Identification and evaluation of sediment sources

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ABSTRACT

A field mapping procedure was developed to identify the nature and spatial distribution of active sediment sources in the Washington D.C. suburban area. In the study area, four potential source categories were recognized: agricultural sources; construction sites; sand and gravel mines; and stream channels. Sediment source sites were identified and evaluated on the basis of geomorphic features indicative of recent sediment erosion, transportation or deposition. A relative site grade was assigned from the average of all factors used in the evaluation. Adjacent stream channels were also surveyed to indirectly evaluate upland sediment contribution, and directly evaluate in-channel sediment production and storage. The evaluations suggest that sediment supply is controlled primarily by land use, while sediment delivery is controlled by local physiography.

INTRODUCTION

Identification of specific areas that actively contribute sediment to the stream channel network is a necessary prerequisite for understanding the sediment delivery process and developing successful sediment management programs. This paper describes a field mapping procedure designed to identify and evaluate areas that actively deliver sediment to adjacent stream channels. Evaluation is based on the identification of geomorphic features and management practices that indicate recent sediment erosion, transportation or deposition. Off-site sediment delivery rather than on-site erosion is emphasized. The technique has been applied to the Anacostia river basin, an urbanizing basin in the Washington, D.C. metropolitan area, Figure 1 (Century, 1985).

A variety of techniques exist for measuring or predicting either on-site erosion or drainage basin sediment yields. These include such methods as soil loss prediction equations, land use loading estimates, and sediment rating curves. While all of these techniques have been successfully applied, they don't always provide sufficient information for developing and managing sediment control programs. Knowledge of average sediment yields from basins with multiple land use or physiographic settings is too indeterminate to effectively direct sediment control strategies. Because only a fraction of the sediment eroded from

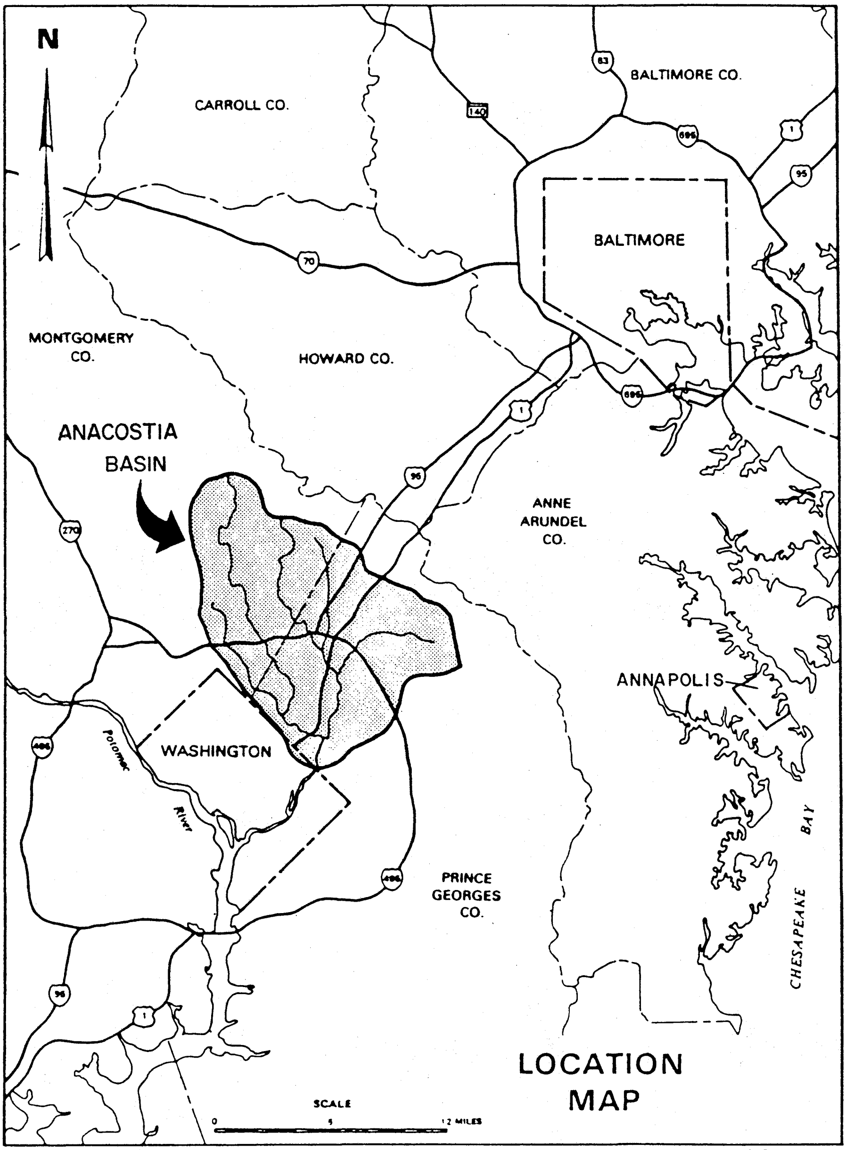

FIGURE 1

the landscape actually leaves a basin during historic time periods (for review see Walling, 1983), estimates of on-site erosion alone are insufficient for developing management programs concerned with off-site impacts. The present procedure locates" and qualitatively evaluates areas of relatively large sediment production and delivery. These areas can then be considered as point sources for directing sediment control programs. It is intended for use as a planning tool and only indicates relative magnitudes of sediment yields.

STUDY AREA

The field mapping methodology presented here was applied to the Anacostia River Watershed, a 330 square kilometer basin that drains both Piedmont and Coastal Plain physiographic provinces before joining the Potomac River at Washington, D.C. Approximately half of the basin lies within the moderate relief of the crystalline Piedmont. The remaining area drains the low relief topography of the Atlantic Coastal Plain. Climate is uniform throughout the study area. Precipitation is fairly constant throughout the year and averages 1,062 mm/year.

Since the founding of Washington, D.C. in 1791, land use in the basin has progressively changed from rural to urban. The amount of farmland in the basin has decreased steadily since 1860 (U.S. Census reports). In 1981, 48% of the basin was urbanized and 29% forested. Pasture or cultivated land accounted for 23% of the land. The largest single area devoted to crops is the USDA Beltsville Research facility. Average suspended sediment yields from modern cropland in the area range from 236 to 1,563 t/ha (.65 to 4.3 tons/acre) (Yorke & Herb, 1978).

Since 1930, rapid urban develoment has been the major cause of environmental change within the basin. As the metropolitan area has expanded, rural areas have been cleared for construction. These disturbances produce high sediment contributions that can elevate sediment loads in the drainage basin (Wolman, 1967). Following urban construction storm runoff increases as much as 30 percent with as little as 15 percent urban development (Yorke & Herb, 1978). In response, small urban streams in the region have enlarged their channel area twofold and width/depth ratios by 70% (Robinson, 1976). Annual suspended sediment yields from recently developed urban areas average 1,345 kg/ha (3.7 tons/acre, most of which is attributed to stream channel erosion (Yorke & Herb, 1978).

In recent years, the decline in cropland, implementation of sediment controls on construction sites, and the stablization of urban areas have resulted in a decrease in annual sediment loads. Present loads from highly urbanized areas are comparable to loads prior to European settlement (Callender et al., 1984). Nevertheless, water quality degradation from suspended sediment is still a major problem in parts of the basin.

METHODOLOGY

The field mapping procedure presented here arose from a need to identify specific areas in the basin that deliver significant quantities of sediment to the channel network. The procedure ordinally ranks specific areas and can be used to evaluate the importance of single or multiple sources. Comparison can only be made between areas where climatic influence can be considered constant.

Following an initial land use survey of the watershed and literature search for the region, potential sources of excessive sediment production were identified. Four general sources were considered: agricultural areas; construction sites; surface mines; and stream channels.

Before field reconnaissance, all known agricultural areas, surface mines and active construction sites were identified on a set of field maps (1:24,000 U.S.G.S. topographic quads). This information came from a variety of sources, including county land use maps, surface mining permits, and sediment control plans on file with the local Soil Conservation District. Although the county land use maps were based on a 1981 survey, considerable changes had occurred in the basin over the intervening four years. Many areas that had been designated as agricultural land were either fallow, abandoned or developed. These rapid changes emphasize the importance of field verification in urbanizing basins.

A list of assessment factors was developed for each source (Tables 1-4). The items on these lists succinctly cover the range of factors necessary to describe the production and off-site transport of sediment. The format of each inspection list has been adopted from the Pacific Southwest Interagency sediment yield computation method (Amimoto, 1981). Individual sites were rated in the field by grading each factor as either high, medium, or low, according to predetermined criteria. A high score indicates the evaluator felt a factor had a relatively large influence on sediment production and delivery at the site. A total site grade was then assigned using the cummulative score (Table 1). For example, a high rating for a particular construction site indicates the site produces a disproportionate amount of sediment relative to other construction sites. All of the evaluations were made jointly by two inspectors, and a total of only three inspectors participated in the field work.

Individual factors found in the assessment lists are discussed below. The factors of land use/ground cover, topography and soil erodibility are primarily concerned with the on-site production of sediment. The off-site delivery of sediment is assessed in the factors concerning sediment control measures, buffer zones and proximity to water courses. The potential of an area to continue producing sediment unless controls are implemented was assessed in the Disturbance Period and Future Supply factors.

<u>Land Use/Ground Cover</u> is a factor that assesses how well the surface of an area is protected from erosion by vegetation. In agricultural areas, this is a function of both land use and management: whether cropped, pasture or fallow; the percentage of total cropland; and the extent and effectiveness of conservation practices (Table 1). This factor is analogous to the crop management factor used in the Universal Soil Loss Equation (U.S.L.E.). At construction sites and surface mines, the percentage of vegetation was used for evaluation (Tables 2 and 3).

Generally, an increase in vegetation decreases the susceptibility to erosion by reducing raindrop impact and overland flow velocities. Studies have shown that for a given precipitation, the quantity of sediment eroded from fallow land or land in row crops is roughly 80 times the amount eroded from grasslands

TABLE 1
ASSESSMENT OF AGRICULTURAL AREAS

	FACTOR	FACTOR IMPORTANCE High (10)	Med (5)	Low (0)
1.	Land Use	a) >50% crops b) <50% crops, but poorly maintained	a) <25% crops b) active pasture c) effective conservation	a) fallow or abandoned b) conservation tillage c) orchard
2.	Topography	steep upland slopes 40 - 100%	moderate upland slopes 20 - 40%	gentle slopes 0 - 20%
3.	Soil Erodibility	high $k > 0.37$	moderate $0.25 < k < 0.37$	low $k < 0.25$
4.	Sediment Delivery	a) adjacent to water course b) no buffer zones	a) not adjacent to water course b) adequate buffer zones	a) not adjacent to water course b) effective buffer zones

General Site Status

Very High	30-40
High	20-30
Moderate	10-20
Low	0-10

(Leopold, et al. 1964). However, the exact relationship between percent cover and soil loss is uncertain. Runoff and erosion have been shown to increase rapidly on slopes with less than 70 percent vegetal cover (Copeland, 1975). In Zimbabwa, where percent vegetal cover has been used to determine erosion hazard, a rapid increase in soil loss did not occur until total vegetal cover fell below 30 percent (Elwell and Stocking, 1976). Although conservation cropping and no-till farming can reduce yields, these practices were not observed in the Anacostia basin.

Topography refers to the relief and slope morphology of a site. In particular, the percentage of steeply sloping land within the site was used in the evaluation (Tables 1, 2 and 3). A variety of topographic features influence the erosion potential of an area. Slope angle is an important factor governing the effectiveness of splash erosion (Ellison, 1940) and is a common parameter in soil loss prediction equations (Musgrave, 1947; Wischmeier & Smith, 1978). Although not all studies indicate an increase in erosion with increasing slope angle, erosion often peaks on slopes between 5-10% (for review see Evans, 1980).

Slope length also influences erosion (Smith & Wischmeier, 1957; Evans, 1980). As length increases, erosion is assumed to increase due to greater accumulation of runoff. Our field observations suggest that areas with discontinuous slopes and irregular microtopography have a greater capacity for on-site sediment accumulation. Therefore, the overall percentage of steeply sloping area was considered in the evaluations.

Soil Erodibility is the potential for different soils to erode at different rates when other factors are similar (Tables 1, 2 and 3). The erodibility factor used in this evaluation is the k-factor of the Universal Soil loss equation. The factor is defined as the rate of erosion per unit erosion index from a standard plot, and is a quantitive description of the inherent erodibility of a particular soil (Wischmeier & Smith, 1978). Specific values used in this study were obtained from Soil Conservation Service county soil maps. Within the study basin, erodibility factors ranged from 0.37 to 0.25.

Sediment Delivery concerns the potential of eroded sediment to be transported from the site of detachment to the stream channel network (Tables 1, 2 and 3). The evaluation is based on the proximity of the source to permanent stream channels, and the occurrence of natural or artificial buffer zones. The effectiveness of buffer zones was evaluated on the presence of rills, gullies or ephemeral channels that could deliver sediment directly to the permanent channel network during storm events. Buffer zones without channels and with microtopography capable of trapping significant quantities of sediment were considered effective.

Areas with pathways and ephemeral channels that connect erosion sites and stream channels received high Sediment Delivery Ratings. Adjacent stream channels were also assessed for evidence of unusual upland sediment delivery (see Upland Contribution, Table 4).

TABLE 2
ASSESSMENT OF CONSTRUCTION SITES

	Factor	Factor Importance High (10)	 Med. (5)	 Low (0)
1.	Topography	steep upland slopes 40 - 100%	moderate upland slopes 20 - 40%	gentle slopes 0 - 20%
2.	Soil Erodibility	High $k > 0.37$	Moderate $0.25 < k < 0.37$	Low $k < 0.25$
3.	Ground Cover	High (minor cover) $<20\%$ cover	Moderate 20 - 40% cover	Low (good cover) 40% cover
4.	Sediment Control	a) do not exist b) not effective, off site sed. delivery	controls exist but: a) not maintained b) incomplete coverage	controls are adequate a) maintained b) good coverage
5.	Sediment Delivery	a) no buffer zones b) adjacent to water course	a) buffer zones b) not adjacent to water course	buffer zones and not close to water course
6.	Disturbance Period	disturbance for more than 1 year 1 year	disturbance about 1 year 1 year-1 month	disturbance less than 1 month 1 month

General Site Status

Very High	50-60
High	30-50
Moderate	15-30
Low	0-15

Sediment Control evaluates the effectiveness of on-site management in reducing off-site sediment delivery (Tables 2 and 3). Maryland legislation dictates that construction sites and surface mines have approved erosion and sediment controls installed prior to any site disturbance. In general, controls have proven effective (Yorke & Herb, 1982), although poor construction or maintenance can greatly reduce the effectiveness of individual sites (Fox 1975).

At individual sites, the effectiveness of controls was based on their ability to reduce sediment production and off-site export. The most common controls observed were: seeding or covering of exposed ground; installation of sediment barriers around the perimeter of the site; and construction of sediment trapping basins at drainage outlets. Areas with minimal ground exposure, effective sediment barriers entirely enclosing the site, and well maintained sediment ponds received low ratings.

Disturbance Period is a factor related to the time that construction sites or surface mines will be potential producers of sediment. The period of surface disturbance in urbanizing areas can vary significantly but is generally less than two years (Wolman, 1967; Guy, 1965). In evaluation of construction sites, an arbitary value of one year was used to distinguish between medium and high ratings (Table 2). For surface mines, site reclamation by natural revegetation or artificial reclamation was the key element in the evaluation (Table 3).

Upland Contribution used in the evaluation of stream channels was determined from evidence of accelerated channel aggradation. Streams that received high ratings were areas with relatively large amounts of recently deposited sediment. The geomorphic features used as evidence of accelerated upland supply included: recently deposited silt draping gravel substrates, recent mid-channel bar growth, wetlands development or channel brading; and the presence of vegetation buried by sediment. This approach treats excessive in-channel accumulation as a potential and transient source since the sediment will be remobilized at higher discharges.

Channel Contribution considers the erosion of stream banks or beds as a potential source of sediment (Table 4). Included are areas where stream channel enlargement or migration is actively removing sediment adjacent to the channel. The actual evaluation was based on the general appearance of the stream banks. Stream reaches with extensive areas of exposed, unvegetated banks were considered to be significant contributors of sediment relative to other stream reaches.

Future Supply is an assessment of the potential of a stream reach to continue sediment production. This factor is analogous to the disturbance period factor used in evaluating construction sites and surface mines. Stream reaches with wide flood plains or with areas where channel erosion is not supply limited were considered to be potential future sources. Stream reaches receiving high ratings may warrant bank protection measures.

TABLE 3 - ASSESSMENT OF SURFACE MINES

Factor	Factor Importance		
	High (10)	Medium (5)	Low (0)
1. Topography	steep upland slopes 40 - 100%	moderate upland slopes 20 - 40%	gentle slopes 0 - 20%
2. Soil Erodibility	High 0.37	Moderate 0.25 k 0.37	Low 0.25
3. Ground Cover	High 20% cover	Moderate 40% cover	Low (good cover) 40% cover
4. Sediment Control	a) do not exist b) not effective, off site sediment delivery	Controls exist but: a) not maintained b) incomplete coverage	Controls exist and are adequate
5. Sediment Delivery	a) no buffer zones b) adjacent to water course	a) buffer zones b) not adjacent to water course	Buffer zones and not close to water course
6. Disturbance Period	a) no evidence or reclamation b) only incipient reclamation, no effect on short term	existing reclamation is reducing or will shortly reduce yields	reclamation complete and appears effective

General Site Status

Very High	50-60
High	35-50
Moderate	15-35
Low	0-15

RESULTS

Following field evaluation, sites were delineated on 1:12,000 scale maps and stippled to indicate their overall rating. A total of 251 sites were visited and evaluated. Thirty-two percent of the sites received high or very high ratings. Twenty-five percent received low ratings. The results from individual sources are discussed below.

Agricultural Sources

Since Colonial times, agricultural lands in Maryland have been important sources of sediment (Gottschalk, 1945; Costa, 1975; Brush, 1984; Jacobson and Coleman, in press). Although the percentage of land devoted to agriculture in the Anacostia basin has been declining since 1860, they are still important sources of fine grained sediment. Their importance results from the longevity of the source, not from the magnitude of sediment produced at any given time. Over short periods, uncontrolled surface mines or construction sites can produce greater quantities of sediment.

The size of agricultural areas in the basin ranged from small fields and pastures in the headwaters of the Piedmont to the

TABLE 4
ASSESSMENT OF STREAM CHANNELS

Factor	High (10)	Factor Importance Med. (5)	Low (0)
1. Upland Contribution	a) channel aggr. b) braiding c) buried vegetation	a) mid channel bars b) silt drapes	no apparent channel modification
2. Channel Contribution	a) active cut banks, long extent exposed to water b) pronounced 'U' shape, enlarging channel	occassional bank erosion a) active cut bank in meander b) bank(s) subject to high water flow force	protected or vegetated banks
3. Future Supply	a) thick valley bottom deposits b) wide flood plain c) active meanders	normal channel activity	a) protected banks b) narrow or no flood plains

Non-Scoring Observations

1. Abundance of urban debris such as cans, bottles, tires, plastic, shopping carts, etc.
2. Channel section appears natural or modified with channel shaping, lining or other control measures.
3. Presence or absence of wetland area on flood plain through soil or vegetation evidence.

General Site Status

Very high	20-30
High	15-20
Moderate	5-15
Low	0-5

large land holdings of the USDA Beltsville Agricultural Research Center in the Coastal Plain province. The 54 sites identified and visited were nearly equally distributed between the Coastal Plain and Piedmont physiographic provinces.

There are striking differences between the assessments of agricultural lands in the two provinces. In the Coastal Plain 11% of the sites were rated as high or very high sediment sources. In contrast, 46% of the Piedmont sources rates as high or very high sources. Topography and sediment delivery consistantly rated higher for the agricultural lands in the headwaters of the Piedmont. Nevertheless, 52% of the Piedmont agricultural sites still received low sediment delivery ratings.

Construction Activity

Construction activity associated with urbanization is a well known source of sediment in the Wasington D.C. Metropolitan area (Guy, 1965; Wolman, 1967; Vice, et al., 1969; Yorke & Herb, 1978). Unlike other sources, sediment production from construction sites is a high magnitude short duration phenomona that continually changes location. While only 25% of the construction sites are open for more than a year (Wolman, 1967), yields from uncontrolled sites can range between 5.68×10^7 and 2.73×10^8 $kg/km^2/year$ (Guy, 1965; Vice et al., 1969; Wolman, 1967).

A total of 32 sites were visited and evaluated, 81% of which were located in the Piedmont physiographic province. Only construction activity covering an area greater than 1 acre (.4 ha) was considered. The majority of these were condominium housing developments. Only 9% of the sites received very high total ratings. Medium or low ratings were given to 53.2 percent of the sites.

Multiple regression analysis indicates that the extent of sediment control measures and the slope of construction sites are the most significant factors affecting off-site sediment production in the region (Yorke & Herb, 1978). The presence of vegetative buffer zones, the proximity of the site to stream channels, and the period of disturbance explain yields to a lesser degree.

In response to apparent downstream impacts caused by construction site sediment production, sediment control measures have been mandatory and enforced by state and county governments since 1971. Following implementation and inspection of controls, a 60% to 80% reduction in suspended sediment yields was observed in subbasins that had active construction activity (Yorke & Herb, 1978). During the present study, all but one of the 32 sites had some form of sediment controls. Only 16% of the sites were considered inadequately controlled. The most common problem was lack of maintenance rather than inadequate construction or coverage.

The average slope of the construction site is also a significant factor affecting site yields (Yorke & Herb, 1978). Apparently extensive rill and gully erosion on slopes greater than 10%

results in high sediment yields. In addition, greater slopes also require a greater amount of earth moving and land disturbance necessary for construction. Due to the consistancy of slopes in the Mid Atlantic landscape, slopes are less significant in comparing the relative contributions between sites within a physiographic province. For example, 50% of the Coastal Plain construction sites received a low rating while 73% of the Piedmont sites received a medium rating or high rating.

The presence of buffer zones and the proximity to stream channels have a variable affect on site yields. Generally, yields increase as the amount of construction within 300 feet of the stream channel increases (Yorke and Davis, 1972). However, the presence of buffer zones did not significantly affect yields when multiple site factors were considered in a regression analysis (Yorke & Herb, 1978). Our observations suggests that the effect of buffer zones vary considerably and depend primarily on local microtopography.

The duration of construction activity at an individual site effects yields in a variety of ways. The largest effect of the duration of distrubance appears to be a reduction in the effectiveness of the sediment control devices. Generally, controls are poorly maintained. As basins become filled, their trap efficiency is reduced. As sediment fences become filled, they often breach and their effectiveness is greatly reduced.

Surface Mines

Abandoned, open pit, sand and gravel quarries are a major source of sediment in the Anacostia watershed (Century, 1981). Therefore, a separate classification system was developed to evaluate individual mines. The evaluation scheme is similar to the system used to evaluate construction sites, since both sources are the result of mechanized earth movement. Nevertheless, the type of sediment produced, the magnitude and impact of the sources is radically different.

A total of 22 quarries exist in the basin. They occur in only three of the eight subbasins, and 41% occur in one of the subbasins. Most of the mines were abandoned before 1977 when state legislation required reclamation. Therefore, many of the mines are unreclaimed and without adequate sediment containment structures. However, several of the mines are scheduled for reclamation.

All of the mines occur in Coastal Plain sediment composed of well rounded pebbles of quartzite, sandstone and chert within a matrix of fine sand and silt (Cooke, 1972). Typically, the mines have internal ponds and swamps that trap significant amounts of sediment. However, most mines are large enough to support perennial streams. Downstream from the mines these streams flow turbid at most discharges. Stream morphology suggests channel aggradation: coarse grained mid-channel bars; buried vegetation; and wetlands. Aggradation is localized since downstream transport of coarse bedload sediment is relatively slow and limited by culverts and other artificial obstructions.

All of the mines have large areas of exposed, nonvegetated surfaces. Because the natural rate of revegetation on the exposed gravel slopes is extremely slow, these slopes can produce sediment for extended periods. Even though most of the mines have been abandoned for more than 10 years, only 27% had sufficient ground cover to receive a low ground cover rating. Although some surface armoring has occurred, the accumulation of fine grain talus at the base of these slopes indicates they are still active sources.

Roadways are not only major sources of sediment, but also act as conduits for sediment washing down from other areas. In a monitored watershed in Appalachia, roadways were the major source of sediment (EPA, 1976). Observations in the Anacostia suggest that the intersection of roadways and the perennial drainage system significantly enhances the export of sediment from the mines. Furthermore, illegal off-road vehicles continually rework the surface of the roadways and further increase the supply of sediment.

Stream Channels

Sediments derived from stream channel erosion can be a significant source of the total sediment load of a stream (Vanoni, 1975). With graded channel conditions, the sediment contribution from stream bed and bank is generally offset by the deposition of other source sediments (Mackin, 1948). However, Many land use changes are capable of producing channel disequilibrium and subsequent enlargement. These include urbanization (Hammer, 1970; Robinson, 1975), mining (EPA, 1976) and agriculture (Odemerho, 1984). The net result of channel enlargement is that stream channels become a source of sediment.

Stream channel sites in the Anacostia basin ranging from small first order tributaries (less than 1 km^2) to the main outlet channel (330 km^2) were field checked and rated at 144 separate locations. Slightly more than half of these stream reaches (56%) were Piedmont channels. Little difference was found between the site ratings in the two physiographic provinces, 35% of Coastal Plain sites and 27% of Piedmont streams were rated as high or very high sediment sources. Most of this small difference can be explained as a result of greater upland sources in the Coastal Plain. Thirty percent of the Coastal Plain reaches were rated high for the upland source factor (see Table 4), while only 14% of Piedmont reaches were rated high for this factor. In addition, a greater percentage (25% to 16%) of the Coastal Plain sites rated high for future supply potential.

In general, the great majority (70%) of stream channel sites were judged to have moderate to low importance as sediment sources. Individual factors were rated as moderate to low at 79-84% of the sites. Some of the worst sites were small tributaries draining storm sewered subdivisions in the steep Piedmont uplands. In these areas, channels were gullying and rapidly enlarging. Most of the high rated reaches in the Coastal Plain were the result of accumulations from surface mining activities. The total contribution of these sources is, however, low in magnitude. The total sediment load of the basin attributed to channel sources is estimated at 16.5% (Century Engineering, Inc., 1981). The significance of this value has been inflated over the actual sediment volume because of a high sediment delivery from channel sources.

CONCLUSIONS

After evaluation of 252 sites in the Anacostia basin, we conclude that large volumes of sediment are produced in small, definable areas. Field observations suggest that abandoned surface quarries probably are the largest single producers of sediment. Construction sites can be significant, transient sources, but are reasonably well controlled. Agricultural lands are locally important producers of fine grained sediment. Stream channels are also locally important, but generally do not produce large amounts of sediment. However, because sediment is delivered directly, stream channel contributions may have greater impacts per unit volume contributed than other sources.

Evaluation of these sites suggests that within areas of similar physiography and climate, sediment supply is controlled principally by land use and secondarily by physiography. On the other hand, sediment delivery is controlled primarily by local physiography and secondarily by land use.

Land use directly affects sediment supply by influencing factors that control sediment production: the amount of exposed ground; duration of distrubance; and the effectiveness of sediment control measures. Agriculture, surface mining and construction all remove protective vegetation, expose and disrupt the ground surface and enhance erosion. Physiography, in this case, the topography factor, was only considered to have a "high" influence in 5% of the sites.

In contrast, the transport of sediment from sites of erosion to the stream channel network appears to be controlled principally by local topography. Our observations suggest that areas with irregular microtopography (swales), or gentle slopes with abundant surface vegetation, are effective in trapping sediment before it enters the permanent channel network. Areas where tributary channels connect sites of erosion with permanent stream channels produce high off-site sediment transport.

Among sites with high or very high overall ratings, 50% received high sediment delivery ratings. Since only half of the "problem" sites can efficiently deliver sediment, a substantial decrease in basin yields should result from controlling yields at these locations. Because the majority of agricultural areas in the basin already have buffer zones and low sediment delivery potential, measures that decrease on-site sediment production may be more effective than additional buffer zones that aim to reduce off-site delivery.

The evaluation method used here emphasizes the need to consider sediment delivery as a question of scale and magnitude. Sediment delivery ratios are commonly applied as constant for a single basin or land use. In the Anacostia basin, this is not true at the scale of our field evaluation, sites of only several hectares in area. There appears to be great variability of sediment delivery among equally sized drainage basins, and within the same land use. Therefore, when considering large areas with a number of specific sediment sources, sediment delivery reflects both supply and transport. Aspects of the density and magnitude of sources, and the transport/storage process are included with the single value of the sediment delivery ratio.

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