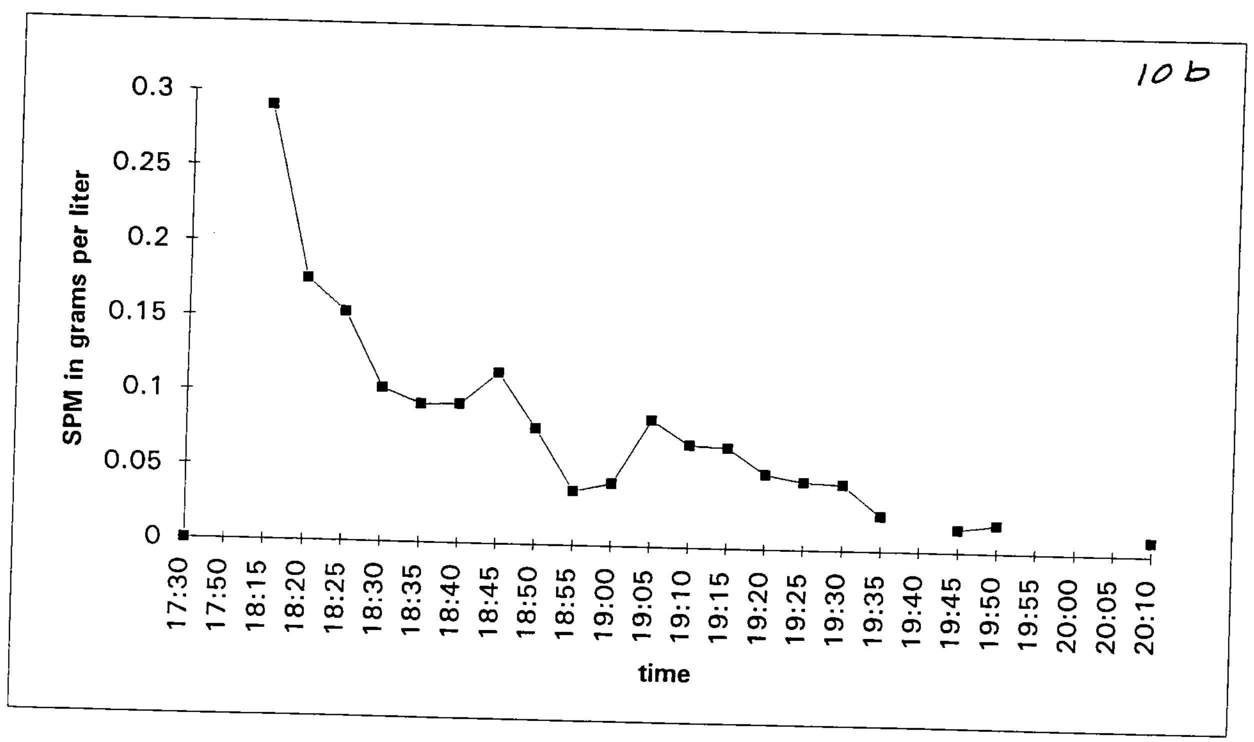
Table 1: Estimated annual soil loss for selected subwatersheds on the Saw Kill, Dutchess County, New York

Subwatershed	Area (ha)	Est. Annual Soil Loss (kg/year)	Soil Loss/ Unit Area (kg/year)/ha
1 - Forested	68.5	260	4
2 - Landfill	91.5	850,000	9300
3 - Agriculture	369.0	34,000	92
4 - Orchard	114.0	120	1
5 - Residential	48.5	245	5

If stormflow events could be sampled simultaneously on the five subwatersheds they might be expected to produce sediment loads that vary in proportion soil loss/unit area estimate (by as much as three or four orders of magnitude). However, sediment delivery is strongly influenced by watershed and stream channel morphometry and riparian zone conditions. For example, the effect of an agricultural field, with and without vegetated buffer strips protecting the adjacent stream channel, would vary considerably. Predictions for levels of nitrogen are more difficult since generalized functions to estimate the export of available and

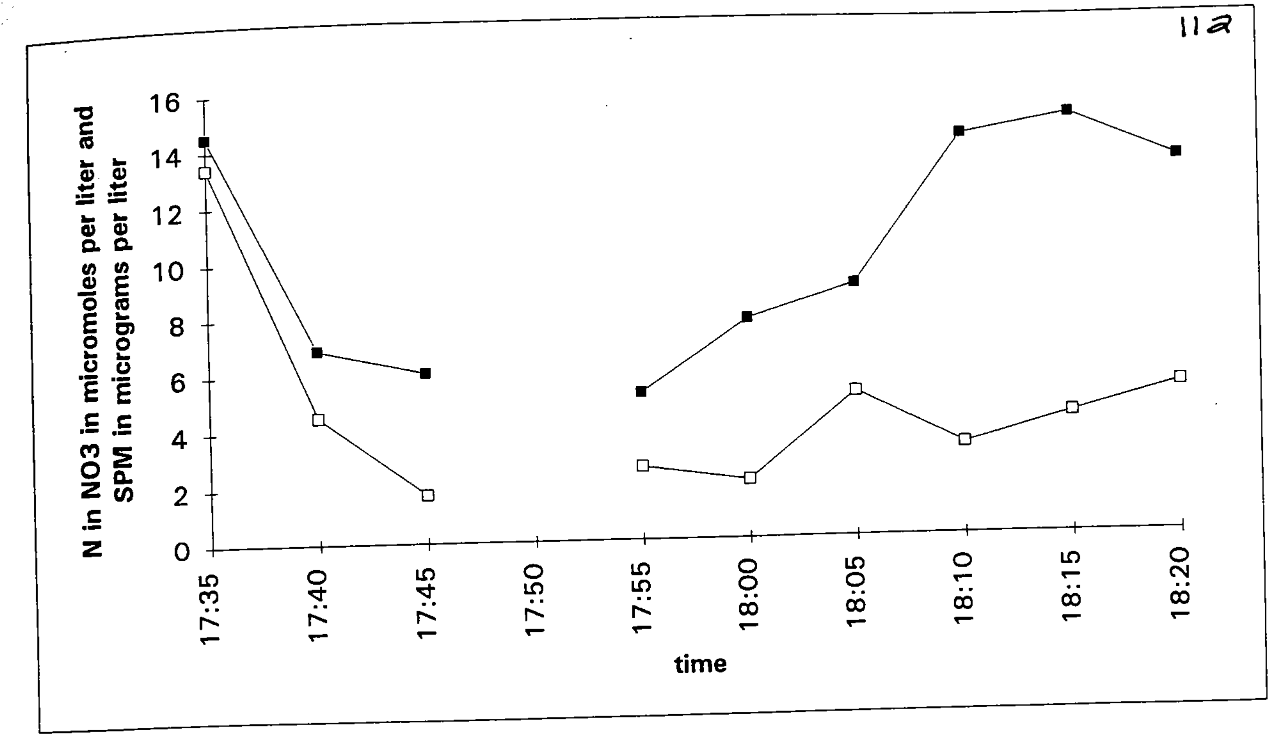
mobile nitrates and organic nitrogen for different land uses and vegetative covers do not exist in the current literature. The expectation that a precipitation event would produce a pulse of nitrogen (Figure 10a) and sediment (Figure 10b) in the stream water was verified by samples taken from the forested subwatershed during a high intensity rainstorm on June 21, 1993. This storm was apparently sufficient in volume and intensity to produce shallow subsurface flow and erosion in and around the stream channel. However, precipitation events of lesser volume and intensity (July 17 and 29, 1993) did not produce the same kind of pulse, but rather a more constant rise and decline in stream water constituents (Figures 11a and 11b). The accumulated soil moisture deficits were so large, relative to the storm size and intensity, that only a meager flow response was observed.

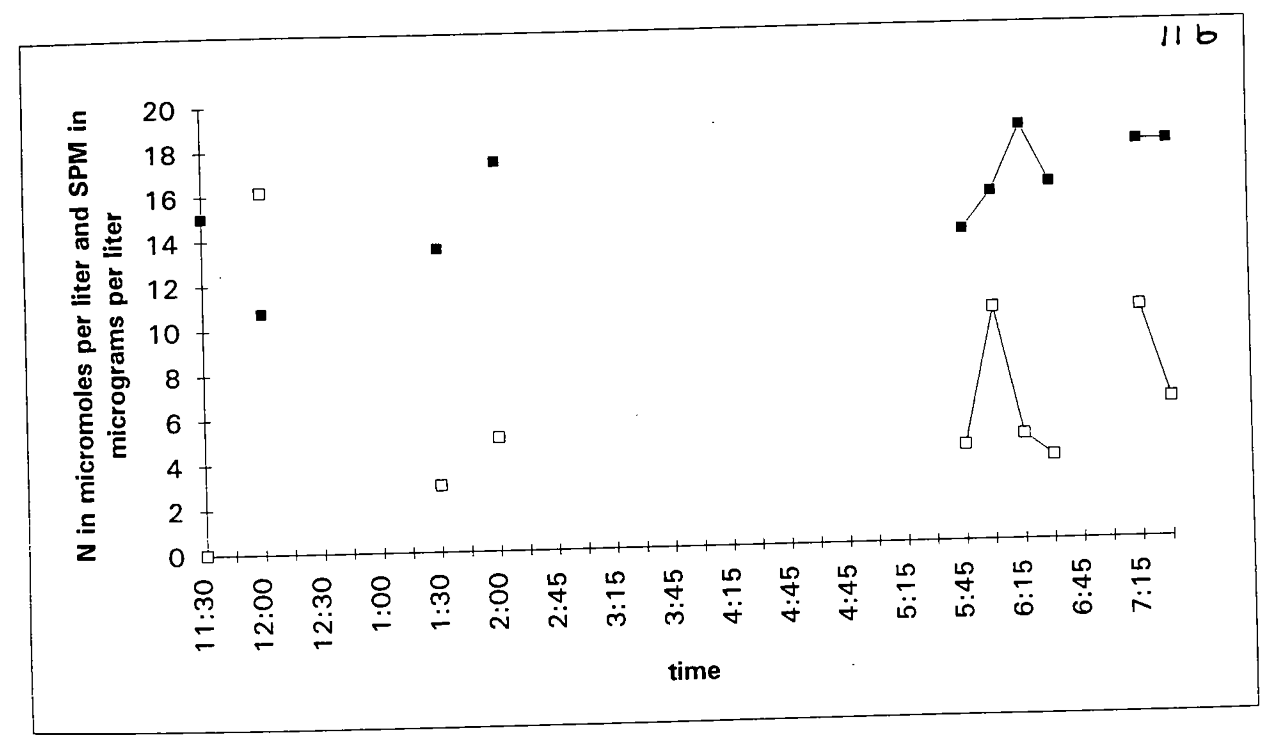




Figures 10a and 10b:

(a) Nitrogen (NO_3^-) and (b) suspended particulate matter (SPM) concentration versus time, June 21, 1993, forested subwatershed (#1), Saw Kill watershed, Dutchess County, New York





Figures 11a and 11b:

(a) suspended particulate matter (SPM) concentration versus time and (b) nitrate (NO_3^-) concentration versus time, mixed agriculture subwatershed (#3), Saw Kill watershed, Dutchess County, NY. The filled squares are July 17; the open squares are July 29, 1993.

SUMMARY

Because of the diverse character of land use on the five subwatersheds, it would be ideal to measure all the sites simultaneously. As shown by the infrequent storms of the June through August of 1993, the intensity and duration of different precipitation events produces varied effects in discharge and stream water chemistry. A simultaneous sampling regime would overcome the difficulty of comparing different storm events. This would require automated equipment to extract water samples and measure water level at pre-set intervals of time or discharge.

Channel shape and bed slope varies all along the Saw Kill. Hence, sediment deposition may occur downstream from the sampling sites (but upstream of the last sampling site near South Bay). Therefore, sampling at the cumulative sites described by Norwood (1993) along the main branch of the Saw Kill, as well as measurements at the confluence with South Bay, are needed to quantify the total export of sediment and nutrients from the watershed to the estuary.

ACKNOWLEDGEMENTS

I thank the Hudson River Foundation (HRF) and the Hudson River National Estuarine Research Reserve (HRNERR) for funding and support for this project. In particular, I am grateful to John R. Waldman (HRF) and William C. Nieder (HRNERR). I also am grateful to my faculty advisers at Yale, Paul K. Barten and Gaboury Benoit. Joel Tilley provided generous assistance in the laboratory.

REFERENCES

Beaulac, M.N., and K.H. Reckhow. 1982. An examination of land use -- nutrient export relationships. Water Resources Bulletin 18(6):1013-1024.

Berner, E.K., and R.A. Berner. 1987. The global water cycle. Prentice-Hall, Englewood Cliffs, NJ, 397 pp.

Brooks, K.N., P.F. Folliott, H.M. Gregersen, and J.L Thames. 1991. Hydrology and the Management of Watersheds, Iowa State Univ. Press, Ames, 392 pp.

Dunne, T., and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman Co., NY, 818 pp.

Fetter, C.W. Jr. 1980. Applied Hydrogeology. C.E. Merrill Publishing, Columbus, OH, 488 pp.

Nieder, W.C. and E.A. Blair. Water quality monitoring for the Hudson River National Estuarine Research Reserve.

Norwood, J. 1993. A strategic plan for watershed research on the Saw Kill., M.S. Project Report, Yale University, School of Forestry and Environmental Studies, New Haven, CT, 23 pp.

Parsons, T.L., and G.M. Lovett. 1991. Land use effects on Hudson River tributaries. In: E.A. Blair and J.R. Waldman (Editors) Reports of the 1991 Tibor T. Polgar Fellowship Program, Hudson River Foundation, NY, 34 pp.

Ponce, S.L. 1980. Water quality monitoring programs. U. S. Department of Agriculture Service. Watershed Systems Development Group Technical Paper, WSDG-TO-00002. 66 pp.

Reichheld, E.A., and P.K. Barten. 1991. Characterization of streamflow and sediment source areas for the Saw Kill watershed. In: E.A. Blair and J.R. Waldman (Editors) Reports of the 1991 Tibor T. Polgar Fellowship Program, Hudson River Foundation, NY, 50 pp.

Stednick, J.D. 1991. Water quality sampling and analysis. Academic Press, San Diego, CA, 217 pp.