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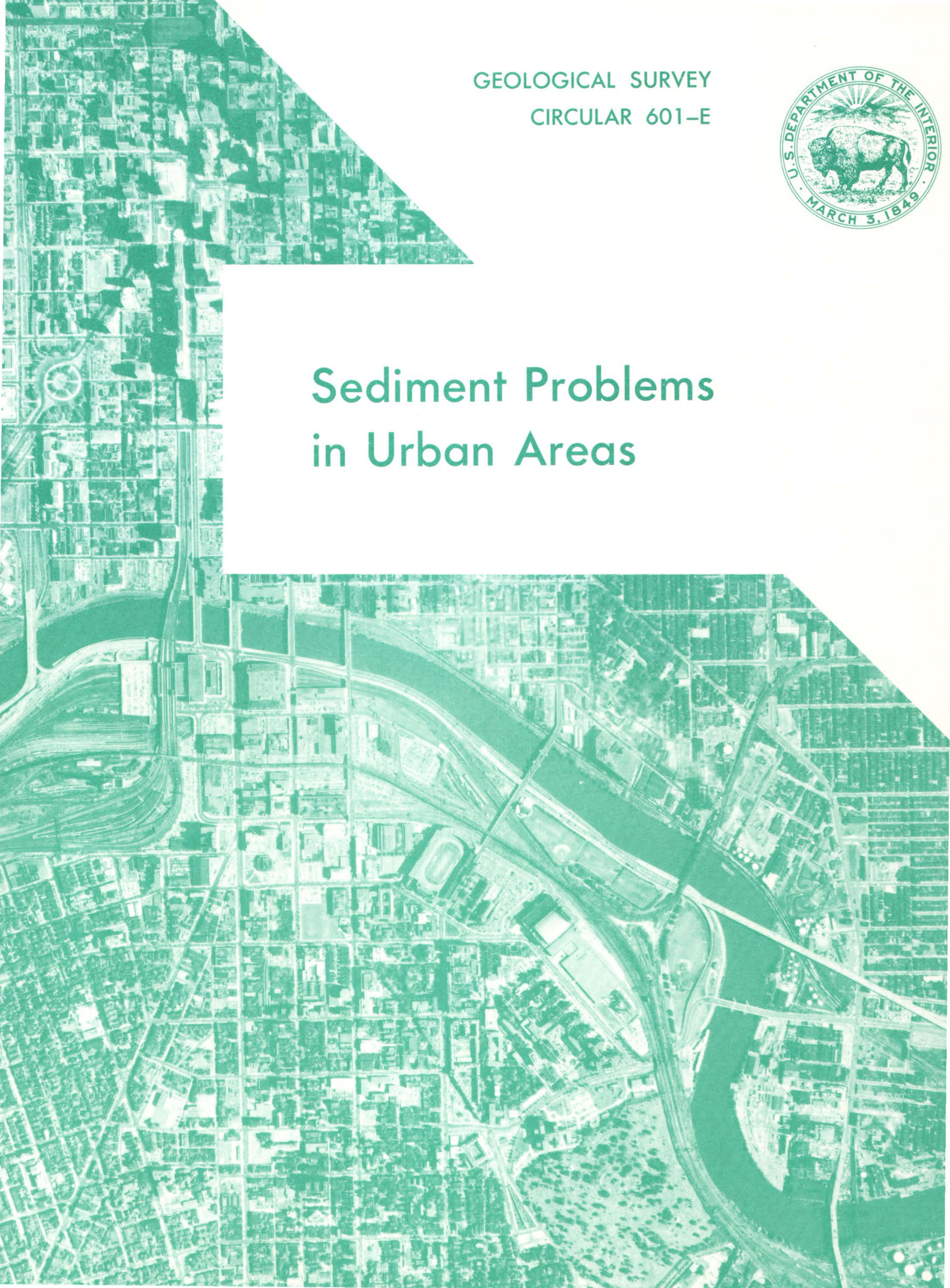
Sediment Problems in Urban Areas



Sediment Problems in Urban Areas

By Harold P. Guy

WATER IN THE URBAN ENVIRONMENT

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FOREWORD

Urbanization—the concentration of people in urban areas and the consequent expansion of these areas—is a characteristic of our time. It has brought with it a host of new or aggravated problems that often make new demands on our natural resources and our physical environment. Problems involving water as a vital resource and a powerful environmental agent are among the most critical. These problems include the maintenance of both the quantity and quality of our water supply for consumption, for recreation, and general welfare and the alleviation of hazards caused by floods, drainage, erosion, and sedimentation.

A prerequisite to anticipating, recognizing, and coping intelligently with these problems is an adequate base of information. This series of reports is intended to show the relevance of water facts to water problems of urban areas and to examine the adequacy of the existing base of water information.

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Water in the Urban Environment

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INTRODUCTION

A recognition of and solution to sediment problems in urban areas is necessary if society is to have an acceptable living environment. Soil erosion and sediment deposition in urban areas are as much an environmental blight as badly paved and littered streets, dilapidated buildings, billboard clutter, inept land use, and air, water, and noise pollution. In addition, sediment has many direct and indirect effects on streams that may be either part of or very remote from the urban environment. Sediment, for example, is widely recognized as a pollutant of streams and other water bodies.

One obstacle to a scientific recognition and an engineering solution to sediment-related environmental problems is that such problems are bound in conflicting and generally undefinable political and institutional restraints. Also, some of the difficulty may involve the fact that the scientist or engineer, because of his relatively narrow field of investigation, cannot always completely envision the less desirable effects of his work and communicate alternative solutions to the public. For example, the highway and motor-vehicle engineers have learned how to provide the means by which one can transport himself from one point to another with such great efficiency that a person's employment in this country is now commonly more than 5 miles from his residence. However, providing such efficient personal transport has created numerous serious environmental problems. Obstacles to recognition of and action to control sediment problems in and around urban areas are akin to other environmental problems with respect to the many scientific, engineering, economic, and social aspects.

PROBLEM EXTENT

In a study of sediment problems in urban areas, it is necessary to remember that sediment movement and deposition was a part of the natural environment before the intervention of civilization. Like flooding, the sediment problems become important only when man is affected. Sometimes the problems result from natural conditions, but usually they result when the natural circumstances are altered to effect such a different kind of environment that previous small unnoticed problems are greatly magnified. Severe sediment problems occur, for example, when covering vegetation is removed in construction areas, when the flow regime in channels is altered by realinement or by increased or decreased flow, or when fill, buildings, or bridges obstruct the natural flowway.

The average sediment yield from the landscape and the condition of the stream channels tend to change with the advancing forms of man's land-use activity, as indicated by table 1. As in many other situations involving intensive use of resources and rapid growth, one can expect that sediment problems will be most serious during the urban construction period (E). This is not to say that problems are not likely to occur during the stable period (G) because physical and esthetic values or quality standards with respect to both water and property are expected to increase with time. For example, a stream carrying an average suspended-sediment concentration of 200 mg/l (milligrams per liter) after 2 years into the stable period may be more acceptable than 100 mg/l after 20 years into the stable period.

It is impossible to isolate sediment problems completely from the many interrelated problems

Table 1.—*Effect of land-use sequence on relative sediment yield and channel stability*

[Modified from Wolman (1967)]

Land use	Sediment yield	Channel stability
A. Natural forest or grassland.	Low	Relatively stable with some bank erosion.
B. Heavily grazed areas.	Low to moderate	Somewhat less stable than A.
C. Cropping	Moderate to heavy	Some aggradation and increased bank erosion.
D. Retirement of land from cropping.	Low to moderate	Increasing stability.
E. Urban construction.	Very heavy	Rapid aggradation and some bank erosion.
F. Stabilization	Moderate	Degradation and severe bank erosion.
G. Stable urban	Low to moderate	Relatively stable.

associated with urban development, especially with respect to water (Anderson, 1968; Leopold, 1968). However, the sediment problems can usually be classed into groups related to land and channel erosion, stream transport, and deposition processes (Guy, 1967), regardless of the land-use phases mentioned in table 1. Land erosion, including the sheet, rill, and gully forms, is likely to be most severe during the urban construction period (E), though it may be present to some degree regardless of land use. Channel erosion is most severe during the stabilization period (F), especially when channels have been realined, waterways have been constricted, and (or) the amount and intensity of runoff have been increased because of imperviousness and "improved" drainage. Sediment transport problems are usually associated with the pollution of water by sediment from either or both the esthetic or physical utilization viewpoints. Transport problems also occur in regard to coarse sediment when the transport capacity in a stream section does not match the input supply of the coarse sediment—hence, aggradation or degradation. The sorting and differential transport of sediment result in deposition problems ranging from the fan deposits at the base of graded banks to deposits in reservoirs and estuaries.

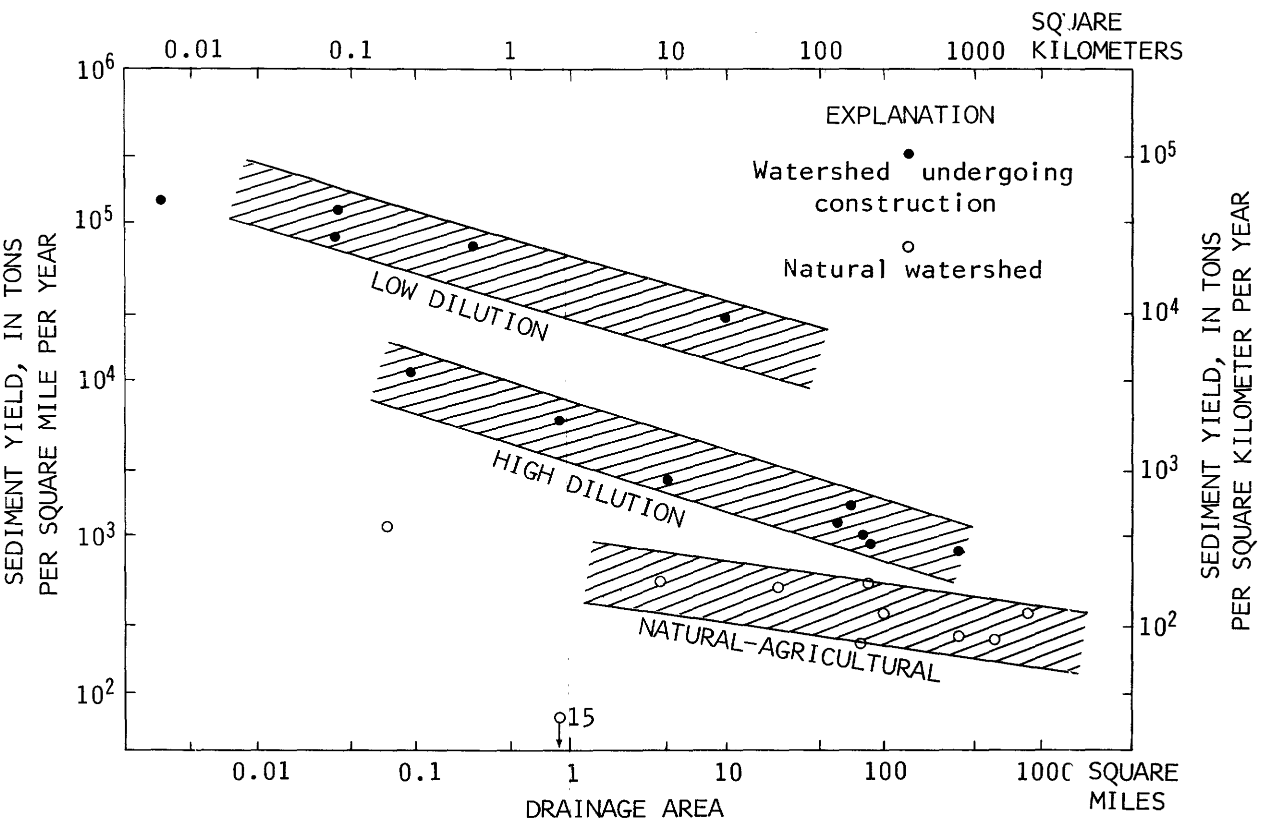

Figure 1.—Effect of construction intensity and drainage area on sediment yield (from Wolman and Schick, 1967, p. 455). Most of the data are from the Baltimore and Washington, D.C., metropolitan areas. The term "dilution" refers to drainage from relatively stable nonconstruction areas.

The following is a list of some of the urban sediment erosion, transport, and deposition problems:

1. Public health may be affected in a number of ways. Efforts to control mosquito breeding have been ineffective because sediment has filled drainage channels. Also harmful bacteria, toxic chemicals, and radionuclides tend to be absorbed onto sediment particles. The absorbed substances may not be harmful in their original residence but become hazardous when transported into a water supply or deposited and perhaps concentrated at a new location.
2. Sheet, rill, and gully erosion and associated deposition may cause undesirable changes in graded areas typical of urban construction sites. Figure 1, from Wolman and Schick (1967, p. 455), shows the effect of the intensity of construction and drainage-basin size on sediment yield. In figure 2 it will be rather expensive to remove the deposit in the yard, to repair the erosion damage on the graded bank, and to repair the drainage channel on the terrace. Erosion and subsequent deposition in cut-and-fill areas can easily exceed 1 cubic yard for each 100 square feet.

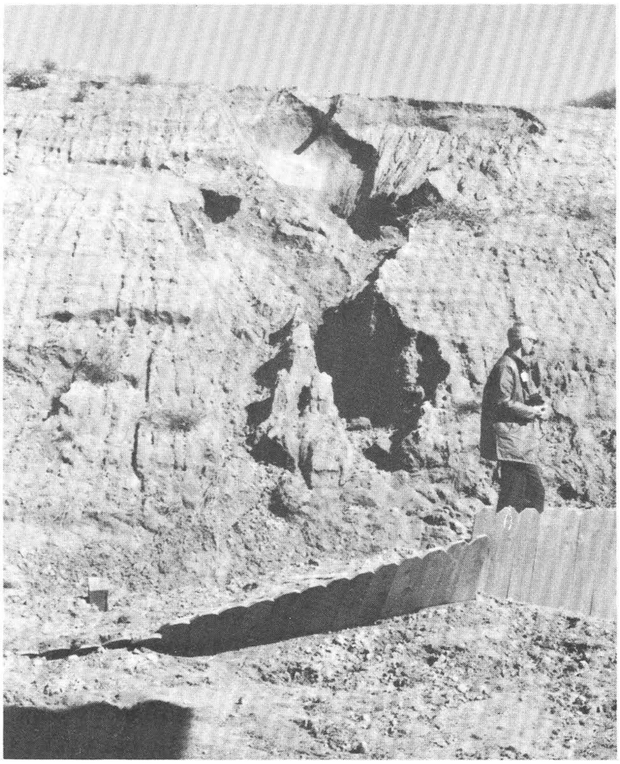

Figure 2.—Severe rill and gully erosion from the January 1969 storms in a new residential area near San Bernardino, Calif.

3. Dispersion of soil particles by raindrop impact seals the land surface and thereby reduces infiltration, increases stream runoff, and decreases groundwater recharge.
4. Deposition of coarse sediments may reduce the flow capacity or completely plug natural and manmade open channels (fig. 3) as well as subsurface drains.
5. Floodwater damage is increased manyfold in homes, stores, and factories because of sediment. Evaporation can erase many of the effects of a "pure water" flood, but it cannot do so when the flow contains suspended sediment.
6. Streams and other bodies of water are damaged esthetically by unsightly deposits as well as by fine sediment in suspension. Though stream esthetics are

A

B

Figure 3.—Effect of coarse-sediment deposition on flow capacity in urban channels. *A*, Flow of sediment in floodwater from the January 1969 storms plugged a Glendora, Calif., concrete-lined channel and caused overflow and deposition on nearby property. The channel had been partly cleaned after the flood and before the picture was taken. *B*, Three feet of deposition in the lower part of this boulevard channel in Boulder, Colo., caused flooding by a flow of less than one-fifth the design capacity of the channel.

considered much more inclusive than recreation alone, Brown (1948, p. 79) has estimated that recreation losses in the Meramec River basin near St. Louis, Mo., in 1940 amounted to 49,090 person-days as a result of above-normal flows (but less than floodflows) of high turbidity.

7. Water-treatment costs for domestic and industrial uses are increased. Reduction of Potomac River sediment turbidity to optimum could produce an annual savings of $25,000 per year (1963 values) for Washington, D.C. (Wolman, 1964, p. 68).
8. Erosion and (or) deposition in channels (fig. 4), estuaries, and other water bodies may cause bridge or culvert failure as well as serious ecological changes by alteration of species composition and population density (Peters, 1967).

A

B

Figure 4.—Examples of channel erosion and deposition resulting from urbanization. *A*, Bank erosion and degradation from increased runoff from impervious areas, tributary to Montclair Creek, Mobile, Ala. *B*, Deposition and plugging of drain from intensive sediment movement during residential construction, tributary to Rock Creek near Washington, D.C.

9. Impoundments for municipal water storage are often built upstream from cities. The release of clear water from such impoundments can create serious degradation and bank erosion in downstream areas where picnic and other recreational facilities are planned.
10. Reservoir storage and channel conveyance for water supply are lost. Wolman (1964, p. 63) indicated that the alternative cost per acre-foot of storage lost to sediment in water storage and recreation reservoirs in Maryland ranges from less than $100 to over $78,000.
11. Maintenance costs are increased for streets, highways, and other public-use areas. (See fig. 5.)
12. As implied in the introduction, perhaps the most serious urban sediment problem is the general deterioration of the total environment—a condition usually not recognized by the public.

As with many hydrologic problems, most urban sediment problems have visual impact for relatively short periods of time because they are rainstorm related (Guy, 1964). Also, because these problems are usually rooted within the urban or urbanizing area, they are limited to relatively small areas of the country. However, because of the intense capital investment in and human use of urban areas, the recognition of and solution to sediment problems become socially and economically very important.

Sediment damage is apparent when a storm-drain inlet becomes clogged, rill erosion cuts a graded area, a traffic accident occurs because of a wet fine-sediment deposit on a street, a swimming area must be closed because of

Figure 5.—More than 1,000 cubic yards of debris deposited on a short section of Ledora Avenue, Glendora, Calif., during the January 1969 storms by sediment flow and floodflow from nearby recently burned foothill area.

turbid water, a water-treatment plant cannot clarify water, or a recreation lake is filled with sediment (Guy and Ferguson, 1962). Because sediment is often part of a complex environmental problem (Guy and Ferguson, 1970), many other sediment problems go unnoticed even though they may be economically significant. A study of air pollution in Chicago showed that dustfall amounts ranged from 21 to 61 tons per square mile per month at 20 stations during 1966 (American Public Works Association, 1969, p. 25). The Chicago study also showed that street-litter sweepings consisted of more than 70 percent dirt and rock by weight—the remainder was classified as metal, paper, vegetation, wood, and glass. Higher percentages of dirt occurred in the litter after rainstorms, even in a business area that was 100 percent built up.

A sound sediment-measurement program in and adjacent to urban areas will help people to recognize what the problems are, where they occur, and when to expect them. Such a sediment-measurement program should document erosion sources and amounts, concentration in runoff, stream-channel changes, and the location and amounts of deposition. The measurement program, though mostly a documentation of the nature of conditions, will provide the basis upon which research needs (Guy, 1967) can be evaluated.

There are many laws concerning problems of sedimentation (Busby, 1962, 1967). In general the cases make it eminently clear that downstream owners can recover damages if changes and costs are well documented. In States where the civil law rule applies, a higher land is entitled to have flow discharge across the property of a lower landowner as it does in nature. Sometimes, however, a "reasonableness of use" rule is applied (*Sainato* v. *Potter,* 159 A. 2d 632, 222, Md. 263) where strict application of the civil law rule would result in hardship to either party. In considering aspects of sedimentation law, the following quotation from the decision in *Neubauer* v. *Overlea Realty Co.* (142 Md. 87, 98, 120 A. 69, 73) is of additional interest,

> It is no answer to a complaint of nuisance that a great many others are committing similar acts of nuisance upon a stream. Each and every one is liable to a separate action, and to be restrained.

Roalman (1969) described "a bounty on water polluters" based on the Harbor Act of June 29, 1888 (25 Stat. 209), as amended on June 7, 1924 (S. 1942), whereby any private citizen can bring action against almost any water polluter. Though it has been little used for the past 80 years, it provides for a stiff fine and a jail sentence for the polluter, and it specifically directs that a bounty be paid to the citizen who proves his case—literally a bounty law on water polluters.

SOME ASPECTS OF PROBLEM SOLUTION

Of the many facets of sediment problems in urban areas, the foremost are recognition and evaluation. Recognition would be easier if specific data on the cost of the many kinds of sediment problems in urban areas were available. The costs of sediment problems are rarely computed, and then they are generally estimated, even under the relatively less dynamic and more familiar rural conditions. Moore and Smith (1968) showed that "rural erosion and sediment" problems in the United States cause more than a $1-billion loss each year, $800 million of which occurs from erosion of cropland. Brown (1948) reported that annual damage from sediment deposition alone in rural areas amounts to $175 million. This in itself is 1.7 times the average annual flood damages for the 20-year period 1925–44. In the accounting of flood damages, sediment deposition was apparently not considered a flood cost.

The economic aspects of sedimentation in all its forms from erosion to deposition have been discussed recently by Maddock (1969). His section with regard to municipalities consists of only two paragraphs, as follows:

> The economic problems associated with the control of turbidity in municipal and industrial water supplies are well known. Equally or perhaps more important, however, every community has its water courses. As the community grows, it seems inevitable that there will be a decision of some kind that will modify the behavior of these streams. Discharges are diminished or increased, stream channels are straightened or confined, and sediment loads are modified. These modifications generally result in problems that are solved at relatively high expense. The expense for one modification is not very great, but there are so many modifications that the aggregate costs are large.
>
> The writer has discussed this phase of the erosion and sediment problem with engineers whose practice is largely in the municipal engineering field. Almost without exception, they all say that the control of natural drainage is one of the most irritating and aggravating problems they have to deal with. Many high-cost drainage projects result from an inability to cope with what appear to be relatively simple problems. Thus an alluvial channel must be transformed into a pipe or a lined channel because its slope is too steep for the amount of water it is expected to carry. Straightening alluvial channels seems to be a minor adjustment but it inevitably leads to more serious problems. A realization that most natural channels respond to the movement of both water and sediment would do much to prevent obvious mistakes.

Evaluation of the sediment problem is also complicated because sediment measurements are rather expensive and because sediment erosion, movement, and deposition are occurring in a highly dynamic and complicated environment. For example, in a drainage basin undergoing residential development (Guy, 1965), the area denuded of vegetative cover and subject to intensive erosion is continually changing. The process is complicated by the fact that storms occur as somewhat random events. The environment, too, is complicated by the fact that subsoils of varied erodibility are exposed to varying degrees with time and that manmade drainage may concentrate the magnitude and location of channel flow. During stabilization after urban construction (table 1, F), channel instability is marked by serious degradation and severe bank erosion as a result of increased flows of relatively low sediment concentration from impervious areas as indicated by figure 4A.

As already mentioned, heavy loads of sediment are moved into channels below construction areas; the fine particles move through rapidly and the coarser particles tend to fill the channel system (fig. 4B). In regard to the period of returning stability after development, Dawdy (1967, p. 242) stated,

> the slug of coarse sediment produced during construction may well travel through a channel system as a discrete mass or wave, causing geomorphic changes. These, in turn, change the hydraulics of the channel, cause bank erosion, and may alter the ecology of the stream. No data nor studies of the impact of urban sediment on downstream ecology are available, however. If a channel system is steep enough and discharge is sufficiently great to transport the contributed sediment, the geomorphic and hydraulic effects may be short lived, and the impact of the sediment and of its associated problems is transferred downstream to a major river, a lake or reservior, an estuary, or the ocean.

With our advanced state of technology, solutions to the physical urban sediment problem are usually available even though the problem may occur under a dynamic and complicated environment. Such solutions may seem economically and socially expensive, but in the light of our high standard of living the expense will prove to be relatively low. Because of the importance of sediment control, it is to be hoped that implementation will not be fraught with institutional difficulty.

In many situations, a program to obtain sediment knowledge is justified in order to wisely choose a suitable solution among many alternatives. A complete sediment-evaluation program may, in reality, be a complete systems study of input-storage-output components. For example, where the problem involves a stream channel, it is essential to know the sources of the inflowing sediment, the degree and extent of transport in the stream, and the nature of the deposit, in terms of time and space, at the estuary or other body of water.

Several steps needed to achieve control of urban sediment have been outlined by Guy and others (1963). These are:

1. Public-program adjustments, including a specific policy toward potential problems, planning and zoning, local ordinances, and assistance to insure proper judicial interpretation.
2. Erosion-control measures, including the proper use of vegetation for both temporary and permanent control, diversions and bench terraces, stabilization structures, storm drainage systems, storage of excess rainfall on lots, floodwater retarding structures, and the provision of "blue-green areas," usually parks, along streams and in headwater areas having critical runoff.
3. Adequate education of both the general public and urban officials is essential. Such education in turn requires adequate sediment information, without which neither 1 nor 2 can be effectively accomplished.

Attempts to control some of the sediment problems in the Los Angeles area have involved the construction of numerous "debris" basins on small streams draining steep foothill areas. Figure 6 shows debris accumulation in Santa Anita basin after the storms of January 1969. Sediment yields of as much as 124,000 cubic yards per square mile per year have been noted to occur as long as 5 years after the accidental burning of the vegetal cover (Tatum, 1965, p. 891). The primary purpose of these debris basins is to prevent heavy sediment loads from clogging drains and streams in developed urban areas. Bank erosion and other sediment problems are reduced in the Los Angeles area by stabilization of banks and sometimes streambeds in an attempt to increase the flow capacity through urban areas.

A good example of an institution attempting to control sediment in urban development, and thus to

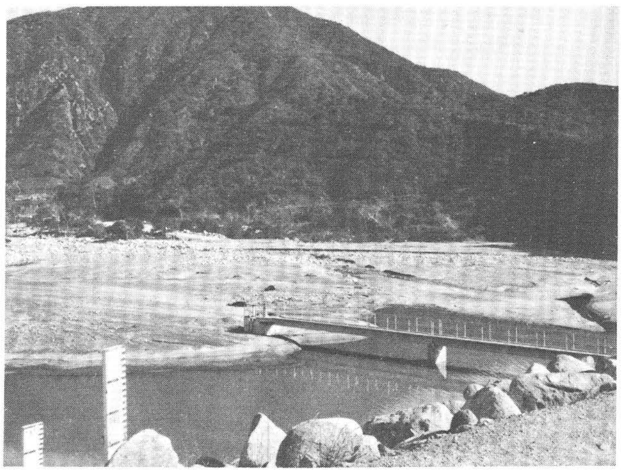

Figure 6.—Sediment accumulated in Santa Anita debris basin near Sierra Madre (Los Angeles area), Calif., as a result of the storms occurring during January 1969. Inspection of the delta at the spillway and channel downstream indicated that much sediment of the larger sizes had overflowed the system at the end of the storm period.

eliminate or reduce many sediment problems, is Montgomery County, Md. It was the first county (July 1965) to adopt a "Sediment Control Program" that requires approval of subdivision development plans by the Department of Public Works, which in turn is in consultation with the Soil Conservation Service. If the developers' plan for erosion and sediment control seems inadequate, then the Soil Conservation Service is asked to recommend suitable measures. Sometimes the measures may include only revision in timing and location of construction activity. In October 1966, the Fairfax (Va.) Board of Supervisors adopted a set of subdivision land-erosion-control measures similar to those of Montgomery County.

Sediment control is also being effected as a result of Executive Order 11258 issued in 1966 through the authority of the Water Quality Act of 1965. This order requires a review of all Federal and federally aided operations where there is a significant potential for reduction of water pollution by sediment. The reviewers may prescribe suitable remedial practices as necessary. This should prove particularly significant in view of sediment problems in connection with urban and suburban highway construction (Vice, Guy, and Ferguson, 1969).

CONCLUSIONS

Much of the disturbed soil in urban construction areas erodes and becomes sediment in streams; the sediment damages water-control works and aquatic habitat, degrades water quality, increases flood damages, and lowers the environmental attractiveness. During the process of stabilization of an area after construction, streams tend to erode their beds and banks as a result of increased runoff. All such sediment, whether from construction erosion or from channel erosion, is transported by streams and often deposited somewhere downstream at a location previously assigned to the movement or storage of water.

Documentation of erosion sources and amounts, of sediment concentration in runoff, of stream-channel changes, and of the location and amounts of deposition together with an economic analysis of sediment damages and a pertinent research program will provide the knowledge needed to find the best solutions to a wide variety of existing and future urban sediment problems. Aside from the knowledge needed for better design of systems, documentation of sediment conditions will provide baseline information from which damages, both on site and downstream, can be evaluated. Defense against damage claims often rests upon attempts to demonstrate that the claimant had no knowledge of preexisting conditions, that the source of damages was not discernable, or that conditions had always been so.

Increasing numbers of communities will likely attempt to alleviate their many sediment problems because of the adverse effects of such problems on the local environment. The public sentiment needed to support such programs to control sediment is built from a series of events that restrict, offend, or otherwise concern people.

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