NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **18**

# EROSION CONTROL ON HIGHWAY CONSTRUCTION



HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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# EROSION CONTROL ON HIGHWAY CONSTRUCTION

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
- HIGHWAY DESIGN
- HIGHWAY DRAINAGE
- ROADSIDE DEVELOPMENT
- CONSTRUCTION
- MECHANICS (EARTH MASS)

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING 1973

## NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectvity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

**NCHRP Synthesis 18**
Project 20-5 FY '72
ISBN 0-309-02131-6
L. C. Card No. 73-83749

**Price: $4.00**

This report is one of a series of reports issued from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the Federal Highway Administration. Individual fiscal agreements are executed annually by the Academy-Research Council, the Federal Highway Administration, and participating state highway departments, members of the American Association of State Highway Officials.

The study reported herein was undertaken under the aegis of the National Academy of Sciences—National Research Council. The National Cooperative Highway Research Program, under which this study was made, is conducted by the Highway Research Board with the express approval of the Governing Board of the NRC. Such approval indicated that the Board considered that the problems studied in this program are of national significance; that solution of the problems requires scientific or technical competence, and that the resources of NRC are particularly suitable for the oversight of these studies. The institutional responsibilities of the NRC are discharged in the following manner: each specific problem, before it is accepted for study in the program, is approved as appropriate for the NRC by the NCHRP Program Advisory Committee and the Chairman of the Division of Engineering of the National Research Council.

Topics for synthesis are selected and defined by an advisory committee that monitors the work and reviews the final report. Members of the advisory committees are appointed by the Chairman of the Division of Engineering of the National Research Council. They are selected for their individual scholarly competence and judgment, with due consideration for the balance and breadth of disciplines. Responsibility for the definition of this study and for the publication of this report rests with the advisory committee.

Although reports in this category are not submitted for approval to the Academy membership nor to the Council, each report is reviewed and processed according to procedures established and monitored by the Academy's Report Review Committee. Such reviews are intended to determine *inter alia,* whether the major questions and relevant points of view have been addressed, and whether the reported findings, conclusions and recommendations arose from the available data and information. Distribution of the report is permitted only after satisfactory completion of this review process.

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**NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM**

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National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

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## PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Highway Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices without in fact making specific recommendations as would be found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available concerning those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

# FOREWORD

*By Staff*
*Highway Research Board*

This report should be of special interest to highway engineers responsible for soils, landscaping, materials testing and specifications, maintenance, and construction. The report contains information on construction activities subject to high erosion risks, on factors affecting erosion and sediment production, and on prevention techniques.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information is often fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem is frequently not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to resolve this situation, a continuing NCHRP Project, carried out by the Highway Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems—synthesis being defined as a composition or combination of separate parts or elements so as to form a whole greater than the sum of the separate parts. Reports from this endeavor constitute a special NCHRP Report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems. This is the eighteenth report in the series.

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As a result of the public concern for the quality of the environment, as manifested by the National Environmental Policy Act of 1969, much attention has been directed to the control of soil erosion and sedimentation of streams on highway construction projects by both the federal and state governments. Highway construction operations that may contribute to erosion are clearing and grubbing, construction of haul roads, earth moving and grading, ditch construction, and foundation excavation and channel changes at stream crossings. Curtailment of construction for the winter months without adequate provision for controlling erosion can result in severe erosion and sedimentation damage.

This report of the Highway Research Board provides information on design procedures to minimize erosion, construction practices to control erosion, beneficial landscaping procedures, and maintenance practices to sustain erosion control installations. More specifically, the report provides information on practices on: (a) seeding, planting and mulching; (b) design of sediment basins and traps; (c) slope protection; and (d) berms.

To develop this synthesis in a comprehensive manner and to insure inclusion of significant knowledge, the Board analyzed available information (e.g., current practices, manuals, and research recommendations) assembled from many highway departments and agencies responsible for highway planning, design, construction, and maintenance. A topic advisory panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data and for reviewing the final synthesis report.

As a follow up, the Board will attempt to evaluate the effectiveness of this synthesis after it has been in the hands of its users for a period of time. Meanwhile the search for better methods is a continuing activity and should not be diminished. An updating of this document is ultimately intended so as to reflect improvements that may be discovered through research or practice.

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**ACKNOWLEDGMENTS**

This synthesis was completed by the Highway Research Board under the supervision of Paul E. Irick, Assistant Director for Special Projects. The Principal Investigators responsible for conduct of the synthesis were Thomas L. Copas and Herbert A. Pennock, Special Projects Engineers.

Special appreciation is expressed to Robert B. Thornton, Ithaca, New York, who, as special consultant to the Advisory Panel, was responsible for the collection of data and the preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Advisory Panel, consisting of Charles R. Anderson, Chief, Bureau of Landscape Architecture, Maryland State Highway Administration; Harold D. Dolling, Chief Landscape Architect, Roadside Development Section, Iowa State Highway Commission; Wesley L. Hottenstein, Landscape Architect, Chief, Esthetics and Ecology Group, Federal Highway Administration; Charles C. Johnson, Highway Engineer, Specifications Branch, Construction and Maintenance Division, Office of Highway Operations, Federal Highway Administration; William O. Ree, Research Leader, Agricultural Research Service, U.S. Department of Agriculture; Robert D. Schmidt, Engineer of Construction, Illinois Department of Transportation; and William P. Somers, Chief Hydrologist, Office of Water Programs, Environmental Protection Agency.

W. G. Gunderman, Engineer of Materials and Construction, and L. F. Spaine, Engineer of Design, both of the Highway Research Board, assisted the Special Projects staff and the Advisory Panel.

Information on current practice and ongoing research was provided by many highway agencies. Their cooperation and assistance were most helpful.

# EROSION CONTROL ON HIGHWAY CONSTRUCTION


## SUMMARY

Much attention has been directed to the control of erosion and sedimentation by both federal and state governments. As a result, highway construction specifications have been revised to include protective measures for land and water. Additional items of work have been included in project plans and new construction techniques have been developed to minimize erosion and prevent sediment damage. However, erosion and the resulting sedimentation from highway construction continue to be a problem.

Construction activities that are subject to high erosion risks include right-of-way clearing, earthwork, ditch construction, haul roads, culvert installation, channel changes, pier or abutment work in streams, temporary stream crossings, borrow pit operation, and hydraulic or mechanical dredging.

Factors in addition to exposed area that affect erosion and sediment production are: rainfall intensity, slope, soil type, rate of runoff, and depth and velocity of runoff.

Erosion potential must be assessed during the route study and location phases. Soil types, anticipated cuts and embankments, grades, proximity to critical areas, and channel change requirements should be studied and costs estimated if special protection is necessary.

Sediment traps, settling basins, stage seeding and mulching, temporary slope drains, special berms, terraces, ditches and dikes, temporary seeding, sodding, contouring, benching, serrated slopes, and erosion control mesh are placed in the construction contract by the engineer. When necessary, special provisions may restrict or control the contractor's schedule for construction. Additional right-of-way or specific easements are provided for erosion control or sediment collection efforts. Special attention may be directed to the timely paving of ditches, placing of riprap, or other permanent erosion control measures. It has been accepted practice to maintain smooth slopes on embankments and to prohibit any standing water in construction projects. These practices are no longer valid. Rough slopes hold water, seed, and mulch.

There has been much improvement during the past few years in the efforts to limit erosion and contain sediment on construction projects. Further improvements can be obtained through increased emphasis on education for construction forces in erosion control techniques. This applies equally to the agency inspection and the contractor's supervisory personnel. Effectiveness of the erosion control effort is in a large sense dependent on the ability of the construction forces to carry out the contract provisions and to anticipate the need for supplemental work.

Additional information is needed on where, and what size, sediment traps and basins are required. The information compiled by the Soil Conservation Service should be made more usable for the design and construction engineer. Protective sprays or treatments that appear on the market from time to time need to be evaluated. Specific research is warranted to develop design and construction criteria for the management of storm water on construction projects.

CHAPTER ONE

# INTRODUCTION

## IDENTIFICATON OF PROBLEM

It is almost axiomatic that highway construction causes soil erosion, erosion causes pollution, pollution causes degradation of the environment. A highway project with an average right-of-way width of 100 ft (30 m) could contribute up to 15,000 tons per mile (8,500 kg/m) if no effort were taken to minimize the problem (Fig. 1).

Rightly or wrongly, highway construction activities receive heavy public criticism, often being cited as prime contributors to stream turbidity, spoiled fishing, clogged channels, impairment of water supplies, and deposition of erosional debris on adjacent private properties. Erosion and sedimentation do occur during construction, but examination of hundreds of miles of finished highways will attest to the attention given and action taken by highway agencies to revegetate construction sites and to control erosion. Increasing public attention requires that erosion control during and immediately after construction will get additional attention.

Even the best of erosion control efforts often are compromises among the best known practices. Frequently, the basic information needed for specific solutions is lacking altogether or needs modification to meet the erosion control requirements of highway construction.

Resistance by contractors or highway officials may have delayed the adoption and use of improved erosion control measures. Unfamiliarity with new erosion control practices and techniques slows their acceptance, indicating a need for continuous training throughout the highway industry. Administrative support is needed for intra- and interagency exchange of information on erosion control and sediment collection.

General awareness of ecologic values is increasing. Destroyed plant communities, dead streams, and upset fish and wildlife habitats are tied in part to excessive erosion, heavy sedimentation, and the resulting pollutants.

Public pressures and concerned administrators demand immediate and continuing control. Some added costs will be encountered; however, these usually can be justified against the benefits derived to the construction project and the adjacent properties.

## PAST AND PRESENT CONCERN

The policy on erosion control for highway agencies has been stated (*1*) as follows:

> Erosion prevention is one of the major factors in the design, construction, and maintenance of highways. Erosion can be controlled to a considerable degree by geometric design, particularly that relating to the cross section. In some respects the control is directly associated with proper provisions for drainage and fitting landscape development. Effect on erosion should be considered in the location and design stages.

Today's review (1972) of the 50 state specifications for highway construction reveals 15 with the term "Erosion or Erosion Control" in their index. Many of the other agencies have published special provisions or specification changes reflecting their recent concern with erosion on construction. It was not until the mid- and late 1960's that erosion control was elevated to a position of major concern. Increased attention is being given to the *prevention of erosion* and its related effects.

*Executive Order 11258* (dated November 17, 1965), re prevention, control, and abatement of water pollution, brought forth numerous memoranda from the Federal Highway Administration (FHWA). These clarify the impact on direct federal and federal-aid highway projects and formulate guidelines for inclusion in construction contracts involving federal funds.

*Instructional Memorandum* (IM) *20-3-66* interpreted Executive Order 11258 for federally supported highway activities, reiterated conservation and protective policies, and required plans and specifications to contain provisions that would keep pollution of all waters by highway construction to a minimum. It also required consideration of erosion, sedimentation, and pollution as part of the engineering analysis leading to selection of a highway location.

*IM 20-6-67* required highway agencies to apply the guidelines developed by the Secretary of Transportation and Secretary of Agriculture for minimizing soil erosion from highway construction. A copy of the guidelines was attached to the IM. The guidelines were drawn in compliance with the Federal-Aid Highway Act of 1966 and were submitted to Congress on June 28, 1967. The Federal-Aid Highway Act of 1970 directed the Secretary of Transportation to issue the guidelines and requires their application on all projects.

*IM 20-1-68* included a special provision on minimizing erosion and preventing siltation to be used with the "Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects," FP-61. [The wording of this special provision was substantially incorporated into the revised "Standard Specifications . . .," FP-69.]

*Policy and Procedures Memorandum* (PPM) *20-8* (Jan. 14, 1969) required that conservation, including erosion, sedimentation, wildlife, and general ecology, be studied as one of the factors in determining the effect of highway location and design on "social, economic, and environmental effects."

*IM 20-3-70* sets forth provisions for temporary project water pollution control aimed at minimizing soil erosion during construction. These provisions were further explained in a Circular Memorandum dated June 25, 1970.

The National Environmental Policy Act of 1969 (PL-91-190) and other acts directed to environmental considerations also have had an impact on highway design and construction. These legislative effects were summarized in an *NCHRP Research Results Digest* (*2*).

A review of the legal principles governing drainage and waters as they apply to highway construction and maintenance may be found in *Highway Research Record No. 78* (*3*). There is general acceptance by highway agencies of the common law that when damage is acknowledged it will be paid for or repairs will be made.

In some cases, additional restrictions have been imposed on state highway agencies by county or local ordinances when they are more stringent than federal or state regulations.

A bill (H.R. 12444) was introduced in 1972 in the House of Representatives "To authorize federal standards for the prevention of siltation and the control of erosion on certain federal and federally assisted construction projects." The standards would be issued by the Environmental Protection Agency. It is likely that this bill and/or others will be introduced in 1973.

## OPERATIONS CONTRIBUTING TO THE EROSION PROBLEM

Highway construction operations that contribute to erosion are clearing and grubbing, construction of haul roads, earth moving and grading, ditch construction, and foundation excavation and channel changes at stream crossings. Particularly bad are equipment tracks running up slopes, which quickly erode into deep rills or gullies. Stream crossings with equipment frequently add to sediment development and increased turbidity and sometimes cause washouts of the disturbed stream bed during flash floods. Borrow pits left bare during and after construction without consideration to drainage or reseeding pass sediment into adjacent streams. Reshaping and revegetation of erodible borrow pit slopes and waste areas in many cases has received too little consideration.

Cuts and fills, with their exposure of bare ground, must be accepted as a part of normal highway construction. However, the time interval from the start of earthwork to finished grade to revegetation is a big factor in erosion and sediment production. There have been uncoordinated split contracts that left earthwork bare up to two years. This results in heavy erosion losses that often require reworking before final construction operations can commence.

Curtailment of construction for the winter months without prior installation of adequate provisions for controlling erosion can result in severe erosion and sedimentation damage.

Release of groundwater flows from water-bearing lenses or wet-weather streams in the soil strata contributes to the amount of sloughing and slippage.

Construction often causes blockage and other radical changes in the natural drainage patterns, resulting in flow concentrations and velocities that erode formerly stable areas.

*Figure 1. Erosion and sediment damage on highway right-of-way.*

Culverts concentrate flows and create high velocities. This erodes stream beds, creates washouts, and undermines the outlet ends of culverts. This often is a major erosion control problem both during and after construction.

Highway encroachment of streams, as well as stream widening, deepening, realignment, and bank clearing or smoothing, change the hydraulic characteristics of the streams, increasing or decreasing velocities, creating bottom scour with subsequent deposition in the form of sediment and sand bars, which again encourage meandering and bank cutting and additional problems at a new location.

Placement of bridge piers and abutments at stream crossings may change flow characteristics of the stream, causing bed or bank erosion that produces sediment.

Hydraulic dredging without measures to precipitate sediment can increase turbidity manyfold for miles downstream (*4*). Gravel and fill removal from stream banks or beds without protective barriers can affect the stream sediment load and increase turbidity.

## FACTORS AFFECTING EROSION AND SILTATION

In moving over unprotected soil water detaches and carries away soil particles either in suspension or by rolling them along the soil's surface. Impact of falling rain can also detach soil particles and add them to the load. Land laid bare by cultivation or excavation is particularly susceptible to this action.

The extent of the erosion damage will depend on the rate and quantity of runoff, the depth and velocity the runoff attains, and the resistivity of the soil surface to soil particle detachment. Each of these three principal factors—runoff, runoff depth and velocity, and soil surface—is examined in the following.

The *rate of runoff* (that is, the volume or quantity of water per unit of time) as contrasted to speed of flow passing a given point on the land surface is a function of the intensity of the rain, the ability of the land surface to soak up the rain, and the size and nature of the upstream drainage area. No control, of course, can be exerted over the intensity of the rain. However, a knowledge of the intensity of past rains and their frequency is required for probability predictions for future events.

The rate of infiltration can be controlled to some extent by preventing sealing of the soil surface and maintaining infiltration capacity. This is desirable practice in agriculture, but it may not be practical during highway construction. Excessive infiltration delays resumption of grading activities and also can make cut and bank slopes unstable. So the highway engineer is faced with a dilemma so far as infiltration is concerned. He wishes to be quickly rid of the rainwater, and this requires low insoak rates. Yet, at the same time he wants to avoid erosion and to prevent off-site sediment damages caused by construction activities, and this requires high insoak rates. Probably, no practical control can be exerted over infiltration rates and insoak during highway construction. After protective plantings are in place, however, high insoak rates are definitely desired to assure the vegetation of the water needed for survival and growth.

The size of the drainage area can be controlled by the use of barriers or diversions. Also, high runoff production can be limited by keeping the disturbed areas to a minimum. The nature of the drainage area includes its slope, topography, and soil. Slope and topography of highway cuts, embankments, and drainage ways can be controlled by design. However, there are conflicts here, too. When slopes are made gentle to reduce flow velocity, they become long and the accumulation of rainwater is increased. The type or classification of soil governs runoff rate by its influence on infiltration rates. Often, the exposed soils of heavy construction sites are clays having low infiltration rates and high runoff rates.

The *depth and velocity of the runoff* that cause soil detachment and removal are a function of the rate of runoff, the steepness of the slope, and the roughness of the surface. The velocity of runoff is a function of the square root of the slope. The force exerted by the flow on the stream bed is directly proportional to the slope of the stream and the depth of the flow. The rate of removal and transport of soil particles is dependent on depth and speed of the runoff.

The resistance of the *soil surface* to particle detachment is governed by the texture (particle size); the proportions of sand, silt, and clay; and by the stability of the soil aggregates. Soils with high percentages of sand tend to be noncohesive and are readily eroded. Those with high clay percentages are cohesive and resist soil particle detachment. However, when detached, clay particles are readily washed away because of their small size.

Limited research data indicate that from 10 to 70 percent of total soil displaced by erosion is carried off the site as sediment and deposited elsewhere. The remaining material is redeposited on the site. The amount varies with the size of the drainage area, and the topographic and soil characteristics.

The stability of a stream is often precarious at best. Its banks are attacked by flow currents, ice flows, freezing and thawing, and burrowing animals. A stream achieves a measure of stability against these forces by adapting its cross section and grade to the water and sediment flows it must convey, and receives protection from vegetation on its banks. This uneasy equilibrium can easily be upset. Changes in flow and sediment volumes will cause a change in cross section and grade. Removal of bank vegetation can start rapid bank erosion. Channel blockage by debris (trees, junk, temporary construction) can change flow direction and start bank undercutting. Changes of channel alignment, particularly straightening, can increase grades and thereby flow velocity and erosion.

Wind erosion is most common in arid and semi-arid regions, but can occur in any region during construction. When wind velocities reach 8 to 9 mph (12.9-14.5 km/hr) 6 in. (150 mm) above dry bare ground, the soil particles start to move. The fine, light silt and clay particles are picked up and blown away as dust. The heavier sand particles rarely become airborne, but move in a series of short leaps (called saltation). The coarse, droughty, sandy, infertile residue left presents very difficult revegetation problems and is highly erodible when intense rains occur.

Considering total acreage, areas outside the highway right-of-way may be the major wind erosion sources. To control them may require a joint effort with adjacent landowners, community groups and conservation agencies. Mechanical and/or vegetative measures are employed to lower ground-level velocities, thus minimizing wind erosion and controlling deposition.

CHAPTER TWO

# LOCATION AND DESIGN

## LOCATION

### System Considerations

Highway route location studies should be concerned with much more than the shortest distance between two points, the amount of cut and fill, or the load-bearing properties of the roadbed foundation. Lately, investigation of the erosion potential of the various soils that are to be disturbed is often required or given consideration during the location stage. However, the advantages and disadvantages of any particular route because of soil erosion projections are weighed against all of the other engineering, social, economic, and environmental considerations, such as right-of-way cost, safety, grades, drainage, access, noise, and alignment. These considerations usually take precedence over erosion control recommendations during the location study; however, there have been cases where probable erosion damage to valuable private or public property near a proposed route has warranted alignment shifts. It is also common practice during the location stage to develop the initial estimate for the cost of providing acceptable erosion and sedimentation control.

The type of system and the geographic area are also factors that affect selection of a specific route location. Special attention should be given to streams and drainage channels. Rural, secondary, forest, and park roads can accept lesser alignment and grade requirements than segments of the primary, Interstate, and other high-capacity systems. Rural and urban requirements also differ in the amount of wind and water erosion that is acceptable.

### Erosion Potential

Aerial photography is widely used in the selection of the final route to minimize topographic damage. Subsurface surveys and surface soil surveys are studied with respect to geologic formations, streams, drainage channels, strata tilt, slippage, limestone caves, mining tunnels, soft soil pockets, and other unique soil characteristics. Studies include soil depth and characteristics that affect erodibility, including ease or difficulty in accomplishing revegetation. Existing vegetation on the contributing watersheds is evaluated to assess storm drainage yield and disposal. Climate, particularly rain, snow, ice, or wind, can affect location regarding slope aspect and the revegetation.

During the location stage, most highway agencies are giving some attention to the damage potential to area streams, public water supplies, flood control structures, irrigation systems, recreational waters, and adjacent agriculture lands. Some agencies now require a complete sedimentation plan for each project. However, the importance of identifying the need for additional right-of-way for sedimentation traps, diversion channels, and other preventative measures is not always recognized during the location stage.

Route location choices that relate directly to the control of erosion on construction include (a) distance from or proximity to critical areas and/or structures, (b) roadway grades, (c) side slopes, (d) depth of cut, (e) weight of fill, (f) streams and drainage channels, (g) channel changes, and (h) relationship of topography to alignment.

## DESIGN

There are some designers who recognize that design considerations for erosion control on construction should start with the location study. However, in many cases the first serious consideration of this problem takes place during design, and often without full benefit of the data accumulated during the location study. Information that usually is available to the highway designer is reviewed in the following. Appendix C provides design check sheets. A complete erosion and sediment control plan often is prepared by the design section.

### Soils

Information is available to the designer from soils data collected during route explorations, previous experience with similar soils, geologic soil maps, and standard soil maps prepared by the U.S. Soil Conservation Service (SCS). The analysis of the soil includes erodibility and ease or difficulty of reestablishing vegetation, in addition to soils engineering data.

#### *Erodibility*

Soil losses from highway construction sites can be estimated with the Universal Soil Loss Equation developed by the SCS from controlled research studies of erosion losses on agricultural areas, including limited measurements from housing developments, commercial sites, and highway construction areas:

$$A = R\,K\,L\,S \qquad 1(a)$$

or

$$= \mathrm{EI}\,K\,L\,S \qquad 1(b)$$

in which

$A$ = the computed soil loss per acre, in tons;
$R$ = the average annual rainfall erosion index;
EI = the rainfall erosion index for a part of a year;
$K$ = the soil erodibility factor;
$L$ = slope length factor; and
$S$ = slope-gradient factor.

Lists of $K$ factors for B and C horizons have been tabulated (*5*). *L* and *S* have been computed into one combined value known as the *LS* value (*5*).

The predicted soil losses with their attendant sediment loads should influence the degree of planning and indicate the intensity of treatments required for proper control of erosion and sediment. The equation is amenable to predicting for a whole year, a part of the year, or for single storms of assumed magnitude. It is used to compute the soil loss from sheet erosion in tons per acre, but can be converted into cubic yards. Rill and gully erosion losses must be computed separately. The parameters involved are rainfall intensity, soil erodibility factors, slope length, and slope gradient.

The necessary data for the major soils groups of the 15 Northeast states from Maine to Virginia, and west to Kentucky and Ohio have been published (*5*). These generalized data are being refined and published on state and county levels. Similar data are being developed for the other states east of the Mississippi River. The *K* factor (erodibility) is being refined as additional research data become available.

Wischmeier et al. (*6*) report as follows:

> A new soil particle-size parameter was found and used to derive a convenient erodibility equation that is valid for exposed subsoils as well as farmland. A simple nomograph provides quick solutions to the equation. Only five soil parameters need to be known: percent silt, percent sand, organic matter content, structure, and permeability. The new working tool opens the door to several new considerations in sediment-control planning.

The nomograph discussed and a comparison of the *K* values are shown in Figures 2 and 3, respectively.

Modifications and refinements are also being undertaken by some state highway soils engineers to blend erosion factors more closely with construction sequences.

### *Soil and Vegetation*

A good understanding of the basic functions of soils is important to revegetation programs. The chemical and physical qualities of soils determine their ability to support plant growth; the *depth* of soil determines how far plant roots can penetrate; the *texture*, how much water can be stored for plant use. The *structure* of soil determines resistance to erosion and rate of water intake.

Because soil texture dictates most vegetative and management practices, it is important to consider textures and their influences (Fig. 4). Various soil layers, depth, and texture changes can be observed on freshly cut banks and ditches during construction. Excessive sand in soils may prevent retention of moisture and fertilizers. Soils with high clay contents may absorb and hold too much moisture. They are inclined to become plastic and can curtail construction operations or delay seed bed preparation until they dry out. Excessive silt (40 percent or more) in a soil causes poor internal drainage, shallow root penetration, and high erodibility.

*Structure* is the term used to describe the grouping of soil particles into crumbs or granules. Organic matter and colloidal clay particles are involved. Structure affects the ease with which plant roots can penetrate the soil, the amount of air present, the rate of water intake and movement through the soil, nutrient release, and resistance to wind and water erosion. Little can be done to change colloidal clay content, but good tillage practices, mulches, and organic additives can improve soil structure.

*Compaction* is the loss of pore space, particularly in heavy soil types. Such soils, when wet, develop impervious layers, retard water movement into the soil, increase runoff, or create surface sealing and crusting. Where compaction has become severe, plowing or ripping is required prior to seeding.

*Infiltration* refers to water intake at the soil surface, whereas *percolation* refers to the movement of water through the soil mass, each affecting erodibility.

All soils reflect their *parent material.* Some parent materials are rich in nutrients and minerals, others, such as quartz, are poor in all plant nutrients. In humid regions, many soils have lost much of their available nutrients through leaching. In arid regions, mineral salts have accumulated to the extent that deliberate leaching is required before vegetation can be established. In areas where saline and alkaline soils are encountered, chemical analyses are used to measure and identify salt content. If irrigation is employed, irrigation waters must also be analyzed lest they add to the problem.

### *Soil Surveys*

Standard soil surveys published by the SCS in cooperation with the state Agricultural Research Stations classify, name, and delineate on maps each kind of soil. Many include valuable qualitative information for engineers and contractors. In some states, highway soils engineers are feeding back route study data to the SCS for inclusion in the survey reports.

Several highway agencies are using the SCS soil maps to assess the erosion potential for each alignment possibility. Although some of the SCS maps only have agriculture information, others contain engineering data on the surface and subsurface strata.

Descriptions of soil series are available from the SCS Regional Technical Service Centers. Accompanying each description are soil survey interpretations. Of particular interest to engineers is the section headed "Degree of Limitations and Major Soil Features Affecting Selected Use." The soil erodibility factor is also indicated. If he knows the soil series encountered in his route survey, the highway engineer can request the description sheets for the particular soil series encountered. Appendix E gives the location of SCS field offices.

## Climate

### *Plant Response*

The climate of an area largely determines the kinds of plants that can be grown. Wind, soil, rainfall distribution, sunshine, cloudiness, and humidity of the air interact to affect evaporation and transpiration rates and available water for plants. Temperature extremes affect development and survival. Neither average temperature nor total rainfall can assure successful plant performance.

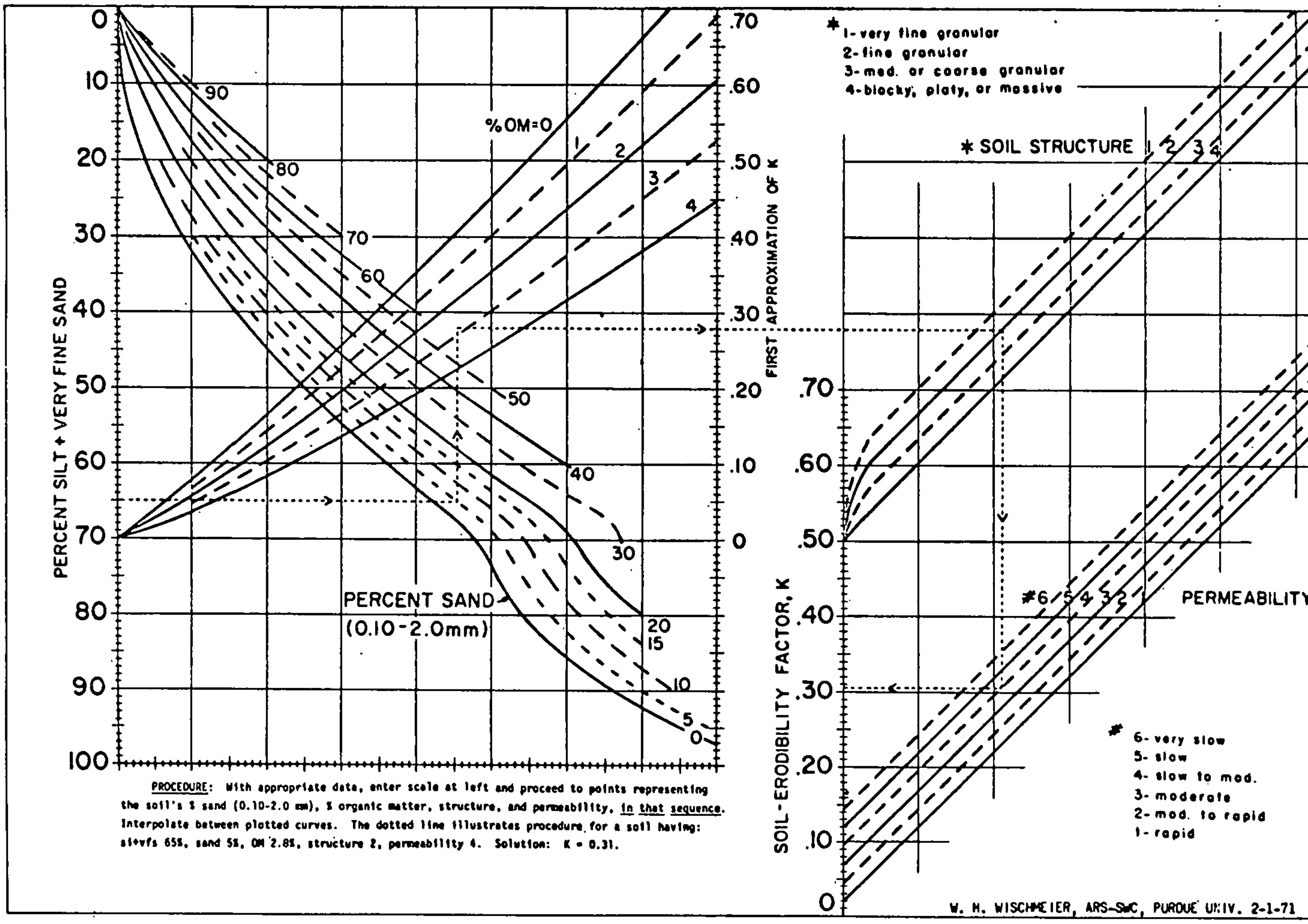
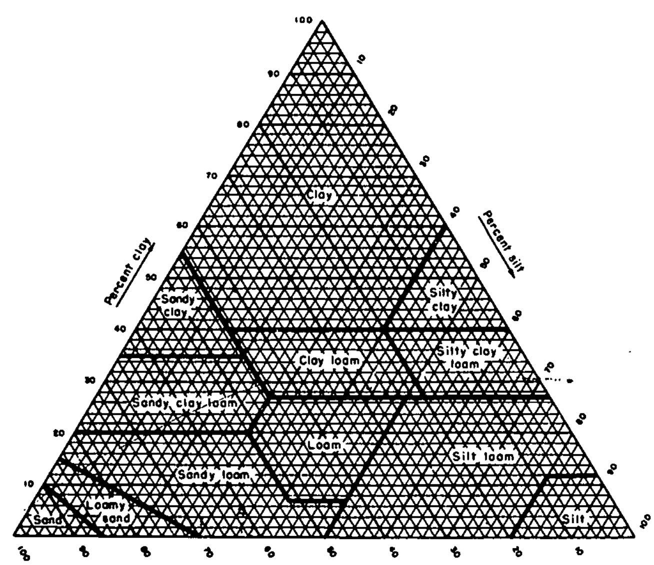



*Figure 2. Soil erodibility nomograph.*

| Soils | Predicted K Values | Established K Values |
|---|---|---|
| Austin c. Temple, Tex. | 0.28 | 0.29 |
| Caribou g l, Presque Is., Maine | 0.27 | 0.28 |
| Cecil s l, Statesville, N. C. | 0.28 | 0.28 |
| Fayette si l, LaCrosse, Wis. | 0.42 | 0.38 |
| Keene si l, Zanesville, Ohio | 0.46 | 0.48 |
| Lexington si l, Holly Springs, Miss. | 0.45 | 0.45 |
| Loring si l, Holly Springs, Miss. | 0.49 | 0.51 |
| Mansic c l, Hays, Kans. | 0.33 | 0.32 |
| Marshall si c l, Clarinda, Iowa | 0.32 | 0.33 |
| Mexico si l, McCredie, Mo. | 0.33 | 0.32 |
| Shelby l, Bethany, Mo. | 0.39 | 0.41 |
| Tifton l s, Tifton, Ga. | 0.09 | 0.10 |
| Zaneis f s l, Guthrie, Okla. | 0.26 | 0.22 |

*Figure 3. Comparison of predicted K values with established K values for benchmark soils.*




PERCENTAGES OF CLAY (BELOW 0.002 mm.), SILT (0.002 TO 0.05 mm.), AND SAND (0.05 TO 2.0 mm.) IN THE BASIC SOIL TEXTURAL CLASSES

*Figure 4. Composition triangle of the basic soil textural classes (U.S. Soil Conservation Service).*

Temperature ranges limit the distribution of plants and partially account for the flora of different regions. High temperatures can be lethal to seedlings during the establishment stage and may be harmful to mature plants. Low temperatures weed out those not having a mechanism for dormancy. Rates of water withdrawal from the soil are modified by transpiration and related climatic factors. Revegetation efforts must be coupled with knowledge of the season of major precipitation. Midsummer rains may dictate selection of warm-season plants; late fall and winter rains, selection of cool-season plants. Areas receiving high precipitation intensities can have severe drought conditions if they have high runoff rates. Freezing and thawing have their effects on the persistence of vegetative cover; frequent cycles can create severe heaving and root breakage, whereas deep freezing and snow cover can actually protect vegetative covers.

Use of adapted native species and proven exotics, such as crown vetch, lovegrass, smooth bromegrass, and Bahia grass, assures long-time protective cover with a minimum of maintenance. This practice has progressed furthest in the Great Plains and Pacific West.

### *Effects on Soil*

Rainfall is dominant among the climatic factors. Where it is adequate, and when it is accompanied by moderate temperatures, vegetation growth is abundant and humus, the organic residue, accumulates. Where high temperatures prevail, the organic material decays rapidly and soil organic matter is low. High annual rainfall infiltrating the soil leaches nutrients; conversely, low annual rainfall permits salts to be brought to the surface by capillary action and the evapotranspiration process. High-intensity storms erode the land where vegetation is sparse or lacking. The floods that follow deposit the erosion products and cause changes in the stream channel. These processes have transported, deposited and redeposited, consolidated, and reweathered the soil mass until many soils have developed, each with its own texture and water-holding capacity, natural fertility, and erosiveness.

Temperature is another climatic factor important in soil formation. Its effect on organic content has been mentioned. In addition, it can affect soil water intake by freezing the ground and preventing infiltration. Under other conditions, a snow cover can keep the soils open and receptive to water intake. Also, freezing and thawing of some heavy soils create upright columns of soil and water (finger frost), causing daily erosion and requiring extra erosion control efforts. Rain falling in hot weather during high winds can be totally ineffective in increasing soil moisture.

To the designer, intensity of rainfall usually relates to structure size and safety. Total annual precipitation is another concern, but season of occurrence can involve ice flows and other hazards. Season of occurrence also affects construction seasons and sequences.

Interpretations and recommendations from the soils and vegetative specialists are used by the design engineers to prepare specifications, standards, and special provisions for erosion control, sedimentation traps, seeding, and sodding. Erosion control practices that may be used during construction are discussed in Appendix D.

### Grades and Slopes

Side slopes usually vary with the height of cut or fill and, depending on the erosiveness of the material involved, can directly affect erosion control and revegetation measures. Most standard sections require that the tops of cut and fill slopes be rounded. Sharp angles are avoided to facilitate erosion control where contour grading is specified.

The requirement for flatter embankment slopes has increased the total surface area that is subject to erosion; however, erosiveness is lessened and revegetation is facilitated. The gambrel roof (or break-in-grade) section, however, collects runoff on a gentle slope and passes it to a steeper slope where erosion may be more of a problem (Fig. 5). At some locations it has been necessary to collect this runoff and carry it over the steeper slope in a paved ditch or pipe.

Where high cuts and fills are involved, some contracts specify finishing, seeding, and mulching by increments as work progresses. For example, one state specifies: "Cut slopes with vertical height 20 ft or greater shall be seeded in three approximately equal increments; two increments for slopes between 5 and 20 ft; 5 ft or less in one operation." To assist in erosion control and permit increment seeding of fill slopes, the inclusion of bench terraces to catch overspill can help reduce damage to lower-level plantings. Consideration must be given to possible increased water intake causing slumping. The soil material involved governs use of terraces.

Serrated cuts have been specified at suitable locations. Sites usually involved are those containing rotten or fragmented rock or soft shales that slake readily upon exposure (Fig. 6).

Designers generally feel that roadway and channel grades can be adjusted to minimize erosion on projects with independent lane alignment. This design technique is also used to reduce heights of fills and cuts and to avoid problem areas.

### Streams and Drainage Channels

Hydraulic data are provided by the drainage engineer for selection and design of appropriate and safe drainage structures and ditches. Ditches should be large enough to carry the expected maximum flow and be stable against the erosive force of the flow. Vegetation can provide the needed protection if flow velocity is not excessive. Velocity in a ditch is controlled by limiting ditch gradient and by selecting an appropriate cross section. In general, a trapezoidal or parabolic cross section will have a lower maximum velocity than a V-shaped ditch. Table 1 gives the permissible velocities for channels lined with vegetation. The designer should stay below these velocities, because few sods receive the required fertilizer or are maintained at maximum density. Until the grass is established, the bottom of ditches should be lined with jute netting or similar material to prevent washouts. Bank slopes of the channel should be three to one or flatter to permit maintenance.

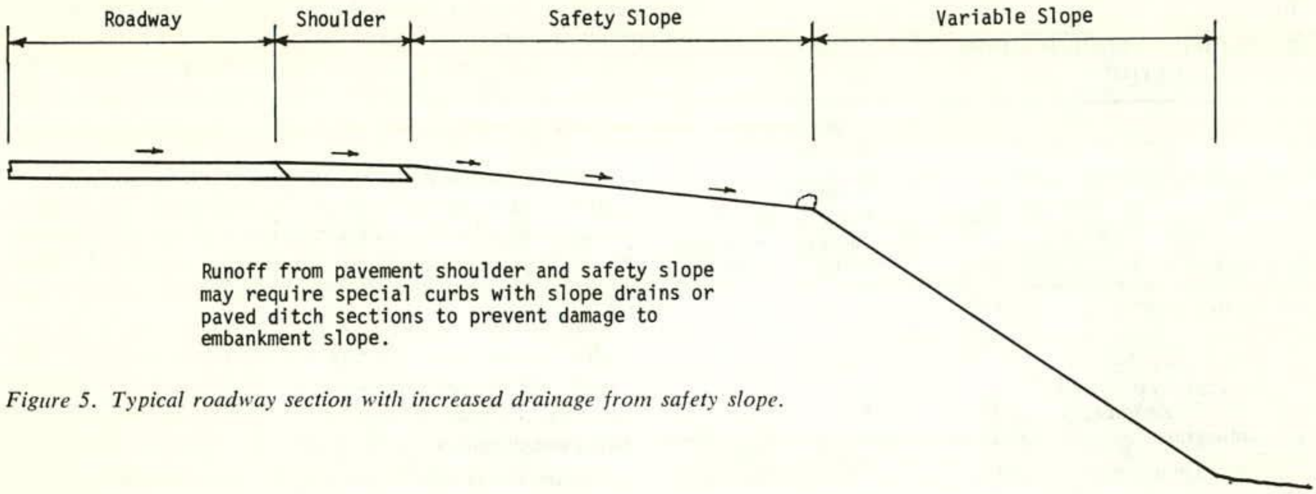



*Figure 5. Typical roadway section with increased drainage from safety slope.*

*Figure 6. "Mini-bench" cut slopes to aid in erosion control (Idaho-Montana border).*

TABLE 1

PERMISSIBLE VELOCITIES FOR CHANNELS LINED WITH VEGETATION

| NO. | COVER | SLOPE RANGE (%) | PERMISSIBLE VELOCITY [a] (FPS) [b] EROSION-RESISTANT SOILS | EASILY ERODED SOILS |
|---|---|---|---|---|
| 1 | Bermudagrass | 0–5 | 8 | 6 |
| | | 5–10 | 7 | 5 |
| | | > 10 | 6 | 4 |
| 2 | Reed canarygrass, tall fescue, Kentucky bluegrass | 0–5 | 7 | 5 |
| | | 5–10 | 6 | 4 |
| | | > 10 | 5 | 3 |
| 3 | Grass-legume mixtures | 0–5 | 5 | 4 |
| | | 5–10 [c] | 4 | 3 |
| 4 | Red fescue, Redtop, sericea lespedeza | 0–5 [d] | 3.5 | 2.5 |
| 5 | Annuals,[e] common lespedeza, sudangrass, small grain | 0–5 | 3 | 2.5 |

[a] Use velocities exceeding 5 fps only where good vegetative cover and proper maintenance can be obtained.
[b] 1 fps = 0.3048 m/sec.
[c] Do not use on slopes steeper than 10%, except for side slopes in a combination channel.
[d] Do not use on slopes steeper than 5%, except for side slopes of a channel.
[e] Used on mild slopes or as temporary protection until permanent covers are established; use on slopes steeper than 5% is not recommended.

Where channel curves are unavoidable, the concave side in most instances will require special treatment, such as rock riprap or paving.

### Interchange Ramp Layout

Interchange design requires increased attention to erosion control practice. The layout of the interchange, and particularly individual ramps, can be designed to disturb the least area. Slopes can be reduced by increasing ramp length and by using waste material to fill depressions that are not wooded. Existing vegetation is preserved where possible, and denuding of the interchange area is kept to a minimum.

### Erosion Control Measures

Normal erosion control measures, both vegetative and mechanical, have been developed over the past 40 years and are somewhat standardized. Continuing modifications have taken place with the acquisition of new knowledge, techniques, and equipment. Past standards and specifications were, however, pointed toward permanent erosion control measures and repairs, with establishment of vegetation often coming late in the construction sequences. Present standards require mitigation of the effects of accelerated erosion during construction.

Recent emphasis on controlling erosion, minimizing siltation, and avoiding water pollution has instigated a reappraisal of control measures. Coming under scrutiny are the timing of existing procedures and the addition of special provisions and practices.

New ideas and practices are evolving or are in the process of being accepted. The following measures are available to the highway designer:

- Specifications to limit the maximum surface area of erodible soil to be exposed at any one time. The project engineer usually has authority to increase or decrease exposed acreage based on contractor capability, work progress, and storm season.
- Bid items for permanent and temporary drainage and erosion control measures provided for in the contract. This permits the project engineer to use his judgment and authority to react to unforeseen conditions encountered during construction.
- Time limits can be set for the establishment of temporary and permanent erosion control measures. When conditions prevent permanent installations, temporary control measures are required between successive construction stages. (See "Temporary Erosion and Sediment Control Provisions," Appendix F.)
- Acceptance and payment of seeded and mulched units as soon as work is performed, rather than at the end of the project, is permissible in many states. This encourages quick application because the contractor is relieved of further responsibility. Reasonable limits are placed on the minimum size of treated area to qualify for acceptance.
- Specifications need not call for complete stripping of all topsoil or removal of all three stumps. Topsoil and stumps can remain where topsoils are thin or the A horizon no longer exists, where fills may be 6 ft or more, and where areas will be allowed to revert to native woody vegetation.
- Grading limits are shown on the clearing and grubbing plans to save desirable trees and shrubs on the right-of-way beyond the safety zone and to prevent overclearing.
- Fill sections generally are less erodible than cut sections, hence the vertical and horizontal alignment as it relates to the topography can affect the erosion potential. Sidehill sections should be avoided when possible. Following the natural contours as closely as possible and using independent grade alignment minimizes cuts and fills (Fig. 7).
- Proper location and alignment of culverts under the road to avoid severe erosion at outlets and siltation at inlets, and to minimize damage to the structure and adjacent lands. Raised inlets can be used to trap construction sediment; however, this may require outlet protection if the velocity is increased.
- Design vegetated channels with low gradients, wide bottom, and gentle side slopes to carry flows at nonerosive velocities.
- Stone and other baffles can be embedded in lined channels to act as energy dissipators, but channel size may have to be increased to compensate for slower velocities.
- Curbs can be built on the top of fills to collect runoff water and guide it into temporary or permanent slope pipes. Installation of permanent slope pipes or other devices on steep slopes, although initially expensive, gives better erosion protection and reduces maintenance costs.

*Figure 7. Independent alignment to reduce disturbed area.*

• Much trouble results from failure to provide protection far enough up the channel at inlet ends and to make provision for energy dissipation at the outlets. Information concerning energy dissipators can be found in *Highway Research Record No. 373* (*7*).

One of the most important factors is to require channels to be constructed and protected as a first order of business, where feasible.

Where extremely erodible conditions are known to exist near water supplies or other vulnerable properties, special provisions (such as permanent silt basins; covering of all slopes until appropriate seeding dates; rock, brush, or baled-straw filter barriers; and earth dikes to intercept eroding soil and direct surface runoff to stabilized sites) have been planned, designed and incorporated in contract specifications.

Many highway agencies have or are in the process of developing more inclusive standards and specifications for erosion control on construction projects. They usually include detailed installation instructions and diagrams. Some were borrowed from local Soil Conservation Service, Bureau of Reclamation, and/or other offices. Some procedures have been modified to fit highway construction conditions more closely. Some of the items (how-to-do-it sheets) included by the designer in the construction contract are:

- Permanent and temporary seeding, mulch, and fertilizers.
- Mulch anchoring methods and mulching without seeding.
- Topsoiling (slope dressing) with procedures and quality specifications.
- Sodding—installation, geometric design, and quality control.
- Vegetative tidal bank plantings.
- Planting sprigs of Bermuda, reed, Canary, and similar grasses.
- Slope stabilization with riprap, sod, and erosion nettings.
- Jute netting, excelsior pads, etc.

- Check slots (erosion stops) with jute mesh or glass matting.
- Designed berm (interceptor) ditches at top of cuts.
- Designed diversion terraces with outlets.
- Level-lip spreader construction.
- Gravel blankets for steep slopes and wind erosion.
- Grassed or sodded waterways with permissible velocities.
- Temporary grade stabilization structures.
- Ditch blocks and dams to control water velocities.
- Ditch linings.
- Energy dissipators in flumes and at outlets.
- Cobbled gutters.
- Slope drains of pipe or protected with fiber mats, rubble, portland cement or bituminous concrete, plastic sheets.
- Designed sediment basins with perforated riser and emergency spillways.
- Debris or sediment basins upstream from culverts and bridges.
- Straw bales for filters.
- Serrated slope designs.

#### Right-of-Way Considerations

One design factor that often affects right-of-way requirements is the character and extent of erosion and sediment control requirements. Determination of land needs for this purpose usually precedes final setting of right-of-way limits. The right-of-way should be wide enough to permit low slope gradients and areas for the disposal of silt from sediment basins. This area may be on the right-of-way or on leased land. Space for filters or retaining dikes between the toes of fill slopes and streams or adjacent property should be identified and provisions made to purchase or lease. The cost of purchasing added right-of-way should be weighed against the benefits, including avoidance of damage suits.

#### Working Schedules

Increased attention is being given to the need for improved coordination of the construction effort. The designer can work with construction representatives to set priorities and construction sequences that will ensure the timely installation of erosion control and sediment collection measures. It is widely recognized that strict adherence to a maximum exposed area limitation requires significant changes in the scheduling of many construction operations. The imposition of time or seasonal limits also affects construction planning and operations. Some highway agencies work closely with contractors' associations to develop and implement realistic and practical construction schedules and controls. Design and construction both play a major role in this effort that must take place well before the construction contract.

#### Cost Estimates

Cost estimates for construction erosion control measures will be more easily obtained as experience and cost records are developed. Few firm cost figures, or even ranges, are obtainable. Data submitted indicate wide variation by region, as well as by rural versus urban construction. Price ranges are exemplified by the following:

| | |
|---|---|
| Mulch alone.......... | $7.11 per 1,000 sq ft ($7.65 per 100 m$^2$) |
| Seeding with mulch.... | $7.53 per 1,000 sq ft ($8.10 per 100 m$^2$) |

Jute matting prices have ranged from $5.50 to $11.44 per 100 sq ft ($0.59 to $1.23/m$^2$).

Some agencies are developing unit costs on an item basis for hand-laid riprap, topsoiling, erosion control mesh, temporary seeding, reforesting borrow pits, water for grass, overseeding mulched areas, rock and gravel mulch, crown vetch seeding, glass roving (blown on), and glass fiber mat. Other states are using a percentage (2 percent to 5 percent) of earthwork cost as an estimate for temporary erosion control cost.

Regardless of how estimated costs are obtained, cost analysis of alternatives should be made, and where possible cost-benefit ratios should be determined.

#### Design Problem Areas

Problems encountered in the design of erosion control and sediment collection provisions on highway projects include the following:

- Inability to predict the type of season when major items of work will be undertaken.
- Choice between adding right-of-way versus taking some risk with erosion. In practically all cases, the balance will weigh in favor of controlling erosion because sediment deposit must be kept to a minimum.
- Inaccurate prediction of sediment.
- Uncertainty of construction operations.
- Too little soil data for predicting runoff.
- Coordinating protective effort with other involved agencies.
- A minimum of design or construction experience with erosion control measures.
- The "let construction handle" attitude.
- Determining the minimum and maximum delays between the start or completion of work and the application of seeding, paving, etc.
- Preparation of accurate estimates for erosion control work that may be performed piecemeal.

CHAPTER THREE

# CONSTRUCTION

A 1972 survey of highway agencies indicates that increased emphasis is being placed on erosion control during construction. The practice today, in most agencies, is to complete much of the erosion control procedures at the earliest practical date. Just how soon is "practical" remains an unanswered question (Fig. 8).

One advantage of using permanent erosion control items is the avoidance, in many cases, of payment for temporary control measures. This saving, however, may not be realized when normal construction activities are severely restricted or when permanent work must be performed in small increments.

Erosion control items that are now called for in the construction plans include berms, dikes, construction and cleaning of sediment basins, diversion channels, and soil blankets (Appendix D). These items, when timely used with mulch and either temporary or permanent seeding, can substantially reduce both erosion and the amount of sediment that is transported from the construction project. However, their inclusion in the plans has not automatically assured success. Lack of cooperation between the contractor and the field inspection teams has been identified as one of the reasons.

## PRECONSTRUCTION CONFERENCE

Historically, the contractor has been held accountable, or even liable, for everything that takes place on or because of the construction project. Most, and perhaps all, standard specifications contain a general clause that spells out this responsibility. More recently there has been a concerted effort by all highway agencies to ensure improved performance by the contractor by requiring that a specific planning effort be directed to the control of erosion and sediment on highway construction projects.

All new contracts involving federal highway funds now contain the following statement, or variations thereof:

> At the preconstruction conference the contractor shall submit for acceptance his schedules for accomplishment of temporary and permanent erosion control work, as are applicable for clearing and grubbing; grading; bridge and other structures at watercourses; construction; and paving. He shall also submit for acceptance his proposed method of erosion control on haul roads and borrow pits and his plan for disposal of waste materials. No work shall be started until the erosion control schedules and methods of operations have been accepted by the engineer.

One of the major problems encountered by the contractor in the preparation of his construction schedule is the need for predicting the periods of extensive rainfall that change the potential for erosion damage and sediment accumulation. His planning must include provisions for handling emergency situations. The preconstruction conference provides the first opportunity for the representatives of the highway agency and the contractor to review jointly the work to be performed, the seasons involved, the contractor's experience, equipment and organizational capability, the proposed work schedule, and agency engineering and inspection forces assigned to the project. If the prime contractor owns seeding and mulching equipment, it is usually less difficult to get small areas treated than if he leases equipment or uses a subcontractor. The work schedule and the erosion control effort should be reviewed critically by all parties.

There have been numerous projects where the preconstruction conference did not adequately treat erosion con-

*Figure 8. Growing grass shares scene with earthwork to reduce cut erosion.*

trol procedures. The most common mistake is for the contractor to underestimate the time required to perform segments of the work, resulting in continued exposure of erodible surfaces. The preconstruction conference offers a medium for discussing alternatives to the construction schedule and any possible need for temporary erosion protection.

## PROCEDURES AND PROVISIONS

Attitudes on construction and construction inspection have changed during the past few years. The common thought at one time was to cut ditches and blade slopes to get all water off the project as rapidly as possible. Standing water was not permissible. Today, much attention is given to rough or serrated back slopes, sediment ponds, and even sediment traps in medians. More attention is given to slowing the water down to prevent erosion (Fig. 9).

The final responsibility for erosion control rests with the project engineer. Here is where the provisions of the plans and specifications are checked against field performance and the decisions made that modify or extend the contract provisions. It is a rare project that does not require some on-the-spot solution of an erosion or sediment problem.

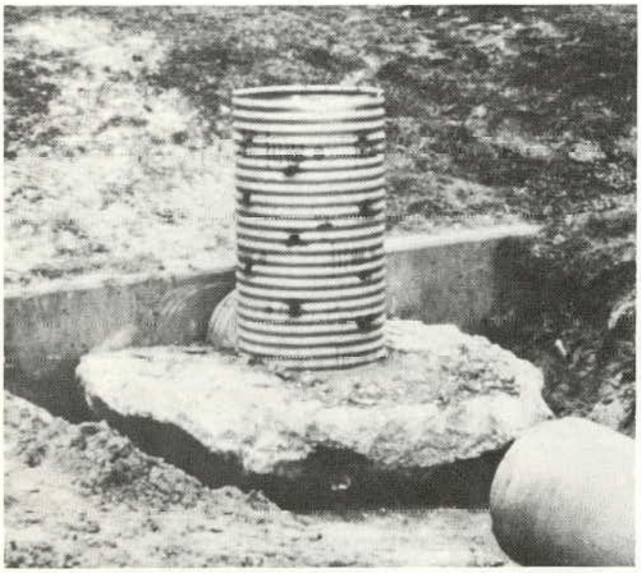
According to engineers and inspectors on major construction projects, the erosion control effort is directly related to the attitude of the contractor's management and the availability of seeding and mulching equipment. Some are aware of the present public attitude toward stream pollution and make every atttmpt to control erosion and to collect sediment. Others, working with the same engineer and the same specifications, resist every effort to reduce pollution and only the threat of a complete shutdown gets action. In many cases, the contractor's resistance is equal to the inspector's will or authority. Public reaction, damage claims, and better-trained inspectors are correcting this situation.

Present practices to eliminate erosion during construction generally are limited to those items of work contained in the contract. There has been a strong effort to change the sequence for performing erosion control measures. More contractors are being required to construct drainage channels and place slope paving sooner, install riprap at the earliest possible time, and seed and mulch cuts and embankments as soon as practical after grading is completed. The exact time lag that should be permitted is not well defined. Therefore, the judgment of both the engineer and the contractor is critical. Several agencies do specify seeding and mulching to be performed after the embankment or cut has reached predetermined heights.

Many agencies indicate that a specific area stipulation for limiting clearing and grubbing or grading operations is not practical. Some suggest that control be established by grading balance, drainage area, construction season, or past experience record. It appears that a cooperative contractor will do a better job with little or no controls than others with rigid controls. However, many contractors do recognize the advantage of performing erosion control measures promptly.

Several agencies work with their local contractors' association or group to establish better understanding of the problems and to attain improved cooperation. The association receives copies of all agency plans, specifications, special provisions, etc., and sits in on discussions of current procedures. Often the contractor's representative can suggest better methods of getting the job done at a lower cost.

There does not appear to be any complete solution for the disposal of accumulated sediment. In fact, there is no firm direction on the maintenance of sediment collection sumps. Sediment basins generally are cleaned when one-half to two-thirds of the capacity has been filled. Smaller basins at culvert entrances and outlets may require clean-out after each major rainfall. It is recognized that clean-out



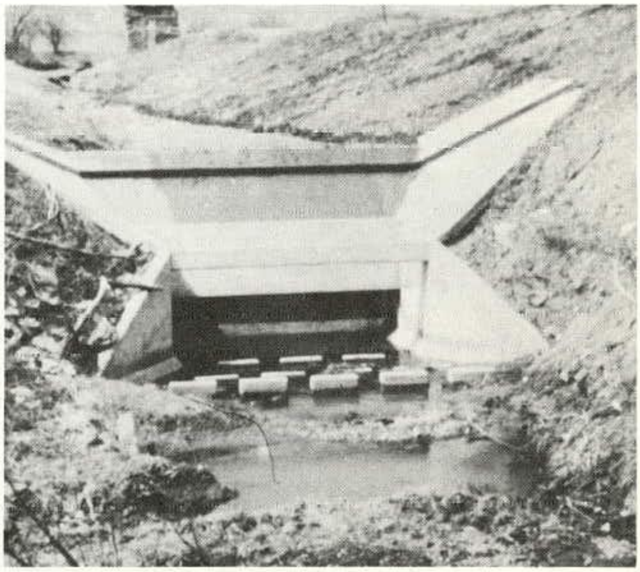


*Figure 9. Inlet (left) and outlet (right) sediment collection and erosion control.*

must be accomplished; however, how to pay for the work and when to require clean-out is uncertain. Some pay a percentage of the original cost; others include the cost of maintenance in the project cost, and some pay on a cubic yard basis.

Straw and hay mulches present special problems, largely in the urban areas. Dry mulch has been burned or has been displaced by children using cut slopes for slides, or has been blown off by traffic. Asphalt tack can lead to objections from parents. Both problems are best handled by anchoring the mulch and keeping it moist until a stand of grass is present. In lieu of straw or hay, excelsior mulch, excelsior mat, sod, glass roving, and similar materials resistant to destruction can be used as mulch.

Specific problems that have been encountered on construction include the following:

- Impressing upon both contractor and inspectors the importance of erosion control and sediment collection.
- Insufficient right-of-way for carrying out erosion prevention or sediment control work.
- Incomplete training of inspection personnel in erosion and sediment control practices.
- Cooperation problems with contractors.
- Inability to have the contractor's representative or agency inspectors on the project during storms.
- Disposal of sediment on near-completed projects.
- Access to sediment collection basins under high embankments.
- Maintenance of erosion control measures during project shutdowns.
- Insufficient authority to react to emergency conditions not anticipated in the contract.
- Requirement for removal of control and collection devices as part of the final cleanup.
- Inability to water new grass on large slopes.
- Investigation of claims and complaints of affected property owners.
- Lack of data on normal stream behavior prior to construction.
- Identification of project sediment mixed with sediment from other adjacent construction or farming operations.
- Development of training course that will enable agency inspectors to improve erosion control effort.
- Assignment of responsibility for increases in stream sediment and turbidity.

CHAPTER FOUR

# SEEDING, PLANTING, AND MULCHING

Much of the success or failure of erosion control measures on construction projects depends directly on the effectiveness of the revegetation work. Both permanent and temporary measures in many areas rely heavily upon seeding and mulching. The following basic information on seeding, planting and mulching practices should be useful to both design and construction personnel.

It is recognized that the effects of highway construction can be reduced by using mulch and grasses to dissipate the force of raindrops, disperse and retard sheet flow, and increase the tortuosity of the water paths. Because several weeks are required for a satisfactory stand of grass to develop, it is the mulch that must deter early erosion on highway slopes.

## SEEDING

Grasses are widely used to revegetate areas laid bare during construction. Use is also made of legumes, forbs, and ground covers like ice plant, ivy, and honeysuckle vine. A review of seeding recommendations shows that some agencies modify their approved species and rates for particular sites. The site may be medians, slopes, drainage ways, nonmowable areas. The recommendation also may change for major soil divisions (clays, loams, sands) and climatic zones within the state. The choice of species is regulated by total rainfall, distribution pattern, and extremes of temperature. Use of irrigation extends the use of some species beyond their common range. An example of highway seeding rates for an eastern U.S. county is given in Table 2. Additional pertinent information can be secured from the technical guides of local Soil Conservation Districts, from County Agents, and from other state and university agronomy or soils personnel. Some of these individuals may have more experience with highway cut and fill conditions than others.

Native species, especially grasses, are well adapted to their respective climatic-soils areas; however, obtaining adequate quantities of native seed with acceptable purity and germination is often difficult. Once established, they are generally better suited than cultivated sod to low levels of maintenance.

Adaptability tables by precipitation range for useful species can be developed for regions with limited effective rainfall. In areas to be returned to woody cover, bunchgrasses are used as companion crops with direct seedings of

TABLE 2

SEMI-PERMANENT AND PERMANENT SEEDINGS AND SEEDING DATES *

| SEEDING MIXTURE [a] | | | SEEDING RATE [b] | | SEEDING DATES | | | |
|---|---|---|---|---|---|---|---|---|
| NO. | USE | TYPE | LB/ ACRE | LB/1,000 SQ FT | FEB. 1– MAY 15 | MAY 16– AUG. 15 | AUG. 16– OCT. 15 | OCT. 15– JAN. 30 |
| 1. | SP | Kentucky 31 tall fescue | 60 | 1.37 | X | | X | |
| 2. | SP | Kentucky 31 tall fescue | 50 | 1.13 | X | | X | |
| | or P | Korean lespedeza, inoculated | 15 | 0.34 | X | | X | |
| 3. | SP | Kentucky 31 tall fescue | 50 | 1.13 | X | | X | |
| | or P | Sericea lespedeza, inoculated [c, d] | 20 | 0.46 | X | | X | |
| 4. | P | Kentucky 31 tall fescue | 50 | 1.13 | X | | X | |
| | | Birdsfoot trefoil, inoculated [d] | 10 | 0.23 | X | | X | |
| 5. | P | Crownvetch, inoculated | 15 | 0.34 | X | | X | |
| | | Kentucky 31 tall fescue | 40 | 0.92 | X | | X | |
| | | *Droughty Areas* | | | | | | |
| 6. | SP | Kentucky 31 tall fescue | 30 | 0.69 | X | | | |
| | or P | Redtop | 5 | 0.11 | | | X | |
| 7. | P | Weeping lovegrass | 4 | 0.09 | X | | | |
| | | Sericea lespedeza, inoculated [c, d] | 25 | 0.57 | X | | | |
| | | *Poorly Drained Areas* | | | | | | |
| 8. | P | Kentucky 31 tall fescue | 30 | 0.69 | X | | | |
| | | Reed canarygrass | 10 | 0.23 | | | X | |
| | | *Shaded Areas* | | | | | | |
| 9. | SP | Kentucky 31 tall fescue | 30 | 0.69 | X | | X | |
| | or P | Creeping red fescue | 30 | 0.69 | X | | X | |
| | | *Alkaline Areas* | | | | | | |
| 10. | SP | Kentucky 31 tall fescue | 50 | 1.13 | X | | X | |
| | or P | Sweet clover, inoculated | 15 | 0.34 | X | | X | |
| 11. | SP | Kentucky 31 tall fescue | 83 | 1.90 | | | | |
| | | Redtop | 2 | 0.04 | | X | | |
| | | Weeping lovegrass | 5 | 0.11 | | | | |
| | | Millet | 10 | 0.23 | | | | |
| 12. | SP | Abruzzi rye | 60 | 1.37 | | | | X |

* After: Erosion-Siltation Control Handbook, County of Fairfax, Va. (Nov. 1971).
[a] SP = semi-permanent; P = permanent.
[b] 1 lb/acre = 0.112 kg/1,000 m²; 1 lb/1,000 sq ft = 4.94 kg/1,000 m².
[c] Hulled seed for spring and unhulled seed for fall seedings; increase listed seeding rate by 25% when using unhulled seed.
[d] Seedings with sericea lespedeza or birdsfoot trefoil should be used only when cover will remain two or more years.

woody shrubs to provide space for shrub development and temporary protection.

Several of the factors affecting seeding practices are discussed in the following.

### Mowed Turf

The sod-forming species are selected where a lawn-like appearance is desired. Such species are bluegrass, creeping red fescue, Bermuda, and buffalo grass. The high-maintenance turfs, like bentgrass and fine Bermuda, are avoided.

### Seeding Seasons

Most states have developed a schedule of acceptable seeding dates, for both temporary and permanent seedings, when the moisture and temperature regimes are most favorable to establishment. Efforts are under way to extend these fixed dates through modification in seeding, mulching, seed mixes, and after care.

### Fertilizers

It is common practice to use one type of fertilizer on all cuts and embankments. However, experimental work has been done with formulas, application rates, and multiple applications on problem areas.

### Permanent Seedings—Companion Crops

Construction periods and seeding dates frequently coincide, so that adequate erosion control is accomplished with standard seeding techniques and permanent seeding mixes.

Some agencies include a companion crop in their standard seed mixes. The companion is usually an annual or short-lived perennial, which helps provide a favorable environment for the germination and development of the permanent cover. Where a companion crop is used, its percentage is kept low to prevent severe competition with the permanent cover. Annual ryegrass, grains, winter legumes (rose and crimson clovers, vetch, etc.) are the most common late fall species. Midsummer species include Sudan grass, sorgums, millets, and broom corn. The warm-season species also are grown to produce mulch, in situ, or for abatement of wind erosion.

#### Temporary Seedings

Temporary seedings are made to create an erosion-protective cover until the proper season for permanent plantings. An example for midwestern temporary seeding is as follows:

March 1-May 20: Cereal rye or oats + Ky.31 fescue
May 21-August 20: Sudan grass
August 21-September 30: Cereal rye + hairy vetch
After September 30: Rough finish; mulch optional.

The species are the same as those listed previously as companion crops. Rates of seeding are, however, increased materially because immediate erosion control is the prime objective and the resultant vegetation is, in most cases, incorporated into the seed bed. Timely removal of seed heads to prevent reseeding is important.

#### Rates of Seeding

The practice of throwing on more seed to compensate for poor seed bed preparation is beginning to wane. Many nationwide experiments have been carried out on seeding rates. The results indicate that 40 to 60 lb per acre (4.5 to 6.7 kg/1,000 $m^2$) is adequate for broadcast seeding. Rates in the range of 120 to 160 lb (13.4 to 17.9 kg/1,000 $m^2$) have been found to be detrimental to the development of strong seedlings. The number of pure live seed per square foot often is used as a basis for setting rates.

#### Seeding Methods

Both broadcast and drill seeding methods are employed by highway agencies. Broadcast seedings are accomplished by using hydroseeders, aircraft, hand and machine cyclone, cultipacker, and hand sowing (Fig. 10). Drills are used in low-rainfall areas to place the seed deep into the soil moisture zone and for grain seedings. Where site conditions permit, broadcast seedings are incorporated into the seed bed using a cultipacker, drag, scotch chain harrow, pick chain, or power rake. Mulch provides the only practical seed covering in inaccessible areas. Incorporating seed into the seed bed gives best results. Where jute net is added, two-stage seedings are used—one-half before laying jute netting and one-half after—followed by rolling the jute and seed into a friable seed bed. Irrigation, either by water wagon or by permanent installation, is in some sites the only reliable method of assuring a satisfactory stand.

### VEGETATIVE PLANTINGS

Cost usually limits the use of plants and plant parts to critical sites. Culm plantings (three to four stems with roots) are used to still inland and coastal blowing sand as the initial step in revegetation. Plugs, sprigs, and plant crowns are space-planted. The intervening spaces may or may not be overseeded with a temporary cover. Solid sodding is used in vegetative waterways subject to immediate flow and other areas requiring immediate complete cover. Spot and strip sodding are occasionally used with overseeding; also strips of reed canary grass are placed to serve as check dams.

Sodding operations are inspected during and after laying, and at the close of the maintenance period (Fig. 11). Time limits between cutting and placement need to be set to avoid heating and drying. Specifications usually indicate the minimum thickness that is acceptable. Sometimes sod shingling or overlapping is specified. Applications of fertilizer and lime are made immediately prior to placing sod. Burial of the upper ends into the soil often prevents undercutting. Pinning the sod down with pegs, wire staples, erosion net, or jute net is used in critical areas. Incorporating or overlaying open porous soils with heavier soils gives better bonding.

Sprigging is accomplished by tearing the sod apart and planting the rhizomes and/or stolons. The sprigs are either broadcast and punched into the planting site or transplanted with special sprig planters. The area is firmed by rolling or cultipacking after planting. Irrigation is often used to assure establishment. Tests are being run on sprigging through a hydroseeder applying wood fiber mulch mixed with sprigs or the mulch alone after sprigging by planter.

#### Topsoil Plantings

In topsoil plantings the soil is mixed with live roots and crowns and spread on the area to be revegetated. The area is rolled and kept moist until new growth appears. Suitable species are Bermuda grass, Kikuyu grass, and reed canary grass.

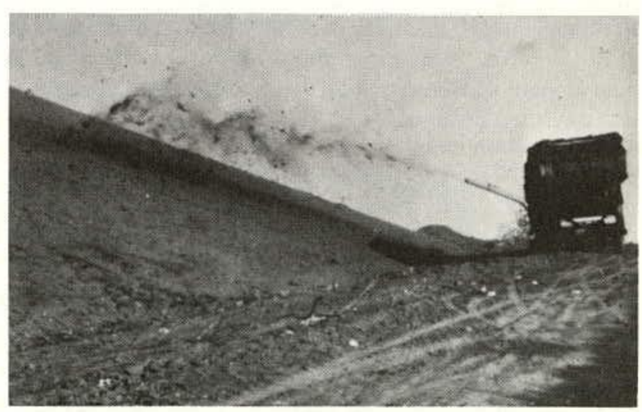


*Figure 10. Application of seed, fertilizer, and mulch with hydroseeder.*

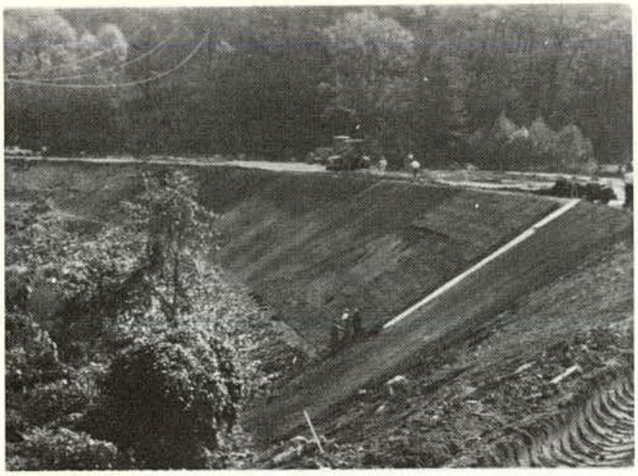


*Figure 11. Sod is placed on critical slopes of highway embankment.*

## SEED BED PREPARATION

Seed beds do not have to be smooth except in areas to be mowed. Rough seed beds are acceptable on slopes; however, compacted areas must be reworked. Specifications are varied to obtain the required depth. For temporary seedings during construction very little smoothing is called for or desired. Areas to receive topsoil are roughened by scarifying, ripping, or disking to obtain a bond between the topsoil and the subsoil. Soil amendments (such as lime, gypsum, iron sulfate) are specified to correct acidity, alkalinity, and minor element deficiency. These additions often improve the soil structure. Organic amendments (such as humus, sludge, peat moss) are in limited use. Fertilizer recommendations are based on chemical soil analysis or by developing standard fertilizer rates and ratios for broad soil groups. Emphasis is placed on available nitrogen for temporary seedings where quick response and rapid coverage are paramount. Use of mixed soluble with slow-release nitrogen sources is gaining acceptance for permanent seedings to prolong the feeding period. Phosphorus and potash are less likely to leach and total amounts needed are usually applied in the initial application. Critical subsoil areas may require application of amendments to correct deficiencies. These applications are in addition to treatments of the topsoil or fertilizers applied through hydroseeders. The basic principles for incorporating amendments thoroughly into the seed bed are understood, but too often are not written into the contracts, or are not enforced. Minimum incorporation should be 2 in. (50 mm) and 3 in. (75 mm) if mulch is to be anchored into the seed bed.

Correction of pH varies by soil texture and organic content. Correction also increases availability of most soil nutrients as the pH approaches 7.0.

## TOPSOIL

Placement of topsoil is an expensive item; however, it is required for some sites. Topsoil that is stripped from the project should have had both chemical and mechanical analyses made prior to removal and stock piling. Organic matter content is less important than texture. Ideal topsoil would have 60 percent sand, 40 percent silt clay, with more clay than silt and at least 1.5 percent organic matter. Variations up and down from this midpoint are acceptable and limits are often set. Higher sand content tends toward droughty conditions; high clay contents limit aeration and drainage. A limit of 500 ppm is usually placed on soluble salt content.

The subsoil should be tilled before topsoil placement. Refirming the soil during or after the time of seeding is called for in order to reestablish capillarity and bring soil moisture up to the seed. Many tools are available to accomplish this. Those that leave small ridges or pockets across the slope are gaining favor. The effectiveness of running crawler tractors up and down the slope before topsoiling and after seeding to bind the two layers, pack the seed bed, and create hundreds of little dams to slow down surface flow of rainfall, is under test.

Some subsoils have the right texture for holding moisture and applied nutrients. Although they are lacking in organic matter, they can be used in lieu of surface soil for slope dressing. Where suitability has been determined, mixing of surface soils and acceptable subsoil is recommended. A broad subsoil textural map of a state can be developed and used as a guide to topsoiling needs.

## MULCHES AND MULCHING

Extensive experiments have given positive proof of the effectiveness of mulching as an erosion control practice. Mulch protects the soil from the force of raindrops and winds, increases water infiltration into the soil, decreases water runoff from slopes, and usually lowers surface soil temperatures, thereby providing a microclimate favorable to seed germination and seedling establishment. Incorporated organic mulch may temporarily tie up nutrients, but decay releases them gradually, thereby reducing leaching losses. Some specifications call for or permit mulching as a temporary erosion control measure until the appropriate season for permanent seeding.

The anchoring of the mulch is of critical importance to mulching. Methods used include (a) pressing the mulch into the soil with a mulch-anchoring tool to a depth sufficient to anchor it but not bury it, (b) tacking with various emulsified asphalts, and (c) tying down with cotton netting or wire mesh. Excessively dry or rotten mulch will break or cut with inadequate anchoring. Modified sheepsfoot rollers are used to anchor mulch on slopes too steep for cross-slope operations; they are winched up and down the slope. Clod-buster (pick) chains are also used, but they require multiple passes to achieve good mulch anchoring and may drag up mulch that is already anchored. Peg and string tied down is practically obsolete because of labor costs.

Mulching materials are as varied as the locally available materials that can be acquired at a reasonable cost. They include natural materials (hay, straw, wood chips, excelsior) and manufactured materials (nettings; wood cellulose fibers; glass, paper, plastic, and asphalt sprays). Chemical sprays that give temporary protection by gluing the soil particles together are still in the developmental stage. Hay or straw mulch cut into the soil is effective against wind and turbulent air created by passing traffic. Jute netting and excelsior blankets are widely used for erosion control (Figs. 12 and 13). In Japan, fine-woven net impregnated with seed and fertilizer is pinned to steep slopes with fine soil sifted over the top.

Several wood products are useful as mulch: wood cellulose pulp placed with a hydroseeder, wood fibers blown on, wood excelsior blankets placed and stapled, wood and bark chips blown or hand-placed. Conversion of unsalable wood products and scrub brush into chips for mulch may become more economically feasible than other methods of disposal with the increase of bans on burning. Depth of application is critical. Excessive depths of 4 to 6 in. (100 to 150 mm) prevent the establishment of vegetation. Extra nitrogen is usually required with this raw organic matter.

#### MATERIALS FOR PROTECTIVE FILMS

Dozens of experimental chemicals have been tried as dust palliatives and for temporary erosion control. Resin-in-water emulsions (such as Soil Seal, Coherix, Curasol) have shown some promise (see Appendix G).

Asphalt sprays are used for tacking loose mulch. They are sometimes applied directly to the soil surface. If the soil is dry, it should be irrigated first. Asphalt sprays are more effective on sandy soils than on silty clay and clay soils, due to the swelling and shrinking of the latter. Resin-in-water performs in like manner.

Latex emulsions tried to date have not proved satisfactory; the heavy films limit movement of water into the soil.

Solid and perforated plastic sheets have been tested as seed bed coverings under semiarid climates to conserve moisture and modify soil temperatures. Reflective qualities are important. Clear plastic allows lethal temperatures to develop; opaque plastics prevent adequate light penetration. Effective grass seedings were established using perforated white plastic sheets in southern New Mexico.

#### STONE MULCH

Where desert conditions or wind erosion prevail and where establishment of vegetation is almost impossible, gravel, stone, and crushed rock blankets are used as mulches. If the individual pieces are no smaller than ½ in. (13 mm) in diameter, these mulches will withstand wind velocities (measured at 50 ft (15 m) above the ground surface) up to 85 mph (137 km/hr) (*8*). A 1-in. layer of aggregate or gravel is normally adequate for areas not subject to traffic. For such areas the material generally is graded as follows:

| | |
|---|---|
| Passing 1½-in. sieve | 100 percent |
| Passing 1-in. sieve | 60-90 percent |
| Passing ¼-in. sieve | 0-20 percent |

*Figure 12. Checking jute netting on cut slope.*

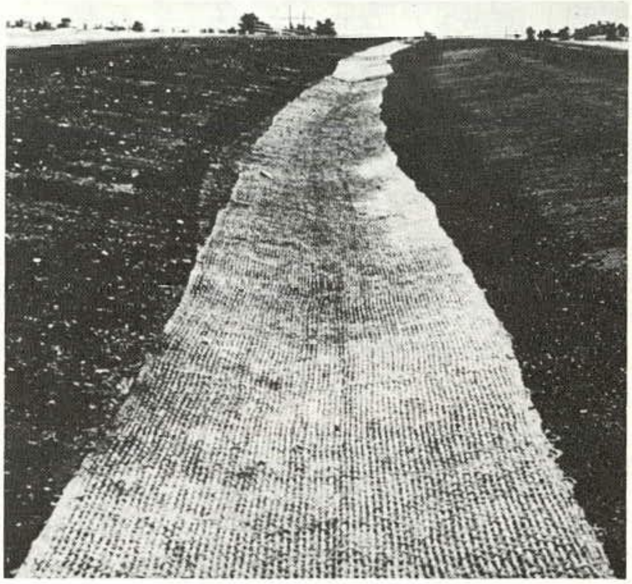


*Figure 13. Jute netting protection for drainage channel.*

CHAPTER FIVE

# SUPPORTING FIELD PRACTICES

## BERMS

Earth berms or dikes constructed along the top edges of embankments intercept runoff water and protect construction slopes. Where soils are porous, berms may increase water intake and bring about soil instability. In this case, the berms should be laid out with a gradient to remove the water laterally, but safe disposal areas must be provided for the discharge. Use of earth berms, rather than diversion terraces, minimizes disturbance of existing vegetation.

Edge berms are widely used to prevent surface water from spilling over partially completed embankment slopes (Fig. 14). Material for the berm may be bladed from the roadway and replaced when the berm is no longer required. The edge berm may be constructed by placing the material for the next lift along the edge and shaping it to drain to the inside (Fig. 15). Transverse berms are placed across the top of the embankment to intercept the flow of surface water and direct it into a median or slope drain.

The construction of edge berms and the sloping of embankment surfaces to protect slopes is contrary to the experience of some construction personnel. Earlier practice was to crown the embankment at the end of each day or when rain was anticipated.

Earth berms can also be used to prevent saturated sediment from spreading after it has been removed from settling basins. Level spreaders are a type of berm that can be used to change channel flow to sheet flow (Fig. 16). However, under certain terrain conditions the water will converge at a low point and resume channel flow.

Topsoil storage piles should have earth berms constructed at the downhill toe if there is likelihood of sediment flow. For long storage periods they should be seeded to a temporary cover. Plastic sheets can be used to prevent stockpile erosion and to keep the material dry.

*Figure 14. Earth berm to protect seeded embankment.*

Closed-end terraces (syrup pans) can be used in semi-arid areas to control erosion and increase water intake into the soil for the benefit of the revegetation program.

## SLOPE DRAINS

Berming of fills and cuts and installation of temporary down drains to carry water down the slopes during construction is now common practice. Slope drains are either flexible or rigid and are easily extended as the cut or fill advances (Fig. 17). Flexible pipe, plastic sheets, and asphaltic concrete are some of the items used (Fig. 18). Portable flumes and inlets are also available. Devices for dissipation of high-velocity outflow energy are provided where necessary. Where damage from erosion is extremely critical and construction is proceeding during the period of heavy rainfalls, the engineer can require the building of berms at the top edges of fills every night prior to work stoppage. Decisions should be based on local and extended weather forecasts. In heavy rain areas, permanent let-down structures or sodded channels can be used.

## SEDIMENT BASINS

Sediment basins are now included in the erosion control effort on most highway projects where rainfall is anticipated during the construction period (Fig. 19). Large basins are

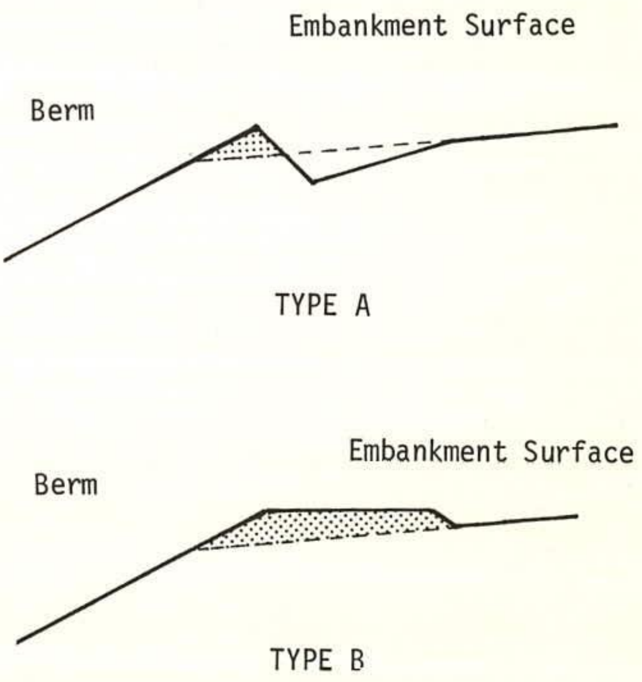




*Figure 15. Edge or transverse berms; size and spacing vary with roadway width, grade, and rainfall estimates.*

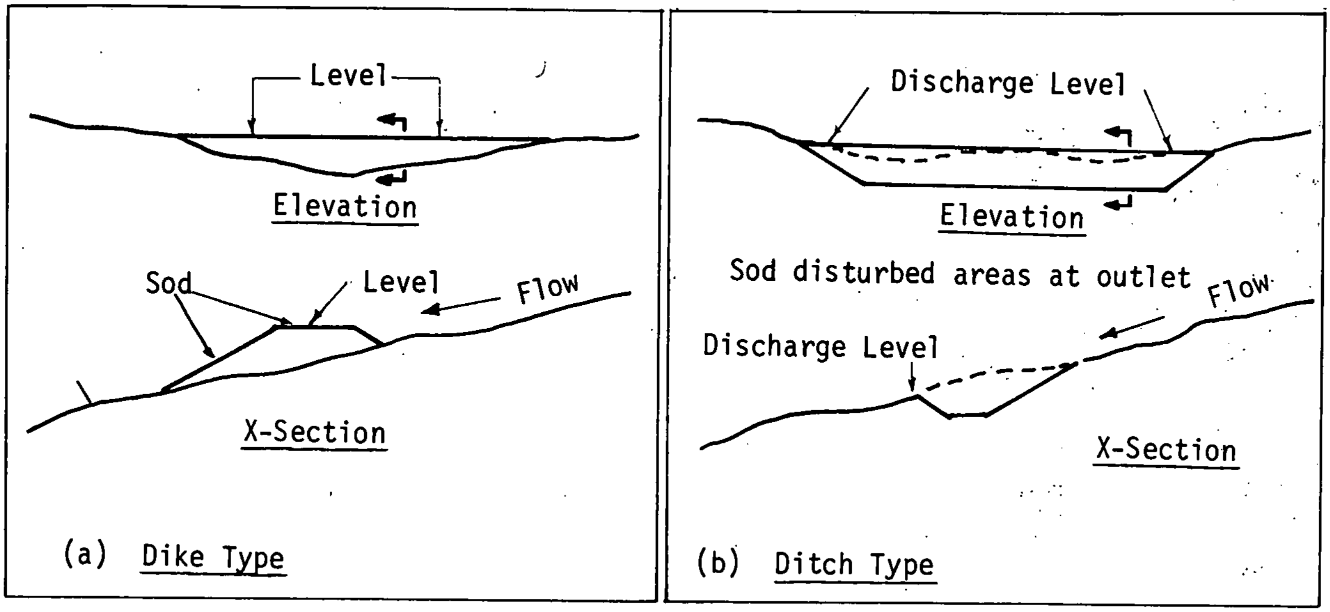



*Figure 16. Level spreaders; either type may be fitted to the ground contours.*

designed and included in the plans. Small basins and sediment traps are usually located by the project engineer and the contractor to meet immediate or temporary needs. This is largely a judgment decision that must consider the soil type, exposed area, slope, anticipated rainfall, and duration of exposure. Provisions for cleaning out collected sediment permit construction of smaller basins. Payment for clean-out has been (a) based on the volume of material, (b) based on a percentage of the basin cost, and (c) included in the cost of the basin. Field personnel, generally, feel that payment should be based on a bid price per cubic yard for removal and disposal of sediment as necessary. Some contractors have been most reluctant to install sediment basins when a pay item for this effort was not included in the construction price.

Sediment basins may be either temporary or semipermanent. The temporary basins are maintained until permanent erosion control efforts are effective. Some feel that it is desirable to have the sediment basin cleaned just before the project is accepted by the highway agency to serve future needs. They point out the difficulties associated with obtaining a completely effective erosion control effort, particularly if the seeding and mulching has just been completed. Others, however, desire that the basin be removed and the site seeded at the end of construction.

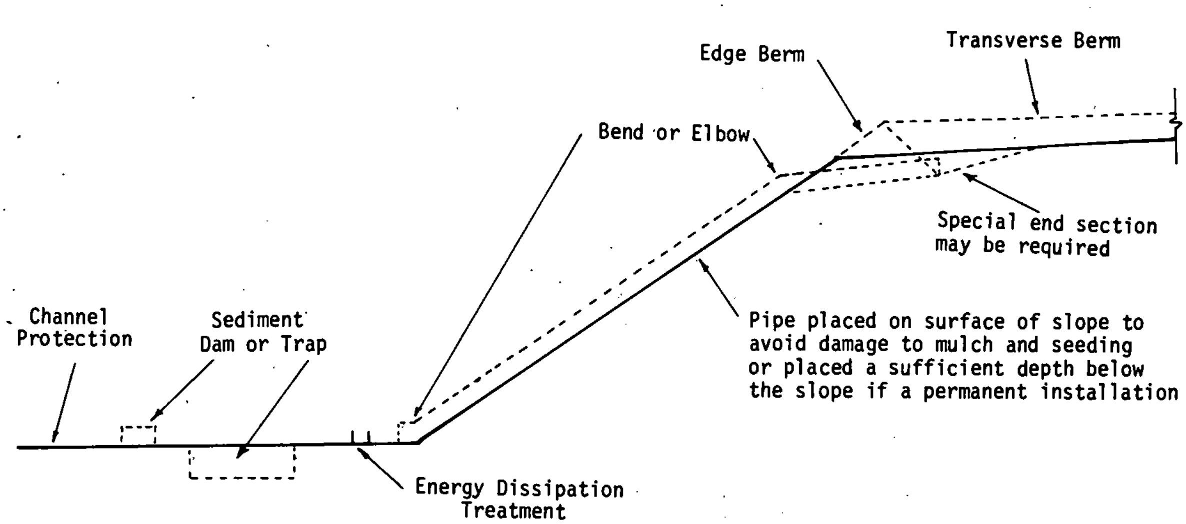



*Figure 17. Temporary slope drain on embankment or cut (transverse berm may not be required for cut).*

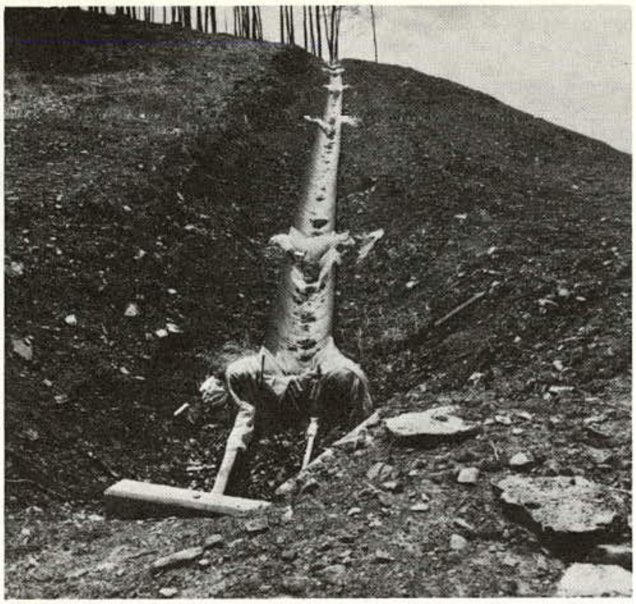


*Figure 18. Slope drain.*

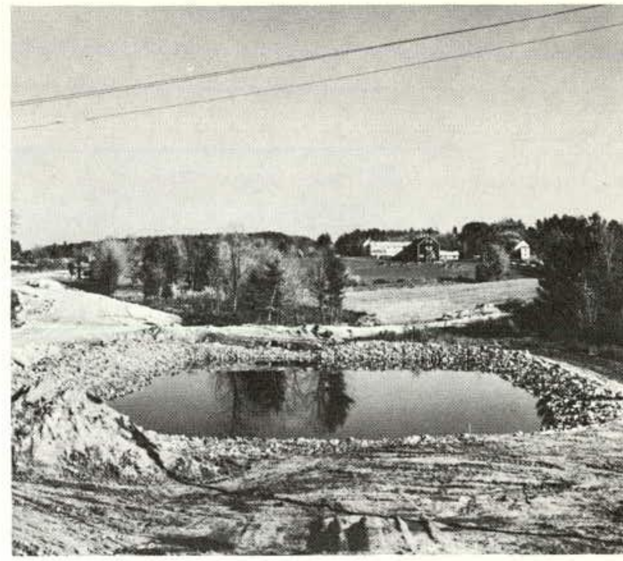


*Figure 19. Sediment basin.*

**SEDIMENT TRAPS**

Sediment traps or pits usually are smaller than sediment or settling basins. They are used at culvert inlets and outlets, upstream from brush or straw-bale filters, at or near curb or drop inlets, near the toes of slopes, and at any other drainage channel where sediment is being transported (Figs. 20, 21, 22). They also require continuous clean-out during construction, but usually are graded and seeded, sodded, or paved near the end of construction. An exception is the traps at culverts, because of their need to protect adjacent property after construction has been completed.

There is no sure-fire rule-of-thumb for determining the size or location of sediment traps. They often fill during a single storm and permit sediment to pass. The practice of constructing a trap at both inlet and outlet helps to lessen the chance of sediment passing off the right-of-way.

When traps are used to support brush or filter barriers, they are constructed upstream from and before the barrier is placed. This protects the filter device from excessive amounts of sediment that could result if the reverse procedure were followed.

**BARRIERS AND FILTERS**

Filter dams are used to collect sediment and debris before they pass off the right-of-way. Filter bales of hay or straw have been used extensively for this purpose by both highway and housing contractors. This practice has not always been successful; however, many of the failures have resulted from improper use or placement. They are of little value in roadside ditches with even slight grades because of the limited storage behind the bales and the tendency of the water to cut a path around the edge (Fig. 23). Another problem with bales is the breaking of strings; this results in loose material that blocks downstream drainage. Dry bales have been set afire and strings have been cut by vandals. Each bale should be held in place with two steel pins or large stakes.

Filter bales are most effective when they are supported

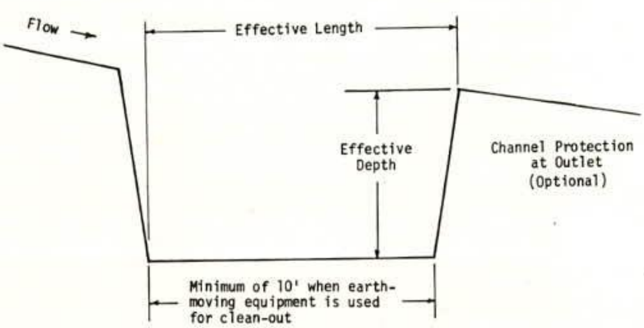



*Figure 20. Pit-type sediment trap (size varies with soil type, watershed, stream gradient, rainfall estimates, and clean-out frequency).*

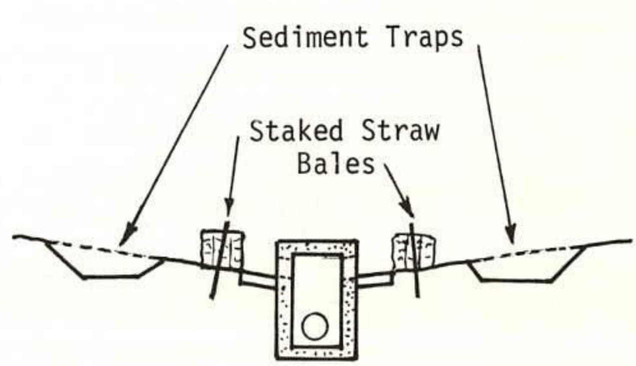



*Figure 21. Median or drop inlet drain protection.*

*Figure 22. Sediment trap.*

by a wire fence or other adequate support, and where the flow is well spread to keep the maximum velocity low (Fig. 24). Bales should be jammed together to prevent silt-laden water from passing directly between individual bales. In some locations the baled material can be used as supplementary mulch at the end of construction.

Brush barriers for silt collection are being used increasingly, particularly in rural or forest areas. Slashings from the right-of-way clearing can be used in combination with check dams, or the brush can be used alone at the toes of fills (Fig. 25).

The FHWA has had much satisfactory experience with the use of brush barriers on park and forest construction in the Smoky Mountains area. At the end of construction, additional brush is placed as needed and the toe of the slope is walked with a crawler tractor. Protruding limbs

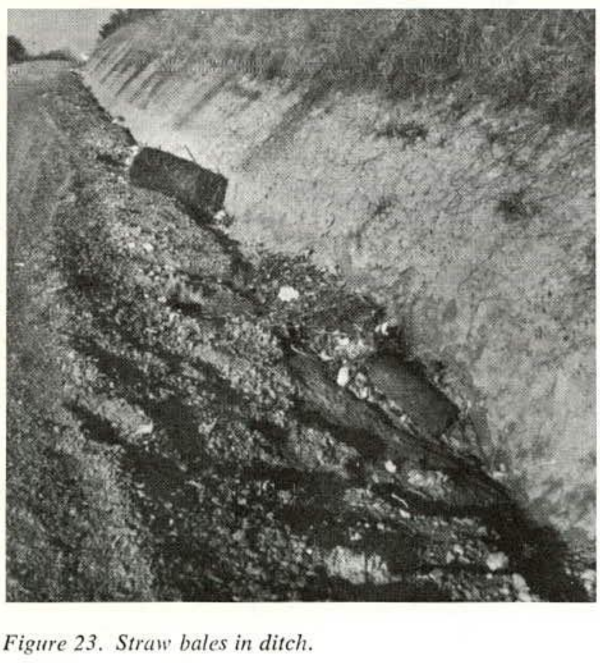


*Figure 23. Straw bales in ditch.*

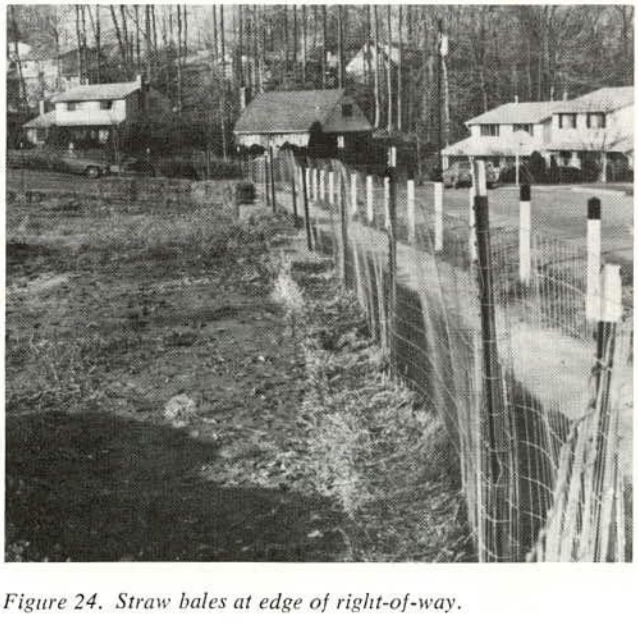


*Figure 24. Straw bales at edge of right-of-way.*

*Figure 25. Brush barriers to slow flow and collect sediment.*

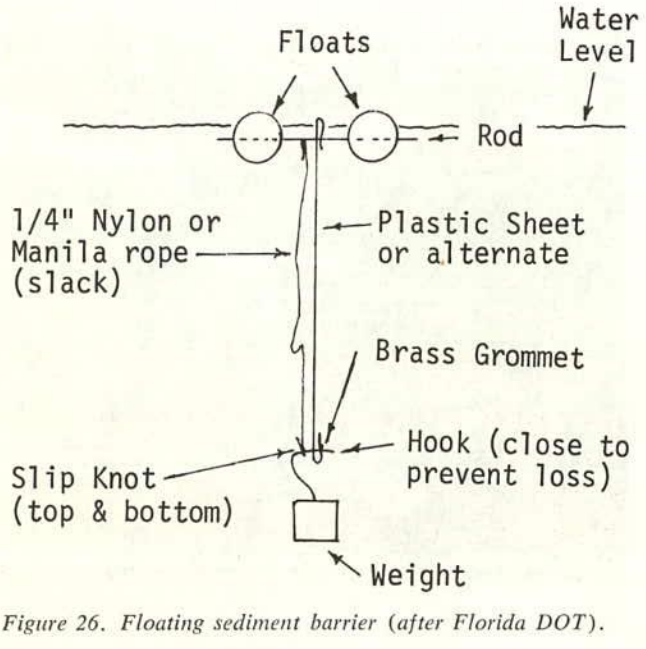



*Figure 26. Floating sediment barrier (after Florida DOT).*

are cut at the slope surface. After a few years, vegetation completely covers all evidence of the brush.

Figure 26 shows one type of floating sediment barrier used to reduce stream turbidity.

#### CHECK DAMS

Check dams are constructed of timber, shot rock, or other material that does not erode. Concrete is used for many of the permanent check dams. Provisions for removing sediment at these dams should be included in the contract. Supplemental filter material may be desirable if larger sizes of unchoked shot rock are used for the dams (Fig. 27).

#### CHANNEL PROTECTION

Almost all the permanent erosion control measures used for channel protection are used during construction. Paved ditches are paved at the earliest possible date. Sodding is placed as work progresses. Jute netting is used to hold

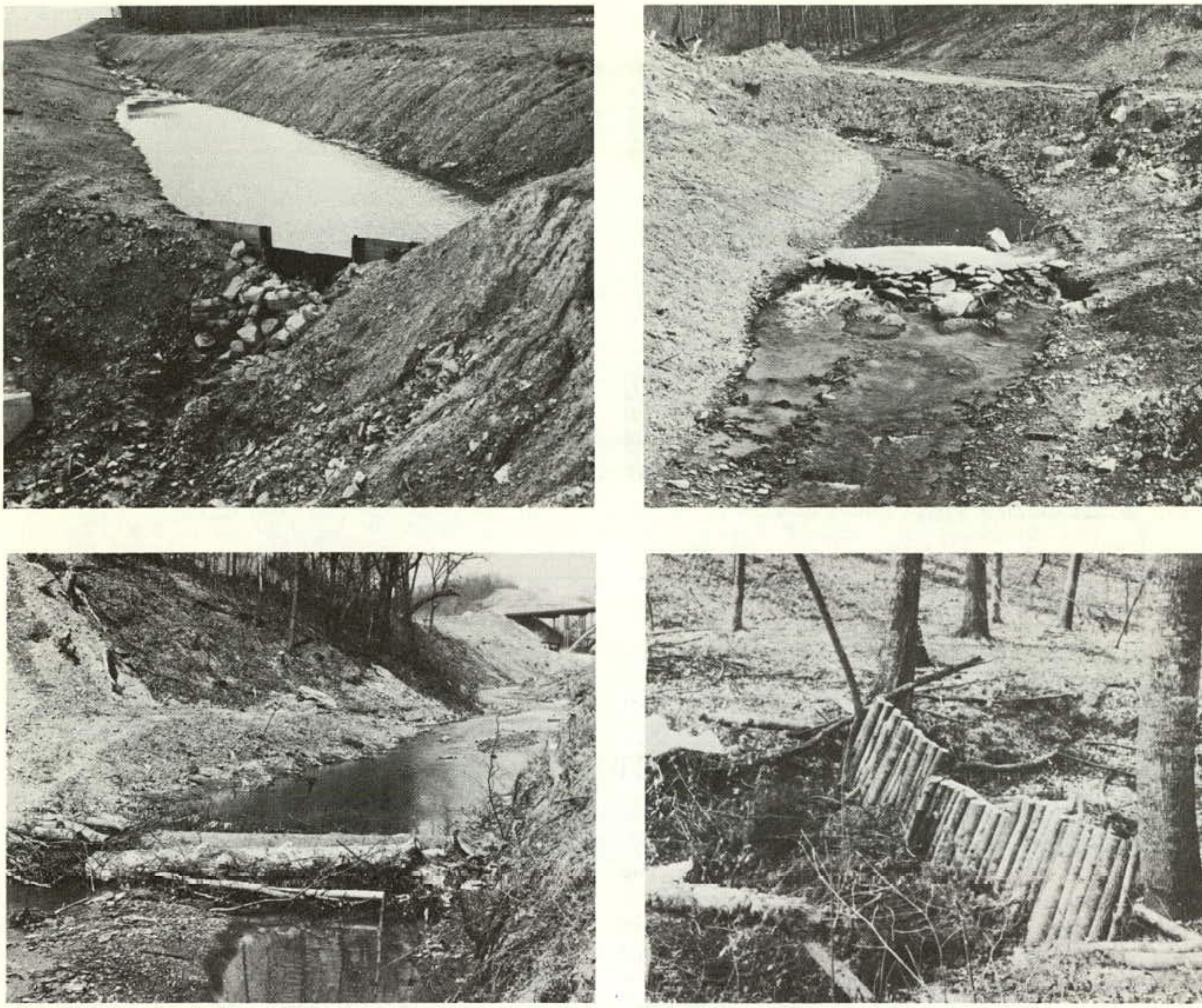


*Figure 27. Check dams to slow flow and collect sediment.*

mulch in place. Riprap in most cases is placed as soon as channel work is completed. Temporary sacked sand riprap for temporary channel protection is shown in Figure 28.

*Figure 28. Temporary channel protection.*

**SLOPE PROTECTION (URBAN)**

Special efforts have been required to limit erosion and sedimentation damage from highway construction in urban areas. In these locations the available right-of-way is limited, the adjacent property is valuable, and any failure is obvious. Retaining walls are used to lessen the right-of-way requirements and to limit the amount of slope exposed to erosion. Paved slopes and plastic sheets are also used (Fig. 29). Sod may be placed almost immediately after the embankment is placed or the cut is made. Seeding is completed at the earliest date with mulch well anchored or held in place with jute. In some areas the use of asphalt to hold the mulch is not desirable because of the poor public relations developed if children are permitted to play in the area after working hours.

*Figure 29. Embankment protected with plastic sheets.*

CHAPTER SIX

# CONCLUSIONS AND RECOMMENDATIONS

There is much information on soil erosion that is available to highway planners, designers, and construction personnel. Part of this information can be used immediately without modification. Data, maps, and manuals published by the Soil Conservation Service and others may require some modification or explanation, and, in some cases, further study before being used by highway designers in specific areas. Vegetation alone is not a cure-all and often requires supporting measures involving hydraulics and engineering design. Several disciplines are required to resolve erosion problems.

## LOCATION

Erosion prevention and control begins with the route study. Terrain characteristics; soil types; and estimates of cuts, fills, grades and slopes, should be considered along with the usual climatic conditions. Most of these items can be estimated with sufficient accuracy during the location phase to permit comparative evaluation.

The threat of erosion and siltation problems will rarely necessitate the abandonment, or even a major shift, of a proposed route. This advance study, however, will identify problem areas that warrant additional attention by the design team and construction forces.

## DESIGN

Erosion control and sediment collection during construction is highly dependent on the provisions in the project plans and the items of work that are available to the construction forces. It was at one time the standard practice to specify that the contractor was responsible for all damage that resulted from his operation. This is no longer satisfactory. The designer must provide sufficient right-of-way to permit sediment to be trapped. Sediment traps, energy dissipation devices, diversion dikes, berms, stage seeding, temporary seeding, special slope drains, ditch protection, and filter systems are a part of the items available to the designer to fight the erosion and sediment problem. In many cases, only an estimate of the quantities that might be required is possible, however, if work items are provided in the contract, the construction forces are better equipped to control the problem on the job site.

There is a need for additional information for the designer on erosion prevention, sediment production, and sediment collection.

There is a need to develop clear, workable specifications for the various erosion control items and to incorporate appropriate reference to erosion control into the "general provisions" of each agency's standard specifications.

## PRECONSTRUCTION CONFERENCE

The preconstruction conference provides the designer, project engineer, contractor, and any other interested individual or groups an opportunity to assess erosion control and silt collection measures. Work schedules can be presented and compared with permissible clearing limits or other restrictions. In most cases, oversights can be corrected and revisions proposed to meet altered conditions. Special attention should be given to stream and drainage channel crossings.

## CONSTRUCTION

Recent modifications of standards and specifications have materially aided erosion control on new construction. By minimizing the area of denuded soils in each phase of construction, the erosion potential can be limited. Good practice now requires that finishing and revegetation practices closely follow the grading operation. High cuts and fills are mulched and seeded in increments. Berms are essential for the protection of slopes from surface water. Permanent drains, slope protection, and ditch paving should be completed at the earliest practical time.

Serrated cuts have been used successfully in rotten or fragmented rock or soft shale. This technique reduces the velocity of the surface runoff, provides an improved seed bed, holds moisture for plant growth, and reduces the amount of material reaching the ditch that must be removed by maintenance forces.

Waste material from the construction project should not be dumped into streams or drainage channels. Provisions for disposal of washwater, rejected materials, and surplus excavation should not contribute to erosion or sediment problems.

It has always been accepted practice to maintain smooth slopes on the embankments and to prohibit any standing water on construction projects. These practices are no longer valid. Rough slopes hold water, seed, and mulch.

Sediment traps are essential at median inlets, cross drains, and other specified locations to protect both drainage structures and the adjacent property.

Borrow areas require continuous attention to minimize erosion and sediment damage. They should be restored at the earliest practical date.

Adequate and timely inspection of the erosion control effort is vital. Filled sediment traps should be cleaned out. Washed-out berms or temporary slope drains should be repaired immediately.

An improperly applied control measure, or one that is not properly maintained, invites failure and can create more damage than if no measure had been taken. One excellent time to check on the performance of all project control measures is during a rainstorm. The experience gained by this type of inspection is valuable to both the contractor and the project inspection team.

## EDUCATION AND TRAINING

"An ounce of prevention is worth a pound of cure" holds well for erosion control during construction. Forseeing potential trouble spots and planning appropriate preventative and control measures is half of the battle. Timely installation of correctly selected and applied measures is the other half. Both actions require a thorough knowledge of the effectiveness and weakness of each control measure and why, when, and where they are applicable. A well-planned and well-executed development and training program for agency personnel at the appropriate levels is needed to provide this knowledge.

Awareness training and education of the construction workers to develop in them a concern for erosion control during construction are important.

The "Guidelines for Minimizing Possible Soil Erosion from Highway Construction," report to Congress (July 1, 1967) stated:

> Several disciplines of science and engineering are required to reach an acceptable solution to most erosion problems. Highway designers, project engineers, and maintenance personnel need the advice of hydrologists, hydraulic engineers, soil engineers, soil scientists, agronomists, landscape architects, and other specialists to minimize erosion problems. Development and training of personnel in erosion preventive measures that should be considered in the location, design, construction, and maintenance of highway facilities must be increasingly stressed. Much research information and many practicable techniques for minimizing erosion are available in research publications and design bulletins, but refresher courses and promotion of the use of these data are badly needed. Guidelines and design manuals serve an excellent purpose, but they alone are not enough. Adequate technical staffs in the various highway agencies are necessary to cooperate with agencies at all governmental levels which are responsible for the prevention, abatement, and control of pollution and soil and water conservation.

Training courses should be organized that include methods of making inspections, reporting deficiencies to design sections, judging the adequacy of vegetative cover, preventive and corrective erosion control measures. Field inspections and design review teams can pinpoint weaknesses where additional training is needed.

Planning and design check lists can be developed on which appropriate erosion control measures are indicated for each construction activity. These can be identified by reference to station location.

Check lists, memory joggers, and similar tools are effective in developing recognition of erosion and pollution hazards. Because unforeseeable erosion control measures often are required, the project engineer must be well-schooled in effective control measures, particularly the temporary ones.

Supervisors and instructors of training courses should attend instruction courses given by other agencies or highway departments in order to keep abreast of new developments in erosion control practices.

Experience has shown that good erosion control and sediment collection practices can save money for the contractor and the highway agency.

## RECOMMENDED PRACTICES

Many of the good practices that have been followed by highway agencies to minimize erosion damage on construction projects have been discussed. Some of these are included in the following recommended practices:

- Start erosion control planning with route selection.
- Obtain stream data for a season or more prior to construction.

- Select and incorporate appropriate measures during design.
- Develop sediment collection plans during location and design.
- Assure timely and correct establishment through guidelines, specifications, surveillance, and training.
- Control by contract stipulations the maximum area of unprotected soil that can be exposed for each phase at any one time.
- Make use of clearing and proposed grading lines to limit clearing and protect native cover.
- Reduce the duration of unprotected soil exposure by requiring stage seeding and mulching as work is completed.
- Use materials from the project (i.e., brush, logs, chippings) to control erosion, filter sediment, and serve as mulch.
- Provide measures for sediment control from borrow areas, haul roads, and waste disposal areas during use, with restoration after use.
- Protect bodies of water and running streams from siltation with temporary measures such as berms, dikes, and sediment basins until permanent measures are effective.
- Plan for temporary and permanent control of concentrated runoff from construction areas (sediment traps, filter barriers).
- Provide protection at inlet and outlet ends of culverts, drainage channels, and other flow junctions, including adequate energy dissipators.
- Convert intercepted surface runoff to sheet flow (level spreader) where there are stable discharge areas, such as woods, sod, rock, or concrete rubble.
- Use flat slopes to maximize erosion control by vegetation.
- Make liberal use of temporary seedings between construction phases and when permanent seedings are out of season.
- Be wary of using maximum permissible velocities in vegetated channels because few sods are maintained at maximum density by the usual fertilization and mowing practices.
- Use adaptable mulches to the maximum consistent with the erosion hazard. Apply mulches as soon as possible in the construction sequence, using proven anchoring methods.
- Anchor hay or straw into the soil, especially in areas of high winds.
- Seed and mulch by segments on high cuts and fills.
- Wherever possible, incorporate amendments into the seed bed before seeding and mulching.
- Provide for access to slopes where it is shown that maintenance practices have to be used to retain vegetation effectiveness.
- Use slope ratios of 10:1 to 20:1 in areas where wind erosion is a problem.
- Start the control of wind erosion at the sources, even if this means cooperative efforts by the highway agency, adjacent landowners, and conservation agencies.
- Use native plant species to the greatest extent possible, especially west of the Mississippi. Use proven long-lived species requiring a minimum of maintenance.
- Use the design team approach for solution of complex erosion control measures and to spot training weaknesses.
- Convert research data into simplified working tools.
- Take full advantage of information and services available from other agencies with like concerns.
- Develop and maintain contacts with the construction industry (e.g., contractor associations) to share problems and develop solutions.
- Carry out inspections in depth to point out training needs and to strengthen design.
- Document events that occur during construction. Color slides can be most helpful if claims are presented.

## RESEARCH AREAS

Ongoing research that has been identified is given in Table 3.

The same construction methods and sequences are not applicable to all regions. Variations employed should be sought state-by-state, evaluated with respect to erosion and sediment reduction, and tabulated on a geographic-climatic basis.

Small watershed projects are being studied in limited numbers. These studies should have expanded objectives to determine the effects of highway construction on stream sedimentation and to measure the effectiveness of various erosion control measures. Knowledge of stream behavior prior to construction will be required.

Although many compounds have been evolved and tested to provide soil surface film protection and dust abatement, industry should be encouraged to continue efforts to formulate effective economical materials equal to or superior to the straw or hay mulches. In addition to wind and water erosion control, they must be amenable to vegetation establishment.

Seed supplies practically determine what species and varieties are specified for highway plantings. Most were developed for highly fertile agricultural land, not the raw exposed subsoils. Efforts to maintain them have resulted in innumerable fertility and management studies. A deeper search should be made by plant scientists to select, develop, test, and stimulate seed sources of those species known to pioneer or persist on subsoil sites. Companion studies of establishment techniques and erosion control effectiveness by species should be carried out.

Wind erosion as it affects highways during and after construction appears to have received the minimum of attention. Practices developed for protecting agricultural lands should be fully tested and, if necessary, modified to provide effective controls for highways. Practices presently used or under test need summation and distribution.

Sedimentation in streams is receiving much attention by both environmentalists and scientists. The anticipated and actual production, together with damage evaluation, are lacking. Furthermore, studies have been concentrated in the humid regions, but siltation in the semiarid areas is extensive and highly critical because of high-intensity storms and the impossibility of developing dense vegetative cover. Existing cover rarely exceeds 25 percent.

Erodibility for some subsoil formations has been pretty well developed, although it is subject to some refinement

TABLE 3

RESEARCH ACTIVITIES RELATED TO EROSION CONTROL ON HIGHWAY CONSTRUCTION [a]

| RESEARCH PROJECT TITLE | RESEARCH AGENCY | HRIP NO.[b] |
|---|---|---|
| Reverse Filter Erosion Protection | University of Connecticut | 23 041592 |
| Design to Control Erosion in Roadside Drainage Channels | University of Minnesota | 23 089321 |
| Sediment Yield from Highway Slopes in the South | Department of Agriculture, SWC Research Div. ARS | 23 203716 |
| Stabilization and Runoff Regulation in Conifer Watersheds of Western Washington and Oregon | Oregon State University, Pacific NW Forest & Range Exp. Sta. | 23 203728 |
| Roadside Development (Weed Control, Erosion Control) | Purdue University | 24 012591 |
| Stabilization of Batter Slopes with Vegetation | Ministry of Works (New Zealand) | 24 060798 |
| Grass Planting on Green Strips in Road Construction | Gartenbauschule Kant, Berne (Switzerland) | 24 063269 |
| The Effect on the Properties of Virgin Soil of the Methods Used to Extract, Store, and Cover It | Federal Institute for Road Research (Germany) | 24 064287 |
| Sodding Experiments on Highway Slopes | National Highway Department (Brazil) | 24 066565 |
| Stability and Erosion Resistance of Earth Slopes | Ministry of Works (Kenya) | 24 069309 |
| Evaluation of Woody Plants and Development of Establishment Procedures for Direct Seeding and/or Vegetative Reproduction | Maryland State Department of Transportation; Soil Conservation Serv., Agr. Dept. | 24 081369 |
| Establishment and Maintenance of Roadside Vegetation | Texas Transportation Institute | 24 204474 |
| Selection, Establishment, and Maintenance of Vegetation for Erosion Control on Roadside Areas in Georgia | University of Georgia; Georgia State Highway Department | 24 213538 |
| Vegetative Cover for Highway Rights-of-Way | Washington Department of Highways | 24 215242 |
| Plant Materials Study | U.S.D.A. Soil Conservation Service | 24 220114 |
| Erosion Evaluation Study | Louisiana Department of Highways | 24 220215 |
| Asphalt Binding of Cobbles for Riprap | Bureau of Reclamation | 31 081629 |
| Erosion-Controlled Measures in Highway Construction, Pennsylvania | Geological Survey | 33 208235 |
| Establishment and Maintenance of Roadside Plantings and Turf | Kentucky Department of Highways | 40 007076 |
| Selection of Woody Plants to be Used for Highway Landscaping and Erosion Control | Arkansas State University, Jonesboro | 40 019357 |
| Preventing or Controlling Accelerated Erosion of Unstable Forest Soils—Northern Rocky Mountains | Agricultural Res. Service, Agr. Dept., Intermountain Forest & Range Ex. Station | 61 203674 |
| Stabilization of Slopes | Bureau of Reclamation | 62 043527 |
| Protection of Slopes Against Erosion | Civil Engr. Res. Institute (Japan) | 62 061223 |
| Soil Stabilization for Erosion Control | Purdue University and Indiana State Highway Commission | 62 221354 |
| Logging Methods and Management of Cutover and Burned Lands to Maintain Soil Stability in Douglas Fir and Mixed-Conifer Watersheds | Agriculture Department, Pacific NW Forest & Range Exp. Sta. | 63 040289 |
| Re-Vegetating Silt Cutbacks for Erosion Control | Alaska Department of Highways | 63 213682 |

[a] As of January 1973. [b] Acquisition number assigned by the Highway Research Information Service of the Highway Research Board; HRIP = publication entitled *Highway Research in Progress* (current issue).

from added research findings. The erodibility determinations for all subsoils throughout the U.S. should be supported to take the guesswork out of erosion and sediment yields from highways during construction. Erodibility (*K* factors), mostly developed for agriculture, should be reworked so that the factors are entirely acceptable to highway soils engineers.

Time of detention of sediment by particle size in settling pools seems to be poorly defined. The result is that many pools now being constructed are totally inadequate except to trap the coarser granules with negligible effects on turbidity. Without reliable methods to calculate sediment yields and basic data relative to settlement time requirements, it is not possible to accurately design, or even determine the need for, sediment pools. Empirical solutions have dramatically displayed the need for basic data. What amount of turbidity can be tolerated and for how long?

There is an apparent need for research to develop design criteria for stormwater management. Various types of channel linings, including grasses, sod, jute, plastic films, gravel blankets, and riprap, should be considered with other factors, such as soil type, rainfall intensity, channel grade, and channel side slopes. Special techniques, such as level spreaders, or special dikes, should be included. The results of this type of research should be helpful to construction operations and reduce erosion losses.

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# APPENDIX A

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# APPENDIX B

## GLOSSARY OF TERMS

AASHO CLASSIFICATION (soil engineering)—The official classification of soil materials and soil aggregate mixtures for highway construction used by the American Association of State Highway Officials.

AERATION, SOIL—The process by which air in the soil is replenished by air from the atmosphere. In a well-aerated soil the air in the soil is similar in composition to the atmosphere above the soil. Poorly aerated soils usually contain a much higher percentage of carbon dioxide and a correspondingly lower percentage of oxygen. The rate of aeration depends largely on the volume and continuity of pores in the soil.

AGRONOMIST—A specialist in agriculture (as affecting roadside grasses, erosion control, and soil management).

AIR POROSITY—The proportion of the bulk volume of soil that is filled with air at any given time or under a given condition, such as a specified moisture condition. Commonly considered to be the larger pores; that is, those filled with air when the soil is at field capacity. Sometimes called noncapillary pore space when determined as the bulk volume of pores that are unable to hold water when subjected to a tension of 60 cm of water.

ALKALI SOIL—(1) A soil with a high degree of alkalinity (pH 8.5 or higher) or with a high exchangeable sodium content (15 percent or more of the exchange capacity) or both. (2) A soil that contains sufficient alkali (sodium) to interfere with the growth of most crop plants.

ANGLE OF REPOSE—The angle between the horizontal and the maximum slope that a soil assumes through natural processes.

ANNUAL PLANT—A plant that completes its life cycle and dies in one year or less.

APRON—A floor or lining to protect a surface from erosion; for example, the pavement below chutes, spillways, culverts, or at the toes of dams.

ASPECT (forestry)—The direction that a slope faces.

AVAILABLE NUTRIENT—That portion of any element or compound in the soil that readily can be absorbed and assimilated by growing plants. Not to be confused with "exchangeable."

AVAILABLE WATER-HOLDING CAPACITY (soils)—The capacity to store water available for use by plants, usually expressed in linear depths of water per unit depth of soil. Commonly defined as the difference between the percentage of soil water at field capacity and the percentage at wilting point. This difference multiplied by the bulk density and divided by 100 gives a value in surface inches of water per inch depth of soil.

BAFFLES—Vanes, guides, grids, grating, or similar devices placed in a conduit to deflect or regulate flow and effect a more uniform distribution of velocities.

BASE FLOW—The stream discharge from groundwater runoff.

BASIN (hydrology)—The area drained by a river. (2) (irrigation) A level plot or field, surrounded by dikes, that may be flood irrigated.

BEDLOAD—The sediment that moves by sliding, rolling, or bounding on or very near the streambed; sediment moved mainly by tractive or gravitational forces, or both, but at velocities less than the surrounding flow.

BERM—A raised and elongated area of earth intended to direct the flow of water, screen headlight glare, or redirect out-of-control vehicles.

BLOWOUT—(1) An excavation in areas of loose soil, usually sand, produced by wind. (2) A breakthrough or rupture of a soil surface attributable to hydraulic pressure, usually associated with sand boils.

BORROW PIT—The excavation resulting from the extraction of borrow.

BROADCAST SEEDING—Scattering seed on the surface of the soil. Contrast with drill seeding, which places the seed in rows in the soil.

BRUSH MATTING—(1) A matting of branches placed on badly eroded land to conserve moisture and reduce erosion while trees or other vegetative cover are being established. (2) A matting of mesh wire and brush used to retard streambank erosion.

BUNCHGRASS—A grass that does not have rhizomes or stolons and forms a bunch or tuft.

CAPILLARY WATER—The water held in the "capillary" or small pores of a soil, usually with tension greater than 60 cm of water. Much of this water is considered to be readily available to plants.

CHANNEL—A natural stream that conveys water; a ditch or channel excavated for the flow of water.

CHANNEL STABILIZATION—Erosion prevention and stabilization of velocity distribution in a channel using jetties, drops, revetments, vegetation, and other measures.

CHECK DAM—A small dam constructed in a gully or other small watercourse to decrease the streamflow velocity, minimize channel scour, and promote deposition of sediment.

CHISELING—Breaking or loosening the soil, without inversion, with a chisel cultivator or chisel plow.

CHUTE—A high-velocity, open channel for conveying water to a lower level without erosion.

CLAY (soils)—(1) A mineral soil separate consisting of particles less than 0.002 mm in equivalent diameter. (2) A soil textural class. (3) (engineering) A fine-grained soil that has a high plasticity index in relation to the liquid limits.

CLEARING—The removal of vegetation, structures, or other objects as an item of highway construction.

CLIMATE—The sum total of all atmospheric or meteorological influences, principally temperature, moisture, wind, pressure, and evaporation, which combine to characterize a region and give it individuality by influencing the nature of its land forms, soils, vegetation, and land use.

CLOD—A compact, coherent mass of soil ranging in size from 5 to 10 mm (0.2 to 0.4 in.) to as much as 200 to 250 mm (8 to 10 in.); produced artificially, usually by the activity of man by plowing, digging, etc., especially when these operations are performed on soils that are either too wet or too dry for normal tillage operations.

CLONE—A group of plants derived by asexual reproduction from a single parent plant. Such plants are, therefore, of the same genetic constitution.

COMPANION CROP—Seeding of a short-life crop with the permanent species to aid in erosion control until the permanent species are established.

CONSERVATION—The protection, improvement, and use of natural resources according to principles that will assure their highest economic or social benefits.

CONSTRUCTION EASEMENT—(See EASEMENT)

CONTOUR—The shape of a land surface as expressed by contour lines.

CONTOUR DITCH—A ditch laid out approximately on the contour.

CONTOUR GRADING PLAN—A drawing showing an arrangement of contours intended to integrate construction and topography, improve appearance, retard erosion, and improve drainage.

CONTOUR LINE—(1) An imaginary line on the surface of the earth connecting points of the same elevation. (2) A line drawn on a map connecting points of the same elevation.

CONTROLLED BURNING—The deliberate use of fire where the burning is restricted to a predetermined area and intensity. Syn., PRESCRIBED BURNING.

COOL-SEASON PLANT—A plant that makes its major growth during the cool portion of the year, primarily in the spring, but in some localities in the winter.

CRITICAL VELOCITY—The velocity at which a given discharge changes from tranquil to rapid flow; that velocity in open channels for which the specific energy (sum of the depth and velocity head) is a minimum for a given discharge.

CUBIC FOOT PER SECOND—The rate of fluid flow at which 1 cu ft of fluid passes a measuring point in 1 sec. Abbr., cfs. Syn., SECOND-FOOT; CUSEC.

CURVILINEAR ALINEMENT—A design concept whereby the centerline projection has been developed in accordance with topographic and manmade controls and influences using a minimum of tangent sections.

CUT-AND-FILL—A process of earth moving by excavating part of an area and using the excavated material for adjacent embankments or fill areas.

CUTOFF—(1) A wall, collar, or other structure, such as a trench, filled with relatively impervious material intended to reduce seepage of water through porous strata. (2) In river hydraulics, the new and shorter channel formed either naturally or artificially when a stream cuts through the neck of a bend.

DAM—A barrier to confine or raise water for storage or diversion; to create a hydraulic head; to prevent gully erosion; or for retention of soil, rock, or other debris.

DEBRIS—A term applied to the loose material arising from the disintegration of rocks and vegetative material; transportable by streams, ice, or floods.

DEBRIS DAM—A barrier built across a stream channel to retain rock, sand, gravel, silt, or other material, such as trash or leaves.

DEBRIS GUARD—A screen or grate at the intake of a channel, drainage, or pump structure for the purpose of stopping debris.

DEPOSITION—The accumulation of material dropped because of a slackening movement of the transporting agent (water or wind).

DESILTING AREA—An area of grass, shrubs, or other vegetation used for inducing deposition of silt and other debris from flowing water, located above a stock tank, pond, field, or other area needing protection from sediment accumulation.

DETENTION DAM—A dam constructed for the purpose of temporary storage of streamflow or surface runoff and for releasing the stored water at controlled rates.

DIKE—A berm of earth or other material constructed to confine or control surface water in an established drainage system.

DIVERSION—A channel constructed across the slope for the purpose of intercepting surface runoff; changing the accustomed course of all or part of a stream. (See TERRACE)

DRAINAGE—(1) The removal of excess surface water or groundwater from land by means of surface or subsurface drains. (2) Soil characteristics that affect natural drainage.

DRAINAGE EASEMENT—(See EASEMENT)

DRILL SEEDING—Planting seed with a drill in relatively narrow rows, generally less than a foot apart. Contrast with BROADCAST SEEDING.

DROP-INLET SPILLWAY—An overfall structure in which the water drops through a vertical riser connected to a discharge conduit.

DROP STRUCTURE—A structure for dropping water to a lower level and dissipating its surplus energy; a fall. A drop may be vertical or inclined. Syn., DROP.

EASEMENT (CONSTRUCTION, DRAINAGE, PLANTING, SLOPE)—A right to use or control the property of another for designated highway purposes.

- CONSTRUCTION EASEMENT—An easement to permit the full development of the construction prism.
- DRAINAGE EASEMENT—An easement for directing the flow of water.
- PLANTING EASEMENT—An easement for reshaping roadside areas and establishing, maintaining, and controlling plant growth thereon.
- SLOPE EASEMENT—An easement for cuts or fills.

ECOLOGY—The branch of science concerned with the relationship of organisms and their environment.

EFFECTIVE PRECIPITATION—That portion of total precipitation that becomes available for plant growth. It does not include precipitation lost to deep percolation below the root zone or to surface runoff.

EMERGENCY SPILLWAY—A spillway used to carry runoff exceeding a given design flood.

ENDEMIC SPECIES—Restricted to a relatively small geographic area or to an unusual or rare type of habitat.

ENGINEER (RESIDENT, DESIGN, PROJECT)—A person trained in the science and profession of engineering.

ENVIRONMENT—The sum total of all the external conditions that may act upon an organism or community to influence its development or existence.

ENVIRONMENTAL DESIGN—A design (of a highway) that includes consideration of the impact of the facility on the community or region based on esthetic, ecological, cultural, sociological, economic, historical, conservation, and other factors.

ERODIBLE (geology and soils)—Susceptible to erosion.

EROSION—The wearing away of a land surface by detachment and transporting of soil and rock particles by the action of water, wind, or other agents.

EROSIVE—Refers to wind or water having sufficient velocity to cause erosion. Not to be confused with erodible as a quality of soil.

EXOTIC—An organism that has been introduced from another continent.

FERTILITY, SOIL—The quality of a soil that enables it to provide nutrients in adequate amounts and in proper balance for the growth of specified plants when other growth factors (such as light, moisture, temperature, and the physical condition of the soil) are favorable.

FIREBREAK (forestry)—An existing barrier, or one constructed before a fire occurs, from which inflammable materials have been removed to stop or check creeping or running fires. Also serves as a line from which to work and to facilitate the movement of men and equipment in fire suppression. Roads can also be designed for firebreaks.

FLUME—An open conduit on a prepared grade, trestle, or bridge for the purpose of carrying water across creeks, gullies, ravines, or other obstructions. It may also apply to an entire canal where it is elevated above natural ground for its entire length. Sometimes used in reference to calibrated devices used to measure the flow of water in open conduits.

FORB—An herbaceous plant that is not a grass, sedge, or rush.

GRADE—(1) The slope of a road, channel, or natural ground. (2) The finished surface of a canal bed, roadbed, top of embankment, or bottom of excavation; any surface prepared for the support of construction, like paving or laying a conduit. (3) To finish the surface of a canal bed, roadbed, top of embankment, or bottom of excavation.

GRADED STREAM—A stream in which, over a period of years, the slope is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for transportation of the load (of sediment) supplied from the drainage basin. The graded profile is a slope of transportation. It is a phenomenon in which the element of time has a restricted connotation.

GRADIENT—The rate of regular or graded ascent or descent.

GRASSED WATERWAY—A natural or constructed waterway, usually broad and shallow, covered with erosion-resistant grasses, used to conduct surface water from cropland.

GRAVEL—A mass of pebbles.

GRAVEL ENVELOPE—Selected aggregate placed around the screened-pipe section of well casing or a subsurface drain to facilitate the entry of water into the well or drain.

GRAVEL FILTER—Graded sand and gravel aggregate placed around a drain or well screen to prevent the movement of fine materials from the aquifer into the drain or well.

GROUND COVER—Herbaceous vegetation and low-growing woody plants that form an earth cover.

GROUNDWATER—Phreatic water or subsurface water in the zone of saturation.

GROWING SEASON—The time during which a plant is periodically producing growth. This period will vary depending on the climate and is usually specified in the contract. It reflects climatic conditions and normal growth periods for the area in which the work is to be accomplished.

GRUBBING—The process of removing roots, stumps, and low-growing vegetation.

HARDPAN—A hardened soil layer in the lower A or in the B horizon caused by cementation of soil particles with organic matter or with materials such as silica, sesquioxides, or calcium carbonate. The hardness does not change appreciably with changes in moisture content, and pieces of the hard layer do not slake in water.

HAUL ROAD—A temporary road, generally unimproved, used to transport material to and from highway construction, borrow pits, and waste areas.

HEAVING—The partial lifting of plants out of the ground, frequently breaking their roots, as a result of freezing and thawing of the surface soil during the winter.

HERBACEOUS—Vegetation that is nonwoody.

HERBICIDES—Chemicals used to control or eradicate vegetation.

HUMID—A term applied to regions or climates where moisture, when distributed normally throughout the year, should not be a limiting factor in the production of most crops. The lower limit of precipitation under cool climates may be as little as 20 inches annually. In hot climates it may be as much as 60 inches. Natural vegetation is generally forest.

HUMUS—(1) That more or less stable fraction of the soil organic matter remaining after the major portion of added plant and animal residues has decomposed, usually amorphous and dark colored. (2) Includes the F and H layers in undisturbed forest soils. (See SOIL ORGANIC MATTER; soil horizons 01 and 02.)

HYDRAULIC GRADE LINE—In a closed conduit, a line joining the elevations to which water could stand in risers or vertical pipes connected to the conduit at their lower end and open at their upper end. In open channel flow, the free surface of the water.

HYDRAULIC GRADIENT—The slope of the hydraulic grade line. The slope of the free surface of water flowing in an open channel.

HYDRAULIC JUMP—The sudden turbulent rise in water level from a flow stage below critical depth to a flow stage above critical depth, during which the velocity passes from supercritical to subcritical.

IMPOUNDMENT—Generally, an artificial collection or storage of water, as a reservoir, pit, dugout, sump, etc. (See RESERVOIR.)

INDIGENOUS—Produced, growing, or living naturally in a particular region or environment.

INFILTRATION—The flow of a liquid into a substance through pores or other openings, connoting flow into a soil in contradistinction to "percolation," which connotes flow through a porous substance.

INLET (hydraulics)—(1) A surface connection to a closed drain. (2) A structure at the diversion end of a conduit. (3) The upstream end of any structure through which water may flow.

INOCULATION—The process of introducing pure or mixed cultures of microorganisms into natural or artificial culture media for legume seed treatment.

INTERCEPTION CHANNEL—A channel excavated at the top of earth cuts, at the foot of slopes, or at other critical places to intercept surface flow; a catch drain. Syn., INTERCEPTION DITCH.

INTERCEPTOR DRAIN—A surface or subsurface drain, or a combination of both, designed and installed to intercept flowing water.

INTERCHANGE—A system of interconnecting roadways in conjunction with one or more grade separations, providing for the movement of traffic between two or more roadways on different levels.

INTERNAL SOIL DRAINAGE—The downward movement of water through the soil profile. The rate of movement is determined by the texture, structure, and other characteristics of the soil profile and underlying layers and by the height of the water table, either permanent or perched. Relative terms for expressing internal drainage are none, very slow, slow, medium, rapid, and very rapid.

INVERT—The lowest part of the internal cross section of a lined channel or conduit.

LANDSCAPE ARCHITECT—A person trained in the art and science of arranging land and objects upon it for human use and enjoyment.

LANDSCAPE PERSONNEL—Persons trained, engaged in, or associated with roadside development. The term may include agronomists, architects, engineers, foresters, horticulturists, landscape architects, and others.

LANDSLIDE—The failure of a slope in which the movement of the soil mass takes place along an interior surface of sliding.

LEACHED SOIL—A soil from which most of the soluble materials ($CaCO_3$, $MgCO_3$, and more soluble materials) have been removed from the entire profile or have been removed from one part of the profile and have accumulated in another part.

LEACHING—The removal of materials in solution from the soil.

LEGUME—A member of the legume or pulse family, *Leguminosae*. One of the most important and widely distributed plant families. The fruit is a "legume" or pod that opens along two sutures when ripe. Flowers are usually papilionaceous (butterflylike). Leaves are alternate, have stipules, and are usually compound. Includes many valuable food and forage species, such as the peas, beans, peanuts, clovers, alfalfas, sweet clovers, lespedezas, vetches, and kudzu. Practically all legumes are nitrogen-fixing plants.

LINING (hydraulics)—A protective covering over all or part of the perimeter of a reservoir or a conduit to prevent seepage losses, withstand pressure, resist erosion, and reduce friction or otherwise improve conditions of flow.

LOESS—Material transported and deposited by wind and consisting of predominantly silt-sized particles.

MEDIAN—The portion of a divided highway separating the traveled ways for traffic in opposite directions.

MULCH—A natural or artificial layer of material placed on exposed earth to provide more desirable moisture and temperature relationships for plant growth. It is also used to control the occurrence of unwanted vegetation.

NATIVE SPECIES—A species that is a part of an area's original fauna or flora.

OUTFALL—The point where water flows from a conduit, stream, or drain.

OVERFALL—An abrupt change in stream channel elevation; the part of a dam or weir over which the water flows.

PARENT MATERIAL (soils)—The unconsolidated, chemically weathered mineral or organic matter from which the solum of soils has developed by pedogenic processes. The C horizon may or may not consist of materials similar to those from which the A and B horizons developed.

PARTICLE-SIZE ANALYSIS—Determination of the amounts of different particle sizes in a soil sample, usually by sedimentation, sieving, micrometry, or combinations of these methods.

PERCOLATION, SOIL WATER—The downward movement of water through soil, especially the downward flow of water in saturated or nearly saturated soil at hydraulic gradients of the order of 1.0 or less.

PERENNIAL PLANT—A plant that normally lives for three or more years.

PERMEABILITY—The capacity for transmitting a fluid. It is measured by the rate at which a fluid of standard viscosity can move through material in a given interval of time under a given hydraulic gradient.

PERMISSIBLE VELOCITY (hydraulics)—The highest velocity at which water may be carried safely in a channel or other conduit. The highest velocity that can exist through a substantial length of a conduit and not cause scour of the channel. Syn., SAFE or NONERODING VELOCITY.

pH, SOIL—A numerical measure of the acidity or hydrogen ion activity of a soil. The neutral point is pH 7.0. All pH values below 7.0 are acid and all above 7.0 are alkaline.

PLANT REGENERATION—The development of volunteer vegetation from seed or by other natural reproductive processes from plants existing nearby.

PLANTING SEASON—The period of the year when planting and/or transplanting is considered advisable from the standpoint of successful establishment and good horticultural practices.

POLLUTION—Contamination of any component of the total environment by harmful substances, sounds, smells, or sights degrading or injurious to humans and other living organisms.

PURE LIVE SEED—The product of the percentage of germination plus the hard seed and the percentage of pure seed, divided by 100.

RAINFALL INTENSITY—The rate at which rain is falling at any given instant, usually expressed in inches per hour.

RESERVOIR—An impounded body of water, or controlled lake, in which water is collected or stored.

RESTORATION—The act of bringing back to a former position, condition, or character; relates to roadsides, buildings, monuments, and sites.

REVETMENT—A facing of stone or other material, either permanent or temporary, placed along the edge of a stream to stabilize the bank and protect it from the erosive action of the stream.

RIGHT-OF-WAY—A general term denoting land, property, or interest therein, usually in a strip, acquired for or devoted to transportation purposes.

RILL EROSION—An erosion process in which numerous small channels only several inches deep are formed; occurs mainly on recently cultivated soils.

RIPRAP—Broken rock, cobbles, or boulders placed on earth surfaces, such as the face of a dam or the bank of a stream, for protection against the action of water (waves); also applied to brush or pole mattresses, or brush and stone, or other similar materials used for soil erosion control.

ROUGHNESS COEFFICIENT (hydraulics)—A factor in velocity and discharge formulas representing the effect of channel roughness on energy losses in flowing water. Manning's $n$ is a commonly used roughness coefficient.

ROUNDING, SLOPE—The modeling or contouring of roadside slopes to provide a curvilinear transition between several planes; e.g., tops, bottoms, and ends of cuts and fills.

RUNOFF (hydraulics)—That portion of the precipitation on a drainage area that is discharged from the area in stream channels. Types include surface runoff, groundwater runoff, or seepage.

SALINE SOIL—A nonalkali soil containing sufficient soluble salts to impair its productivity but not containing excessive exchangeable sodium. This name was formerly applied to any soil containing sufficient soluble salts to interfere with plant growth, commonly greater than 3,000 ppm.

SALTATION—Particle movement in water or wind where particles skid or bounce along the streambed or soil surface.

SAND—(1) a soil particle between 0.05 and 2.0 mm in diameter. (2) Any one of five soil separates: very coarse sand, coarse sand, medium sand, fine sand, and very fine sand. (3) A soil textural class.

SAUSAGE DAM—A dam of loose rock which has been wrapped with wire into cylindrical bundles that are laid in a horizontal or vertical position.

SCALPING—Removal of sod or other vegetation in spots or strips.

SCARIFY—To abrade, scratch, or modify the surface; for example, to scratch the impervious seed coat of hard seed, or to break the surface of the soil with a narrow-bladed implement.

SCOUR—To abrade and wear away. Used to describe the wearing away of terrace or diversion channels or streambeds.

SEDIMENT—Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

SEDIMENT LOAD—The quantity of sediment, measured in dry weight or by volume, transported through a stream cross section in a given time. Sediment load consists of both suspended load and bedload.

SEDIMENT POOL (BASIN)—The reservoir space allotted to the accumulation of submerged sediment during the life of the structure.

SEDIMENTATION—The action or process of depositing particles of waterborne or windborne soil, rock, or other materials.

SEED PURITY—The percentage of the desired species in relation to the total quantity, including other species, weed seed, and foreign matter.

SEEDBED—The soil prepared by natural or artificial means to promote the germination of seed and the growth of seedlings.

SEEPAGE—(1) Water escaping through or emerging from the ground along an extensive line or surface as contrasted with a spring where the water emerges from a localized spot. (2) The process by which water percolates through the soil. (3) (percolation) The slow movement of gravitational water through the soil.

SELECTED MATERIAL—Suitable native material obtained from roadway cuts or borrow areas, or other similar material used for subbase, roadbed material, shoulder surfacing, slope cover, or other specific purposes.

SEMIARID—A term applied to regions or climates where moisture is normally greater than under arid conditions but still definitely limits the growth of most crops. Dryland farming methods or irrigation generally are required for crop production. The upper limit of average annual precipitation in the cool semiarid regions is as low as 15 inches, whereas in tropical regions it is as high as 45 or 50 inches.

SETTLING BASIN—An enlargement in the channel of a stream to permit the settling of debris carried in suspension.

SHEET EROSION—The removal of a fairly uniform layer of soil from the land surface by runoff water.

SHEET FLOW—Water, usually storm runoff, flowing in a thin layer over the ground surface. Syn., OVERLAND FLOW.

SHEET PILING—A diaphragm made of meshing or interlocking members of wood, steel, concrete, or other material, driven individually, used to form an obstruction to percolation, prevent movement of material, stabilize foundations, and build cofferdams.

SIDE SLOPE (engineering)—The slope of the sides of a canal, dam, or embankment. It is customary to name the horizontal distance first, as 1.5:1, or, frequently, 1½:1, meaning a horizontal distance of 1.5 feet to 1 foot vertical.

SILT—(1) A soil separate consisting of particles between 0.05 and 0.002 mm in equivalent diameter. (2) A soil textural class.

SLASH—The branches, bark, tops, cull logs, and broken or uprooted trees on the ground after logging.

SLIP—The downslope movement of a soil mass under wet or saturated conditions; a microlandslide that produces a microrelief in soils.

SLOPE—The degree of deviation of a surface from the horizontal, usually expressed in percent or degrees.

SLOPE CHARACTERISTICS—Slopes may be characterized as concave (decrease in steepness in lower portion), uniform, or convex (increase in steepness at base). Erosion is strongly affected by shape, ranked in order of increasing erodibility from concave to uniform to convex.

SLOPE DRAINS—Permanent or temporary devices that are used to carry water down cut or embankment slopes. May be pipe, half sections, paved, or have special plastic lining.

SOD—A closely knit ground cover growth, primarily of grasses.

SOD GRASSES—Stoloniferous or rhizomatous grasses that form a sod or turf.

SOIL—The loose surface material of the earth in which plants grow.

SOIL CONDITIONER—Any material added to a soil for the purpose of improving its physical condition.

SOIL EROSION—The detachment and movement of soil from the land surface by wind or water. (See RILL EROSION, SHEET EROSION, WIND EROSION.)

SOIL HORIZON—A layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics, such as color, structure, texture, consistency, kinds and numbers of organisms present, degree of acidity or alkalinity.

SOIL ORGANIC MATTER—The organic fraction of the soil that includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil sample passed through a 2-mm sieve.

SOIL SURVEY—A general term for the systematic examination of soils in the field and in laboratories; their description and classification; the mapping of kinds of soil; the interpretation of soils according to their adaptability for various crops, grasses, and trees; their behavior under use or treatment for plant production or for other purposes.

SPOILBANK (WASTE)—A pile of soil, subsoil, rock, or other material excavated from a drainage ditch, pond, or other cut.

SPRIGGING—The planting of a portion of the stem and root of grass.

STABILIZED GRADE—The slope of a channel at which neither erosion nor deposition occurs.

STILLING BASIN—An open structure or excavation at the foot of an overfall, chute, drop, or spillway to reduce the energy of the descending stream.

STUBBLE MULCH—The stubble of crops or crop residues left essentially in place on the land as a surface cover during fallow and the growing of a succeeding crop.

SUBCRITICAL FLOW—Flow at velocities less than critical.

SUBSOIL—The stratum of material beneath the surface soil.

SURFACE SOIL—The uppermost part of the soil, ordinarily moved in tillage, or its equivalent in uncultivated soils, ranging in depth from about 5 to 8 inches. Frequently designated as the plow layer, the Ap layer, or the Ap horizon.

TERRACE—An embankment or combination of an embankment and channel constructed across a slope to control erosion by diverting or storing surface runoff instead of permitting it to flow uninterrupted down the slope. Terraces or terrace systems may be classified by their alignment, gradient, outlet, and cross section. Alignment is parallel or nonparallel. Gradient may be level, uniformly graded, or variably graded. Grade is often incorporated to permit paralleling the terraces. Outlets may be soil infiltration only, vegetated waterways, tile outlets, or combinations of these. Cross sections may be narrow base, broad base, bench, steep backslope, flat channel, or channel.

TOE (engineering)—The terminal edge or edges of a structure.

TOLERANT—Capable of growth and survival under restricted growing conditions.

TOPOGRAPHY—The configuration of the earth's surface, including the shape and position of its natural and manmade features.

TOPSOIL—The upper layer of soil, containing organic matter and suited for plant survival and growth.

TOTAL DESIGN—The integration of all elements relating to a highway, its roadsides, and its environs into a single, unified, interrelated design.

TRANSITION—The gradual change from one condition, quality, or character to another.

TRANSPIRATION—The process by which water vapor is released to the atmosphere by the foliage or other parts of a living plant.

TRAP EFFICIENCY—The capability of a basin to trap sediment.

TURF—The surface mat of grasses and plant roots in soil.

VEGETATION—Plant life collectively.

WARM-SEASON PLANT—A plant that completes most of its growth during the warm portion of the year, generally late spring and summer.

WASTE (SPOIL)—Excess earth, rock, vegetation, or other materials resulting from highway construction.

WASTE AREA—An area on or off the right-of-way providing for the disposal of waste.

WATER CONTROL (soil and water conservation)—The physical control of water by such measures as conservation practices on the land, channel improvements, and installation of structures for water retardation and sediment detention (does not refer to legal control or water rights as defined).

WATERSHED AREA—All land and water within the confines of a drainage divide or a water problem area, consisting in whole or in part of land needing drainage or irrigation.

WATERSPREADING—The application of water to lands for the purpose of increasing the growth of natural vegetation or to store it in the ground for subsequent withdrawal by pumps for irrigation.

WIND EROSION—The detachment and transportation of soil by wind.

# APPENDIX C

## EROSION CONTROL CHECK LISTS

### LOCATION, DESIGN AND CONSTRUCTION CHECK LIST

The following is a suggested list of questions. Each agency should develop a list to meet its own requirements.

#### LOCATION

Are soil maps and aerial photographs available to help locate areas or sections with high erosion potential? ☐

Has erosion potential been considered for each alignment alternative? ☐

How will adjacent and nearby streams, ponds and lakes be affected by project construction? ☐

Can sediment from construction activities be collected on or near the project? ☐

Will special erosion control and sediment collection measures be required to protect adjacent properties? ☐

#### DESIGN

Has the soil survey or foundation investigation been analyzed to assess erosion potential? ☐

Are there areas where soil conditions indicate that severe erosion is a possibility? ☐

Does the adjoining or nearby property require special erosion control or sediment collection methods? ☐

Should additional ROW or easements be provided to permit sediment allocation? ☐

Will special easement be required during construction or for maintenance operations? ☐

What effect will construction sequence, method of operations or season of work have on control measures? ☐

Are special provisions, plans or plan notes required for construction? ☐

Is coordination required with others? ☐

Have sediment traps, settling basins, diversion dikes, berms, slope drains, sodding, ditch paving, slope paving, and other work items been identified on the plans and provided in the contract? ☐

Are provisions made for sediment removal and disposal? ☐

Are extra funds included for emergency or unforeseen work? ☐

Was joint design-construction PS&E erosion check made in field? ☐

Will a design representative that is familiar with project erosion control measures attend the preconstruction conference? ☐

Has a design review been established to review project design, including erosion control measures? ☐

## CONSTRUCTION

Has one staff or project member been assigned specific responsibility for discussing erosion control? ☐

Are there utilities, other agencies or private companies that should participate in erosion control discussion? ☐

Does the contractor have an acceptable work plan that includes satisfactory provisions for erosion control? ☐

Has the contractor assigned a specific individual to work with project personnel to monitor erosion control measures? ☐

What erosion control and sediment collection measures are required before clearing and other work is started? ☐

Are maximum disturbed area restrictions satisfied? ☐

Are the plan measures satisfactory? ☐

What other measures are needed? ☐

Do they require force account, plan change or supplemental agreements? ☐

Are joint field checks made by project and contractor personnel during rainstorms? ☐

Is the maintenance of all devices and measures satisfactory? ☐

Is the contractor completing stage work such as seeding and mulch, sodding, ditch paving, or riprap as soon as practical? ☐

Are borrow and/or waste operations, erosion control and sediment collection measures satisfactory? ☐

Are photographs or other efforts needed to document actual job or adjacent property conditions? ☐

Will it be desirable that selected sediment devices be incorporated into permanent erosion control measures? ☐

Have inadequacies in planning, design and construction been identified and reported? ☐

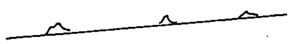
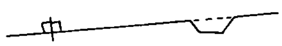
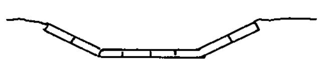
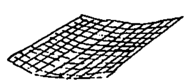
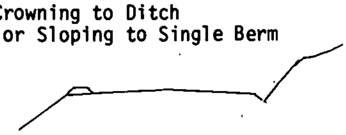
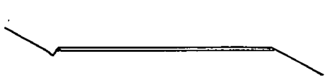
SEDIMENT COLLECTION
CHECK LIST

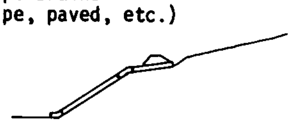
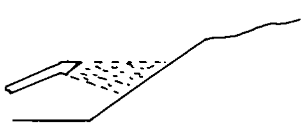
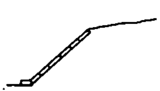
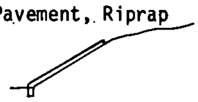
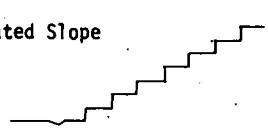
| CONSTRUCTION OPERATION | A. SETTLEMENT PONDS | B. SEDIMENT BASINS | C. CHECK DAMS | D. FILTER BARRIERS | E. DIVERSION DIKES AND DITCHES | F. BERMS | G. SLOPE DRAINS | H. LEVEL SPREADERS | I. SEEDING/MULCHING | J. MULCHING | K. SODDING | L. DITCH PAVING | M. SLOPE PAVING | N. RIPRAP | O. OTHER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. CLEARING AND GRUBBING | | | | | | | | | | | | | | | |
| 2. CULVERTS | | | | | | | | | | | | | | | |
| 3. CHANNEL CHANGES | | | | | | | | | | | | | | | |
| 4. BRIDGE STRUCTURES | | | | | | | | | | | | | | | |
| 5. PIER CONSTRUCTION | | | | | | | | | | | | | | | |
| 6. STREAM CROSSINGS | | | | | | | | | | | | | | | |
| 7. HAUL ROADS | | | | | | | | | | | | | | | |
| 8. EXCAVATION | | | | | | | | | | | | | | | |
| 9. BORROW | | | | | | | | | | | | | | | |
| 10. WASTING | | | | | | | | | | | | | | | |
| 11. EMBANKMENT | | | | | | | | | | | | | | | |
| 12. SUBGRADE | | | | | | | | | | | | | | | |
| 13. BASE COURSE | | | | | | | | | | | | | | | |
| 14. PAVING | | | | | | | | | | | | | | | |
| 15. SHOULDERS | | | | | | | | | | | | | | | |
| 16. LANDSCAPING | | | | | | | | | | | | | | | |

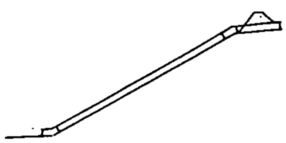
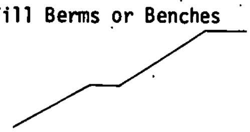
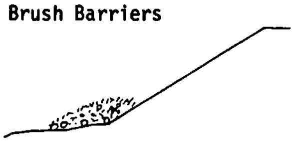
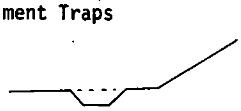
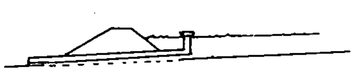
(after PennDot)

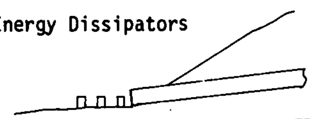
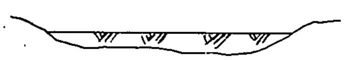
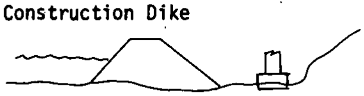
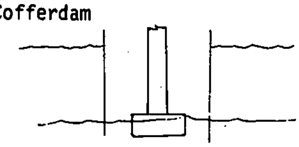
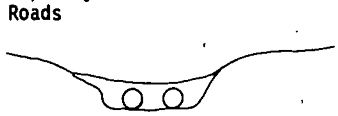
# APPENDIX D

## EROSION CONTROL PRACTICES

| Treatment Practice | Advantages | Problems |
|---|---|---|
| ROADWAY DITCHES | | |
| Check Dams<br> | Maintain low velocities<br>Catch sediment<br>Can be constructed of logs, shot rock, lumber, masonry or concrete | Close spacing on steep grades<br>Require clean-out<br>Unless keyed at sides and bottom, erosion may occur |
| Sediment Traps/ Straw Bale Filters<br> | Can be located as necessary to collect sediment during construction<br>Clean-out often can be done with on-the-job equipment<br>Simple to construct | Little direction on spacing and size<br>Sediment disposal may be difficult<br>Specification must include provisions for periodic clean-out<br>May require seeding, sodding or pavement when removed during final cleanup |
| Sodding<br> | Easy to place with a minimum of preparation<br>Can be repaired during construction<br>Immediate protection<br>May be used on sides of paved ditches to provide increased capacity | Requires water during first few weeks<br>Sod not always available<br>Will not withstand high velocity or severe abrasion from sediment load |
| Seeding with Mulch and Matting<br> | Usually least expensive<br>Effective for ditches with low velocity<br>Easily placed in small quantities with inexperienced personnel | Will not withstand medium to high velocity |
| Paving, Riprap, Rubble | Effective for high velocities<br>May be part of the permanent erosion control effort | Cannot always be placed when needed because of construction traffic and final grading and dressing<br>Initial cost is high |
| ROADWAY SURFACE | | |
| Crowning to Ditch or Sloping to Single Berm<br> | Directing the surface water to a prepared or protected ditch minimizes erosion | None - should be part of good construction procedures |
| Compaction | The final lift of each day's work should be well compacted and bladed to drain to ditch or berm section. Loose or uncompacted material is more subject to erosion | None - should be part of good construction procedures |
| Aggregate Cover<br> | Minimizes surface erosion<br>Permits construction traffic during adverse weather<br>May be used as part of permanent base construction | Requires reworking and compaction if exposed for long periods of time<br>Loss of surface aggregates can be anticipated |
| Seed/Mulch | Minimizes surface erosion | Must be removed or is lost when construction of pavement is commenced |

| Treatment Practice | Advantages | Problems |
|---|---|---|
| CUT SLOPES | | |
| Berm @ top of cut  | Diverts water from cut<br>Collects water for slope drains/paved ditches<br>May be constructed before grading is started | Access to top of cut<br>Difficult to build on steep natural slope or rock surface<br>Concentrates water and may require channel protection or energy dissipation devices<br>Can cause water to enter ground, resulting in sloughing of the cut slope |
| Diversion Dike  | Collects and diverts water at a location selected to reduce erosion potential<br>May be incorporated in the permanent project drainage | Access for construction<br>May be continuing maintenance problem if not paved or protected<br>Disturbed material or berm is easily eroded |
| Slope Benches  | Slows velocity of surface runoff<br>Collects sediment<br>Provides access to slope for seeding, mulching, and maintenance<br>Collects water for slope drains or may divert water to natural ground | May cause sloughing of slopes if water infiltrates<br>Requires additional ROW<br>Not always possible due to rotten material etc.<br>Requires maintenance to be effective<br>Increases excavation quantities |
| Slope Drains (pipe, paved, etc.)  | Prevents erosion on the slope<br>Can be temporary or part of permanent construction<br>Can be constructed or extended as grading progresses | Requires supporting effort to collect water<br>Permanent construction is not always compatible with other project work<br>Usually requires some type of energy dissipation |
| Seeding/Mulching  | The end objective is to have a completely grassed slope. Early placement is a step in this direction. The mulch provides temporary erosion protection until grass is rooted. Temporary or permanent seeding may be used. Mulch should be anchored. Larger slopes can be seeded and mulched with smaller equipment if stage techniques are used. | Difficult to schedule high production units for small increments<br>Time of year may be less desirable<br>May require supplemental water<br>Contractor may perform this operation with untrained or unexperienced personnel and inadequate equipment if stage seeding is required |
| Sodding  | Provides immediate protection<br>Can be used to protect adjacent property from sediment and turbidity | Difficult to place until cut is complete<br>Sod not always available<br>May be expensive |
| Slope Pavement, Riprap  | Provides immediate protection for high risk areas and under structures<br>May be cast in place or off site | Expensive<br>Difficult to place on high slopes<br>May be difficult to maintain |
| Temporary Cover | Plastics are available in wide rolls and large sheets that may be used to provide temporary protection for cut or fill slopes<br>Easy to place and remove<br>Useful to protect high risk areas from temporary erosion | Provides only temporary protection<br>Original surface usually requires additional treatment when plastic is removed<br>Must be anchored to prevent wind damage |
| Serrated Slope  | Lowers velocity of surface runoff<br>Collects sediment<br>Holds moisture<br>Minimizes amount of sediment reaching roadside ditch | May cause minor sloughing if water infiltrates<br>Construction compliance |

| Treatment Practice | Advantages | Problems |
|---|---|---|
| FILL SLOPES | | |
| Berms at Top of Embankment  | Prevent runoff from embankment surface from flowing over face of fill<br>Collect runoff for slope drains or protected ditch<br>Can be placed as a part of the normal construction operation and incorporated into fill or shoulders | Cooperation of construction operators to place final lifts at edge for shaping into berm<br>Failure to compact outside lift when work is resumed<br>Sediment buildup and berm failure |
| Slope Drains  | Prevent fill slope erosion caused by embankment surface runoff<br>Can be constructed of full or half section pipe, bituminous, metal, concrete, plastic, or other waterproof material<br>Can be extended as construction progresses<br>May be either temporary or permanent | Permanent construction as needed may not be considered desirable by contractor<br>Removal of temporary drains may disturb growing vegetation<br>Energy dissipation devices are required at the outlets |
| Fill Berms or Benches  | Slows velocity of slope runoff<br>Collects sediment<br>Provides access for maintenance<br>Collects water for slope drains<br>May utilize waste | Requires additional fill material if waste is not available<br>May cause sloughing<br>Additional ROW may be needed |
| Seeding/Mulching | Timely application of mulch and seeding decreases the period a slope is subject to severe erosion<br>Mulch that is cut in or otherwise anchored will collect sediment. The furrows made will also hold water and sediment | Seeding season may not be favorable<br>Not 100 percent effective in preventing erision<br>Watering may be necessary<br>Steep slopes or locations with low velocities may require supplemental treatment |
| PROTECTION OF ADJACENT PROPERTY | | |
| Brush Barriers  | Use slashing and logs from clearing operation<br>Can be covered and seeded rather than removed<br>Eliminates need for burning or disposal off ROW | May be considered unsightly in urban areas |
| Straw Bale Barriers  | Straw is readily available in many areas<br>When properly installed, they filter sediment and some turbidity from runoff | Require removal<br>Subject to vandal damage<br>Flow is slow through straw requiring considerable area |
| Sediment Traps  | Collect much of the sediment spill from fill slopes and storm drain ditches<br>Inexpensive<br>Can be cleaned and expanded to meet need | Do not eliminate all sediment and turbidity<br>Space is not always available<br>Must be removed (usually) |
| Sediment Pools  | Can be designed to handle large volumes of flow<br>Both sediment and turbidity are removed<br>May be incorporated into permanent erosion control plan | Require prior planning, additional ROW and/or flow easement<br>If removal is necessary, can present a major effort during final construction stage<br>Clean-out volumes can be large<br>Access for clean-out not always convenient |

| Treatment Practice | Advantages | Problems |
|---|---|---|
| PROTECTION OF ADJACENT PROPERTY (continued) | | |
| Energy Dissipators  | Slow velocity to permit sediment collection and to minimize channel erosion off project | Collect debris and require cleaning<br>Require special design and construction of large shot rock or other suitable material from project |
| Level Spreaders  | Convert collected channel or pipe flow back to sheet flow<br>Avoid channel easements and construction off project<br>Simple to construct | Adequate spreader length may not be available<br>Sodding of overflow berm is usually required<br>Must be a part of the permanent erosion control effort<br>Maintenance forces must maintain spreader until no longer required |
| PROTECTION OF STREAM | | |
| Construction Dike  | Permits work to continue during normal stream stages<br>Controlled flooding can be accomplished during periods of inactivity | Usually requires pumping of work site water into sediment pond<br>Subject to erosion from stream and from direct rainfall on dike |
| Cofferdam  | Work can be continued during most anticipated stream conditions<br>Clear water can be pumped directly back into stream<br>No material deposited in stream | Expensive |
| Temporary Stream Channel Change | Prepared channel keeps normal flows away from construction | New channel usually will require protection<br>Stream must be returned to old channel and temporary channel refilled |
| Riprap | Sacked sand with cement or stone easy to stockpile and place<br>Can be installed in increments as needed | Expensive |
| Temporary Culverts for Haul Roads  | Eliminate stream turbulence and turbidity<br>Provide unobstructed passage for fish and other water life<br>Capacity for normal flow can be provided with storm water flowing over the roadway | Space not always available without conflicting with permanent structure work<br>May be expensive, especially for larger sizes of pipe<br>Subject to washout |
| Rock-lined Low-Level Crossing  | Minimizes stream turbidity<br>Inexpensive<br>May also serve as ditch check or sediment trap | May not be fordable during rainstorms<br>During periods of low flow passage of fish may be blocked |

| Treatment Practice | Advantages | Problems |
|---|---|---|
| BORROW AREAS | | |
| Selective Grading and Shaping | Water can be directed to minimize off-site damage<br>Flatter slopes enable mulch to be cut into soil | May not be most economical work method for contractor |
| Stripping and Replacing of Topsoil | Provides better seed bed<br>Conventional equipment can be used to stockpile and spread topsoil | May restrict volume of material that can be obtained for a site<br>Topsoil stockpiles must be located to minimize sediment damage<br>Cost of rehandling material |
| Dikes, Berms<br>Diversion Ditches<br>Settling Basins<br>Sediment Traps<br>Seeding & Mulch | See other practices | See other practices |

# APPENDIX E

## SOIL CONSERVATION SERVICE OFFICES

### REGIONAL TECHNICAL SERVICE CENTERS

| REGION | LOCATION |
|---|---|
| Northeast | Upper Darby, Pa. |
| Midwest | Lincoln, Nebr. |
| South | Fort Worth, Tex. |
| West | Portland, Ore. |

### STATE OFFICES

| STATE | CITY |
|---|---|
| Alabama | Auburn |
| Alaska | Palmer |
| Arizona | Phoenix |
| Arkansas | Little Rock |
| California | Berkeley |
| Colorado | Denver |
| Connecticut | Storrs |
| Delaware | Newark |
| Florida | Gainesville |
| Georgia | Athens |

### STATE OFFICES (*Continued*)

| STATE | CITY |
|---|---|
| Hawaii | Honolulu |
| Idaho | Boise |
| Illinois | Champaign |
| Indiana | Indianapolis |
| Iowa | Des Moines |
| Kansas | Salina |
| Kentucky | Lexington |
| Louisiana | Alexandria |
| Maine | Orono |
| Maryland | College Park |
| Massachusetts | Amherst |
| Michigan | East Lansing |
| Minnesota | St. Paul |
| Mississippi | Jackson |
| Missouri | Columbia |
| Montana | Bozeman |
| Nebraska | Lincoln |
| Nevada | Reno |
| New Hampshire | Durham |
| New Jersey | New Brunswick |
| New Mexico | Albuquerque |
| New York | Syracuse |
| North Carolina | Raleigh |
| North Dakota | Bismarck |

**STATE OFFICES** *(Continued)*

| STATE | CITY |
|---|---|
| Ohio | Columbus |
| Oklahoma | Stillwater |
| Oregon | Portland |
| Pennsylvania | Harrisburg |
| Rhode Island | Storrs (Conn.) |
| South Carolina | Columbia |
| South Dakota | Huron |
| Tennessee | Nashville |
| Texas | Temple |
| Utah | Salt Lake City |
| Vermont | Burlington |
| Virginia | Richmond |
| Washington | Spokane |
| West Virginia | Morgantown |
| Wisconsin | Madison |
| Wyoming | Casper |
| Dist. of Col. | Washington |
| Puerto Rico | San Juan |

# APPENDIX F

## EROSION AND SEDIMENT CONTROL PROVISIONS (MARYLAND)

July 1, 1970
Revised July 28, 1970
Revised Aug. 19, 1970
Revised Feb. 13, 1973

### EROSION AND SEDIMENT CONTROL

#### Description

This work shall consist of the application of measures throughout the life of the project to control erosion and to minimize the siltation of rivers, streams and impoundments (lakes, reservoirs, bays and coastal waters). Such measures shall include, but are not limited to, the use of berms, dikes, dams, sediment basins, sediment traps, filters, fiber mats, netting, gravel or crushed stone, mulch, grasses, slope drains and other methods. Erosion and siltation control measures as described herein shall be applied to erodible material exposed by any activity on the project.

Erosion and sediment control measures shall be coordinated with the construction of the permanent drainage facilities, such as pipes, culverts, headwalls, ditch paving, flumes, etc., which shall be constructed prior to or as soon as practicable after the grading operation is begun to assure economical, effective and continuous erosion and siltation control.

Reference is made to applicable standard plates in Category 3 of the Book of Standards.

#### Materials

a. Seed, mulches, fertilizer, soil conditioner and other materials for seeding shall be in accordance with the State of Maryland S.R.C. Specifications.
b. Temporary slope drains shall be constructed of material acceptable to the Engineer; i.e., pipe, fiber mats, rubble, plastic pipe and plastic sheets.
c. Other materials as required may be specified by the Engineer.

#### Erosion and Sediment Control Plan

At the preconstruction conference or prior to the start of the applicable construction, the Contractor shall submit for acceptance his schedules for accomplishment of temporary and permanent erosion control work, as are applicable for clearing and grubbing, grading, bridges and other structures at watercourses, construction, and paving. No work shall be started until the erosion control schedules and methods of operations have been accepted by the Engineer.

#### Construction Requirements

The Contractor shall shape the graded area in such a manner as to permit the runoff of precipitation and shall construct earth berms along the top edges of embankments to intercept runoff water. Earth berms shall be compacted to the satisfaction of the Engineer. Temporary slope drains shall be provided to carry runoff from cuts and embankments. The slope drains may be of flexible or rigid construction but shall be capable of being readily shortened or extended as the cut or fill advances. Pipe and sections shall be provided at the entrance to the temporary slope drains and where necessary, energy dissipaters at the outlet.

Cut slopes shall be dressed, prepared and seeded as the work progresses in accordance with the following sequence unless otherwise directed by the Engineer.

a. Slopes whose vertical height is 40 feet or greater shall be seeded in 3 approximately equal increments of height.
b. Slopes whose vertical height is less than 40 feet but more than 10 feet shall be seeded in 2 approximately equal increments of height.
c. Slopes whose vertical height is 10 feet or less may be seeded in one operation.

The dressing, preparing and seeding of slopes shall be performed immediately following the completion of each increment of height stated and immediately following the suspension of grading operations.

Fill slopes shall be dressed, prepared and seeded as the embankment proceeds to the extent considered desirable and practicable.

The Engineer will limit the area of excavation and embankment operations in progress commensurate with the Contractor's capability and progress in keeping the finish grading, mulching, seeding and other such permanent pollution control measures current in accordance with the accepted schedule. Should seasonal limitations make such coordination unrealistic, erosion control measures shall be taken immediately to the extent feasible and justified. All construction shall be confined to the minimum area necessary to accommodate the Contractor's equipment and work force engaged in this project.

Each grading unit will be limited to the amount of surface area of erodable earth material exposed at one time not to exceed 750,000 square feet of Grubbing and 750,000 square feet of Grading (erodable slopes) Operations, unless the Contractor obtains the Engineer's approval for a greater area based on project conditions. A "grading unit" is defined as a complete grading spread consisting of earthmovers, hauling units, graders, compactors, etc. The Contractor shall be prepared to dress and seed back of each grading unit as noted above.

There are individual project conditions where the following areas would be eliminated from the 750,000 square feet limits for clearing and grubbing:

Forest or mountainous areas where the timber is removed but the forest floor or earth is left generally undisturbed.

Low-lying bog or swamp areas where it is necessary to clear the entire project to facilitate drying before the soil can be worked.

These areas are indicated on the project plans.

The Contractor will be required to incorporate all permanent erosion control features into the project at the earliest practicable time as outlined in his accepted schedule. Temporary pollution control measures will be used to correct conditions that develop during construction that were not foreseen during the design stage; that are needed prior to installation of permanent pollution control features; or that are needed temporarily to control erosion that develops during normal construction practices, but are not associated with permanent control features on the project.

Sediment traps, sediment basins, and ditches shall be maintained for the winter season and during other such times when project is closed down.

Where erosion is likely to be a problem, clearing and grubbing operations should be so scheduled and performed that grading operations and permanent erosion control features can follow immediately thereafter if the project conditions permit; otherwise, erosion control measures may be required between successive construction stages.

Wherever rock excavation is available in the immediate vicinity of the project, an 8- to 15-inch layer of such material shall be spread over the lower region of embankments in the immediate vicinity of stream crossings and shall be used to riprap ditches, channels and other drainage ways leading away from cuts and fills; however, all drainage ways shall be prepared for riprapping to the extent necessary to avoid reducing their cross-section. In the event rock excavation is not available on the project, soil stabilization matting shall be used as the covering material and shall be installed in accordance with the applicable specifications for such materials. The limits of the area to be covered will be as directed by the Engineer.

#### Permits

The Contractor's attention is directed to the provisions and requirements of Chapter 245 of the Acts of 1970.

Under this Act it is necessary for the Contractor to obtain permits and/or approvals from the appropriate County agency for any off-site work which includes off-site borrow pits, waste areas and the treatment of these during and after the completion of the grading. The County agency will refer the plan for such areas to the soil conservation district for review and approval of the erosion and sediment control provisions. A copy of the permits and/or approvals must be furnished to the Engineer prior to starting any work covering the said permits and/or approvals.

Attached is a list of County agencies where permits and/or approvals will be obtained.

In the event of conflict between these requirements and pollution control laws, rules or regulations of other Federal or State or local agencies, the more restrictive laws, rules or regulations shall apply.

The Engineer reserves the right to inspect erosion control measures in off-site borrow pits and waste areas and to report violations of permit requirements to the County agencies.

#### Method of Measurement and Payment

In the event that erosion and pollution control measures are required due to the Contractor's negligence, carelessness or failure to install permanent controls as a part of the work as scheduled, and are ordered by the Engineer, such work shall be performed by the Contractor at his own expense. Erosion and pollution control work required, which is not attributed to the Contractor's negligence, carelessness or failure to install permanent controls, will be performed as ordered by the Engineer.

Where the work to be performed is not attributed to the Contractor's negligence, carelessness or failure to install permanent controls and falls within the specifications for a work item that has a contract price, the units of work shall be paid for at the proper contract price.

Excavation of sediment basins, sediment traps, temporary ditches and cleaning as required will be measured and paid for as Class 2 Excavation unless such work is to be classified under a separate item as otherwise provided.

Temporary pipe installed in connection with sediment basins will be paid for on a linear foot basis; the price shall include materials, placement, maintenance, adjustment and removal. All material to be the property of the Contractor.

All costs of temporary berms shall be incidental to the excavation items and will not be measured. Temporary slope drains shall be measured and paid for on a linear foot basis; the price shall include materials, placement, maintenance, adjustment and removal. All material to be the property of the Contractor. Should the work not be comparable to the project work under the applicable contract items, the Contractor shall be ordered to perform the work on a force account basis, or by agreed unit prices.

Soil stabilization matting will be paid for on the basis of the number of square yards measured in place at the price bid per square yard which price shall include the cost of all labor, equipment and materials necessary to satisfactorily complete the work as specified.

Wherever rock excavation is available for placing or spreading over the lower region of embankments in the immediate vicinity of stream crossings, the excavation placing and spreading of the rock shall be included in the cost of Class 1 Excavation for utilizing all suitable materials from excavation in the construction of fills throughout the entire length of the project.

Wherever rock excavation is available to riprap ditches, channels and other drainage ways, the riprap shall be constructed and paid for in accordance with the plans and Specifications, Article 35.06.

In case of repeated failures on the part of the Contractor to control erosion, pollution and/or siltation, the Engineer reserves the right to employ outside assistance or to use his own forces to provide the necessary corrective measures. Such incurred direct costs plus project engineering costs will be charged to the Contractor and appropriate deductions made from the Contractor's monthly progress estimate.

The Contractor's attention is directed to the fact that under his permits and/or approvals pollution control may include construction work outside the rigtht-of-way where such work is necessary as a result of roadway construction—such as borrow pit operations, haul roads and equipment storage sites.

Under the provisions of the Contractor's Erosion and Sediment Control permits and/or approvals for work outside the right-of-way, pollution control shall be inspected by the Administration's project engineer. Any deviation from or noncompliance with the provisions of the permits and/or approvals shall be reported to the appropriate agency to enforce compliance.

The erosion control features installed by the Contractor shall be acceptably maintained by the Contractor for the duration of the contract.

# APPENDIX G

## EXPERIMENTAL SPRAYS FOR EROSION CONTROL

### EROSION CONTROL STUDIES *

By Karl Baumeister

The current concern over ecology, together with recently enacted laws to protect environmental quality, have resulted in the need for more effective erosion control on highway construction projects.

The main sources of erosion along California highways are rain and wind. Also, considerable damage is caused by frost and flowing surface or subsurface water. Water, from whatever source, flowing over bare ground can pollute domestic water supplies and erode slopes. Wind blown sand and dust can blast the paint off passing vehicles, create a safety hazard because of reduced visibility, harm and kill vegetation, and is often a source of irritation to the local inhabitants.

The best long term control of erosion to date, in terms of effectiveness and economy, is vegetation. In a highway cut or fill slope it is often necessary to control erosion in some other manner until vegetation can take hold.

The principal method of erosion control used by the California Division of Highways in embankments or in loose soils has been straw rolled into slopes with studded rollers. In cut slopes, wood fiber mulch sprayed on the surface has been the most popular application method. In both cases the slopes are seeded with grasses and fertilized at the time of mulch applications.

In many areas, these treatments prove to be very effective in controlling erosion and expediting the growth of vegetation. In some locales, however, straw or fiber may not be the best materials to use. Rolled-in straw in rainy areas tends to col-

* From *Random Samples* (Aug.-Sept. 1972), published by the Materials and Research Department, California Division of Highways.

lect water and promote saturation, thereby causing possible slides. Also, straw is difficult to apply to very steep or rocky slopes. Wood fiber, while it can be applied by spraying, is usually inferior to rolled-in straw in controlling erosion and often washes away with the winter rains.

During the past 18 months, the Engineering Geology Unit of the Materials and Research Department, directed by Marvin McCauley, has tested various sprayed-on materials to ascertain their abilities to control erosion without polluting the environment or inhibiting vegetation.

Table G-1 includes the more successful products tested, plus some recent entries which have yet to be proven under rain and/or wind erosion.

As a result of the first tests near San Ardo, 10 out of 12 products tried were found to be unsatisfactory or marginal at this location in resisting rain erosion. The second series of trials near Indio eliminated 9 out of 16 products for withstanding wind erosion under local conditions.

Most of the materials used in the later investigations at Boron were found satisfactory for other locations in resisting wind erosion and considered capable of encouraging the growth of vegetation. At the desert site, various products were applied alone, with wood fiber, and over rolled-in straw. It is still too early to draw any firm conclusions from these tests.

In June, 1972, five of the worst erosion locations in the state (the last 5 sites in Table G-1) were sprayed with Landlock (a polymer) and wood fiber in combination with seed and fertilizer. This polymer had previously been sprayed in sites at Buellton, Indio, Boron, Monterey, Mariposa and the Collier Tunnel and was found to be successful in resisting erosion. These tests, as well as others conducted by Dr. Burgess Kay of the University of California, suggest that its use encourages growth of vegetation; possibly because of the "hydrophilic" (water retaining) properties of the polymer. Increased strength appears to be imparted to the soil-polymer film by the wood fiber.

The results of the tests to date indicate several sprayed-on products show promise in the field of erosion control, if used selectively. The investigations also suggest that traditional erosion control methods of rolled-in straw and sprayed on fiber are still the most effective methods of control in most instances.

Considerable new information will be gained from observation of the test applications in the coming winter season and will be available to the Division of Highways and other interested State and Federal agencies in the form of written reports and by consultation.

TABLE G-1

EXPERIMENTAL EROSION CONTROL SPRAYS

| Date | Hwy. Route | Location | Slope | Materials | Soil | Remarks |
|---|---|---|---|---|---|---|
| Nov. 1971 | 49 | 15 miles south of Mariposa | 1-1/2:1 fill | Loose straw placed over fiber, seed & fertilizer | Decomposed granite | Largely ineffective. Most of straw washed down slope along with much of seed and fertilizer. Where straw was not washed down slope it seemed to inhibit germination of seed |
| Oct. 1971 | 154 | Near intersection with | 1-1/2:1 cut | Landlock (polymer dissolved in acetone mixed with water at nozzle) | Sand | Forms flexible spongy, cohesive layer of soil and polymer on surface. Good growth of grass occurred in sprayed area. No rutting after 1 season |
| Sep. 1971 | " | " | 1-1/2:1 cut | Fiber, seed & fertilizer | Sand | Poor growth in vegetation after one season. Some rutting |
| Dec. 1971 | 10 | Thousand Palms | Flat | Landlock | Sand | Surface film resistant to vehicle traffic. Encouraged germination of weeds but they died because of insufficient precipitation |
| Feb. 1972 | 58 | Boron | Flat | Landlock<br>Curasol<br>Surfaseal<br>Soil Seal<br>Dustmaster C<br>Wood fiber<br>Rolled in straw | Fine silt & sand | Chemicals were sprayed alone, with fiber and over straw. All of area was seeded with native seeds and fertilized prior to erosion control. No germination has occurred except for the barley seed in the straw. Insufficient rain has fallen for germination of native seed. Insufficient time has passed to evaluate fully |
| Mar. 1972 | 199 | Collier Tunnel | 1:1 | Landlock & fiber with seed & fert. 26 combinations | Weathered shale | Greatly diminished ravelling of slopes. Healthy grass in most heavily sprayed area of fiber and Landlock. |
| June 1972 | 89 | North of Luther Pass | 1-1/2:1 | Soil-Lok | Decomposed granite (fines with boulders) | To date, slope seems stabilized. Hard surface seems to be holding fines. Too early for full evaluation |
| " | " | " | 1-1/2:1 | Soil-Bond | Decomposed granite (fines with boulders) | Same as above. Surface slightly flexible |
| " | " | Emerald Bay | 1-1/2:1 | Soil-Lok | Ravelling decomposed granite | Surface sprayed seems to have stopped ravelling to date. Too early for full evaluation |
| " | " | " | 1-1/2:1 | Soil-Bond | Ravelling decomposed granite | Same as above |
| " | 156 | Near intersection of 101 Pruendale | 1-1/2:1 | Landlock, fiber & fertilizer | Sand | Too early for evaluation |
| " | 120 | Near Groveland | 1:1 | Landlock, fiber & fertilizer | Decomposed granite | Same as above |
| " | 89 | Near Luther Pass | 1:1 & 1-1/2:1 | Landlock, fiber & fertilizer | Decomposed granite | Same as above |
| " | 80 | Near Farad | 1:1 | Landlock, fiber & fertilizer | Glacial moraine | Same as above |
| " | 5 | Near Weed | 1:1 | Landlock, fiber & fertilizer | Volcanic debris | Same as above |

TABLE G-1 (*Continued*)

| Date | Hwy. Route | Location | Slope | Materials | Soil | Remarks |
|---|---|---|---|---|---|---|
| Feb. 1971 | 101 | Near San Ardo | 2:1 | Wood fiber (3,000 #/acre) | Fine sand & silt | Showed fair growth of vegetation during dry year. Retained continuous flexible covering full season |
| " | " | " | 2:1 | Orzan (Lignin-sulfonate) | Fine sand & silt | Penetrated to depth of 3 inches. Hard surface supported foot traffic for 1 year. Dark brown color: cracks due to shrinkage. Soil nutrient but vegetation grows only in cracks. |
| " | " | " | 2:1 | Rolled in straw | Fine sand & silt | Good erosion control - with vegetation |
| Mar. 1971 | 10 | West of Indio | 2:1 | $Na_2SiO_3 + CaCl_2$ | Sand | Hard durable surface. Very expensive. Will not allow vegetation. |
| " | " | " | 2:1 | Curasol AE (Polymer dispersion) | Sand | Surface scoured but not penetrated after end of windy season |
| " | " | " | 2:1 | Curasol AH (Polymer dispersion) | Sand | Same as above but slightly thicker and less brittle surface film |
| " | " | " | 2:1 | Soil Seal (copolymer emulsion) | Sand | Surface scoured but not penetrated after end of windy season |
| " | " | " | 2:1 | Surfaseal (unknown composition) | Sand | Same as above. Three passes of spray equipment with drying time required in between |
| " | " | " | 2:1 | Terra Krete (unknown ingredients in latex base) | Sand | Same as above |
| " | " | " | 2:1 | Wood fiber (3,000 #/acre) | Sand | Retained continuous flexible covering. Fine layer of blow sand over fiber helped fiber in resisting erosion |
| Sep. 1971 | 101 | Ventura | 1:1 | $Na_2SiO_3 + CaCl_2$ | Sandstone | Has been successful to date in preventing erosion |
| " | 89 | Luther Pass | 1-1/2:1 | Curasol AE (polymer dispersion) | Decomposed granite | Sedimentation due to erosion was 15% of that in unsprayed area during the first 4 months. One year after spraying precipitation and frost heaving eradicated film |
| Oct. 1971 | " | " | 1-1/2:1 | Aerospray 70 (polymer dispersion) | Decomposed granite | Same as above except sedimentation was 18% that in unsprayed area |
| Nov. 1971 | 49 | 15 miles south of Mariposa | 1-1/2:1 cut & fill | Wood fiber, seed & fertilizer | Decomposed granite | Partly effective in fill area, with considerable rutting throughout area. Vegetation better in fill than in cuts. Largely ineffective in cut areas. Addition of dispersed polymer to fiber did not seem to help |
| " | " | " | 1-1/2:1 fill | Rolled in straw, seed & fertilizer | Decomposed granite | Very effective erosion control and good vegetation. Some minor sloughing due to saturation during wet season |

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