G.I.S. MODELING OF NONPOINT SOURCE POLLUTION WITH REMOTELY SENSED DATA

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INTRODUCTION

One of the most significant uses of geographic information systems (GIS) in hydrologic investigations and water management applications is the assessment of nonpoint source (NPS) pollution. Soil erosion and sedimentation contribute to NPS pollution and are controlled by variables such as land use/land cover, topography, soils and rainfall. In areas for which a spatially registered database containing these variables exists, GIS analysis techniques can be used to identify locations which contribute high amounts of sediment and other nonpoint source pollutants to the drainage network.

The Center for Remote Sensing and Mapping Science (CRMS) at the University of Georgia, in cooperation with the Georgia Department of Natural Resources (DNR), has developed a dynamic GIS-based computer modeling approach to quantify the amount of sediment reaching Lake Allatoona, Georgia. Preliminary results for total and average gross erosion and total sediment load are presented for the region corresponding to the USGS 1:24,000 scale South Canton quadrangle. This area covers the upper third of the lake and lies within the Lake Allatoona watershed.

MATERIALS AND METHODS

In order to model the amount of sediment reaching the drainage network of a watershed, information must be gathered on the factors contributing to the detachment and transport of soil. These factors include the plant cover and topography of the land surface, the erodibility of the soil, and the combined impact of rainfall and its resulting runoff.

A Landsat Thematic Mapper multispectral satellite image of 30-m resolution was used to map land use/land cover classes, including forest, urban, agriculture, fallow, wetland, bare ground, and water. Topographic information was derived from USGS 1:24,000 scale topographic quadrangles and digital elevation models (DEMs) and from automated stereocorrelation techniques applied to 10-m resolution SPOT panchromatic stereo image data (Welch 1989). Information on soil erodibility was extracted from the State Soil Geographic Data Base prepared for the State of Georgia by the U. S. Department of Agriculture, Soil Conservation Service (STATSGO 1991). The rainfall-runoff index is a constant for the study area (Wischmeier and Smith 1978).

These layers of information form a database from which overland flow pathways can be identified and values for sediment load calculated (Figure 1). The watershed is sub-divided into five-acre cells and the Universal Soil Loss Equation (USLE) applied to estimate the amount of potential soil loss for each cell. Local topography is used to calculate the amount of detached soil which is available for transport along the flow pathways. Output information includes the location of flow pathways, potential gross erosion, and estimated sediment load. These information layers can be processed by statistical or raster GIS packages and displayed as digital maps.

RESULTS

The study area includes twenty-five USGS 1:24,000 scale topographic quadrangles (approximately 1,000,000 acres) covering the watersheds of the Etowah River draining into Lake Allatoona. In order to estimate the amount of sediment coming from the areas surrounding the upper third of Lake Allatoona, the modeling approach was applied to the region corresponding to the South Canton quadrangle. This area encompasses a total of 41,085 acres or 8,217 five-acre cells. The overall results are listed in Table 1.

Although the average gross erosion value for the overall region is relatively low, an examination at the sub-watershed level shows areas where much higher amounts of soil are being detached and transported. Sub-watersheds with average sediment yield values as high as 28.1 tons/acre/year have been identified by the model. This demonstrates the potential of GIS-based models to identify specific problem areas at the local level.

The modeling approach provides the additional capability to simulate alternative land use patterns. This feature allows natural resource managers to estimate the effect of proposed land use changes on gross erosion and sediment load values.

Table 1. Estimated Gross Erosion for the Watershed Area Covered by the South Canton Quadrangle.

Total Gross Erosion	87,527	tons/year
Average Gross Erosion	2.1	tons/acre/year
Total Sediment Load	28,742	tons/year

CONCLUSION

GIS-based models are well suited for the development and analysis of techniques that consider the spatial properties of sediment transport and deposition. The modeling procedure described above is currently being applied to the remainder of the study area and will provide important input to the land management planning for the Lake Allatoona resource area. In addition, vital information can be generated to support decisions regarding the potential land use changes within the resource area. The modeling approach has been implemented on standard IBM-compatible personal computers and can be utilized by state agencies and by scientists in agronomy, forestry, ecology and related disciplines.

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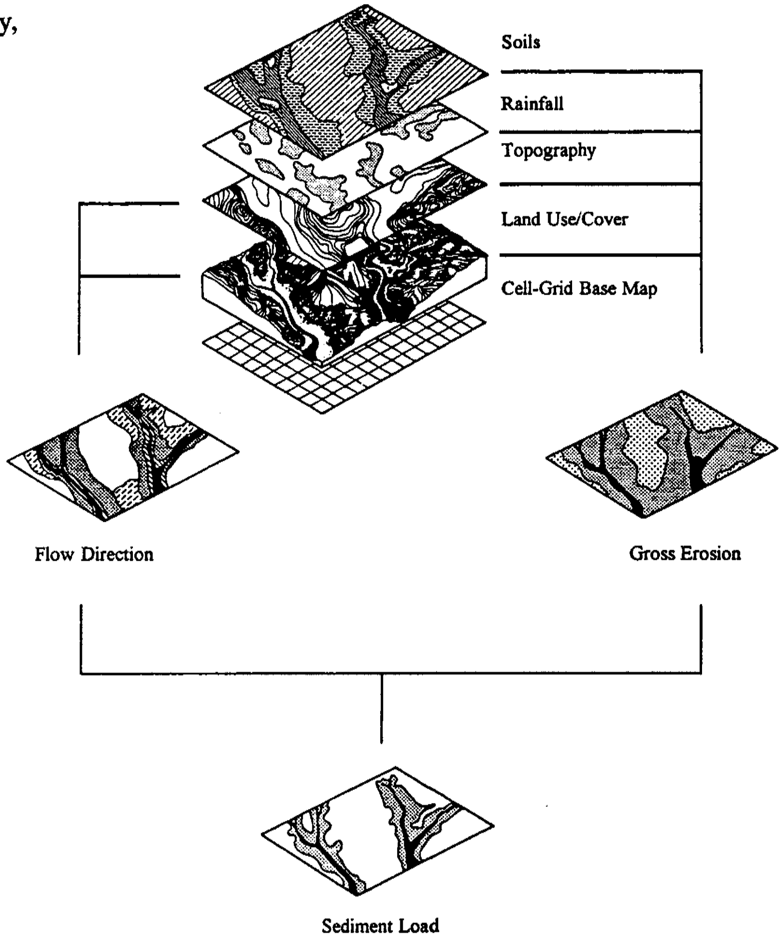

Figure 1. Input database and information layers generated by the model.

STREAM REHABILITATION IN A DISTURBED INDUSTRIAL WATERSHED

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INTRODUCTION

Since 1988, a 140 acre industrial watershed in Athens, Georgia has been treated with an unusual combination of stormwater and sediment controls. The site had a prior history of sedimentation, channelization, and altered hydrologic regime. Rehabilitation design was aimed at capturing mobile sediment, stabilizing stream channels, suppressing peak storm flows, augmenting base flows, and establishing wetlands. This multipurpose approach, and some aspects of the specific features developed to implement it, were not foreseen in the state's erosion and sediment control manual (State Soil and Water Conservation Committee, 1978). This paper reports the results of the project through the present date. As described below, the objectives have been substantially realized.

SITE HISTORY

Like most of the Piedmont, the watershed has suffered a cycle of disturbance since European settlement (Trimble, 1974). Under cotton farming during the 19th century and the first half of the 20th century, the uplands eroded an average of 12 inches, and delivered a corresponding volume of sediment to headwater floodplains. Since the middle of this century, cotton fields have been abandoned to vegetative succession, depriving the streams of their sediment load and causing stream incision into the deposited sediment masses. Judging from an aerial photograph and a topographic map (Ferguson, 1992), by 1964 the watershed was largely in a combination of cultivated field, young pine plantation, older (dense) pine plantation, and hardwood forest.

As of 1988, when field inspection began, the sediment history was still reflected in stream morphology. In the larger of the watershed's two branch streams, terraces of sediment rose about 5 feet above the channel. The narrow channel was only partly adjusted with lateral meandering and widening. The headwaters of this branch were obscured by a farm pond, built perhaps in the 1930s. The smaller branch was apparently less maturely adjusted in 1988. The stream corridor was marked only by a level swampy lowland, terminated at the downstream end by a 6 foot deep trench, obviously an active headcut eroding the cotton sediment and bringing it down to the base level established by the larger, faster eroding branch.

Urban Disturbances

Beginning in the mid-1980s, a second cycle of disturbance began with urbanization of the watershed, in the form of an industrial park. Locally developed parts of the park were 90% or more impervious; the overall watershed was 30% impervious by about 1990. Urbanization alone would be expected to generate sediment during construction, followed by increased volumes and rates of storm runoff, increased channel erosion, and deprivation of base flow in dry summers (Ferguson and Suckling, 1990; Wolman, 1967).

In addition, direct disturbances to the stream system caused further channel instability and internal sediment generation. A channel had been dug through the old farm dam in about 1989, apparently to drain the pond; stream flow down a 10 foot drop through the dam breach was eroding the dam and generating sediment. Pond drainage was accompanied by exposure of accumulated sediment on the former pond bottom. Also in the main branch, a narrow trench was excavated through a terrace of cotton sediment to replace a segment of channel filled by construction. A "dry" detention basin was installed near the bottom of the main branch, but did little to capture stream sediment or inhibit erosion, because all flows of water and sediment exited from the bottom of the basin.

Project Initiation

Thus the watershed before rehabilitation was characterized by excess mobile sediment, unstable channels and other active sediment sources, and erosive pulses of storm runoff from urban land covers. These problems were reflected in downstream residential properties in the forms of channel erosion, stream discoloration and sediment deposition.

The project reported here was initiated by a legal dispute between the industrial developer and downstream property owners. At the time of this writing the lawsuit itself is not resolved, but the experience between 1988 and 1992 of retrofitting of the watershed with stormwater and sediment controls stimulated by the suit has been instructive.

REHABILITATION MEASURES

This project's approach to stream rehabilitation can be considered an urban adaptation of that developed by Heede (1977) in overgrazed watersheds in the semiarid west. Heede observed that check dams stabilized eroding gullies by stabilizing and raising the local base level, preventing further gully downcutting. The height of the check dams reduced effective gully depth, which together with bank toe stabilization led to gentler gully side slopes which in turn allowed vegetation to become established. Although in some cases channel scarps developed where check dams were spaced farther apart than the sediment wedge extended, these scarps were small and growth of channel vegetation greatly slowed their upstream advance.

In this project, as in Heede's, the system of structures installed into the stream system was aimed to stabilize sediment already mobilized in the stream system, and to slow or prevent further instream erosion. In addition, it was aimed to combat the stressful urban hydrologic regime by suppressing peak storm flows and augmenting base flows. Structures to meet these aims had to be installed amidst established land uses and the relicts of prior stream disturbances.

Structures Installed

Near the bottom of the main branch, a preexisting detention (peak flow control) basin with perforated standpipe outlet was modified for sediment capture and enhanced peak flow control by wrapping the standpipe in a filter fabric, forcing low flows to to be filtered while passing through the standpipe's perforations. Upstream, the breached, eroding earthen dam was stabilized with a filter-backed gabion drop structure, and reclaimed for capture of upstream sediment by raising the weir elevation above the upstream channel, forcing filtration of low flows. Both reclaimed basins provide permanent storage for captured sediment. Between the two basins was the channelized reach; here two low (3 ft) filter-check dams were placed, consisting of crushed stone with an internal filter fabric for capture of low-flow sediment.

In the smaller branch, two new basins were constructed in series. The upper one, where topography and land use allowed provision of sediment storage capacity, included outlet filtration. One filter-check dam was installed downstream, where sewer manholes and angled property lines prevented construction of a sediment basin.

With field experience an economical, stable construction of filter-check dams was worked out. The interior of the dams is of small, economical stone (#57). Filter cloth completely wraps this stone, in order to prevent movement in any direction, particularly in the downstream direction. The faces of the dam are of larger, more expensive stone (50 lb) to prevent movement during high flows.

RESULTS

Field investigations found that, since installation, sediment has been accumulating in basins and behind check dams due to a combination of filtration by fabric and settling out in temporarily ponded water. In Heede's (1977) study, sand made up a large portion of the sediment deposited behind check dams, although it was only a minor constituent of suspended load, because suspended silt and clay were carried through the unfiltered rock check dams. In this project, suspended sediment has a large proportion of fines, but trapped sediment appears to be composed of a mixture of grain sizes, due to filtration of all sediment during low flows. Sandy sediment has been deposited in alluvial deltas at the heads of ponding in basins, and fine sediment on basin floors and sides and at outlet filters.

Over many years sediment may accumulate up to the top of the standpipes and weirs, converting the stream system to a series of low-gradient stream steps in basins and behind check dams. Water flows over the accumulating sediment with decreasing gradient and velocity, recharging groundwater in the sediment to augment downstream base flows. A moist substrate for wetland vegetation and base flow augmentation is gradually growing.

Natural wetland vegetation has been colonizing all basin interiors and sediment surfaces, apparently enhancing channel stability. In two basins, following root flooding of preexisting vegetation, growth of herbaceous phreatophytic vegetation has been encouraged by death of preexisting canopy trees and letting in of sunlight to the wetland floor. In other basins, plantings of grass and willows have been very successful, such that little evidence of erosion is now visible. The drained farm pond has vegetated very thoroughly despite only incidental seeding, possibly due to the release of trapped nutrients in newly aerated but still moist sediments and the presence of buried weed seeds in the sediments.

As is typical in small urban watersheds, the absence of a permanent stream gaging station did not permit direct observation of flow rates. However, stormflow modeling (Ferguson, 1992) indicated that the system of rehabilitation measures is adequate to reduce 10-year peak flows from existing (partly developed) land use due to the low permeability of filter fabric, the limited capacity of weirs and culverts, and the storage volumes in basins. However, although the measures capitalize on the capacity of the stream corridors to the degree that existing land use allows, they are not, by themselves, adequate to control the effects of future industrial development in the watershed. Future development must include on-lot provisions to control hydrologic and sediment discharges. Design criteria for on-lot infiltration were worked out that would be effective in suppressing future peak flow (Ferguson, 1992).

Field inspections also disclosed the outcomes of poor construction by a low-bid contractor, and led to repair or reconstruction of some structures. Excavation quantities for basin capacities were corrected. At the old farm pond, the gabion weir elevation was raised to regain basin capacity, wings were retied into the earthen dam, and a second layer of filter fabric was installed to assure filtration of inflowing sediment. At the filtered standpipe, asymmetry of the cone of accumulated sediment suggested that some unfiltered flow was passing through an improperly sealed junction between the standpipe and the culvert; plans are underway to correct this.

The channelized stream segment has continued to erode, widening itself by lateral undercutting and bank collapse. An early check dam in this vicinity had failed.

If further work is done on this watershed, more check dams in the vicinity of the channelized segment and gypsum riffles to flocculate fine sediment for faster settling will be considered.

The 6 ft headcut at the bottom of the smaller branch, located off the developer's property, remains an important sediment source and long-term hazard to upstream structures.

CONCLUSIONS

This project offered the challenge of stabilizing eroding Piedmont streams despite their history of anthropogenic sedimentation and urban hydrologic stress. The experience leads to the following conclusions:

1. Streams respond morphologically to urban disturbances; they are not passive recipients of flows from their watersheds. The principle of stream equilibrium requires that a change in hydrologic regime be balanced with a corresponding change in morphology; and such a change must generate sediment in the stream system (Wolman, 1967). To control sediment discharges from watersheds or urban developments is not enough; any change in hydrologic regime must be accompanied by management of the stream system to control the adjustment or recapture sediment and readjust the hydrology. This is especially true in an environment where streams are already unstable due to a history of anthropogenic sedimentation and artificial channelization.

2. Filtration with fabric appears to be effective at capturing mobile sediment from stream flows. The filter-wrapped perforated standpipe appears to be a viable alternative to an unwrapped perforated standpipe or a perforated standpipe surrounded with stone, and to a permanent pool for sediment settling. The filter-check dam appears to be a viable alternative to an unfiltered check dam for trapping fine-grained sediment. If small stone is used on the interior of a dam, filter fabric on the dam's downstream slope is necessary for stability. Gabions are a valuable construction material for supporting filters against steep slopes or large drops: their stability, being based on simple mass and flexibility, is not substantially impaired even when the gabions are poorly installed.

3. Where sediment is captured, large capacity for permanent sediment storage, leading to a growing wetland, appears to be a viable alternative to smaller basins intended to be dredged at intervals of time. Sediment need not be resuspended by disturbance during dredging. Vegetation is free to establish itself on surfaces of moist sediment. Vegetation may enhance water quality improvement (Schueler and Helfrich, 1989).

4. Accumulating sediment raises the base level

of eroding streams and reduces channel erosion. Heede (1977) found that cost effectiveness could be enhanced by limiting check dams only to the larger streams (third and fourth order) because stabilizing the downstream base level also slowed erosion on smaller tributary gullies. In this project, if anything, more check dams should have been installed in the vicinity of the highly unstable channelized reach.

5. Deposited stream sediments form miniature aquifers, elevated above the preexisting stream profile, recharged by normal and detained flows and able to exfiltrate gradually through filter fabrics, rock check dams, and earthen dams. Heede (1977) found that sediment deposition behind check dams, combined with increased grass cover within eroded gullies (increasing infiltration), resulted in conversion of ephemeral flow to perennial flow. In the Georgia watershed, flow was already perennial, but it is likely that baseflow enhancement will occur as a result of long-term storage in deposited stream sediments.

6. Where artificial structures such as culverts and check dams are relied upon, vigilant control of construction and frequent postconstruction field inspection and refinement are essential. In private urban development, the consulting designer must be contractually empowered to make postconstruction inspections and corrections.

7. Regular, documented examination of the site is needed before, during and after installation, to reveal directions of change and degree of effectiveness. From systematic, detailed records, generalizations can be carefully built for application in future projects. Such a system of regular site records must be made a conventional part of practice.

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