A GIS Model to Calculate Sediment Yields from a Small Rural Watershed, Old Woman Creek, Erie and Huron Counties, Ohio[1]

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Abstract. Upstream sediment yields have a potential impact on the Old Woman Creek National Estuarine Research Reserve. This project developed a GIS-based soil erosion model to calculate sediment delivery ratios and intrabasinal storage, and then developed a sediment routing model to identify portions of the drainage basin that are significant sediment contributors.

A 120-meter grid spacing was used to divide the 69.5 km^2 drainage basin into 4843 polygons (each 1.44 ha in size). Soil erosion was calculated for each polygon using RUSLE and a GIS data base. This study also modified the RUSLE by using a DEM to calculate length-slope factors. RUSLE soil loss values ranged from 1.6 to 97.3 (average 7.26) metric tons/ha/yr. These values are significantly (26%) greater than previous estimates based on RUSLE calculations by hand, primarily due to modification of length-slope factors and higher sampling density.

A 502-day hydrological data base collected by Heidelberg College was used to calculate an average annual suspended sediment load for Old Woman Creek. Given that suspended sediment is 30-35% of the total sediment load, comparison of sediment load and RUSLE soil erosion indicates sediment delivery ratios between 21-25%, and intrabasinal storage of 75-79% for the catchment.

The sediment routing model tracks sediment from polygon of origination down elope to adjacent streams. This model predicts highest sediment yields from the southeast portion of the drainage basin. Protection efforts for the estuarine reserve should emphasize crop management practices in this region.

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INTRODUCTION

Significant changes have occurred in the hydrogeology of Ohio's drainage basins over the past two hundred years as a consequence of settlement, land clearance, and the advent of large-scale agriculture. The state population increased from approximately 40,000 at inception of statehood (1803) to about 800,000 within twenty years, and to 1.5 million by 1840 (Weisenburger 1941), most of these being farmers. Studies have shown that agriculture increases soil erosion rates between one and three orders of magnitude in comparison to undisturbed watersheds (Ursic and Dendy 1965, Wolman 1967, Trimble 1974, Trimble and Lund 1982).

Soil erosion is the rate of removal of soil particles from a representative area of landscape, measured either as mass removed per unit area per unit time, or as soil thickness removed per unit time. Soil erosion can be accomplished by wind, mass wasting, and glacial activity, but in eastern North America the most significant soil erosion process operating now is the down slope movement of running water. Soil particles are detached by rain-splash erosion (Young and Wiersma 1973) and then entrained by overland flow, when the shear stress exerted by the flow overcomes the critical or resistant shear stress of the material (Foster and Meyer 1975). Soil erosion at any location is a function of numerous variables, including climate (especially rainfall intensity), soil properties (soil texture, soil structure, and soil thickness), bedrock type, vegetation type and density, presence of burrowing organisms, land use, and aspects of topography such as relief and microtopography in the form of rills and gullies (Musgrave 1947; Musgrave and Holtan 1964; Wischmeier and Smith 1965, 1978; Harvey et al. 1985; Foster 1986).

Sediment yield refers to the rate at which sediment passes a particular point in a drainage basin, usually measured in mass removed per unit area per unit time (Haan et al. 1994). While soil erosion documents annual soil loss at some point, sediment yield is a more dynamic measure of the flow of sediment through a drainage basin. Sediment yield depends on: (1) input functions such as soil erosion, mass wasting, and dust fallout, (2) intrabasinal storage such as deposition in rills, gullies, or valleys, and (3) output functions such as stream sediment load and wind erosion (Meyer and Wischmeier 1969, Foster et al. 1977, Lane and Nearing 1989, Storm et al. 1990, Lewis et al. 1990).

Stream sediment loads refer to the amount of sediment transported by rivers and streams. Sediment loads are typically subdivided into three modes: bedload (clasts that slide, roll, or saltate near the stream bed), suspended load (clasts that remain mixed throughout the water column due to turbulence), and dissolved load (chemicals in solution as ions or as molecules adsorbed to colloids). For each of the three modes, sediment load (mass) is calculated as the product of sediment concentration (mass per volume), discharge (volume per unit time) and time. However there are differences in sampling each of the three types of sediment loads. Large data sets of bedload measurements are particularly difficult to obtain (e.g., Dunne and Leopold 1978). Average suspended sediment loads in this study

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were 30-35% of the average total sediment loads.

These issues are important for the following reasons. Soil erosion results in loss of agricultural productivity (e.g., Dunne and Leopold 1978), and erosion of soil particles with adsorbed agricultural chemicals is a significant cause of non-point source pollution (Schmidt 1972). Sediment yield determines stream sediment loads within a drainage basin and historical changes in sediment yields (due to changing landuse) can dramatically alter the hydrogeology of a watershed (e.g., Trimble 1983). Increased suspended sediment loads can result in numerous problems, including increased turbidity, reduction in light penetration into a stream, increased water temperature, abrasion damage to aquatic organisms, siltation of reservoirs, and change of substrate (e.g., Dendy and Champion 1978, Milhous 1982). Regulatory agencies face the problem of determining how to allocate funding and research efforts to best address these concerns.

The purpose of this study is to propose and test a model to determine soil erosion and sediment yield from a small watershed, determine where maximum sediment loadings occur into tributary streams, and calculate intrabasinal storage. The Old Woman Creek drainage basin was chosen in this study because of availability of supporting data and because this stream terminates in the Old Woman Creek National Estuarine Research Reserve, administered by the National Oceanic and Atmospheric Administration and the Ohio Department of Natural Resources. A sediment budget for this reserve has been identified as one of the priority research needs for successful management (Klarer, personal communication; 1993).

BACKGROUND

Geology and Hydrogeology

Old Woman Creek has a drainage basin area of 69.5 km^2, and is located in Erie and Huron Counties, of north central Ohio (Fig. 1). Buchanan (1982) subdivided the drainage basin into three physiographic units: (1) the upper drainage basin or "till plain," where dendritic stream patterns formed on exposed glacial tills, (2) the lower drainage basin or "lake plain," where parallel stream patterns formed on predominantly glacial-lacustrine sediments, and (3) the narrow "bedrock escarpment" region in the middle of the basin, where both dendritic and rectangular stream patterns formed on an incised bedrock surface.

The bedrock geology consists of the Huron Shale Member and the Cleveland Shale Member of the Devonian Ohio Shale, the overlying Mississippian Bedford Shale and the overlying Mississippian Berea Sandstone (Pepper et al. 1954, Herdendorf 1963, 1966). Bedrock exposures are only found locally in the middle of the drainage basin, but bedrock served as the sediment source for the overlying glacial deposits, and bedrock resistance helped to determined the distribution and thickness of those tills (Campbell 1955, Buchanan 1982).

Pre-glacial erosion of the bedrock surface formed a series of bedrock valleys, representing tributary channels of the "preglacial Huron River" which drained north and northeast into the Lake Erie lowland (Hobson et al. 1969, Herdendorf 1963, Buchanan 1982). The fill of the buried valley has a thickness of 43 m. The modern Huron River has reoccupied much of its pre-glacial valley (Herdendorf 1963), and the modern Old Woman Creek follows one of these tributary bedrock valleys (Buchanan 1982).

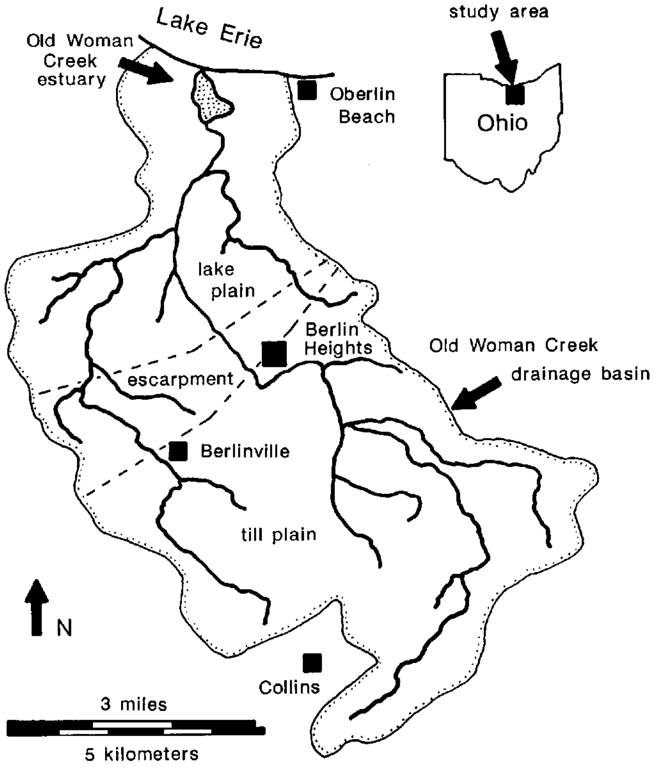

FIGURE 1. Location map showing Old Woman Creek drainage basin, towns, the estuary, and the three geomorphic provinces described by Buchanan (1982). Map is modified from Woods (1987), Buchanan (1982) and Herdendorf (1966).

Glacial sediments in the drainage basin include both tills and glacial-lacustrine silts and clays. Campbell (1955) recognized two till units in the region, a lower sandy till (26% sand, 49% silt, and 25% clay) and an upper clayey till (16% sand, 44% silt, and 40% clay). The two tills have been correlated to the Early Cary (or Kent) till and the overlying Late Cary (or Hiram) till (White 1951, Shepps 1953, Campbell 1955). Tills are exposed at or near the surface in the upper part of the drainage basin. Tills in this region are typically thin (<8 m) sheets that thicken or thin in response to the paleotopography of the bedrock surface, such as resistant sandstone ridges or bedrock valleys (Herdendorf 1963, Campbell 1955).

Buchanan (1982) found that the upper clayey till, mostly derived from the upper drainage basin, is the most significant sediment source within the Old Woman Creek drainage. The sand fraction of the upper clayey till is 60% to 70% quartz, with accessory feldspar, magnetite, biotite, sedimentary rock fragments, and igneous rock fragments. The clay fraction of the upper clayey till is mostly quartz, illite, and chlorite, with minor amounts of kaolinite, mixed-layer clays, and feldspar (Buchanan 1982).

There are two types of glacial-lacustrine sediments in the region: sandy beach ridge complexes (including eolian dunes, offshore bars, and small deltas) and silt-clay lake basin sediments. Beach ridge complexes from the Maumee, Whittlesey, and Warren glacial lakes stages are found adjacent to the bedrock escarpment in the central part of Old Woman Creek's drainage basin (Herdendorf 1966). Buchanan (1982) found that beach ridge complexes contribute little sediment to the drainage basin due to erosional resistance and because they occupy a small fraction of the total drainage basin. Glacial-lacustrine sediments are typically <6 m thick, and are mostly found in the lower part of the drainage basin (Herdendorf 1963).

Soil Associations and Vegetation

There are six major soil associations found within the drainage basin (Redmond et al. 1971, Ohio Department of Natural Resources 1989). Each soil association represents a group of similar soils with slight differences in horizon development, thickness, and average moisture content (mostly a function of microtopography). Parent materials (tills, glacial-lacustrine sediments, alluvial sediments, and bedrock) determine the overall distribution of soil associations and their attendant properties. The characteristics of these soils have been compiled in Table 1.

The original vegetation for these soils includes lowland mixed oak and mixed mesophytic forest, small inliers of prairie and wet prairie, and wetlands (Gordon 1966). The present landuse is predominantly agricultural (51%), with lesser amounts of pasture (16%), woodlands (21%), vinelands and orchards (3%), and commercial or residential (10%) purposes (Krieger and Klarer 1992). For most of the drainage basin, extensive artificial draining was a precondition for agricultural use. Many of the agricultural soils are very susceptible to erosional loss, for example the Mahoning Soil has a high soil erodibility factor and occupies 27% of the total drainage basin, being mostly in the upper part of the drainage basin (Buchanan 1982).

Previous Studies

Buchanan (1982) studied the sedimentary history of Old Woman Creek estuary using a variety of tools, including core stratigraphy, sedimentation rates calculated from ^{14}C radiometric ages, historical aerial photograph sets, and some preliminary hydrological measurements. In order to reconstruct the sediment budget of the estuary, Buchanan (1982) calculated modern soil erosion rates for the watershed using the Universal Soil Loss Equation (USLE, see next section). Buchanan (1982) also collected approximately two months (7/14/77 to 9/13/77) of data for stream discharge and suspended sediment concentrations during low flow (late summer) conditions.

Buchanan (1982) found that the estuary sediment fill fined-upwards over the past 8000 years, probably as a consequence of the rising levels of Lake Erie following deglaciation, and related decrease in stream gradient and competence. Within the past two hundred years, sedimentation rates in the estuary have risen from a long-term average of about 0.7 mm/yr to about 10 mm/yr, probably as a consequence of land clearance, agriculture, and resulting soil loss (Buchanan 1982, Reeder and Eisner 1994) .

Woods (1987) established and monitored nine channel cross-sections upstream of Old Woman Creek estuary for approximately six months (10/1/84 to 4 /19/85). Channel hydraulic geometry at these cross-section sites varies considerably, however consistent stage-discharge relationships and consistent discharge-suspended sediment concentration relationships were obtained for each station during Woods' study interval.

Heidelberg College's Water Quality Laboratory established automated samplers upstream and downstream of the estuary during the interval from 4/15/89 to 8/31/90 (464 days of record and 38 days of non-record). Each automated sampler recorded discharge, total suspended solids, total phosphorous, soluble reactive phosphorous, silica, conductivity, and pesticide concentrations at eight-hour intervals (Krieger 1993). Krieger (personal communication; 1996) has made available the data set for discharge and suspended

TABLE 1

Soil properties in drainage basin.

Soil Association*	% Drainage Basin	% Soil in Association	Soil Texture	Soil Erodibility (RUSLE K factor)
1. MBHJ Assoc.	(67%)			
Mahoning	27%	40%	silt loam	0.49
Bogart	10%	15%	loam	0.32
Haskins	7%	10%	loam	0.32
Jimtown	7%	10%	loam	0.28
minor soils	17%	25%	----	n/a
2. KTC Assoc.	(21%)			
Kibbie	7%	35%	sandy loam	0.37
Tuscola	7%	35%	sandy loam	0.37
Colwood	4%	20%	silt loam	0.37**
minor soils	2%	10%	----	n/a
3. AG Assoc.	(4%)			
Arkport	2%	40%	loamy sand	0.28
Galen	1%	30%	loamy sand	0.28
minor soils	1%	30%	----	n/a
4. DL Assoc.	(4%)			
Del Ray	3%	60%	silt loam	0.43
Lenawee	1%	30%	silt clay loam	0.43**
minor soils	<1%	10%	----	n/a
5. AF Assoc.	(2%)			
Allis	1%	70%	silt clay loam	0.43
Fries	<1%	20%	silt clay loam	0.43**
minor soils	<1%	10%	----	n/a
6. Marsh	1%	100%	variable	n/a

*Soil Association names are simple combinations of the names of the soils, for example the DL Association is composed of the Del Ray and Lenawee Soils.
**Estimates used for this study.
Data from: Buchanan 1982, Redmond et al. 1971.

sediment load from the automated sampler upstream of the estuary, at which point flow from 84% of the drainage basin is recorded.

Gregory (1996) conducted a study of the Old Woman Creek drainage basin to test scale dependency and aggregation techniques for the Agricultural non-point source (AGNPS) pollution model. The drainage basin was sub-divided into approximately 1700 grid cells. Attempts to group contiguous grid cells into larger spatial units was made difficult by convergent flow, looping flow, flow beyond the watershed domain, and presence of sink cells (Gregory 1996). The presence of sink cells in the mode would suggest significant intrabasinal storage within the catchment.

METHODOLOGY

Soil Erosion Calculation

The Universal Soil Loss Equation (USLE) determines soil erosion loss at any given point as a function of rainfall energy and intensity, soil erodibility, slope length, slope gradient, soil cover, and conservation practices (Wischmeier and Smith 1965). The Revised Universal Soil Loss Equation (RUSLE) has the same form as the USLE, but includes revisions for slope length and slope gradient calculations, more elaborate calculations for soil cover and conservation practices, and new terms to account for freeze-thaw effects and rill formation on erosion (Renard et al. 1993). The term "soil erosion" in RUSLE/USLE is somewhat of a misnomer, because it is recognized that much of the soil displaced from its original site is deposited subsequently in adjacent portions of the field, where the sediment transport capacity is lower (Haan et al. 1994).

RUSLE/USLE values for soil erosion are the product of a series of factors, as follows:

$$A = RKLSCP$$

where A = soil loss (mass/area/unit time),
R = rainfall erosivity factor,
K = soil erodibility factor,
L = hillslope length factor,
S = hillslope gradient factor,
C = cropping management factor, and
P = erosion control practice factor.

Each factor is determined relative to standardized conditions, for example, slope gradient factor S is the ratio of soil loss from a slope of given steepness relative to soil loss from a 9% slope. Although USLE was created using standard American units (e.g. short tons/acre/yr), all calculations in this study were converted to metric units (e.g., metric tons/hectare/yr).

Both USLE and RUSLE are intended as means of calculating soil loss in relatively small, homogeneous areas. For such areas, the total soil loss (T) in metric tons/year can be calculated as the product of the RUSLE/USLE soil loss (A) in metric tons/hectare/year and the area in hectares. Determining total soil loss for a larger, more heterogeneous area requires summation of the contiguous sub-areas. Finally, extrapolation of soil loss data to calculate sediment yields would require calculating sediment delivery ratios.

The sediment delivery ratio (D) is:

$$D = (Y / T) \times 100$$

where D = sediment delivery ratio (percent),
Y = sediment yield (metric tons/year), and
T = total soil erosion loss (metric tons/year).

Boyce (1975) has shown that there is an inverse relationship between sediment delivery ratios and drainage basin size (Fig. 2). Measured sediment delivery ratios in the field only approach 100% for small, urbanized watersheds. For a drainage basin the size of Old Woman Creek, sediment delivery ratios could be expected to range between 10% and 25%, with an average of about 16% (Boyce 1975).

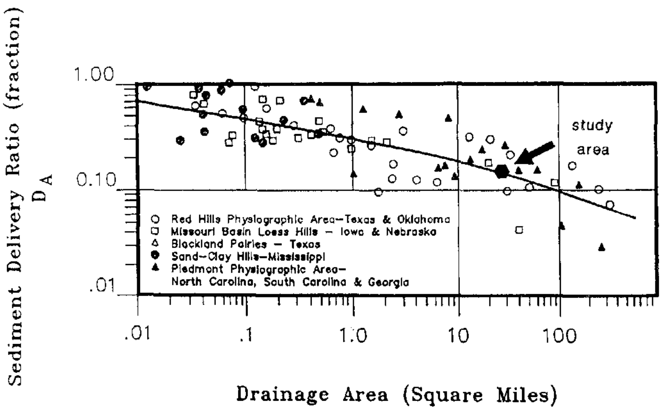

FIGURE 2. Sediment delivery ratio versus drainage basin area, for RUSLE/USLE soil erosion loss data, showing that the sediment delivery ratio for a basin the size of Old Woman Creek could range from 10% to 25%, with an average of about 16% (modified from Boyce, 1975). The sediment delivery ratio calculated in this study ranges from 21-25%.

GIS-based Soil Erosion Model

The RUSLE model was designed to be calculated in the field, using tables, nomographs, and figures to obtain the various factors, and performing the calculation by hand. In this study, RUSLE calculations were performed by producing maps for various factors and overlaying them, using a Geographical Information System (GIS) called ARC/INFO. An introduction to the technology is provided by Antenucci et al. (1991).

Existing map data was scanned and co-registered with a topographic base map that was overlain by a 120-meter grid spacing to create 4843 polygons for the entire drainage basin. Individual maps could then be generated, including maps for soils, landuse, and slopes (Seamon 1994). The slopes map was created by utilizing a digital elevation model (DEM) to convert a topographic contour map into a map of slope gradients. DEMs were obtained from the US Geological Survey and have 30-meter resolution. There are two reasons why we found it necessary to consolidate 30-meter DEMs to 120-meter grid cells. First, coverage gaps were discovered in the 30-meter resolution dataset, which were eliminated by consolidation. Second, we found that our GIS system could not manipulate the approximately 30,000 polygons created by 30-meter grid cells without causing continuous fatal error messages with regard to Triangular Irregular Network (TIN) computations. These problems were also eliminated by consolidation to 120-meter scale. RUSLE soil erosion values were then calculated for each of the 4843 polygons over the watershed (Seamon 1994).

Sediment Routing Model

A subroutine of ARC/INFO, called Network, was developed by landuse planners to determine the flow of automobile traffic through an urban transportation system. By determining the parameters that would change the rate and volume of traffic flow between two points (e.g., time of day, types of roads, traffic lights, and so forth), values can be calculated such as the fastest or most efficient route of travel.

Network was used for sediment routing to determine the path followed by eroded soil particles in reaching the nearest drainage channel. The initial step was to connect the centroids of polygons. Impedance values were then inserted, based upon elevation. At any point, the executed program would determine the impedance values of all connected polygons, then choose a path determined by the maximum change in elevation between two adjacent polygons. This procedure would continue until the program had completed a routing path to a cell with zero impedance (i.e., reached a drainage channel). The total sediment yield for each routing path was calculated by summing all of the soil loss values from the polygons connected along that route. This allowed determination of stream sediment loadings at certain locations within the drainage basin.

RESULTS AND DISCUSSION

Soil Erosion Calculation

The GIS-based model for calculating RUSLE soil loss for Old Woman Creek found that soil erosion varied from 1.6 to 97.3 metric tons/ha/yr, with a basin-wide average value of 7.26 metric tons/ha/yr (Fig. 3). These values are significantly (26%) higher than hand-calculated values found by Buchanan (1982), probably as a consequence of our using a DEM to calculate length-slope (LS) factors, and also possibly as a consequence of greater sampling density (thus accounting for drainage basin heterogeneity at a finer-scale). It is important to note here that Buchanan (1982) had errors in converting USLE values from standard American units to metric units. We corrected these conversion errors while making the comparison between his results and our results.

Buchanan (1982) calculated that the upper 67% of the drainage basin (4658 ha) had average USLE soil loss of 5.83 metric tons/ha/yr, or a total soil loss of 27,143 metric tons/yr. The lower 33% of the drainage basin (2294 ha) had average USLE soil loss of 4.48 metric tons/ha/yr, or a total soil loss of 10,284 metric tons/yr. Thus, Buchanan found that total USLE soil loss for Old Woman Creek was 37,427 metric tons/yr (Buchanan 1982).

Our direct calculation gave a RUSLE soil loss of 50,484 metric tons/yr for the Old Woman Creek drainage basin. In addition, in order to calculate sediment delivery ratios, it became useful to separately calculate the soil loss for the upper 84% of the drainage basin because the stream gauging station located upstream of the estuary monitors this portion of the basin. The GIS model calculated that RUSLE soil loss for the upper 84% of the basin is 44,731 metric tons/yr.

Sediment Delivery Ratios and Intrabasinal Storage

Three hydrologic data sets were available for Old Woman Creek: the data collected by Heidelberg College's Water Quality Laboratory (Krieger 1993), Woods (1987), and Buchanan (1982). Heidelberg College's data set is the most extensive, consisting of automated discharge, suspended sediment, nutrient, and pesticide measurements every 8-hours from 4/15/89 to 8/31/90 (464 days of record and 38 days of non-record). The station upstream of the estuary monitored the upper 84% of the drainage basin, recording 4,245,650 kg of suspended sediment over 464 days of record, or an average annual suspended sediment load of 3340 metric tons/yr. Sediment transport in Old Woman Creek is highly episodic, being mostly during spring melt-off. For example, the three 8-hour recordings for a single day (5/26/89) totaled 863 metric tons, in other words, one day of record represented 26% of the average annual suspended sediment load.

Woods (1987) established rating curves and discharge-suspended sediment relationships for nine channel cross-sections upstream of Old Woman Creek estuary for approximately six months (10/1/84 to 4/19/85). We extrapolated Woods' six month data to obtain annual values from the two cross-sections (#8 and #10) located upstream and downstream of the site used by Heidelberg College. The average annual suspended sediment loads is 3497 metric tons/yr. This calculated average annual suspended sediment load is higher than values calculated from the data set of Heidelberg College, probably because it was extrapolated from a six month data set collected during higher flow conditions. Woods recorded the maximum daily suspended sediment load on 2/25/85 of 35 metric tons, or 1% of the average annual suspended sediment load. Comparison with the maximum daily load from the Heidelberg College data set highlights the episodic nature of flow and sediment transport in this drainage basin.

Buchanan's (1982) data set was not useful in this analysis, because it was too short term (7/14/77 to 9/13/77), and because it was collected during low flow conditions of late summer. Buchanan did record one high flow event (7/21/77) with a maximum daily suspended sediment load of 26 metric tons.

The sediment delivery ratio was calculated for the upper 84% of the drainage basin, using the GIS model RUSLE soil erosion loss of 44,731 metric tons/yr for that portion of the watershed, and using the average annual suspended sediment load of 3340 metric tons/yr determined from the Heidelberg data set (Krieger, personal communication; 1996). Buchanan (1982) had estimated that suspended load was approximately 20% of the total sediment load of Old Woman Creek, however there is no field data to support this estimate, and this estimate does not match his other observations, including the prevalence of fine-grained fill in the estuary. Buchanan noted that the input for his calculated sediment budget significantly underestimated the observed sedimentation rates in the estuary.

Our preliminary data indicate that suspended sediment load varies with hydrological conditions from about 20% to 100% of the total sediment load in Old Woman Creek, and 30-35% is used here as an annual average. If suspended load is 30-35% of the total average annual stream sediment load, then the delivery ratio for this watershed can be calculated to be between 21% and 25% (Table 2). These values are within the range of values shown by Boyce (1975), but are higher than the empirically calculated average (Fig. 2).

Intrabasinal storage was not measured directly in the field. An indirect calculation for intrabasinal storage can

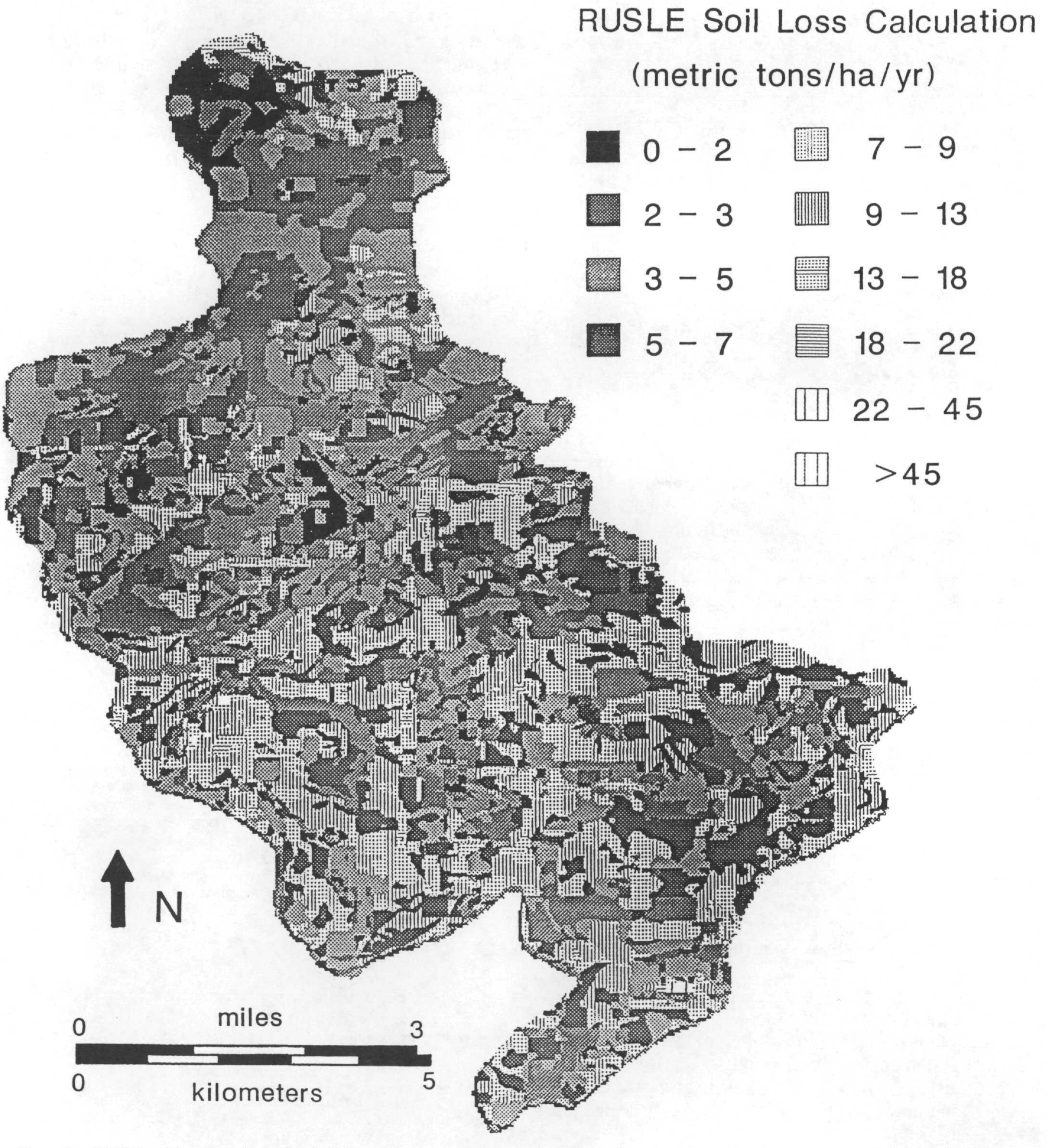

FIGURE 3. RUSLE soil loss data for each of 4843 polygons created by a 120-meter grid spacing over the Old Woman Creek drainage basin.

TABLE 2

Calculations for intrabasinal storage.

percentage suspended load to total load	Y total sed. load (mt/yr)	D delivery ratio (%)	S intrabasinal storage (mt/yr)	intrabasinal storage USLE soil loss
25%	13,359	29.87%	31,372	70.13%
30%	11,133	24.89%	33,599	75.11%
35%	9,542	21.33%	35,189	78.67%
40%	8,349	18.67%	36,382	81.33%
45%	7,422	16.59%	37,310	83.40%

Explanation: Mean annual suspended sediment load is known (3340 mt/yr), so total stream sediment load is calculated for given ratios of suspended load to total load. Total sediment load is treated as sediment yield (Y) for the purpose of calculating sediment delivery ratios (D = Y/T x 100). The USLE soil loss (T) for the upper 84% of the basin is 44,731 mt/yr. Intrabasinal storage is calculated from mass balance relationships (input function is USLE soil loss, output function is sediment yield).

be made using mass balance relationships:

Input = 0utput ± change in Storage

or:

$$T = Y \pm S$$

where T and Y are defined previously as total soil erosion (metric tons/yr) and sediment yield (metric tons/yr), respectively, and S is intrabasinal storage in equivalent units. In this study, total stream sediment loads are used as a proxy for sediment yield. If suspended load is 30-35% of average annual sediment loads, then intrabasinal storage is between 33,599 and 35,189 metric tons/yr. In other words, intrabasinal storage is between 75-79% of average total soil erosion rates in this watershed (Table 2).

Weaknesses in the approach we have used include the following considerations. First, the hydrologic data set is comprehensive, but only short-term. The importance of episodic sediment transport was illustrated earlier, where the Heidelberg College data set indicated that a single 24-hour period transported approximately 26% of the average annual suspended sediment load. Such large outliers make statistical averaging methods risky. Second, bedload transport data and channel storage data (in the form of ripples, dunes, and bars) are unavailable, a common problem due to the complexity of these measurements. Finally, Gregory's (1996) study indicates that there may be complexities to flow path length and direction from sites of soil erosion to adjacent streams.

Sediment Loadings

One additional value of the routing model is the ability to depict sediment yield at a point as stream sediment loadings. A map can be constructed that shows the increase in sediment load as a function of downstream position (Fig. 4). For Old Woman Creek, the southeastern portion of the watershed is much more significant in terms of sediment yield and resulting loadings. This region has Mahoning-Bogart-Haskins-Jimtown soils, which have the highest erodibilities (Table 1). In addition, some of this region is at the transition from till plain to escarpment, and has greater slopes.

This kind of information would be useful to regional planners and regulatory agencies to reduce non-point source pollution in a watershed and its deleterious effects. Such a model could be manipulated to predict the results of proposed landuse changes.

SUMMARY AND CONCLUSIONS

This study created a GIS-based soil erosion model by creating map data that could be superimposed and manipulated using ARC/INFO. RUSLE soil erosion values were calculated for each of 4843 polygons over a 69.5 km^2 watershed. These values ranged from 1.6 to 97.3 (average 7.26) metric tons/ha/yr for the various combinations of soil types, slopes, vegetation, landuse, and agricultural practices. These are average annual rates of soil removal, and not the results of any specific storm.

Comparison of soil loss and sediment yield data for the upper 84% of Old Woman Creek's drainage basin indicates that sediment delivery ratios are between approximately 21-25%, which is close to expected for a drainage basin of this size. Mass balance calculations would indicate that intrabasinal storage is between 75-79% of eroded sediment within the basin. Our model would not indicate where intrabasinal storage occurs,

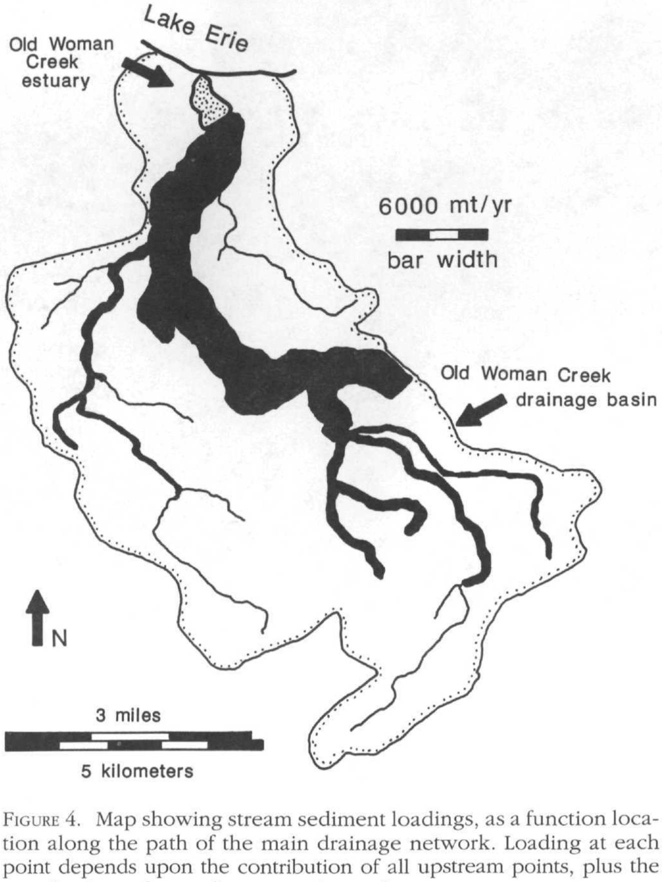

FIGURE 4. Map showing stream sediment loadings, as a function location along the path of the main drainage network. Loading at each point depends upon the contribution of all upstream points, plus the contributions of any adjacent routing paths.

while other models (such as Gregory's (1996) study using AGNPS) might indicate such sites. Finally, sediment routing models indicate that the greatest proportion of stream sediment loading comes from an area in the southeastern part of the catchment. This region combines highly erodible soils with moderate relief. Improvement of agricultural management practices in this region could have beneficial effects on sediment management for Old Woman Creek estuary.

GIS-based models for soil erosion and sediment yield can be powerful tools for landuse managers and regulatory agencies. Once models are produced and calibrated, data can be manipulated and updated to provide baseline calculations and to make or test predictions for changes in watershed conditions. Additional studies that would improve the model include extended hydrologic data sets and evaluation of in-channel sediment storage.

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LITERATURE CITED

Antenucci, J. C., K. Brown, P. L. Croswell, M. J. Kevany, and H. Archer 1991 Geographical Information Systems: A Guide to the Technology. Van Nostrand Reinhold Publishing Company, New York. 312 pp.

Boyce, R. C. 1975 Sediment routing with sediment delivery ratios. *In*: Present and Prospective Technology for Predicting Sediment Yields and Sources. U.S. Department of Agriculture, Publication ARS-S40 pp. 61-65.

Buchanan, D. B. 1982 Transport and deposition of sediment in Old Woman Creek estuary, Erie County, Ohio. M.S. Thesis, Ohio State University, Columbus, OH. 198 pp.

Campbell, L. J. 1955 The late glacial and lacustrine deposits of Erie and Huron Counties, Ohio. Ph.D. dissertation, Ohio State University, Columbus, OH. 197 pp.

Dendy, F. E. and W. A. Champion 1978 Sediment deposition in United States reservoirs: Summary of data reported through 1975. U.S. Dept. of Agriculture, Miscellaneous Publication 1364. 84 pp.

Dunne, T. and L. B. Leopold 1978 Water in Environmental Planning. W. H. Freeman and Company, San Francisco, CA. 483 pp.

Foster, G. R. 1986 Understanding ephemeral gully erosion. *In*: Soil Conservation, Assessing the National Resources Inventory, Volume 2. National Academy Press, Washington, DC.

Foster, G. R. and L. D. Meyer 1975 Mathematical simulation of upland erosion by fundamental erosion mechanics. *In*: Present and Prospective Technology for Predicting Sediment Yields and Sources, U.S. Department of Agriculture, document ARS-S-40. pp. 190-207.

Foster, G. R., L. D. Meyer, and C. A. Onstad 1977 An erosion equation derived from basic erosion principles. Transactions American Society of Agricultural Engineers 20: 678-682.

Gordon, R. B. 1966 Native vegetation of Ohio, at the time of the earliest land surveys. Ohio Biological Survey, map and text.

Gregory, K. E. 1996 Spatial aggregation, parameterization, and scale dependence in distributed nonpoint source pollution modeling. Ph.D. dissertation, Kent State University, Kent, OH. 255 pp.

Haan, C. T., B. J. Barfield, and J. C. Hayes 1994 Design Hydrology and Sedimentology for Small Catchments. Academic Press, San Diego, CA. 588 pp.

Harvey, M. D., C. C. Watson, and S. A. Schumm 1985 Gully erosion. U.S. Department of the Interior, Bureau of Land Management Technical Note 366.

Herdendorf, C. E. 1963 The geology of the Vermilion quadrangle, Ohio. M.S. Thesis, Ohio University, Athens, OH. 182 pp.

Herdendorf, C. E. 1966 Geology of the Vermilion West and Berlin Heights quadrangles, Erie and Huron Counties, Ohio. Ohio Geological Survey, Report of Investigations 60, map with text.

Hobson, G. D., C. E. Herdendorf, and C. F. M. Lewis 1969 High resolution reflection seismic survey in western Lake Erie. Proceedings on Great Lakes Research 12: 210-224.

Krieger, K. A. 1993 A method for estimating fluxes from coastal wetlands into the Great Lakes, with an example from Lake Erie. Ohio Sea Grant Program Technical Bulletin OHSU-TB-025-93, Ohio State University, Columbus, OH. 27 pp.

Krieger, K. A. and D. M. Klarer 1992 Macroinvertebrate communities of the Old Woman Creek State Nature Preserve and National Estuarine Research Reserve. Old Woman Creek National Estuarine Research Reserve, Technical Report No. 9, National Oceanic and Atmospheric Administration. 92 pp.

Lane, L. J. and M. A. Nearing 1989 Water erosion prediction project: Hillslope profile model documentation. U.S. Department of Agriculture, National Soil Erosion Research Laboratory, Report 2.

Lewis, S. M., B. J. Barfield, and D. Storm 1994 An erosion model using probability distributions for rill flow and density. Transactions of the American Society of Agricultural Engineers.

Meyer, L. D. and W. H. Wischmeier 1969 Mathematical simulation of the process of soil erosion by water. Transactions of the American Society of Agricultural Engineers 12: 754-758.

Milhous, R. T. 1982 Effect of sediment transport and flow regulation on the ecology of gravel-bed rivers. *In*: R. D. Hey, J. C. Bathurst, and C. R. Thorne (eds.), Gravel-Bed Rivers. John Wiley & Sons, New York. pp. 819-841.

Musgrave, G. W. 1947 The qualitative evaluation of the factors in water erosion, a first approximation. J. of Soil and Water Conservation 2: 133-138.

Musgrave, G. W. and H. N. Holtan 1964 Infiltration. *In*: V. T. Chow (ed.), Handbook of Hydrology. McGraw-Hill, New York. 211 pp.

Ohio Department of Natural Resources 1989 Soil survey of Huron County, Ohio. Ohio Dept. of Natural Resources. 43 pp.

Pepper, J. F., W. DeWitt, and D. F. Demarest 1954 Geology of the Bedford Shale and Berea Sandstone in the Appalachian Basin. U.S. Geological Survey, Professional Paper 259. 111 pp.

Redmond, C. E., T. J. F. Hole, C. H. Innis, and M. Wachtman 1971 Soil survey of Erie County, Ohio. U.S. Department of Agriculture, Soil Conservation Service. 166 pp.

Reeder, B. C. and W. R. Eisner 1994 Holocene biogeochemical and pollen history of a Lake Erie, Ohio, coastal wetland. Ohio J. Sci. 94: 87-93.

Renard, K. G., G. R. Foster, G. A. Weesies, D. K. McCool, and D. C. Yoder 1993 Predicting soil erosion by water — A guide to conservation planning with the Revised Universal Soil Loss Equation RUSLE. Agricultural Research Service, U.S. Dept. of Agriculture, Washington, DC.

Schmidt, B. L. 1972 Agricultural sources of water pollution. *In*: W. A. Pettyjohn (ed.), Water Quality in a Stressed Environment. Burgess Publishing Company, Minneapolis. pp. 80-87.

Seamon, D. E. 1994 A model for soil erosion rates and sediment yields that utilizes geographic information systems, from Old Woman Creek watershed, north-central Ohio. M.S. Thesis, Bowling Green State University, Bowling Green, OH. 78 pp.

Shepps, V. C. 1953 Correlation of tills of northeastern Ohio by size analysis. J. of Sedimentary Petrology, 23: 34-48.

Storm, D. E., B. J. Barfield, and L. E. Ornsbee 1990 Hydrology and sedimentology of dynamic rill networks. I. Erosion model for dynamic rill networks. University of Kentucky, Water Resources Research Institute, Report 178.

Trimble, S. W. 1974 Man-induced soil erosion on the Southern Piedmont, 1700-1970. Soil Conservation Society of America. 80 pp.

Trimble, S. W. 1983 A sediment budget for Coon Creek basin in the driftless area, Wisconsin. American J. of Sci. 283: 454-474.

Trimble, S. W. and S. W. Lund 1982 Soil conservation and the reduction of erosion and sedimentation in the Coon Creek Basin, Wisconsin. U.S. Geological Survey, Professional Paper 1234. 35 pp.

Ursic, S. J. and F. E. Dendy 1965 Sediment yields from small watersheds under various land uses and forest covers. U.S. Department of Agriculture, Miscellaneous Publication 970. pp. 47-52.

Weisenburger, F. P. 1941 The Passing of the Frontier, 1825-1850. Ohio State Archaeological and Historical Society, The History of the State of Ohio, Volume III. 567 pp.

White, G. W. 1951 Pleistocene stratigraphy of northeastern Ohio. Geological Society of America Bulletin 63: 1489-1506.

Wischmeier, W. H. and D. D. Smith 1965 Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. U.S. Department of Agriculture, Agricultural Handbook 282. 246 pp.

Wischmeier, W. H. and D. D. Smith 1978 Predicting rainfall erosion losses – A guide to conservation planning. U.S. Department of Agriculture, Agricultural Handbook 537.

Wolman, M. G. 1967 A cycle of sedimentation and erosion in urban river channels. Geografiska Annaler 49A: 45-62.

Woods, A. J. C. 1987 Fluvial erosion, sedimentation, and hydraulic geometry in the contributing watershed of Old Woman Creek National Estuarine Research Reserve. National Oceanic and Atmospheric Administration, Technical Memorandum 12. 140 pp.

Young, R. A. and J. L. Wiersma 1973 The role of rainfall impact in soil detachment and transport. Water Resources Research 9: 1629-1636.

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