

**CHARACTERIZATION OF STREAMFLOW AND SEDIMENT SOURCE AREAS
FOR THE SAW KILL WATERSHED¹**

A Report of the 1991 Polgar Fellowship Program

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and

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ABSTRACT

An accurate depiction of water movement through the landscape forms the foundation of water resource management and many types of ecological research. Characterizing the complex interaction of terrain features, soils, vegetation, and land use is the necessary first step to understanding the structure and function of large, heterogeneous watersheds. A geographic information system (GIS) database was developed for these landscape elements in the Saw Kill watershed in northern Dutchess County, New York. This 6900 hectare area is the principal upland tributary for South Tivoli Bay in the Hudson River National Estuarine Research Reserve. The GIS was used to estimate rates of shallow subsurface flow and surface erosion. Maps of the primary streamflow and sediment source areas in the Saw Kill watershed were developed from the flow and erosion estimates. Both maps highlight the spatial variation that was expected within a watershed with complex surface topography and geologic structure, 34 soil types, and 21 classes of land use and vegetative cover. Less than 1 percent of the watershed generates one-half of the total annual soil erosion. Approximately one-third of the watershed is likely to generate the majority of the streamflow that reaches South Tivoli Bay. The results of this study and the GIS database can be used to guide research and management activities within the Saw Kill watershed.

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INTRODUCTION

An accurate depiction of water movement through the landscape forms the foundation of water resource management. Accurate predictions of water supply and water quality degradation, and their respective sources, are usually constrained by our ability to quantify the spatial variation and complex interaction of numerous elements. These watershed characteristics include: soil physical and hydraulic properties, slope, current and historical land use patterns, and vegetative cover. The climatic regime also has a direct effect upon the structure and function of watersheds.

The unwieldy task of systematically integrating heterogeneous data at the watershed scale has usually led to land capability classification or environmental impact assessments conducted on a site-by-site basis. These studies may neglect downstream impacts or be compelled to average disparate characteristics over large and diverse areas simply to complete the task at hand.

Some areas within a watershed contribute much more to streamflow than others. The spatial variation of the streamflow source area is directly influenced by a site's proximity to the stream channel network and soil hydraulic properties (e.g., infiltration capacity, permeability, porosity, etc.) (Brooks et al., 1991; Dunne and Leopold, 1978; Pearce et al. 1986). Maintaining or improving the quality and availability of water largely depends upon effective land use

management within these critical source areas. For example, a single family home may have minimal impact if it is placed on a well-drained sandy soil at a reasonable distance from the riparian zone. Conversely, the same house is likely to have a substantial adverse impact on water quality if it is located in poorly drained organic soil, immediately adjacent to a stream.

While basic biophysical information and common sense can guide assessments of individual projects, it is difficult to develop a comprehensive and objective view of land use-water quality interactions within large, heterogeneous watersheds. Recent advances in computer software (e.g., Eastman 1990; Tomlin 1990) have greatly improved spatial analysis and cartographic modeling capabilities. A Geographic Information System (GIS) allows researchers and managers to analyze these large databases, thereby providing the information necessary to adapt land uses to terrain, or when this is not feasible, to modify existing land uses to meet water quality goals. The GIS provides the opportunity to directly link upstream causes (land use changes) with the downstream effects (water quality changes). This paper describes the development and application of a GIS to characterize the hydrologic structure and function of the Saw Kill watershed in northwestern Dutchess County, New York. The analyses include the preliminary mapping of streamflow source areas and the estimation of annual soil losses.

OBJECTIVES

The primary objectives of this project were to:

1. Develop primary GIS layers (topography, soil type, vegetative cover/land use) for the Saw Kill watershed.
2. Develop secondary GIS layers (slope, soil thickness, porosity, permeability, erodibility) for the Saw Kill watershed.
3. Use the GIS to produce a spatially-referenced solution of Darcy's Law (the governing equation for flow through saturated soils) and the Modified Universal Soil Loss Equation (annual soil erosion in tons per acre) for the watershed.
4. Delineate source areas for streamflow and sediment, based upon the results of the analyses outlined above.
5. Estimate the current rate of sediment delivery to South Tivoli Bay.

SITE DESCRIPTION

The Saw Kill watershed encompasses 6886.5 hectares (17,017 acres or 26.6 square miles) in northwestern Dutchess County, New York (figure 1). The watershed includes portions of the Townships of Red Hook, Tivoli, and Milan. The Saw Kill is tributary to South Tivoli Bay, a shallow embayment on the east shore on the Hudson River (river mile 100). This site (with North Tivoli Bay) is one of four sites in the Hudson River National Estuarine Research Reserve.

The Saw Kill provides approximately 90 percent of upland streamflow into South Tivoli Bay (Paul K. Barten, unpublished field notes and monitoring data). Figure 2 shows the watershed boundary, stream network, and primary transportation network. The Saw Kill watershed is located in the Hudson-Mohawk physiographic region, bounded to the west by the Hudson River and to the east by the Taconic Mountains.

Climate

The mid-Hudson River Valley climate is influenced by continental-polar and maritime air masses. Mean January and July air temperatures are -4 and 23 °C (25 and 73 °F), respectively. Annual precipitation typically ranges from 900 to 1,100 mm (36 to 44 inches) and is relatively uniform in distribution throughout the year (Dutchess County Department of Planning, 1985).

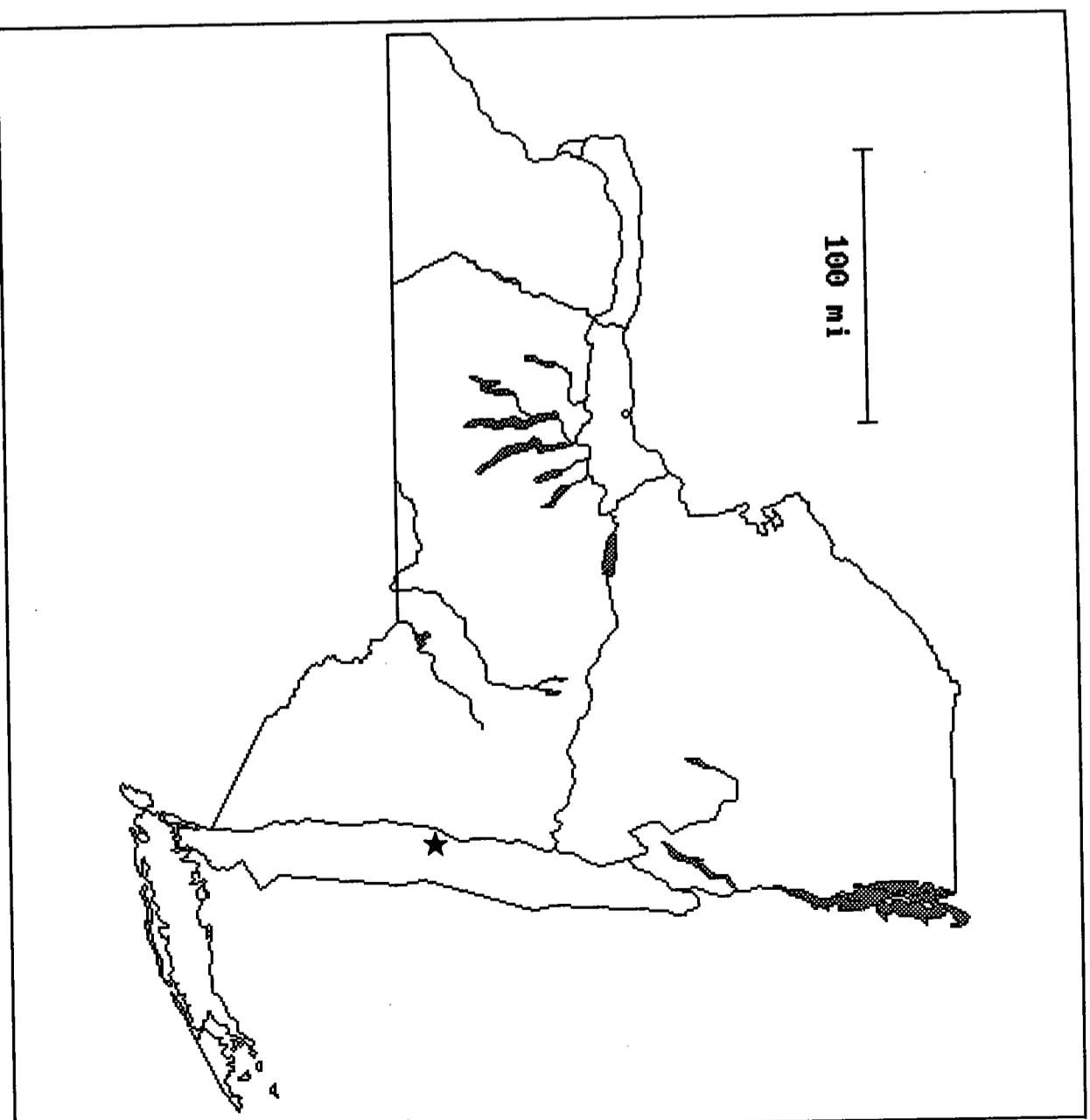
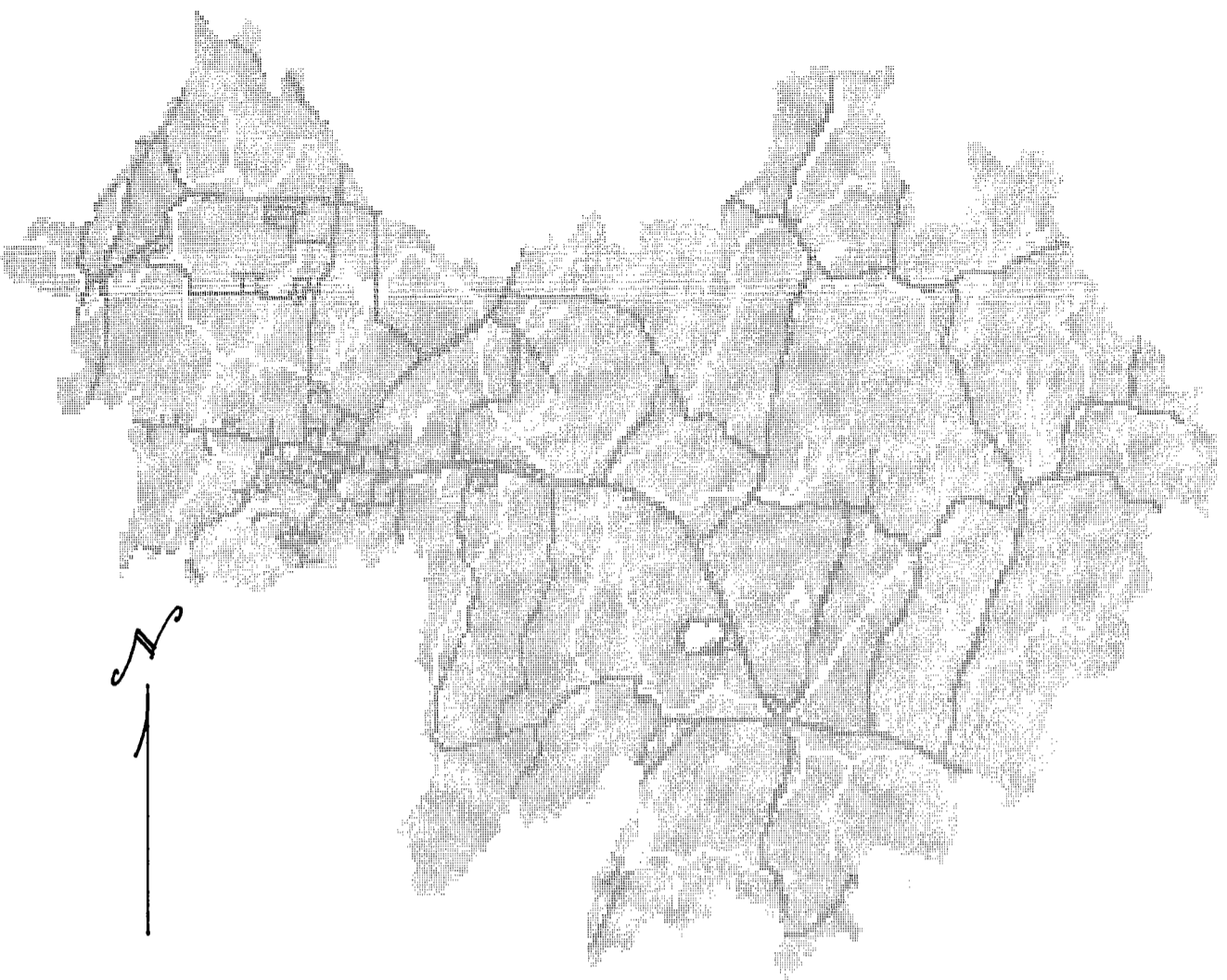


Figure 1: Location map for the Saw Kill watershed (marked with a star) and the Tivoli Bays (Hudson River National Estuarine Research Reserve, Dutchess County, New York. Reprinted from PC Globe, Inc., Tempe, Arizona, USA.



South Tivoli Bay and the Hudson River

Figure 2: Base map of the Saw Kill watershed, Dutchess County, New York (watershed = light gray; water features = white; roads = dark gray)

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Topography

Figure 3 (raised relief) and figure 4 (slope map), both produced with the GIS, illustrate the topography of the Saw Kill watershed. The watershed's highest elevations and steepest slopes are found in its eastern region. The maximum elevation is 263.5 meters (865 feet). Slopes range from 0 to 37 percent, with a median slope of approximately 7 percent.

The watershed has two topographically distinct sections. While the watershed spans approximately 17.6 km (8 miles) along its major (east-west) axis, the majority of the 263.5 meter decrease in elevation occurs over a 9 km (4 mile) section of the eastern region. In the next 8 km, the Saw Kill and its tributaries meander through an extensive glacial outwash plain before dropping over the steep escarpment at the 43 meter (140 foot) contour, to South Tivoli Bay, which lies slightly above sea level. This glacially-formed landscape has directly influenced the Saw Kill's north-south tributary structure and meandering drainage. Shale bedrock ridges and glacial till formed drumlins and kames (Carey and Waines 1987), at a relatively uniform spacing in a northeast/southwest direction, which led to a dendritic-trellised drainage pattern.

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Figure 3: Raised relief map (U.S. Geological Survey National Mapping Program digital elevation data) for the Saw Kill watershed, Dutchess County, New York

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South Tivoli Bay
and the Hudson River

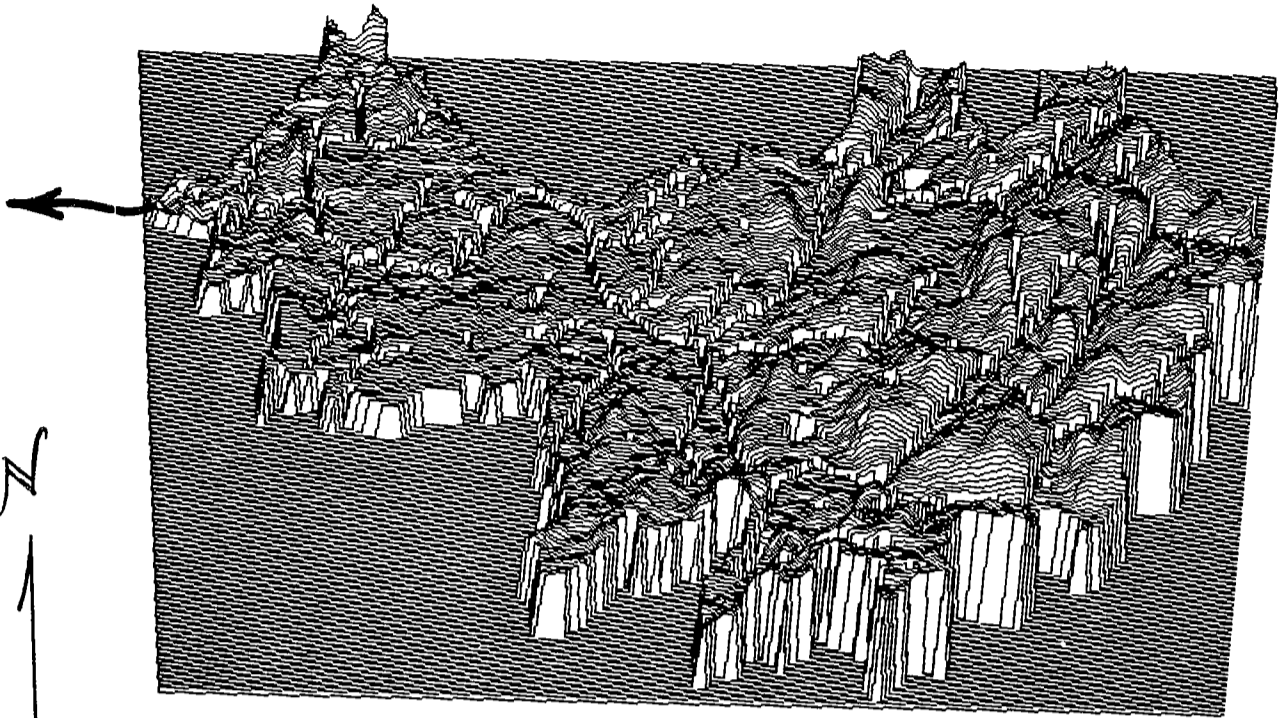
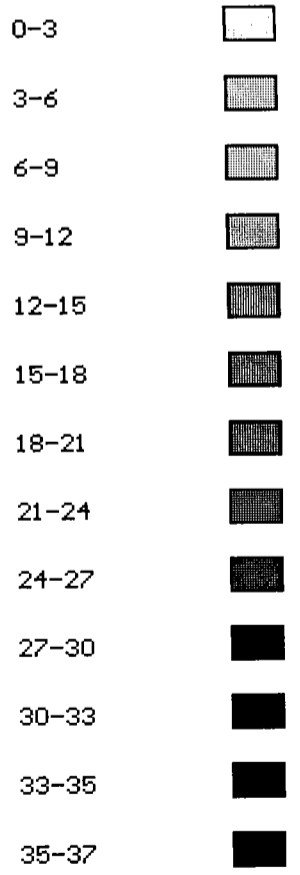
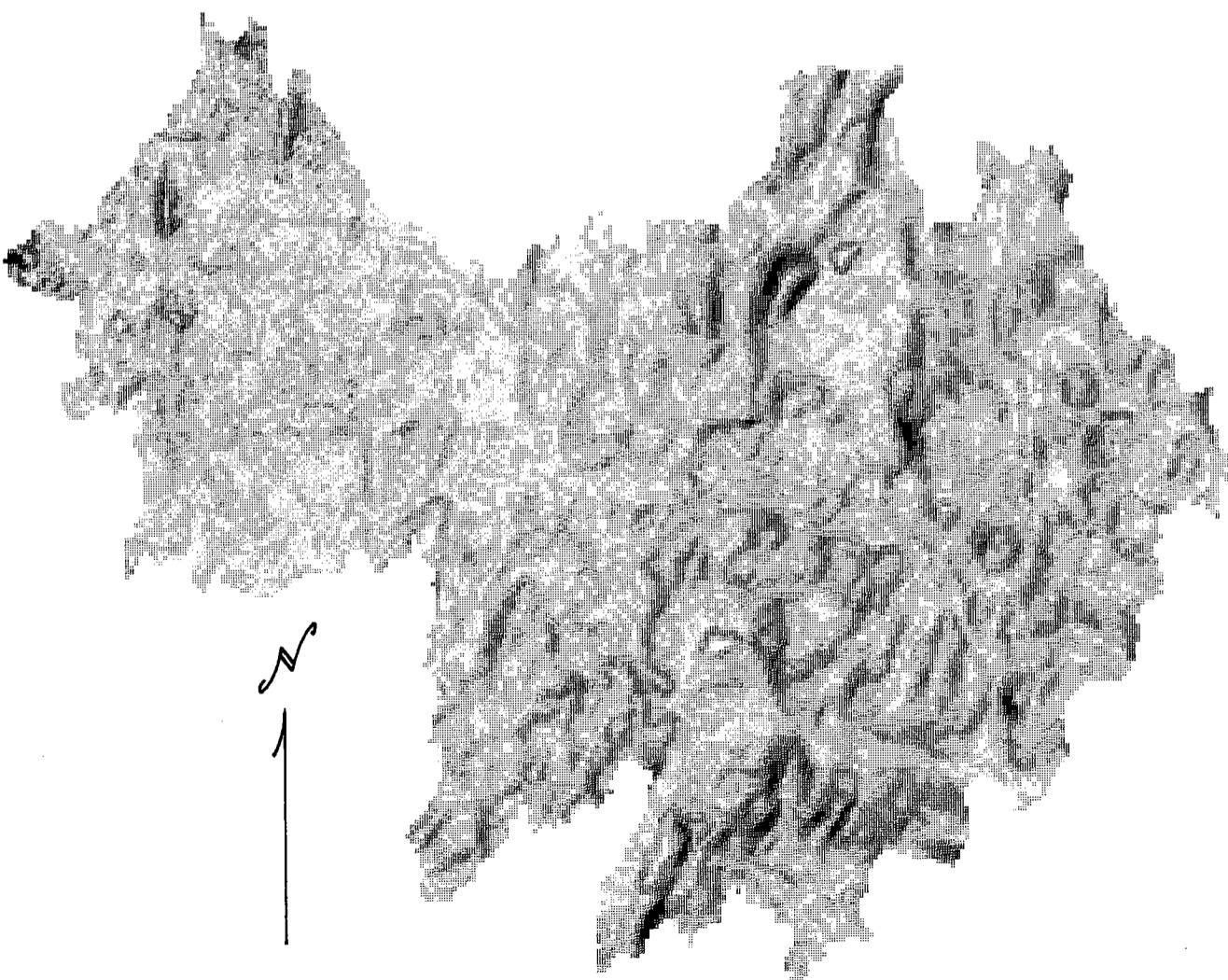


Figure 4: Slope map (percent) of the Saw Kill watershed, Dutchess County, New York

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Soils

The Saw Kill watershed has 34 soil mapping units and complexes (USDA SCS, in press). These 34 soil units were grouped according to their primary textural class (proportion of sand, silt, and clay) to create the GIS layer depicted in figure 5. The limited number of gray shades available in the GIS software necessitated this simplification.

The soils of the Hudson-Mohawk physiographic region have a systematic spatial distribution. Approximately 12-15,000 years ago, Glacial Lake Albany extended well beyond the current Hudson River shoreline to the 250 foot (76 meter) contour (Carey and Waines 1987; USDA SCS, in press). Lacustrine sediments, fine silts, and clays, were thickly deposited in this area. To the east, sand and gravel were deposited in Lake Albany's delta and shoreline. Glacial till overlying shale bedrock replaces the sands and gravels as the slope and distance from the Hudson River increase. In general, these soils are now composed of thick layers of silty loams or silty clays over sand, gravel or channery sediments. While soil drainage properties range from well-drained to poorly-drained, clay and silt layers frequently restrict drainage within the soil mantle (Dutchess County Department of Planning, 1985).

Dutchess-Cardigan and Nassau-Cardigan complexes cover 45 percent of the watershed. These soil complexes are silt loams derived from glacial till on hilltops and slopes. They are

silt loam/lo	□
silt loam/sa	▒
silt loam/cl	▓
loam/loam	▒
loam/sand-gr	▓
loam/clay	▒
organic	▓
urban	▒
gravel pit	▓

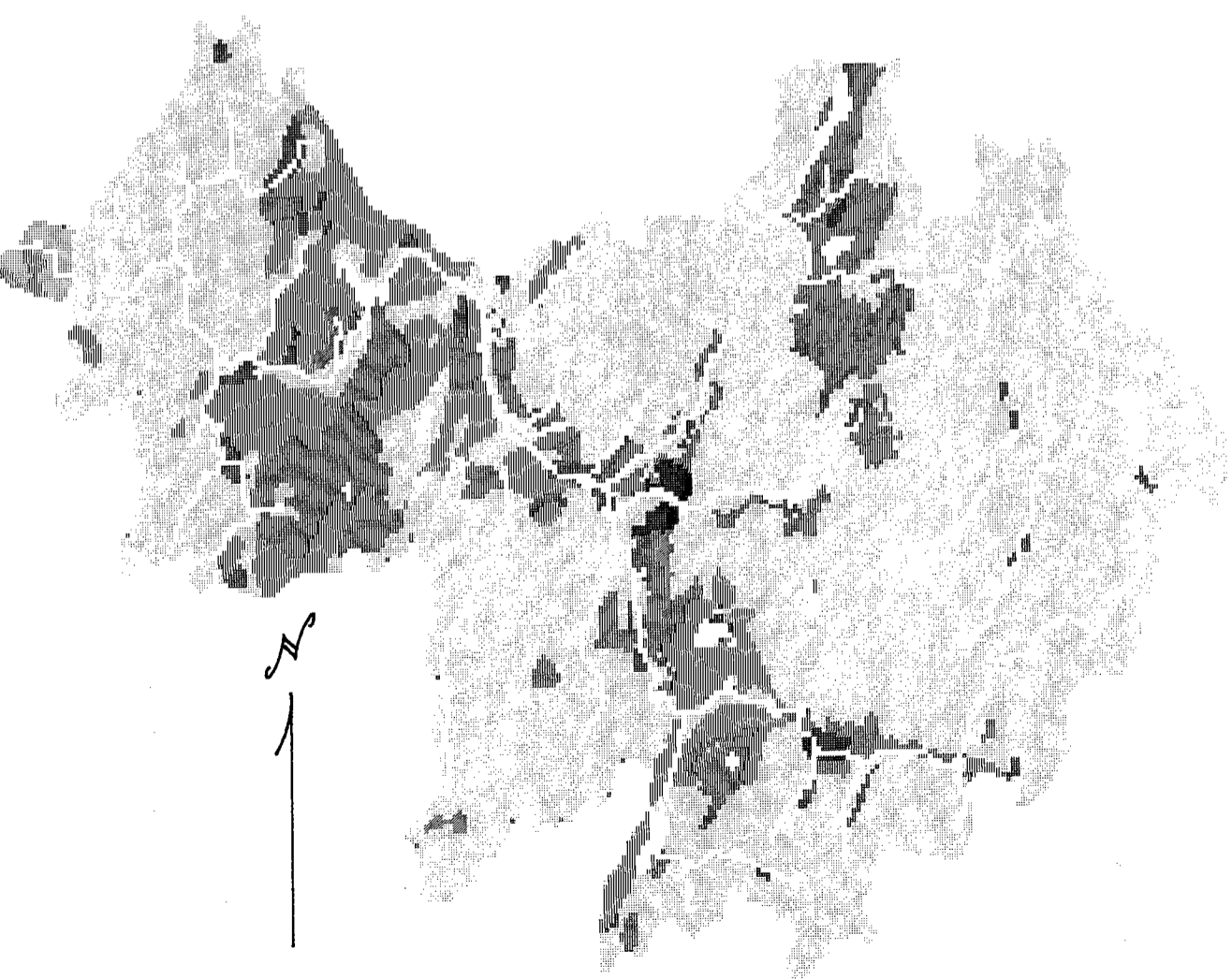


Figure 5: Saw Kill watershed soils grouped by textural classes (USDA Soil Conservation Service, in press)

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shallow (0.8 meters to bedrock) to moderately deep (2.3 meters to bedrock), with a relatively well-drained surface layer underlain by a poorly-drained layer. Silt loam alluvial deposits (the Wayland, Sun, and Livingston series) are among the most erodible soils in the watershed.

Land Use and Vegetative Cover

Figure 6 illustrates the spatial distribution of land uses and vegetative cover in the Saw Kill watershed. Table 1 provides a detailed classification of land use, along with corresponding areas, for each major category. The extensive forested area (51.1%) is largely second growth deciduous and coniferous forest, and includes forested strips along streams. Agricultural land uses, primarily hayfields (10.7%), account for 25.8 percent of watershed land use. Residential use (including farmsteads) accounts for 13.6 percent. High density residential and commercial development is largely centered in the Village of Red Hook. Low and medium density residential land use occurs as subdivision development in patches throughout the watershed. Examples of this are found along the high eastern ridges with panoramic views of the Catskill or Taconic Mountains, and throughout the extensive glacial outwash plain just north of Red Hook. Commercial use occupies only 2.8 percent of the Saw Kill watershed. Bare soil sites, accounting for only 1 percent of land area, are primarily, active construction sites (1990-91) and the Red Hook-Rhinebeck landfill.

Table 1: Land use and vegetative cover within the Saw Kill watershed, Dutchess County, NY (April 1990 aerial photographs, July/August 1991 field check)

Land Use or Cover Type	Area (ha) ⁴	Fraction of watershed (%)
Forest		
Deciduous	2,276.5	33.1
Coniferous	964.9	14.0
Mixed	271.0	4.0
Agricultural		
Hayfield	740.3	10.7
Fallow field	174.8	2.5
Row crop	353.1	5.0
Pasture	253.3	3.7
Orchard	215.0	3.1
Tree farm	46.2	0.7
Livestock feeding area	0.5	<0.1
Urban		
Farmstead	47.5	0.7
Residential, low density	519.1	7.5
Residential, med. density	227.3	3.0
Residential, high density	164.8	2.4
Commercial, low density	101.0	1.5
Commercial, med. density	92.5	1.3
Commercial, high density	9.0	<0.1
Water Features		
Lakes, ponds	106.7	2.0
Wet areas	212.7	3.0
Bare Soil		
Dumps, excavated sites	69.8	1.0
Other		
Cemetery, playground, etc.	40.5	0.6
Total Watershed Area	6,886.5	100.0

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⁴ 1 ha = 1 hectare = 10,000 m² = 2.471 acres

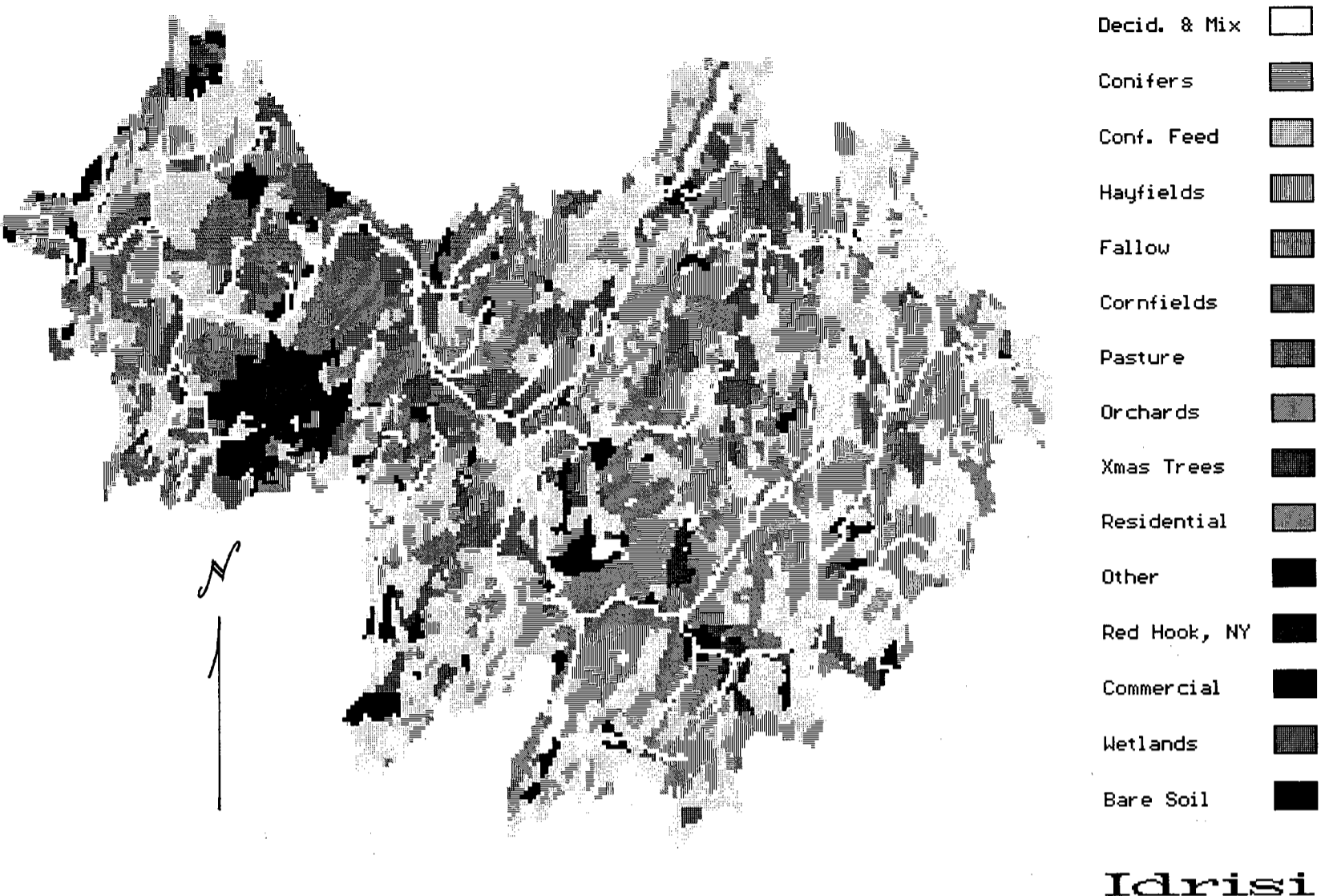


Figure 6: Land use and vegetative cover within the Saw Kill watershed, Dutchess County, NY (April 1990 aerial photographs, July/August 1991 field check)

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METHODS

The GIS database is composed of primary, secondary and derivative (calculated) layers of spatial information (Barten et al. 1991 and in preparation). A complete listing of the layers appears in Table 2. The primary layers are the topography (elevation), soils, and vegetative cover/land use. Secondary layers, referenced to the primary layers, depict soil physical and hydraulic properties (e.g., thickness, porosity, permeability) that influence the movement and storage of water. The derivative layers show the relative contributions of different watershed areas to streamflow generation and soil erosion. These layers were developed by combining the information contained in the primary and secondary layers as shown in the footnotes following table 2 and equations 1, 2, and 3.

A base map was created for the watershed by tracing the watershed boundary, the Saw Kill and its tributaries, other water features, and major roads from the 1:24,000 scale USGS (7.5 minute) topographic quadrangles. This scale was used as the standard for all other maps. The spatial information was digitized and analyzed using the IDRISI (Eastman 1990) GIS package at a grid cell resolution of 50 x 50 meters (0.25 hectares or 0.6178 acres).

Topography Layer

Digital elevation (DEM) data were acquired from the USGS Earth Science Information Center -- a part of the National

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Mapping Program. The digital data consist of elevations for ground positions at a spacing of 30 by 30 meters for each USGS topographic quadrangle. The availability of DEM data greatly increases the efficiency of primary layer development.

Table 2: Primary, secondary, and derivative GIS layers for the Saw Kill watershed, Dutchess County, New York

Primary Layers	Secondary Layers	Derivative Layers
Topography	Slope gradient S factor L factor	
Soils ⁵	Permeability Porosity Thickness K factor	Flux ⁶ Flow ⁷ Total storage ⁸ Soil erosion ⁹
Vegetation/ Land Use	VM factor	

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- 5 secondary GIS layers were created for the upper and lower soil layers, numbered 1 and 2, respectively
- 6 equation 1, page II-27
- 7 equation 2, page II-28
- 8 Total Storage = (Thickness₁ * Porosity₁) + (Thickness₂ * Porosity₂)
- 9 Soil erosion is calculated (equation 3, page II-29) with the S, L, K, and VM factor secondary layers

Soils Layer

Dutchess County initiated a new soil survey in the mid-1980's, and completed the survey during the summer of 1991. Orthographically corrected blue line drawings, and copies of black and white aerial photos, at 1:24,000 scale with designated soil mapping units were provided by the Dutchess County Soil and Water Conservation District (USDA SCS, in press) to develop the soils layer needed for this study (figure 5).

Vegetative Cover and Land Use

A vegetative cover and land use layer (figure 6) was developed from 1:12,000 black and white aerial photographs flown for the Dutchess County Real Property Tax Department in April 1990. Color infrared (CIR) photography flown by NASA during the National High Altitude Photography (NHAP) Program at a scale of 1:58,000 provided supplemental information. The classification scheme used for this study is compatible with Tier II in the USGS land use system (Lillesand and Kiefer 1979). Additions to this system were made when a site's erosion potential (such as a bare soil site) required a distinct identifying category. Other modifications were made to highlight sites which, because of land use, could be key elements in a water quality sampling network designed with the aid of the GIS. For example, the confined feeding areas for dairy herds and other livestock are not included in the USGS classification system, yet they could be important sites for

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water quality sampling. This layer does not attempt to represent property boundaries, simply areas of homogeneous land use for the development of, and correlation with, streamflow and sediment source areas. The vegetative cover/land use classification system used in this study is summarized below. The minor categories are listed in parentheses after the major groups.

Forest (deciduous, coniferous, mixed species)

It is not necessary to determine the species composition of forests to estimate soil erosion. However, it may be advisable to add categories (e.g., red pine, white pine, hemlock ...under conifers) for more detailed ecosystem studies.

Agriculture (pasture, hayfield, orchard, fallow fields)

The fallow field category includes fields which are now used as lawns and which once may have been in agricultural use. The aerial photos from 1986 (NHAP) and 1990 (Dutchess County Tax Office), together with field verification in 1991 provided the information needed for accurate classification. Urban (residential, commercial, industrial)

Residential use was categorized according to its density, measured as the number of homes per 10 acre area: High = 7-10 houses, Medium = 3-6 houses, Low = 1-2 houses. High density areas are generally in the vicinity of the Village of Red Hook. Medium density residential areas are generally subdivisions, and low density areas are typically isolated

homes or groups of homes. In agricultural areas, it was often difficult to delineate a residence from a commercial use, particularly for small farms. Small (hobby) farms were identified as residential while medium and large farms were designated commercial. The latter designation is assigned to the buildings and associated impervious areas, while fields are categorized according to their specific use (orchard, row crop, etc.). Schools are included in the residential category. Commercial land uses, such as: shopping centers, gravel pits, landfills and dumps, and airports, were also divided into high, medium, and low densities. The vast majority of commercial (mercantile) land use in the watershed is located in the center of Red Hook. There are no industrial manufacturing facilities in the watershed.

Disturbed Lands

This category includes bare soil sites identified as areas with potentially high erosion rates.

Water Features (ponds, lakes, wetlands)

This study did not attempt to delineate wetlands according to their legal definition. Wet areas were particularly difficult to identify on aerial photographs. They were verified by field inspection in most cases. U.S. Fish and Wildlife Service wetland delineations, at a spatial resolution of 1 acre, will soon be available on the Dutchess County Department of Environmental Management's GIS database.

This wetland layer could be added to the GIS database developed in this study.

A systematic approach to aerial photograph delineation was adopted to ensure consistency in the final map and GIS layer. Initial delineation was done by viewing the 1:12,000 scale aerial photos in stereo pairs with a magnifying mirror stereoscope. Each photograph was covered with transparent drafting film and various land uses or vegetative cover types were outlined with a drafting pen. Whenever an area could not be classified with certainty, the current land use was verified in the field. A composite map was made from the 43 individual overlays in preparation for digitizing. It was photographically reduced to the base map scale of 1:24,000.

Secondary and Derivative GIS Layers

Secondary GIS layers were developed for soil thickness, porosity, permeability, and erodibility with the recent soil survey data for Dutchess County (USDA SCS, in press). Each of the 34 soils was represented by either a one-layer or a two-layer system, depending upon the vertical variation in permeability. Where a clear difference (e.g., greater than 2X) in permeabilities existed between layers, we classified the soil as a two-layered system. Where permeability was uniform, or changed only slightly over the thickness, we classified the soil as a one-layer system. Some soil properties were estimated with basic equations (Hanks and Ashcroft, 1980; Hillel 1980). For example, porosity was

calculated from the bulk density data for each soil layer. An adjusted value for porosity was then derived from the percent coarse fraction as estimated in the field (USDA SCS, in press). Conventional spreadsheet software was used to manage this extensive database. In the case of soil complexes, which are composed of several different soil mapping units, properties were estimated by weighting the percentage contribution of each soil mapping unit within the complex. This adjusted value includes the contribution of each soil type to the cumulative properties of the complex.

Streamflow Source Areas

The flux of water (q_s) through saturated soil is described by Darcy's Law (Hillel, 1980). The ability of each area of the watershed (i.e., each grid cell) to transmit water is governed by slope gradient and soil permeability. The potential transmission rate (flux) under saturated conditions was calculated for each grid cell using the following computational form of Darcy's Law...

$$q_{si} = K_{si} * [\% \text{ slope}/100] \quad (1)$$

where:

$$q_{si} = \text{flux } [(m^3/day)/m^2]$$

$$K_{si} = \text{permeability } [(m^3/day)/m^2]$$

$$[\% \text{ slope}/100] = \text{estimate of the hydraulic gradient} \\ \text{(dimensionless)}$$

$$i = \text{soil layer 1, 2}$$

The total potential flow (Q) through the soil monolith (the unconsolidated material comprising the A, B, and C soil horizons) was calculated with equation 2.

$$Q = \sum_{L=1}^2 q_{si} * Y * Z_i \quad (2)$$

where:

Q = total monolith flow (m³/day)

q_s = flux through soil layer i [(m³/day)/m²]

Y = grid cell width (50 m)

Z = thickness of soil layer i (m)

i = soil layer 1, 2

The range of total potential flows was divided into 15 different drainage categories for graphical presentation in the GIS.

Sediment Source Areas

Soil erosion is the detachment and transport of soil particles from the soil surface by the action of raindrops, overland flow, and wind (Brooks et al. 1991). Climate, topography, soil characteristics, vegetative cover, and land use affect erosion. Annual soil erosion was estimated for each 0.25 hectare (0.6178 acre) grid cell within the Saw Kill watershed. In its current form the GIS (Eastman 1990) does not provide for the simulation sediment transport between grid cells.

The Modified Universal Soil Loss Equation (MUSLE), developed from the Universal Soil Loss Equation (USLE), was used as the empirical model for calculating annual soil loss.

The USLE was first developed by Wischmeier in 1965 from over 10,000 plot-years of source data from agricultural areas under natural rainfall events by the USDA Agricultural Research Service (Brooks et al., 1991). The MUSLE was developed to extend the USLE to forest and range lands. It is a multiplicative regression model presented in the following computational form:

$$A = R \cdot K \cdot L \cdot S \cdot V_M \quad (3)$$

where:

A = soil erosion (tons/acre)/year

R = rainfall erosivity factor

The R value reflects an average annual measure of the erosive forces imparted to the soil surface by rainfall and the resulting overland flow. All rainfall events are included, including the annual maximum (USEPA, 1980). An R value of 140 is used by the USDA SCS (and in this study) for northern Dutchess County.

K = soil erodibility factor

The K value represents a soil's intrinsic resistance to surface erosion. It quantifies the combined effects of soil texture, structure, organic matter content, and degree of aggregation. The K value was first developed empirically with standard 72.6 foot bare soil plots with a uniform slope of 9 percent (USDA SCS 1983).

L = slope length factor

Soil erosion is directly proportional to slope length; as a direct result of the greater volume and momentum of overland flow. The L value is defined as the distance from the origin of overland flow to the point of deposition, channel entry, or disturbance. Developing slope lengths and contributing areas for nearly 28,000 grid cells in the 17,017 acre watershed was beyond the scope of this study. Therefore, a uniform slope length of 50 meters (one grid cell width) was used for this initial assessment of soil loss in the Saw Kill watershed. Hence, the erosion rates predicted with the

GIS will underestimate soil losses on long, continuous slopes. Standard exponents were applied to modify the L value assigned to each grid cell (US EPA, 1980). This accounts for differences in slope length as a function of steepness.

S = slope gradient factor

Soil loss is directly proportional to slope steepness. The S factor was derived for each grid cell with the formula presented by the US EPA (1980).

VM = vegetation management factor

The VM factor is the ratio of soil loss from land managed under specified conditions to the corresponding loss from bare soil (control) plot. Hence, it ranges from 0 to 1 as site conditions range from well-protected (e.g., forest land) to no protection (e.g., a construction site). The VM factors used by the Dutchess County Soil and Water Conservation District (B. Dibble, USDA SCS, personal communication) were applied in this study. In some cases, the VM factors were modified with reference to the USDA Soil Conservation Service (1983) National Engineering Handbook. VM factors range from 0.0005 for forested land, 0.01 for pasture and residential land, to 1.0 for bare soil. The Dutchess County SCS applies a cropping management factor of 0.39 to silage corn crops and a value of 0.29 for grain corn (spring plowing, high management intensity). Because grain corn and silage corn were not differentiated in our land use delineation, an average value of 0.34 was applied as the vegetation management factor.

Sediment Delivery

The methods described earlier can be used to estimate the spatial distribution and total quantity of annual soil erosion in a watershed. However, only a portion of the soil eroded within a watershed makes it way into the stream system, and ultimately, to the outlet. While physically-based modeling of the soil erosion - sediment transport - sediment deposition process is beyond the scope of this study, an estimate of the

sediment deposition rate in South Tivoli Bay can be made with empirical methods. This deposition rate is of interest to researchers and managers at the Tivoli Bays.

A method developed by Roehl (1962) and further described by Hadley and his co-authors (1985) allows the preliminary estimation of sediment delivery in the absence of field measurements. The sediment delivery ratio (SDR) is defined as the total mass of sediment delivered to the watershed outlet divided by the total mass of soil erosion that occurred on the watershed. Although the majority of sediment transport occurs during large storm events, the SDR represents an annual average value. Roehl (1962) found that the sediment delivery ratio was inversely proportional to watershed area for a wide range of sites in the United States. This reflects the greater opportunity for sediment deposition and storage as watershed area increases. Applying Roehl's sediment delivery ratio function for the central and eastern U.S. region to the Saw Kill watershed (68.9 km²) yields a value of 0.18 -- approximately 20 percent of soil eroded on the watershed is likely to reach the watershed outlet.

RESULTS AND DISCUSSION

Soil Physical and Hydraulic Properties

The secondary GIS layers depict the soil physical and hydraulic properties contributing to the total storage and flow capacity of the soil monolith. These physical and hydraulic properties, summarized in table 3, include: soil thickness, adjusted porosity, permeability (saturated hydraulic conductivity), erodibility, total acreage, and percentage of the watershed area.

Soil Water Storage Capacity

Soil water storage capacity has a major influence on the hydrologic regime of a watershed. Available (actual) storage varies at several time scales (seasonally, daily, even hourly) in response to changes in the balance between precipitation inputs and evaporative losses. Available storage can be determined by detailed field measurements or estimated with a physically-based water budget model. Field measurements are complex, time consuming, and expensive. Currently available hydrologic models have a limited capability to represent spatial variation of soils, topography, vegetation, and land use within large, heterogeneous watersheds. Consequently, it is very difficult to develop valid estimates of actual soil water storage. Potential storage capacity represents the upper boundary condition for each soil unit. Since it is not time dependent, it provides a comparable measure to examine the relative influence of each soil type within the watershed

on streamflow generation. It supplements the information provided by subsurface flow rate estimates.

The potential water storage capacity is determined by the thickness, area, and porosity of a soil (Hillel, 1980). The available pore space is strongly influenced by the soil texture. Because porosity increases with decreasing particle size, fine textured silt or clay soils of a given depth can store greater quantities of water than coarse-textured sandy soils. The porosities of soils in the Saw Kill watershed range from 0.86 (organic mucks) to approximately 0.25 (in gravel pits). Soil thicknesses average 0.6 meters for the upper soil layer and 1.4 meters for the lower soil layer. Figure 7 shows the distribution of potential water storage capacity (at saturation with no entrapped air) throughout the watershed. The lowest water storage capacities, 0.2 m to 0.4 m, are found in the highly permeable and relatively shallow Dutchess-Cardigan and Nassau-Cardigan soil complexes, and the Haven loam soils located in the glacial outwash plains. Higher water storage capacities are found where thick soils have developed in silty-textured lacustrine and alluvial deposits. The maximum estimated storage capacity is 1.6 m; the mean storage capacity is 0.5 m. This does not include the water held in the bedrock beneath the soil. Shale, the most prevalent bedrock type in the watershed, can have porosities between 0.05 and 0.15. The effective porosity of all rock outcrop areas within soil complexes was assumed to be zero.

Figure 7: Potential water storage capacity in the Saw Kill soil monolith (meters)

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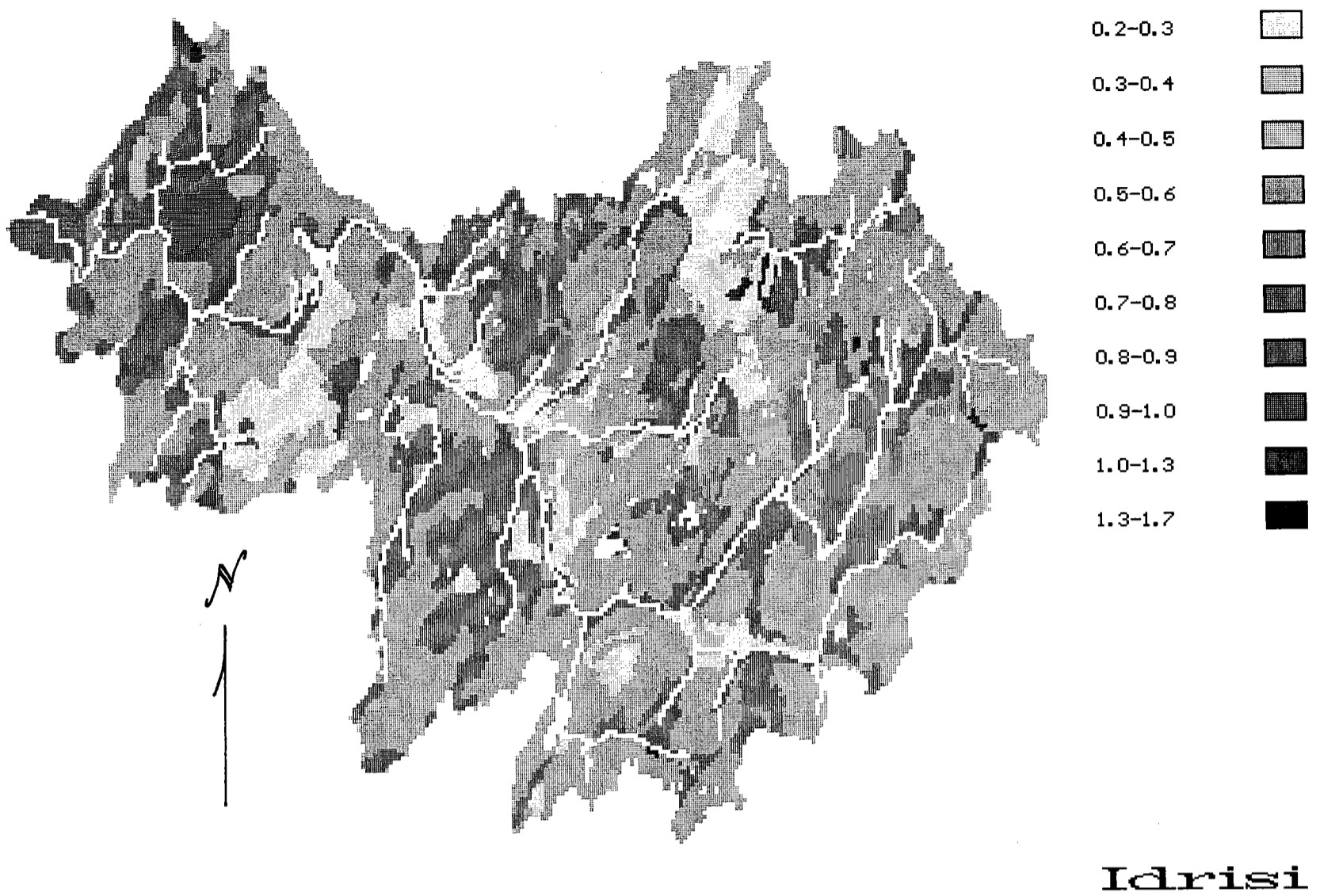


Table 3 Saw Kill watershed soil physical and hydraulic properties.

Soil Abb.	Soil Name	Soil layer	Total thickness (meters)	Adjusted porosity	Saturated hydraulic conductivity (meters/day)	Erodibility index	Acreage	Watershed Area (%)
Be	Bernardston SL	1	0.51	0.52	0.79	0.28	102.3	0.6
		2	1.02	0.31	0.08			
Cc	Carlisle Muck	1	2.03	0.93	1.89	0.1	5.6	neg.
		2						
Du	Dutchess SL	1	2.18	0.45	0.79	0.34	508.4	3
		2						
Dw	Dutchess-Cardigan Complex	1	1.26	0.36	0.79	0.34	3581.1	21
		2	1.58	0.24	0.1			
Fc	Farmington-Galaway Complex	1	0.54	0.35	0.79	0.31	29.4	0.2
		2	1.58	0.24	0.1			
Fe	Farmington-Rock Outcrop Complex	1	0.37	0.3	0.63	0.25	11.16	0.06
		2	1.56	0.23	0.12			
Ff	Fluvaquents-Udfluvents Complex	1	0.19	0.43	3.47	0.32	57.7	0.3
		2	1.56	0.28	6.18			
Fr	Fredon SL	1	0.66	0.51	0.7	0.28	274.7	1.6
		2	1.12	0.47	7.93			
Gl	Galaway-Farmington Urban Complex	1	0.45	0.25	0.6	0.24	135.1	0.8
		2	1.49	0.23	0.12			
Gf	Galaway-Farmington Complex	1	0.57	0.35	0.79	0.31	94.2	0.5
		2	1.58	0.24	0.1			

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Soil Abb.	Soil Name	Soil layer	Total thickness (meters)	Adjusted porosity	Saturated hydraulic conductivity (meters/day)	Erodibility index	Acreage	Watershed Area (%)
Gs	Georgia SL	1	0.66	0.49	0.79	0.32	217.60	1.30
		2	1.37	0.36	0.08			
Ha	Halsey MSL	1	0.46	0.72	0.79	0.24	222.60	1.30
		2	1.07	0.46	6.28			
He	Haven Loam	1	0.71	0.51	0.79	0.32	1574.20	9.20
		2	1.12	0.42	12.20			
Hf	Haven- Urban Complex	1	0.44	0.25	1.18	0.18	297.60	1.70
		2	1.06	0.13	10.67			
Hs	Hoosic GL	1	0.56	0.49	6.16	0.17	1320.60	7.70
		2	0.97	0.42	12.20			
Ht	Hoosic CL fn	1	0.56	0.49	6.16	0.17	30.40	0.20
		2	0.97	0.42	12.20			
Hv	Hudson Vergennes Complex	1	0.43	0.51	0.38	0.49	91.10	0.50
		2	1.18	0.48	0.07			
Hy	Hydraquents- Medisaprists Complex	1	0.81	0.48	2.81	0.23	0.00	0.00
		2	1.47	0.31	1.10			
Kn	Kingsbury- Rhinebeck Complex	1	0.24	0.48	0.24	0.49	0.00	0.00
		2	1.44	0.45	0.06			
Ku	Knickerbocker- Urban Complex	1	0.38	0.28	1.17	0.16	26.00	0.20
		2	1.24	0.27	7.85			

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Soil Abb.	Soil Name	Soil layer	Total thickness (meters)	Adjusted porosity	Saturated hydraulic conductivity (meters/day)	Erodibility index	Acreage	Watershed Area (%)
Kr	Knickerbocker FSL	1	0.51	0.51	2.44	0.20	187.20	1.20
		2	1.52	0.42	3.66			
Lv	Livingston SCL	1	0.18	0.49	0.24	0.49	45.30	0.30
		2	1.65	0.48	0.06			
Mn	Massena SL	1	0.23	0.53	0.79	0.28	213.90	1.20
		2	1.60	0.37	0.20			
Nw	Nassau- Cardigan Complex	1	0.57	0.29	0.74	0.31	4200.50	24.60
		2	1.70	0.24	0.12			
Nx	Nassau- Rock Outcrop Complex	1	0.47	0.20	0.56	0.23	455.10	2.70
		2	1.80	0.25	0.06			
Pc	Palms Muck	1	0.89	0.86	1.89	0.10	88.70	0.50
		2	1.14	0.40	0.67			
Pw	Pittstown SL	1	0.74	0.49	0.79	0.28	118.40	0.70
		2	1.30	0.30	0.20			
Pz	Punsit SL	1	0.58	0.47	0.79	0.28	2.50	neg.
		2	1.45	0.31	0.08			
Ra	Raynham SL	1	0.56	0.49	0.67	0.49	216.40	1.30
		2	1.47	0.47	0.08			
Sk	Stockbridge SL	1	0.71	0.48	0.79	0.28	205.20	1.20
		2	1.32	0.35	0.20			

Soil Abb.	Soil Name	Soil layer	Total thickness (meters)	Adjusted porosity	Saturated hydraulic conductivity (meters/day)	Erodibility index	Acreage	Watershed Area (%)
Su	Sun SL	1	0.23	0.53	0.79	0.28	1471.90	8.60
		2	1.80	0.42	0.06			
Ud	Udortheints	1	0.10	0.43	6.12	0.37	64.50	0.40
		2	1.68	0.40	1.85			
We	Wappinger L	1	0.84	0.51	0.79	0.49	0.00	
		2	0.69	0.48	6.71			
Wy	Wayland SL	1	0.18	0.54	0.67	0.43	1134.60	6.60
		2	1.85	0.48	0.08			

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Estimated Subsurface Flow through the Soil Monolith

Predicted subsurface flow rates through the 50 by 50 meter grid cells in the Saw Kill watershed range from nearly 0 to 180 m³/day. Spatial variation in the rate of subsurface flow (figure 8) leads directly to differences in soil water content; ranging from at or near saturation (dark gray tones) in the primary source areas of the stream to very dry areas (light gray tones) along ridges and steeper slopes, or in deep, highly permeable, lowland deposits of sand and gravel. While porosity limits the total amount of water that a given volume of mineral soil can store, it is most often inversely related to soil permeability. The size distribution, shape, and arrangement of the pore space has a greater influence on permeability than the total porosity (Hanks and Ashcroft 1980; Hillel 1980). Therefore, the silts and clays, although capable of greater water storage, usually transmit water to streamflow at a much slower rate. In contrast, sand and gravel deposits can readily transmit large volumes of water through interconnected, large diameter pores. Consequently, at any given time, the slowly permeable, poorly-drained clay soils will be wetter than the highly permeable, well-drained sandy soils. As a result, the relative contributions of different soil types along a drainage catena (Brady 1974) vary in a systematic manner. The wet soils in close proximity to the stream channel contribute continuously to streamflow (both baseflow and stormflow). Droughty soils near the watershed

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