Factors That Affect Water Erosion From Construction Areas

William G. Weber, Jr., Professional Engineer, Etters, Pennsylvania

The various factors that affect water erosion from agricultural lands are reviewed. Methods for predicting soil loss from agricultural lands appear to be well established and can be generally applied to farmlands. A review of the conditions existing on construction sites, however, indicates that they bear only a limited similarity to conditions on agricultural lands. The need to develop new means for predicting sediment yield from construction areas is evident. The factors that determine soil loss from a construction site are likely to be quite different from those used in determining soil loss from agricultural lands. Methods for controlling water erosion from construction areas are briefly discussed. The major factor is control of runoff water during the construction period. Current work to define the factors involved in erosion-control measures and the relative efficiencies of such measures are discussed.

Erosion is a naturally occurring part of the weathering process. Without natural erosion the landforms we know would not exist. Thus, only the elimination of excessive erosion caused by the activities of man, and not the complete elimination of erosion, is desirable. The two common erosion-producing factors are flowing water and wind. This paper deals only with water erosion.

In nature the rate at which water erosion occurs is controlled by gentle slopes and vegetative cover; many of the fertile agricultural areas are formed in this way. Human agricultural and construction activities expose the bare soil and thus accelerate erosion, causing downstream damage and loss of agricultural lands. Control of this accelerated rate of erosion is essential to the preservation of our way of life. Although agricultural activities are now generally conducted so as to minimize accelerated erosion, concern has recently arisen about accelerated erosion from construction activities. That concern has resulted in a need to predict where and how much erosion will occur in construction areas for the purpose of designing protective measures.

This paper examines (a) the factors that affect water erosion from construction areas for the purpose of predicting the amount of such erosion and (b) the factors that should be considered in the design of erosion-control devices.

PREDICTIVE METHODS

When the Soil Conservation Service was established in 1935, research on predicting soil erosion from farmlands was accelerated. Until that time only casual research had been conducted on the factors causing erosion. The result of 20 years of research by the Soil Conservation Service is the now widely recognized universal soil-loss equation (1). The following table lists the factors included in the soil-loss equation and the categories of erosion activity in which they may be grouped:

Category	Factor
Climate	Rainfall
Site conditions	Slope gradient
	Slope length
	Soil erodibility
Human activity	Crop management
	Erosion control

The equation predicts average expected soil loss per unit of area per year on a given farmland cultivated in continuous fallow. Since 1965 many researchers have attempted to modify the universal soil-loss equation (2, 3, 4), mostly by attempting to modify one of the terms—generally the rainfall factor. All of the equations developed include the same three categories. None of these other equations, however, has found widespread use and acceptance.

The development of the computer made possible studies that model the erosion process. Most of these studies are incomplete and currently put to only limited use. Because of the wide variation in climatic and site conditions, an extremely complex computer model will probably be required that, because of its complexity, will not be widely used.

Recent concern about preventing erosion from construction areas resulted in widespread use of the universal soil-loss equation or some modification of this equation. It soon became evident, however, that the equation did not apply to construction sites. Limited attempts were then made to develop equations from data obtained from construction sites (4). The same three categories—climate, site conditions, and human activity—were considered, and the factors considered in the universal soil-loss equation were generally included in some modified form. This approach has resulted in equations of only limited usefulness.

CLIMATE

Rainfall Factor

Naturally, water erosion cannot occur unless water is present, usually in the form of rainfall or flowing water. A measure of the ability of a rainstorm to detach and transport the soil particles—the rainfall erosion index—was developed by Wischmeier and Smith (1). Many other investigators, working over a 20-year period, contributed to the development of the concept (5, 6, 7). There is thus a large amount of data to substantiate its use.

The rainfall erosion index (EI) is the product of two rainstorm characteristics: the total kinetic energy of a storm times its maximum 30-min intensity. The data used in the development of this concept were obtained from cultivated farmland in continuous fallow. Under these conditions the soil is in a loose, porous state and it is reasonable to expect the energy and intensity of rainfall to be an index of the ability of a storm to detach the soil particles.

The process by which soil particles are detached and transported by the action of rainfall can be described as follows for farmland conditions. First, the soil of a farmland in continuous fallow is in a very loose condition with a high water-retention capacity. The cohesion between soil particles is poor. When rainfall starts, the water is rapidly absorbed into the soil. Generally the first 0.62 to 1.25 cm (0.25 to 0.5 in) of rainfall is absorbed. A layer of soil whose moisture content is above the liquid limit is formed on the surface. When a raindrop hits this soft, saturated soil the amount of soil detached is a function of the energy of the raindrop. As rainfall continues small puddles of water form in the rough surface of the soil. Runoff does not occur until the soil is saturated and all depressions are filled with water. As further rainfall occurs, rills are formed by the flowing water and further soil detachment is caused by the velocity of the flowing water. The rills then collect to form gullies, and the flowing water detaches and transports larger soil particles.

Under construction-site conditions, it is not reasonable to expect rainfall energy and intensity to be the controlling factors in soil erosion. At a construction site, compacting of fills and earth placement are normally done simultaneously. The area is also bladed relatively smooth to facilitate movement of earth-moving equipment. Thus, the rain falls on a smooth, compacted soil surface that has good soil cohesion and a very low infiltration rate. When rainfall begins, very little of it [0.25 to 0.62 cm (0.1 to 0.25 in)] penetrates the soil surface. Because of the relatively smooth condition of the surface, sheet flow forms and the raindrops expend their energy on a water surface and not on the soil surface. The water does collect in rills and later in gullies, as in farmland flow, but provision is made on most construction projects for collecting the water in controlled waterways so that gullies do not form. Rainfall impinging on the cut-and-fill slopes is proportional to the projected slope areas, which are generally small compared to flat areas. Control of the water by intercepter trenches and staged seeding and mulching greatly reduce erosion from these slopes.

In recent years the author has witnessed erosion on several construction projects. Examining the saturated soil scraped off the compacted fill after a rainfall revealed that the water only penetrated 0.2 cm (0.12 in) or less compared to a penetration of 2.5 to 5 cm (1 to 2 in) on adjacent farmland. Sheet flow was generally observed to occur in construction areas (8); little or no sheet flow was observed on adjacent farmlands. In construction areas only a few rills were seen to form, and these generally in wheel tracks and poorly graded areas. Generally many rills formed on the agricultural land. On one construction project, gullies were observed where uncontrolled runoff was allowed to flow over the side of an embankment. Although usually heavy rainstorms occurred on the farmlands, only a few gullies were observed because of the use of good farming practices. The action of the rain on cut slopes was minor in most cases. The use of intercepter ditches prevented concentrated flow over the face of the cut. On a well-dressed slope that was seeded and mulched, only minor rills formed; the same was observed on embankment slopes.

Because of recent concern about stream pollution from construction sites, an effort was made to predict soil loss at such sites by means of the universal soil-loss equation. Researchers (2, 3, 4) soon realized that storm energy and intensity were not the controlling factors at construction sites. Studies of various rainfall parameters indicated that runoff rates were correlated with sediment yield from construction sites. The runoff factor now appears to be gaining acceptance as a simplified approach to the problem.

Studies on sediment yield from construction sites conducted by the Pennsylvania District of the U.S. Geological Survey have indicated that this may be an oversimplification. It appears that the surface dust on construction sites is rapidly carried to streams by runoff and that, as further water flow occurs, a much reduced sediment yield occurs. The hydrograph in Figure 1 shows the effect of two consecutive rainstorms on sediment yield. The first storm occurred after 7 d of construction operation and produced 12.6 kg (27.74 lb) of sediment/93 m^2 (1000 ft^2) of exposed area. The second storm occurred 2 d later and produced 3.1 kg (6.84 lb) of sediment/93 m^2 (1000 ft^2) of exposed area. As a result, such factors as days between storms, contractor operations, and season of the year are being included in the joint study by the Pennsylvania office of the U.S. Geological Survey and Pennsylvania State University.

The time period between storm events and the season of the year appear to have a major influence on sediment yield but are difficult to include in a predictive equation. These factors may explain the poor correlation reported between direct runoff and sediment yield.

Freezing Areas

An important climatic factor in the snow regions is ground freezing and thawing. When the ground is frozen there is a very small loss (or no loss) of soil by erosion. This is also true for snowmelt conditions as long as the soil remains frozen. When the soil thaws, however, it is in a saturated, soft condition and water from snowmelt or rainfall then results in excessive sedimentation. Spring thaw periods may thus produce sediment yields many times those produced by storms during the summer months. This is important in the design of erosion-control measures at construction sites because such measures must be completed before the winter shutdown.

Storm Events

It is important to remember that the universal soil-loss equation was developed for gross annual soil loss and thus the yearly EI summation is used. It may be modified for use on an individual-storm basis, which would be especially applicable in estimating construction sediment yields for design purposes. But what is the typical design storm in erosion control? For economic reasons erosion-control measures should not be designed for a storm that would not normally be expected to occur during the short life of the project. The joint study conducted by the U.S. Geological Survey and Pennsylvania State University is expected to provide a guide to the storm frequency that should be used. That frequency should be based on the anticipated number of years the construction project will be exposed to erosion conditions.

SITE CONDITIONS

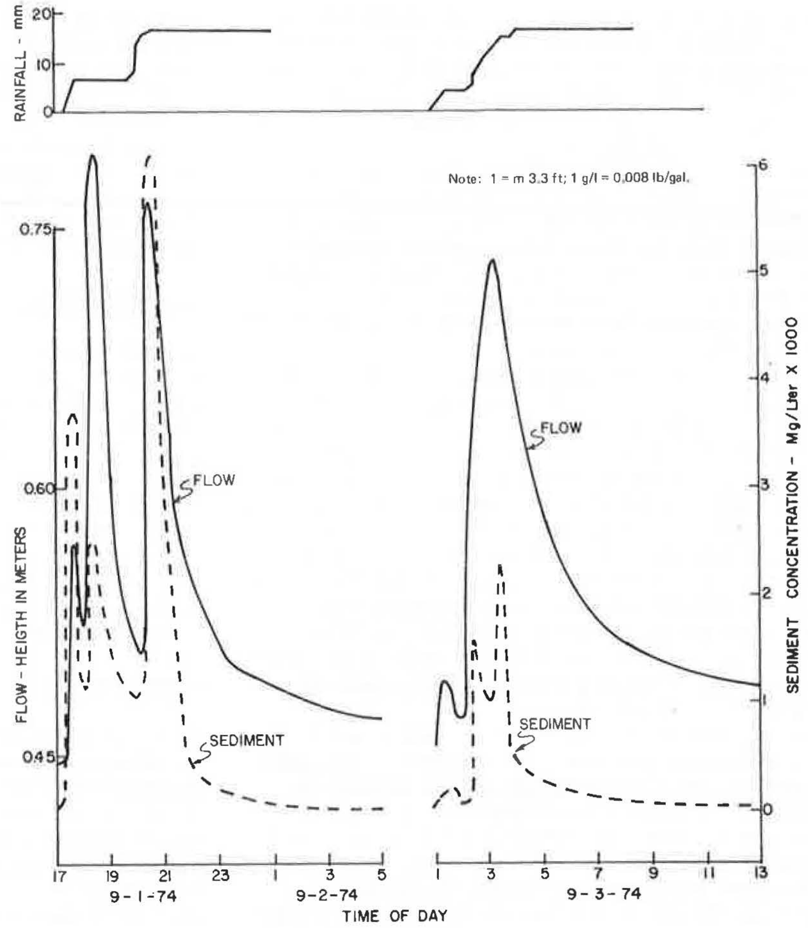
Slope Gradient

The slope of the land generally determines the velocity with which water flows across the slope. Such items as vegetative cover have a large effect on the velocity of runoff water. In sheet flow, rill flow, and gully flow, the velocity of water flow determines how much sediment the water will transport and causes the detachment of soil particles from the soil mass. Thus both detachment and transport of soil particles are functions of the slope of the soil surface.

To isolate the slope effect in developing the universal soil-loss equation, a 9 percent slope was adopted as standard. A standard roughness condition existed for land cultivated in continuous fallow. A slope effect was obtained by standardizing other factors, and this was applied as a factor to the 9 percent standard slope. Other researchers have since studied the effect of slopes on sediment yield, but the universal soil-loss concept is generally used.

Construction projects are usually characterized by cut-and-fill slopes and relatively flat work areas. The cut-and-fill slopes are steep and originally produced considerable sediment yield. Because of the practice of controlling the surface water so that it does not run

Figure 1. Effect of consecutive storm events on sediment yield.



over the top and down the slope, erosion has been greatly reduced. The standard practice of using intercepter trenches, dikes, and down drains has been very effective. Rain falling directly on the slope results in runoff, which produces a sediment yield. Continual fine grading of the slope and staged seeding and mulching have been observed to result in a sheet flow with minor sediment yield. Thus, good construction practices appear to be preventing the high sediment yields expected from slopes.

Work areas tend to be relatively flat with slopes that seldom exceed 5 percent. Studies in Pennsylvania have indicated that work areas are the principal source of sediment yield at construction sites [yields are of the magnitude of 45.4 kg (100 lb) of sediment/186 m^2 (2000 ft^2) of exposed area] (8). This would indicate that about 0.025 cm (0.01 in) of soil is removed from the work area, or about the thickness of the dust layer. During normal construction operations, little can be done to prevent erosion from work areas except to attempt to remove the sediment from the water before it flows from the site.

Researchers now tend to eliminate the slope factor from erosion-prediction equations for construction areas (4). Because of somewhat uniform slope conditions in construction operations, this factor is likely to remain constant as long as good construction practices are followed.

Slope Length

In erosion from cultivated farmland, sediment yield has been found to be a function of slope length (1). [A standard slope length of 22 m (72.6 ft) was used in developing the universal soil-loss equation.] Rills form rapidly in cultivated farmland; sediment yield can be expected to be a function of the length of the rill because the length of the flow path of water determines the amount of soil that is detached and, thus, the sediment yield. This is a reasonable assumption in soft, saturated soil conditions such as those on cultivated farmlands. In construction areas with compacted soils, however, the length of the flow path may not determine the sediment yield because the rainfall washes the loose surface dust off the compacted soil.

Researchers have found that slope gradient and slope length, as defined by the universal soil-loss equation, do not appear to relate to sediment yield from construction areas (2, 3, 4). Attempts are being made to combine other drainage-basin parameters into one factor so that these basin characteristics can be estimated based on sediment yield. There does not appear to be any uniformity in the results currently being obtained. When soil conditions are considered, there is no reason to expect the sediment yield from construction areas to be similar to that from agricultural land. In addition, flow paths in construction areas are short because of the practice of providing for the collection and control of surface runoff.

Efforts have been made to determine the sediment yield produced by sheet, rill, and gully flows (8). Table 1 gives construction-site data for the composition of suspended solids in runoff water. The sheet and rill flows are from an embankment surface, and the gully flow is from an embankment slope where the water flowed freely down the slope. The data show no relation between

Table 1. Percentage composition of suspended solids in runoff water.

Condition	Suspended Solids (mg/L)	Composition (%) Gravel	Sand	Silt	Clay
Native soil		3	26	41	30
Sheet flow	3690	0	3	47	50
Rill flow	4270	0	5	47	48
Gully flow	6030	2	10	41	47

Note: 1 g/L = 0.008 lb/gal.

the composition of the native soil and that of the transported solids. The percentage composition of the transported materials is similar for the sheet, rill, and gully flows. Similar results have been obtained by the author on other construction projects. The relatively uniform slopes and short length of flows in construction areas seem to produce somewhat uniform results. Slope gradient and slope length are expected to become constants for construction areas and to be included in the constants for predictive equations.

Soil Erodibility

The wide variation in the erodibility of various soils under similar conditions is attributable to the variation in chemical, physical, and in situ soil properties. Soil erodibility has been defined as the inherent susceptibility of soil particles to detachment and transport by raindrops and runoff. Thus, erodibility is, by definition, a property of each soil.

Soil erodibility has generally been determined by holding other factors constant or by controlling their variation and measuring the quantity of soil removed. The factors are then calculated by using various soil properties. [This is how the K-factor was determined for the universal soil-loss equation (1).] The K-factor is obtained for the A horizon in standard cultivated condition, generally by use of a nomograph. Roth and others (9) prepared such a nomograph for subsoils such as those encountered in construction and, for conditions existing in their tests, the erodibility factors are all valid. Care and judgment must be used, however, when these factors are applied to predicting sediment yield from construction sites.

The following table lists in three broad categories some of the many factors used by researchers to study soil erodibility.

Chemical	Physical	In Situ
Organic	Mechanical analysis (sand, silt, clay, colloids)	Density
Sesquioxide	Plasticity	Percolation rate (permeability)
pH	Specific gravity	Moisture content
Exchangeable base	Moisture equivalent	Cohesion
Fe_2O_3, Al_2O_3, S_1O_2, %	Percentage suspension (dispersibility)	Soil structure
Ionic dispersion	Partial surface area	Aggregation
Lime content		Shrinkage and swelling
		Depth of A, B, and C horizons
		Artificial channels

Some researchers have used ratios of two or more of these factors to express various soil properties, but only the basic factors are discussed here.

The chemical category defines the ability of water to detach the soil particles and retain them in suspension; it is not generally practical to use this category for routine determination of a soil-erodibility factor. The erodibility of subsoils has been defined as a function of the percentage of sand and the oxides of iron, aluminum, and silica in the soil. A well-equipped laboratory can easily determine the percentage of these oxides. But, although they frequently define some of the physical properties of the soil, it is hard to understand how they can define the significant in situ properties. In view of the fact that in construction operations the in situ properties often determine the sediment yield, it is questionable if chemical properties can be used in predicting sediment yield from construction areas.

Because the physical properties of soils can readily be determined in a soils laboratory, they have been widely used in estimating soil erodibility. But they do not define the in situ properties; thus, some in situ properties are often included, as they are in the universal soil-loss equation. The physical properties give an indication of the ability of water to detach soil particles and a reasonable approximation of the ability of soil particles to remain in suspension. Physical properties will probably continue to be widely used in some form in predicting sediment yield.

The in situ properties of soils can be approximated with some degree of accuracy before construction. Information on in situ properties for farmlands can be obtained from U.S. Department of Agriculture maps. In situ properties primarily indicate how easily the soil particles may be detached from the soil mass. Some in situ properties such as soil structure relate to the ability of the soil particles to remain in suspension, but these are of minor importance. In situ properties are of major importance in predicting sediment yield from construction areas. The difference between the in situ properties of soils from agricultural and construction sites is probably the major reason why an agricultural soil-erodibility factor should be used with such care for construction sites.

Soil-erodibility factors have been determined by means of test plots and are only valid for the existing test conditions. Erodibility factors are expressed by either equations or nomographs. To the author's knowledge no erodibility factor has ever been determined for construction conditions. In their joint study, the U.S. Geological Survey and Pennsylvania State University will conduct limited research in this area, using watersheds as test plots.

The differences in the erodibility of soils from agricultural lands and soils from construction sites are basically caused by (a) in situ properties resulting from the physical processing of the earth and (b) major use of subsoils and rock in earthwork construction. In situ properties probably cause the principal differences in the erodibility factor. If the major difference at construction sites is the previously mentioned washing action of rainfall, then the contractor's operations will have a major influence on sediment yield; that is, if there are no construction operations in an area, only minor sediment yield will result after the first storm. To evaluate this factor, data are being collected in the joint study by the U.S. Geological Survey and Pennsylvania State University.

In recent years attempts have been made to determine the erodibility of soils by means of laboratory tests. To be useful, a laboratory test must duplicate field conditions for the detachment and transport of soil particles. At the present time there appears to be no test that accomplishes this for conditions at construction sites. The existing tests are basically meant to provide solutions to specific problem areas. It may be necessary to develop a soil-erodibility test for earth used in construction.

HUMAN ACTIVITY

Crop Management

Vegetation is used in nature for erosion control. Vegetative cover absorbs the energy of raindrops. The organic residue from vegetation covers the ground and further absorbs the energy in raindrops and also provides storage for the water. When runoff occurs the vegetative material acts as a filter to reduce the sediment yield. Thus nature uses vegetation to control the rate at which erosion occurs. This is the natural process in humid regions. In semiarid areas, although the vegetative cover is sparse and major erosion occurs with heavy rainfall, the soils are frequently pervious and runoff is greatly reduced.

Man removes vegetative cover to produce food and shelter, accelerating erosion by exposing the soil directly to rainfall and runoff. The vegetative cover is then partially restored by agricultural crops. The management of crops has a major effect on the rate at which erosion occurs. Agricultural erosion-prediction equations such as the universal soil-loss equation contain factors that account for crop management (1). In construction activities the restorative approach is also used at the completion of a project: Vegetative cover is established in areas not protected by structures so that natural conditions are restored. During construction, however, the ground surface is bare to the effects of erosion, and this has become an area of concern.

Although crop management refers to agricultural practices, it is also applicable to construction sites. Good crop-management practices eliminate uncontrolled erosion and improve the appearance of the facility being constructed. This has been standard practice for many years and is not discussed further here.

Erosion Control

Erosion control may be defined as the use of various measures to reduce the rate of accelerated erosion. Engineers have recently attempted to prevent all sediment yield from leaving the construction site, but is this reasonable or desirable? It can only be done at great effort and expense. Preventing accelerated erosion during the construction process is the desirable approach. When water at the site would normally be clear, no sediment yield should be produced by the construction activities; when the water is normally muddy, no water leaving the construction site should contain a greater than normal amount of sediment. These results can be achieved by use of good construction practices and erosion-control techniques.

The two basic processes in erosion control are (a) preventing the detachment of soil particles and (b) removing the sediment that is being transported by the water. The usual way to prevent detachment is to cover the ground surface. Reed (8) has reported that vegetation at a construction site will reduce the sediment yield from the planted area by as much as 90 percent. This approach is of limited value, however, during major earthwork operations because only completed areas can be seeded and mulched. During construction operations, surface water is normally collected and then removed by means of controlled paths that may vary from closed pipes to open ditches. Among many methods used to protect the exposed soil are jute matting or plastic sheeting, sod placement, and fiberglass matting (10). Grasses are established as rapidly as possible to complete the protection of the soil. Where high water velocities will occur, materials such as rock, cemented soil, and concrete are used to line the channel and reduce the detachment of soil particles. Where the soil cannot be protected from the flowing water, it may be desirable to reduce soil detachment by reducing the velocity of the water. This can be done by using straw bales, rock dams, and ponds. One frequently overlooked method of protecting the soil from the flowing water is placing the base on roadways, parking areas, and other areas to be paved. Reed (8) has reported that placing the base on a roadway project reduced sediment yield from the covered area by 90 percent.

The second area of concern is the transport of soil by moving water. The principal method of removing the soil particles from the water is to allow them to settle under the force of gravity, which requires reducing the velocity of the water to zero or near zero. This is generally done by forming a pond of some type (11). It has been shown (8) that the efficiency of various ponding devices ranges from 5 to 85 percent depending on the size of the suspended soil particles, the ratio of rainfall and area of erosion to pond size, and other factors. These interrelations are complicated, and all the factors have not been fully investigated. They must be considered, however, whenever suspended sediment is removed from flowing water.

Solids can also be removed from water by the use of chemical flocculants. This method, which can be very effective and produces nearly clear water, should only be used in special situations. Care must be taken that the chemical used does not result in downstream pollution of water-supply systems.

The velocity factor is frequently overlooked in removing sediment from flowing water. The velocity of the water determines the maximum particle size that the water will move downstream. The piles of sand and gravel often observed at the downstream portion of a gully on a slope are the result of a reduction in the velocity of the water. Small dams, enlarged areas, and other methods of velocity reduction in a channel will also remove sands and gravels from flowing water. However, to remove silt and clay-size particles from the water, the velocity must in effect be reduced to zero. Days may then be required for the removal of the fine soil particles from the water, and extensive ponding would be required. Researchers are currently working to evaluate some of the factors involved in removing suspended solids from ponded water.

In any erosion-control plan it is desirable to prevent the water from forming its own flow path by providing flow paths in which its velocity can be controlled. The detachment of soil particles can thus be reduced and suspended solids removed as the water flows to the main waterway. Methods for reducing the sediment yield can then be used to reduce the amount of sediment leaving the construction site. This implies a degree of control over the contractor's operations, which contrasts with the present method of noninterference in the contractor's performance of the work. If any erosion-control plan is to be successful, such control is necessary and must be provided for in the specifications. The necessary sequence of operations must be detailed so that the contractor can bid intelligently on the project. The location and the design of the erosion-control devices must be shown, and descriptive information must be given on when these control devices are required to be operational. A well-designed erosion-control plan will enable the contractor to construct the project efficiently, without major problems, and to control the flow of water at all times.

Energy dissipators have been widely used for many years to reduce the velocity of water leaving the boundaries of construction areas. The use of conduits to carry water from the upstream to the downstream limits of a construction project usually results in an increase in velocity, which can cause extensive erosion of the stream channel downstream of the project. For this reason, energy dissipators are used at the exit ends of culvert pipes. Similar situations can exist in culverts or open channels within the project limits. In these cases, simple rock dams, roughened channel linings, or hydraulic jumps can be used to dissipate the energy of the water. The use of energy dissipators should be considered in any erosion-control plan. Failure to provide for energy dissipation can result in major erosion damage during construction or after completion of a project.

On almost all construction projects, waterways are crossed by the construction. If bridges are used, only minor work should have to be done in the channel. However, if conduits or pipes are used to channel the water across the project, major sediment yields may occur. If work is performed in the channel, sediment yields result even without rainfall and a normally clear water flow can become dirty. No work should be allowed in the channel except the construction of temporary crossings for the construction equipment. All conduits and pipes must be placed outside the normal water channel, and the downstream and upstream connections to the channel must be constructed so as to minimize the production of sediment. The use of good construction practices will result in the production of only minor sediment loads.

The Pennsylvania District of the U.S. Geological Survey has done an outstanding study of the efficiency of various erosion-control techniques (8). Their findings indicate that engineers will need to use imagination and basic engineering principles to solve many of the problems in erosion control. The key word appears to be control—that is, keeping the flow of runoff water under control at all times. If this is done, erosion-control measures will perform as anticipated for any rainfall up to the design-storm level. It will then be possible to use some type of efficiency factor in the predictive equations and to estimate the sediment yield.

CONCLUSIONS

The factors that affect sediment yield from agricultural lands are not the same as those at construction sites. The concept of rainfall intensity times energy that is used in agricultural soil-loss predictions does not appear to be a reasonable approach to estimating soil loss from construction sites because of drastically different soil conditions. The slope and length factors used in agricultural soil-loss predictions do not appear to be major factors in construction areas. A new approach to the prediction of sediment yield from construction areas is needed, and it is anticipated that new predictive techniques will soon be developed.

Reducing the rate of accelerated erosion from construction areas is currently of major concern. The rate of erosion can be greatly reduced by careful use of existing erosion-control measures. The results of existing studies on the effectiveness of erosion-control measures indicate that many existing concepts need to be revised. The time required to remove clay-size particles from water makes ponding methods of questionable value. Wherever possible greater emphasis should be placed on the prevention of erosion during construction.

REFERENCES

1. W. H. Wischmeier and D. D. Smith. Predicting Rainfall-Erosion Losses From Cropland East of the Rocky Mountains. U.S. Department of Agriculture, Agriculture Handbook 282, 1965.
2. J. R. Williams and H. D. Berndt. Sediment Yield Computed With Universal Equation. Journal of Hydraulics Division, Proc., ASCE, Vol. 98, No. HY12, Dec. 1972, pp. 2087-2098.
3. E. G. Diseker and J. T. McGinnis. Evaluation of Climatic, Slope, and Site Factors on Erosion From Unprotected Roadbanks. Trans., American Society of Agricultural Engineers, St. Joseph, Mo., 1967.
4. L. M. Younkin. Prediction of the Increase in Suspended Sediment Transport Due to Highway Construction. Bucknell Univ., Lewisburg, Pa., 1974.
5. G. W. Musgrave. The Quantitative Evaluation of Factors in Water Erosion. Journal of Soil and Water Conservation, No. 2, 1974.
6. A Universal Equation for Predicting Rainfall-Erosion Losses. Agricultural Research Service, U.S. Department of Agriculture, ARS 22-66, 1961.
7. W. H. Wischmeier and D. D. Smith. A Universal Soil-Loss Estimating Equation to Guide Conservation Farm Planning. Trans., 7th Congress of International Soil Science Society, Vol. 1, 1961.
8. L. A. Reed. Effectiveness of Sediment-Control Techniques Used During Highway Construction in Central Pennsylvania. Pennsylvania District, U.S. Geological Survey, Harrisburg, 1976.
9. C. B. Roth, D. W. Nelson, and M. J. M. Romkens. Prediction of Subsoil Erodibility Using Chemical, Mineralogical and Physical Parameters. U.S. Environmental Protection Agency Technical Services, June 1974.
10. T. H. Sellers. Making Erosion Control Work. Highway Focus, Vol. 8, No. 3, Oct. 1976.
11. T. J. Novak. Experiences With Sediment Basin Construction for Temporary Erosion Control. Highway Focus, Vol. 8, No. 4, Dec. 1976.

Publication of this paper sponsored by Committee on Environmental Factors Except Frost.