A STUDY on INFORMATION on ENGINEERING DESIGN and TECHNICAL CRITERIA for THE CONTROL of SEDIMENT FROM LOGGING HAUL ROADS

ENVIROMENTAL PROTECTION AGENCY

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A STUDY OF INFORMATION

on

ENGINEERING DESIGN AND TECHNICAL CRITERIA

for

THE CONTROL OF SEDIMENT FROM LOGGING HAUL ROADS

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I. INTRODUCTION

Engineering criteria for the planning, design, construction and maintenance of logging haul roads directed toward sediment minimization is a part of the total engineering criteria needed for logging haul roads. The appropriate spectrum of this criteria is related to the major role logging roads play in forest land management.

Sediment control design criteria may be the same as, or parallel to, other design criteria that will result in an efficient, economic logging road system for sound forest land management. Examples of "overlap" or parallel criteria are:

1. Relating road location and design to the total forest resource, including short term harvest pattern, reforestation, fire prevention, fish and wildlife propogation and water quality standards.
2. Relating road location and design to current timber harvesting methods.
3. Preparing road plans and specifications to the level of detail appropriate and necessary to convey to the road builder, be he timber purchaser or independent contractor, the scope of the project and enable him to prepare a comprehensive construction plan of procedure, time schedule, and cost estimate.
4. Design investigations and companion design decisions directed toward minimizing the opportunity for "changed conditions" during construction with their consequent costs in dollars and time.

5. Analysis of certain road elements relative to first cost versus maintenance cost such as culverts and embankments versus bridges; ditch lining versus ditches in natural soils; paved or lined culverts versus unlined culverts; sediment trapping devices (catch basins, sumps) versus culvert cleaning costs; retaining walls versus placing and maintaining large embankments and embankment slopes; roadway ballast or surfacing versus maintenance of dirt surfaces; and balanced earthwork quantities versus waste and borrow.

Specific inclusion of design criteria to minimize sediment may be appropriately evaluated as a broadening of the design criteria spectrum under some conditions. In these circumstances additional first cost may not result in companion maintenance cost reductions as suggested in the previous paragraph. Examples of these circumstances are:

1. Spur roads built for one harvest in one season of a small area and/or to one use landings.
2. Short term sedimentation control measures for use during road construction and immediately thereafter until long term measures are installed or established.
3. Improvements outside of what has been regarded as the road right-of-way or corridor such as specially constructed filter strips, "downhill" culvert extensions, settling basins and provisions for debris collection.
4. End haul of excess excavation to selected waste areas.
5. More restrictive limitations on the road construction season

thereby, in some instances, requiring more seasons to complete the road with companion delay in the timber harvest (time cost of money).

6. "Tipping the scales" in an evaluation of a fragile or sensitive area toward the conclusion that existing road design and construction technology will allow no road construction.

7. Restriction or elimination of a timber harvest method due to the road needs of the method (i.e. jammer logging) and conversion to another harvest method that results in a higher long term harvest cost.

Many regional writers believe that forest roads have often significantly contributed to sediment reaching streams by surface erosion and mass soil movement. George W. Brown states that: "The compacted surfaces of logging roads, skid trails, and fire lines often carry surface run-off during storm events. Road surfaces are a significant source of sediment in forests because of such run-off. (1) Fredriksen's studies in Western Oregon watersheds report that "Landslides are the major source of stream sedimentation" and that "their occurrence is more frequent where logging roads intersect stream channels". (2) He also suggests that midslope road mileage be minimized and further where these roads are necessary across steep sideslopes, "all knowledge available to the engineer should be used to stabilize roads".

Swanston's investigations on mass soil movements in forests indicate that road building is the most damaging activity and believes that soil failures therefrom result primarily from slope loading with embankments, sidecasting, inadequate provision for slope drainage and cut slopes. (3)

Mass movements have occurred in the Alaska maritime coast, Idaho and on the western slopes of the Cascades. These movements have often produced companion sedimentation problems and significant water quality degradation.

Megahan and Kidd's studies of sediment production rates in the Idaho Batholith showed increases of sediment production an average of 770 times per unit of road prism for a six year study period. (4) Although surface erosion following road construction decreased rapidly with time, major impact occurred from a road fill failure after a single storm event.

This report deals with engineering techniques that have been used or can be used to minimize the sedimentation originating from logging haul roads. The techniques reported or discussed in this text do not have universal application throughout all forested lands in Washington, Oregon, Idaho and Alaska. To the contrary, the first and cardinal rule for the solution of any engineering design problem is to deal with the actual circumstances at the individual site in question. As Robert W. Larse has suggested, "the designer must have a knowledge and understanding of design criteria and principles, but must be free and have sufficient experience and ability to design for specific conditions, rather than to apply generalized design rules to all situations". (5)

In the Summary and Recommendations Section of their report on slope failures in the Idaho Batholith, M. J. Gonsior and R. B. Gardner suggest a need for a reorientation or philosophical change in engineering approach as follows:

> "In addition, there appears to be a need for a subtle philosophical change in the traditional engineering approach to problem solving and design. Usually, the integrity of a road, dam, or any other structure is viewed as the primary goal, and thus natural processes

> such as erosion, seepage, and settlement are considered as impositions on the structure which must be controlled or withstood. Instead, the road or structure might better be viewed as an imposition upon the various natural processes, and location and design might better be oriented toward assuring the continuity of, or at least compensation for changes in, these natural processes. By so reorienting design philosophy not only should the integrity of roads and structures be better guaranteed, but the chances for causing undesirable changes in the functioning of natural systems should be considerably reduced. Of course, by changing the question from "What are the natural processes which will endanger the road's integrity"? to "How will the road influence natural processes"? the designer is forced to consider a broader spectrum of environmental factors. Thus, multidisciplinary cooperation and teamwork become not only desirable, but absolutely essential to the completion of the planners' and designers' work". (6)

The chapters that follow this introduction are in the order that a logging road develops namely: (1) planning and reconnaissance, (2) design, (3) construction and (4) maintenance. These divisions are not meant to imply that an appropriate engineering organization for every forest land owner will be similarly structured. Each owner's engineering staff will be structured in accordance with his individual circumstances in terms of size, terrain, policy, private or public, product and goals. A good case can be made for the procedure that assigns to one individual or team the responsibility to deliver a completed road. Such a procedure provides continuity in the planning and reconnaissance, design and construction phases. Also, an organization whose personnel policies result in the maintenance of a stable engineering staff possessing many years of experience on the land that it manages and/or harvests has a great asset when approaching the problem of minimizing the creation and transport of sediment.

Writings on the subject of sediment creation and transport in the forest are extensive. A large reservoir of knowledge is also possessed by individual experienced forest engineers, knowledge that they have not recorded. There are no doubt many successful techniques of sedimentation control omitted from the chapters that follow.

A. SUMMARY AND CONCLUSIONS

There is an abundance of written material available on the subject of minimizing the creation and transport of sediment accruing from logging haul roads. Further sources of information are the experiences of individuals long associated with the design, construction and maintenance of these roads.

The value of a thorough planning and reconnaissance program for a proposed road is emphasized by many authorities. No amount of design or construction expertise can recover from an approach based upon inadequate reconnaissance information. Field reconnaissance evaluations must include attention to the potential for mass movements as well as surface erosion. In steep terrain, it is likely that the engineering investment to insure a stable road will be much more exhaustive than on gentle terrain.

The general approach to design must be the classic engineering approach of according individual treatment to the individual circumstances of the site. Creative design is needed.

Many mass failures are drainage associated. Drainage design often appears to have lacked attention to one or more of the following features.

1. Determination of the design flood.
2. Evaluation of the potential for debris blockage.
3. Choice of stream crossing method.

4. Attention to installation requirements at both the design and construction levels to insure structural integrity.

Minimization of surface erosion and sediment transport begins with the appropriate treatment or design of slope protection and continues with the necessary attention to ditch size, lining, culvert intakes, culvert integrity and culvert outlets.

Under most conditions vegetative or other forms of permanent cover are essential to prevent excessive surface erosion from cut and fill slopes. Vegetation establishment should be initiated as soon after soils disturbance as possible. Various grass and legume seed mixtures are suitable for establishment of vegetation in Region X depending on climatic and other environmental conditions. Seeding should be accompanied by fertilization and re-fertilization as necessary and by watering to maintain vegetative vigor. Mulches, chemical soil stabilizers, or mechanical measures are necessary to prevent high initial rates of soil loss during vegetation establishment and in some cases to aid in vegetation establishment.

It is important to sequence the construction in a manner that affords the least exposure to storm damage during construction. Contractural relationships between owner and road builder should be such that a quick response can be made by all parties to changed circumstances during construction. Failure to respond promptly can greatly enhance the potential for sediment creation and transport. New types of construction equipment are needed for clearing and excavating for narrow roads in steep terrain.

The key factor in a successful maintenance program is motivation and knowledge of maintenance personnel. Individuals control sediment transport attendant to maintenance operations.

Occasional slides can be expected along logging roads even with the best of location and design practices. In some cases, abandonment of the road may be preferable to removal of slide debris and correction of the problem. Where it is necessary to remove slide debris, it should be placed in selected spoil areas.

Water quality parameters including temperature, turbidity, dissolved oxygen levels, and dissolved minerals concentrations should be monitored before, during and for as much as a year following logging road construction. Sampling stations should generally be located directly upstream and downstream of the subject area. Sampling should be timed to coincide with significant construction activities and meteorological conditions.

Although inclusion of design criteria for sediment control may increase initial capital outlay, it does not necessarily increase total annual cost over road life. There may be offsetting savings in annual maintenance costs. Stable cuts and fills and adequate culverts and bridges are desired by forest owners and users for many reasons other than sediment control. Features for sediment transport minimization constructed outside of the roadway corridor are the most obvious examples of capital outlay for sediment purposes only.

When construction is accomplished in accordance with adequate plans and specifications in a workmanlike manner under strict supervision, the control of sediment tends to be coincident.

B. RECOMMENDATIONS

The trend toward obtaining a thorough field reconnaissance for logging roads should be continued and even accelerated.

The Universal Soil Loss Equation, with recent modifications, is an acceptable methodology for prediction of soil loss by erosion for some conditions. Considerable expansion, refinement, and potential modification of the equation through research and field testing are needed before reasonably reliable predictions can be made for a wide range of site and design conditions.

A system of high altitude rain and stream gaging stations, established in advance of logging or road building operations, would be helpful to the determination of mountain stream flows.

Organizations should assign responsibility and authority to experienced engineers at the local level to plan and design the logging roads. Personnel policies should support the retention of experienced engineers in or near the forests they serve.

Highway engineering tools, criteria and techniques developed for state, county or municipal roads should not be blindly applied to forest roads.

Equipment manufacturers may have to be lured into developing the kinds of equipment that will construct narrow roads in steep terrain with relative economy and speed. Such incentives may come from denial of use of current equipment by contract requirement and/or funding of appropriate applied research by the forest land owners.

II. ROUTE PLANNING AND RECONNAISSANCE

Route Planning and Reconnaissance are regarded by many as the most important phase of logging haul road development. It is at the planning and reconnaissance level that first evaluations of soil erodibility, the potential for mass movement, and the potential for sediment transport must be made. These evaluations may confirm the proposed road corridor, cause a change in forest harvest procedure, indicate the need to survey an alternate corridor or contribute to a no road decision.

The importance of road reconnaissance has been expressed in numerous ways. Crown Zellerbach Corporation's "Environmental Guide, Northwest Timber Operations," states in Chapter V, Road Building: "Special emphasis must be placed on proper road planning, design of cross sections, and field location to reduce soil erosion problems and consequent stream siltation and stream blockages." (7) R. W. Larse, in a paper entitled "Prevention and Control of Erosion and Stream Sedimentation from Forest Roads," emphasized planning and reconnaissance when he stated: "Road planning and route selection is perhaps the most important single element of the road development job." (8) The U. S. Forest Service Region 6's Recommendation 3.1 from "Timber Purchaser Road Construction Audit" is: "Preconstruction geotechnical investigations, transportation planning, and construction inspection on earthwork and drainage should receive the highest priority for manpower." (9) The Siuslaw National Forest's "Implementation Plan" to the Region 6 Audit agrees that "the greatest potential for land impacts from road construction lies in areas of steep topography and unstable soils." (10) The Boise National

Forest's publication "Erosion Control on Logging Areas" states: "To a great extent erosion can be prevented by controlling the location of roads and skidways in relation to the natural drainage, slopes, and soil conditions." (11)

In the recommendations contained in "Flood Damage In The National Forest of Region 6," Jack S. Rothacher and Thomas B. Glazebrook believe that any procedures designed to minimize unusual weather impacts on soil must be based on increased knowledge of geomorphic history, climate, hydrology, vegetation, soils and landscape features of the land. (12) "The importance of reconnaissance is indicated by the fact that failure to consider all alternates may result in future excessive costs far beyond any savings effected by not accomplishing a complete reconnaissance." (13) (Bureau of Land Management "Roads Handbook" 1965)

R. D. Forbes in "Forestry Handbook" quantified the total planning and design effort required when he stated: "The importance of adequate surveys, and careful planning for road construction justifies engineering costs up to 5% of total cost for low standard while 10% to 15% is reasonable for engineering permanent heavy-duty hauling roads in rough country." (14)

Neither the competent designer nor the competent road contractor can economically overcome faults in a road concept that are related to inadequate planning and reconnaissance.

The discussion of route planning and reconnaissance that follows begins at the point where the forest land manager has determined that a road is required. The manager has made some preliminary decisions as to the purpose of the road and companion decisions as to the general corridor that is preferable from a management viewpoint. He conveys this information to his engineering staff for implementation. Results of the subsequent engineering planning-reconnaissance phase may alter the initial management decision.

Section A of this chapter covers engineering planning aspects and the engineer's communication with land management. Section B discusses the field reconnaissance by geotechnical forest and civil engineering personnel. Section C discusses economic evaluations. The chapter is divided in this manner partly for the convenience of presentation. The planning and reconnaissance activities are often very interrelated depending upon the type of organization and the nature of the road project under study.

A. PLANNING

1.00 Management-Engineering Dialogue

The engineers' introduction to the Forest Land Manager's road requirement may occur in a variety of ways (formal to informal). Often this introduction develops into a dialogue between the two parties. The communication may encompass road standards, intended use, harvest methods and road life. The discussion may result in a program of road feasibility studies or simply a direct road reconnaissance and design.

Initial communications become critical to the road development particularly when minimum environmental impact roads, including sediment minimization, are required. In their communications, both the engineer and the land manager must attempt to reach a complete and explicit understanding to avoid communication gaps. An illustrative case is the China Glen Road on the Warren Ranger District, Payette National Forest, Idaho.

The road was to serve a salvage timber sale in three fragile water sheds. Special instructions from management were to minimize watershed damage. Road standards had, to some extent, been established by the forest management. Engineering appeared to have accepted these standards.

Prior to construction, management reviewed the design documents and road construction was begun. However, gaps in their initial communication became evident as is reported by W. S. Hartsog and M. J. Gonsior.

> "During field inspection, land managers expressed concern that the road would have more impact than had been anticipated. They felt that cuts and fills were larger than desirable or necessary. Apparently, they could not fully visualize the final product from the design sheets, which indicates a need for better communications." (15)

The China Glenn Road experience demonstrates the need for communication when roads in ecologically sensitive areas are envisioned. In some cases, (particularly steep terrain) small soil and geologic disturbances result in measurable ecological differences including stream siltation and sediment. In these circumstances the responsible forest engineer continues the dialogue and provides "feed back" to the forest land manager by evaluating the terrain's situs condition. The engineer will evaluate the terrain in such terms as elevation, aspect, soil strength, ground slope, ground water, geologic formation and precipitation.

The need for the engineer to evaluate management's decision is accentuated by the fact that a large part of the commercial forest lands in Region X are located on land that requires a careful assessment of the road's potential performance. This assessment should embrace a determination as to whether or not existing technology is equal to the ambient circumstances within a particular road corridor.

2.00 Engineer's Assessment of Management's Decision

The technological tools available to the engineer to accomplish a pre field reconnaissance evaluation of a proposed road corridor might include his own knowledge of the area, performance of existing roads in similar terrain, topographic maps, geology maps, soil resource maps and hydrology data. His evaluation should permit him to advise management that a preliminary assessment of the proposed road corridor has led to one of the following answers:

1. There is no chance of a stable road being constructed.
2. The road envisioned by management cannot be constructed but one of lesser design criteria in terms of width, grade and horizontal curvature might be constructed pending confirmation by field reconnaissance.
3. A road might be constructed into the general area with companion modification of the harvest procedure.
4. Management's road might be constructed pending confirmation by field reconnaissance.
5. Management's road can be constructed with relative ease pending confirmation by a brief field reconnaissance.

2.01 State of the Art Techniques

Within the past few years, some forest land owners have developed a keen awareness of the hazards of sediment production. From this awareness, a number of land management devices which attempt to evaluate the timber production land base have been developed. Several of these devices focus on the effect of unstable terrain on forest land management practices including road construction. These land evaluation tools are of basically two orders, regional to sub-regional (i.e. Pacific Northwest divided into homogenous land form unit like the Northwest Olympic Peninsula), sub-regional to local (i.e. Northwest Olympic Peninsula land form units of 10 acres or larger homogenous units). The following paragraphs illustrate techniques which have been developed by Region X researchers and practitioners to critique sensitive terrain.

1. The Forest Residue Type Areas Map produced by the U. S. Forest Service for Region 6 is an example of the larger scale. This information shows geomorphic provinces, timber species associations and geomorphic sub-provences. The smallest mapping unit is approximately 10 miles square. (16)
2. The U.S. Forest Service's soil resource inventory for Forest Service Region 6 and other regions represents the next level of forest land identification. "Soils have been defined and mapped at an intensity sufficient for broad management interpretations which can be used to develop resource management policies." (17) (Gifford Pinchot National Forest Soil Resource Report) In addition to these uses, forest soils are rated as to their potential erosion class, very slight, slight, moderate, severe and very severe. "The land manager can use this information to determine which areas will need special erosion protective measures. These will need to be developed on a site by site basis." (18) These maps serve transportation planning needs as well.

"Conditions and problems can be met or avoided based on information such as landscape stability, soil depth, soil drainage and/or bedrock type and competency." (19)

3. The Bureau of Land Management, Oregon State Office, is accomplishing intensive inventories of its western Oregon lands. The objective is to provide the manager with detailed, in place information about timber production sites for which he is responsible. (20) The intensive inventories deal with the total land mass by separating the land base into various categories of potential forest production. One category, designated as fragile, pertains to adverse soil and geologic conditions. Fragile sites are defined by slope gradient, ground water, geologic material (bedrock) and soil strength. Appendix 5 to Bureau of Land Management Manual Supplement No. 5250 - "Intensive Inventories", dated February 7, 1974, deals with procedures for identifying fragile sites. "Guide to Reduce Road Failures in Western Oregon" by Burroughs, Chalfant, and Townsend includes a general outline of Western Oregon geology, and discusses basic slope stability, and techniques for constructing stable roads on specific geologic materials and soils. (21)

4. The Siuslaw National Forest has developed two schemes for evaluating terrain roadability.

    a. "Workload Analysis - Geo-technical Investigation for Timber Sale Roads." (22)

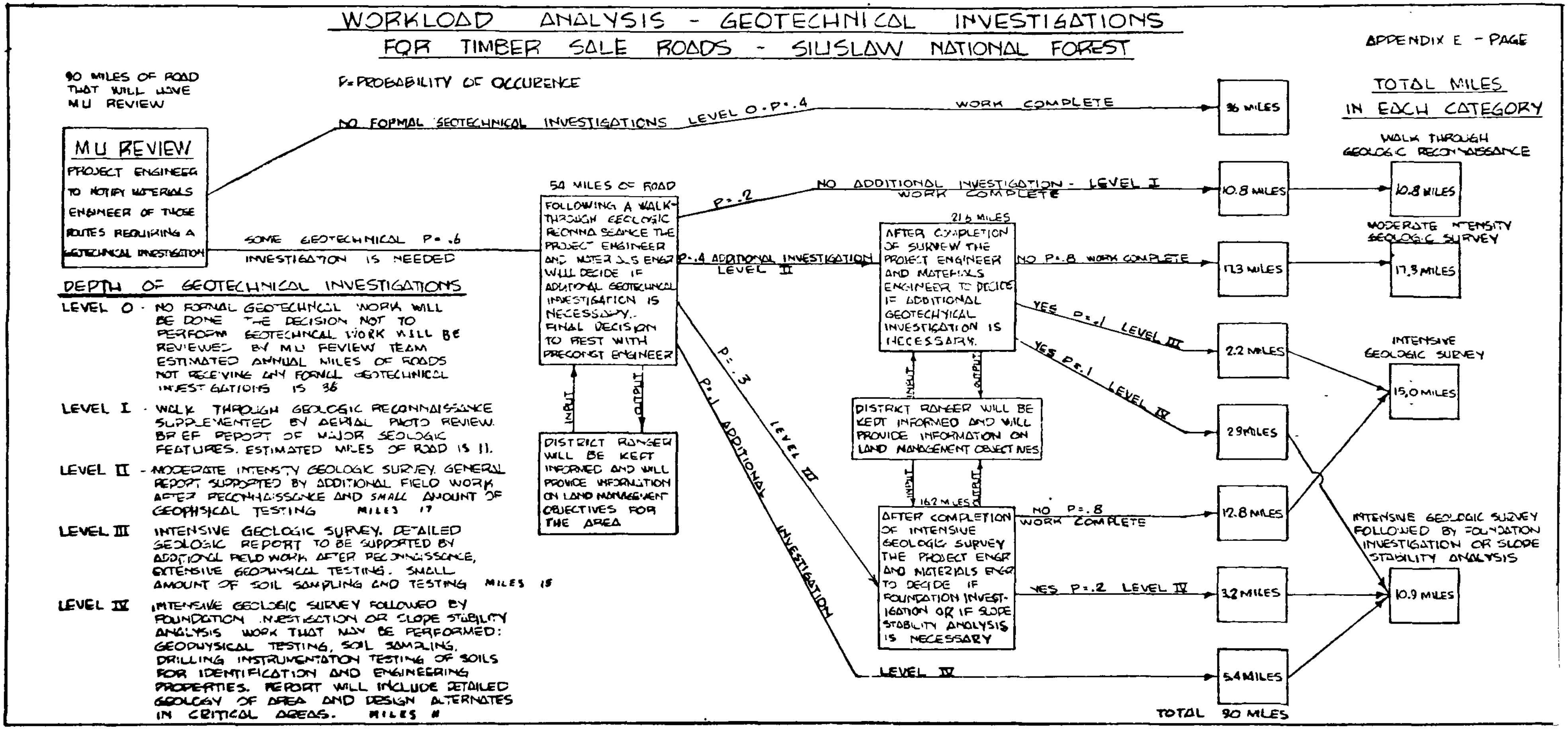
    b. "A Proposed Method of Slope Stability Analysis," Jennings and Harper.

The work load analysis uses a factor "P" which expresses a percent probability that a given section of road location will require a given level of geo-technical investigation. Figure 11A-1 is taken from Appendix E of the Siuslaw Implementation Plan and illustrates the use of the "P" factor.

The Proposed Method of Slope Stability Analysis attempts to answer many forest land administrators and planners who have expressed a need for a quantitative evaluation system to rate slope stability. This report proposes a slope evaluation system based on a soil mechanics safety factor formula and named "The Stability Index (SI)". It is intended to describe the generalize slope stability of a soil mapping unit, separating only the effect of slope. It is not to be used to evaluate on-site stability for specified projects "but with additional input it could be used as a starting point for project site analysis." (23)

5. "Highway Cut and Fill Slope Design Guide Based on Engineering Properties of Soils and Rock" by Larry G. Hendrickson and John W. Lund is a valuable design guide for specifying cut and embankment slopes. (24) This design approach attempts to reduce the use of intuitive techniques and substitutes a more rational approach. This approach uses soil strength properties and recognizes the need for flatter slopes as cut heights increase. This work is incorporated into the U. S. Forest Service's Transportation Engineering Handbook for Region 6 as Supplement No. 19, dated February 1973. The supplement digest explains the Design Guide as follows:

Figure II A-1


WORKLOAD ANALYSIS - GEOTECHNICAL INVESTIGATIONS
FOR TIMBER SALE ROADS - SIUSLAW NATIONAL FOREST
APPENDIX E - PAGE
90 MILES OF ROAD THAT WILL HAVE MU REVIEW
P=PROBABILITY OF OCCURENCE
MU REVIEW
PROJECT ENGINEER TO NOTIFY MATERIALS ENGINEER OF THOSE ROUTES REQUIRING A GEOTECHNICAL INVESTIGATION
NO FORMAL GEOTECHNICAL INVESTIGATIONS LEVEL O-P=.4
WORK COMPLETE
36 MILES
SOME GEOTECHNICAL P=.6
INVESTIGATION IS NEEDED
54 MILES OF ROAD
FOLLOWING A WALK-THROUGH GEOLOGIC RECONNAISSANCE THE PROJECT ENGINEER AND MATERIALS ENGR WILL DECIDE IF ADDITIONAL GEOTECHNICAL INVESTIGATION IS NECESSARY. FINAL DECISION TO REST WITH PRECONST ENGINEER
INPUT
OUTPUT
DISTRICT RANGER WILL BE KEPT INFORMED AND WILL PROVIDE INFORMATION ON LAND MANAGEMENT OBJECTIVES FOR THE AREA
P=.2
NO ADDITIONAL INVESTIGATION - LEVEL I
WORK COMPLETE
10.8 MILES
P=.4 ADDITIONAL INVESTIGATION
LEVEL II
21.6 MILES
AFTER COMPLETION OF SURVEY THE PROJECT ENGINEER AND MATERIALS ENGINEER TO DECIDE IF ADDITIONAL GEOTECHNICAL INVESTIGATION IS NECESSARY.
NO P=.8 WORK COMPLETE
17.3 MILES
YES P=.1 LEVEL III
2.2 MILES
YES P=.1 LEVEL IV
2.9 MILES
DISTRICT RANGER WILL BE KEPT INFORMED AND WILL PROVIDE INFORMATION ON LAND MANAGEMENT OBJECTIVES
P=.3 LEVEL III
16.2 MILES
AFTER COMPLETION OF INTENSIVE GEOLOGIC SURVEY THE PROJECT ENGR AND MATERIALS ENGR TO DECIDE IF FOUNDATION INVESTIGATION OR IF SLOPE STABILITY ANALYSIS IS NECESSARY
NO P=.8
WORK COMPLETE
12.8 MILES
YES P=.2 LEVEL IV
3.2 MILES
P=.1 ADDITIONAL INVESTIGATION
LEVEL IV
5.4 MILES
TOTAL 90 MILES
TOTAL MILES IN EACH CATEGORY
WALK THROUGH GEOLOGIC RECONNAISSANCE
10.8 MILES
MODERATE INTENSITY GEOLOGIC SURVEY
17.3 MILES
INTENSIVE GEOLOGIC SURVEY
15.0 MILES
INTENSIVE GEOLOGIC SURVEY FOLLOWED BY FOUNDATION INVESTIGATION OR SLOPE STABILITY ANALYSIS
10.9 MILES
DEPTH OF GEOTECHNICAL INVESTIGATIONS
LEVEL O - NO FORMAL GEOTECHNICAL WORK WILL BE DONE THE DECISION NOT TO PERFORM GEOTECHNICAL WORK WILL BE REVIEWED BY MU REVIEW TEAM ESTIMATED ANNUAL MILES OF ROADS NOT RECEIVING ANY FORMAL GEOTECHNICAL INVESTIGATIONS IS 36
LEVEL I - WALK THROUGH GEOLOGIC RECONNAISSANCE SUPPLEMENTED BY AERIAL PHOTO REVIEW. BRIEF REPORT OF MAJOR GEOLOGIC FEATURES. ESTIMATED MILES OF ROAD IS 11.
LEVEL II - MODERATE INTENSITY GEOLOGIC SURVEY. GENERAL REPORT SUPPORTED BY ADDITIONAL FIELD WORK AFTER RECONNAISSANCE AND SMALL AMOUNT OF GEOPHYSICAL TESTING MILES 17
LEVEL III INTENSIVE GEOLOGIC SURVEY. DETAILED GEOLOGIC REPORT TO BE SUPPORTED BY ADDITIONAL FIELD WORK AFTER RECONNAISSANCE, EXTENSIVE GEOPHYSICAL TESTING. SMALL AMOUNT OF SOIL SAMPLING AND TESTING MILES 15
LEVEL IV INTENSIVE GEOLOGIC SURVEY FOLLOWED BY FOUNDATION INVESTIGATION OR SLOPE STABILITY ANALYSIS WORK THAT MAY BE PERFORMED: GEOPHYSICAL TESTING, SOIL SAMPLING, DRILLING INSTRUMENTATION TESTING OF SOILS FOR IDENTIFICATION AND ENGINEERING PROPERTIES. REPORT WILL INCLUDE DETAILED GEOLOGY OF AREA AND DESIGN ALTERNATES IN CRITICAL AREAS. MILES 11

"Incorporates slope design guide. This is a guide which provides general values or recommendations for cut and fill slope ratios. Data needed to use the guide are soil classifications, general field conditions in respect to density and moisture, and height of cut or fill.

"The recommendations given must be modified to fit local conditions and experiences." (25)

6. Douglas N. Swanston and others of the U. S. Forest Service developed a pilot program for determining landslide potential in glaciated valleys of southeastern Alaska. This development was in response to investigations which had shown erosion to be a predominate problem in southeast Alaska.

Land stratification techniques were used to classify potential landslide hazard. Data on land features were characterized by "accurate location and distribution of all active and potential land slides and snow slides and the estimated or probable major variations in a slope stability characteristics from one location to the next within the investigated area." From this information a hazard rating system was devised to stratify land zones. (26)

Their experience with the southeast Alaska's steep slopes with shallow coarse grained soils lead them to use three classifications.

a. "A slope above 36° is highly unstable even under the most favorable of natural conditions.

b. Slopes between 26°and 36° may or may not be stable depending on local variations in basic soil characteristics, soil moisture content and distribution, vegetation cover, and slope.

c. Slopes below 26° (49%) were considered stable although local steep, hazardous areas not picked up in the initial survey may exist, and operations on them should be governed by the rules for more unstable areas."

Swanston emphasizes the many natural unstable slope conditions in Southeastern Alaska and observes that man's activities will aggravate them. He believes that the land manager must decide whether "to accept the consequences of logging over steepened slopes or to control the effects of these activities in order to minimize mass movements." (27) He suggests that control can be accomplished by direct methods of slope stabilization or by avoiding areas of known or expected instability.

2.02 Roads & Harvest Method Relationships

There is a general trend in forest land management toward a closer coordination of road planning with harvest methods. One of the factors supporting this trend is the realization that past practices have sometimes resulted in haphazard road patterns resulting in more total road mileage than necessary. Minimizing the road mileage is a way to minimize the need to deal with the sediment creation and transport problem.

Recognition of the problems attendant to over roading is not new. In 1956, the Boise National Forest's guide lines for erosion control reported a tendency for an excess of roads with the increased use of heavy construction equipment and "especially if the construction chance is easy." This publication further stated: "Too many roads within an area completely destroy the protective soil mantle." (28)

Fredriksen studied erosion and sediment resulting from timber harvest and road construction in watersheds within the H. J. Andrews Experimental

Forest. (29) A watershed harvested by clear cutting with Skyline logging without roads yielded less sediment than a watershed harvest by patch clear cutting, high lead logging and parallel logging roads.

Although harvest method - road relationships are not exclusively the forest engineers domain, or are they exclusively pertinent to the subject of sediment, serious attention to these relationships is believed to be an important part of the engineer's initial discussions with the land manager. The engineers pre-field reconnaissance response to the land manager as to the engineering feasibility of a proposed road may appropriately include a response to management's assumed logging method as previously mentioned. Alternately, the engineer may be asked to assist the land manager in determining the type of harvest method compatible to the type and location of road that can be constructed in the proposed corridor.

Knowledge of the harvest method and its effect on road location, width and alignment is of vital importance in defining the scope of the field reconnaissance. Part B "Reconnaissance" of this chapter will discuss this aspect of the proposed harvest method in more detail.

3.00 Conclusions

After the engineer's report to the land manager, a mutually agreeable definition for the road reconnaissance should be ideally established. Since a "no road" decision is complicated in marginal terrain, a field reconnaissance to affirm this decision may be desirable.

A specific understanding of management objectives is a need that was emphasized in Recommendation 6.1 of the U. S. Forest Service Region 6

Road Audit. (30) The Siuslaw National Forest Implementation Plan urges detailed management inputs including trade offs considered, allowable impacts on road geometry that are acceptable to attain an objective and the inclusion of "realistic confidence levels expected in the designer." (31)

B. ROUTE RECONNAISSANCE

Route reconnaissance is the examination of the entire area surrounding the proposed project with the intent to segregate routes on their relative merits of economics, service and ecological impacts. The talents appropriately involved in a reconnaissance for a particular project will vary with the scope of the proposed road, the relative sensitivity of the terrain, the knowledge and experience of personnel and the amount of data already available about the proposed corridor.

Larse points out that "all too frequently the location of a specific road is a one-man effort with little consideration or recognition of alternative opportunities, watershed values, land form or soil characteristics and stability, or other environmental conditions." (32) A reconnaissance team might consist of a hydrologist, soil scientist or soils engineer, geologist, landscape architect, forester, forest engineer, civil engineer, watershed specialist, biologist and others. The disciplines listed above might be those assembled for a major undertaking in highly sensitive terrain about which little applicable data is available.

Members of a reconnaissance team whose duties would include observations for and the gathering of data to determine potential problems of sediment creation and transport are the geologist and/or soils engineer, the forest engineer and the civil engineer. The depth of investigation necessary for these disciplines cannot be generalized in the abstract without specific knowledge of the actual site conditions for a proposed road. As pointed out in Part A 2.01 of this Chapter, the Siuslaw National Forest has a procedure for determining the depth of geotechnical investigation required for a given road location.

As the introduction to this Chapter emphasized, an adequate field reconnaissance is of great importance when the goal of sediment minimization is a part of logging road performance criteria. Historically, road failures have been related to the following oversights or errors.

1. Inadequate geotechnical information.
2. Application of rigid rules regarding horizontal curvature and vertical gradients.
3. Over roading or misplaced roads due to a lack of or a poor land management and transportation plan.
4. Road locations to support an inappropriate harvest procedure.

The discussion that follows is divided into three parts: (1) Factors affecting surface erosion, (2) Erosion and mass wasting considerations, and (3) Civil and Forest Engineering Reconnaissance.

1.00 Factors Affecting Surface Erosion

1.01 Introduction

Planning for effective prevention and control of soil erosion is dependent upon a basic understanding of erosion processes. Many factors with often complex interrelationships are involved. Considerable research effort has been expended on identifying these factors and their relationships, but predictive methodologies (mathematical formulas for calculating erosion as a function of measurable field parameters) still fall short of accurate prediction of soil erosion and resultant downgradient sediment production, particularly in a forested environment. Additional information and data are needed and methods need to be refined. However, the available research studies have been invaluable in identifying the major factors influencing soil erosion and providing a relative measure of their importance.

1.02 Soil Loss Equations

The relationships among the principal factors controlling soil erosion, notably sheet erosion, have been embodied in several somewhat similar predictive equations (33, 34). Most of the methods available to date have been developed for cropland areas. Of these methods, the "Universal Soil Loss Equation" for the prediction of sheet erosion as presented by Wischmeier and Smith in USDA-ARS Agriculture Handbook 282 (33) has gained the most widespread acceptance. The equation was originally developed for cropland areas east of the Rocky Mountains, but has since been adapted to other uses (36) as well as for forested areas including forests of the Pacific Northwest (35). Although modified in consultation with Wischmeier, it is important to point out that the Bureau of Land Management's adaptations as proposed in Reference 35 have not been field tested to any significant extent.

1.03 Universal Soil Loss Equation

The Universal Soil Loss Equation takes into account the influences of rainfall characteristics, soil characteristics, topography, and land cover conditions. The Universal Equation is as follows:

$$A = RKLSCP \qquad \text{(Eq. II B-1)}$$

where A is the potential soil loss in tons per acre per year, R is a rainfall factor, K is a soil-erodibility factor, L and S are slope length and steepness factors, C is a cover and management factor, and P accounts for supporting conservation practices such as terracing, strip cropping, and contouring. Use of some of these factors must be modified slightly for use of the equation in a forested environment.

a. Rainfall Erosion Factor. The rainfall erosion factor, R, accounts for the combination of rainfall kinetic energy available for detachment of soil particles and associated runoff available to transport them and to detach others. The factor is defined to be the total kinetic energy of a storm times its maximum 30-minute intensity as indicated by the following relationship:

$$R = \frac{\sum EI}{100} \qquad \text{(Eq. II B-2)}$$

where E is the storm energy in foot-tons/acre-inch and I is the maximum 30-minute rainfall intensity in inches/hour. For a season or year, the total R is the sum of the individual storm values. The kinetic energy of rainfall, E, is related to rainfall intensity by the following formula (36):

$$E + 0.0916 + .0331 \log_{10} I \qquad \text{(Eq. II B-3)}$$

To compute E, the rainstorm is divided into increments of approximately uniform intensity and the energy for each increment is computed using Equation II B-3 . The sum of these incremental values of E for the entire storm represents the E value to be used in Equation II B- 2 . The I value to be used is the maximum 30-minute intensity during the storm.

R values have been computed for the U.S. east of the Rocky Mountains and published as iso-erodent maps (33) . R values for areas west of the Mississippi River have been correlated with the 2-year, 6-hour precipitation. The relationship is presented on Figure II B-1 . Wischmeier calculated R values for Portland, Oregon, and they correlated reasonably well with values obtained using Figure II B-1 (35) . Actual R values for specific locations in USEPA, Region 10 can best be calculated using local rainfall records corrected for elevation of the subject area or as a less accurate alternative, the R value can be obtained by converting the 2-year, 6-hour precipitation values shown on Figure II B-2 to R values by means of Figure II B-1. Two-year, 6-hour precipitation values can be obtained for the northwestern United States and Alaska from U.S. Weather Bureau publications TP-40 (37) and TP-47 (38).

b. Soil Erodibility Factor. The erodibility of a particular soil is dependent upon its resistance to detachment and once detached to its susceptibility to transport. Water intake capacity and structural stability are the overall controlling factors.

Extensive research on identification of individual soil characteristics influencing erosion including studies leading to development of simplified means for determination of the K-factor in the Universal Equation indicates the interrelated involvement of numerous characteristics including soil texture; type, amount, orientation, and chemical properties of colloids (clay size particles), particularly the presence of swelling clays; organic matter content; percentage of coarse aggregates and other large, essentially non-erodible particle; and chemical properties of the eroding fluid in the case of some clays. Soil permeability and the presence of impervious layers at shallow depth are also very important because of their effect on runoff.
Of the individual characteristics, particle size and degree of aggregation have the most influence. Clays, for example, have very small particle size which are easily transported by water, but are not easily detached because of high aggregation. Sands,on the other hand, are very easily detached, but are not easily transported because of much larger particle size. Silts have relatively small particle size,

although not as small as clays, and are generally relatively easily detached and easily transported, thus making them most vulnerable to erosion.

The soil erodibility factor, K, in the Universal Soil Loss Equation defines the inherent erodibility of the soil. The K-value for a particular soil is inherent in its makeup and is independent of geographical or other factors. Data used to obtain the K-value can be obtained by field and/or laboratory tests.

In development of the simplified means of determination of the K-Factor, the standard USDA textural classification system commonly used by the Agricultural research Service was found to correlate poorly with soil erodibility. To obtain better correlation, it was necessary to modify the size differentiation between silt and sand as shown in Table II B-1 because fine sand was found to behave like silt. The Unified Soil Classification System,particle size classifications and U.S. Standard Sieve sizes for the classification divisions in the Universal Equation are also shown for comparison.

TABLE II B-1

GRAIN SIZE IN MM

	Universal Equation		USDA	Unified
	Size	U.S. Standard Sieve Size		
Clay	<.002	-	<.002	unspecified
Silt	.002-.10		.002-.05	- to .074
		140		
Sand	.10-2.0		.05-2.0	.074-4.76
		10		

To facilitate use of the textural data, a parameter was developed to describe the entire particle size distribution for a given soil. This parameter takes into account the percentage of silt and the clay-to-sand ratio. The parameter, in graphical form, comprises the left section of the nomograph shown on Figure II B-3 . In general terms, this parameter reveals that silt-size particles are most easily eroded and that soils become less erodible as either the sand or the clay fractions increase. For a given increment of silt, increases in the clay-to-sand ratio decrease the erodibility.

Even though the new size distribution parameter alone accounted for about 85 percent of the variance between actual and predicted values of erosion from test plots, it was necessary to include three more parameters to remove wide deviations between actual and predicted values for a few plots. These new parameters, which comprise the remainder of the nomograph shown on Figure II B-3 , include organic matter content, soil structure, and permeability. Descriptive definitions of soil structure and permeability are included on Figure II B-3 . Unless extensive disturbance is expected, all values to be used in the nomograph except permeability are for the top 6 to 7 inches of soil.

The test results used in developing the nomograph indicated that organic matter content is inversely related to sediment production. This relationship was strongest for silts and silty and sandy loams and declined significantly as clay content increased. Also, soils with blocky or massive overall structures or with high permeability were found less susceptible to erosion.

The method developed for nomograph determination of the K-factor does not take into account soils particles above 2 mm in diameter. These coarse aggregates commonly comprise a significant percentage of the upper soil profile in forested mountain areas of USEPA, Region 10. In introducing the nomograph, Wischmeier (39) states that the percent of coarse fragments in the soil can have a significant influence and that beyond some limiting density would be expected to act much like a protective mulch. However, because of limited data on erosion from soils with coarse aggregates, Wischmeier was not able to state the minimum density required or provide any numerical relationships quantifying their importance. From his extensive independent study of factors influencing erosion on logging roads in the northern Rocky Mountains, Packer (46) concluded that the presence of water-stable aggregates larger than 2 mm in diameter on road surfaces and cut slopes above roads had a very significant effect on preventing erosive cutting. In modifying the Universal Equation for western Oregon the Bureau of Land Management (35) suggested reduction of the K-factor by the percentage of coarse fragments in the upper soil. This approach appears reasonable until additional research data becomes available.

c. Slope Length and Steepness Factors. The capability of runoff to detach and transport soil material increases rapidly with increases in runoff velocity. Theoretically, doubling velocity enables water to move particles 64 times larger, carry 32 times more material in suspension, and increases the erosive power 4 times (40). Runoff velocity increases as the runoff rate increases, as the flow concentrates (often because of increased slope length), or as the slope steepens. Increasing the steepness of a slope from 10 percent to 40 percent, for example, doubles the flow velocity.

The dimensionsless factors L and S in the Universal Soil Loss Equation account for the effects of slope length (L) and steepness (S). The slope factors have a value of unity for the basic test plot dimensions of 9 percent gradient and 72.6 feet length as used in the final stages of development of the simplified means of determination of the soil erodibility factor, K. Equations and a chart are presented in Reference 33 for consideration of gradient and length effects on slopes not exceeding 20 percent and of moderate length (approximately 400 feet or less). However, in mountainous forested areas of USEPA, Region 10, slopes often exceed 20 percent by a large margin and may have unimpeded lengths exceeding 400 feet.

In modifying the Universal Equation for use in western Oregon, the Bureau of Land Management (35) presents new equations for computing L and S factors for slopes with greater steepness and length. The equations are presented below:

$$L = \frac{(\text{slope length (Ft.)})^{0.6}}{75} \qquad \text{(Eq. II B-4)}$$

$$S = \frac{(\%\ \text{slope})^{1.4}}{9} \qquad \text{(Eq. II B-5)}$$

The slope length (L) and gradient (S) have been combined as LS and may be obtained directly from Figure II B-4 for slopes up to 50 percent with lengths up to 2,000 feet.

When a slope is irregular, the average steepness does not accurately predict the slope effect. The soil loss rate at the toe of a convex slope (steepening towards the toe) is greater than on a uniform slope of equal elevation change while the opposite is true for a concave slope. Significant differences in soil loss can occur in slopes of equal elevation changes because of different shapes as illustrated on Figure II B-5. For more detailed information, the reader is advised to consult references 41 and 42.

d. Cover-Management Factor. Raindrops striking bare soil act like miniature bombs to break up soil aggregates and splatter soil particles as much as 2 feet into the air. Raindrops also compact the exposed soil surface causing increased rates of surface runoff. Some conception of the striking force can be envisioned from the fact that raindrops strike the ground at velocities of about 30 fps and 1 inch of water over an acre of area weighs more than 110 tons.

Erosion can be materially reduced by maintenance of a dense ground cover as protection against raindrop impact. Vegetation is the most effective means of providing this cover. Vegetation canopy and resultant ground litter both act to absorb and disperse raindrop impact. Vegetation also stabilizes the soil surface with a dense mat of roots.

The cover-management factor, C, in the Universal Equation is used to account for the efficiency of different cover and management combinations in protecting against soil loss. C ranges in value from near zero for excellent sod or a well-developed forest to 1.0 for continuous fallow, construction areas, or other extensively disturbed soils.

Although initially developed for cropland areas, the C-factor can be applied to other environments. Along newly constructed logging roads or other extensively disturbed construction areas, C reflects the influences of various types and rates of mulch, application of slash debris to slopes, methods of revegetation, degree of compaction of fill slopes, as well as other such factors. The effects of some of these factors have been investigated for specific environments and the information published in numerous references. The effects of different mulches and mulch rates on reducing erosion are discussed in Section III B-1.03 of this report. This type of information can be used to develop C-factors for logging roads in the forest environment.

e. Conservation Practices Factor. The conservation practices factor, P, as developed for cropland areas in the Universal Equation reflects the runoff control and erosion-reducing effects of conservation practices such as contour farming, terracing, or strip cropping. The counterparts of these conservation practices serve equivalent purposes in forested areas. Terraces, or benches, and diversions on steep slopes above or below logging roads can be used to reduce effective slope length and prevent concentration of flow in undesired areas.

Provision of buffer strips between areas disturbed by logging road construction and stream courses, which is anaolgous to strip cropping of farmland, is an important conservation practice in logging and logging road construction.

Several researchers including Packer (46) and Trimble and Sartz (47) have studied the effect of various types of buffer strips and other factors on the movement of sediments downgradient of logging roads. The reader is advised to consult these references for an indication of the effectiveness of these various conservation factors on reducing the movement of sediments.

1.04 Stream Sedimentation

It is important to note that the quantitative procedures embodied in the Universal Equation are limited to on-site erosion. There is no provision in the predictive methodology to compute the proportion of eroded sediments reaching watercourses. To extend the predictive ability, Dissmeyer (48, 49) has reportedly developed a method called the First Approximation of Suspended Sediment (FASS) to evaluate the impact of disturbances or control practices on suspended sediment contribution to surface waters. In addition to the contribution from sheet erosion, FASS also takes into account gully and channel erosion. When available, this method may have some application for the care of logging road sediment contribution to streams. Several other predictive equations developed to date can be used to evaluate downstream sedimentation for a given set of upstream conditions (40), but only for watershed-size areas and not for individual construction areas or for evaluation of specific conservation practices as would be required in the case of logging road construction.

1.05 Other Information Sources

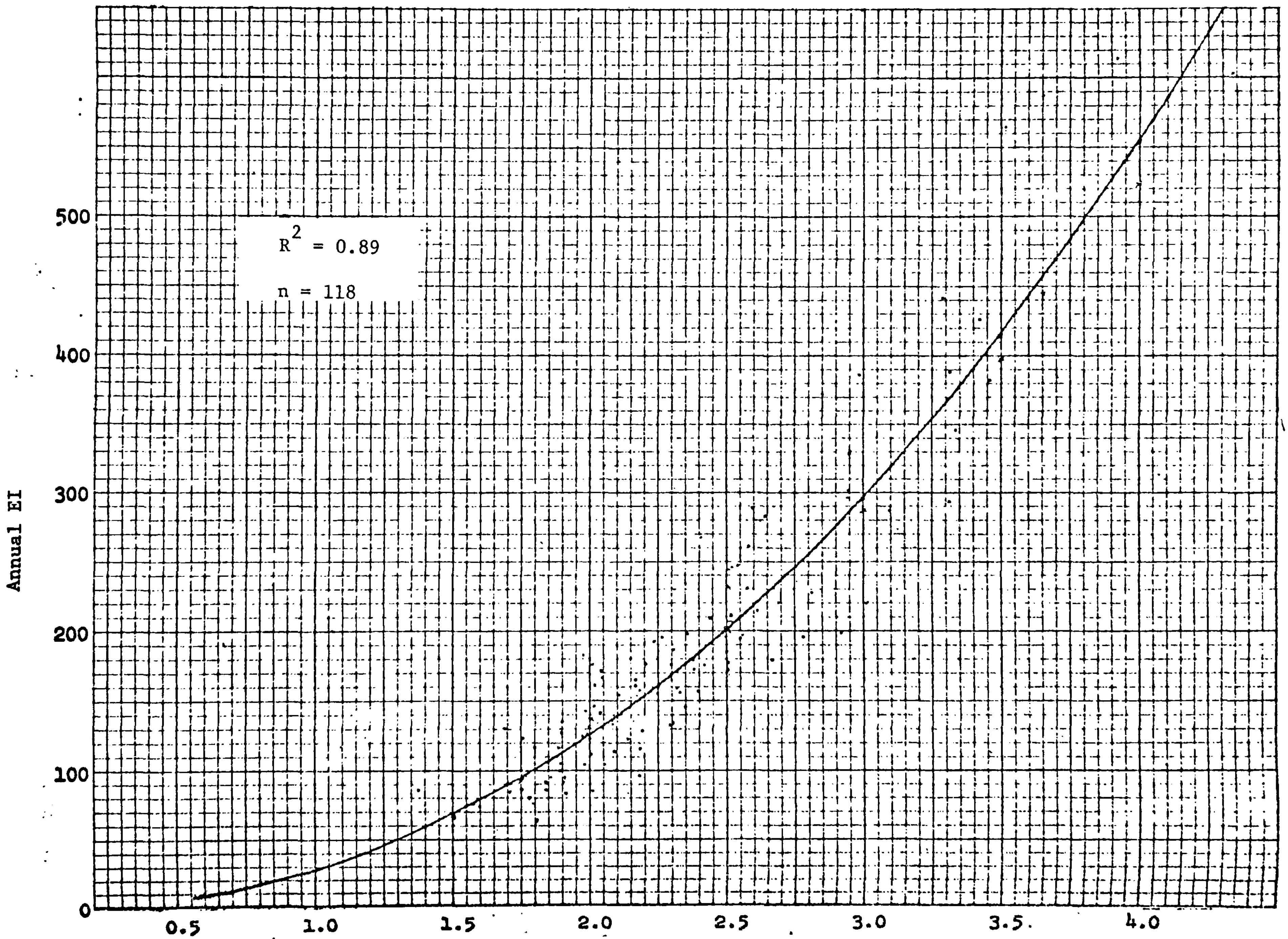
For more extensive and complete bibliographies on factors affecting erosion and other closely related subjects, interested readers are advised to consult references 36, 49 and 50.

Figure II B-1

Relation of Annual EI to 2-Year 6-Hour Rainfall

West of the Mississippi River

Source: Reference 35



2-YEAR 6-HOUR RAINFALL (INCHES)

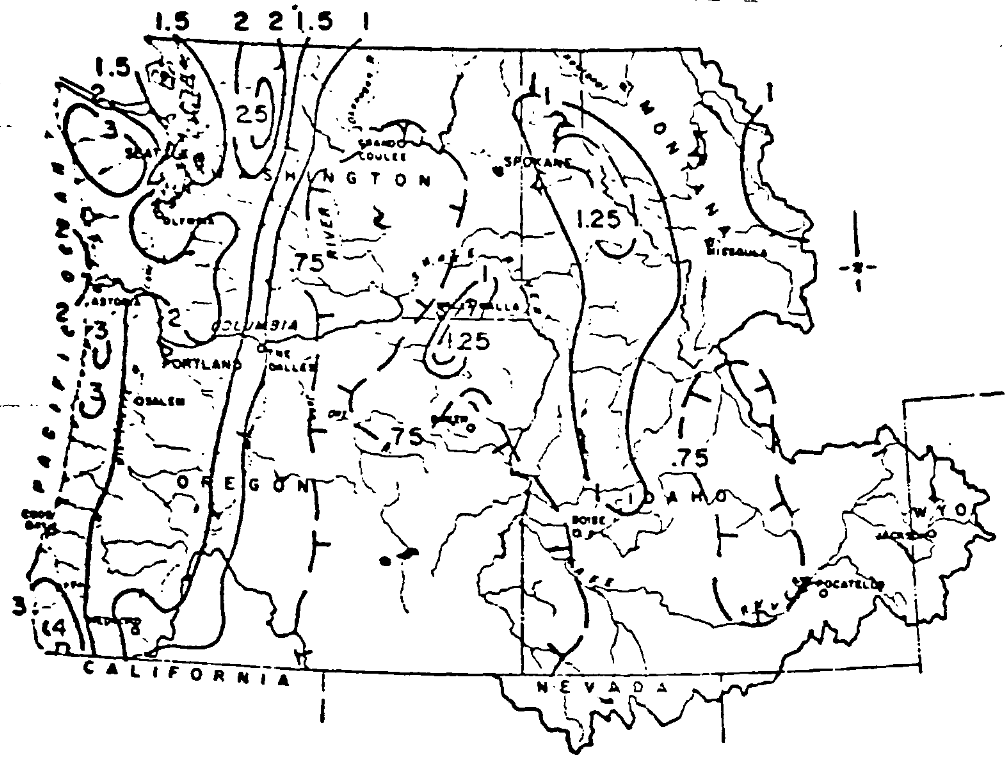


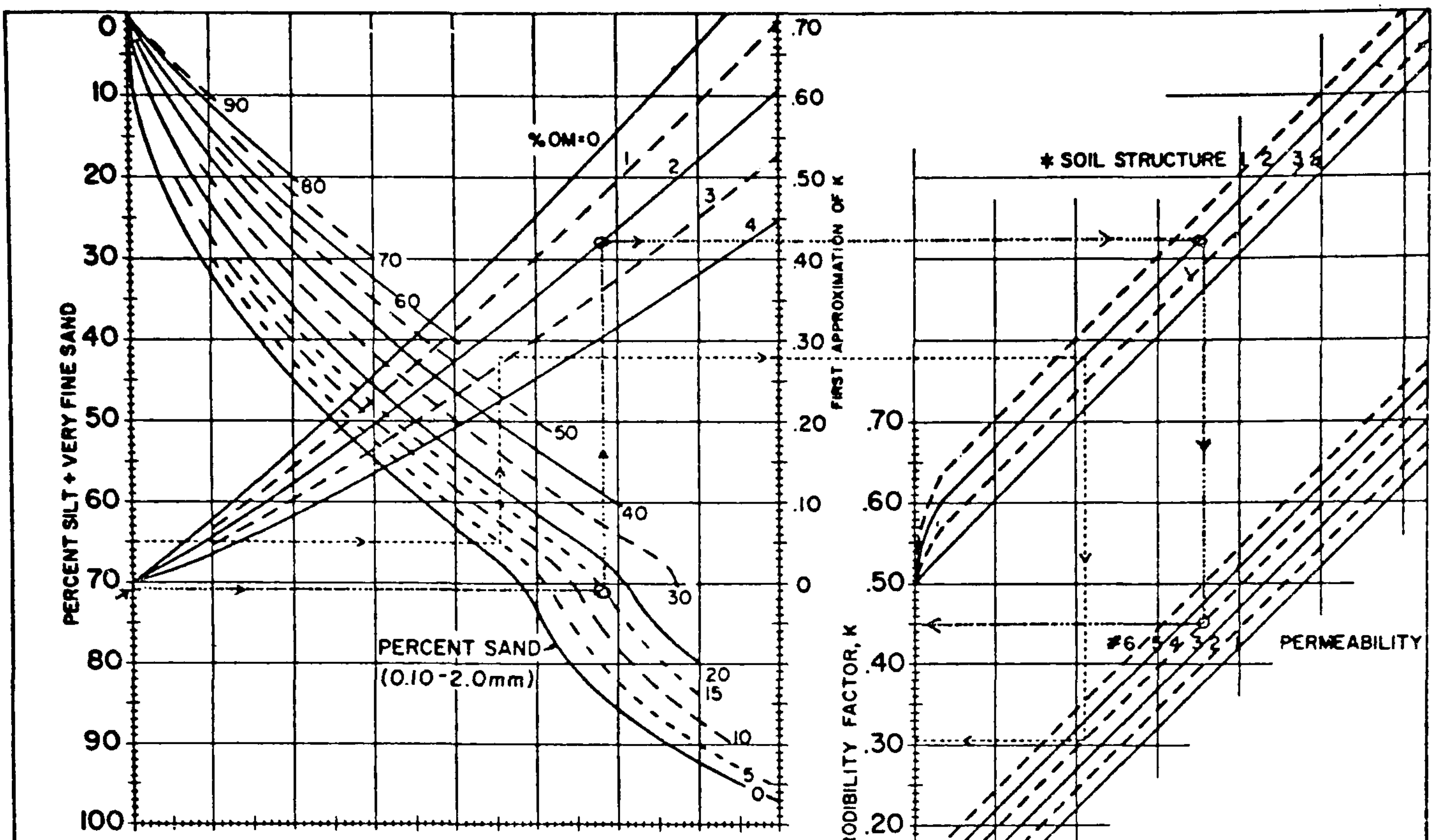
Fig IIB-2

Source : Climatological Handbook Columbia Basin States, Precipitation, Vol. 2.

(also avail. for entire U.S. in U.S. Weather Bureau TP40)

Meteorology Committee
Pacific N. W. River Basins
Commission, Sept. 1969

Figure II B-3. Soil-Erodibility Nomograph



PROCEDURE: With appropriate data, enter scale at left and proceed to points representing the soil's sand (0.10-2.0 mm), % organic matter, structure, and permeability, *in that sequence*. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having: si+vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4. Solution: K = 0.31.

Structure Index	Definition
1	Very fine granular
2	Fine granular
3	Medium or coarse granular
4	Blocky, platy, or massive

Permeability Class	Definition
1	Rapid
2	Moderate to rapid
3	Moderate
4	Slow to moderate
5	Slow
6	Very slow

Source: Reference 36

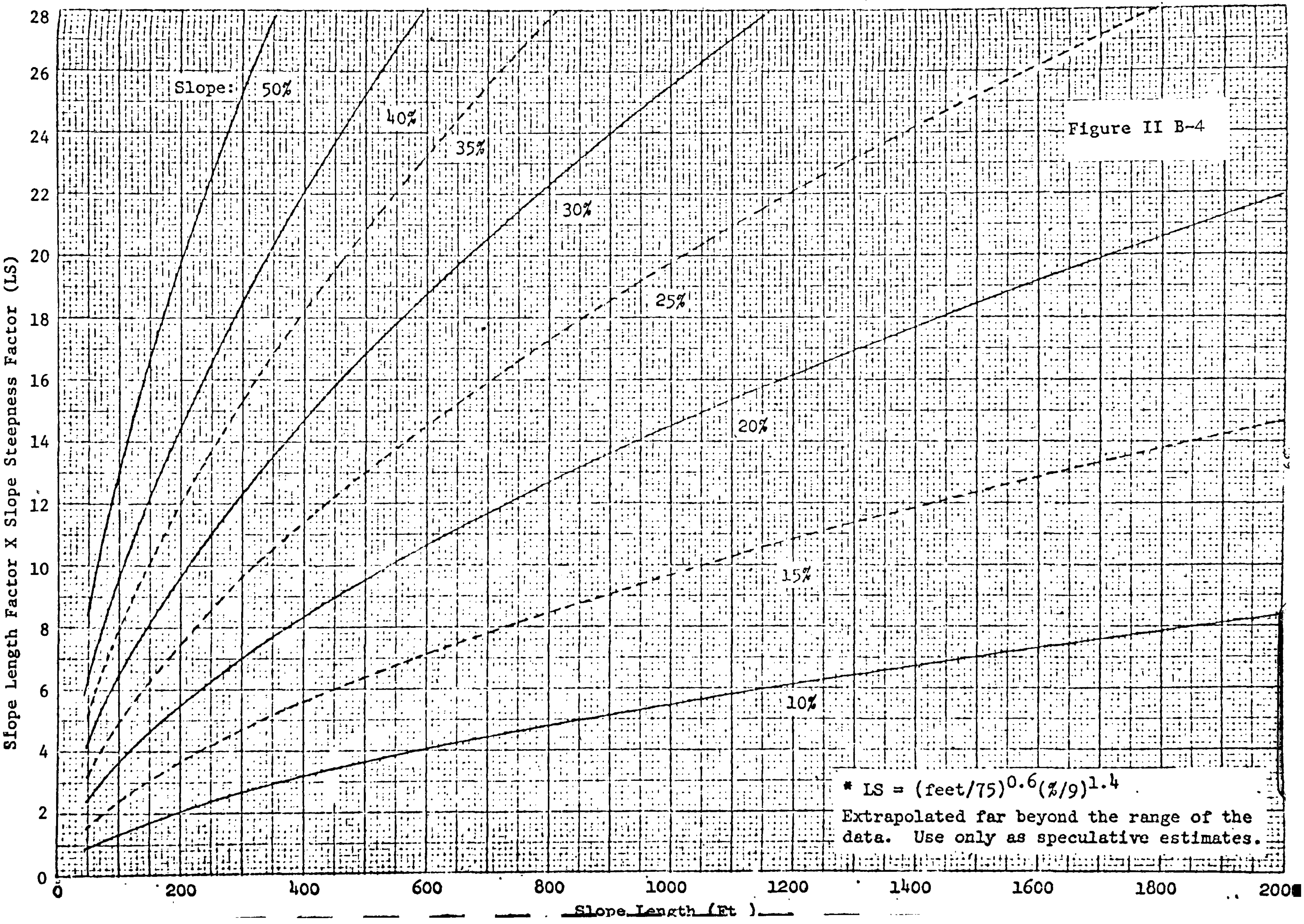
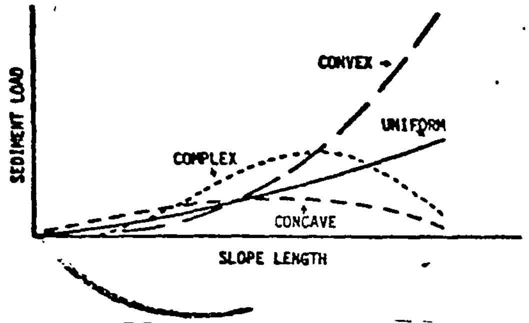

Source: Reference 35
Figure II B-4
Slope: 50%
40%
35%
30%
25%
20%
15%
10%
* LS = (feet/75)^0.6 (%/9)^1.4
Extrapolated far beyond the range of the data. Use only as speculative estimates.
Slope Length Factor X Slope Steepness Factor (LS)
Slope Length (Ft)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
200
400
600
800
1000
1200
1400
1600
1800
2000

Fig. IIB-5

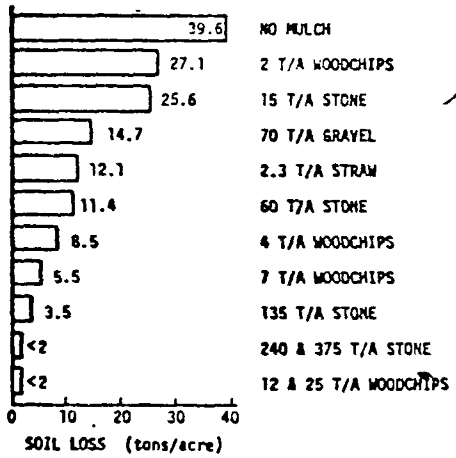
Figure 3. Influence of land slope shape on sediment load.



(36)
(not original)

Fig. IIB-6

Figure 5. Influence of several mulch types and rates on soil loss from 5:1 construction side-slope (rain intensity = 2.5 in./hour; total applied = 5 in.; slope length = 35 ft).



delete

(43)

2.00 EROSION AND MASS WASTING CONSIDERATIONS

2.01 Introduction

Roads can have a serious impact on the hydrologic functioning of watersheds. In many cases, 90 percent or more of the accelerated erosion in forested watersheds has been attibuted to roads (53). Higher runoff rates and increased surface erosion and mass wasting account for these increases. Much of the soil movement could be avoided by proper road location and design. Adequate field and office investigative work is necessary to assure that the essential information needed for selection of the best route and proper road design is available (66).

During the planning process discussed earlier in Section IA, the need for the road is established and road termini and intermediate points are defined resulting in delineation of a general road corridor(s). Other controlling design parameters such as type and volume of anticipated use, type of road, and any special features required are also defined. However, prior to any actual design work reconnaissance studies must be conducted to locate the best road alignment and gather information needed for design of the road itself and associated drainage, erosion, mass wasting, and other control measures. The source of the reconnaissance information can range from office maps and reports through detailed investigative programs involving field explorations and laboratory analyses.

Information of various types from a broad-based team of technical specialists is required to develop a road design that best suits its intended purposes while minimizing economic and environmental costs. However, because of the scope of this study, only those factors affecting road performance with regard to surface erosion and mass wasting as they affect water quality are included herein. Some of the information that may be required to guard against stream sedimentation resulting from surface erosion and mass wasting includes soil texture and aggregation; subsurface soil strength, depth, and other soil or rock conditions; slope lengths, steepness and aspect; existing surface erosion and mass movement behavior along the route; precipitation and streamflow characteristics; groundwater conditions; surface drainage network; soil fertility and other conditions affecting vegetation establishment; and up-gradient and down-gradient slope vegetation patterns.

The importance of the reconnaissance investigation cannot be overemphasized. It is during the reconnaissance work that the major decisions are made. Once the road is located and constructed, mistakes are often difficult or impossible to correct later on. Failure to do an adequate job of reconnaissance can easily result in future construction, maintenance, transportation, and environmental costs far in excess of savings realized from an incomplete or inadequate reconnaissance (62).

2.02 Aids

Use should be made of all available aids, including topographic maps, geologic and soils maps and reports, aerial photographs, and other sources in order to reduce the requirements for field investigations.

However, these aids should only be used as supplements and not substitutes for field investigations. As a minimum for simple cases where information obtained from these aids is deemed sufficient for design purposes, their accuracy should be field checked. Some of the available aids and potential applications are described in the following sections.

a. Aerial Photographs. Aerial photographs are particularly valuable in the planning stage for gaining an overall feel for a general area and detecting differences between local areas that are important to route corridor selection. However, they are also of considerable value in final route selection and design during the reconnaissance investigation. Aerial photographs of at least one usable scale are available for most areas and in some areas more than one scale is available. Many photos are available in stereoscopic pairs permitting viewing in three dimensional perspective. Land forms, vegetation, geologic, and hydrologic features are among the features easily identifiable from such photographs.

Aerial photographs of small scale provide a broad scale perspective of an area. Whole landscapes can be surveyed enabling study of drainage networks, geologic features and land forms, and vegetation patterns. Mass movements, particularly large failures, are easier to detect. Rotational movements are often indicated by arc-shape bedrock exposures accompanied by uneven lands downslope or variations or abrupt changes in vegetative patterns. Avalanche activity can be similarly identified by abrupt changes in vegetative patterns perpendicular to the ridge system. Large features of this nature are often much easier to identify from such photographs than through use of other aids or on-ground observations.

Aerial photographs of large scale can be used to refine interpretations made from the small-scale photos as well as enabling more detailed inferences of drainage, geologic, topographic, vegetative, and other factors. Geologic bedrock types can often be identified and some degree of accuracy can be developed regarding the fracturing and jointing pattern of a particular bedrock type. The extent of talus, alluvial and other deposits can usually be identified. Slope gradients can be determined with some degree of accuracy and stream channel and other drainage characteristics can be studied. Vegetative patterns and types can be identified. Other interpretations such as soil types can often be made based upon interaction of geologic and land form characteristics, vegetation, color, and other factors. Mass movement or erosional activity of small scale can often be identified.

b. Topographic Maps. Topographic maps of various scales are available for most areas. Such maps, particularly of the 7½- and 15-minute series, are quite useful for road location and design purposes (69). Information on slope gradients and other topographic features can generally be obtained with a reasonable degree of accuracy, particularly if over-story vegetation was not dense at the time of photography for mapping. Geologic inferences, including landform, slope steepness and irregularity, arrangement and incision of drainage networks, and other features can be made from topographic information. Topographic maps provide considerable information on stream systems such as gradients and channel sizes in easily obtainable form. Topographic maps are quite useful as base maps and provide an easily available source of gradient information for trial road alignments.

c. Soil Surveys. Numerous types of soils are exposed during road construction in USEPA, Region 10. They are formed from many different parent materials including glacial till, alluvial deposits, and granite to name a few. These soil materials commonly have various unfavorable physical and chemical properties that affect road performance, stability against erosion and mass wasting, and revegetation. Some of these soil characteristics and related topographic conditions that may affect subsequent road behavior include steep slopes, south and west exposures, shallowness to rock or other restrictive layers, unfavorable pH, low fertility, fine texture and low aggregation, low permeability, high groundwater table, high shrink-swell potential, massive disturbance as a result of previous slide activity, low strength characteristics, and high compressibility.

Soil surveys furnish considerable information on the extent of these interacting features. Such surveys are generally compiled as a single unit for large areas such as counties or natural forest, thus providing a wealth of information on a broad scale well suited to route selecion as well as providing general guidance in road design. Soil surveys are made and published by a variety of governmental agencies and private organizations but mostly by the federal government. The Soil Conservation Service has published detailed soil surveys for many counties within USEPA, Region 10, while the Forest Service has published soil surveys for many of the national forests (69). New surveys are continually being developed by these agencies and older surveys updated. The Weyerhaeuser Company has recently completed and published an extensive soil survey of their land holdings as well as contiguous adjacent lands.

In addition to providing information on many of the individual soil properties mentioned previously, most surveys also provide considerable interpretative information on soil suitability for various uses, including limitations on uses. Such ratings may include suitability for road location and construction; surface erosion potential; susceptibility to cut or fill bank, mass movement, sloughing, or raveling; limitations on cut and fill slope seeding; suitability for various types of vegetation establishment; and numerous other behavioral characteristics under various uses.

d. Geology Maps. Geology maps of various degrees of detail are available for many areas. These maps range in scale from state or areawide to maps of much smaller areas, such as portions of counties or 7½- or 15-minute topographic quadrangles (69). Depending upon the degree of detail, geology maps may include information on topography, descriptions and extent of surface outcrop materials, geologic cross sections, and strike and dip of formations. Such maps may also include geologic hazards such as faults, degree of slope, flood-prone areas, high groundwater table areas, landslide topography, and areas susceptible to various types of surface erosion.

e. Other Aids. Several other less used but often equally important aids are often of value. These include precipitation intensity-duration maps, vegetation maps, hydrographic studies, or other general or detailed reports available for the study area or similar areas.

2.03 Field Reconnaissance

Field reconnaissance is an essential step in any road location or design study. In all but the simplest cases where the designer has access to proven aids and is thoroughly familiar with an area, a field reconnaissance should be made before final route location or design. The purpose of the field reconnaissance is to confirm inferences made from the aids, verify the accuracy of the information obtained from the aids, and to gather otherwise unavailable or more detailed information needed for either road location or design (68). In only rare cases is published information generally of sufficient detail and accuracy to be considered suitable for final design purposes.

During the field reconnaissance, the applicable published aids such as maps and aerial photographs should be used. These are valuable in determining the location of control points and are generally reliable for use as base maps for field layout work.

Generally, more than one field reconnaissance trip will be necessary. Depending on the amount and quality of available data, these field investigations may be a phase process in which a preliminary field reconnaissance and soil survey of the corridor is accomplished by a team of experienced specialists. The team of specialists should include an experienced engineering geologist. The preliminary reconnaissance and soils survey should establish the erosion and mass wasting potential within the corridor and areas adjacent to the corridor. This preliminary work should also include delineating areas of potential hazard and, where possible, outlining alternate routes to enable avoiding the hazards. The next phase of work should consist of detailed investigations of the hazard areas and possible alternate routes. The detailed investigation may include test pits, borings, undisturbed sampling for strength testing, installation of piezometers to obtain valid water table information; and in some cases installation of slope indicators to determine the amount of existing or future movement.

Many factors must be considered and properly evaluated during field reconnaissance surveys if surface erosion and mass movement are to be minimized. The factors primarily include surface and subsurface soil and geologic conditions; topography, including slope steepness, length, and aspect; precipitation; groundwater conditions; and vegetation. How each of these and other factors affects sediment contribution to streams due to surface erosion and mass wasting will be discussed in the following sections.

a. Surface Erosion. Numerous factors affect the potential for soil erosion from forest roads and contribution of such sediments to streams. All except locational factors are incorporated in the Universal Soil Loss Equation which is discussed in Section IIB-1.00. These factors primarily include soil texture, aggregation, and other intrinsic properties; topographic factors such as slope steepness, length and aspect; nearness of the road to the stream system; precipitation amounts and severity; and upgradient and downgradient vegetation. Roadway design, including slope protection and drainage provisions, can also have a large influence.

Intrinsic soil properties affecting erosion potential are discussed in considerable detail in Section IIB-1.00. The nomograph provided to determine the inherent erodibility of a particular soil is undoubtedly the most accurate such aid developed to date.

By far the most important factor influencing soil erosion is soil texture with silt-size particles being the most erodible and erosion potential decreasing as the percentage of sand or larger and clay-size particles increases. However, other soil characteristics, including organic matter content, overall soil strength, and soil permeability also have an influence.

Detailed evaluation of the soil texture and organic matter content, which is necessary to make use of the nomograph, would be somewhat difficult in the field because of need for use of scales, wet sieves, hydrometers, heating and drying devices, and other such equipment.

However, an equipment package containing these essentials could be developed in semi-portable form for field use. Otherwise, laboratory tests of bulk samples appears to be the most feasible method of making these necessary determinations.

In many cases, experienced field personnel would be able to make a reasonably accurate estimate of the textural and other necessary information without resorting to field or laboratory analyses. Textural and organic matter content, as well as overall strength and permeability characteristics, can be determined approximately by visual inspection and use of shake, pat, kneading, and other types of simple field tests.

One such field classification guide for use in estimating inherent soil erosion potential was developed prior to the K-factor nomograph. This guide is shown in Table IIB-2 (63). This guide is based on the Unified Soil Classification System which is presented in Table IIB-3 (69) along with field identification procedures and several of the simple tests that can be used to aid in classifying soils according to the Unified System.

Although the Unified System does not define silt- and sand-size particles within the same size categorization as required by the Universal Soil Loss Equation, the system can be used as a field guide for determining an erosion index. This may be desirable in situations where the only information available for a subject area is Unified Soil Classifications or where only rapid visual inspection of a subject area is warranted. The Unified System is being used by the Forest

Service (70) and others involved with logging road construction, and its use is increasing in popularity. Additional work will be required to verify whether the Erosion Index as obtained from a Unified Soil Classification correlates reasonably with the K-factor nomograph.

There are numerous procedures which may be used during a field reconnaissance to obtain soil samples for textural identification. Among these are the hand-operated 1½-inch screw-type soil auger (ship's auger). With the use of extensions, these augers are capable of obtaining small samples of the soils from depths of 3 to 15 feet (65). However, this auger is of limited use in soils containing large percentages of gravel or in bedrock. Shallow samples for textural identification could be obtained from hand-dug pits in the coarser-grained materials. Also, information on shallow as well as deeper soil strata can be obtained from exposures within or near the corridor and soil conditions correlated with those along the proposed route.

Other soil factors besides those strictly influencing erosion and mass wasting should also be investigated during the field reconnaissance. Such factors include moisture regime and fertility. These factors are of value in planning the revegetation program.

Topographical considerations are very important in road location. Among these are slope steepness, slope length, slope aspect, and nearness to stream channels.

Roads should be located in stable areas well away from streams. Routes through steep narrow canyons; slide areas; through steep, naturally dissected terrain; through marshes or wet meadows; through ponds; or along natural drainage channels should be avoided. Where it is impractical to avoid any of these conditions, corrective stabilization measures should be incorporated into road design. Road locations should be fitted to the topography so that minimum alterations of natural conditions are necessary (54).

Valley bottoms have the advantages of low gradient, good alignment, and little earth movement. Disadvantages are flood hazard, number of bridge crossings, and proximity to stream channels. Wide valley bottoms are good routes if stream crossings are few and roads are located away from stream channels. Roads in or adjacent to stream channels should be avoided. Roads should be located far enough away to prevent transport of sediment into stream channels (65).

Roads in valley bottoms should be positioned on the transition between the toe slope and terrace to protect the road slopes from flood erosion, being careful to avoid undercutting an old slide or landflow. Road drainage structures will also function better and discharge less turbid water into live streams. Any stream crossings should be selected with particular care to minimize channel disturbance, minimize approach cuts and fills, and produce as little disturbance as possible of natural stream flow. Valley bottoms should not be roaded where the only choice is encroachment on the stream (64).

Hillside routes have the advantage of being away from streams which eliminates flood and stream damage; and intervening undisturbed vegetation acts as a barrier. Disadvantages are higher grades, more excavation, longer slopes, poor alignment from following grade contours, and cut banks that expose soil to erosion (65). When locating roads along sidehill routes, benches and the flatter transitional slopes near the ridge and valley bottoms should be used. Midslope locations on steep, unstable dissected slopes, particularly in areas of deep plastic soils or weathered or decomposed rock formations, should be avoided (64).

Ridge routes have the advantages of good alignment, good drainage, light excavation, and fair grades (65). Other advantages include practically non-existent upgradient slopes and large expanses of undisturbed vegetation or logging slash to act as buffer strips for stream protection. Disadvantages are secondary roads that may have adverse hauling grades and greater total road mileage (65). Ridgetop roads should be located to avoid headwalls at the source of tributary drainages. These are often extremely unstable slopes, and any erosion or slope failure will flow directly into live streams (64).

Another locational characteristic, aspect, also has some influence on soil stability. However, aspect influences the functional characteristics of forest roads more than it does their geometric design and stability. North-facing slopes retain snow and ice for longer periods than south-facing slopes (63). However, Renner's (60) study on the Boise River watershed showed that erosion differed sharply according to exposure. Soils on south exposures eroded most severely.

Packer and Christensen's (61) study showed that erosion rates are higher on south-facing slopes. This was attributed to the loosening of the soil by frost heaving. Also, south and west slopes in many areas are considerably less densely vegetated than north and east slopes. Runoff and sediment trapping characteristics are greatly influenced by this effect. This in turn influences the design of the road prism and the drainage structures. Aspect also helps determine the degree of success or failure in reestablishment of vegetative cover after disruption by road construction.

During the field reconnaissance, vegetation along the proposed route should be surveyed. Vegetation along the route of the proposed road is an indicator of other factors, such as soil fertility and moisture regime, but most importantly is its effect on retarding runoff both upslope and downslope of the road prism. Upslope vegetation and ground litter can have a significant effect on the amount of water reaching the road prism. Long, unimpeded upgradient slopes with poor infiltration characteristics can contribute large quantities of overland flow causing erosion of the road prism.

Probably more important than upslope vegetation is the vegetative and ground cover downslope of the road prism. Downslope vegetative cover can retard overland runoff and discharges from cross drains and other road drainage structures causing suspended sediments to be settled out before reaching stream systems. Several investigators, including Trimble and Sartz and Packer, have studied the buffering and filtering performance of vegetation strips. Packer's investigative work was particularly comprehensive as to the individual parameters affecting buffer strip performance. Packer found that obstructions such as rocks, stumps, and herbaceous vegetation and trees, as well as numerous locational and design factors such as soil aggregates, amount of disturbed slope, cross drain spacing, and distance to the first obstruction, all influenced buffer strip performance. More detailed information on factors affecting buffer strip performance is contained in Section III under road design. All of these factors should be considered during field reconnaissance, especially during the road location work to ensure that adequate buffering is provided between roads and stream systems.

b. Mass Wasting. The most common and perhaps the most significant erosion from forest roads is the result of mass movement caused by undercutting unstable slopes, improper embankment construction, wasting on steep slopes, and drainage system failures (64). Some of the factors affecting mass wasting which should be determined during the reconnaissance are cross slope angles; soil texture, depth, and in-situ strength; groundwater conditions; and identification of old, existing, and potential future unstable areas. Factors affecting mass wasting should be investigated, not only within the corridor, but up and downslope of the corridor.

There are several topographic and vegetation indicators that may be used in identifying existing mass wasting. Among these are u-shaped depressions, downslope depressions, stream bank overhang, mucky surfaces, tension cracks, curved tree butts, and "jackstrawed or crazy" trees.

Some of the indicators of potentially unstable areas are slopes greater than 70 percent, horseshoe-shaped drainage headwalls, fracture patterns, seeps and springs, and piping (71, 72). All of these factors can be identified by an experienced engineering geologist.

Other important factors which should be determined to evaluate mass wasting potential of an area are in-situ soil strengths, amount of overburden to bedrock, and natural bedding planes within bedrock (71). An approximation of in-situ soil strengths can be made by visual inspection of hand-dug pits and existing soil exposures, both within the corridor and within areas outside the corridor, which are similar in nature. The thickness of overburden is oftentimes difficult to determine; however, an experienced engineering geologist familiar with the area and its geologic past can often provide good approximations after a field reconnaissance of the area. A geophysical survey may be required along the alignment to evaluate overburden thickness (65,67). However, this survey is ofttimes expensive and can only be used under certain conditions. It must be remembered that a geophysical survey does not evaluate the type or strength of the soils within the overburden.

In addition to these other factors, the location of the water table (which in most cases will be perched) along the alignment should be investigated during the reconnaissance phase of investigation. The water table may be located by mapping springs and seeps in the corridor, identifying certain types of vegetation which exist only where water is readily available, and locating areas which exhibit some thickness of soft spongy highly organic materials. In addition, the water table may be located through use of relatively shallow explorations such as hand-dug pits, hand-auger holes, or by probing.

After completion, compilation, and interpretation of the data obtained during the reconnaissance, areas which present potential hazards should be further investigated by more sophisticated means. The major problems involved in performing a detailed investigation of potential problem areas is that these areas normally have only limited accessibility and, in many cases, may require that equipment needed for such an investigation be either packed in or flown in by helicopter. Detailed investigation of these areas should be accomplished by a specialist in soil mechanics or rock mechanics. Details of such an investigation should be established on an individual basis and based on the field conditions at each site.

In summary, it should be remembered that a logging road design which limits potential for erosion and mass wasting is only as good as the information which is available for the alignment; the best design based on the wrong conditions is of little use. In addition, the conditions encountered in the reconnaissance may vary somewhat from the conditions encountered during construction due to the complicated nature of deposition and formation of soils and bedrock. Provisions should be made to alter the design during construction based on the actual conditions encountered.

Table IIB—2A guide for placing common soil and geologic types into erosion classes (63)

Erosion Class	I	II	III	IV	V	VI	VII	VIII	IX	X
Erosion Index	10	20	30	40	50	60	70	80	90	100
Standard soil texture and Unified System Soil Groups	SM* ML	SM ML	Silt (Unconsolidated) (B) OL MH	Silt (Consolidated) (B) OL MH CL	Silty clay loam (A) Silty clay (A) Sandy clay (B) SC, GM, OH, CH	Clay loam (A) Silty loam (A, B) Clay, varying with type, cohesiveness & compaction (A) Sandy clay (B) CH, GM	Loamy sand (C) Sandy loam (B) Sand (B) GC	Coarse sand (C) SW SP Sand (C)	Fine gravel (C) SW SP	Rock (C) Cobble (C) Gravel (C) GW, GP
Special cases	Decomp. granodiorite (C) Highly decomp. granites (C)	Decomp. sandstone (B,C) Mod'ly decomp. granites (B)	Fine soils derived from rocks high in mica (C)	Coarse soils derived from rocks high in mica (C)		Some volcanic ash or fine pumice (C)				Fractured loose basalt or shale (A)

NOTE: (A) indicates nonporous materials; (B) indicates moderately porous materials; (C) indicates highly porous materials.

*SM, ML, etc. refer to the Casagrande soils classification system.

Source: Reference 63

Table IIB3—Unified Soil Classification (Including Identification and Description) (68)

Major Divisions			Group Symbols	Typical Names	Field Identification Procedures (Excluding particles larger than 3 inches and basing fractions on estimated weights)		
1	2		3	4	5		
Coarse-grained Soils. More than half of material is larger than No. 200 sieve size. (The No. 200 sieve size is about the smallest particle visible to the naked eye.)	Gravels. More than half of coarse fraction is larger than No. 4 sieve size. (For visual classification, the ¼-in. size may be used as equivalent to the No. 4 sieve size)	Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.		
			GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
		Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures.	Nonplastic fines or fines with low plasticity. (for identification procedures see ML below)		
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below).		
	Sands. More than half of coarse fraction is smaller than No. 4 sieve size.	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.		
			SP	Poorly-graded sands, gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity. (for identification procedures see ML below)		
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below).		
					Identification Procedures on Fraction Smaller than No. 40 Sieve Size		
					Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)
Fine-grained Soils. More than half of material is smaller than No. 200 sieve size.	Silts and Clays	Liquid limit less than 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium
			OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight
	Silts and Clays	Liquid limit greater than 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium
			CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High
			OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to medium
Highly Organic Soils			Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel and frequently by fibrous texture.		

(1) Boundary classifications: Soils possessing characteristics of two groups are designated by combinations of group symbols.

Source: Reference 68

FIELD IDENTIFICATION PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS

These procedures are to be performed on the minus No. 40 sieve size particles, approximately 1/64 in. For field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests.

Dilatancy (Reaction to shaking)

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky. Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (Crushing characteristics)

After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness (Consistency near plastic limit)

After removing particles larger than the No. 40 sieve size, a specimen of soil about one-half inch cube in size is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.

3.00 Civil and Forest Engineering

The task of the civil and forest engineers on field reconnaissance is to establish a road location that best satisfies the intended road use within the constraints of the terrain. The engineers are assisted and advised by geotechnical specialists (see the previous section) and by field surveyors. Hopefully, experienced engineers enter the field reconnaissance phase with some rational guidelines from their superiors about road use and harvest method and with latitude to interpret these guide lines in the light of actual field conditions.

3.01 Harvest Method

Planning aspects of the road-harvest method relationship are discussed in paragraph 2.02, Section A of this Chapter. Adoption of modern cable logging methods appear to be increasing partially due to environmental constraints that have the effect of reducing the miles of spur and jammer roads. In addition to less roads, the advantage from the sediment aspect is that landings for these operations are preferably located near ridge tops or on high benches as uphill yarding distances are much greater than downhill yarding distances. Roads that connect these landings are therefore high on the hillside away from the live stream. Yarding uphill permits at least one end of the "turn" to be lifted clear of the land for a longer distance than does downhill yarding. Downhill yarding concentrates ground cover disturbance at the road or landing and may create the potential for sediment movement to roadside ditches.

An exception to the above description of road location for modern logging methods is the circumstance in much of Southeastern Alaska.

Although Wyssen and high lead systems are used in Alaska, downhill yarding is often employed. Many ridge or hill tops are above the timber line or are above the zone of merchantable timber. Further, it is often desirable to leave timber on the upper sections of a hillside to inhibit avalanches. Roads tend to be appropriately located near valley bottoms.

The high mobility of new equipment suggests that logging operations may be accomplished in more inclement weather than was previously considered appropriate. Equipment size may place constraints on allowable horizontal road curvature. Equipment weight may require closer scrutiny of the stability of proposed landings or the road itself if it is proposed to utilize a road turnout as a landing.

3.02 Existing Road Audit

An audit of existing nearby roads in similar terrain and their maintenance and construction records may be of value to reconnaissance engineers. This audit will be useful from an overall design standpoint as well as for potential sediment control problems. Specific features deserving attention are:

1. Surface condition of cut and fill slopes (Slope raveling).
2. Ditch adequacy in terms of size, shape, and effectiveness of any lining.
3. Culvert entrances and exits.
4. Performance of sediment control devices such as trash racks, settling basins, downslope debris barriers.
5. Culvert spacing.
6. Geology and soils as may be revealed by exposed cut banks.

7. Road surface condition i.e. crown, ballast performance, presence of surface rills.
8. Alignment relative to shape of terrain.

Maintenance records of the audited road, if available, or similar roads may be valuable as a cross check of personal observations. The records may provide a chronological order of events and data on the amount and kind of work accomplished at each maintenance problem. These records may indicate that certain culverts were undersized, improperly constructed or should have had different entrance or exit treatments. They might also indicate the extent and location of sloughing and roadside slumping and the frequency at which roads were reshaped. These recordings will aid engineers in identifying potential problem conditions during the field reconnaissance.

Construction inspection reports are not always available as a part of maintenance records. These reports may record particular problems during construction and indicate if they were due to the road design or specific construction techniques.

3.03 Route Placement

In the process of establishing a route, the engineer may ask himself the following questions as a device for ensuring a thorough study of the circumstances:

1. What are the potential risks and attendant damages?
2. What precautions are necessary to mitigate the risks?
3. What deviations in the road standard are acceptable in order to better accommodate corridor conditions?
4. What are the costs in time and money in the event of failure?

5. What are the environmental results of failure?
6. What are the alternates in terms of road location, road alignment and alternate solutions to specific features?

Natural features of the corridor that should receive particular attention with respect to the potential for a sediment problem include:

1. Proximity of live streams.
2. Capability of downslope areas to act as filters or buffers.
3. Terrain slope.
4. Shape of terrain in terms of degree of natural dissection.
5. Type of vegetative cover.
6. Evidence of natural soil erosion.
7. Presence of ground water.
8. Signs or indicators of natural slope stability or instability.
9. Circumstances at possible stream crossing points.

The civil and/or forest engineer will be assisted in the evaluation of some of the above features by the geotechnical specialist. However, the engineer, as the generalist, should make his own evaluation of the circumstances based on his knowledge of the area and his concept of the potential effect of a road. Road effect includes not only the effect after road completion but during construction bearing in mind the practicalities of construction season, construction practices and construction equipment.

An important aspect in road location is the desirability of fitting the road to the terrain. This aspect is stressed both in writing and orally by experienced forest engineers. Although it may be appropriate to enter a reconnaissance with idealized criteria about minimum horizontal curvature, maximum and minimum vertical gradients, and balancing of earthwork quantities, these criteria must yield to the shape of the terrain. For example, where short lengths of steep vertical gradients will avoid or reduce midslope roads in the type of terrain described by Frederiksen, (73) they should be utilized. Where a "field adjusted" horizontal curve will avoid or reduce excavation into a potentially unstable hillside, it should be considered over adherence to the mathematical niceties of a constant radius curve.

All other factors being equal, a minimum vertical gradient of 2 to 3% is desirable to provide good drainage. Flatter grades are difficult to drain, may contribute to ponding and consequent road surface deterioration under heavy truck traffic. This in turn can cause sediment. Rolled grades provide convenient places to collect and remove drainage. Grades exceeding 10% may require special attention to the potential for ditch and roadway surface erosion.

Where roads are close to live streams, an evaluation of the ability of the vegetation and the terrain between the road and stream to act as a natural barrier to the transport of sediment should be made. Brown believes the buffer strip has limited valve in the mountainous West because it assumes that sheet flow similar to eastern agricultural soils is the major soil erosion mechanism. He points out that the highly dissected, rough surfaced topography in most forest watersheds precludes sheet flow. Water flows to rills or channels which converge to larger channels. "Since channel flow predominates, eroded materials are carried through a buffer strip." (74)

All other factors being equal, crossing a stream at right angles to its axis affords the minimum construction in and around the channel. The designer will rely heavily on the reconnaissance observations in determining the appropriate stream crossing method. The importance of stream crossings is discussed by many writers including Fredriksen's studies in Western Oregon watersheds, (75) and Jack S. Rothacher and Thomas B. Glazebrook's evaluation of Region 6 flood damage during the 1964-1965 floods. (76)

Features of the proposed stream crossing requiring reconnaissance evaluation include:

1. Non manufactured debris in the channel at and above the proposed crossing.
2. Stability of natural banks.
3. Evidence of old abandoned channels or presence of natural over flow channels.
4. Natural constrictions to high water.
5. "High water mark" signs.
6. Suitability of circumstances for ford, culvert or bridge.
7. Classification of visible soils strata.
8. Opportunity for flood water bypass channel over proposed approach roadway.
9. If culvert, round, pipe arch or plate arch?

Advantages and disadvantages of type of topography are discussed in paragraph B - 2.03 of this chapter.

Subsurface ground water can be converted to surface flow in mountainous areas where a slope is cut to form a level roadbed. Shallow coarse textured soils overlaying relatively impermeable bedrock is a circumstance where this phenomena can occur. Walter F. Megahan observes that conditions are ideal for its occurrence in the Idaho Batholith. (77) The potential for this circumstance to occur should be evaluated during reconnaissance so that the designer may recognize ground water effects in his design of drainage features and his evaluations of the stability of cuts and fills.

3.04 Field Survey Information

In addition to the normal route traverse and cross sectioning done by the land surveyors, there is field data to record relating specifically to the sediment control portion of the road design. The following is a listing of such information:

1. Survey crews should be made aware of key vegetative slope stability and ground condition indicators (see Table II B-4 for a plant indicator key developed for use in the Siuslaw National Forest). These indicators (plant colonies and tree dispositions) should be plotted with the traverse.
2. Survey crews should be alerted to take additional cross sections at suspect problem sites or abutting sensitive areas (i.e. locations adjacent to old slide areas and streams) as may be designated by the engineers and geotechnical specialists.
3. Additional information regarding cross sections at streams should be emphasized by the engineer. This is particularly important in order to design the appropriate culvert entrance and exit and for determination of channel capacity. At a stream crossing which will require a large culvert or bridge, the engineer must visit the site with the land surveyor and prescribe the topography required.

4. The engineer, from his field reconnaissance, may direct the land surveyor to take notes on natural residue and debris which could prove to be maintenance problems.
5. The surveyor should be directed to provide location data on unique features that influence the road in the road corridor and not just "on line" data. The following items are examples.
   a. Rock outcroppings and condition thereof.
   b. Hummocky surfaces.
   c. Terracetts.
   d. Over steepened slopes.
   e. Ground cracks or fissures.
   f. Islands of over or under vigorous trees.
   g. Natural stream scouring (continuous or intermittent streams).
   h. Natural drainage courses.

Survey notes are one of the designer's basic aids. Recorded observations by survey crews and accompanying sketches, if appropriate, are of great value. A portable dictating machine is of value for recording observations.

The USFS Region 6 audit points out that "inaccurate compaction factors and unanticipated soil changes can lead to overwidth roads and earthwork waste." (78) From the sediment aspect, it is desirable to handle the minimum earth possible. "Overwidth" roads may not fit the terrain as initially conceived thereby introducing extra load on steep terrain or a stability problem for a sliver fill. Appropriate field survey data is mandatory to the goals of obtaining accurate earthwork quantities, minimum changes during construction, handling only the earth quantities necessary and fitting the road to the terrain.

TABLE II B-4

SIUSLAW NATIONAL FOREST - PLANT INDICATORS 11-9-72

	Very Dry	Dry	Moist	Wet	Very Wet	Remarks
Douglas fir	x	s	s	s	s	) Leaning,bowed, or pistol butt trees indicate
W. hemlock		x	x	x	R	) recent slide activity.
W. red cedar				x	x	) Young trees may indicate recent slide activit
Red alder			s	s	s	) Seral also on deeply disturbed dry area.
Goats beard lichen	x					Indicates Site Class V
Madrone	c					
Ocean spray	x	c				Site Class IV with yellow-green lichen.
Poison oak	c	R				
Oregon grape	c	c				
Salal	R	x	R			Usually Site Class III
Red huckleberry	R	c	R	R		
Rhododendron	R	c				
Vine maple		R	x	R		) With Salal may indicate igneous rock
Sword fern		R	x	x	c	) Site Class I or II when together
Oxalis			x	c	c	)
Salmonberry			R	x	c	) Dominance increased by disturbance
Wild lily-of-the-valley			R	c	R	) Expect intense brush competition and
Indian lettuce			R	c	c	) slide hazard.
Deerfern			R	c	c	)
Bleeding heart				R	c	)
Devils club					c	)
Stink currant					c	) Only red cedar or red alder adapted to the
Horse tail					c	) extremely wet conditions (slide hazard) - also
Skunk cabbage					c	) drainage problems.
Lady fern					x	
Maiden hair fern					x	
Bracken fern	s	s	s	s		Mature height indicates site quality, moisture
Thimble berry			s	s		forms dense seral stands with salmonberry
Trailing blackberry		s	s	s	s	) preferred elk food.
Grasses	s	s	s	s	s	)

x = CLIMAX DOMINANT s = SERAL DOMINANT c = COMMON R = RARE

Source: Siuslaw National Forest Engineer

C. ECONOMIC EVALUATIONS

The introduction to this report suggested that wherein sediment control design criteria was the same or parallel to other road design criteria, the capital cost of a road designed with sediment control features specifically included may be no greater than had these features not been considered. No forest land manager or logger relishes the costs of a road failure to his operation in terms of repair cost and lost time during a harvest season. R. B. Gardner observed that: "The investment that may be required to achieve satisfactory stability will generally be repaid by the road's longer useful life, reduced maintenance cost, serviceability and contribution to improved water quality and quantity." (79)

1.00 Cost Analysis

The trend toward fitting the road to the terrain with companion change or revision of road standards to support this goal often results in less quantities of earthwork per station or mile than accrued with wider roads and/or roads with higher traveling speed alignments. Offsetting the potential cost reduction from less quantities of material may be the earth handling method. The narrower road (less quantities) constructed full bench with end haul of waste may cost more than did the wider road (more quantities) with the waste sidecasted.

Wherein road elements are designed to satisfy the goal of road stability such as stable cuts and fills and adequate stream crossings, the cost of sediment minimization related to these elements is likely to be included in the cost necessary to obtain a stable design. Other road features lend themselves to analysis embracing construction cost versus maintenance cost such as ditch cleaning where tributary slopes are bare versus ditch cleaning where tributary slopes are planted. Elements specifically included for sediment control such as settling basins and downstream check dams outside of the roadway corridor are examples of capital costs that are likely to be unrelated to road stability or maintenance savings.

The Western Wood Products Associations' Forest Roads Subcommittee has studied the minimum land impact road concept. Appendix A to the minutes of one of the committee's meetings listed the following as part of criteria for minimum land impact roads.

1. "It should be understood that a minimum land impact road will not necessarily be a low-cost road, especially in steep-sloped terrain with highly erodible soils. However, provisions for minimum roadway and clearing width in difficult terrain situations will mean less cost for initial road construction and subsequent maintenance, site restoration, and revegetation for soil erosion control.

2. "The total cost of construction, operation, and maintenance of a road should be carefully assessed at various design standards to find the optimum output for the three principal cost centers. The various levels of road design standards should be compared to the degree of impact each design standard places on the resources and immediate environment. A possible output mix of costs and impacts could be developed for comparison between alternatives." (80)

Gardner offers some guidance on road standards, economics and environment in terms of amortized construction cost over road life, maintenance and operating cost, the cost centers suggested by WWPA. Tables II C-1, II C-2 and II C-3 are reproduced from his paper. Tables II C-1 and II C-2 demonstrate the value of an investment in roadway ballast as the annual cost of gravel roads is less than stabilized and primative roads. On the basis that the minimum road has less environmental impact, Gardner suggests that the user cost for the environment is represented in Table II C-3 by the difference in annual cost between two lane paved and one lane gravel roads. (81) The cost figures shown in the tables are not applicable to all of Region X. Gardner does suggest a cost analysis approach that includes environmental considerations.

TABLE II C-1

1.--Comparison of annual road costs per mile, 10,000 vehicles per annum (VPA)

Cost distribution	Road standard					
	2-lane paved	2-lane chip-seal	2-lane gravel	1-lane gravel	1-lane spot stabilization	1-lane primitive
	Dollars per mile					
Initial construction	50,000	40,000	30,000	20,000	15,000	10,000
	Annual dollars per mile (20-year period)					
[1]Depreciation	4,360	3,490	2,610	1,740	1,310	870
Maintenance	200	400	600	800	1,100	500
Vehicle use	2,200	2,300	2,700	3,000	4,400	8,500
Total annual	6,760	6,190	5,910	[2]5,540	6,810	9,870

[1]20 years at 6% using capital recovery.
[2]Lowest annual cost.

TABLE II C-2

2.--Comparison of annual road costs per mile for 20,000 and 40,000 vehicles per annum (VPA)

Cost distribution	Road standard					
	2-lane paved	2-lane chip-seal	2-lane gravel	1-lane gravel	1-lane spot stabilization	1-lane primitive
	Dollars per mile					
Initial construction	50,000	40,000	30,000	20,000	15,000	10,000
	(20,000 VPA)					
[1]Depreciation	4,360	3,490	2,610	1,740	1,310	870
Maintenance	400	800	1,200	1,600	2,200	1,000
Vehicle use	4,400	4,600	5,400	6,000	8,800	17,000
Total annual	9,160	[2]8,890	9,210	9,340	12,310	18,870
	(40,000 VPA)					
Depreciation	4,360	3,490	2,610	1,740	1,310	870
Maintenance	800	1,600	2,400	3,200	4,400	2,000
Vehicle use	8,800	9,200	10,800	12,000	17,600	34,000
Total annual	[2]13,960	14,290	15,810	16,940	23,310	36,870

[1]20 years' depreciation at 6% using capital recovery.
[2]Lowest annual cost.

TABLE II C-3

3.--Comparison of single-lane versus double-lane costs for three different vehicle-per-annum (VPA) categories

VPA	Total annual cost per mile		Difference
	1-lane gravel	2-lane paved	
	Dollars		
10,000	5,540	6,760	-1,220
20,000	9,340	9,160	+ 180
40,000	16,940	13,960	+2,880

Source: Gardner, R. B., "Forest Road Standards As Related to Economics and the Environment," USDA Forest Service Research Note INT-45, August 1971, 4 pages

For readers interested in vehicle operating costs on logging roads, R. J. Tangeman has proposed a model for estimating these costs relative to characteristics of forest roads. (82)

The Environmental Protection Agency's publication "Comparative Costs of Erosion and Sediment Control, Construction Activities" includes a procedure for determining the annual economic cost of conserving soil. The procedure recognizes amortized cost of the capital investment and annual maintenance costs. The report cautions that "each particular location offers a unique soil loss potential, erosion control costs and corresponding sediment removal penalties." (83)

2.00 Economic Justification

An economic justification for additional capital investment in road elements to achieve greater road stability under adverse conditions is the risk of potential cost of a road failure. To illustrate, culverts and bridges should be designed to survive an anticipated storm event. This will mean hydrology studies and site surveys at bridge and culvert crossings. Hydrology studies and detailed site surveys cost money and the results of these studies may produce large capital expenditures. However, this type of investigation is essential if washed out bridges and culverts are to be prevented.

The 1964-65 Winter season floods in Oregon have been classified as 50 year floods in higher elevations. "The transportation system suffered by far the greatest monetary loss. Damage to roads, bridges and trails in Oregon alone was estimated at $12,500,000 - 4 percent of the total investment of $355 million." (84) This estimate does not include down time cost or other inconveniences which accompanied these losses. The flood damage estimate to USFS Region 6 roads and bridges for the 1973-74 season is in excess of the 1964-65 damage estimate.

Sediment control can also act as preventative maintenance. Slope seeding for erosion control can prevent slope raveling. Slope raveling can diminish the roadway prism and cause high ditch and culvert maintenance costs.

Economic justification should be related to the role the intended road is to play in the overall land management goal. The broader the goal, the more varied are the inputs to the economic analysis. Legal requirements such as water quality criteria are "givens" to the engineer as a part of the land management goal. Within these "givens", the engineer must exercise his traditional role of preparing cost effective, economic designs.

III DESIGN

> "Road design is the process of transplanting planning objectives, field location survey data, materials investigations and other information into specific plans, drawings and specifications to guide construction." (85)

The designer's task is to translate this data into a design which recognizes and provides for sediment control.

Upon initiating a design, a designer must grasp an understanding of the field work, reconnaissance and planning that has preceeded him. He must also understand management's objectives and policy. This information may be provided to him in a number of ways depending upon the organization's structure. For example, in some cases the designer has been a part of the reconnaissance, and will be the construction supervisor. In other organizations, he may have only limited personal contact with reconnaissance people. Regardless of the organizational size and procedures or the designers disposition, there are several general features which the designer should know in order to intelligently proceed. The following list is not all inclusive.

1. The designer must be aware of the road's intended use, such as, whether the road will be used principally for a truck haul road or will have other demands. Prior knowledge of this kind may affect such choices as water bars or pavement, fords or bridges, and grades and curvature.
2. A review of the reconnaissance and field information should indicate to the designer the circumstances within the reconnaissance corridor. If this review arouses doubt or lack of understanding,

he must communicate with those who accomplished the field work. Preferably, the designer should at least visit the site of specific key features within the project such as stream crossings and steep hillsides.

3. The designer should have authority to obtain additional field information and to alter design standards in order that a stable road will be attained.

4. The designer should know to what extent he will be able to follow the job through, and what control he or others will exercise on workmanship. Quality construction is imperative to the control of sediment.

5. Will the road be used as a log landing or yarding platform.

The designer must familiarize himself with erosion control and roadway stabilizing techniques. He must also develope a commitment to sediment control and exercise a degree of creative thinking. This chapter is divided into four parts, Part A discusses matters of the roadway design itself, Part B is devoted to matters of slope stabilization including a discussion of seeding and planting, mulches and mechanical treatments. Since many of the recorded mass failures on forest roads appear to be drainage related, Part C is devoted entirely to drainage design including ditches, culverts and stream crossings. Part D discusses features of the construction specifications, prepared as part of the design task, that support the goal of minimizing sediment.

A. ROADWAY

Many features or concepts for the roadway design may have been developed or established as a part of the reconnaissance. However, the process of converting field reports, field survey notes and planning goals to drawings with attendant horizontal and vertical control will direct attention to the resolution of key details and controls that will appropriately refine and execute the reconnaissance and planning information. This part discusses sediment features of the roadway design elements of alignment, roadway prism, roadway surfacing, and buffer and filter strips.

1.00 Horizontal and Vertical Alignment

Horizontal and vertical alignment are design features that can be used to develop a road sensitive to sediment control. In developing such a road, these features must be manipulated by the designer to adjust the road alignment as the constraints of the terrain demand. The discussion on reconnaissance in Chapter II emphasized the importance of fitting the road to the terrain.

The designer must also recognize the limits that may be placed on him by the reconnaissance data and location as has been previously indicated. With the aid of field surveys, geo-technical, civil and forest engineering information, he can adjust the horizontal and vertical alignment to the terrain with companion attention to road use requirements.

1.01 Horizontal Alignment

The potential for roadway sediment can be mitigated by utilizing a horizontal alignment that reduces roadway cuts and fills, and avoids or minimizes intrusion upon unstable ground. The designer must have flexibility to adjust curve radii, if necessary, from that established by arbitrary road standards. The designer's practical experience and judgement are a part of his approach. The sediment control aspect has to be weighed in company with other features.

1.02 Vertical Alignment

Vertical alignment, like horizontal alignment, can be used to aid in controlling sediment. In unstable steep terrain, adjusting the vertical alignment to reduce cuts and fills and to position the road on stable benches is an intelligent approach. In level areas sediment control is aided by providing appropriate drainage to the roadway and roadway ditch. A minimum grade of 2% will prevent ponding and reduce subgrade saturation.

Roads from log landings provide another opportunity to practice sediment control and preventive maintenance. A 5% adverse grade from landing to road for approximately one hundred feet will reduce the potential for mud and debris movement to the haul road.

Use of steep pitches to reach stable terrain must be accompanied by appropriate treatment of the road surface, otherwise the road surface can be subject to serious rill erosion. This matter is further discussed in paragraph 3.00.

2.00 Road Prism

The roadway prism is defined as the geometric shape generated by a through fill, through cut, partial bench or full bench. Part C of this Chapter discusses the roadway ditch portion of the prism, Part B discusses slope stabilization and paragraph 3.00 of this part, roadway surfacing. The following discussion is limited to excavation, embankment and balanced construction.

2.01 Excavation

Back slopes can contribute up to 30% of the total road sedimentation and up to 85% of the first year road sedimentation. (86, 87) Sediment can be reduced by slope stabilization techniques as considered in Part B and/or by designing the back slope for the given soil characteristics. Part B of Chapter II discussed geo-technical and engineering reconnaissance techniques to develop field data for the design of stable back slopes. There are two approaches to back slope design, experience, and rationale or technical procedure.

Use of "rules of thumb" or "standard" backslope steepness guides without knowledge of specific soils conditions is dangerous. If an able forest engineer with long experience in a particular area has been successful in establishing stable backslopes for road cuts, his approach, advice and experience should be utilized.

Part A of Chapter II noted that the U. S. Forest Service has adopted a method of specifying cut and embankment slopes developed by Hendrickson and Lund. (88) This concise rational method does not require extensive laboratory equipment to obtain soil type, grain size, and distribution for the unified soil classification. It, in addition, takes into consideration blow count, ground water, site conditions and slope height. This design method is presented in both graphical and tabular form for convenient use along with illustrative examples. Also, and perhaps equally important, are the application and limitation discussions which accompany the design guide. (89)

Rodney W. Prellwitz has developed a slope design procedure for low standard roads in USDA Forest Service Northern Region (Montana, Northern Idaho and Eastern Washington). Prellwitz's procedures are most applicable to Northern Region conditions of (1) steep natural slopes and cut slopes, (2) seepage - often parallel to surface slope, (3) "non-cohesive" soils, (4) shallow and erratic soil depth, and (5) seasonal ground water fluctuations. (90)

Vertical cuts in banks less than six feet are being tried in various parts of Region X including Idaho and Alaska. The rational behind the vertical cut concept is that these cuts will reduce excavation quantities and the area of exposed new backslope. However, it is difficult to predict the reliability of this practice from a sediment control standpoint or how universally this practice can be applied as the practice is quite new.

2.02 Embankment

Numerous researchers suggest that fill slopes are the great initial producers of road sediment. They also point out that fill slope erosion can be drastically reduced by erosion control techniques. (See Part B)

Mass failure of the fill is the other source of sediment from fills.

Mass failures can be the result of poor fill material, improper fill compaction, incorrectly designated fill slope, improper foundation preparation, weak foundation support, improper culvert design and installation within the fill, or a combination of more than one of the above factors. The design of a fill is a structural problem with the companion necessity to recognize the site circumstances. The procedure developed by Hendrickson and Lund mentioned in the discussion on excavation has application to the design of embankments.

Examination of the underlying strata where a fill is proposed must be accomplished during the reconnaissance. If the strata is too weak for the proposed load, the road must be relocated, the fill height reduced or an alternate structural solution such as a trestle considered.

A common fault has been failure to provide for proper preparation of the ground by clearing and stripping of vegetation and organic material. A further problem has been the presence of too much organic and vegetable matter in fill material. Chapter IV discusses fill placement techniques. Sidecasting, as a construction method, has limited value.

Benching of fills into sloping terrain has been utilized successfully. On narrow roads in steep terrain, the bench may be equal to the road width suggesting that there is a point where terrain slope and road width combine to require a full bench section rather than a fill from a practical as well as a stability viewpoint.

A stable fill slope is dependent upon the quality of the fill material and the amount of area of the supporting ground that must be utilized to support the superimposed load.

Provision for the passage of uphill overland water through a fill can often be made by placing a granular blanket on the ground as the first fill layer. Otherwise, the fill may act as a dam to the water with dangerous damage potential. This blanket is also advantageous when the ground is soft to the operation of equipment.

The foregoing are a few observations on fill stability. The stability question is broader in scope than the matter of sediment minimization only. Waste sites are also fills and must be designed accordingly. Culvert design is discussed in Part C of this Chapter.

2.03 Balanced Construction

No simple statement can be made as to whether or not the concept of balancing the quantities of excavation and fill materials has merit from the viewpoint of sediment minimization. If the excavation can be confined to the amount of earth needed for fill and other factors are equal, this is advantageous.

On steep terrain, the necessity to excavate full bench to obtain stability often results in the production of excess material. "Sliver" fills on steep terrain have proven to be difficult stability problems. In order to reduce excavation, an alternate to the"sliver"fill might be a driven sheet or soldier pile and logging wall. The economic tradeoffs would be excess excavation costs plus haul of excess material and waste site development versus the wall cost.

3.00 Road Surfacing

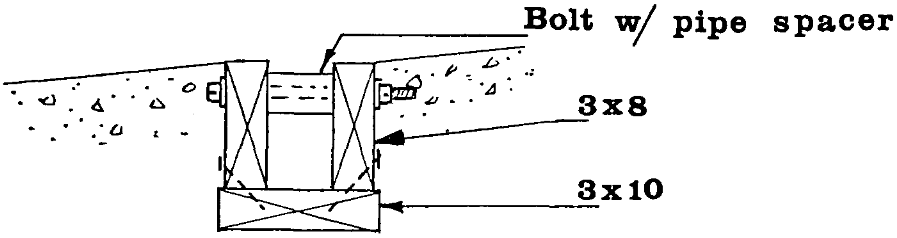
There is a broad range of surfaces and surface treatments used on logging roads. Selection of surfacing or surface treatment may depend upon material availability, road use, road location and construction practices. In Southeastern Alaska, nearly all roads are constructed with "shot rock" ballast and overlaid with gravel or crushed rock. In some areas of Oregon, Washington and Idaho, the absence of quality surfacing rock may result in soil surface roads or bituminous surfacing.

There is no doubt that durable surface roads result in the potential for less surface erosion. However, surfacing a road does not necessarily eliminate sediment problems. The bulk of the stream sediment in the Northwest occurs in the rainy season, late Fall to early Spring. In many parts of the region the logging season carries into these transitional weather periods and, in lower elevations, logging may contiue year around with only occasional winter shut-downs. Log hauling operations during this period place additional demands on roads. It is the designers task to anticipate this use if appropriate and to design a base and surface for the particular subgrade and wheel loads. (The design must be coupled with good construction practice).

The road surfacing does more than provide smooth travel and a load distributing media. It also provides a "roof" for the subgrade by being a dense roadway surface, crowned sufficiently to rapidly disperse water. Non-bituminous log haul roads should be crowned 4% minimum to insure the movement of surface water, thereby reducing potential subgrade saturation.

In addition to designing a road base and surfacing to support truck traffic and the selection of the road crown, the following are other design considerations which may directly or indirectly effect the potential for roadway erosion and sediment.

1. Pit-run gravel surfacing must have an aggregate gradation which will compact to a dense water dispersing surface.
2. Crushed rock surfaces rely on their angular faces and gradation of the aggregate to knit the surface into a dense, near impervious layer.
3. Asphaltic concrete or other pavements decrease the time for rain water to concentrate in ditches and other drainage structures.
4. Granular surfaced roads can become sediment producers if a soft crushed rock is used or if the gradation does not permit a dense, locked, shear resistant surface.
5. Water bars are often used as cross drains on steep longitudinal grades as shown in Figure III A-1.



WATER BAR
Fig. III A-1

However, they require continual maintenance if they are placed in too flat a grade. A minimum longitudinal roadway grade of 5% is suggested for use of water bars.

6. If steep grades in excess of 10% are used, asphaltic concrete or bimuninous surfacing may be required in lieu of water bars to maintain a stable road surface.
7. Asphaltic concrete or bituminous surface can be used as approach aprons to bridges. They reduce material tracking tracking which

wears bridge decks, and sediment washing into streams.

8. Gravel surfaces may have an economic trade-off when the annual traffic operating costs and maintenance costs offset those of soil stabilized or primitive roads. (91)

9. Choice of gravel surfacing on outslope roads, versus stabilized or soil surface is related to the potential for rill erosion. See the discussion in paragraph 1.04 of Section C.

4.00 Buffer Strips

The concept of minimizing or retarding downslope sediment movement with vegetation and/or obstructions has been studied and used for a number of years. The procedure is often coupled with the outslope road with surface cross drains. Drainage features of the outslope road including criteria for cross drain spacing are discussed in Part C-1 of this Chapter. Reservations regarding the ability of vegetation and terrain to act as a barrier to sediment movement in the West as expressed by one writer are mentioned in Chapter II, Part B.

Most of the data developed is on the basis of studies accomplished in Idaho, Eastern Washington and Montana where the outslope road is quite common. Harold F. Haupt studied sediment movement in the Boise National Forest in 1959. He developed an equation relating sediment flow distance to a slope obstruction index, cross ditch interval, embankment slope length and cross ditch interval times road gradient. The Slope Obstruction Index was approximately equal to the average spacing in feet of major obstructions along the direction of slope.

> "With proper substitution of the variables, this equation predetermines the distance or width of protective strip needed to dissipate sediment movement that may occur from a road to be built." (92)

Haupt pointed out that the method was a tool for the designers and was not a substitute for experience and good judgement.

Packer believes that the interaction between the spacing of downslope obstructions and the kind of obstruction, and the spacing between obstructions are the two most important factors in evaluating sediment movement. Figure III A-I, "Obstruction Spacing," is reprinted from Packer's 1967 Study. (93) Packer also discovered that, as the age of the road increased, the distance sediment moved downslope increased. This was because the remaining capacity of obstructions to stop sediment decreased the longer they were installed.

Packer also developed criteria for protective strip widths based on obstruction spacing, kinds of obstructions, age of road and cross drain spacing. Table III A-I is reproduced from Packer's report. The table is also contained in the booklet "Guides for Controlling Sediment from Secondary Logging Roads" by Packer and George F. Christensen. (94) This booklet is pocket field manual size and contains a complete treatment of the subjects of cross drain spacing, and protective strip widths and tells how to apply the information in a manner that will control erosion and sediment. The booklet is for use in the USDA Forest Service Northern Region.

Table III A-I

Protective-strip widths required below the shoulders(1)of 5-year old(2) logging roads built on soil derived from basalt,(3)having 30-foot cross-drain spacing,(4) zero initial obstruction distance,(5) and 100 percent fill slope cover density.(6)

Obstruction spacing	Protective-strip widths: Depressions or mounds	Logs	Rocks	Trees and stumps	Slash and brush	Herbaceous vegetation
			Feet			
1	35	37	38	40	41	43
2	37	40	43	46	49	52
3	39	43	47	52	57	61
4	40	46	52	58	64	70
5	41	48	56	63	71	78
6		50	59	68	77	86
7		52	62	73	84	94
8		53	65	77	89	101
9		54	67	81	95	108
10				85	100	115
11				88	104	121
12						127

(1) For protective-strip widths from centerlines of proposed roads, incarease above widths by one-half the proposed road width.
(2) If storage capacity of obstructions is to be renewed when roads are 3 years old, reduce protective-strip widths 24 feet.
(3) If soil is derived from andesite, increase protective-strip widths 1 foot; if from glacial silt, increase 3 feet; if from hard sediments, increase 8 feet, if from granite, increase 9 feet; and if from loess, increase 24 feet.
(4) For each 10-foot increase in cross-drain spacing beyond 30 feet, increase protective-strip widths 1 foot.
(5) For each 5-foot increase in initial obstruction distance beyond zero (or the road shoulder), increase protective-strip widths 4 feet.
(6) For each 10-percent decrease in fill slope cover below a density of 100 percent, increase protective-strip widths 1 foot.

Source: Packer, Paul E., "Criteria for Designing and Locating Logging Roads to Control Sediment", Reprint from Forest Science, Volume 13, Number 1, March, 1967.

B. SLOPE STABILIZATION

1.00 Surface Erosion

1.01 Introduction

The construction of forest roads is the major cause of stream sedimentation in the forest harvest system. Large quantities of sediment can be contributed both as a result of surface erosion and mass wasting.

Revegetation of areas disturbed by logging road construction is the most effective means of reducing sediment production. Mulches, chemical soil stabilizers, and mechanical treatment measures are often required initially to aid in vegetation establishment and to reduce erosion during the critical period while vegetation is becoming established.

The reduction in erosion potential resulting from these slope stabilization procedures is dependent upon the soil, weather, drainage, and topographic conditions at each location. A great deal of research is required before the qualitative effects of this reduction in erosion potential can be assigned a value for use as the cover factor in the Universal Soil Loss Equation presented in Section IIB 1.00. However, each procedure does have a positive effect on sedimentation potential along the logging road. At this time the value for the Universal Soil Loss Equation can only be based on the experience, even though limited, of the design team.

The various types of slope stabilization procedures and general effect of reducing sedimentation are discussed in the following section.

1.02 Seeding and Planting

a. Introduction. Numerous studies indicate that forest cover is one of the most effective vegetation types in maintaining and protecting soil from erosion (104). This vegetation cover reduces the effects of rainfall intensity, and raindrop impact through interception processes; decreases runoff velocity and erosive power; increases granulation, soil porosity, and biological processes associated with vegetative growth; and dries soil by evapotranspiration.

Logging road construction removes natural vegetation and exposes soils which commonly have properties unfavorable for plant growth (101) Revegetation by planting and seeding can be a successful method of stabilizing backslopes and fills, of "putting roads to bed" that are no longer being used, and of filtering sediment-laden water flowing into water courses (95)

The decisions as to which plant species and methods to use in Region 10 for roadside stabilization are currently made by a variety of agencies and individuals, usually the Soil Conservation Service, individual county agents and landscape architects, and the Forest Service. These decisions depend upon the management objectives as well as the unique features of each site. Although there are published Forest Service Standard Specifications for erosion control using revegetation techniques, the actual methods used vary from forest to forest and even among the districts of a given forest (99).

b. General. The "state of the art" is surprisingly variable from one area in Region 10 to another. Each area has unique soil, climatic, and financial problems with which to deal. Although revegetation procedures are variable within Region 10, there are some recommendations which apply to revegetation in general.

A 50 percent (2:1) slope is assumed to be the maximum slope upon which vegetation can be satisfactorily established and maintained. Optimum vegetative stability requires slopes of 25 percent (4:1) or less. The maximum slope should only be applied to ideal soil conditions where the soil is not highly erodible and has an adequate moisture holding capacity. For droughty soils (those which exhibit a poor moisture holding capacity due to excessively high permeability and a low percentage of fines) and for highly erodible soils, the maximum permissible slope should be considerably less than 50 percent (95).

Local soil conditions may require different rules of thumb. For example, in northwestern Washington where soil is largely glacial till, the maximum slope on which seeding is an effective erosion control method is 2:1 on a fill slope and 1.5:1 on a cut slope (102).

Knowledge of the soil characteristics of the slope to be seeded is essential to insure success of the project. For instance, the volcanic tuffs and breccias of the Malheur, Umatilla, and Fremont National Forests in eastern Oregon respond very well to grass seedings

(98). On the other hand, soils which hold water very poorly, such as coarse shale and gravel, will probably require structural methods of erosion control rather than revegetation.

Where it is impossible to avoid road building through areas where roadside seeps and springs will be an inevitability, the most effective methods to use around the seeps and springs will be structural ones presented in other chapters.

c. Revegetation Objectives. The main objective of seeding roadsides is to create conditions which favor re-colonization by native shrubs and herbs (98) Native plants require the least expense and maintenance as well as being visually harmonious with the forest landscape. In addition to physically enhancing the soil, seeded grasses and legumes* improve the organic-mineral balance of road cut soils. They also act as "nurse plants" to young native plants by providing shade which reduces the rate of water depletion from the soil.

Grass seeding is usually considered as an erosion prevention treatment applied at a sacrifice to tree regeneration. However, in southeast Alaska, grass seeding of exposed mineral soils aids establishment of spruce and hemlock seedlings by reducing the disruptive influence of frost heave and by retarding alder invasion (106).

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*legume: any of a large group of plants of the pea family. Because of their ability to store and fix nitrates, legumes are often plowed under to fertilize the soil.

Shrubs are sometimes planted on wet silty and clayey soils where the slope is not steep. Native willows (Salix spp.) and alders (Alnus spp.) are used in Region 10 because they absorb large amounts of water from the soil and, in effect, dry out the soil. They are also more deeply rooted than grasses or legumes.

d. Seed Mixtures. The seed mixtures in Tables III-B 1 through III-B 3 are recommended for use in some part of Region 10 for erosion control along forest roads, skid trails, landings, and firelines (109)

Appendix III-B 1 provides a conversion table listing common names and scientific names for all plant species mentioned in the tables. Specific site requirements can be met by modifying the seeding mixtures or the density of application. If, for example, a county agent recommends a grass mixture designed mainly for use in rural non-forested areas, increasing the percentage of fescue (Festuca spp.), a shade-tolerant grass, and decreasing the percentage of bluegrass (Poa spp.), which typically requires full sun, will contribute to a more shade-tolerant seed mixture (102)Often on steeper slopes a more dense application of seed is required (100)

Seeding mixtures often contain a legume - usually white Dutch clover. The inclusion of a vigorous fast-spreading legume in the seeding mixture in some cases results in a denser and longer-lasting stand of herbaceous vegetation, presumably because of the nitrogen incorporated into the soil (99). Seeding a legume requires that one also apply an inoculant of the associated root bacteria. The inoculant is usually "glued" to the legume seeds before the seed mixture is made (103).

Table III-B 1

SEED MIXTURES FOR WASHINGTON AND OREGON

West of the Cascade Divide (109)

Species	Seeds Per Acre
Orchard grass	2 lbs.
Timothy	2 lbs.
Alta fescue	2 lbs.
Perennial ryegrass	2 lbs.
Total per acre	8 lbs.

East of the Cascade Divide (109)

	Seeds Per Acre				
	Inches of (effective) Precipitation				
Species	0-9	9-12	12-15	15-18	18-25
Siberian wheatgrass	5 lbs.	6 lbs.	6 lbs.		
Nordan crested wheatgrass	5 lbs.	6 lbs.	6 lbs.		
Pubescent wheatgrass			8 lbs.		
Durar hard fescue				4 lbs.	4 lbs.
Topar pubescent wheatgrass				8 lbs.	8 lbs.
Intermediate wheatgrass				8 lbs.	
Greenar intermediate wheatgrass					8 lbs.
Total per acre	10 lbs.	12 lbs.	20 lbs.	20 lbs.	20 lbs.

Willamette National Forest, Oregon (112)

Species	Seeds Per Acre
Perennial ryegrass	6 lbs.
Meadow fescue	8 lbs.
Colonial bentgrass	4 lbs.
Total per acre	18 lbs.

Fertilizer: 16-20-0 (16% nitrogen, 20% phosphorus, 0% potassium) at 400 lbs./acre.

Table III-B 1 (Continued)

Blue River District, Willamette National Forest, Oregon (6)

Species	Seeds Per Acre
Colonial bentgrass	6¼ lbs.
Creeping red fescue	5 lbs.
Perennial ryegrass	3 3/4 lbs.
Alta fescue	8 3/4 lbs.
White Dutch clover	1¼ lbs.
Total per acre	25 lbs.

Fertilizer: 16-20-0 at 400 lbs./acre.

Oregon Highway Department (100)

Species	Seeds Per Acre
Creeping red fescue	18 lbs.
Chewings fescue	12 lbs.
Perennial ryegrass	4 lbs.
White Dutch clover	6 lbs.
Total per acre	40 lbs.

Fertilizer: 16-20-0 at 400 lbs./acre.

Forest Service Mixture No. 1, Oregon (100)

Species	Seeds Per Acre
Alta fescue	20 lbs.
Annual ryegrass	8 lbs.
Creeping red fescue	3 lbs.
New Zealand white clover	2 lbs.
Big trefoil	2 lbs.
Total per acre	35 lbs.

Fertilizer: 16-20-0 at 400 lbs./acre.

Forest Service Mixture No. 2, Oregon (100)

Species	Seeds Per Acre
Orchard grass	20 lbs.
Annual ryegrass	8 lbs.
Creeping red fescue	8 lbs.

Table III-B 1 (Continued)

Forest Service Mixture No. 2, Oregon (100)

Species	Seeds Per Acre
Colonial bentgrass	3 lbs.
New Zealand white clover	2 lbs.
Big trefoil	2 lbs.
Total per acre	43 lbs.

Fertilizer: 16-20-0 at 400 lbs./acre.

Table III-B 2

SEED MIXTURES FOR IDAHO

For Dry Areas, e.g. Low Elevation Ponderosa Pine Forests (96)

Species	Seeds Per Acre
Annual ryegrass	20 lbs.
Bulbous bluegrass	2 lbs.
Crested wheatgrass	3 lbs.
Intermediate wheatgrass	5 lbs.
Smooth bromegrass "Manchar"	5 lbs.
Total per acre	35 lbs.

For More Moist Areas, e.g. Upper Elevation Ponderosa Pine Forests (96)

Species	Seeds Per Acre
Annual ryegrass	20 lbs.
Intermediate wheatgrass	5 lbs.
Smooth bromegrass "Manchar"	5 lbs.
Timothy	1 lbs.
Orchard grass	3 lbs.
Total per acre	34 lbs.

Table III-B 3

SEED MIXTURES FOR SOUTHEAST ALASKA

General, Southeast Alaska (111)

Species	Seeds Per Acre
Alta fescue or orchard grass	4 lbs.
Reed canary grass	4 lbs.
Dutch white clover	2 lbs.
Total per acre	10 lbs.

Fertilizer: 10-20-20 at 200 lbs./acre plus 100 lbs./acre of ammonium nitrate.

Southeast Alaska (105)

Group I - Suitable for:

Soil sites with few or no physical limitations.
Soil sites with moderate limitations due to low water-holding capacity.
Soil sites with severe limitations due to low water-holding capacity.

Revegetation of highly erosive or disturbed sites.

Species in Order of Preference	Variety Name in Order of Preference	Seeds Per Acre
Meadow foxtail	Common	25 lbs.
Timothy	Engmo Common	10 lbs.
Kentucky bluegrass	Nugget Merion	20 lbs.
Red fescue	Arctard Olds	20 lbs.

Fertilizer: 60-60-60 at 400 lbs./acre.

Table III-B 3 (Continued)

Group II - Suitable for soil sites with moderate limitations due to excess water.

Revegetation of highly erosive or disturbed sites.

Species in Order of Preference	Variety Name in Order of Preference	Seeds Per Acre
Meadow foxtail	Common	25 lbs.

Fertilizer: 60-60-60 at 400 lbs./acre.

Soil sites with severe limitations due to excess moisture.

Must be drained. When drained refer to Group I.

Soils and sites consisting of wet peat materials.

No recommendations.

One problem of including a legume in the seeding mixture is the high palatability to deer, elk, and livestock of the readily available species. Grazing animals will trample out mechanical structures, pack the soil, and create a more erosive condition than existing prior to seeding (96).

The Forest Service Experiment Stations continue to search for vigorous, unpalatable legumes for use in seeding mixtures (97, 99, 107).

The following legumes are suited to use in the Northwest (99)

1. Big trefoil - well suited to Coast Ranges and Cascades of Washington and Oregon; however, winter mortality is higher in the Cascades.
2. White Dutch clover and New Zealand white clover - moderately well suited to all of Region 10, but restricted to the more gentle slopes (102). New Zealand white clover may prove to be better adapted to west Cascades than white Dutch.
3. Birdsfoot trefoil - moderately suited to west Cascades and Coast Ranges.
4. Alfalfa - the most commonly used legume for conservation seeding. It is adapted to a wider range of climate and soil than other legumes. It is extremely palatable to livestock and wildlife; and, therefore, not recommended for use along logging roads.

Rarely are grasses seeded without legumes, and the choice of legumes is an important decision (107).

e. Planting. The role of planting in logging road stabilization is one of utility, not aesthetics. Where soils are plastic (e.g., silty and clayey), native willows or alders are planted to prevent slumping because they deplete soil moisture rapidly, and their roots bind soil to a deeper level than do those of grasses and legumes. Red alder (Alnus rubra) is the species used in Washington and Oregon, and Sitka alder (Alnus sitchensis) is used in southeast Alaska. There are many species of willow common to Region 10, and nearly all root readily from cuttings, as do the alders. Although plantings are rarely made along logging roads in Idaho, nurseryman Bud Mason of Coeur d'Alene is testing and cultivating native woody plants for use along roadsides in the Pacific Northwest (111).

Plantings are much more expensive than seeding operations because of the increased cost of plant materials and labor. Hand planting of grasses and legumes in small, hard to reach sites which require revegetation is done in some parts of Oregon and Washington (98). This procedure is not yet used in Idaho or Alaska (97,110),primarily because of the expense.

Commercial tree species are seldom planted on logging roadsides, although when roads are "put to bed" the goal of revegetation is sometimes forest regeneration.

f. Techniques Used in Establishing Plants. Seeding, as mentioned before, is much less expensive and, therefore, much more widely used than other planting methods. Commonly used methods of seed application are hydroseeding, hand-operated cyclone seeders, and truck-mounted broadcast seeders. Hydroseeding is the application of a slurry of seed and water to the soil (103).Up to one-half of the total amount of fertilizer may be added to the slurry as well as legume seed bearing the bacteria inoculant. Even the mulch may be mixed with the slurry. A variety of mulches--wood cellulose fiber, ground hay, ground newspaper, rice hulls--have been applied by this method. In a single operation, two men can seed, mulch, and fertilize, often without leaving the road (103.

Hydroseeding is used in all parts of Region 10 by Highway Departments. In Oregon and Washington, the Forest Service hydroseeds (98). The Forest Service in Alaska usually uses a cyclone seeder (97). In Idaho, seeding is typically accomplished by using a cyclone seeder. If the seed bed is packed, it may be necessary to drill the seed (96).

Hand planting of grass and legume plants in Washington and Oregon is done in difficult-to-reach places (98). The soil surface, if not freshly prepared, should be roughened along the contours in order to reduce the chance of rilling and to provide safe sites for seed. In Oregon, alder and willow cuttings are hand planted 3 to 4 feet apart (98).

g. When to Seed or Plant. From the standpoint of minimizing sedimentation, roadside revegetation should be started as soon as roads are constructed. The highest volume rate of soil movement off road cut and fill slopes is in the 1 to 2 months immediately following road construction (100,112).Hopefully, this time will coincide with the season which favors the species being planted.

In western Washington and Oregon, seeding before the fall rains begin is recommended. One worker reported success with seeding in September, another in April (100,112).Evidently, if seeding is done west of the Cascade crest anytime from April to September, it will be effective. In Idaho, seeding should be done in late summer or early fall in order to take advantage of the fall rains (96). In Alaska, seed should be applied in April or early May, but summer application before August 1 is acceptable where spring application is not possible (111). For quick temporary cover in Alaska after the recommended planting season, annual ryegrass can be seeded and then the area seeded the next spring or summer to perennial grasses (105).

The advantage to seeding and planting prior to fall rains is that the newly introduced plants are not subjected to undue moisture stress as they would be in summer, at least in dry areas as eastern Washington and Oregon and southern Idaho.

h. Fertilizers. In all cases, an application of fertilizer does enhance revegetation efforts. Fertlizer is applied first with the seed mixture and again the following spring. The recommended fertilizer type and quantity is given in Tables I to III with each seed mixture. In some cases, no specific recommendation was made, but experience indicates that a fertilizer treatment always results in denser stands in a shorter time period than seeding without fertilizer. Usually, a nitrogen, phosphorus-potassium fertilizer is sufficient; although, if the soil pH is less than 5, an application of lime may be required (105). In general, ammonium phosphate-sulfate (16% nitrogen, 20% phosphorus, 0% potassium) is excellent. Soil testing by extension agents of the Soil Conservation Service will reveal any serious deficiencies, and these people can recommend appropriate ameliorative measures.

Because native shrub and grass establishment is the primary goal of roadside grass plantings in Washington and Oregon on Forest Service roads, only one to two fertilizer treatments are applied. Continued fertilizer treatments result in such a vigorous growth of the seeded species that the natives are not able to establish on the seeded area (98).

i. Mulching. Mulching is essential if a proper seedbed cannot be prepared, if seeding is made outside commonly accepted seasons, if soil is highly erodible, or if slopes are steep (108).

If seed cannot be applied immediately after construction, even an application of a mulch, alone, will greatly reduce soil movement down the slope. Common mulches used with grass-legume seed mixtures are straw, hay, commercially prepared wood fiber mulches, and anchored types such as jute-matting, cotton-paper and wood-fiber netting. On steep slopes or easily erodible soils, and if seeding must be done during periods of high runoff, a combination of mulches; e.g., a straw mulch over seed anchored with a wood -fiber net, greatly decreases soil loss.

There are a number of chemical products which can be used to anchor seed or seed and mulch; for example, liquid asphalt, elastomers, and polymers. These products are discussed elsewhere in this report in more detail.

Mulches not only decrease soil loss by buffering rain effects and slowing runoff, but they also retain soil moisture and provide shade for better seed germination and seedling establishment.

In Washington, Oregon, Alaska, and Idaho, road banks are mulched with whatever is available, usually grass, hay, wheat straw, woodchips, or fiber mulch (98,110). If the slope is shallow and freshly prepared, seedling establishment may be successful enough to significantly control surface erosion without mulching.

In Idaho, mulches are seldom used by the Forest Service nor are they used in Alaska, primarily because of the added expense (97,110). Preparation of the seedbed by raking or otherwise roughing up the soil surface creates small depressions which retain the seed. Dragging a harrow or brush-drag over the seeded area helps to cover the seed (96).

j. Summary. In spite of the variety of methods used in Region 10 and the uniqueness of each roadside stabilization project, some generalizations about the usefulness of plants for erosion control can be made. The combination of vegetation and structural methods recommended depend on the objectives of the action. A variety of seed mixtures used in Region 10 are presented in Tables III-B 1 through III-B 3. Although quite expensive, planting of willow and alder is an effective way of drying out wet, heavy soils. Hydroseeding and cyclone seeding are the most common methods of seed mixture application used in Region 10. Hand planting is expensive but necessary in hard-to-reach spots. Slope stabilization projects should begin immediately after construction. The best season in which to seed varies with climate. Applying fertilizer and a mulch consistently improves seed germination and minimizes erosion which can take place before the seedlings are established.

APPENDIX III-B 1

(Table III-B3a)

GRASSES AND LEGUMES FOR SOIL STABILIZATION

Common Name	Variety	Scientific Name
alfalfa		*Medicago sativa*
bentgrass		
colonial	Highland	*Agrostis tenuis*
bluegrass		
bulbous		*Poa bulbosa*
Kentucky		*Poa pratensis*
bromegrass		
smooth	Manchar	*Bromus inermis*
canarygrass		
reed		*Phalaris arundinacea*
clover		
white	Dutch, New Zealand	*Trifolium repens*
fescue		
chewings		*Festuca rubra commutata*
creeping red		*Festuca rubra*
hard	Durar	*Festuca ovina duriuscula*
meadow		*Festuca pratensis*
red	Arctard, Olds	*Festuca rubra*
tall	Alta	*Festuca arundinacea*
foxtail		
meadow		*Alopecurus pratensis*
orchard grass		*Dactylis glomerata*
ryegrass		
annual		*Lolium multiflorum*
perennial		*Lolium perenne*
timothy	Engmo, common	*Phleum pratense*
trefoil		
big		*Lotus uliginosus*
birdsfoot		*Lotus corniculatus*
wheatgrass		
crested	Fairway	*Agropyron cristatum*
crested, standard	Nordan	*Agropyron desertorum*
intermediate	Greenar, common	*Agropyron intermedium*
pubescent	Topar	*Agropyron trichophorum*
Siberian		*Agropyron sibiricum*

1.03 Mulches and Chemical Soil Stabilizers

a. Introduction. Measures intended for overall surface soil stabilization of broad areas can generally be classified as either mulches or chemical soil stabilizers, although some variations of each exist. A mulch can be described as any organic or inorganic material applied to the soil surface to protect the seed, maintain more uniform soil temperatures, reduce evaporation, enrich the soil, or reduce erosion by absorbing raindrop impact and intercepting surface runoff (113, 116). Chemical soil stabilizers can be described as any organic or inorganic material applied in an aqueous solution that will penetrate the soil surface and reduce erosion by physically binding the soil particles together. Some chemical stabilizers also reduce evaporation, enrich the soil, and protect the seed (113,116). In addition to their functions in protecting against water erosion, these measures also protect denuded soil, seeds, and young plants from wind erosion.

Mulches and chemical stabilizers are generally temporary measures which can be expected to lose their effectiveness within one to two years or less. Their primary purpose is generally to provide suitable short-term protection, including erosion reduction, during establishment of permanent vegetative cover, usually over winter months or through hot summer months until conditions are more favorable for vegetative stabilization (113) Vegetation cover is generally the intended long-term means of slope protection. However, some mulches can be used to provide permanent slope protection in areas where adequate vegetative cover cannot be established.

Some of the more commonly available mulches include hay or straw, woodchips, and small stones or gravel. For the case of some mulch applications, particularly hay or straw, it is necessary to provide some means of holding the material in place. Methods of attachment include mechanical means (e.g., notch-bladed disks, crawler tractor with deep treads, sheepsfoot rollers, and others), asphalt or chemical binders, or various commercially available netting products designed for use as a cover over the mulch (113). In order for mechanical means of attachment to be effective, the surface of the slope must be free of significant quantities of rock material.

Besides their applications for mulch stabilization, many of the chemical stabilizers and netting products are designed for use alone for slope protection under appropriate circumstances. Also, several commercially available products incorporate netting and mulch in a single cover. These products (e.g., Excelsior Blanket, Conwed Turf Establishment Blanket, etc.) are more specifically applicable on steep slopes, in small drainage swales, or in other areas where erosive stresses are particularly high (113). Long wire staples are generally used to fasten these and other netting-type products to the slope.

Numerous studies have been conducted to evaluate the need for mulches and chemical stabilizers in the establishment of vegetation and control of erosion during the interim period while vegetation is becoming established. Most of these studies have as their primary purpose evaluated the relative effectiveness of different types of mulches and chemical soil stabilizers in performing these functions. The results of four such studies covering a broad spectrum of mulch types and environmental conditions are summarized in Table III-B 4 to III-B 7 and in Figure III-B 1.

Upon casual examination, the results of some of these and other studies appear contradictory. The prime reason for any apparent contradictions is the diverse circumstances under which such studies have been conducted. In the remainder of this section, the need for slope protection to aid vegetation establishment and control erosion during this critical period and the relative effectiveness of various types of mulches, mulch rates, and chemical stabilizers in this regard will be evaluated.

b. Need for Slope Protection During Vegetation Establishment. Mulches serve two primary purposes during vegetation establishment: (1) prevention of erosion while vegetation is becoming established, and (2) provision of a suitable microclimate for vegetation establishment. Erosion prevention and vegetation establishment are to some degree interrelated. If erosion is severe, most of the seed is generally washed off the slope, resulting in poor vegetation establishment even if the microclimate is suitable. After vegetation establishment, the need for mulch or other protection rapidly declines.

Table III-B 4

AVERAGE CUMULATIVE SOIL LOSS OR GAIN[1/] ON 12 BACKSLOPE PLOTS DURING THE FIRST YEAR AFTER CONSTRUCTION

Treatment and Block	1968		
	April	June	September
		In Inches	
Control (no mulch or seeding):			
1	-0.48	-0.55	-0.83
2	-0.45	-0.59	-0.84
Blue River District mixture (no mulch):			
1	-0.72	-0.72	-0.77
2	-0.42	-0.55	-0.31
Mulch only:			
1	-0.06	-0.08	+0.05
2	--	-0.07	-0.07
Oregon Highway mixture and mulch:			
1	-0.12	-0.13	-0.20
2	-0.11	-0.19	-0.23
Experimental mixture No. 1 and mulch:			
1	2/	2/	2/
2	+0.10	+0.14	+0.17
Experimental mixture No. 2 and mulch:			
1	+0.01	-0.07	-0.07
2	+0.02	+0.08	+0.11

1/ Gain due to upslope ravelling.

2/ Results invalidated by a small slump near the base of the plot.

Table III-B 4 (Continued)

Researcher: Dyrness (114).

Location: Willamette National Forest - Oregon

Time of Application: Early fall, 1967.

Mulch: Wheat straw at rate of 2 tons/acre.

Fertilizer: All except control plots fertilized with 16-20-0 at the rate of 400 lbs./acre.

Soil Type: Clay loam at surface grading to silty clay subsoils.

Table III-B 5

COMPARISON OF CUMULATIVE EROSION FROM TREATED PLOTS ON A STEEP, NEWLY CONSTRUCTED ROAD FILL (IN 1,000 LBS. PER ACRE)

Cumulative Elapsed Time (days)	Cumulative Precipitation (inches)	Control Plot	Group A (Seed, Fertilizer)		Group B (Seed, Fertilizer, Mulch)		Group C (Seed, Fertilizer, Mulch, Netting)		
		Plot Number							
			2	4	3	8	5	6	7
17	1.41	31.9	38.7	38.0	0.1	32.6	0	0	0
80	4.71	70.0	99.2	85.7	7.4	34.6	0.9	0	0.3
157	12.46	72.2	100.2	86.9	11.1	35.1	1.1	0	0.4
200	15.25	79.1	101.0	87.6	11.4	35.7	1.1	0	0.4
255	17.02	82.3	102.8	88.8	11.5	35.8	1.1	0	0.4
322	20.40	84.2	104.7	89.4	11.9	36.0	1.1	0	0.4

Researcher: Bethlahmy and Kidd (115).

Location: Boise National Forest - Idaho.

Time of Application: Fall, 1962.

Slope: 80 percent fill slope.

Soil Type: Loose, weathered granitic soils typical of the Idaho Batholith.

Plot Treatment:

Plot Number	Sequence of Treatment
1	Control - no treatment at all.
2	Contour furrows, seed, fertilizer, holes.
3	Contour furrows, straw mulch, seed, fertilizer, hole.
4	Polymer emulsion, seed, fertilizer.
5	Straw mulch, paper netting, seed, fertilizer.
6	Straw mulch, jute netting, seed, fertilizer.
7	Seed, fertilizer, straw mulch, chicken wire netting.
8	Seed, fertilizer, straw mulch with asphalt emulsion.

Table III-B 5 (Continued)

Details of Treatment:

Seed - All except control plot seeded alike.

Mechanical treatment - Contour furrows placed 6 feet apart and holes punched 2 inches deep at 6-inch intervals.

Mulch and chemical soil stabilizer rates - Straw mulch at 2 tons per acre.

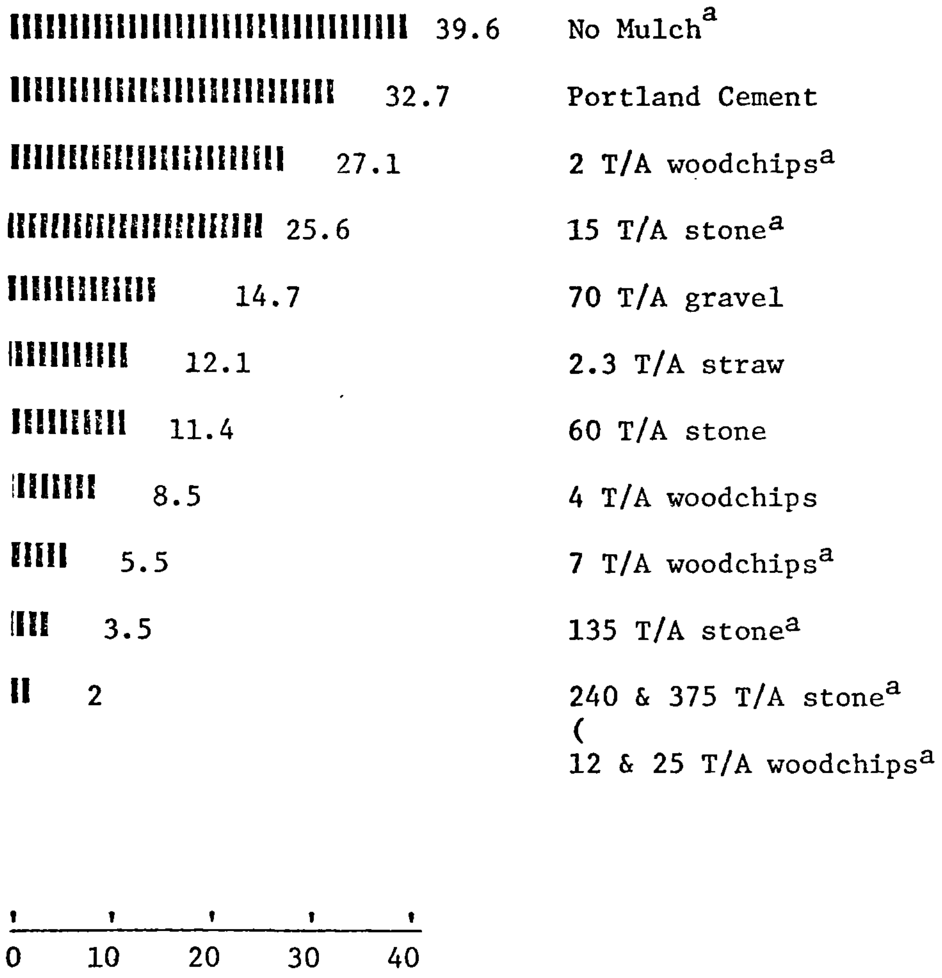
Polymer emulsion at concentration of 1 gallon Soil Set to 9 gallons of water.

Asphalt emulsion at rate of 300 gallons per acre.

All netting attached to ground with 12-inch pieces of No. 9 wire.

FIGURE III-B 1

SOIL LOSSES FROM 35-FOOT LONG SLOPE



Soil Loss (T/A-tons per acre)

[a]Based on one replication only. Values for other treatments based on average of two replications.

Source: Same as Table III B-6

Table III-B 6

EROSION LOSSES FOR LONGER SLOPES[a]

Treatment	Total Soil Loss from 100-Foot Slope Width with Length of: 50 ft.	100 ft.	150 ft.
No mulch	3.0[c]	13[c]	30[c]
Straw			
2/3 tons/a	1.0	3.9	9.8
Stone			
15 tons/a[b]	2.8[c]	13[c]	36[c]
60 tons/a	.7	2.7	8.4[c]
135 tons/a[b]	.2	.6	1.0
240 tons/a[b]	Trace	Trace	Trace
375 tons/a[b]	Trace	Trace	Trace
Gravel			
70 tons/a	.8	4.4	17[c]
Woodchips			
2 tons/a[b]	2.3[c]	10[c]	25[c]
4 tons/a	.9	3.5[c]	12[c]
7 tons/a[b]	.9	8.2[c]	29[c]
12 tons/a[b]	Trace	.6	(d)
25 tons/a[b]	Trace	Trace	Trace
Portland cement	3.0[c]	13[c]	29[c]

[a]Determined by adding inflow to upper ends of 35-foot plots while continuing 2.5-inch per hour rainfall. These tests followed soil losses caused by 5 inches of rain. Test results could be expected to be somewhat different if extensive damage had not occurred on some test plots as a result of the earlier testing.

TABLE III-B 6 (Continued)

[b]Unreplicated treatment.

[c]Severe rilling caused most flow to occur in rills rather than across mulched area. Mulch rate had minor influence on erosion rate.

[d]Severe movement of mulch occurred during high inflow rate, causing abrupt breakdown in erosion control. Erosion rates following breakdown were 10 times those just prior to it.

Researcher: Meyer, Johnson, and Foster (117).

Soil Type: 6-inches silt loam topsoil underlain by compacted calcareous till (AASHO A-4) (Unified ML).

Slopes: Uniform 20 percent.

Mulches:

Wheat straw - chopper blown

Crushed limestone-ranging in size from 1/4-inch to 1-1/2 inches in diameter with about one-half larger than 3/4 inch.

Washed road gravel - similar size distribution as crushed limestone.

Woodchips - mixed hardwood chopped in the green.

Portland cement - applied at the rate of 2 tons/acre.

Portion of soil surface covered by mulches at various application rates:

TABLE III-B 6 (Continued)

Mulch Type	Mulch Rate (tons/acre)	Average Cover (%)
No mulch		3[a]
Straw	2.3	95
Stone	15	16
	60	62
	135	90
	240	100
	375	100
Gravel	70	62
Woodchips	2	32
	4	68
	7	88
	12	99
	25	100
Portland cement		3[a]

[a]Natural gravel larger than 3/8 inch totaled about 5-tons-per-acre cover.

Rainfall Rates:

Simulated rainfall at rate of 2-1/2 inches/hour. Slopes 35 feet long - 1 hour the first day followed by two 30-minute applications the second day.

Longer slopes - Tests conducted on same plots after completion of 35-foot long slope tests. Inflow uniformly added at upper ends of plots during rainfall application to simulate longer slopes.

TABLE III-B 7

EROSION CONTROL EFFECTIVENESS OF COVERING MATERIALS ON VARIOUS SLOPES

EFFECTIVENESS RATING 1/

	Jute	Excelsior	Straw	Straw & Asphalt	Asphalt	Wood Fiber	Sod
Sheet Erosion - 1:1 slope	9.0	10.0	8.0	10.0	6.0	3.0	10.0
Sheet Erosion - 2:1 slope	9.0	10.0	9.0	10.0	7.0	6.0	10.0
Sheet Erosion - 3:1+ slope	10.0	10.0	10.0	10.0	9.0	10.0	10.0
Rill Erosion - 1:1 slope	6.0	10.0	8.0	10.0	6.0	3.0	10.0
Rill Erosion - 2:1 slope	8.0	10.0	9.0	10.0	7.0	5.0	
Rill Erosion - 3:1+ slope	10.0	10.0	10.0	10.0	9.0	10.0	10.0
Slump Erosion - 1:1 slope	10.0	8.0	6.0	7.0	3.0	3.0	8.0
Slump Erosion - 2:1 slope	10.0	9.0	7.0	8.0	5.0	4.0	9.0
Slump Erosion - 3:1 slope	Slumps usually do not occur.						

1/ 10.0 = most effective. 1.0 = not effective.

Researchers: Goss, Blanchard, and Melton (Washington State Highway Commission, Washington State University Agricultural Research Center, and the U.S. Federal Highway Administration, Cooperating) (119).

No. of Tests: Seven independent tests (1966-1969) including fertilizer and mulch tests.

TABLE III-B 7 (Cont'd)

Location: Highways in eastern and western Washington.

Slopes: 1.5:1 to 3:1 cut and fill slopes.

Soils: Silty, sandy and gravelly loams and glacial till consisting of sand, gravel and compacted silts and clays. All are subsoil materials without topsoil addition.

Slope Lengths: Apparently maximum of 165 feet.

Time of Application: Spring and fall.

Mulch Rates:

Cereal straw - 2 tons/acre

Straw plus asphalt - 2 tons/acre straw plus asphalt at rate of 200 gal/ton of straw (one test at rate of 100 gal/asphalt/ton of straw)

Asphalt alone -.20 gal/sq. yd. (968 gal/ac)

Wood cellulose fiber - 1,200 lbs/ac.

Sod - bentgrass strips 18 inches by 6 feet pegged down every third row.

Numerous investigators have concluded that a good mulch or similar cover is essential for protection against erosion for the first few months following construction when the potential for erosion is most critical. Dyrness (114)found that test plots seeded in early fall in Oregon did not begin vegetation growth until the following April and were not fully protected by vegetation until June. Of the various means of slope protection studied by Dyrness (Table III-B 4), the only plots to show consistently high losses by surface erosion during vegetation establishment were the unmulched plots. All mulched plots displayed considerably less soil loss. It was also noted that for the control plot, dry season losses by ravelling were almost as great as rain-caused soil loss. Dyrness concluded that mulching backslopes may be essential for reducing soil loss to a minimum during the first few critical months following construction. Dyrness also concluded that contrary to appearances, a luxuriant growth of grass and legumes during the first-growing season was not conclusive evidence that soil loss was negligible during the preceding winter months.

Research conducted by Bethlahmy and Kidd(115) in Idaho yielded much the same results. Test plots without treatment or with mechanical or chemical treatment in combination with seeding and fertilization (Table III-B 5) had soil losses ranging from about 70,000 to 100,000 pounds per acre during the first 80 days following treatment, while other plots that were protected with mulch and mechanical treatment or mulch and netting in addition to seeding and fertilization had soil losses of less than 7,400 pounds per acre during this same period.

In his study of the effectiveness of numerous mulches and mulch rates, Meyer(117) found that soil losses as a result of simulated rainfall on specially-prepared test plots was over 20 times as great for an untreated plot as for plots with effective mulch protection (Figure 1).

Several other investigators, including Plass (116) and Barnett, et al(120), have observed similar results from untreated test plots when compared with test plots receiving adequate mulch or chemical soil stabilizer treatment.

Research results differ considerably over the value of mulch protection during establishment of vegetative cover. Apparently this factor is particularly sensitive to the severity of individual environmental conditions. In Oregon, Dyrness (114) found that seeded but unmulched plots produced good vegetative cover and that mulch in itself without seeding also produced good vegetative cover. Only the control plots without seeding or mulching produced poor vegetative cover. Plass (116) tested the effects of numerous mulches and chemical soil stabilizers on vegetative establishment and observed much the same results. Plass concluded that some mulches and chemical soil stabilizers improve the growth and vigor of grasses, and some appear to have the opposite effect. Mulches were generally more effective than chemical stabilizers in this regard, but excellent stands of grass on untreated control plots indicated that neither treatment was necessary for vegetation establishment in the eastern United States.

In their tests, Meyer et al (117) concluded that good mulch protection was necessary for vegetation establishment. In September, after completion of erosion tests on their test plots, approximately 30 pounds per acre of grass mixture and 400 pounds per acre of 15-15-15 fertilizer were broadcast on the plots. Erosion damage was not repaired, and no tillage was performed. Stands that had more than 75 percent of the seedlings necessary for complete cover were established on the 240- and 135-tons per acre stone, 12-tons per acre woodchip, 70-tons per acre gravel, and straw-mulched slopes. The no-mulch and cement-stabilized slopes were practically bare of vegetation. These treatments and the 15-tons per acre stone mulched plot had stands of less than 25 percent. Vegetation on the remaining slopes was fair, but stands were generally uneven or spotty.

Other researchers have reached similar conclusions as a result of their work. Heath (123) reported that 50 to 90 percent of the seed planted on a slope is saved from washing away when a mulch is used. Diseker and Richardson (121) have stated that the use of mulch over seedings often was the difference between success and failure and that mulch was necessary on steep slopes. The question of need for mulch protection for vegetation establishment is probably best summed up by Blaser (122) who concluded that mulches aid in turf establishment, particularly under environmental and moisture stress.

c. Performance of Various Mulches and Chemical Soil Stabilizers. The effectiveness of mulches and other soil stabilization measures is a function of surface cover and overall lateral stability of the protection network including its ability to bind or penetrate into the slope (117). Erosive and other environmental stresses determine the effectiveness of a particular treatment measure under a particular set of circumstances. A mulch rate or combination of mulch and other stabilization measures may perform satisfactorily under one set of circumstances and be wholly ineffective under another set of circumstances. In choosing stabilization measures for a given set of field circumstances, the performance drawbacks and advantages of a particular treatment measure must be considered in addition to its availability and economy.

Straw (or hay) is one of the oldest and probably by far the most commonly-used forms of mulch materials. Until only recently has its position been challenged by newer products and revived interest in older products. Straw mulch has proven to be quite effective if used within its moderate capabilities.

Dyrness (114) found straw mulch to be relatively effective in reducing erosion in his studies (Table III-B 4). Bethlahmy and Kidd (115)found straw mulch to be quite effective when supplemented by mechanical treatment measures or netting (Table III-B 5). Goss et al (119)have noted that straw alone is moderately effective in a number of erosion-prevention applications but that its effectiveness could be improved somewhat when used in combination with an asphalt tack (Table III-B 7). Straw plus asphalt emulsion was found to be one of the most effective mulches. Bethlahmy and Kidd (115) found straw mulch tacked with asphalt to be effective but high soil losses were observed during the first seven days after application (Table III-B 5). No explanation was provided. Meyer et al (117) indicated that straw mulch is moderately effective in erosion prevention but that its performance is considerably exceeded by suitably heavy applications of other mulch products when erosive stresses are high (Table III-B 6).

In summary, it appears that straw or hay mulches are generally effective if slope gradient, slope length, and rainfall intensity are not too great. Straw mulches themselves are relatively stable and protect the soil well against raindrop splash, but rill formation underneath the mulch can be a problem. Several researchers, including Meyer et al (117), have observed breakdown of straw mulches through rill formation. This conclusion is also supported by the test results of Bethlahmy and Kidd (Table III-B 5) where straw mulch when used in combination with runoff reducing mechanical treatment measures (contour furrows and holes) provided good slope protection. Similar deductions can be made from the results of other studies. Besides supplementary measures to protect against failure by rill formation, straw mulches must also be provided protection against strong winds (113, 119).

Chemical stabilizers, mechanical measures such as contour furrowing, and application of netting over the mulch can be used to improve attachment of mulch to the slope, thus guarding against wind erosion and rill formation. Properly secured netting has proven particularly effective in this regard with good mechanical treatment following a close second as far as water erosion is concerned (Table III-B 5). Chemical soil stabilizers can also be quite effective (Table III-B 7 and Plass, (116).

Chemical stabilizers used as the sole means of slope protection generally cannot be relied upon to be as effective as some other measures (Tables III-B 5 and III-B 7). However, use of chemical stabilizers in combination with mulches, or as a minimum with wood fibers added, generally increases their effectiveness significantly in controlling erosion and encouraging vegetative establishment (116, 119).

Chemical soil stabilizers, by virtue of their chemical composition, can have an effect upon vegetation establishment. Plass(116) reported that some treatments improve growth and vigor of vegetation, while others have an adverse effect. Adverse effects of some products on vegetation establishment have also been noted by the Washington State Highway Department (126).

A wide variety of chemical stabilizers probably totalling 40 or more, with differing performance levels under different environmental conditions, are available. Some of the current products may already exceed the performance capability of commonly used mulches such as straw. The chemical soil stabilization field is rapidly developing with new products being introduced frequently. With continuing developments, this field appears to offer good potential for the future.

Commercially-available combination mulch-netting products are available. Some of these products have proven relatively effective, even under severe conditions. Except for sod protection, Goss et al (Table III-B 7) found one such product (Excelsior) to be the most consistently effective product tested. Plass (116) has also found some of these products to be quite effective. However, the material and installation costs may be too high to warrant their use for forest road application except in the most severely-stressed areas. Similar products such as jute netting have also been found to be effective in erosion prevention. Use of jute netting is particularly attractive where high tensile strengths are needed to protect against slump erosion (Table III-B 7). Good attachment of netting-type materials to the slope is of prime importance to prevent rill erosion underneath. Jute, for instance, has sufficient strength to bridge even large rills and allow erosion to continue unchecked (119).

Meyer et al (Figure III-B 1 and Table III-B 6) have found gravel and crushed stone mulches to be quite effective, even under relatively-severe conditions. Various application rates of stone and gravel mulches were found to be considerably more effective then 2 tons per acre of straw mulch. Resistance to rill formation is one of their prime advantages, as they slough into rills tending to impede their formation rather than bridging them as do straw mulches or being swept down the slope as do woodchip mulches when subjected to severe erosive stresses. Meyer et al found a rate of application of 135 tons per acre of stone mulch, which averages less than 1-inch depth, to be effective under all conditions tested.

Stone mulches also appear to have other advantages. Meyer et al (117) found grass stands on inert stone and gravel plots to be much more vigorous than on the woodchip and particularly the straw plots where grasses showed symptoms of a nitrogen deficiency. Also, unlike straw and other mulches, stone mulches are not subject to rapid decomposition. Their resistance to decay may render them uniquely valuable for permanent applications where vegetative cover cannot be established.

Woodchip mulches appear to have promise for forest applications. Along with stone mulches, Meyer et al (Figure III-B 1 and Table III-B 6) found woodchip mulches to be a good mulch material if applied at adequate rates. Woodchip mulch at the rate of 4 tons per acre was found to be more effective than 2 tons per acre straw mulch on 35-foot long slopes. Woodchip application at a rate of 25 tons per acre (1½ inches depth) was found to offer good protection under relatively-severe conditions of 20 percent slopes as much as 160 feet long (117). Crabtree (124) found 5 tons per acre of woodchip mulch to be quite effective on 3 to 1 slopes in Iowa. Woodchip mulches are relatively long lasting in comparison with other mulches such as straw or hay, require no tacking to hold them in place due to their weight and shape, and are readily available in forested areas. Use of wood mulches also appears to offer potential for disposal of waste wood material necessitated by recent restrictions on burning (113).

Adequate rate of application of woodchip mulches is particularly important. Meyer et al (117) noted that the consequences of breakdown are more serious for woodchip mulches than for stone, gravel, and straw mulches. When a woodchip mulch broke down, woodchips were grossly displaced and large, deep rills developed. The stone, gravel, and straw mulches were much more stable; and only the 15-tons-per-acre stone treatment was severely rilled (Table III-B 6). Thus, choice of an adequate mulch rate and uniform distribution of the mulch material are more critical for woodchips than for stone, gravel or straw. Anchoring the woodchips might improve their performance at some rates (125)

Wood fibers have also proven beneficial in preventing erosion when used alone or in combination with chemical soil stabilizers. The

Washington State Highway Department has found wood cellulose fiber, particularly when used in combination with chemical binding agents, to be economical and successful in western Washington where straw is not readily available (126). A University of California study (127) of hydroseeding on clay-loam soils reported soil losses of 0, 1,000, and 9,000 pounds per acre from plots with wood cellulose fibers applied at rates of 3,000, 2,000, and 1,000 pounds per acre, respectively, compared with 81,000 pounds per acre of soil loss from plots without any fiber application. On the fiber-treated areas, there were 300, 262, and 86 grass seedlings per square foot compared with none on areas without fiber treatment. Plass (116) reported that plots treated with soil stabilizers, but without wood fibers, generally did not have as tall or dense vegetative cover as when stabilizers with wood fibers and mulches were used. Plass noted that there is a growing trend toward incorporation of wood fibers with soil stabilizers to increase their effectiveness.

Others have reported less favorably on the use of wood fiber for slope protection. Goss et al found that wood fiber does not have sufficient damming ability nor tensile strength to prevent erosion on long slopes, particularly if steeper then 3 to 1 (119). Crabtree (124) found wood fiber applied at rates of 1,000 to 1,400 pounds per acre to be only poorly to moderately effective in checking erosion on 3 to 1 slopes in Iowa.

Protection of wood fibers against wind erosion has been found to be important in eastern Washington. Chemical stabilizers have been found effective for this purpose (126). However, when hydroseeded, wood fibers have been found to resist wind and water erosion better than other materials such as rice hulls, ground straw and ground newspaper.

1.04 Mechanical Treatment

a. Introduction. Mechanical measures may be utilized to inhibit erosion on slopes. Several such measures are currently being successfully used. These consist of diversions or terraces either atop or on slopes; berms, serrations, or other variations in gradient; and roughening or scarification of the slope. Although most of these measures can be used individually for slope protection, their primary usefulness is to supplement mulches and other forms of slope stabilization.

Mechanical slope stabilization measures generally function by reducing the volume and velocity of surface runoff through reduction of effective slope length and increases in filtration. These measures also can be used to prevent concentration of flow in undesirable areas and to provide an improved microclimate for vegetation establishment.

Although numerous references suggest the usage of or describe many of these mechanical measures in a general way, very little specific information is provided on their application, design, and effectiveness. Specific design criteria must generally be developed on an individual basis. Descriptions of the various mechanical measures in common usage are provided in the remainder of this section.

b. Diversions or Terraces. Diversions or terraces are graded channels with a supporting ridge on the lower side constructed across or atop cut or fill slopes. Their purpose is to intercept surface or shallow subsurface runoff and divert it to an outlet where it can be safely disposed of. They can be used to reduce slope length into nonerosive segments or divert water away from critical areas. These structures are generally temporary and may be graded or level in the longitudinal direction. Level terraces have closed ends to retain the runoff, while graded terraces should be designed to carry water at nonerosive velocities to planned disposal areas.

Diversion outlets should be located so that water will empty into natural drainage channels or into relatively low gradient upland areas between drainage channels. Care must be exercised to avoid too great of flow concentration as well as conveyance or discharge of water at erosive velocities. Buffer strips of vegetation between points of discharge and stream courses are extremely desirable to allow suspended sediments to settle out.

c. Berms and Serrations. Berms are steps or benches in steep slopes. Serrations are also steps or benches but are generally smaller and more closely spaced. Also, serrations generally have vertical slope segments between benches, whereas areas between berms are generally sloped. If properly located and designed, these measures reduce slope lengths and divide the volume of runoff into workable slugs that can be more easily handled. Berms can be constructed level to retain precipitation in place or graded with a longitudinal gradient and an outside edge higher than the inside to function as diversions. The benches on serrated slopes are generally graded level.

In addition to their function of retarding runoff down the slope, benches provided by berms or serrations also provide an improved microclimate for vegetation establishment on steep slopes. As a general rule, a 50 percent (2:1) continuous slope is assumed to be the maximum slope upon which vegetation can be satisfactorily established and maintained (113). Horizontal areas on steep slopes as provided by benches or serrations better enable vegetation to gain a foothold.

Serrated slopes are a relatively new method of erosion control and are only applicable under certain conditions, such as cut slopes of soft rock or similar material that will stand vertically for a few years in cut heights of approximately a couple of feet. The Washington Department of Highways is currently using this method successfully in selected areas (128).

Serrations generally consist of steps of 2 to 4 feet vertically and horizontally cut along the normal intended slope gradient. After construction, the slope is seeded, fertilized, and mulched the same as for normal slopes. The horizontal areas provide an improved environment for vegetation establishment free of sliding forces normally experienced on steep slopes. The steps gradually slough and practically disappear within a few years following construction after vegetation has become well-established. If the slope material is soft, it is recommended that the slope be allowed to slough until about 1/3 of the steps are filled before seeding; otherwise, grass may be destroyed by the excessive rate of initial slough. This method is not applicable for any soil types where the rate of slough is high enough such that vegetative cover will be buried and destroyed. More information about the use of serrated slopes can be obtained from (129).

d. Roughness and Scarification. Smoothly graded cut-and-fill slopes are attractive to the eye, but they are not beneficial from the standpoint of erosion control and establishment of vegetative cover. Roughness and scarification serve to increase infiltration and impede runoff (113). If the surface is to be seeded, the roughness or scarification marks retain seed even after severe runoff. These measures also serve to cause mulch to adhere better to the slope.

Slopes may be roughened by a wide variety of construction means. Soils can be scarified by means of a bladed implement equipped with a ripper attachment which loosens surface soils in place without turning it over. Deep cleated dozers traveling up and down the slope can be used to obtain a satisfactory texture on slopes too steep for normal equipment operation. The Washington Highway Department (126) has found that a sheepsfoot roller also works fine for roughening slopes.

The texture of the roughened slope should trend perpendicular to the flow direction (113). Up and down angular cross slope scarification or roughness texture do more harm then good by concentrating flow. Also, care must be exercised to prevent excessive loosening of the upper soils such that the propensity for rill and slump erosion are increased.

2.00 Mass Wasting

2.01 Introduction

From time to time during the course of road design, areas will be encountered which cannot be avoided that will traverse either areas where mass wasting has occurred or is occurring or where slope stability of the proposed road cuts are marginal; this includes areas where a safe cut slope would involve removing a large amount of material upslope from the road cut. In these areas slope stabilization must be achieved by the design of some type of retention structure.

For development of soil pressures on the retention structure for use in design, a good reference is Foundation Design by Wayne C. Teng, and for structural design of the retention structure a good reference is reinforced concrete fundamentals with an emphasis on ultimate strength by Phil M. Ferguson. The actual design of the soil structure interaction depends upon the conditions encountered at each location and therefore is not generalized in this text. The following is a discussion of various types of retention structures and their possible application. The design of each of these structures should be based on a detailed investigation so that the site conditions at each location are known.

2.02 Retaining Wall

The first type of retaining structure is known as a gravity wall which is usually made of plain masonry, rubble, stone or concrete. This wall is usually the simplest and easiest to install but can be only used for relatively low walls, that is less than 8 to 10 feet with moderate soil pressures (130).

The second type of wall is a cantilever wall of which there are three basic types. The first type is a plain cantilever wall that can be used for heights up to approximately 25 feet. These walls usually consist of a reinforced concrete stem founded on a reinforced concrete base slab. The other two types of walls are modifications of a cantilever in which counterforts or buttresses are added to the wall. The counterforts or buttresses add strength to the stem portion of the wall and a degree of rigidity to the wall. The counterfort or buttresses may be used for walls higher than 25 feet with most soil conditions (130).

Another type of wall is a crib wall. This wall is essentially a gravity-type structure made of timber, precast concrete or metal which form an open structure of some dimension. This open structure is then filled with soil forming a relatively-large massive structure. This type of wall is usually suitable for small to moderate-height walls which are less than 21 feet in height and subjected to only moderate earth pressures (130).

In some cases where soil conditions permit, use of sheet pile bulkheads may be advised. The sheet pile bulkheads may either be cantilevered or restrained near the top with anchors. This method of retention is oftentimes expensive. However, installation of the cantilever-type wall is relatively simple and can be done without form work. These walls are usually less than 20 feet in height if drainage is provided behind the wall (131).

In areas where soils are suitable, reinforced earth structures may be constructed. This method consists of placing metal strips perpendicular to the front of either a thin shell concrete or steel wall. Soil is then compacted over the strips for a shallow depth, another set of strips is then placed and the process repeated until the full height of the wall is attained. This process is restricted to granular backfills and walls usually less than 15 feet in height.

The selection of the proper type of wall to be used in any one situation depends upon the purpose of the retention structure and the foundation conditions at the site and the economics involved.

C. DRAINAGE DESIGN

> "A major contributor to both accelerated surface soil erosion and mass soil failures was lack of adequate drainage provided at man-made improvements. Drainage includes practices that prevent concentration of water and those that foster dispersal of water into stabilized land areas or into stabilized stream channels. Failure or impairment of road drainage facilities was involved in almost all road-connected storm damage." (132)

To minimize sediment production and transportation from forest roads, the planning, design and construction of drainage facilities must be executed for the particular conditions encountered and not on a basis of generalized criteria.

Chapter V of this report will discuss Maintenance but designers and owners should recognize that the designs and suggestions contained under this heading will not function adequately without inspection, maintenance and possible change of individual drainage features. The first such inspections should be made, hopefully by the design engineer, during or immediately after the first storm.

1.00 Ditches and Berms

There are two primary functions of ditches and berms; namely to intercept runoff before it reaches erodible areas; and to carry sediment, during high flows, to properly designed settling basins when circumstances warrant the use of these basins. Important places for the installation of ditches or berms are at the top of cut and fill slopes and adjacent to the roadway. Midslope berms with ditches may be especially helpful in controlling sediment before erosion control cover is established.

The ditch size (area) can be determined by considering the slope of the ditch, area intercepted, intensity and volume of runoff, and the amount of sediment that may be deposited in the ditch during low flow conditions. The shape of the ditch may be trapezoidal or triangular, whichever is appropriate to the particular location.

1.01 Size and Placement

For ditch design, a good reference is "Design Charts for Open Channel Flow," Hydraulic Design Series No. 3, by the Bureau of Public Roads, (Federal Highway Administration) 1961 or later revision. (133) In addition to the ditch size required for full flow capacity, an allowance should be made for anticipated sediment deposit. Minimum full capacity flow velocities should be 2.5 to 3.0 feet per second to permit sediment transport. Refer to Table III C-1 for scour velocities in ditches of various materials.

The full flow water surface for roadway ditches should be at least one foot below the roadway subgrade. This position will prevent ditch water from entering the ballast material, removing the fines and destroying the ballast's effectiveness in supporting the roadway surface. Figure III C-1 shows the water surface level relative to the road subgrade. The suggested minimum size of ditches along roadways or elsewhere is shown in Figure III C-2.

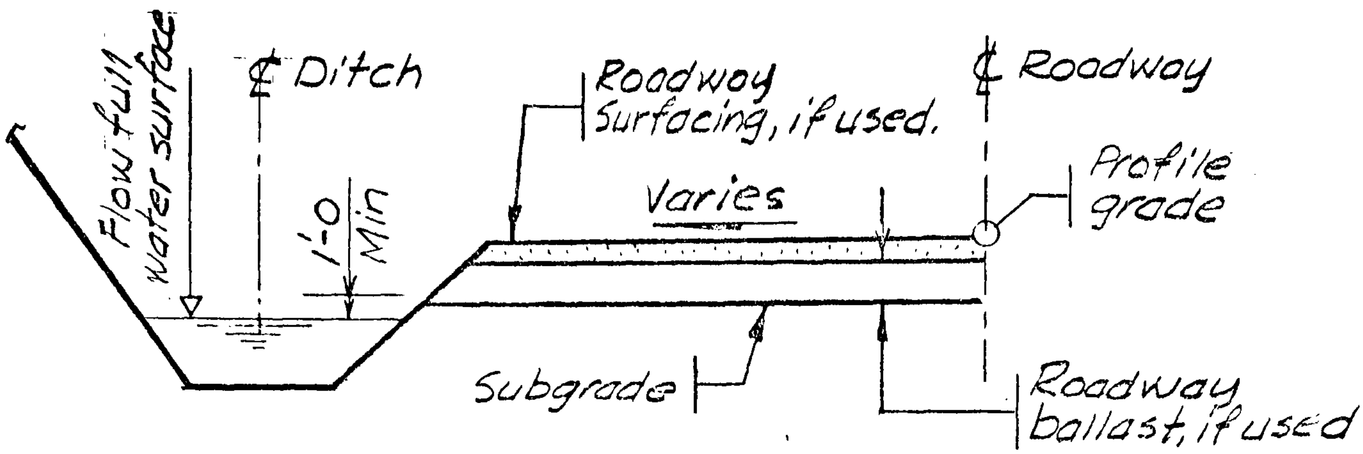


FIG. III C-1

The depth of potential sediment deposit in ditches is directly related to the erodibility of the soils over which water flows to the ditch and the ditch slope. The ditch depth allowance for sediment deposit should recognize the soil erodibility, the kind of erosion control cover planned for tributary slopes and the anticipated maintenance program. Some ditches, due to their slope and/or soil type, may not require a depth allowance for sediment build-up. The designer should refer to the information obtained during the planning-reconnaissance phase of the project for information relative to the erodibility of the soils that will be encountered within the road corridor.

All ditches constructed in erodible soils are themselves subject to erosion from runoff and may require stabilization by such means as riprap, rock rubble lining, jute matting, seeding and/or other acceptable erosion control device. Table III C-2 shows permissible velocities for ditches lined with vegetation. Plastic sheeting can be used as a

Table III C-1

Maximum permissible velocities in erodible channels, based on uniform flow in continuously wet, aged channels*

Material	Maximum permissible velocities for-- Clear water	Water carrying fine silts	Water carrying sand and gravel
	F.p.s.	F.p.s.	F.p.s.
Fine sand (noncolloidal)	1.5	2.5	1.5
Sandy loan (noncolloidal).	1.7	2.5	2.0
Silt loam (noncolloidal)	2.0	3.0	2.0
Ordinary firm loam	2.5	3.5	2.2
Volcanic ash	2.5	3.5	2.0
Fine gravel	2.5	5.0	3.7
Stiff clay (very colloidal).	3.7	5.0	3.0
Graded, loam to cobbles (noncolloidal) .	3.7	5.0	5.0
Graded, silt to cobbles (colloidal). . .	4.0	5.5	5.0
Alluvial silts (noncolloidal).	2.0	3.5	2.0
Alluvial silts (colloidal)	3.7	5.0	3.0
Coarse gravel (noncolloidal)	4.0	6.0	6.5
Cobbles and shingles	5.0	5.5	6.5
Shales and hard pans	6.0	6.0	5.0

*As recommended by Special Committee on Irrigation Research, American Society of Civil Engineers, 1926, for channels with straight alinement. For sinuous channels multiply allowable velocity by 0.95 for slightly sinuous, by 0.9 for moderately sinuous channels, and by 0.8 for highly sinuous channels (45, p. 1257)

Source: Design of Roadside Drainage Channels, U. S. Department of Commerce, Bureau of Public Roads Washington: 1965, page 54.

Table III C-2

Maximum permissible velocities in channels lined with uniform stands of various grass covers, well maintained* (2)

Cover	Slope range	Maximum permissible velocity on--	
		Erosion resistant soils	Easily eroded soils
	Percent	f.p.s.	f.p.s.
	0-5	8	6
Bermudagrass	5-10	7	5
	Over 10 . . .	6	4
Buffalograss			
Kentucky bluegrass	0-5	7	5
Smooth brome	5-10	6	4
Blue grama	Over 10 . . .	5	3
	0-5(3) . . .	5	4
Grass mixture	5-10(3) . . .	4	3
Lespedeza sericea			
Weeping lovegrass			
Yellow bluestem			
Kudzu	0-5(4) . . .	3.5	2.5
Alfalfa			
Crabgrass			
Common lespedeza (5)			
Sudangrass (5)	0-5(4) . . .	3.5	2.5

(1) From Handbook of Channel Design for Soil and Water Conservation. (See footnote 5, table 2.)

(2) Use velocities over 5 f.p.s. only where good covers and proper maintenance can be obtained.

(3) Do not use on slopes steeper than 10 percent.

(4) Use on slopes steeper than 5 percent is not recommended.

(5) Annuals, used on mild slopes or as temporary protection until permanent covers are established.

Source: Design of Roadside Drainage Channels, U. S. Department of Commerce, Bureau of Public Roads Washington: 1965, page 54.

temporary erosion control device during the construction period.

Riprap or rubble lined ditches will tend to act as a flow retardent which will allow movement of water and retain the sediment at low flow periods. The depth allowance for ditches lined with riprap or rock rubble can be coincident with the depth allowance for sediment deposit.

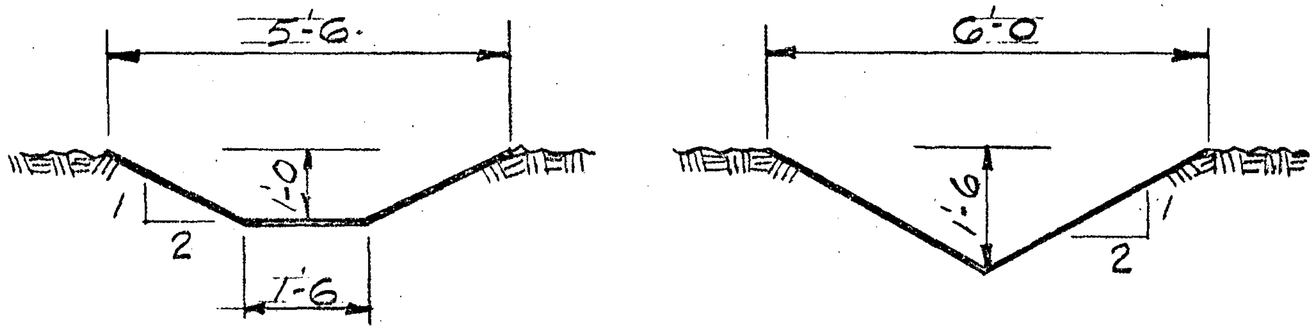
Berms (Figure III C-3) can be constructed of native material provided the material contains enough fines to render the berm impervious and the material can be shaped and compacted to about 90% of maximum density.*

Figure III C-4 portrays the general location for ditches and berms in relation to a finished roadway section. Additional locations for temporary ditches and other drainage facilities may be necessary during the construction phase. Refer to Section IV, Construction.

Ditches at the top of slopes may be needed when:

1. The natural ground above slope "daylight" point continues up sharply.
2. Ground cover above "daylight" point has low moisture absorbing ability (i.e. rock or clearcut area).
3. Exposed soils on cut slope are highly erodible, the exposed area is large, rain intensities are high and erosion control measures need time for establishment.
4. Quantity of runoff will flood or tend to flood the roadway ditch below the cut slope.

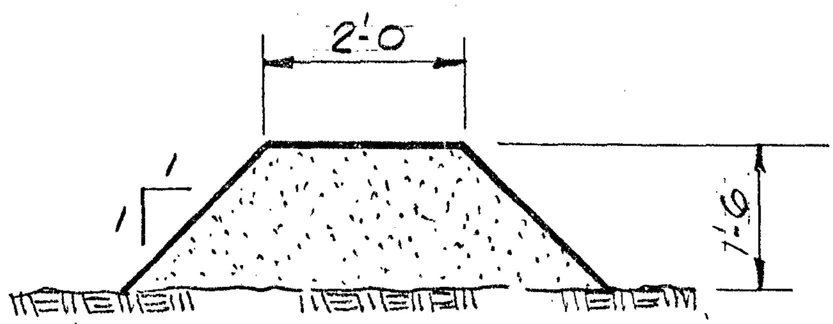
*Maximum density is a term used in earthwork specifications to mean the oven-dry weight per cubic foot of soil at optimum moisture content. The American Association of State Highway Officials (AASHO), the American Society of Testing Materials (ASTM) and other organizations have established field testing procedures to determine if compacted earthwork meets a specified percentage of maximum density.



TRAPEZOIDAL **TRIANGULAR**

MINIMUM DITCH SIZE

FIG. III C-2



BERM

FIG. III C-3

1.02 Ditch Profiles

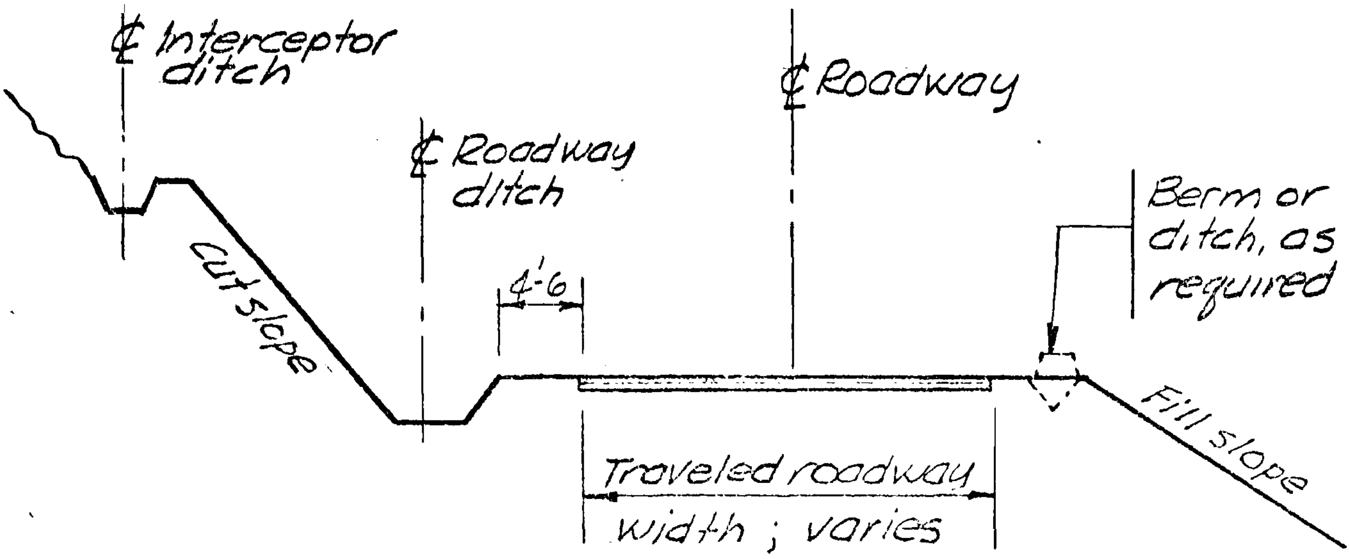
Roadway ditch profiles will generally follow the roadway grade. The minimum grade should be 1%. If flatter grades are necessary, ditches may need to be larger or alternately, the ditch can be separately profiled to obtain the necessary minimum gradient.

Other ditch profiles should be consistent with the ditch section used and quantity of flow. As previously suggested, the full flow velocity in all ditches should be at least 2.5 to 3.0 feet per second to permit sediment transport. (See Section 1.01)

1.03 Ditch Outlets

Ditches will outlet or discharge into natural streams, other drainage channels, culverts or settling basins. Ditches that outlet into natural drainage channels or streams may require a catch basin with culvert outlet or other sediment trapping device, 100-150 feet upstream from the intersection with the drainage channel or stream as shown in Figure III C-5. If the roadway cut slopes, fill slopes and ditches are stabilized, there should be minimal risk of sediment entering the stream or natural channel from the last 100-150 feet of the ditch shown in Figure III C-5.

Ditches will also outlet into culverts. If the soils are erodible in and around the ditch, the circumstances may require a catch basin structure prior to culvert entry. See Section 2.00 "Culverts" for culvert and catch basin discussion.



DITCH PLACEMENT

FIG. III C-4

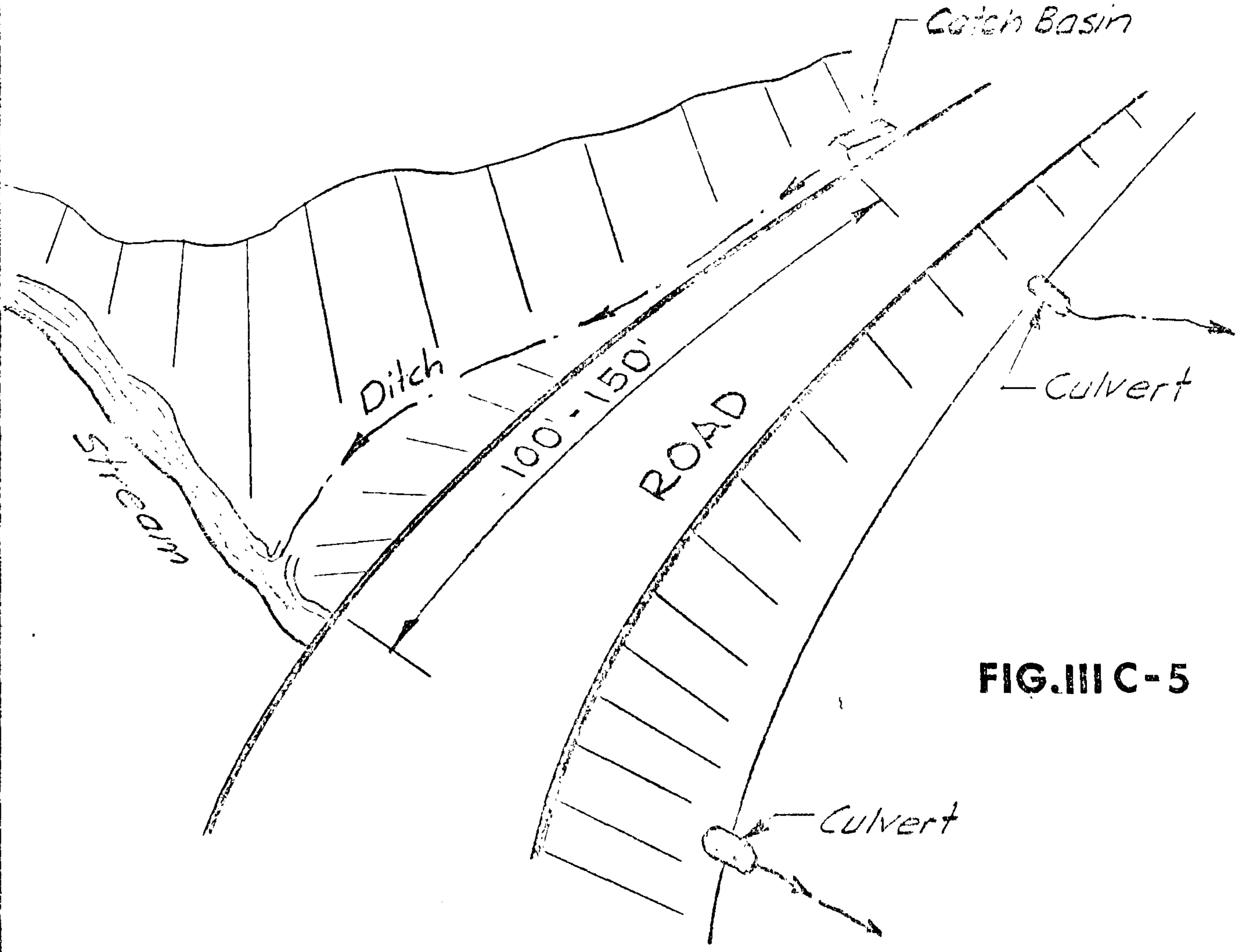


FIG. III C-5

1.04 Sloped Roadway Alternate to Roadside Ditches

Construction of out and in sloped roadways with surface cross drains has been a popular way to build forest roads. Although this type of construction has a place in forest road work, misuse of the concept can result in a sediment problem.

From the "Proceedings of A Symposium Forest Land Uses and Stream Environment" at Oregon State University, Larse recommends: "Design outslope or alternating inslope and outslope roadbed sections without a drainage ditch when overland surface flows are slight and road gradients can be 'rolled' sufficiently to self-drain without surface channeling." (134)

In 1967 Paul E. Packer completed studies and published "Criteria for Designing and Locating Logging Roads to Control Sediment." (135) These studies were directed toward the control of rill or gully erosion on outslope road surfaces in the Northern Rocky Mountains. Each study site had to meet the following criteria:

1. "Drainage structures immediately above and immediately below the road segment must have diverted all surface runoff and eroded soil originating above them onto the fill slope below the road without allowing any discharge to continue down the road surface.

2. The road segment must not have been affected by waterflow from side drainages.

3. The road segment must not have had an inside ditch along the toe of the road cut.

4. Sediment discharged from the lower or downgrade drainage structure, or eroded from the fill below it, must have been stopped on the slope before reaching a stream channel, a downslope road, or a major topographic barrier, such as a bench.

5. The entire study site, including the slope above the road cut and the slope below the fill, must have been located on soil derived from similar parent material.

6. The site must have been on an area where the timber sale was not more than 5 years old."

The report included a table for cross drain spacing required to prevent rill or gully erosion deeper than one inch on secondary logging roads in certain types of soils on various road grades. The "Guides for Controlling Sedimentation from Secondary Logging Roads" by Packer and Christensen also contains the table. The table is included herein as Table III C-3. Care must be exercised in the use of the table to ascertain that it is applied under circumstances that are closely comparable to the conditions under which Packer's studies were made. Packer and Christensen recommend that where combination of soil and topographic features require cross drain spacings of less than thirty feet, "no logging roads should be built unless they will be surfaced with gravel or crushed rock." (136)

In their China Glenn road report, Hartsog and Gonsior offer the following conclusion as to the success of the outslope road section as used at this particular location:

> "The authors suspect that outsloping is more an idealistic concept than a realistic solution to the water control problem. In theory, water generally will be uniformly distributed in minimal concentration over the road shoulder. However, unless the road can be graded to close tolerances and left undistorted, concentration is virtually unavoidable. Depressions left by wheels allow water to concentrate and run along the road. Even if the road has no grade, water will tend to concentrate and spill over depressions. If soils are loose and erodible, slight concentrations tend to erode depressions and channels that lead to greater concentrations and accelerated erosion. Although it can be argued that such problems rarely occur, the major part of all stream sedimentation is caused by relatively infrequent circumstances. Most of any stream's annual sediment load is contributed and transmitted (under natural or disturbed conditions) during a few hours or days. It is tentatively recommended that outsloping be specified only where surfaces are relatively nonerodible (e.g., at full-bench sections)." (137)

Table III C-3

Cross-drain spacings required to prevent rill or gully erosion deeper than 1 inch on secondary logging roads built in the upper topographic position (1) of north-facing slopes (2) having a gradient of 80 percent. (3)

Road grade (percent)	Cross-drain spacing					
	Hard sediment	Basalt	Granite	Glacial silt	Andesite	Loess
	Feet					
2	167	154	137	135	105	95
4	152	139	122	120	90	80
6	144	131	114	112	82	72
8	137	124	107	105	75	65
10	128	115	98	96	66	57
12	119	106	89	87	57	48
14	108	95	78	76	46	37

(1) On middle topographic position, reduce spacings 18 feet; on lower topographic position, reduce spacings 36 feet.
(2) On south aspects, reduce spacings 15 feet.
(3) For each 10-percent decrease in slope steepness below 80 percent, reduce spacings 5 feet.

Source: Criteria for designing locating Logging Roads to Control Sediment, Paul E. Packer, Reprinted from Forest Science, Volume le, Number 1, March, 1967.

The following conditions are favorable for the use of no ditch outslope roads with surface cross drains.

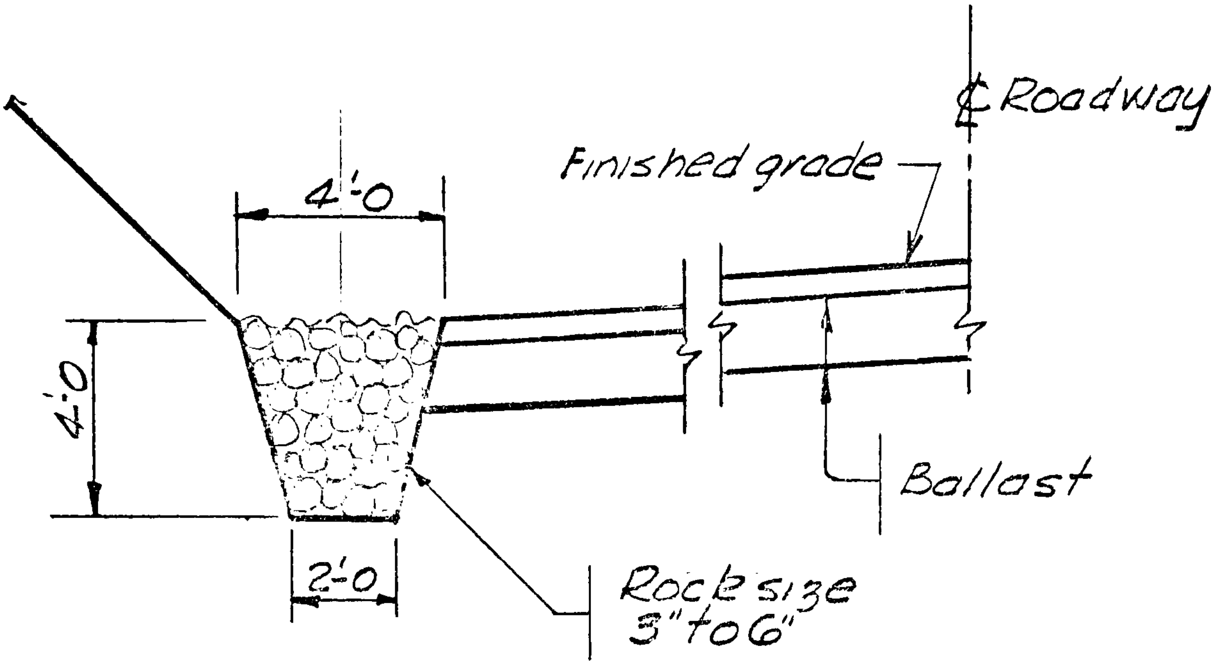
1. Short backslopes
2. Terrain slope less than 20%
3. Seasonal road use
4. Spur (light traffic) roads
5. Favorable geographic area (i.e. Idaho)
6. Non continuous longitudinal grades steeper than 3%
7. Conditions permitting immediate planting and growing of vegetation on cut and fill slopes.

The following conditions are unfavorable for the use of no ditch outslope roads.

1. Long backslopes
2. Continuous steep longitudinal grades
3. Terrain steeper than 20%.

1.05 Rock Sub-drain Alternate to Roadside Ditches

Another alternate is the use of the Rock Sub-drain. The Rock Sub-drain is located between the toe of the cut slope and the edge of the roadway as shown on Figure III C-6. An advantage for its use as compared to an open ditch is that the total grading width of the road will be less. Rock Sub-drains may be used when longitudinal grades are steeper than 2%. Critical to the longevity of the sub-drain is the establishment and maintenance of vegetation on the slopes above the drain. Any limitations on construction procedures for installing the rock sub-drain in order to maintain backslope stability and prevent contamination of the sub-drain should be included on the plans or in the accompanying specifications.



ROCK SUB-DRAIN

FIG. III C-6

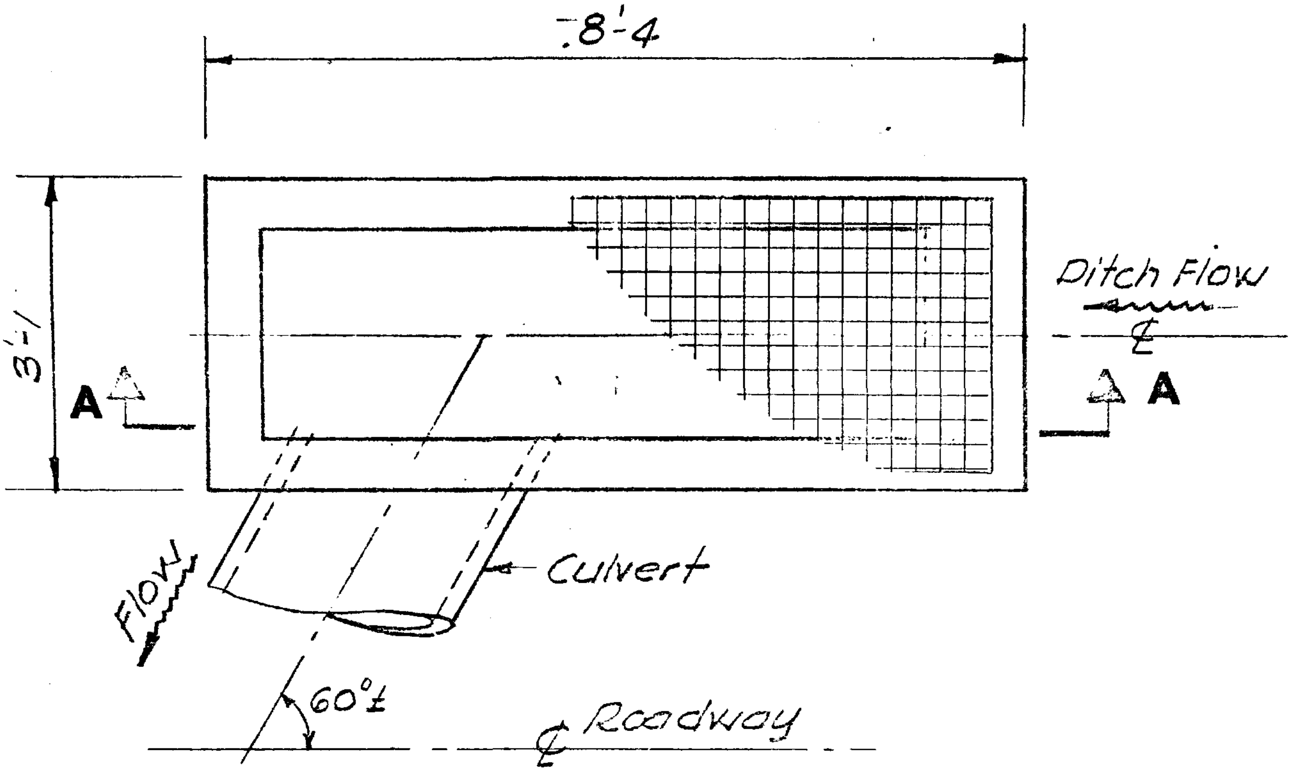
Rock Sub-drains can outlet similarly to the open ditch, through a "Ditch Inlet Structure" (See Section 2.00) and a cross culvert or to a natural channel.

2.00 Culverts

"A culvert is an enclosed channel serving as a continuation of and a substitute for an open ditch or an open stream where that ditch or stream meets an artificial barrier such as a roadway, embankment or levee." (138) Forest road culverts are used primarily for draining the roadway surface (outletting roadside ditches) and to allow streams or natural channels to pass through a roadway embankment.

"Culvert failure, another common cause of road damage, was most often related to plugging with debris. In most cases, the hydraulic capacity of the culvert was sufficient to carry the volume of water as long as it remained unplugged." (139)

The fact that culvert intakes do become blocked with debris, sediment, rocks, etc., requires that serious consideration be accorded the use of a culvert intake protecting device. A "Ditch Grating Inlet Structure," with or without a Catch Basin (See Fig. III C-7 & Fig. III C-8), is such a device. The degree or amount of culvert intake protection needed will vary with individual site circumstances from a simple riprap treatment of ditch bottom and sides at the intake point to the more elaborate treatments that can include trash racks, catch basins and/or the grating inlet structure. Intake protection should also be evaluated in the light of the anticipated ditch and culvert maintenance program and the companion treatment that may be accorded the culvert outlet. In a series of several culverts outletting a ditch, varying degrees of treatment to intakes might be considered so that at least one or more of the culverts would function under very adverse circumstances.



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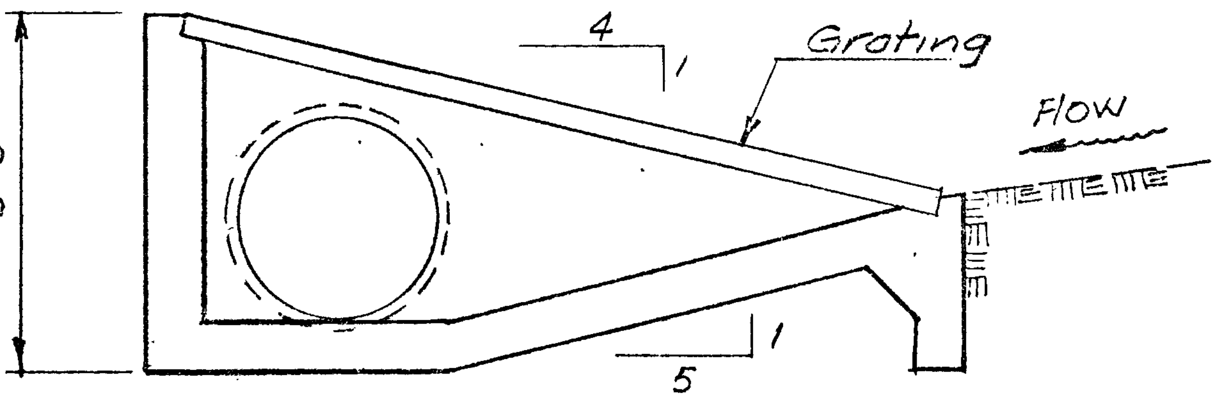
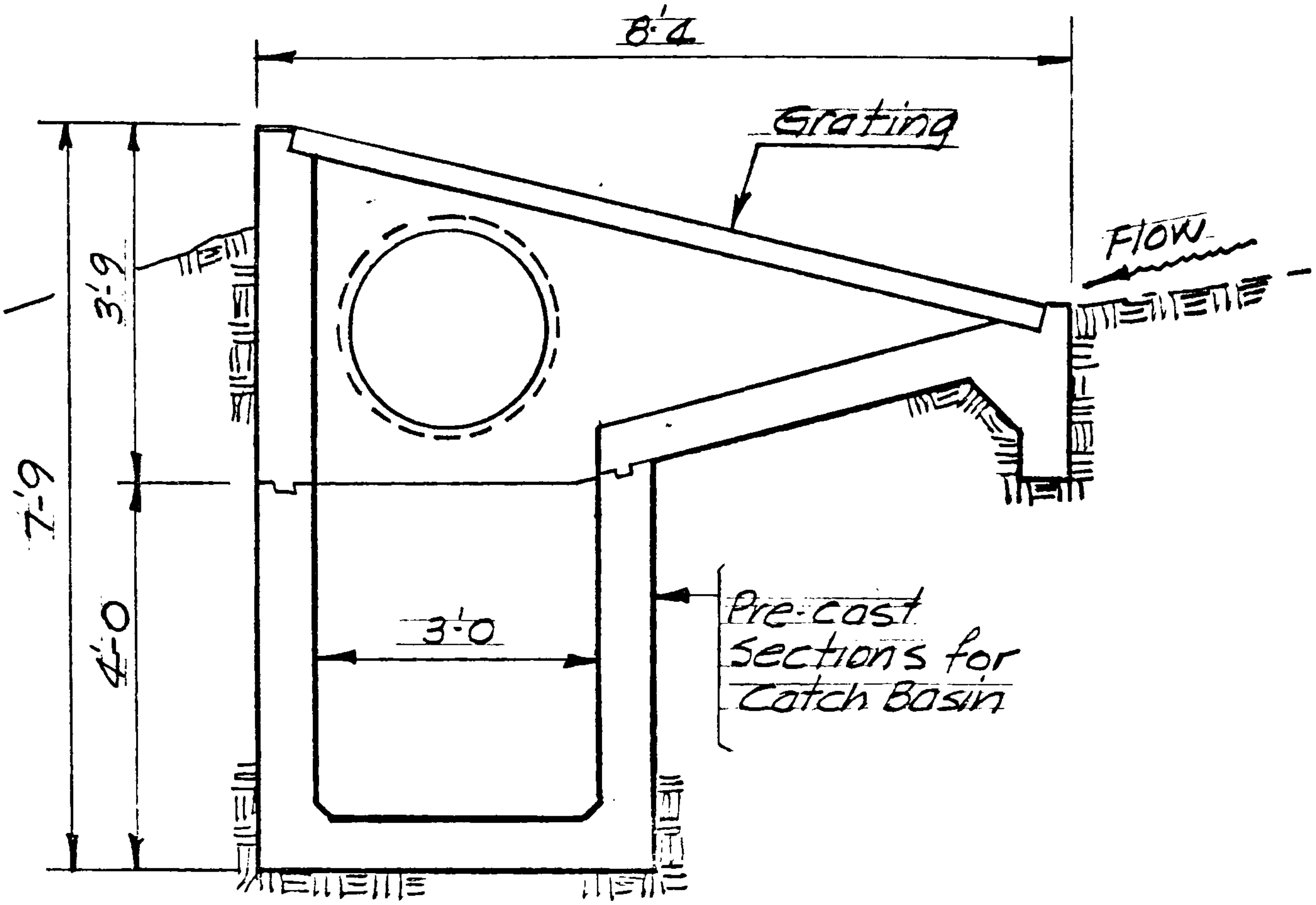


SECTION A-A

DITCH INLET STRUCTURE

FIG. III C-7



DITCH INLET STRUCTURE WITH CATCH BASIN

FIG. III C-8

The roadway culvert should have a minimum depth of cover of approximately four feet. This depth is required to prevent crushing the culvert by passage of truck live loads. An inactive culvert (crushed) can cause roadway wash-out, erosion and sediment.

"The frequency, location and installation method of ditch drainage culverts is much more important than capacity or size. However, minimum sizes of 15 inch or 18 inch diameter is the accepted practice, depending on the rainfall intensity..... (runoff and area intercepted)..... and the influence of ditch debris".(140) A minimum diameter of 18 inches is suggested.

Ditch outlet culverts should be designed so that the half full velocities are 2.5 to 3.0 feet per second in order to transport sediment through the culvert. Should the ditch become over silted and the catch basin or other intake device fail to function, the sediment should pass through the roadway culvert to outlet or other necessary downstream sediment collectors. Cleaning culverts is a difficult, expensive, neglected, ignored and often an imperfect procedure. Provision for necessary sediment collection before or at the culvert intake and/or at or after the culvert outlet is recommended. (See Section 4.00 for discussion of sediment collection devices at or beyond culvert outlet points.)

Common culvert materials are corrugated galvanized steel and corrugated aluminum. When culverts are on steep slopes where design flow velocities are 10 feet per second and greater, paved inverts are desirable to reduce barrel wear resulting from sediment scour. The type of coupling band necessary for an installation and whether or not the use of gaskets is appropriate should be related to the anticipated differential settlement that might occur along the length of the culvert. Culvert separation under a roadway has great potential for causing roadway failure and subsequent sediment transport.

The culverts used to pass streams under roadway embankments can be round, structural pipe arch or structural plate arch. The latter two are preferred. The structural pipe arch enables the wide flat bottom to be buried in the stream bed. The structural plate arch has no bottom, so the stream can remain virtually untouched if care is exercised during its installation. (Refer to Section 3.00 for further discussion of stream crossings.)

Outfall ends of culverts under roadways should ideally terminate beyond the toe of the fill. When the fill is shallow this condition may be satisfied by simply extending the pipe as a cantilever beyond the fill slope a sufficient distance to clear the toe of fill. On deep embankments, where the outlet point is a considerable distance above natural ground, a culvert extension anchored to the fill slope may be required. Half round culvert extensions are also employed for this circumstance. Whether the half round will be satisfactory is dependent upon its anchorage, the quantity and velocity of discharge, and the length and steepness of the embankment.

Canvas or "elephant trunk" culvert extensions have also beem employed. They have been subject to vandalism and to freezing shut in cold weather. Placing riprap on the fill slope below the culvert outlet will aid in preventing slope wash.

The problem of protecting the fill slope at the culvert outlet point can be minimized by placing the culvert entirely on or within natural ground. Determination as to the adoption of this alternate is a matter of evaluation of the circumstances at the culvert location in question.

2.01 Sizing Culverts

The complete hydraulic design procedure for all culverts requires:

1. Determination of the design flow - See discussion below and paragraphs 3.00 and 5.00.

2. Selection of the culvert size.

3. Determination of the outlet velocity.

> "The many hydraulic design procedures available for determining the required size of a culvert vary from empirical formulas to a comprehensive mathematical analysis. Most empirical formulas, while easy to use, do not lend themselves to proper evaluation of all the factors that affect the flow of water through a culvert. The mathematical solution, while giving precise results, is time consuming. A systematic and simple design procedure for the proper selection of a culvert size is provided by Hydraulic Engineering Circular No. 5, Hydraulic Charts for the Selection of Highway Culverts and No. 10, Capacity Charts for the Hydraulic Design of Highway Culverts, developed by the Bureau of Public Roads." (141) (142) (Federal Highway Administration.)

This method is based on the results of both laboratory experiment and prototype tests. The method is believed to provide a more rational approach for determining culvert capacity than older procedures.

"The procedure for selecting a culvert is to determine the head water depth from the charts for both assumed inlet and outlet controls. The solution which yields the higher head water depth indicates the governing control." (143) However, the minimum velocity must be 2.5 to 3.0

feet per second at half capacity for transporting sediment through the culvert. The procedure stated above includes a determination of the outlet velocity. Knowledge of this velocity is pertinent to the evaluation of the potential for erosion at the outlet point of the culvert.

The sizing procedure, outlined above, may be augmented by the following considerations:

1. Arbitrarily reduce roadway culvert spacing below the spacing required by mathematical calculation, to recognize the potential for debris and sediment blocking of culvert intakes and/or the circumstances at the outlet end. Large volume high velocity discharge may be difficult to control regardless of the sophistication of the treatment.
2. Arbitrarily increase roadway culvert sizes and/or reduce culvert spacing in recognition of the level of accuracy of data used in determining the design flow.
3. In a run of three or four cross roadway culverts, make one a size or two larger than calculations require as an "insurance" mechanism for the circumstance of one or more culverts becoming plugged.
4. Be realistic in forecasting or assuming the level of ditch and culvert maintenance.
5. Size culverts at the low point of sag vertical curves for twice the calculated flow or alternately size all culverts upstream from the low point for 20 percent more than the calculated flow. Provide an inlet structure for the culvert at the vertical curve

low point. Make liberal use of trash rocks or inlet structures for the culverts along the adjacent negative grades.

6. Since live stream culverts are preferably installed parallel to stream gradient with invert buried in the stream bed, recognize this circumstance in flow capacity evaluation.

7. Evaluate stream culvert calculated size relative to potential stream bed constriction. Pipe arch or plate arch culverts have advantages as described in Section 2.00.

8. Evaluate the potential for manufactured debris upstream from stream culverts in terms of the land management program for the drainage area. If the area is to be logged, provisions must be made to keep manufactured debris out of the stream or the culvert must be sized accordingly. The former is the better procedure, the latter is guess work.

9. From the reconnaissance information, recognize the potential for natural stream bed erosion during storms.

2.02 Design Aspects of Culvert Installation

Culvert design usually includes features of the installation that are important to the performance of the culvert in accordance with design expectations. These features, when appropriately specified by the designer and accomplished by the installer, are germane to the sediment creation potential occasioned by culvert failure.

a. Roadway Culverts It is usual to specify that the trench width shall be limited (pipe diameter plus a distance) and that the trench walls be vertical for a height at least equal to the pipe diameter and preferably more. These limitations are used because wider trenches tend to increase load on the pipe and require more excavation and backfill. Reasonable care in installation is assumed for all design criteria or design tables developed for determing necessary pipe gage. Handling the minimum amount of soil when installing a culvert is also advantageous with respect to the potential for sediment creation. Culverts may be crowned when installed to provide for the deflection anticipated by embankment consolidation.

Culvert trenches are often over excavated and backfilled with select material (pea gravel is popular) in order to obtain proper pipe bedding in lieu of shaping the trench bottom for the pipe barrel, or because of unsuitable foundation material. The select backfill is usually placed at least to the spring line of the pipe. If a situation existed where water was being forced along the outside of a culvert, the presence of pea gravel backfill would tend to allow this passage as opposed to the circumstance of pressure build up and possible culvert blow out. Thus the use of pea gravel backfill for reasons of the structural integrity of the culvert could have the simultaneous advantage of minimizing sediment potential. The Ditch Grating Inlet Structure (Figures III C-7 & III C-8) will act to reduce the opportunity for water to pass along the outside of the culvert.

b. Stream Culverts

The advantages of using structural plate or pipe arch culverts as a means of minimizing stream bed disturbance have been previously mentioned. As with roadway culverts, all of the installation procedures important to the structural integrity of the installed culvert (foundation, backfill quality and method) may have bearing on the potential for sediment creation.

Upstream fill slopes will usually require erosion protection by the use of concrete headwalls, rock riprap or gabions. (See Figure III C-9) A conservative estimate of the height and width of the fill slope adjacent to the culvert requiring this protection is suggested.

In some circumstances, an additional safety factor can be included by provision for an overflow channel across the roadway adjacent to the culvert. The roadway profile might be adjusted to provide an adjacent low spot or sag with companion fill slope armoring within the planned overflow channel. Although some sediment creation and transport may occur, the amount will be much less than that created by a culvert "blow out".

Clearing of the approach channel of natural debris for some distance upstream from the culvert is strongly recommended. The amount of clearing necessary is dependent on the individual circumstances at the site, 100

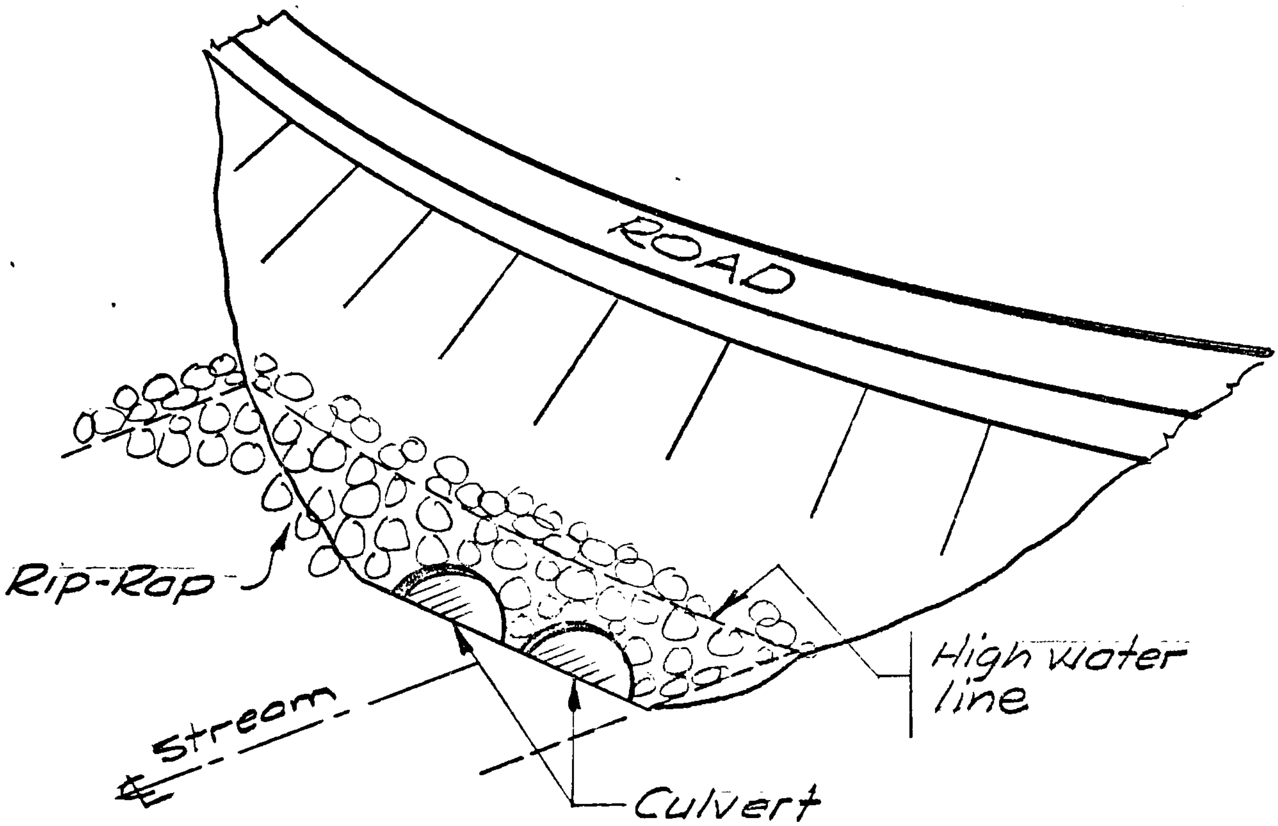


FIG. III C-9

feet upstream is offered as a guide line. Clearing of the approach channel should be an annual accomplishment.

3.00 Water Course Crossings

One of the important forest road design problems is the live stream crossing. Sudden earth slides and minor roadway surface disintegration are capable of disabling a road but the potential for road loss and sediment creation and transport from a washout due to a plugged culvert or extraordinary high water at a stream crossing is probably greater. It is therefore extremely important to exercise the utmost care in the planning, design and construction of water course crossings. Robert W. Larse observed that: "Surveys of road damage and erosion resulting from high stream flows indicates floatable debris to be a major contributing factor, plugging small culverts and restricting flow at large culverts and bridges, and causing severe road embankment, stream bank erosion or channel changes". (144)

Design criteria for minimizing the sediment potential from stream crossings is interrelated with other design factors whose application is necessary to satisfy the functional requirements of the site. If these criteria are not satisfied, the crossing will not provide satisfactory service to the land manager. Therefore the following discussion of criteria is necessarily broader than the topic of sediment minimization. The discussion is not, however, a complete treatment of the design spectrum for stream crossings.

3.01 General

Each stream crossing must receive individual study to determine the best crossing method or medium. Sufficient site data must be available to the responsible designer so that he can accomplish this individual study. This data will be a part of the findings of the reconnaissance phase supplemented by appropriate topographic, foundation and other information that will define the ambient site circumstances in adequate detail for design purposes. A site visit by the project designer is strongly recommended.

The responsible design professional must know the use and purpose of the road of which the stream crossing is a part. The intended road use may relate to the designer's options in selecting a crossing medium, for example, will a ford be satisfactory. His task is to meld the use requirements to the site requirements in a manner that will produce a satisfactory result.

3.02 Sediment features of stream crossing design

The following aspects of stream crossing design have particular relevance to the potential for sediment creation.

1. Hydraulic capacity of opening.
2. Allowances for debris.
3. Bank protection (stream or roadway slopes) adjacent to or within the crossing area.
4. Effect of channel changes or relocation.
5. Amount of excavation or foundation work needed within wetted perimeter of stream.
6. Timing of construction relative to high water.

Based on the quality of information available to him, and his competence, the designer can recognize and treat the first five items listed above in his design solution. The sixth item involves those who program the actual construction as well as the type of design. Appropriate communication on this subject is mandatory.

Sufficient topographic field data for the designer to determine the hydraulic characteristics of the stream channel is basic to analysis of hydraulic capacity. This data is needed for several hundred feet upstream and downstream from the crossing point in order to determine the water surface level relative to stream banks for various design flows. Even with an adequate channel section at the crossing, an inadequate section upstream could produce a circumstance wherein waters will overflow channel banks and result in erosion of approach embankments. Such a circumstance may indicate a need to consider embankment protection riprap, overflow culverts in approach embankments, overflow approach spans for bridges, or provision for flood waters to overtop approach embankments.

Determination of design flows for mountain streams and rivers is more difficult due to the lack of stream gaging stations and rainfall intensity records in high altitude areas. A nationwide series of water-supply papers entitled "Magnitude and Frequency of Floods in the United States" has been prepared by the United States Geological Survey. Academic calculation of design flows by the USGS method or other approach should be cross checked by the following:

1. Known flood history of the area.
2. Performance of crossings of similar streams.

3. All available gaging records of this and comparable streams.
4. Field data indicating high water marks, natural overflow channels, old stream beds, etc.

Any proposed changes to natural channels or the inclusion of flood way obstructions should be evaluated to determine the changes that might occur in the hydraulic behavior of the stream. Channel relocations, when constructed in the dry, are not necessarily detrimental to the stream. Easing or elimination of sharp bends may remove a constriction to hydraulic capacity. (Stream bed scour may also increase.) The rule is to make a total evaluation of the proposed design. The U. S. Bureau of Public Roads (Federal Highway Administration) "Hydraulics of Bridge Waterways" is a good reference for the analysis of stream obstructions (i.e. bridge piers) for streams or rivers. (145)

Tables III C-1 and III C-2 in 1.01 give scour velocities for certain kinds of ditch linings or ditch soils. Values shown in these tables provide an indication as to the maximum velocities that can be tolerated in channels without using riprap treatments of rock or gabions. The U. S. Bureau of Public Roads "Design Charts for Open-Channel Flow" includes data for grassed channels. Design charts include a procedure for determining maximum permissible velocities without channel scour. (146)

Important to the satisfactory performance of riprap lined channels is the sizing of the riprap and the companion channel side slope. The Bureau of Public Roads "Design of Roadside Drainage Channels" 1965 includes procedures for evaluating the adequacy of channel linings relative to channel slope and flow velocity. This publication recommends that "if the mean velocity at the design flow exceeds the permissible velocity for the particular soil type, the channel should be protected from erosion". (147) Design procedures for the use of various linings are discussed.

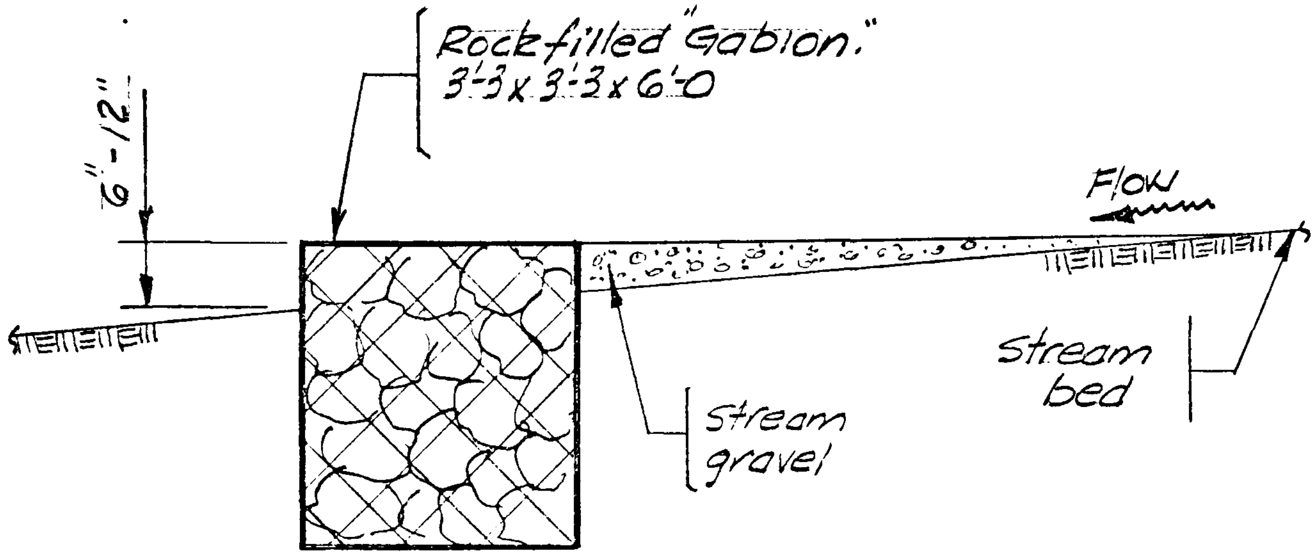
Riprap bank protections should extend to a minimum of two feet below the stream bed. This is to prevent erosion of the bank material and subsequent displacement of the riprap.

3.03 Stream crossing methods

There are three stream crossing methods employed on forest roads, fords, culverts and bridges. Factors influencing the selection of the appropriate crossing method include stream size, debris potential, vertical position of road relative to stream, foundation conditions, construction cost and maintenance cost, and contemplated road use and life.

a. Fords are an attractive alternate for secondary or spur road crossings of small streams particularly if the road use is limited to the dry season when little or no water is in the channel. Ford installation requires minimal disturbance to the stream channel. Problems attendant to bridge or culvert installation such as size of opening, provision for debris passage and channel or embankment riprap are largely avoided.

Gabions for ford crossings have been successfully used in the Modoc National Forest. Allen J. Leydecker in an article entitled "Use of Gabions for Low Water Crossings on Primitive or Secondary Forest Roads" (148) describes the design used. A typical installation cost $3,000 in 1971 and was accomplished on a force account basis. The installation consists of gabions placed at the roadway grade backfilled by stream gravel to form the road surface. "In about a year's time, fines transported by the stream cement the gravel backfill and construction scars heal, leaving a satisfactory stream crossing . . . . " Figure III C-10



GABION FORD

FIG. III C-10

Source: Leydecker, Allen D., "Use of Gabions for Low Water Crossings on Primitive or Secondary Forest Roads" is a reproduction from Leydecker's paper portraying a section through the ford. The ford was not damaged during the following winter when peak flows were estimated by Leydecker to have been approximately 400 cfs.

b. Culverts have been regarded by many designers as the economic solution for small stream highway crossings during the past twenty-five years. They have largely displaced the previously used short span bridge for reasons of economy and the goal of maintaining an uninterrupted roadway and shoulder width. The performance of culverts on forest roads suggests that the determination of use should not be as quickly assumed as has been the case for county roads, city streets and state highways. The site circumstances that may be different from that of a typical public highway installation are steepness of terrain, potential for debris, ability of steep terrain to retain fills adjacent to the culvert and difficulty in compacting fills with equipment usually used in forest road construction. Reliability of the calculation for required culvert capacity is another factor.

The foregoing discussion is particularly directed toward the round culvert. No specific guidelines or "rules of thumb" are available to assist the designer in making a choice between bridge or culvert. Attention to the individual circumstances of the site by a competent professional is the only known rule.

Other features of culvert design are discussed under Section 2.00.

c. Forest road bridges have been designed using a variety of structural materials for substructure and superstructure. The selection of a bridge type for a particular site is dependent upon the functional requirements of the site, economics of construction at that site, live load requirements, foundation conditions, policies or opinions of the owner, maintenance evaluations and preferences of the project designer. The type of design selected can have a bearing on the potential for sediment creation.

The bridge design can go awry if insufficient attention is accorded the site circumstances. A quick conclusion that the site permits the use of an accomplished design from a "similar" site should be avoided.

Location of bridge foundations relative to the normal stream channel and forecasted flood channel can be an important element. While it is not suggested that all bridges must span flood channels, an evaluation of the effect on the channel with an obstruction therein is necessary. Channel obstructions can cause channel scour and contribute to debris blockage.

Although there are different views on the minimum desirable horizontal and vertical stream clearances in streams not subject to navigation, some arbitrary rules based on judgment and experience in the area should be established. Vertical clearances should not be less than 5 feet above the 50 year flood level plus .02 of the horizontal distance between piers. Horizontal clearance, between piers or supports in forested lands or crossings below forested lands, should not be less than 85% of the anticipated tree height in the forested lands or the lateral width of the 50 year flood.

In considering a longer span bridge, there are economic tradeoffs, higher superstructure cost versus possible reduction in foundation cost as compared to a short span. Subacqueous foundations are expensive and involve a degree of risk attendant to the operations of cofferdam construction, seal placement and cofferdam dewatering. In addition to the water quality degradation that can occur with a lost cofferdam, the time and money loss will be significant. Subacqueous foundations often limit the season of construction relative to water level and relative to fish spawning activities. Thus, construction timing has to be rigidly controlled.

Type of foundation support also deserves consideration from a sediment perspective. If deep excavations are necessary to reach suitable strata for direct bearing footings, pile supports may result in less disturbance of the ground in and around the stream thereby reducing the amount of excavation, shoring and backfilling. A careful review of the economic tradeoffs is appropriate rather than an immediate conclusion that direct bearing footings are correct because the support strata is present at some depth.

The remoteness of many forest road bridge sites suggests the maximum use of precast or prefabricated superstructure units for economic reasons. The use may be limited by the capability to transport the units over narrow, high curvature roads to the site, or the horizontal geometry of the bridge itself. Precast or prefabricated superstructure units avoid a requirement to falsework the stream as is required for a cast-in-place concrete bridge. A cast-in-place structure may place limits on the construction season as the falsework may block the stream and is very vulnerable to debris damage. Any delays to construction (changed foundation conditions) that result in false-work being placed later in the season than initially anticipated can be hazardous. Some streams are subject to flash floods even in the "dry" season.

The U. S. Forest Service is constructing nine steel girder bridges on Forest Development Roads, South Tongass National Forest, Prince of Wales Island, Alaska. Short construction season and the remote sites (no local source of concrete aggregates) influenced the designer's decision to maximize use of prefabricated steel elements for both superstructure and substructure units.

The abutments for three of the bridges are U-shaped made entirely of steel sheet piling. The structures clear span the normal water level, end supports interfere slightly with estimated high water. Although minimization of the opportunity for the creation of sediment may not have been a stated design goal, the abutment design is one that clearly accomplishes this. Placing of the sheet pile abutments require minimum handling of natural soils as compared to an abutment designed in reinforced concrete.

A conservative vertical clearance for debris at high water was also provided. A lateral bracing system was provided in the plane of the top flanges of the girders, a system was not provided in the plane of the lower girder flanges because of vulnerability to drift and debris during high water.

4.00 Culvert Outlet Treatments

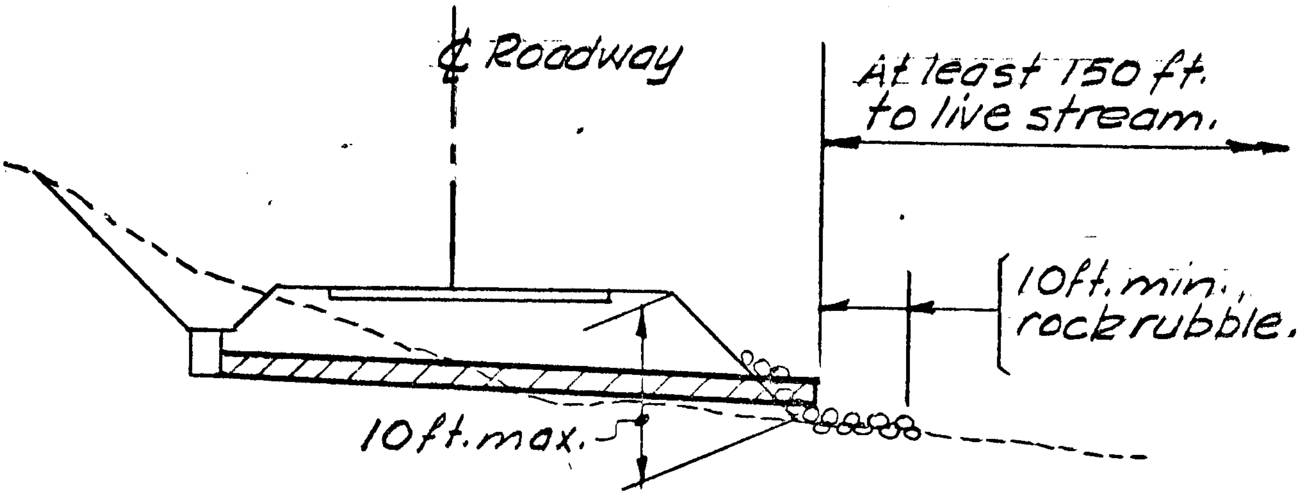
The last opportunity to control or inhibit the movement of sediment in the roadway drainage system is at or near the culvert outlet point. The action of the water at the outlet point can also create sediment if the flow velocity is of a magnitude that will scour the natural soils at the outlet.

Due to the many variables involved, all possible solutions to this problem are not included in the following discussion. A few practical solutions that can be adapted as the designer may determine are outlined.

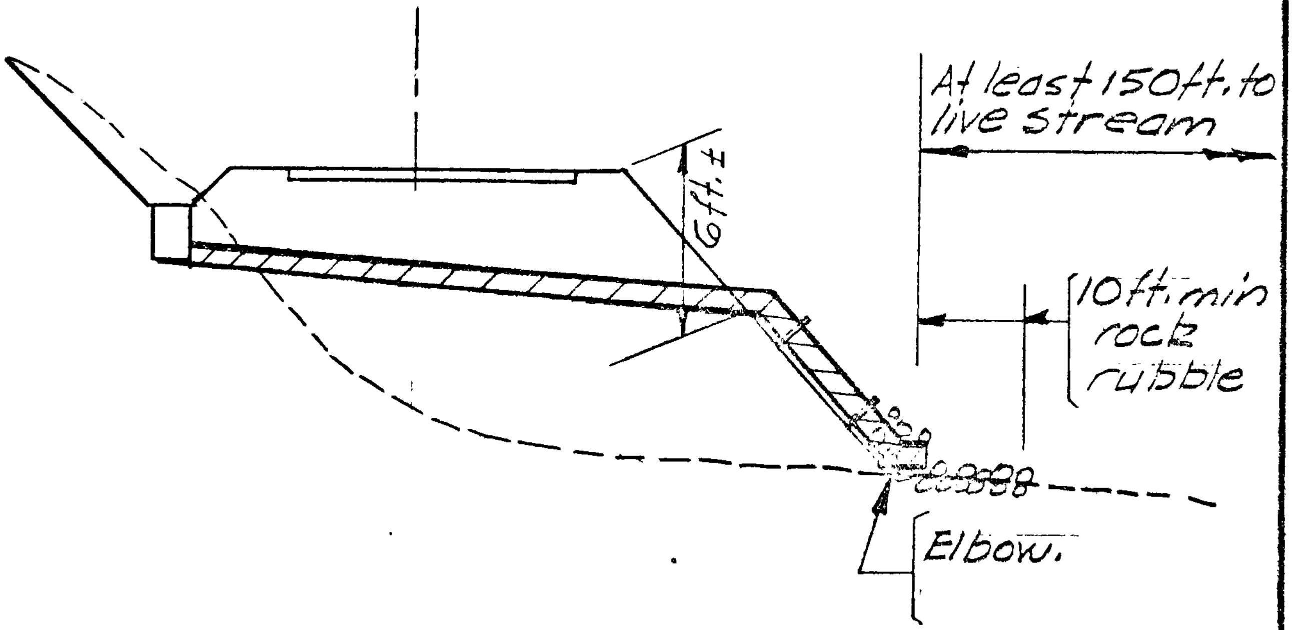
If appropriate upstream measures have been taken for sediment control, the degree of treatment at the culvert outlet may be minimal. Appropriate upstream measures may include:

1. Adequately designed and constructed ditches with appropriate linings as outlined in Section 1.00.
2. A "Ditch Inlet Structure with Catch Basin" that functions properly to trap sediment, Section 2.00. Sediment that is not deposited in the ditch and bypasses the catch basin is considered as flowing through the roadway culvert to its outlet. Whether or not storm waters are likely to contain significant sediment at the culvert outlet depends upon the erodibility of soils over which these waters have passed and the volume and velocity of flow.

Figures III C-11 and III C-12 show two roadway culvert outlet conditions. The culverts shown in Figure III C-11 outlet at least 150 feet from a live stream. For this condition a short length of lined culvert apron at the outlet point to act as an energy dissipator and a scour



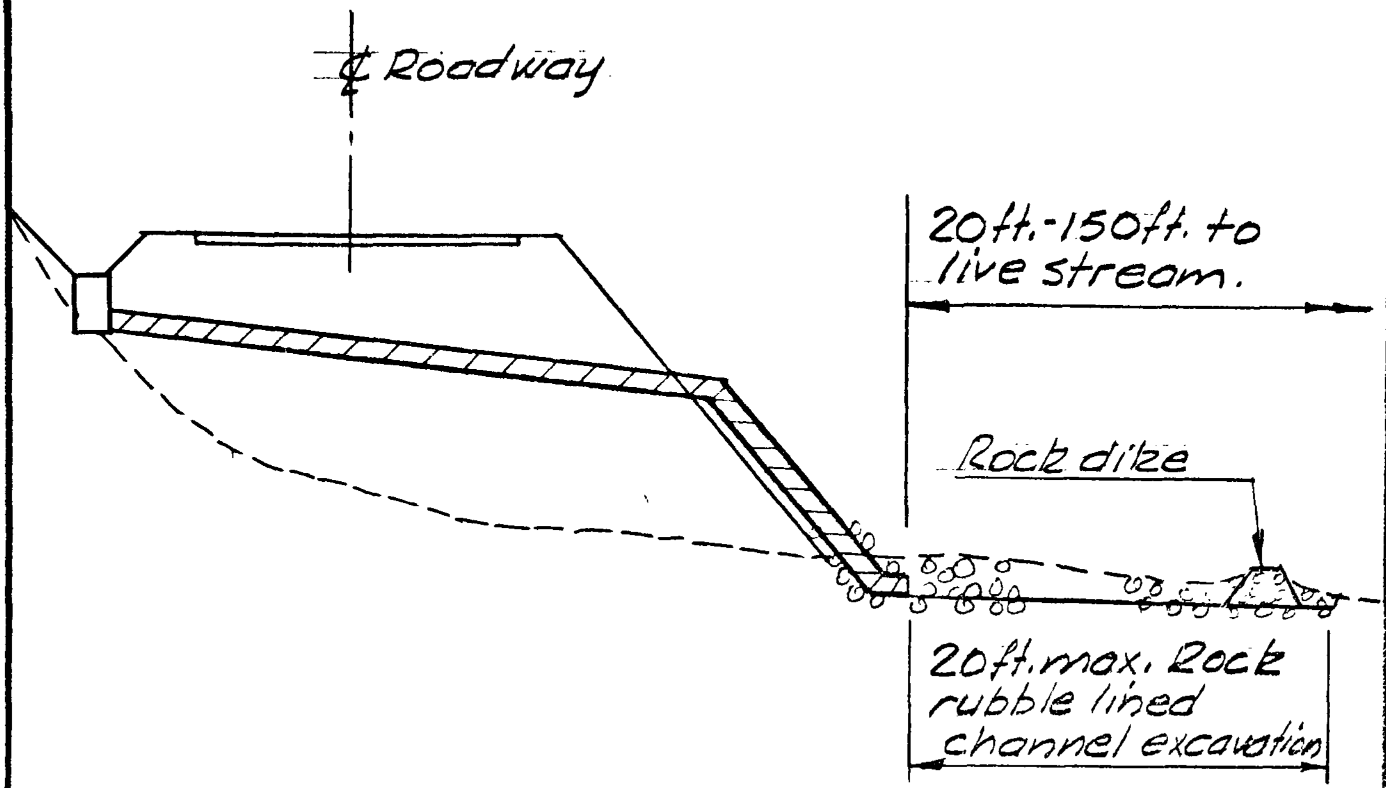
SHALLOW FILL-SHALLOW CULVERT



HIGH FILL-SHALLOW CULVERT

CULVERT OUTLETS

FIG. III C-11



CULVERT OUTLET NEAR STREAM

FIG. III C-12

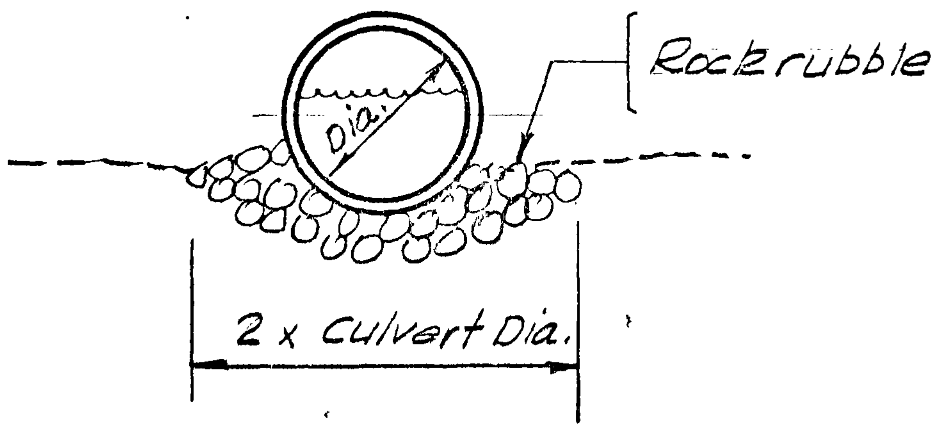


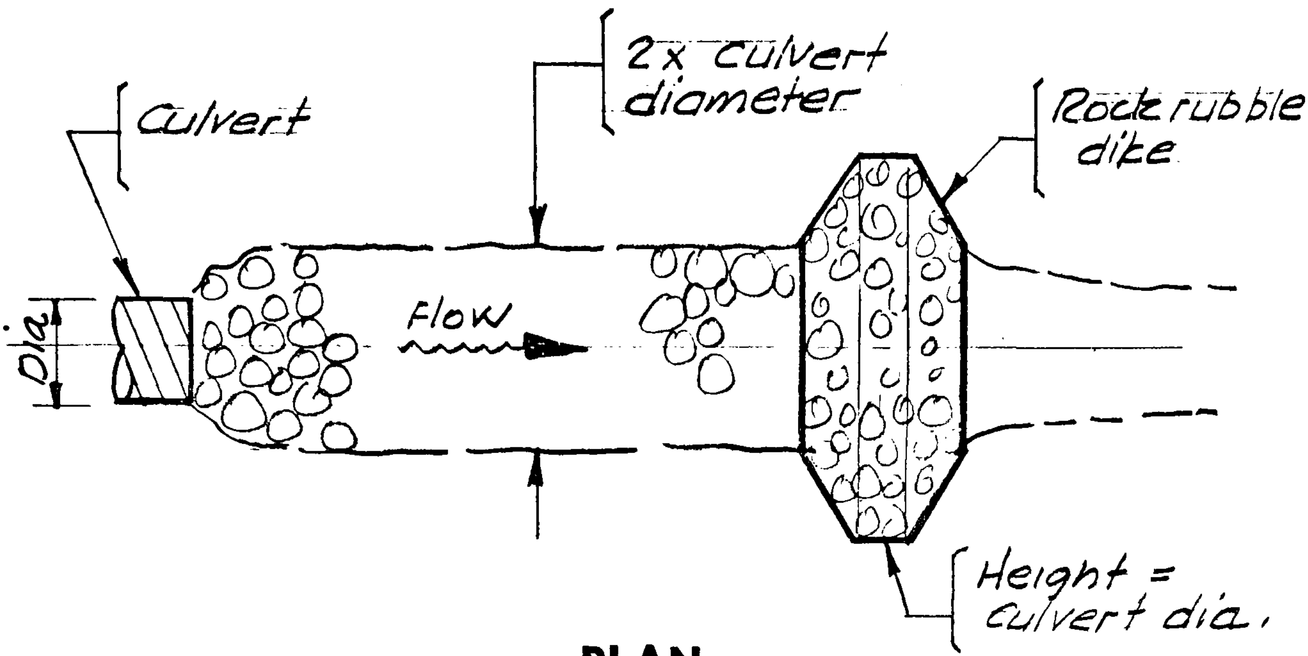
FIG. III C-13

inhibitor has merit. The lining can be rock rubble, ten feet minimum in length with a width equal to twice the culvert diameter as shown in Figure III C-13.

If the remaining distance to the live stream is relatively flat and contains vegetation, channel flow velocity will tend to decrease. Remaining sediment will tend to deposit in the vegetation. If the remaining distance to the stream is steep and bare, additional energy dissipation may be necessary in order to permit sediment deposit. The rock apron can be continued further beyond the culvert outlet and a rock dike with height equal to the culvert diameter and width equal to twice the culvert diameter installed in the outlet channel as shown in Figure III C-14. In addition, a further measure might be the placing of slash from the roadway clearing to act as a sediment barrier.

Figure III C-12 shows a roadway culvert outlet in close proximity to a live stream. In this case, placing the outlet end of the culvert in a rock lined channel whose minimum depth is at least twice the culvert diameter as shown in Figure III C-15 may be appropriate. If the culvert exit velocity is 10 feet per second or greater, a rock dike as shown in Figure III C-14 to act as an energy dissipator may be necessary in order to insure sediment deposit before storm waters intersect the stream.

If suitable rock is not available for a channel lining, an alternate might be the use of clearing slash to construct gravel filled crib wall channel linings as shown in Figure III C-16. Gabions and sacked riprap can also be used but they are costly. The use of slash has the secondary advantage of providing a disposal method for some of the clearing debris.



PLAN

ROCK DIKE

FIG. III C-14

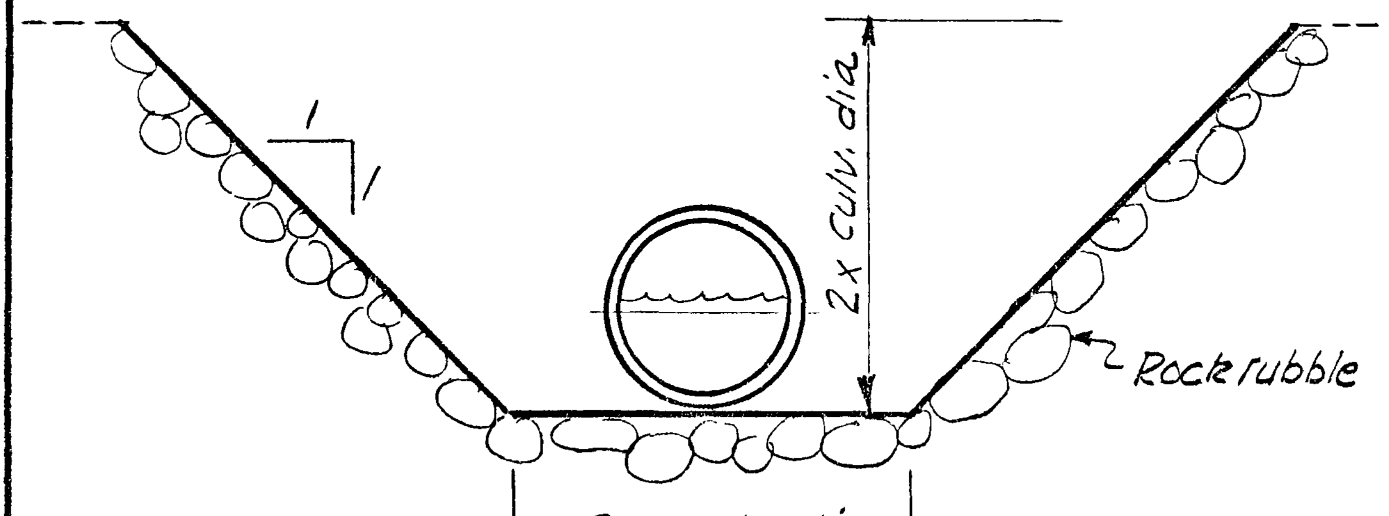
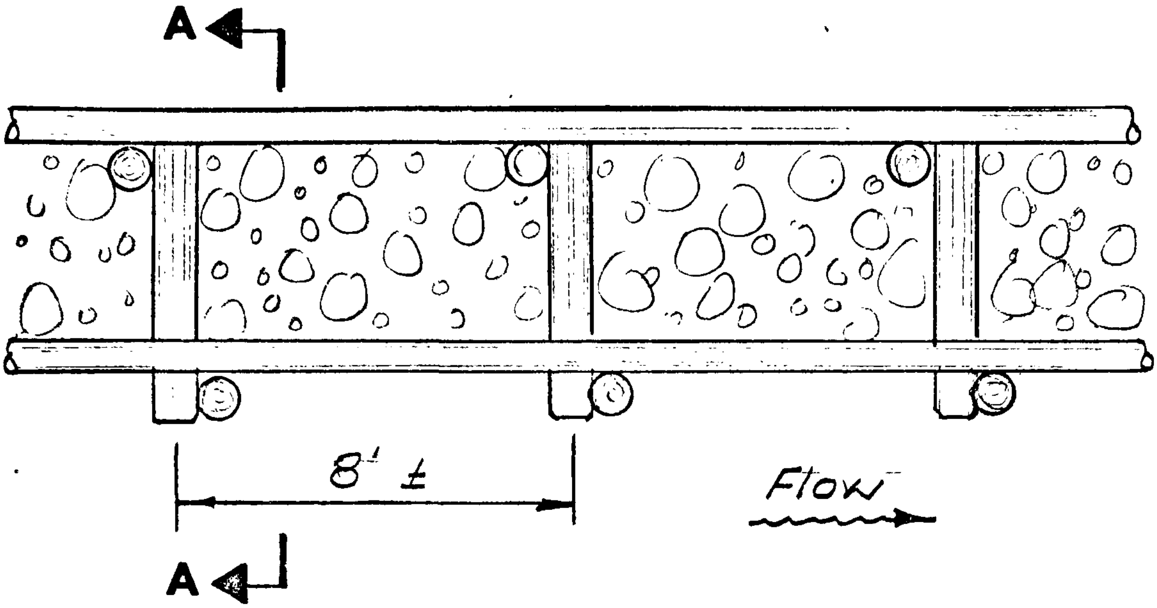
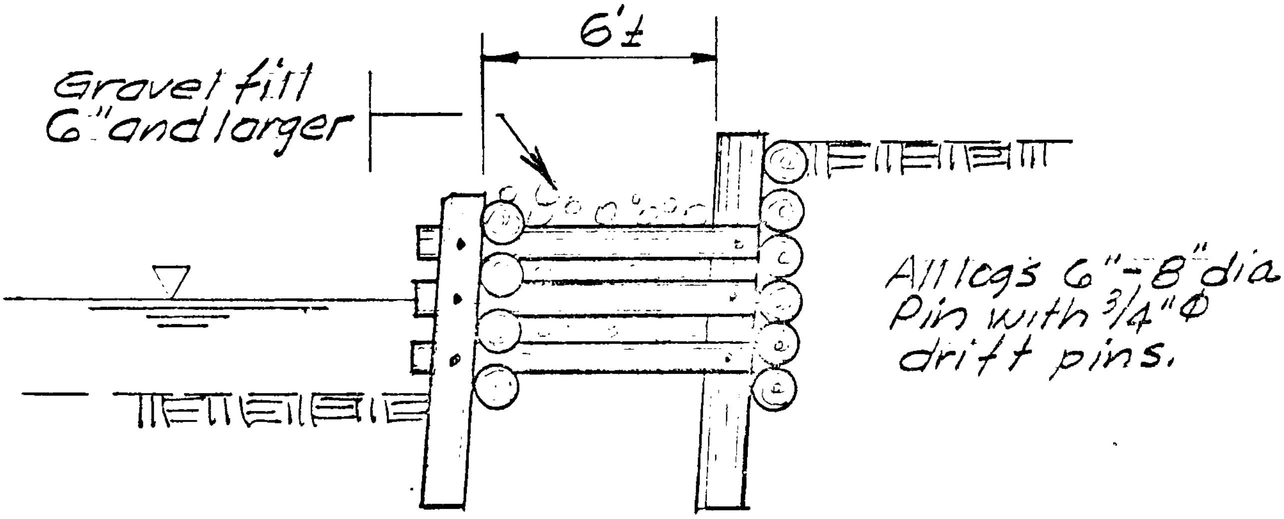


FIG. III C-15



PLAN



SECTION A A

GRAVEL FILLED CRIB WALL

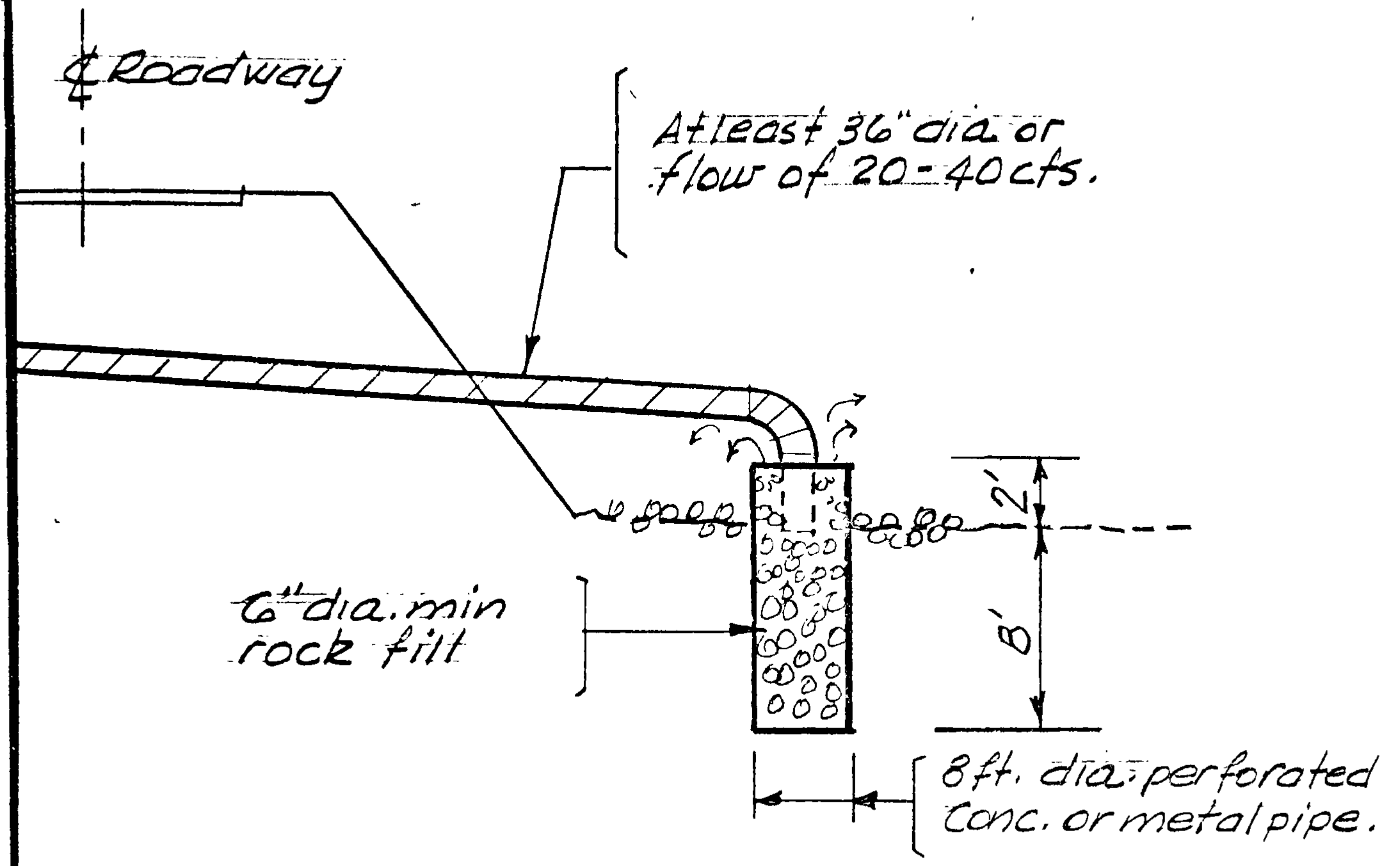
FIG. III C-16

An outlet treatment for a large culvert with high storm water flows is shown in Figure III C-17, an Energy Dissipating Silo.

Even with the upstream sediment control features of catch basins and rock lined ditches, there may be a period when excessive sediment transport can exist. This period will be during construction and for a time thereafter until new vegetation and soils stabilization measures become effective. Figure III C-18 shows a roadway culvert (or combination of culvert discharges e.g. collector ditch at toe of slope) discharging into a sediment pond (basin).

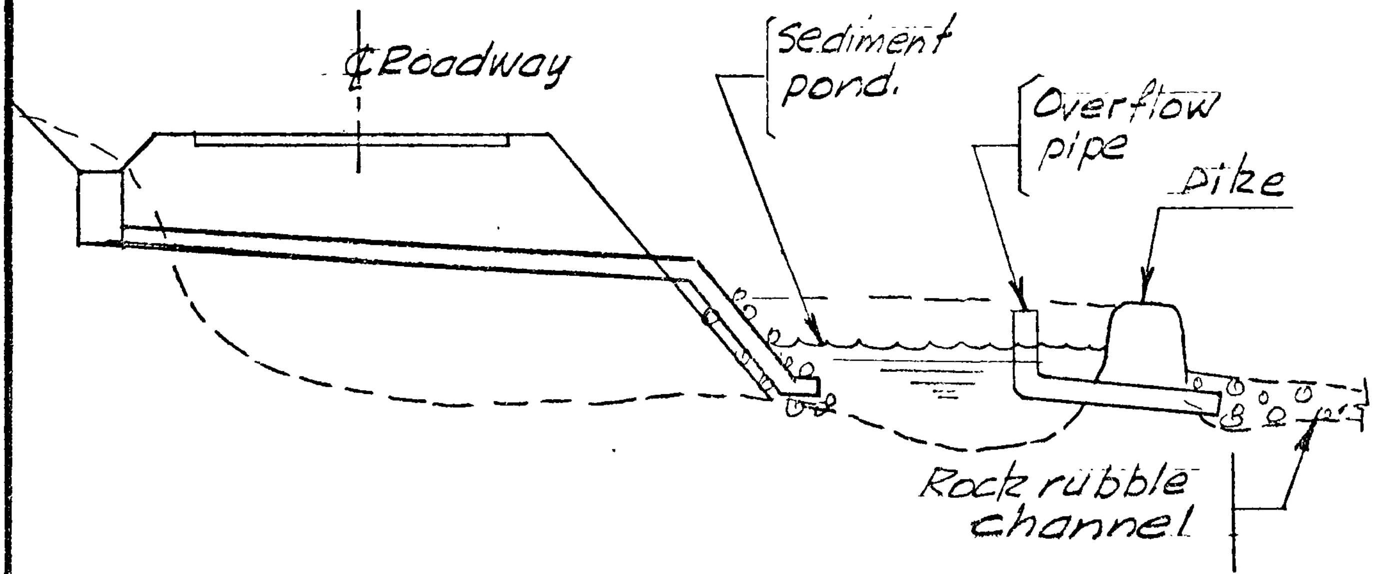
The velocity of flow through the sediment pond should be approximately one foot per second and preferably less in order for settling to take place. Settling velocities of sand and silt in still water are shown in Table III C-4.

The tabulation in this table suggests that the sediment pond should be large enough to retain the maximum flow input for at least one hour if the pond is designed for a two foot water depth in order to settle silt sized sediment. The designer will have to determine the actual pond size, dependent upon, topography, soils porosity etc. . . After a period of use, the fines will tend to seal the pond. After the road project is completed and upstream erosion control measures become effective, the performance of the pond may be of less importance.



ENERGY DISSAPATING SILO

FIG. III C- 17



CULVERT OUTLET TO SEDIMENT POND

FIG. III C-18

Table III C-4*

Diameter of Particle	Order of Size	Settling Velocity	Time required to settle one foot
mm.		mm./sec.	
10.0	Gravel	1,000	0.3 seconds
1.0		100	3.0 seconds
0.8		83	
0.6		63	
0.5	Coarse Sand	53	
0.4		42	
0.3		32	
0.2		21	
0.15		15	
0.10		8	38.0 seconds
0.08		6	
0.06		3.8	
0.05	Fine Sand	2.9	
0.04		2.1	
0.03		1.3	
0.02		0.62	
0.015		0.35	
0.010		0.154	33.0 minutes
0.008		0.098	
0.006		0.065	
0.005	Silt	0.0385	
0.004		0.0247	
0.003		0.0138	
0.002		0.0062	
0.0015		0.0035	
0.001	Bacteria	0.00154	55.0 hours
0.0001	Clay Particles	0.0000154	230.0 days
0.00001	Colloidal Particles	0.000000154	63.0 years

From the tabulation it would appear that the sediment pond should be large enough to hold the maximum flow input for at least one hour, if the pond was built with a two foot depth, to settle out all sediment, down to silt size. The designer will have to determine the actual pond size, dependent upon, topography, soil porosity etc.

*The Water Encyclopedia by David Keith Todd, 1970 (Page 86)
Water Information Center, Port Washington, N. Y.

5.00 Hydrology

Preceding parts of this section on drainage design have pointed out the importance of the determination of the design flow to the successful performance of a drainage system. The designer is interested in determining whether the activities of logging and road building in the forest, and the location of a forest, will have a significant effect on the flow volumes he should provide for, with respect to road drainage and stream crossings.

5.01 Logging and Roadbuilding

Rothacher reports that an increase in annual stream flow in the Pacific Northwest may be expected after clear cutting. He also points to an increase in early Fall seasonal flows after clear cutting because the soil moisture content is higher in a clear cut area as compared to the soil moisture content under old-growth forest. Thus less of the Fall precipitation is needed to recharge storage within the soil. Rothacher does not believe that clear cutting significantly changes peak flood flows in areas west of the Cascades. Flood flows normally occur after the soil is saturaged, "wet mantle" condition, and are directly related to the amount of precipitation. Rothacher points to some contrary evidence on small drainages containing roads as well as having been clear cut. (149)

R. Dennis Harr and others believe that it is unlikely that there will be culvert and bridge damage in Oregon Coast drainages as a result of clear cutting, provided designs are made on a 25 year storm frequency basis. They believe that the effect on roads in small drainages can be more serious as roads are permanent and will exist during large storms:

> "Success or failure of a certain size culvert or bridge might depend heavily on the amount of roads that eventually will be built in the watershed whose outlet stream is to be contained within a culvert or bridge." (150)

Rothacher and Glazebrook believe that the Pacific Northwest storms of December 1964 and January 1965 were very unusual. They predict that storms similar to these can be expected in the Cascade and Coast Ranges at least once in 50 to 100 years. They also observe that localized storms of these intensities can occur oftener: therefor "our plans and actions must give them adequate consideration." (151) The authors state that flood probabilities and forecasting have been evolved mainly for the requirements of downstream communities and that "much of the information currently in use has not been verified for mountainous areas."

These articles suggest that a conservative approach to the calculation of the design flow for a stream crossing be employed especially if precipitation data for the immediate area is not available. Other considerations involved in determining the appropriate opening size for bridge or culvert are discussed in the previous sections on Culverts (2.00) and Stream Crossings (3.00).

5.02 Subsurface water considerations

Another consideration is the potential for roadway cuts to intercept ground water flows thereby converting this flow to overland flow into ditches of a roadway drainage system. Attention was invited to this phenomena in Section B.3 of Chapter II with respect to field reconnaissance. Megahan's studies in the Pine Creek drainage, a tributary of the Middle Fork of the Payette River, Idaho showed that the quantity of water whose source was intercepted ground water flow was many times greater than the quantity whose source was overland flow.

> "Interception of subsurface flow is one of the more insidious effects of road construction because its occurrence often is not readily apparent. Subsurface flows occur only during large rains and/or snowmelt when large volumes of water are supplied to the soil. Such flows begin, reach a peak, and recede within a short period. Many times, the climatic event that generates subsurface flows also limits access, making it impossible to see flows as they occur. This is particularly true during snowmelt and rain-on-snow events in the mountains. As soon as subsurface flow ceases, most exposed roadcuts dry out completely and little evidence of flow remains. Another factor leading to the lack of recognition of subsurface flow is the fact that flow emergence is not limited to drainage bottoms, but may occur on straight or even convex side slopes as well." (152)

Megahan believes that total volume of watershed runoff increases when subsurface flow is converted to surface flows. Whether peak flow rates are increased is dependent on the simultaneous occurrence of the normal peak flows from the watershed with the flow from intercepted subsurface water. Certainly the local effect on ditches and culverts at or near subsurface discharge or outlet point could be significant.

Other effects are related to questions of stability of cut banks, potential road surface erosion and stability of fills. Megahan believes that much of the road erosion reported in the Idaho Batholith "is very likely a direct result of subsurface flow interception."

5.03 Forest Location

There is little question that total precipitation amounts increase with elevation, except in areas of pronounced rain shadow effects, but considerable controversy appears to exist as to the effects of elevation upon rainfall intensity. Dorroh's (153) evaluation of rainfall data from the southwestern United States indicated that, although both total precipitation and the frequency of thunderstorm occurrence tend to increase with elevation, the heaviest individual rains occur in the valleys. Croft and Marston (154), however, stated that higher rainfall intensities could be expected on the windward slopes of the Wasatch Mountains in Utah than in the adjacent valleys. In the very different climate of coastal British Columbia, precipitation at higher elevations is apparently characterized not so much by higher intensities as by longer duration at a given rate. (155)

Schermerhorn (156) studied the effects of various parameters, most notably elevation, upon annual rainfall amounts in western Oregon and Washington, where extremes of 20 inches to 150 inches of average annual precipitation occur. His work revealed very little relation between station elevation and annual rainfall, but that most of the variation in average annual precipitation for the 280 stations studied could be accounted for by relatively simple indexes linked to broad scale topographic and latitude factors. Three main index parameters were defined: index elevation, barrier elevation, and index latitude. The index elevation was based upon average highest elevations in the northeast quadrant within 10 miles of the station, while the barrier elevation was based on the average highest elevations in the southwest quadrant between an arc 4 miles from the station and the coast. The index latitude was defined as the actual latitude of a point on the 124° meridian due southwest of the station. Use of a graphical relationship involving these three main parameters to calculate annual precipitation for the 280 stations yielded an unadjusted standard error of estimate of 7.2 inches for an average precipitation of 63 inches. Schermerhorn did not make any attempt to use his method to develop elevation-rainfall intensity relationships.

Cooper (157) reported on an extensive study of elevation-precipitation relationships within a 93 square mile area in southwestern Idaho where continuous rainfall recorders had been installed at an average density of one per square mile and operated for four years. The area had an elevation range of 3,500 feet and climatic variations resulting mostly from elevation and topographic features rather than from regional air mass differences. The rainfall data indicated average annual precipitations increased about 4 inches for each 1,000 feet increase in elevation ranging from 8 inches in the lower part of the valley to 28 inches at the higher elevation. Numerous methods of data analyses to attempt to establish other rainfall-elevation relationships indicated that there was no relationship between elevation and peak rainfall intensity and elevation and several other intensity-related parameters. The only relationship that could be established was that the logarithm of the proportion of rainfall exceeding a given intensity plotted as a straight line against intensity. There was no difference in this relationship when the data were separated by elevation classes. Cooper noted that this relationship is rather universal and holds true for many other parts of the world as well.

Cooper concluded that the apparent lack of relationship between rainfall intensity and elevation suggests that data from accessible valley stations can be used to estimate the relative occurrence of high intensity rains throughout an area of appreciable range in elevation. At least under the conditions encountered in southwestern Idaho, about the same proportion of the seasonal rainfall exceeds a given intensity at high elevations as at low. Because there tends to be more total rain at high elevations, there is likewise more intense rain at mountain stations than in the valleys, but the relative proportions remain nearly constant.

D. CONSTRUCTION SPECIFICATIONS

An essential part of the design for any road project are the companion specifications. Preparation of these specifications must not be separated or removed from the supervision of the forest or civil engineer who is preparing the road design.

A serious mistake is made in those cases where separate personnel are authorized to prepare the specifications for design plans prepared by others. This inadequacy is frequently represented by notation on the plans such as "see specifications for detailed requirements", "see specifications for procedures", "see specifications for further requirements". Such notations frequently mean the designer has not made up his mind as to what the requirements or procedures should be. Definable accomplishment cannot be attained without positive and non-contradictable plans and specifications. The foregoing is a very brief analysis of the relation between plans and specifications and is placed herein to emphasize the need of the utmost correlation between the two companion documents.

1.00 Standard Specifications

Many design organizations have prepared volumes or multicopies of specifications particularly oriented to their endeavor. The volumes have such titles as Standard Specifications for Road and Bridge Construction and set forth general, legal, and specific engineering requirements under which the proposed construction is undertaken as a mutual agreement between the owner and the contractor. These standards are revised from time to time and vary between regions because of different regional circumstances. The U. S. Department of Agriculture has prepared such a volume entitled "Forest Service Standard Specifications for Construction of Roads and Bridges."

A further group of specifications published at regional, national and international levels is devoted primarily to materials and methods of testing materials. Prominent and valuable organizations in this group are The American Society of Testing Materials, The American Standards Association, The American Association of State Highway Officials. Frequently specifications from one or more of this group are included by reference, or quotation in the specifications published or adopted by the owner or agency.

2.00 Special Provisions

To define and describe the individual items of work, local circumstances, special construction items (those not included in the Standard Specifications), times of accomplishment, legal requirements, and payment conditions, a further document is written for each project entitled Special Provisions and is made a part of the contract documents. The Standard Specifications and the Special Provisions combine to form the Construction Specifications. Items specifically related to sediment control will usually be a part of the Special Provisions.

The Special Provisions should include a separate paragraph stipulating that the successful bidder shall prepare and submit within 30 days a detailed schedule of on site construction starts, material purchases and phase accomplishments. The schedule can be of assistance in evaluating whether the contractor recognizes construction elements and sequences relating to sediment control as envisioned by the designers. It can also point out potential problem circumstances during construction due to the forecasted timing of certain operations relative to seasons.

A common practice in special provision writing has been to lump together certain "nuisance" items among them requirements for water quality control within the work site. Elaborate descriptions are often written about the Contractor's obligations, all of which are to be enforced at the sole discretion of the Engineer and for which compensation is to be considered as "incidental to the other items of work involved in the project". Such procedures are of little practical help to a Resident Engineer. While owner's representative and Contractor feud over whether the particular issue is or is not one of the "incidental" items, the problem may magnify and its potential for damage to completed work and resources may increase.

The Special Provisions should provide that the Contractor will be compensated for all labor, materials, tools and equipment he is to furnish including items involved in temporary or permanent sediment control features. They should advise the Contractor as to the manner in which he will be asked to perform various tasks, whether the demand will be intermittent, and whether "extra" or "standby" crews or materials are involved. The importance of dealing with changed circumstances swiftly is discussed elsewhere in this report. The Special Provisions should support this goal by providing means for swift, equitable adjustments in contract compensation.

A possible technique is to establish compensation for certain emergency work on a force account basis with an estimated amount included in the contract documents. This approach has merit provided the estimated amount is a realistic assessment of the circumstances that may be encountered.

In the "Timber Purchaser Road Construction" report by USFS, Region 6, it was found that scheduling techniques are not being used by timber sale road builders and the Forest Service.

> "Historically timber sale road construction activities have been triggered by the timber market demand. This factor is a basic problem in the scheduling difficulty and affects the timing of construction starts and construction progress. There is a general lack of documented, or even oral disclosure of construction schedules. Some inspectors wasted valuable time by constantly visiting project sites just to find out when construction was starting.(158)

Obviously, the potential for sediment creation during construction is related to the season in which certain construction elements are being accomplished. Contract scheduling should provide for construction activities to be accomplished in their appropriate season. If the project is to extend over more than one season, the procedures and requirements for shutdown at the close of each season should be specified. The basis for determining when conditions warrant seasonal shutdown should also be included in the special provisions.

Larse summarizes the construction activity thus:

> "Although there are many commonly practiced techniques to minimize erosion during the construction process, the most meaningful is related more to how well the work is planned, scheduled and controlled by the road builder and those responsible for determining that the work satisfies design requirements and land management resource objectives". (159)

3.00 Conclusions

The foregoing discussion was written in terms of the owner-contractor relationship. The comments are believed applicable in intent to the circumstances of road construction by a timber purchaser or road construction by a land owner's own forces.

IV. CONSTRUCTION TECHNIQUES

Section II of this report stated that Route Planning and Reconnaissance are regarded by many as the most important phase of logging haul road development. In Section III the planning and reconnaissance data are translated by design into plans and specifications to meet all of the road objectives and to guide the construction phase. Larse observed as follows:

> "Construction of the designed facility is a challenge to the road builder to complete the work with a minimum of disturbance and without damage to or contamination of the adjacent landscape, water quality, and other resource values. Some of the most severe soil erosion can be traced to poor construction practices and job management, insufficient attention to drainage during construction and operations during adverse weather conditions". (159)

The Engineer in charge (Resident Engineer) or the inspector is the last link in the long chain of a total effort to produce a logging haul road in a manner that will minimize sediment. Field changes are to be expected. The Resident Engineer acting alone, or with the design engineer, must decide the corrective measures to be taken. Other than field changes the inspector must require adherence to the plans and specifications.

Man power may be a limiting factor to supply sufficient inspectors for the work load in a given region. However as the work load peaks, qualified individuals having other duties could be assigned to inspection activities.

The Resident Engineer and the inspectors must be relentless in their effort to implement fully the plans and specifications as envisioned and designed. The construction specifications should provide a means of payment for many of the processes that the contractor may need to accomplish and which are of benefit in arresting sedimentation including those attendant to changed conditions. These items arise from conditions unforseen by the design engineer such as seasonal variations and foundation and soils inconsistencies. The discussion that follows includes construction features which require individual analysis and the application of the appropriate construction technique in order that erosion or sediment transport may be minimized.

A. CLEARING AND GRUBBING

The Forest Service Standard Specifications for Construction of Roads and Bridges plus amendments clearly define clearing and grubbing activities and methods. Each Region supplements these specifications with methods peculiar to its area.

Clearing and grubbing then is the first activity in constructing a forest road that disturbs the forest floor and surrounding soïls. Flash storms under these conditions can produce instant erosion and sediment problems. This work is a necessary part of the road work and a precaution that should be taken to prevent a part of the potential sediment flow is to not disturb more ground than is absolutely necessary until a satisfactory drainage system is provided. The brush accruing from the clearing and grubbing operation might well be placed at the tow of embankments or below culverts to act as a filter and retardant to sediment flow.

Attempt to begin excavation prior to the completion of clearing have resulted in slash and organic material being mixed with earth. The mixed material acts as a contributor to the sedimentation problem rather than as a filter. It also may have too high an organic content to be used as fill material thus requiring wasting.

Merchantable timber from the clearing operation might be temporarily stacked at the toe of a fill until the fill is stabilized. Small logs may have use as walls for channel linings as was suggested in Part C-4 of Chapter III and shown on Figure III C-15.

Clearing and Grubbing should be scheduled to proceed just in advance of earthwork. Sections which are not going to be graded in the current season should not be cleared and grubbed.

B. EARTHWORK

During excavation and embankment activities the total roadway prism is vulnerable and is subject to erosion and sediment flow from rain storms of relatively slight intensity. Larse states:

> "When soil moisture conditions are excessive, earthwork operations should be promptly suspended and measures taken to weatherproof the partially completed work. . . clearing debris underlying, supporting or mixed with embankment material is a common cause of road failure and mass soil movement. The necessary slope bonding, shear resistance, and embankment density for maximum stability cannot be achieved unless organic debris is disposed of before embankment construction is started". (160)

Road builders on Washington's Olympic Peninsula have found that a shovel can be worked in much wetter weather than can a bulldozer. The shovel does not tend to disturb the subgrade in marginal weather to the degree that a bulldozer does. Shovels on mats are a common soft ground technique on the Olympic Peninsula and across Muskeg in Southeastern

Alaska.

Embankment compaction should be accomplished by one or more of the following types of equipment.

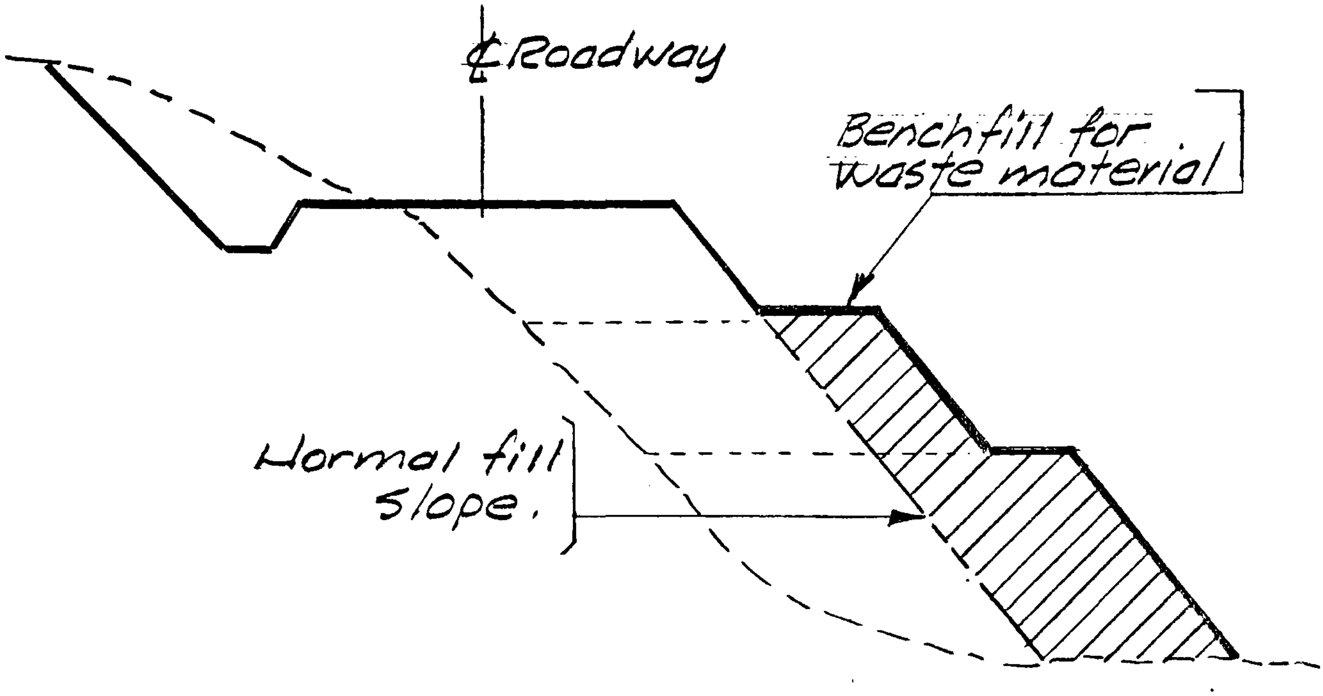
1. Tamping rollers
2. Smooth wheelpower rollers
3. Pneumatic-tired rollers
4. Grid roller
5. Vibratory rollers
6. Vibratory compactor
7. Bulldozer.

In the past, the bulldozer has frequently been the sole compactor used on forest roads. It has proven to be very ineffective when the dozer blade is so wide as to prevent the tracks from covering the entire roadbed width. The dozer may be used provided it can compact from out to out of the total roadway. A more satisfactory compaction job will be obtained by having the dozer do its primary job of moving earth and using equipment specifically designed for compaction to accomplish the compaction.

Embankments should be placed and compacted to the required density to avoid instability, control drainage flow and deter massive movement. Embankment placement in layers with attendant compaction is necessary. The literature on forest road failures contains many references to failures due to improperly constructed embankments.

Waste sites should be as carefully prepared as embankment portions of the roadway. Waste material could be used as a portion of the roadway embankment (as shown in Figure IV B-1) instead of being end hauled an excessive distance.

Borrow pits should be closed by dikes or dams to prevent sedimentary flows into adjacent streams. The dikes or dams should be removed when the borrow pit water ceases to carry sediment. Borrowing from running streams should be prohibited.



ALTERNATE WASTE SITE

FIG. IV B-1

The width and number of benches will be determined by the height of the fill and the quantity and quality of waste material involved.

Ballast may be placed only on shaped and drained subgrades in a manner that will not deform, rut or rupture the subgrade.

C. DRAINAGE

No other item is as important to the permanence and usefulness of the forest road and control of stream sedimentation as the drainage system.

> "In many places, careless and improper construction of a high mountain logging road can nullify all the effort expended in well considered design and location . . . . Poor construction and inadequate drainage have triggered land slumps in watershed after watershed and have resulted in the most serious form of accelerated erosion that occurs during timber harvesting . . . . Therefore during all phases of road construction, protect water quality by using every possible and applicable soil and water conservation measure." (161)

1.00 Drainage during Construction

Section III C-1.01, "Drainage Design", indicated that temporary ditches and other drainage facilities may be necessary during the construction phase. To achieve the goals of permanence of slopes and road beds and to minimize sedimentation, the following suggestions have been of consequantial advantage.

> "Protect all fill areas with surface drainage diversion systems. Place culverts so as to cause the minimum possible channel disturbance and keep fill materials away from culvert inlets and outlets . . . . Allow road machines to work in stream beds only for laying culverts or constructing bridge foundations. Divert stream flow from the construction site whenever possible in order to prevent or minimize turbidity. Clear drainage ways of all woody debris generated during road construction. Windrow the clearing debris . . . . outside the roadway prism (to use as a drainage filtering system)." (162)

The previous paragraph mentioned several antidotes to control construction drainage circumstances. Also the use of visqueen or plastic sheets, temporary flumes, installation of a second culvert (preferably by jacking), culvert extensions and settling basins are other techniques. Roadway surface dips should be installed as soon as possible so that they can be utilized to control storm water while construction continues. The most important technique, however, is that of observing, watching and promptly correcting an installation that does not accomplish its intended function.

During the initial construction period, the Resident Engineer must have all design data, rainfall and stream flow records easily available to him. If any drainage installation does not supply the desired results as to capacity, turbidity, or indicates instability in the early stages of construction, he must have the knowledge and authority to direct the changes that will give the desired results of stability, capacity and turbidity standards. Applying for a re-design study, awaiting authorization from higher echelons and/or additional funds, will serve only to magnify the adversity.

2.00 Drainage Construction

A prevalent concept of drainage construction must be abandoned and a new one evolved. The prevalent concept that the contractor is permitted to install various drainage features when he chooses based on available equipment, subcontractors, accomplishment of like items at one time, such as placing riprap or headwalls, must be pushed aside for the concept of doing in order the things that are needed to stabilize slopes and reduce to a minimum the transportation of sediment. Without doubt application of the new concept will cost more in initial expenditures for the drainage system than would accrue under the now prevalent procedure. An economical comparison between the two would not be realistic unless values can be assigned to the potential cost of reconstruction of water damaged road features and the cost of excessive sediment transport.

The grading of a roadbed should not be extended beyond the construction of the companion and attendant drainage features. No slides should occur on hillsides properly graded and drained, or on slopes guarded against erosion. It is recognized that sudden rains can fall during the construction season. If the ditches require rock linings, matting or other protective measures, the actual ditch grading and shaping should not be too far advanced ahead of the protective treatment. Always grade, shape and finish ditches from the downstream end to the upstream end.

Culverts should be installed as the road work progresses. The culvert and its related drainage features, as required, should be installed in the following order:

1. Place debris and slash to be used as a filter system.
2. Construct sediment ponds.
3. Energy dissipating devices.
4. Rubble rock or matte lined channels.
5. The culvert laid from the downstream end to the upstream end.
6. Ditch inlet structure with or without catch basin.

It is important to note from the above tabulation that <u>all</u> drainage work should start at the downstream end and progress to the upstream end. This installation procedure will enable surface and intercepted subsurface waters to flow in a finished channel downstream and away from the work area. The system must be kept operative at all times.

The reader is reminded of the discussion in Chapter III, Section C-2.02 relative to culvert installation, that the designer assumes reasonable care in culvert installation. Critical features are bedding, backfilling and pipe joints. Hartsog and Gonsior's China Glenn analysis indicates a lack of skill, supervision and appropriate equipment contributing to difficulties with culvert installations. (163)

All drainage construction activities should be closely supervised to insure that the various work items are meshing together at the scheduled time. Correct those items lagging behind schedule immediately.

D. CONSTRUCTION EQUIPMENT

The U. S. Forest Service Region 6 Road Audit states:

> "The use of improper and oversized equipment by timber purchasers was identified as a problem area . . . . Special equipment is needed to properly accomplish some construction tasks and to fully protect forest values during the construction operation . . . . almost all road construction was accomplished with a large crawler (D-8 or D-9) with dozer. In many cases this was the only equipment . . . . Much of the road construction equipment was developed for wide highway and freeway construction. . . . Evidence was found that timber sale road inspectors adjusted their enforcement of specifications to meet the capabilities of the contractors available equipment." (164)

Recommendations from this report include: (1) Constraints on the maximum size of equipment that can be used for a particular road project. (2) Direction and support of inspectors for enforcing specifications relating to equipment size etc. . . (3) Revise cost estimating guides to include costs of doing work with various sizes or kinds of equipment. (4) Make equipment manufacturers who are continually developing new machinery aware of management objectives, such as minimum environmental impact roads, minimizing soil erosion, sediment and aesthetic impacts.

The use of the shovel to accomplish roadway excavation on the Olympic Peninsula and in southeastern Alaska was discussed in Section B of this chapter. The shovel is also commonly used in other areas with steep terrain for the circumstance of excavating full bench sections on narrow roads with waste end hauled. This method results in a much higher unit earthwork cost than was previously experienced with a partial bench and/or sidecast operation with bulldozer excavation. It also results in less road miles being constructed in the short season available in many high altitude areas. Equipment specifically adapted or designed for the circumstance of full bench excavation with end haul on narrow roads is needed.

Hartsog and Gonsior believe that specialized equipment is needed for clearing on steep slopes. On China Glenn, tractors often worked themselves into places low on the slope where they had to be winched upslope by another machine. They believe tractors with a low center of gravity and equipped with a brush blade are the best of the present equipment. The purpose of specialized equipment would be to eliminate or reduce the pioneer road required for present equipment because of the potential contamination attendant to a procedure of excavating before clearing is completed. (165)

The necessity for appropriate equipment to install drainage facilities has been previously mentioned.

V. MAINTENANCE

Concerning maintenance, Robert W. Larse has stated:

> "Planned regular maintenance is necessary to preserve the road in its (as built) condition, but unfortunately is too often neglected or improperly performed resulting in deterioration from the erosive forces of the climatic elements as well as use . . . It is neither practical or economical to build and use a road that requires no maintenance . . . The additional expense of constructing a road, with proper attention to its stability and proper drainage can generally be amortized within a few years by an offsetting lesser cost of upkeep where soil erosion and sedimentation are of concern . . . . ." (166)

To facilitate and expedite maintenance operations and procedures, a complete set of "as built" plans with a record of all maintenance operations and observations should be maintained and be quickly available to the maintenance engineer. This record system will help to equip and supply new personnel with all the previous experience and observations of their predecessors.

The "as built" records should contain the following information:

1. Complete job index.
2. Complete history of the project from start to finish of construction.
3. Photographic records.
4. Exact location of culverts and other drainage features.
5. Unstable conditions in relation to cut and fill slopes and roadway surface.
6. Wet areas that may have caused over excavation and replacement with selected backfill.
7. All major field changes that were made in the original plans.

8. Catalogue and parts listing of all equipment, such as pumps, valves, gauges, etc.

The greatest asset available for any maintenance program is the experience history and knowledge gained by those who have in fact accomplished the maintenance operation. Usually this knowledge is not recorded, but every effort should be made by management to keep competent experienced knowledgeable maintenance personnel at their tasks and/or available for consultation and advice.

The maintenance discussion that follows is divided into three parts: (1) drainage system, (2) road surface, and (3) slide dilemmas.

A. DRAINAGE SYSTEM

Drainage maintenance is not a spectacular task. The greatest and best accomplishments occur in wet ditches, plugged culverts, or slides that impair roadways. For forest roads, particularly in mountainous areas, maintenance cannot be programmed on the yearly calendar but must be accomplished when the individual site or circumstances dictate. Little can be accomplished in snow or in frozen ground with the possible exception of jacking in culverts or solid rock excavation. Snow melts do not usually cause the maximum flows or carry fragmented rock, boulders or fallen timber. The time to accomplish the major drainage maintenance is usually concurrent with the major forest operations of cutting, hauling, planting or thinning.

In spite of this peaking of labor demand, the maintenance program should never be postponed. Rules or procedures for drainage maintenance can be set up only as guide lines as there is a wide variance between localities, construction accomplishments, workable seasons and climatic factors. The following are offered as guide lines only, as each area must modify or amend their procedures to suit their circumstances.

1.00 Culverts and Ditches

Ditches, culverts and catch basins must be kept free of debris and obstructions. On new construction, catch basins may require frequent cleaning, perhaps after each major storm. Grass in ditches should not be removed during cleaning operations. Shoulder and bank undercutting must be avoided. Damaged culverts should be repaired or replaced.

Culverts and inlet structures should be cleaned by flushing downstream only when adequate filtering to protect watercourses are available. Debris from cleaning operations should be hauled to a stable waste site far removed from any watercourse.

> "Regular inspections during or after storms will ensure good drainage because problems are detected before they become serious. Inspections for detection of weaknesses in drainage systems are especially important on new roads. As a general rule, roads should be examined annually in the Spring after the first rains or at the start of snow melt". (167)

Ditches and culverts are particularly vulnerable to debris blockage when a logging operation is occurring on or adjacent to the road. Blockage with limbs, needles and wood chunks can occur rapidly. Maintenance personnel should be alert to the ongoing logging operations and aware of their potential significance to the maintenance program.

Live streams with culverts should be completely free of transportable debris, for at least 100 feet upstream. If the initial construction did not call for debris deflectors or trash racks and subsequent experience shows they are required, install them as part of the maintenance program. The downstream end should also remain free flowing. Debris should be removed from streams or channels by grapples or tongs rather than by equipment in the stream bed.

2.00 Cut and Embankment Slopes

Cut and embankment slopes are so individualistic that only the most elementary precautions are set forth below. Each slope must receive a separate study.

Erosion clefts in cuts may be filled with rock or coarse gravel to create a trickling water movement through the rock fill material. Turf should be replaced in bare earth areas.

Erosion clefts in embankments should be filled, turfed and the water from the roadway directed to a culvert or flume. In the event of indicated large movement, the slope may be dewatered by horizontal drains, wells, or well points until the area becomes stable. Only pervious materials, preferably rock, should be placed as embankment on water giving slopes.

Berms at the top of embankments intended to prohibit water from flowing onto the slope should be monitored for breaks or ruptures and repaired as required.

B. ROAD SURFACE

Road surfaces must be kept well crowned or sloped so they will drain. Surface blading should preferably be accomplished when the moisture content of the material results in neither dust nor mud from the blading operation. Particular attention should be accorded the road crown or slope just in advance of the wet season.

Roads subject to traffic during the wet season will require continual monitoring for surface condition including ability to drain, presence of rutting and loss of ballast. Provisions should be made for ballast replacement where necessary as a condition to continuing operations on the road. Roads sufficiently ballasted for dry weather operations may not be satisfactory for all seasons.

Surface cross drains should be cleaned as required after the logging season to restore their functional ability. If the cross drains do not exist in a road intended for seasonal closure, they should be cut in in advance of the rain and/or snow season.

The snow removal operation can damage the road surface by removing ballast and/or destroying the roadway crown. Factors that contribute to the potential for damage are improper snow removal equipment, improper equipment operation and initiating snow removal at the improper time.

Road condition has to be monitored relative to the freeze thaw cycle. The potential for surface disruption is greater when frozen subgrade or surfacing begins to thaw.

The foregoing express important provisions or guide lines for road maintenance. The most important guide line consists of management educating the maintenance personnel to the importance of minimizing sediment transport to ditches. No one can control the amount or time of rainfall or the amount and rate of snowmelt. Therefore the only control of sediment transport attendant to maintenance operations is by individuals.

There will be circumstances both planned and unplanned wherein sediment from roadway surfaces is transported to side ditches. When such circumstances occur, maintenance forces must examine and properly condition the next line of defense, be it catch basin, culvert, settling pond or whatever to force separation of water and sediment with companion disposition of the collected sediment. All procedures are pointless unless this overall concept is kept in mind and the needed action taken at the needed time. Here again, the local man, intimately familiar with the circumstances, is the one who can make the decision as to what and when to embark upon an undertaking.

C. SLIDE DILEMNA

1.00 Introduction

One of the most difficult, time consuming and often reoccurring maintenance problems along logging roads is the removal, recovery, disposal and correction procedures for slides occurring both up and down slope from the logging road. The slides may involve only minor maintenance on a yearly basis along the road or may involve rebuilding or relocation of the road. Through the proper engineering design of the road the slides can be prevented or at least limited. However, there are areas where active slide areas cannot be avoided and maintenance must be expected. In addition there are areas which were stable at the time of construction and shortly thereafter but due to some natural occurrence have since become unstable. These type of areas require extensive evaluation both as to remedial design if possible or relocation if necessary after an evaluation of continual maintenance.

The slide dilemna raises many problems in conjunction with maintenance and increased erosion potential along the road alignment. Several of these problems are discussed in the following paragraphs.

2.00 Recovering Slide Debris

Slide debris which is deposited on roadways may cause significant increased sediment loads in established roadway drainage systems and may in some cases cause erosion channels to develop outside of established drainages. The removal of this material on the road may be accomplished by heavy construction equipment. However, sidecasting of the material should not be allowed. Slide debris which is located down slope from the logging road poses a different and more difficult problem of removal. The equipment necessary for removal of this material may be restricted to working from existing roadway only. Another problem involved in removing the material is the possibility of damaging surface vegetation and other erosion control devices on the down slope side of the road while trying to remove this debris. Therefore, an evaluation of the potential for erosion from the slide debris versus the potential for erosion caused by the removal of the slide debris should be made and carefully examined before a plan of action is carried out. Specific rules or guidelines for this removal should not be set and each case should be evaluated on an individual basis dependent upon the conditions encountered at each site.

3.00 Wasting Slide Debris

Once the slide debris is removed from its place of deposition the problem arises as what to do with the material. Slide debris is often composed of a mixture of soil, rock and organic debris, and is usually very wet. Material in this condition normally cannot be placed and compacted as fill within a roadway embankment. However, the material may be placed in end-haul disposal areas. Proper placement and compaction of this material must be achieved so that erosion may be limited. Again it should be emphasized that slide debris material should not be sidecast from the roadway or placed in a noncompacted fill which is susceptible to erosion.

4.00 Relocation Versus Correction

Proper evaluation of the erosion potential and economics of relocation versus correction is essential and many factors should be considered before a decision is made. Among these factors are, why did the slide occur, how extensive is the slide, and will the slide occur again. These questions will be discussed in more detail in the following section. Other factors which should be considered before a decision is made involve determining the amount of erosion potential from construction of the newly relocated alignment which may involve construction of a considerable length of new road. This new road may have a higher total erosion potential than the erosion from the slide debris. Correction of the slide area may involve installation of retaining structures, reshaping slopes and/or replacing fill in the roadway alignment. These corrections are oftentimes more desirable than constructing new roads which during their initial stages after construction have a higher erosion potential than the existing roadway alignment. However, there will be times when correction of the roadway alignment is impossible and the slide will reoccur. It is at these locations that the detailed evaluation of both the new alignment and the existing alignment with reoccurring slides must be done.

5.00 Failure Mechanism Investigation

Before corrections can be made within a slide area the extent of the slide, the reason for the slide and the potential for reoccurrence must be determined.

The first step in defining the failure mechanism should be a detailed inspection by an experienced engineering geologist. From this inspection an approximate failure plan can be developed and possible causes evaluated. In many cases this inspection is all that is required for a proper evaluation of the failure. In more extensive and complex slide areas, this initial inspection should be supplemented with a detailed subsurface investigation which would include drilling deep holes from which undisturbed samples may be obtained for strength testing and the installation of piezometers within and above the slide area. In some cases the installation of inclinometers may be justified to determine if movement is continuing and to what extent and range it may be occurring. The amount and extent of this investigation is dependent upon the conditions of that particular site. In any event this work should be accomplished under the auspices of a specialist in either soil or rock mechanics.

VI WATER QUALITY MONITORING

Effective monitoring of water quality can provide a means to assess the effectiveness of various erosion control measures and can also provide a stimulus to designers and contractors for more conscientious efforts to prevent water quality degradation.

Portions of the following discussion of water quality monitoring are based on the publication "Design of Water Quality Monitoring Programs" as prepared by the U.S. Forest Service--Pacific Northwest Region (168).

A. SOURCES OF WATER QUALITY IMPAIRMENT

Several water quality degrading effects originate from the construction and subsequent operation and maintenance of logging roads. Both high short-term impacts during and immediately following construction and generally decreasing long-term impacts during the life of the roads occur. The major pollutants are eroded mineral sediments; organic matter from the forest floor and in the soil originating from plant and animal sources; tree debris (another source of organic matter) in the form of leaves, twigs, and slash; pesticides if used in the maintenance program; and nutrient elements (principally nitrogen and phosphorus) either naturally occurring in soils and in plant and animal matter or from fertilizers. Thermal pollution can also occur as a result of removal of shade cover and consequent exposure of streamflow to solar heating. Of these pollutants, sediment including both organic and inorganic constituents transported to surface waters by overland runoff or by landslides near streams is by far the most serious single cause of water quality degradation (169). Additionally, sediment acts as a carrier of such pollutants as pesticides and nutrients.

B. PARAMETERS TO BE MONITORED

Monitoring should normally be limited to those parameters most likely to be significantly affected by road construction activities. These parameters include water temperature, turbidity, dissolved oxygen, and in some instances specific conductance and stream discharge. With the proper equipment, all of these parameters can easily be monitored in the field. Each of these key parameters is discussed below:

1.00 Water Temperature

The purpose of water temperature monitoring is to determine the effect of shade removal or ponding effects on increasing water temperature. If shade is not removed as a result of stream crossings or other construction in the immediate vicinity of streams or any ponding effects introduced, the monitoring of water temperature loses its primary importance but nevertheless should be recorded because of its relationship to other tests as discussed subsequently.

2.00 Turbidity

Turbidity is a measure of an optical property of water normally expressed in Jackson Turbidity or Candle Units (JTU or JCU). Turbidity is related to the suspended sediment content of the water although the correlation can be quite variable from stream to stream and even for the same stream at different locations and times of the year. The purpose of measuring turbidity is to determine what effects soil disturbance, either leading to soil erosion by surface runoff, landslides, or construction work in the streambed, have on the sediment content of streamflow.

3.00 Dissolved Oxygen

The primary purpose of monitoring dissolved oxygen (D.O.) is to determine the effect of addition of woody debris to streamflow. Physically, the concentration of D.O. at any time is a function of water temperature, which places a reducing upper limit on the saturation concentration as temperatures increase, and channel characteristics such as slope, roughness, and cross-sectional area which control the rate of oxygen exchange between air and water. Biologically, the concentrations of D.O. is affected by aquatic animal microorganisms which utilize the organic material in the stream as an energy source while extracting oxygen from the water in the process; and aquatic plant microorganisms which supply oxygen to the water during daylight hours as a product of photosynthesis. Reductions in D.O. can be caused by increases in stream temperature due to canopy removal or ponding; reductions in turbulence generally as a result of ponding above road structures, landslides, or debris dams; and introduction of organic matter to the water resulting in oxygen uptake during biochemical degradation. Increases in water temperature have a twofold effect: the

the D.O. saturation level is reduced and biochemical degradation activity is stimulated. The most critical period for D.O. levels is generally late summer when temperatures are highest and streamflow lowest.

4.00 Specific Conductance

Specific conductance is a measure of the water's capacity to convey an electric current and is related to the total concentration of ionized mineral substances in the water. These ionized substances may enter the stream from leaching of newly exposed soils by overland runoff. While the individual mineral ions are not identified by specific conductance measurements, gross changes in the overall chemical make-up can be detected. If significant changes are detected, the samples can be subjected to analysis for individual parameters to determine what parameters are causing the increase. Significant increases in specific conductance as a result of logging road construction are not expected in most situations.

5.00 Streamflow

Logging roads planned and constructed with reasonable caution would not be expected to significantly affect streamflow. However, in some instances, stream discharge measurements should be made for the purpose of assisting in interpretation of the data collected for other parameters. Precise measurements are often not required. Sometimes a reasonable estimate of discharge can be made from culverts or other such structures. Major changes in discharge between the upstream and downstream ends of the monitored area may be an indicator of extraneous influences possibly affecting the validity of the monitoring results or may indicate environmental damage such as debris dams or landslides resulting from the road construction activity.

C. SAMPLING LOCATION

Normally sampling stations should be located upstream and downstream from the area under study. This direct comparison generally provides useful data within a short time frame and with a minimum of effort. When using this method, selection of sampling stations where there are intervening influences unrelated to the activity in question (i.e., tributary streams, natural or man-induced sources of water quality degradation, etc.) should be avoided if possible.

In some cases it may be necessary to gain background water quality data before commencement of logging road construction. Under these conditions, a relatively long prior monitoring period over a period of at least one year may be required to attain adequate statistical reliability of the sampling data.

D. SAMPLING FREQUENCY AND DURATION

Sampling frequency and duration are dependent upon many factors. Among these are the needs of the particular situation, availability of manpower, accessibility, and whether hand-operated or automatic recording and sampling equipment is available. Advances in the development of small, portable automatic equipment in recent years show particular promise for use in relatively remote areas where most new logging roads are likely to be constructed. Although automatic equipment is considerably more expensive than conventional manually-operated equipment, use of such equipment would be particularly desirable for the sampling of some parameters, particularly turbidity, in sensitive areas. Adverse effects on water quality would be much more likely to be detected than if samples are collected only periodically by hand. If hand samples are collected, sampling frequency must be carefully established so as to be representative of all ranges of water quality that might be experienced. This means scheduling of sample collection with climatic and streamflow conditions as well as the intensity of construction activities.

1.00 Turbidity

Automatic sampling or recording equipment would be particularly useful in the monitoring of turbidity because major increases in turbidity are most likely to occur during relatively high intensity, short duration storms when accessibility and timing practically preclude collection of hand samples. If turbidity is monitored by hand sampling, samples should be collected no more than two weeks apart during construction activities and at a decreasing rate after termination of construction activities. It is particularly important that turbidity measurements be made during work within or in close proximity to the streambed and during or shortly following periods of moderate or greater intensity rainfall when the brunt of soil erosion is expected to occur. The timing of turbidity sampling is of utmost importance if serious impairments of water quality are to be detected. Turbidity measurements should generally be continued for a year or more following construction unless very little potential exists for road-related sediments to reach streams.

2.00 Water Temperature

Water temperature should be sampled primarily during the critical summer months. Intervals between observations should generally not exceed 2 weeks. Maximum-minimum thermometers, which are relatively inexpensive, can be left in the stream during the intervals between observations to record the upper temperature extremes.

3.00 Dissolved Oxygen

Dissolved Oxygen (D.O.) should be sampled primarily during the summer months, generally at the same frequency and time water temperature measurements are made. D.O. measurements are particularly important when air temperatures are highest and streamflow lowest or following suspected entry of organic matter into the stream. Finely-divided organic debris, particularly needles and leaves which have simple sugars, rapidly exert a high oxygen demand upon entry into the stream system (170).

4.00 Specific Conductance

Specific conductance measurements should be made in connection with turbidity sampling. Significant changes in specific conductance are most likely following entry of overland runoff into the stream system. Normally increases in specific conductance as a result of logging road construction are expected to be relatively minor.

5.00 Stream Discharge

Streamflow measurements can be made when other parameters are monitored. The timing of streamflow measurements depends upon the particular need for the data.

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