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PREVENTION AND CONTROL OF SOIL EROSION: THE STATE OF THE ART

The basic fundamentals contributing to soil erosion are temperature, wind, and water. Weather disrupts rock surfaces through alternate heating and cooling, and ice wedges in the interstices and joints of rock. This prepares the material for transport by wind and water. Water that freezes in surface soil causes heaving and loosens the soil; these processes also prepare it for transport. It is imperative that control measures be devised and implemented that will prevent dislodgment of soil particles and reduce runoff velocities to prevent accelerated soil erosion. Several states have surveyed the soil erosion problem; the survey results should be disseminated to officials responsible for construction and maintenance of roads and to citizens interested in conservation and development of a quality environment. The control of accelerated soil erosion is everybody's job.

"Since the first crude plow uprooted the first square foot of sod, and since man's axe first bit into virgin forest, erosion of the soil has been a problem. It is as old as history. Down through the ages it has influenced the lives of men and the destinies of civilizations. In the United States today, no problem is more urgent." This quotation, from the preface of Hugh Hammond Bennett's book (3) written in 1939, is still applicable. It points out the basic problem in the control of soil erosion by noting the removal of the vegetative cover and exposure of raw soil to the action of the elements. Soil erosion, in itself, is not necessarily destructive. Through the action of temperature, rain, and wind, parent materials are broken down to form soils, and these, by continuing processes, shape the landscape. However, through the removal of the protective cover and the shaping of steep slopes, the natural processes are speeded up and we have accelerated soil erosion, which is the destructive phase.

Accelerated soil erosion depletes agricultural lands and removes large quantities of subsoils and parent materials and deposits these to the detriment of man and his creations. Not only does the loss of topsoil from a field or subsoil from a highway grade result in a direct loss from the affected area, but also it may have a greater economic impact at the place of deposition. Who can accurately calculate the cost of removing the accumulated sediment from homes and industries annually deposited there by floods? Many acres of fertile river bottom lands are lost each year through the deposition of infertile overwash. Streams may have their total ecology changed by the deposition of sediment or the scouring of new channels. What is the economic loss and the suffering for humans, domestic animals, and wildlife in a major dust storm? What percentage of the highway maintenance cost goes into the removal of sediment from structures or the filling of eroded ditches and slopes? Eroding soil is responsible for much of the water pollution that plagues the world and, to a degree, air pollution, all of this in addition to the economic loss of the soil.

FUNDAMENTALS OF EROSION

In addressing ourselves to the problems of soil erosion and its control, we should review a few of the basic fundamentals contributing to it. These are principally temperature, wind, and water. Temperature influences erosion in two ways. It is active in disrupting rock surfaces through alternate heating and cooling and through the wedge action of ice formed in the interstices and joints of the rock. This weathering prepares the material for transportation by wind and water. Also, with the freezing of water in surface soil, frost heaving occurs and loosens the soil so that it may be easily carried away by wind and water or transported downslope through mass movement.

Wind erosion, a problem found principally in the more arid, sparsely vegetated regions, is also of local importance along the edges of highway pavements where the turbulence of passing traffic removes significant quantities of unprotected soil. Chepil (6) observed: "The wind erosion process has several major phases: initiation of movement of the soil and its transportation, sorting, abrasion, and deposition. Each phase is influenced by the condition of the air, the ground surface, and the soil." It is, however, turbulence that causes erosion.

Buckman and Brady (5) consider water erosion to be one of the most common geological phenomena. "It accounts in a large part for the leveling of our mountains and the development of plains, plateaus, valleys, river flats and deltas. The vast deposits that now appear as sedimentary rocks originated in this way. This is normal erosion. It operates slowly, yet inexorably. When erosion exceeds this normal rate and becomes unusually destructive, it is spoken of as accelerated.... Two steps are recognized in accelerated erosion—the detachment or loosening influence, which is a preparatory action, and transportation by floating, rolling, dragging, and splashing."

These authors also note that raindrop impact exerts three important influences: It detaches soil; its beating tends to destroy granulation; and its splash, under certain conditions, effects an appreciable transportation of soil.

Total rainfall and its intensity are both important factors, intensity usually being the most important. However, the slope also influences to a great degree the amount of soil loss. According to Buckman and Brady (5), "Theoretically, a doubling of the velocity enables water to move particles 64 times larger, allows it to carry 32 times more material in suspension and makes its erosive power in total 4 times greater." Bennett (3) feels that this figure is too high and states, "This principle, or law, is based on idealized conditions which never occur in nature. The corresponding law applicable to natural conditions varies more nearly as the fifth power of the velocity, or possibly slightly less. In other words, if the velocity is doubled, the weight (or volume) of the particle that can be moved is multiplied by 32 or a number slightly less." On the question of volume of material that can be transported he states, "Scientific and engineering literature throws even less light, but it may be reasonably safe to state that, by analogy, the quantity of material that can be moved by flowing water under natural conditions would vary as the fourth power; or if the velocity is doubled, the quantity will be multiplied by 16."

In view of the tremendous capacity for flowing water to dislodge and transport not only soil particles but also sand, boulders, trees, other vegetation, and man-made structures, it is imperative that control measures be devised that will first of all prevent the dislodgment of soil particles and also reduce and maintain runoff velocities at or near levels that will prevent accelerated soil erosion.

The National Environmental Policy Act of 1969 and the subsequent issuance of PPM 90-1 by FHWA focused the attention of highway officials on the magnitude of the effects of highway construction on the environment. Those problems that had been regarded as more or less a specialty for the agronomist, horticulturist, or landscape architect suddenly became the prime concern of highway management. These problems are complex in that they involve several diciplines and require cooperative efforts for their solution.

INVENTORY OF ROADSIDE EROSION

In-depth study is the first step in the solution of a problem. In 1969 Wisconsin issued to its citizens a report (4) that was a survey of accelerated soil erosion on state, county, and town roads and that had recorded all areas of 100 sq ft or more where there was a soil erosion problem. Briggs (4) stated that an average of one site for every 4 miles of roadside was found to need erosion control of some kind. There were 21,000 silt-producing sites found on 87,000 miles of roadway.

Statewide cooperation by a number of agencies was required for this effort. Data compiled from the field investigations revealed that 73 percent of the problem was on town roads, 24 percent on county roads, and 3 percent on state roads. This in itself is a reflection of the relative standard to which these various roads are constructed. Generally, town roads are on narrow rights-of-way with comparatively steep profile grades and steep slopes, and little consideration is given to vegetative erosion control practices. County roads are characterized by somewhat lower profile grades and flatter sideslopes. State roads are usually constructed on wider rights-of-way with easy profile grades and moderate sideslopes protected by adequate vegetative cover. These conditions are more or less proportional to the amount of traffic carried by the various classes of roads and the funds available for construction and are not peculiar to Wisconsin.

After this determination of the type and extent of the problem, responsible officials established policies and procedures for vegetating new highways and maintaining established roadsides. This program has also resulted in an action program, particularly on the town and county road systems, whereby equipment has been acquired for efficient seeding and mulching of newly constructed highways, and, above all, there has been public awareness of the problem and its solution.

EROSION CONTROL STRUCTURES

To be efficient and economical, erosion control must be designed into a project and not added cosmetically after construction. This involves a careful analysis of the many factors involved with rainfall, soil, and slope that have an effect on soil erosion. Barnes (2) points out that this must be brought to the attention of those responsible for project planning, design, and construction. "It must also be recognized that needed erosion control measures may significantly increase project costs."

Two of the principal factors that should be considered in corridor location are the soil characteristics and groundwater problems that may be encountered. A most helpful device that may be employed in this study is a county soil map compiled by the Soil Conservation Service. Thus, through the avoidance of highly erosive or otherwise undesirable soils that could adversely affect the proposed highway or by modification of the design to include necessary structures or other controls, soil losses may be held to a minimum during the construction phase of the work and until vegetative cover can be established.

There are a wide variety of structures that can be used to control surface runoff. Among these are diversions that are designed, graded channels constructed across a slope to intercept the water and lead it to an outlet where it can be safely discharged. Diversions may be placed above cut slopes to intercept overburden water, or they may be placed across a slope to reduce its length to nonerosive segments. Berms or benches may also be used on slopes in the same manner as diversions to reduce slope length and divide the runoff into easily handled volumes.

Waterways, either constructed or natural, are used for the disposal of water collected in diversions or berms. They should be lined with vegetation or paved and designed for flow velocities that the lining can safely carry. Pipe outlets may be required to remove water from diversions or berms. They should be designed for a 10-year, 24-hour storm, as a minimum.

Peak runoff may be temporarily stored by a retarding structure and released at a slow rate. Through the use of these structures, consisting of an earth embankment and spillways, runoff is released over a longer period of time and requires smaller waterways or culverts downstream.

Mechanical structures to retain, regulate, or control the flow of water may be required where grade, volume of water, or other factors preclude the use of more simple means. These may be drop spillways, drop inlet spillways, or chute spillways and are usually constructed of concrete, rock masonry, prefabricated metal, or wood. They may be designed for 10- or 25-year frequency storms, although more complex structures may be designed for greater frequencies. Where the flow in these structures is intermittent and the velocity can be kept below the critical level, sod chute spillways are useful for small drainage areas.

Debris basins are structures used to temporarily detain water carrying heavy silt, sand, or gravel. Reducing the velocity allows the load to be deposited in the basin and permits the water to flow away slowly. Debris basins may consist of an earth embankment with perforated pipe spillways, rock dams, or brush dams.

USE OF HERBACEOUS PLANTS FOR EROSION CONTROL ON ROADWAYS

In conjunction with the use of structures for the control of accelerated soil erosion, the importance of a good vegetative cover must not be minimized. Numerous references (3, 5, 6, 12, 15) emphasize the great importance of this cover as a controlling factor. In the nearly 40 years since its inception, the Soil Conservation Service (originally the Soil Erosion Service) has been involved in a national program of research and development of methods and practices for the protection and conservation of soil resources, including the establishment and maintenance of vegetative cover.

Turelle (17) has pointed out a number of legal subdivisions of government that work through the Soil Conservation Service to render assistance to numerous agencies, including highway departments, in the development of plans and procedures for the solution of erosion problems. In addition, its plant material centers and cooperating state experiment stations have developed and improved many plants for use as a more effective vegetative cover for the soil.

Highway designers may use the universal soil loss equation for predicting the magnitude of the erosion problem. This equation is based on rainfall intensity, erodibility of the soil, length and steepness of the slope, supporting conservation practices, and vegetative ground cover. Although originally developed for agricultural use, it has been modified for construction use by development of erodibility factors for subsoils and used to predict soil losses from a given site. Such predictions may influence the design of the facility or the treatment required for stabilization.

Important principles and criteria for establishing vegetation involve correction of soil deficiencies, if they exist; selection of an appropriate species for climate, site conditions, and purpose of planting; preparation of a stable seedbed; and proper seeding and mulching practices where required.

Although use of topsoil is expensive, it should be used when required and when the topsoil is readily available. The additional cost may be justified where highly adverse soil conditions are encountered.

Among the specific characteristics that should be considered in selecting plants for use as vegetative cover are areas of adaptation, growth habits, hardiness, tolerance to adverse conditions, seed properties, required maintenance, and aesthetic qualities. The use of native grasses for roadside stabilization is preferred because of their lower maintenance requirements, low fertilizer needs, competitive nature, and long life.

Numerous techniques are employed in the establishment of vegetative cover along roads. Among these are the use of seeds, planting stock, springs, and sod. Seed is the most widely used because of its low cost. The use of crowns or plugs is expensive but may be feasible for difficult sites. Sprigging is suitable for those grasses that produce stolons and is more prevalent in the establishment of warm-season grasses. Sod is used for either spot, strip, or solid sodding. Where it is necessary to have rapid establishment of cover, sodding is the best method to use, but it is also the most expensive. It is well adapted for use in waterways where erosion may damage unprotected soil.

Mulching is necessary to protect soil, seed, and fertilizer from erosion by wind and water. It stabilizes the microclimate and promotes seed germination and establishment by conserving soil moisture. To be effective, mulch should be anchored in place.

Once a vegetative cover is established on the highway, it must be maintained. This involves mowing, liming, fertilizing, weed and pest control, and repairs as necessary. It is usually less costly to carry on a maintenance program than to make repairs after neglect. Well-maintained plants usually have enough reserve to carry them through emergencies.

CHEMICAL SOIL STABILIZERS

The search for more and better soil stabilizing agents has been enhanced by the recent emphasis on environmental quality as it relates to air and water pollution. This is particularly true in the case of "in-construction" soil stabilization where the use of hay or straw mulch creates as many problems as it solves. Whereas numerous studies have reported the use of chemical soil stabilizers, one of the most comprehensive was conducted by Armbrust and Dickerson (1), who studied 34 materials from the chemical, animal, and petroleum industries for the control of wind erosion in Kansas. Six of the materials met the following criteria: cost less than $50 per acre, prevented erosion initially and reduced it for at least 2 months, did not reduce plant germination and growth, and could be applied easily. Additional studies are under way or have recently been completed by several state agricultural experiment stations and highway departments.

Plass's report (15) covers two series of studies on highly acid, steep slopes of infertile subsoil and parent material that is typical residue of surface mining operations. In the first series of plots a seed mixture of Kentucky 31 fescue, sericea lespedeza, Korean lespedeza, and sudum, a hybrid of sudan grass and sorghum, was applied to all plots along with ammonium nitrate and diammonium phosphate at rates of 85 lb of nitrogen and 50 lb of P_2O_5 per acre. There were 22 plots ¼ acre in size with a northern or western exposure; six plots were 1,000 sq ft in size with a western exposure.

Two mulches alone, three mulches in combination with chemicals, and nine chemical stabilizers were tested in 1971, and the report concludes with the following observations: "Mulches appeared to be more effective than soil stabilizers in aiding the establishment of the sudum hybrid.... some treatments improved the growth and vigor of the sudum hybrid. The excellent growth of the sudum hybrid on the untreated check plots indicates that a mulch or soil stabilizer is not necessary to establish a vegetative cover."

The 1972 series consisted of 19 treatments using 15 materials applied to a moderate slope having a southern exposure. Runoff sub-plots were superimposed on each plot and soil losses were collected. Interestingly, the author states that "many of the soil stabilizer manufacturers recognized the value of wood fiber as a mulch and included it as a part of their treatment."

He concludes that "Vegetation germinated and grew much more rapidly on plots treated with a mulch or a combination of soil stabilizer and wood fiber."

Also "Plots treated with soil stabilizers without wood fiber did not have so dense a cover, nor was the vegetation so tall as on the plots treated with mulch or a soil stabilizer with wood fiber."

Vegetative mulches, principally hay and straw, have been useful for many years for erosion control purposes, and, through experience, methods and procedures have been developed for their use. Such is not the case with these new chemical stabilizers, and much is yet to be learned about their use. Factors such as soil type and texture, soil moisture content, and rainfall following application appear to be significant factors as is the proper curing of the material to ensure proper aggregation of the soil particles. With the emphasis that is being placed on environmental quality and pollution control there can be no question that current materials will be adequately researched and development by industry will be producing newer and better materials for this purpose.

PROMISING MATERIALS AND METHODS FOR EROSION CONTROL

Another approach to the erosion control problem is presented by Peters, Rostler, and Vallerga (14), who describe laboratory and field work undertaken by the U.S. Air Force to prevent the types of erosion common on their worldwide installations. They observe that erosion forces are more severe on and around airfields than, for instance, in agricultural areas because, besides wind and rain, there are additional man-made forces such as downdrafts from helicopters, direct blasts from aircraft, fuel spillage, and vehicular traffic by a diversity of equipment.

The authors' purpose was to explore the available concepts and to recommend materials that can be used routinely and methodically for control of all types of erosion on Air Force installations. In addition, it was stipulated that the material to be used should be a liquid that combines with the surfaces to be treated, forming erosion-resistant surface layers to the depth likely to be disturbed; usable in spray applications; noncombustible; capable of being combined or fortified with other liquids to satisfy the widest possible requirements; commercially available at reasonable cost; and defined by characteristics determinable in standardized testing procedures suitable for acceptance and purchasing specifications.

Four commercially available products were used in this study. All four products, according to the authors, had the following characteristics:

1. A nearly equal emulsification system, cationic in nature, and very high stability,
2. A high-strength thermoplastic elastomer in a solvent, which is a good solvent for all ingredients contained in the oil phases of the four emulsions,
3. High mutual compatibility of all ingredients,
4. A distinguishing and identifying color for each of the emulsions,
5. Miscibility of the emulsions with each other and with water in all proportions, and
6. Ease of penetration into surfaces having measurable porosity to liquids.

These products can be used either by themselves or in combination and are also synergistic in action when used in the proper combinations. These materials may be used individually, consecutively, in blends, and in dilution with water in all proportions depending on the requirements of the problem.

One of the products was used successfully to stabilize soil on an atomic energy reservation at Richland, Washington, where work stoppages had been frequent due to dust storms. A blend of two of the products was applied to natural soil at Edwards Air Force Base, California, and after 3 years' exposure wind and rain have not disturbed the treated areas.

One of these products, which acts as a cementing agent, was applied to railroad ballast as a stabilizer. This treatment bound the loose ballast into a continuous structure that withstood tilting to approximately 45 deg without loss of material while the untreated ballast rolled off. A material having these cementing properties has a valuable place in the treatment of rock riprap on the facings of earth dams or in other areas where a coarse rock mulch is desirable but loose rocks might not be.

Another of the products is a rubberizing agent and has been used for sealing the surface of asphalt pavements.

Their report notes that one of the products is compatible with fertilizer and soil sterilants, but the authors do not clarify the effects, if any, on germination of seeds and establishment of plants. Research by Armbrust and Dickerson (1) reported that this material effected no significant reduction in germination and yield for both tomatoes and beans, but there still remain unanswered questions regarding grasses and legumes.

PENNDOT'S APPROACH TO EROSION CONTROL

Up to this point, this state-of-the-art review has been concerned with a look at the problem of accelerated soil erosion with a casual glance at peripheral areas of concern. Along with a determination of the problem, we have looked at methods and materials by which erosion may be held within tolerable limits. It is also common knowledge that highway departments have been engaged in erosion control work on new construction projects for many years. In past years this work was usually the last item to be performed on the new highway. Moreover, because of seasonal requirements, many highways have become seriously eroded before vegetative cover was ever planted, much less established. This situation can no longer be tolerated, and FHWA has issued an instructional memorandum to ensure prevention, control, and abatement of water pollution that results from soil erosion.

Huber (10) in his report on the current erosion control practices on Pennsylvania's highways lightly passes over the post-construction methods used in that state but emphasizes the steps being taken to reduce soil erosion and the consequent pollution of adjacent waters during the construction phase of highway operations. This problem, though serious in extent, has been passed off as just another one of the multitude of problems involved with grading work. It is difficult, if not impossible, to apply a monetary value to the losses to the state and the contractor or to assess the damage to adjacent lands due to the deposition of this material lost during the construction period. This is probably one of the principal reasons that so little attention has been paid to it. Huber sums up the benefits by stating, "If soil erosion can be kept to an acceptable minimum, it is possible to preserve our natural resources, reduce maintenance, reduce damage claims, and create better public relations."

With the advent of FHWA's memorandum, PennDOT adopted Section 212, on temporary control procedures, that is now a part of the construction specifications and is applicable to all projects let since October 1970, including those using 100 percent state funds.

Among the principal features of Section 212 are the following:

1. It requires coordination of temporary and permanent erosion control features;
2. It encourages designers to incorporate more erosion control items in the plans, thereby making these items biddable;
3. It includes the use of dikes along the top edge of fill slopes, dams placed downstream from the work to catch debris, sedimentation basins, slope drains, diversion and interceptor ditches, ditch lining materials such as sod or jute matting, early seeding and mulching, stage seeding and mulching on long cut or fill slopes, and causeways across streams where crossing is necessary; and
4. It requires the contractor to submit, prior to starting the work, a plan showing his proposed schedules and methods of operation.

Many successful examples of these practices now exist on projects built in the last two construction seasons. The PennDOT Bureau of Design is currently developing a series of standard drawings for the various erosion and pollution control devices, and these will become a part of the PennDOT standards used by all highway designers.

Huber also points out that research on pollution problems arising from highway construction is an important part of the program. Research is currently under way on a project that will evaluate various practices used during and after construction to reduce stream sedimentation. Another research project (18) sponsored by the U.S. Department of Transportation and PennDOT on the sediment load in streams was conducted by Bucknell University. A further project by PennDOT is investigating the effect of relocation on stream life and involves a complete study of the preconstruction ecology of a stream and the period of time required for ecological recovery following relocation.

Other proposed investigations involve the buildup of sodium and chloride ions in roadside soils as a result of de-icing operations and the relative effectiveness of chemical soil stabilizers.

Significantly, the author concludes with the following observation: "It is also important that a continuing search be made for new and improved methods of controlling erosion. Finally, for us to benefit fully from new developments on the state of the art, it is necessary to find means of effectively disseminating this information."

EFFECT OF HIGHWAY CONSTRUCTION ON SEDIMENT LOADS IN STREAMS

Highway construction has long been considered a major contributor to the sediment load of adjacent streams. Younkin (18) reports that few data are available that can establish the exclusive contributor of an area undergoing highway construction. The author points out the salient values of this study when he states that a method of predicting erosion "could be employed simply to determine whether highway construction would be a significant pollution source at a particular site, and, as such, it could be one of the criteria considered by an engineer during location studies. It would define the variation of sediment yield with the construction process, which would allow necessary abatement works to be phased with the construction rather than requiring completion of controls before construction could begin. Thus construction would not be delayed, and the result would be savings of time and money for the public. The predicted values would be useful as the required capacity in the design of desilting basins or sediment traps. It could also be employed as the basis for comparison to determine the effectiveness of attempts to control sediment yield from construction areas."

The research plan recognized three phases in the determination of suspended sediment yield of a stream due to rainfall:

1. The first phase involves detachment of the soil particles and their movement from the construction area. The ease of detachment is a function of the soil and its erodibility and the condition of the soil surface as related to its compaction, which, in turn, is related to the phase of construction and the intensity of construction activity. The transport of the particles is a function of slope length and gradient. Finally, the total yield is related to the area of soil exposed by construction.
2. The second phase, overland transport of the sediment from the construction area to the stream, is highly dependent on slope length, slope gradient, and natural ground surface between them. Antecedent moisture in the ground will affect the infiltration rate and consequently the quality of the sediment reaching the stream. The density and nature of the vegetation and surface debris are factors that tend to trap sediment before it reaches the stream.
3. The final phase is the stream transport process. This process is concerned with the ability of the stream to carry the sediment load it has received. The size and concentration of suspended material, channel cross section, and boundary roughness as well as channel slope are factors in this process.

The construction process was divided into clearing and grubbing, structures, embankment, drainage, and seeding and mulching phases. Clearing and grubbing began in June 1968, and the seeding and mulching were completed in August 1970.

Those factors the author considered to be significant in the development of the prediction equation are total rainfall energy, area of exposed surfaces, average depth of cuts and fills, and proximity of the area to the stream.

Through observation and study, the following basic equation was developed:

$$Q_s = \frac{K R^a (\log A)^b c^D}{P^d}$$

where Q_s is the suspended sediment yield in tons, a, b, c, and d are empirical constants, and K represents the soil erodibility factor. The factor R is the rainfall intensity, A is the area exposed to erosion, D is the height of cuts and fills, and P is the proximity factor.

A graphical multiple regression analysis was performed on 86 sets of data. The solution was transformed back to the equation, which yielded the following prediction equation:

$$Q_s = \frac{0.034 R^{1.5} (\log A)^{2.45} (3.0)^D}{P^{0.72}}$$

which was found to have a standard error of estimate of 24 percent.

The author's discussion of the results points out that the maximum rainfall intensity could be expected in approximately 2 years; the range of exposed area from 3.3 to 168.75 acres would appear adequate for most conditions; a height of cut and fill values of 0 to 3.2 yd, although representative of this project, might be exceeded on others; and the low proximity factor is indicative of the close location of the construction to the stream.

Of the four factors studied, rainfall had the greatest effect on the sediment yield. The depth of embankment indicates the potential erodibility available to the rainfall factor. Although the area exposed is most significant, the depth factor tends to modify this. Though these three factors indicate the potential for sediment leaving the construction area, this is reduced by the proximity factor, which has major influence on the quantity of sediment reaching the stream.

To extend this prediction equation to other areas will require that a soil erodibility factor for the particular soil encountered be developed. For this purpose the universal soil loss equation, as modified, offers a possible approach. Data from three other areas, currently under study in Pennsylvania, should permit evaluation of this factor. These data may also be used to evaluate the effect of slope gradient and the nature of the ground cover because these areas have terrain and land uses different from those of the White Deer Creek basin.

In conclusion Younkin (18) states: "An equation has been developed that may be employed to predict the suspended sediment load carried by a stream system during the period of rainfall-induced erosion of disturbed soils common to highway construction." This equation "considers the effect of the erosive power of the rainfall; the effect of the important construction phase parameters, area of exposed soil system, and average depth of embankment; and the effect of the proximity of the construction to the stream system."

IN SUMMARY—THE LOOK AHEAD

In perspective, the problem of accelerated soil erosion has been investigated to determine what the problem is; broad areas of control methods have been discussed; details of the measures employed by one state were enumerated; and an equation was reported by which the potential sediment load of a stream adjacent to a construction area may be predicted. What then are the next steps to be taken?

Several states have, to date, made surveys of the erosion control problem on their highways. This has been either a 100 percent survey as done in Wisconsin (4) or a percentage sample as done in Georgia (19). No matter what the method employed, the results should be as widely disseminated as possible and particularly to two groups, the officials responsible for the construction and maintenance of these roads and citizens interested in conservation and development of a quality environment. Through these two groups positive action may be introduced that will ensure the establishment and maintenance of the necessary erosion control measures.

The most fundamental erosion control measures on highways take place in the early design stages. On major highways this will be the corridor location phase, whereas on others it will be during the preliminary design phase. At this time there are two principal factors that must be considered. These are the geometric design of the roadway and a consideration of the soils involved.

Good geometric design of a highway dictates that the highway relate the construction elements with each other and with the topography. This requires the application of the principles of curvilinear horizontal alignment together with a gentle but topography-fitting vertical alignment. On multilane highways this may also dictate the use of independent horizontal and vertical alignments for each lane. Through the reduction of cut-and-fill slopes to the minimum commensurate with good design, the problem of slope stabilization is reduced. In addition, adequate right-of-way is necessary to permit the use of flatter slopes, which are easier to stabilize and maintain. Encroachment on the alteration of streams and natural waterways must be avoided if possible or provisions made for protection and restoration where required.

As an aid in corridor location studies, the universal soil loss equation (20), as modified for construction purposes, can be of value in avoiding soils that may be highly erosive and that require extensive erosion control structures or other treatments. If such soils cannot be avoided, the necessary erosion control features can be designed into the project; thereby needless delay and expense may be prevented. Although the Soil Conservation Service has used this equation for some time to predict soil losses on agricultural lands and to determine treatments that will hold these losses within tolerable limits, the modified form has only recently been developed, and its use is not widespread at this time. Additional research directed toward a wider scope and, undoubtedly, modification of the sediment prediction equation as proposed by Younkin (18) should be undertaken so that this additional approach may be used in these preliminary studies. With the current emphasis on environmental quality, the highway designer and builder will need every aid available to reduce and prevent soil losses by erosion and pollution of water by the sediment.

Erosion control is a problem that does not lend itself to one universal treatment. On highways it begins with the design, carries on through construction and post-construction phases, and finally becomes a function of maintenance. Years ago, most of the states adopted vegetative methods for stabilizing the primary highways after they were constructed, but only recently have they done anything about erosion control during actual construction. Here a whole new field opens up because many of the post-construction methods are not adapted to "in-construction" use. Huber (10) pointed out some of the practices now in use in Pennsylvania, and other states are developing methods adapted to their needs. Much stricter control must be exercised over the construction sequence, including limitations on the area that may be exposed to potential erosion at one time, completion of finishing operations, and installation of temporary or permanent erosion control measures.

The limitation on exposed soil may be a variable quantity, becoming smaller in periods when high-intensity rainfall may be expected and greater when normal rainfall is light. Then, too, definite criteria must be established for the use of mulch alone, mulch and temporary seeding, and mulch and permanent seeding. Structures such as diversions, silt or trash basins, paved or sodded waterways, and other erosion control devices should be shown on the construction plans and included in the contract quantities. It is here that the use of chemical soil stabilizers will probably be of greatest value. Materials that aggregate the surface to prevent particle dislodgment, that require no specialized equipment for application, that present no adverse effects on grading and compaction operations, and that are low in cost are needed right now. Along with other "in-construction" problems may be included the disposal of clearing and grubbing waste. One of the methods now in use is the chipping of this material and its use as a mulch. There is no denying the value of this material for mulching purposes, but there are economic and logistics problems that are in need of solution.

Plant materials that provide better vegetative cover are also needed. Here, again, several states (7, 8, 9, 11, 13, 16) have conducted research into both herbaceous and woody materials for this purpose. Many species have been found that offer good protection through better growth or increased survival on the so-called "hostile environment" of the roadsides. In addition, the Soil Conservation Service through its plant material centers has added to the fund of knowledge through the introduction and testing of new materials. There are, however, restrictions on the widespread use of many of these new materials because they thrive best in relatively limited geographical areas. Tree planting studies conducted in Pennsylvania during the past 10 years have shown wide variations in the rate of survival on a statewide basis. When these same data were studied on a major land resource area basis, which considers land use, elevation and topography, climate, soil, and water, an entirely different picture developed. Only three species of trees have had superior survival rates over the state, whereas three other species that have been widely planted in the past should be discontinued on highway planting except where most ideal environmental conditions exist and then only when proper maintenance will be available. Much more work remains to be done on herbaceous and woody plant materials for highway use.

There are also two other limitations that have an effect on the research, development, and use of new methods and materials. Perhaps the greatest of these is an adequate source of supply. Frequently, a promising plant may be difficult to propagate or harvest which makes it economically unattractive to a producer. Some of the native prairie grasses are limited in use for these reasons. Woody plant materials that are used primarily for erosion control usually do not appeal to the nurserymen because of a relatively small and frequently uncertain market. Their production is planned several years in advance of harvest, and they cannot commit the resources of land and funds that are required. Zak et al. (21) have conducted extensive work in Massachusetts over the past 10 years under contractual relations with the Massachusetts Department of Public Works and the FHWA. They have undertaken work in the fields of plant breeding, plant propagation, planting techniques, fertilizer use, and mulching studies. Their work has indicated approaches to supply problems and survival through the use of direct seeding of woody materials, the use of root cuttings, and the planting of container-grown plants.

The development of improved strains of grasses is often based on a selection process rather than breeding. Many plants, including grasses, are heterozygous in nature meaning that they normally develop many differing forms, and, through observation, the more desirable forms are selected and propagated. Merion, delta, and several other improved Kentucky bluegrass selections fall into this category. However, breeding is not overlooked, and many researchers are engaged in this work. Due to the length of time required for investigation and evaluation, most of it is done by university agricultural research stations. Additional funding of this work will be an excellent investment because we need plants with greater tolerance to atmospheric, soil, and water pollutants, a wider adaptability to soil and other environmental conditions, less maintenance, and more effective soil stabilization and that also present a pleasing and attractive appearance.

Therefore, the conclusion may be drawn that the control of accelerated soil erosion is everybody's job. It involves not only the plant and soil scientist but also the engineer, the chemist, the journalist, and, above all, the general public. None of these disciplines can accomplish the task alone, and combined they still need the interest and support of everyone.

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