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LOGGING ROADS AND PROTECTION OF WATER QUALITY

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REGION X
WATER DIVISION
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The Environmental Protection Agency, Region X, has reviewed this report and approved it for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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INTRODUCTION

PURPOSE

The Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500, set a national goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and which provides for recreation in and on the waters. This goal must be achieved by 1983. The Act mandates that pollution caused by runoff from forest lands, as well as other nonpoint sources (mining, construction, agriculture, etc.), be controlled in addition to the control of point sources in order to achieve the national goal of water quality.

This report is a state-of-the-art reference on the protection of water quality in planning, designing, constructing, reconstructing, using, and maintaining logging roads based on data collected in Region X. It is intended to be an aid for dealing with nonpoint source pollution control; and is designed to inform and assist state, federal and local agencies; industry; and the general public. The report is specifically intended to assist in the (1) identification of potential hazards to water quality, and (2) selection of procedures, practices, or methods suitable for preventing, minimizing, or correcting water pollution problems. It also is a reference source to other publications, information and materials; and it provides some regional data and perspective. Figure 1 shows the geographical boundaries of Region X.

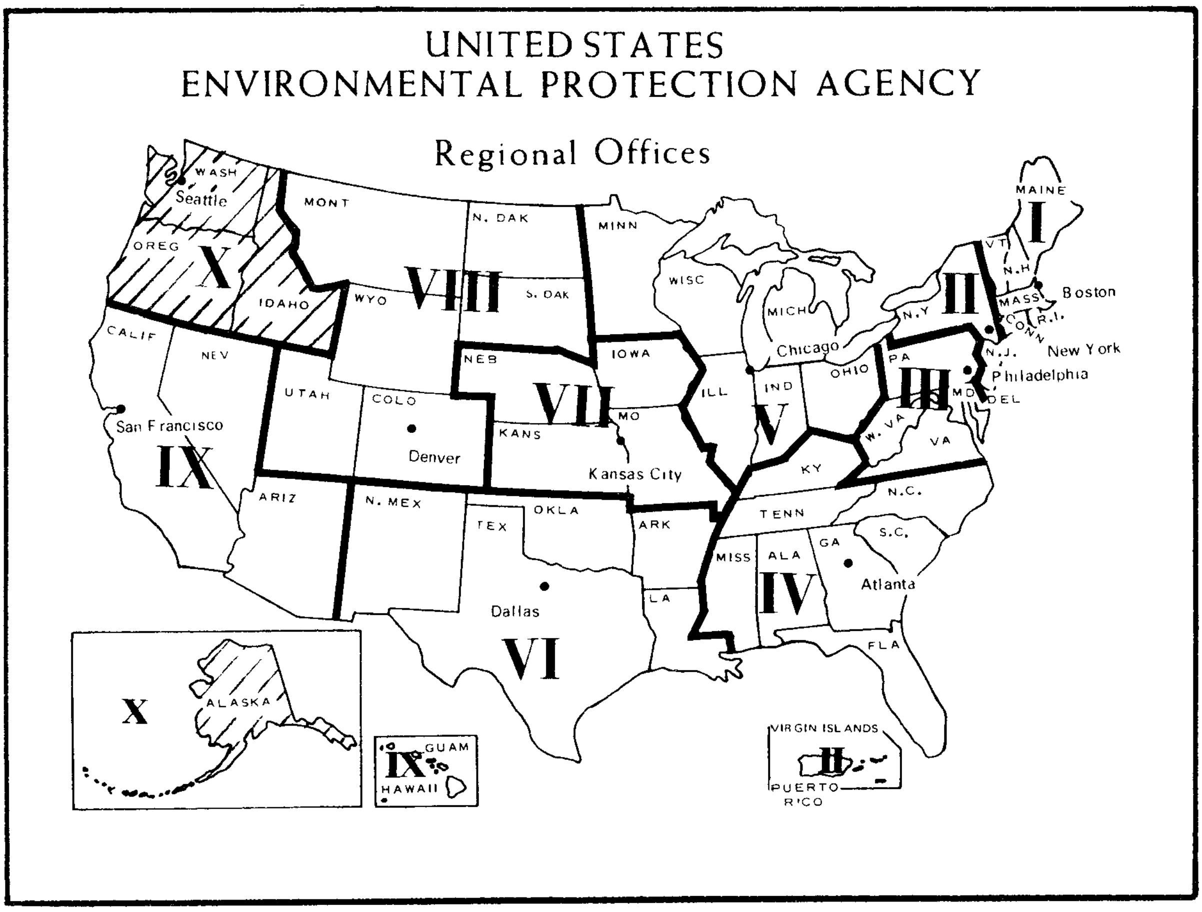


FIGURE 1 REGION X

The Environmental Protection Agency has already prepared a report entitled "Processes, Procedures and Methods to Control Pollution from Silvicultural Activities", which was published in October, 1973. That report covers all forest practices and is, therefore, general in nature. In contrast, this report deals specifically with one important aspect of forest practices.

"Silvicultural activities" comprises a major portion of those forest land activities in Region X that can impact water quality. "Silvicultural activities" is used in a broad context; and covers the actions and results of all forest harvest, production, management and protection systems. Some of the categories of activities included are: logging roads, harvesting methods, silviculture systems, residue management, reforestation, and use of chemicals.

Of all the types of silvicultural activities, improperly constructed and inadequately maintained "logging roads" are conceded to be the principal man-caused source of sediment. Although different logging systems have different road access requirements, all involve to some degree the construction or reconstruction and use of logging roads.

SCOPE

"Logging Road", as used in this document, refers to truck roads which are built or used mostly for log hauling or logging operations. These roads are often subsequently used for the protection and management of successive timber crops and for other forest access purposes.

The text deals with a range of logging road design standards--varying from low-speed narrow, unsurfaced roads to moderately high speed, rocked or paved roads. Paved, two-lane (or more) roads that have design characteristics similar to or higher than secondary state highway standards are beyond the scope of this document.

Although logging haul roads (within the standards range described above) are the primary focus, most of the principles and techniques described have a wider application and can be extended to include all other forest access roads which are similar in standard but are constructed for different specific purposes--e.g., for mining, grazing, recreation and fire protection--or for multi-purposes.

It should be recognized that roads are not an independent entity and must be considered in an overall context. For example, in relation to the total physical systems operating in a watershed, such factors as the total area of land surface exposed by roads at a given time, effects of runoff from roads on channel stability and the degree to which a transportation system can be effectively maintained may be important.

Another important interrelationship is that of the road to total planning of a silvicultural activity. For instance, from a water quality consideration viewpoint, impacts of a total harvesting system must be examined--including logging methods and logging roads. For example, a skyline cable system might result in a low total impact, including fewer roads. However, individual roads might require special design standards to accomodate the overall low impact system.

The foregoing discussion is for illustration only. Detailed examination of total systems' interrelationships is beyond the scope of this report.

Region X, excluding interior Alaska 1/, served as the specific study area for the compilation of this report. While state-of-the-art information was compiled primarily from within Region X, relevant data from outside the Region was also evaluated and used as appropriate. Information from scientists and practitioners outside the Region indicates that most of the principles and many of the techniques in this report will have application to a much wider area that just Region X. As can be noted throughout the report, an important key for incorporating water quality management needs into logging road activities is the intelligent tailoring of available technology to site specific application. This applies irrespective of geographical location.

1/ Two other reports should be useful for dealing with interior Alaska conditions:

Lotspeich, F. B. 1971. Environmental Guidelines for Road Construction in Alaska. Alaska Water Laboratory, U.S. Environmental Protection Agency, College, Alaska.

Lotspeich, F. B. and Helmers, A. E. 1974. Environmental Guidelines for Development Roads in the Subarctic. National Environmental Research Center, U.S. Environmental Protection Agency, Corvallis, Oregon.

PART I

Overview And Setting Of Region X

FOREST LANDS OF REGION X

The information in this section describes some of the physical features of Region X. It is intended to facilitate Region-wide understanding and perspective of potential water quality degradation. Specific principles and application are discussed in Part II and in cited references.

Although significant features are discussed separately, most of them are not independent. They should be viewed together, and in the context of the relationship of logging roads to the water handling and resistance to soil movement--either surface erosion or mass movement--characteristics of a watershed.

It should be noted that soil movement--including mass failure--occurs naturally. The emphasis in this section, however, is "man-caused"--i.e., road related--events.

PHYSIOGRAPHY AND SOILS

TERRAIN

"Terrain", as used in this report, refers to external characteristics (features) of the land such as slope, shape, drainage density, smoothness (or unevenness), slumps and slides. The Encyclopedia of Geomorphology (10) describes geology-terrain relationships and descriptive classifications.

This section is intended only to illustrate the importance of terrain factors in anticipating and estimating potential impacts of logging roads.

Discussion of specific elements, evaluation criteria and procedures for dealing with these factors are discussed in more detail in Part II.

Several terrain features have been specified or implied to be important in planning and constructing stable roadways. Brown (1) cites aspect, elevation and steepness of slope. Way (2) uses topography, drainage--including texture (number of streamcourses) and pattern--and vegetation for terrain analysis. Kojan, et al (3) use slope gradient, sub-surface structure and evidence of landslides. Other authors have cited similar factors.

Several terrain features consistently emerge as important indicators which can aid in estimating the probable impact of logging roads on the terrain and resultant impact on water quality. These are:

(a) drainage density (degree to which streamcourses dissect the land);

(b) slope (gradient, length, shape, position on the slope);

(c) geologic factors such as substrata fracture planes (not always visible externally, but may be observable in landslides); and

(d) "hummocky" slopes.

Generally, the more drainage that dissects the landscape, the more acute the necessity to plan for avoiding water quality impacts in constructing and stabilizing roads. Figure 2 illustrates relatively undissected ("smooth") slopes, and Figure 3 highly dissected slopes.

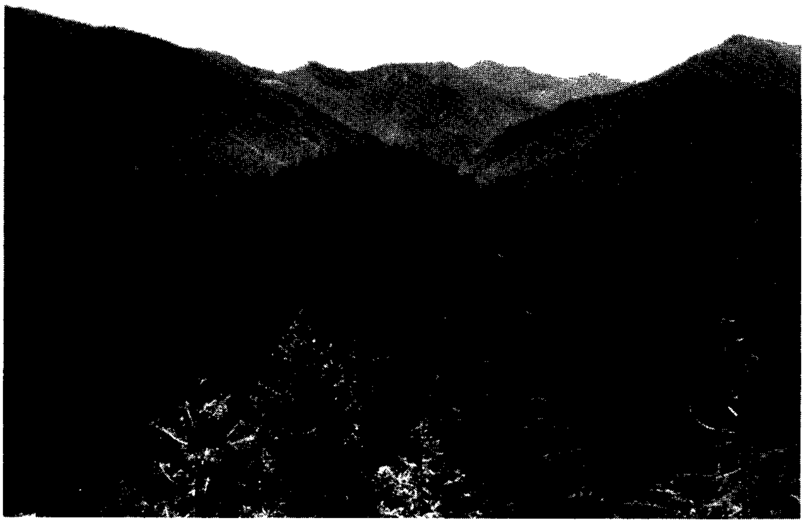


FIGURE 2 RELATIVELY UNDISSECTED SLOPES - ESPECIALLY IN FOREGROUND

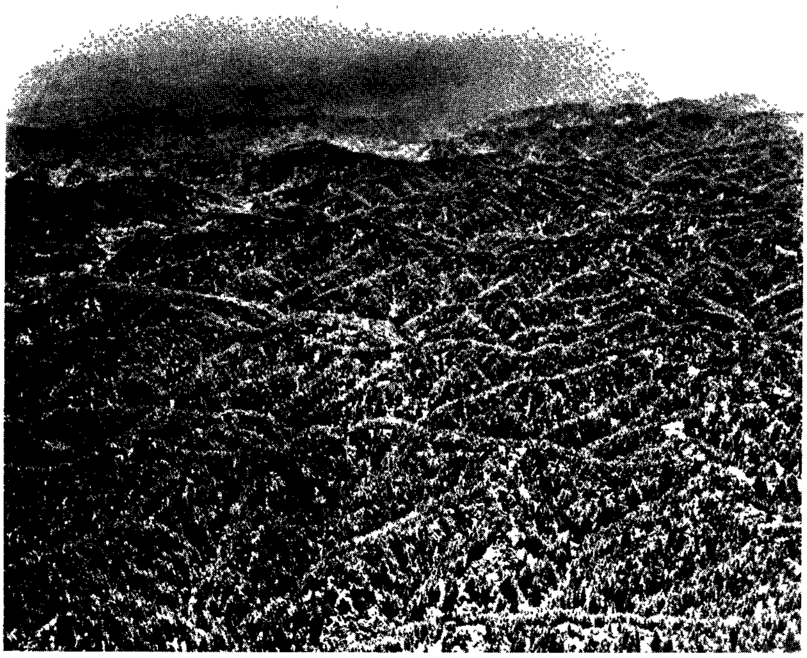


FIGURE 3 HIGHLY DISSECTED SLOPES

Steepness and length are among the more obvious slope indicators. Swanston and Dyrness (4), Swanston (44), Burroughs et al (5) and others describe relationships of slope gradient to potential soil displacement. Usually, the steeper and more sustained the slope, the greater the risk and more frequent the occurrence. There is no precise universal rule that links a given slope steepness to a specific set of problems because other factors must be considered. For example, where the terrain is relatively undissected and relatively stable, road-triggered soil movement problems may become acute when sustained slopes are 60 to 65 percent (or steeper). However, where the terrain is highly dissected and relatively stable, impacts may become severe on slopes 40 to 45 percent (or steeper). If soils or geologic substrata are unstable, major impact problems may occur on slopes of 30 percent or less. Kojan et al (3) reported that few debris slides occurred on slope gradients less than 50 percent. However, they also reported an increasing incidence of translational-rotational earth slides (deep slides associated with substrata failure) on slopes steeper than 30 percent in certain rock material types.

Of all ownerships in Region X, roughly 1/4 of the commercial forest land (CFL) is on slopes steeper than 45 percent and about 1/5 is on slopes steeper than 55 percent (6). The 45 and 55 percent figures are arbitrary demarcations of "steepness".

Kojan et al (3) state "The type and distribution of existing landslides, both active and dormant, is the single most important factor determining the performance and impact from roads..." Others have reported or stated that evidence of past mass soil movement is an important clue for anticipating the results of man's activities on unstable areas. Figures 4 and 10 illustrate some examples of mass soil movement as related to terrain, soils, geology and climate.

GENERAL PHYSIOGRAPHIC AND SOIL VARIATIONS

The major physiographic areas within the Region may be divided into areas of similar geologic structure and climate. These provinces can be separated into major subdivisions, (Figure 5), each subdivision having significantly different characteristics that affect road planning, design, construction, maintenance and use.

Road construction, timber harvest, and many other land management activities have an effect on soil and water resources. It is important to understand the effect and potential consequence relationships. Soils can be grouped according to similar characteristics and general conditions as topography, elevation, climate, water resources and land use. Groupings may include broad areas with similar soil characteristics. The objective of most groupings is to identify areas of land that are relatively uniform in many important relationships.

The general physiographic variations and soils discussion is intended only for a broad regional perspective of soil and land characteristics. The optimum level of information for minimizing water quality

LANDFLOW

ROAD TRIGGERED DEBRIS SLIDE ALONG
A PARALLEL SUBSTRATUM PLANE

FIGURE 4 EXAMPLES OF LANDSLIDE, SLUMP INDICATORS

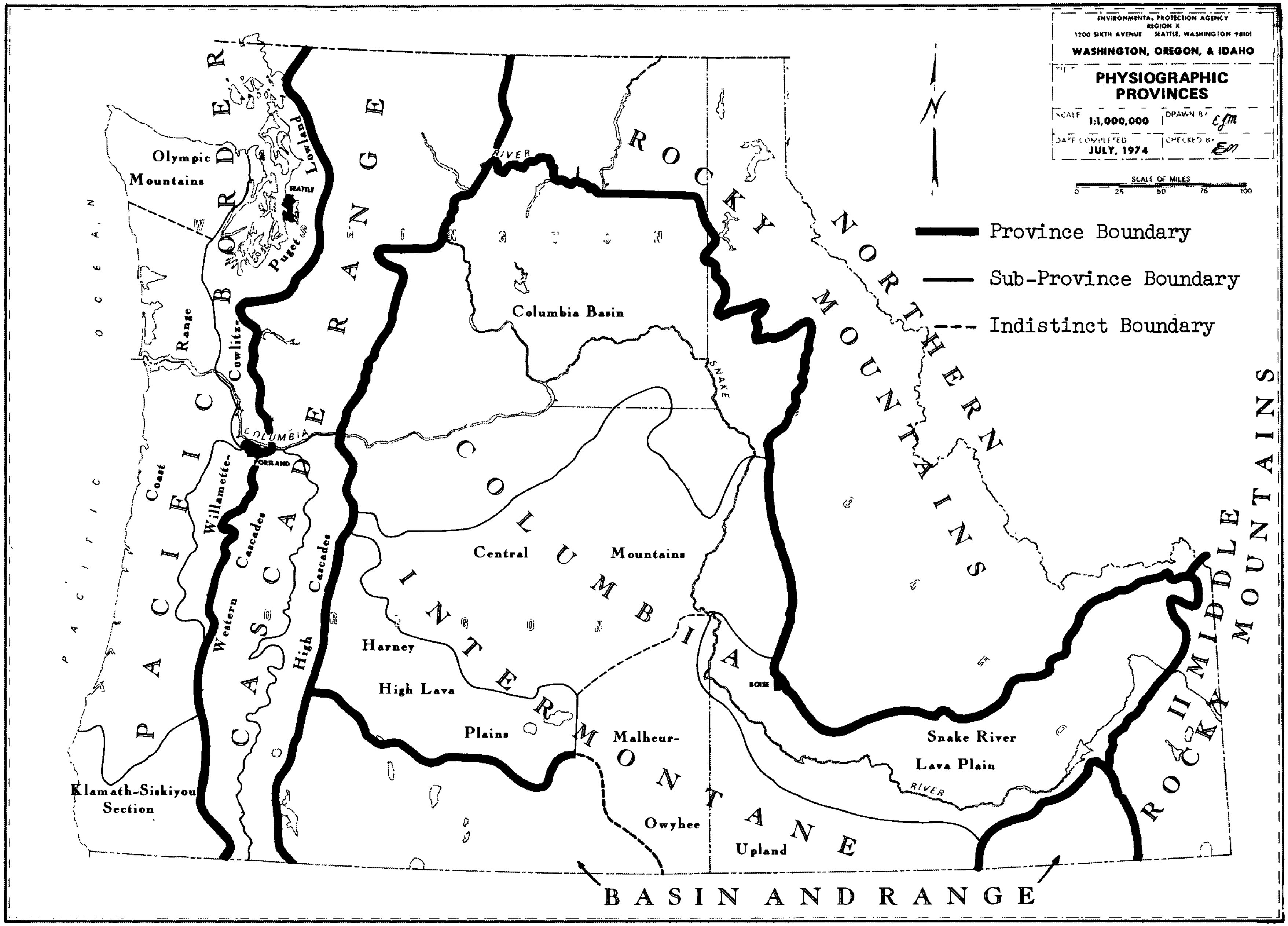

ENVIRONMENTAL PROTECTION AGENCY
REGION X
1200 SIXTH AVENUE SEATTLE, WASHINGTON 98101
WASHINGTON, OREGON, & IDAHO
PHYSIOGRAPHIC PROVINCES
SCALE 1:1,000,000
DATE COMPLETED JULY, 1974
SCALE OF MILES
0 25 50 75 100
Province Boundary
Sub-Province Boundary
Indistinct Boundary
PACIFIC BORDER
CASCADE RANGE
ROCKY MOUNTAINS
NORTHERN
MIDDLE ROCKY MOUNTAINS
COLUMBIA INTERMONTANE
BASIN AND RANGE
PACIFIC OCEAN
Olympic Mountains
Puget Lowland
Coast Range
Cowlitz
Willamette
Western Cascades
High Cascades
Klamath-Siskiyou Section
Columbia Basin
Central Mountains
Harney High Lava Plains
Malheur-Owyhee Upland
Snake River Lava Plain
SEATTLE
PORTLAND
BOISE
COLUMBIA
RIVER
SNAKE
RIVER

FIGURE 5

impacts from logging roads is an on-site assessment or site specific field evaluation of proposed road locations to determine soil and geological characteristics on a project basis. See Section on Route Planning and Reconnaissance, Part II.

Various authors have divided the Region differently. The divisions used in Figure 5 are largely those outlined by Allison (7). Areas treated as subprovinces by some authors are considered provinces by others. However, the basic subdivisions are nearly the same. Soils and geologic information for this section come from several sources: Baldwin (8), Burroughs (5), Campbell (9); several soils survey reports for parts of the Region; and discussions and field observations with forest land managers.

The seven physiographic provinces that lie partly or wholly within the Region (Figure 5):

- Northern Rocky Mountains.
- Middle Rocky Mountains.
- Columbia Intermontane.
- Basin and Range.
- Cascade Mountains.
- Pacific Border.
- Pacific Mountain System (Alaska). 1/

1/ Not shown in Figure 5

Northern Rocky Mountains Province

The province includes parts of northeastern Washington and northern and central Idaho. It is characterized by high mountain ridges and deep intermontane valleys eroded from rocks of moderately complex structure. The irregular mountains of Central Idaho developed from erosion of massive granite rocks. Much of the province is submature to mature in the geomorphic cycle.

Logging road construction is particularly damaging in highly erodible areas of the province, such as the 41,500 km^2 (16,000 square miles) Idaho Batholith. The Batholith of Central Idaho consists of soils developed in granitic materials. These soils present erosion problems, as shown in Figure 6. The Batholith is characterized by steep topography and shallow to moderately deep, coarse-textured soils overlying granitic bedrock. In parts of the province, the concentration of coarse sand increases the susceptability to erosion, during road construction. Surface soil erosion is the major problem in much of the area as shown in Figure 7, where slopes are less than 60 percent. Where slopes are greater than 60 percent, mass erosion is an important problem.

Middle Rocky Mountain Province

A part of the Middle Rocky Mountain Province extends into southern Idaho, where northwesterly trending mountain ridges and valleys have eroded from folded, thrust-faulted, or tilted rocks. The valleys are

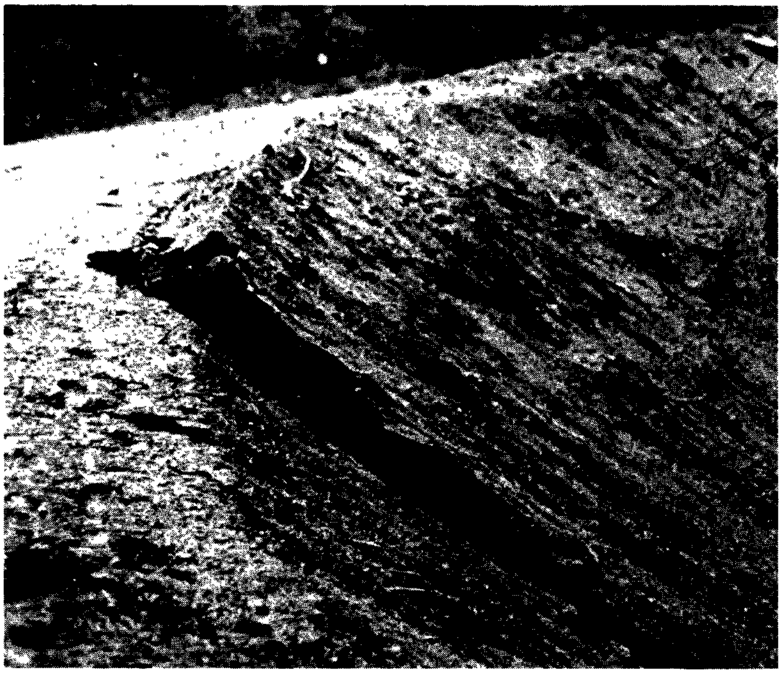


FIGURE 6 SOILS DEVELOPED IN GRANITIC ROCKS WITH STABILITY PROBLEMS

FIGURE 7 SURFACE SOIL EROSION IN BATHOLITH AREA OF IDAHO

about 1,850 meters (6,000 feet) above sea level, with ridges 600 to 1,200 meters (2,000 to 4,000 feet) higher.

The logging road problems in the province are principally related to mass gravity soil movements, such as slumps. Mass failures are associated with sedimentary deposits of sandstone, shale, siltstone, limestone, and volcanic ash. Surface soil erosion may also cause water quality problems in some areas.

Columbia Intermontane Province

This province includes the Columbia Basin, Central Mountains, Harney High Lava Plains, Malheur-Owyhee Upland, and Snake River Lava Plain.

A relatively small percentage of the province is managed for wood fiber production. Logging road activities are limited as compared to the major timber producing provinces (Cascades and Pacific Border). Steep slopes (greater than 60%) are few and are associated with isolated basaltic buttes or canyons. Because of the general climatic conditions (low precipitation), water quality problems relating to logging roads are rather localized, with surface soil erosion being the principal problem.

Basin and Range Province

The northern edge of the Great Basin section of the Basin and Range Province extends into south central Oregon and into southern Idaho. The logging road conditions are generally similar to those discussed for the Middle Rocky Mountain Province.

The part in Oregon in contrast to Idaho is a youthful high lava plain. Small cinder cones are numerous in the western portion, where a sheet of pumice from Mt. Mazama extends over a large area, 26,000 square kilometers (more than 10,000 square miles). This pumice sheet greatly modifies vegetation, surface runoff, and land use. With disturbance for logging road construction and extensive use during the summer or dryer seasons, the soils become very friable and susceptible to surface erosion. Because of the relatively gentle topography in much of the area and the moderate-to-rapid soil permeability, water quality problems due to logging roads are localized.

Cascade Mountains Province

The Cascades of Oregon and the southern half of Washington are a broad upwarp composed of a basal portion of tuffs, breccias, lavas, mudflows, a thick middle section of basalt, and an upper section of andesites and basalts that form the less dissected High Cascade lava platform.

Soils in the province are generally weakly developed and have been influenced by volcanic ash and pyroclastic materials. There is a potential for severe surface erosion on steep slopes when the organic layer is removed. The problem is accentuated by the abundance of streams and surface water and high precipitation in much of the area. Figure 8 illustrates some of the serious water quality impacts associated with logging roads in this province.

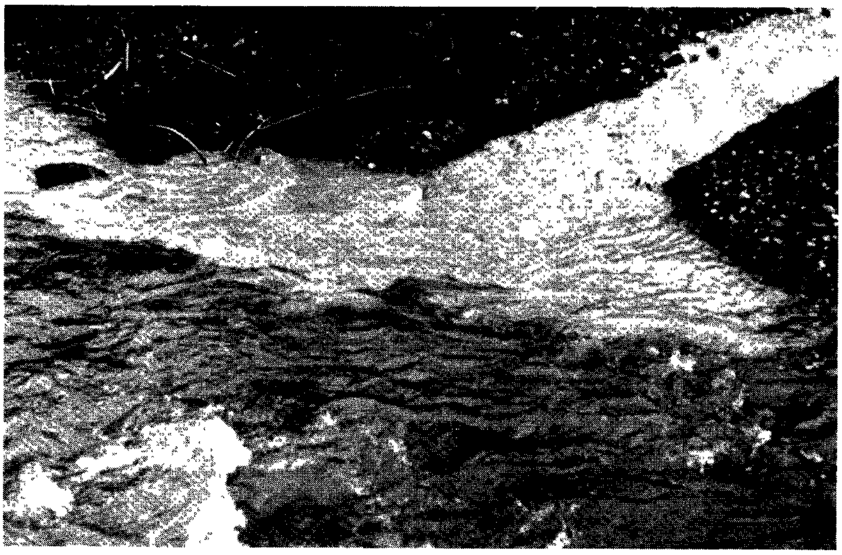


FIGURE 8 SEDIMENTATION FROM LOGGING ROAD CASCADE PROVINCE

FIGURE 9 CONTINUAL ROAD INSTABILITY PACIFIC BORDER PROVINCE

Pacific Border Province

The province includes the Klamath-Siskiyou Section, Coast Range, Olympic Mountains, and Willamette-Cowlitz Puget Lowlands (Figure 5).

Compared to the other provinces the Pacific Border province has some of the most severe and continuous water quality impacts associated with logging roads. The major problem areas are the coastal areas of Washington and Oregon and the Olympic Peninsula. These areas are characterized by high precipitation, as shown in Figure 11. Soils are developed in a wide range of materials, principally sedimentary deposits. They have a variety of textures and drainage characteristics. With the dominance of very high rainfall and steep slopes, many of the soils, especially those in disturbed conditions (some undisturbed), have a high degree of continual instability as shown in Figure 9.

Mass soil failures associated with logging roads as shown in Figure 10, occur in the province. The water quality impacts are particularly acute in steep headwall areas of drainages. These drainages are the principal tributaries to many of the major streams and water bodies of the area. A more detailed discussion of the nature, source and extent of the erosion problem and recommended procedures for dealing with this problem are discussed by Burroughs (5), Brown (1), and Dyrness (35).

Pacific Mountain System

This coastal province extends from the southern boundary of Alaska to the Aleutian Islands (41). However, the following discussion is

FIGURE 10 MASS FAILURE ASSOCIATED WITH LOGGING ROADS
IN PACIFIC BORDER PROVINCE

Photograph taken from road edge looking downslope limited to the southeast portion of this province, from the southern border to Yakutat Bay (42).

The southeast area is composed of a mainland strip and a wide belt of rugged islands with summits generally 750 to 1,050 meters (2,500 to 3,500 feet) in elevation. Most of the mainland strip is deeply indented by fiords. Its peaks rise to about 3,050 meters (10,000 feet) along the Canadian Border. Many of the inter-island waterways and major fiords and streams occupy long linear depressions, most prominent of which is Chatham Strait, a deep trench 6 to 24 kilometers (4 to 15 miles) in width and some 320 kilometers (200 miles) long.

Soils on the broad coastal plain at Yakutat are shallow to deep, gravelly, sandy to silty loams in association with moss peats of variable thickness and depth. Small amounts of waterlaid sands, gravels, and silts occupy broad stream channels and low areas adjoining the fiords. Logging road limitations are slight on well drained soils, becoming moderate to severe with increasing wetness.

Soils on the moraines and foot slopes bordering the plain are shallow, stony and gravelly loams with finer sediments in the vicinity of fiords and peat deposits in depressions. Limitations for these soils are moderate to severe for logging roads, depending on slope. Soils of steep hills and low mountain slopes are very gravelly silt loams over shallow bedrock in association with similar soils having a firm subsoil and occupying low moraines. Peat deposits occupy depressions extensively throughout these soils. Limitations are moderate to severe for use of these soils for road construction (43).

GEOLOGY

Geology as it relates to the physical character and areal distribution of various rock types plays a major role in controlling or effecting the quality of water in streams and rivers. Geology governs the character of soils as rock formations are the parent material for most soils. The erodibility of many sedimentary rock formations is directly related to the degree or amount of cementation. Fine-grained unconsolidated formations can be easily eroded while tightly cemented sediments may be very resistant to erosion.

The physical properties of the rock formations also play an important role in the quantity and time distribution of runoff from a watershed. Rock formations having high porosity and permeability will adsorb water during wet seasons and discharge it to streams throughout the year. The Metolius River in Oregon is an outstanding example of a large stream being maintained at an almost uniform flow throughout the year by the porous and permeable rocks of the area. Conversely, rocks of low porosity and permeability do not have the capability of adsorbing and transmitting large quantities of water. Consequently, streams heading in areas underlain with these rocks exhibit a tremendous fluctuation in flow from season to season and in some cases may respond rapidly to almost every heavy rainstorm. The general geologic character of a drainage basin can generally be interpreted by how a stream draining the area responds to climatic changes.

Construction within a drainage basin may not measurably effect the total loading of sediment being transported by a stream, but it can change the seasonal distribution of the load. A small amount of sediment washed or pushed into a stream in the late summer or early fall months may have a marked effect on water quality, while a similar increase in load during high water periods may be undetectable.

Rock types, as they relate to water quality effects, can be divided into three principal groups:

1. Volcanic Rock
2. Intrusive and Metamorphic Rocks
3. Sedimentary including Pyroclastic Rocks

Volcanic rocks are very common to many forested areas of the Pacific Northwest. They include the basaltic and andesitic lava flows that underlie a large part of the Cascade Mountain Range in Oregon and in the southern part of Washington. They also underlie the Blue Mountains in Southeastern Washington and Northeastern Oregon.

Most volcanic rocks are jointed which provides for the adsorption and storage of water. Permeable lava flows and permeable contact zones between flows generally provide for the movement of water through the formation. Volcanic rocks are the source of many of the very large springs in the Region.

In some of the more humid areas of the Region the older volcanic rocks have been weathered into red lateritic clays. When disturbed or naturally eroded, these weathered lavas can create very turbid water. In the dryer areas of the Region or in areas underlain with younger volcanic rocks, as the High Cascade area in Oregon, the volcanic rocks are relatively unweathered and are resistant to erosion and generally contribute to excellent water quality.

Metamorphic and intrusive rocks which include gneiss, granite and grandiorite are common to the Northern Cascades in Washington, North Central and Northeastern Washington, much of central Idaho, and the Wallowa and Siskiyou Mountains in Oregon. These rocks have relatively few joints or cracks and generally do not adsorb or transmit large quantities of water. Streams draining unweathered rocks of this group generally have large seasonal fluctuation and respond rapidly to rainstorms. Intrusive rocks in the early stage of weathering break down into a sandy material composed chiefly of individual crystals of feldspar. Continued weathering produces kaolinitic clay that can be easily eroded when disturbed.

Sedimentary rocks which are composed of fragments of other rock types exhibit a very large range in porosity and permeability, ranging from an almost impermeable glacial till to very permeable open-work gravel formations that are almost void of sand and silt fractions. A large part of the Coast Range in Oregon, the Willapa Hills in Washington and most of southeastern Alaska are underlain by sedimentary rocks. Because of the widespread occurrence of volcanism in the Region, a very large part of the sedimentary rocks are composed of volcanic ejecta consisting of pumice and ash. These pyroclastic materials are composed chiefly of volcanic glass, weathered to bentonitic clays. These clays are easily eroded, and can create widespread turbidity problems and also serious engineering problems from slides in road construction. The Corps of Engineers in studying the water turbidity problems in the Rogue River Basin of Oregon in connection with the construction of the Lost Creek Dam found that the tributary stream basins underlain with pyroclastic sediments were the chief areas contributing suspended material to that river system.

Detailed geologic maps should be a prerequisite to any large development that will disturb the landscape. Unfortunately, most geologic maps do not have the details necessary to identify rock permeabilities, degree of weathering, erodibility, and such hazards to construction as the probability of slides or slumping. As all of these factors can play an important role in subsequent water quality effects arising from road construction and use, a geologic evaluation of the proposed construction area should be a part of the design of any project. Equally important however is the subsequent use of a geologist to evaluate conditions encountered during construction.

CLIMATE

Climate considerations are essential for logging road planning, design, construction, maintenance and use. Climate, as with soils, terrain and other physical considerations, varies widely throughout the Region. It is apparent from this wide variability that an understanding of site specific conditions is essential to minimize impacts from logging roads. Pollution from sediment, deicers and oils used in road maintenance are greatly influenced by climate.

The wide diversity of precipitation and temperatures for January, July, and annually for dominant forested areas is shown by the mean monthly data in Table 1 for Seattle near the Pacific Coast; Meacham, Oregon and Potlatch, Idaho inland; and Juneau in Southeastern Alaska. Figure 11 illustrates the general regional pattern (excluding Alaska) of mean annual precipitation. More detail maps are essential for project planning. These maps are available from the U.S. Weather Bureau.

PACIFIC NORTHWEST

Precipitation (including both rain and snow) generally increases from south to north, from east to west, and from valleys to mountains. The general movement of storms is easterly from the Pacific Ocean. Annual precipitation varies from 180 centimeters (70 inches) on the southern end of the coastal ranges to more than 380 centimeters (150 inches) on the north. There is also wide variability within some general areas, for example, rainfall varies from approximately 410 centimeters (160 inches) on the northwest tip of the Olympic Peninsula to less than 50 centimeters (20 inches) in the Dungeness area, 130 kilometers (80 miles) to the east. Inland eastward from the coast, precipitation decreases in the Puget Sound--Willamette Trough, increases again in the Cascades, drops very low in the arid central Washington valleys and plateaus, and rises again in the Northern Rocky Mountain Province.

TABLE 1

MEAN MONTHLY AND ANNUAL VARIABILITY OF CLIMATIC CONDITIONS IN REGION

Period	Precipitation cm	Precipitation inches		Temperature °C	Temperature °F
			Seattle, Washington		
January	13	5		5	41
July	3	1		19	66
Annually	86	34		12	53
			Meacham, Oregon		
January	10	4		-3	26
July	3	1		17	63
Annually	84	33		7	44
			Potlatch, Idaho		
January	8	3		-2	29
July	3	1		19	66
Annually	64	25		8	47
			Juneau, Alaska		
January	10	4		-4	25
July	13	5		13	55
Annually	140	55		4	40

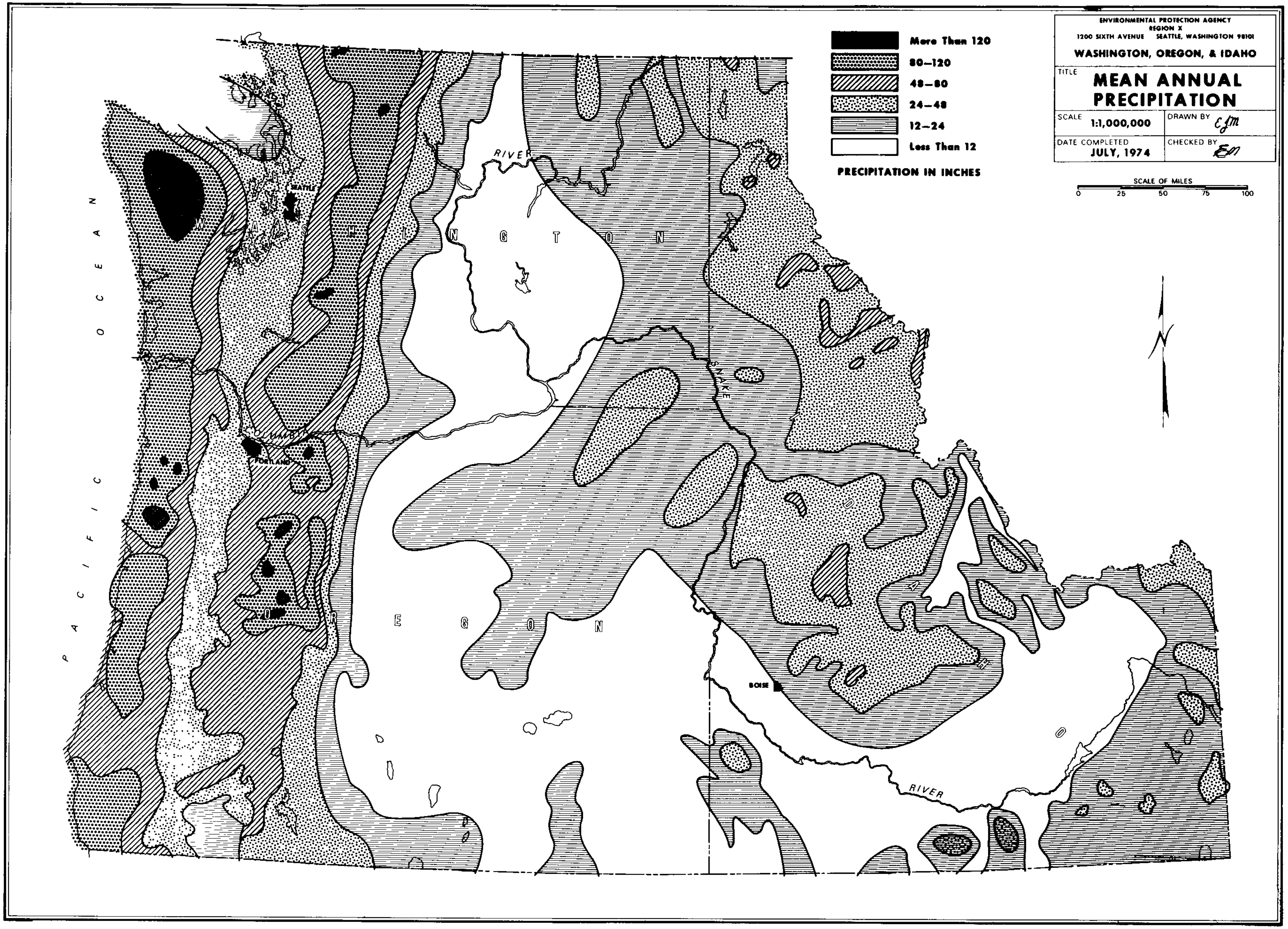


FIGURE 11 MEAN ANNUAL PRECIPITATION

Snow is an important form of precipitation over most of the Region. Mountain snowpacks furnish much of the summer streamflow to the larger rivers. Snow accumulates from December through March, and melts mainly from April through July. Stream throughout the Region drops to low levels in summer and stream temperatures increase.

Temperatures are moderate in coastal areas where, because of marine influence, there is little frost in winter. In the interior the climate is continental with cold winters and hot summers; the winters are longer and summers shorter at higher elevations.

SOUTHEAST ALASKA

The climate is mostly maritime with considerable rain and moderate temperatures. The south coast averages 200 wet days per year, while Haines and Skagway in the north average less than 100. Transitional climate occurs in higher mountains of the mainland.

Regional annual precipitation in the form of snow and rain varies from about 510 centimeters (200 inches) at Port Waller, 391 centimeters (154 inches) at Ketchikan, 155 centimeters (61 inches) at Haines and 140 centimeters (55 inches) at Juneau. Mean daily January temperatures are -3°C (27°F) at Yakutat, 2°C (35°F) at Ketchikan and -4°C (25°F) at Juneau. Mean daily July temperatures range from 12°C (54°F) at Yakutat, 14°C (58°F) at Ketchikan and 13°C (55°F) at Juneau. The rugged terrain greatly influences temperatures and the distribution of precipitation, creating considerable variations in both within relatively short distances (13).

FOREST STATISTICS

FOREST OWNERSHIP

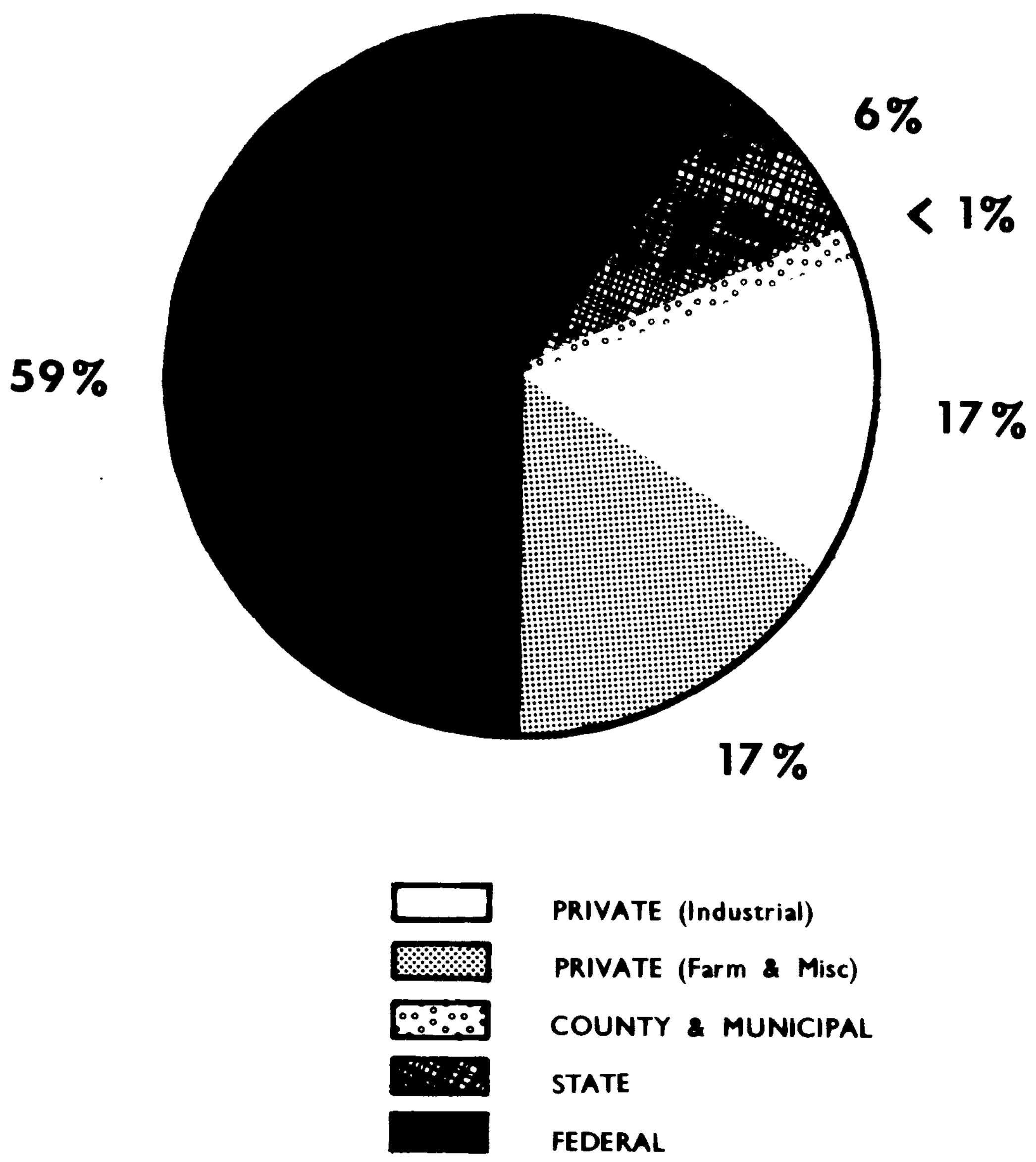
There are about 25 million hectares (65 million acres) of commercial forest land in Region X (14). "Commercial Forest Land" is defined as forest land producing or capable of producing crops of industrial wood (in excess of 20 cubic feet per acre per year) and not withdrawn from timber utilization (14). Ownership distributions for Region X and for individual states are shown in Figures 12 and 13 (15).

"Coastal Alaska" as used in this report is a geographical area described by the Pacific Northwest Forest and Range Experiment Station, U.S. Forest Service (45). It includes southeast Alaska and a narrow zone along the coast north to Kodiak Island. The remainder of the state is termed "Interior Alaska."

There are about 43 million hectares (106 million acres) of forested land in Interior Alaska. By the above definition, these are not classified as "commercial forest land." However, commercial logging is being conducted in some of the Interior forests. As noted previously in this report, other information dealing with Interior Alaska conditions has been published.

LOGGING ROAD ACTIVITY

As of January 1, 1974, there is estimated to be about 400,000 kilometers (250,000 miles) of logging roads, all ownerships, in Region X (16). Within each State, the approximate totals, were:



TOTAL COMMERCIAL FOREST LAND: 26 MILLION HECTARES (65 MILLION ACRES)

FIGURE 12 OWNERSHIP DISTRIBUTION OF COMMERCIAL FOREST LAND, ALL STATES, REGION X

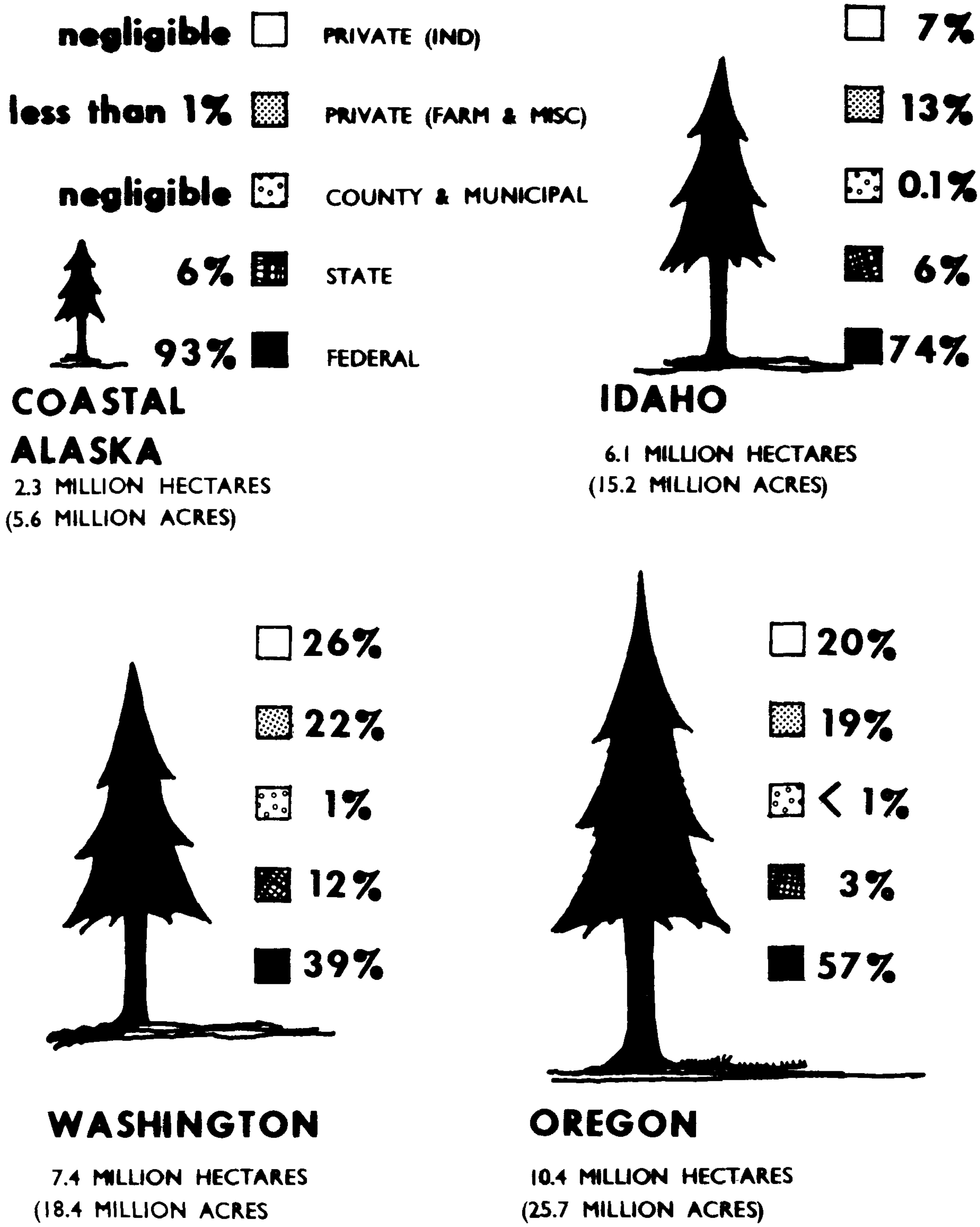


FIGURE 13 OWNERSHIP DISTRIBUTION OF COMMERCIAL FOREST LAND BY STATES REGION X

Oregon	175,000 kilometers (110,000 miles);
Washington	155,000 kilometers (95,000 miles);
Idaho	70,000 kilometers (45,000 miles); and
Alaska (Coastal)	less than 5,000 kilometers (3,000 miles).

On the average, including all ownerships, about 13,000 kilometers (8,000 miles) of new logging roads are built each year in the Region, and roughly 6,100 kilometers (3,800 miles) are rebuilt (16). "Rebuilding" (reconstruction) means relocating, substantially altering the original road prism, or reexposing stabilized cut and fill slopes of existing roads. Although rebuilding a road does not usually add new roads to the system, this activity is often similar to construction in potential water quality impacts.

The estimated average total miles of logging roads built every year in each state of Region X are:

	Kilometers	(Miles)	
Oregon	5,700	(3,500)	built
	3,400	(2,100)	rebuilt
Washington	4,400	(2,700)	built
	1,600	(1,000)	rebuilt
Idaho	2,600	(1,600)	built
	1,100	(700)	rebuilt
Alaska (Coastal)	300 Under 100 rebuilt	(200)	built

LOGGING ROAD COSTS

Road construction costs vary considerably. Factors which influence this include:

(a) standard of road;

(b) amount of road surfacing needed and location of suitable surfacing;

(c) number and size of culverts and bridges;

(d) difficulty in excavating material--amount of rock, terrain, soil types, etc;

(e) density and size of vegetation to be cleared and disposed of;

(f) organizational policies;

(g) amount and kinds of specialized structures and practices--e.g., bin walls, end hauling, etc.;

(h) overhead, engineering, labor and materials costs.

There is a noticeable and consistent difference between construction costs east and west of the Cascade Mountains in both Oregon and Washington. In these States, the road cost per mile west of the Cascades may range from two to ten times more than that east of the Cascades. Reconstruction has a similar cost pattern; but also varies according to the degree of reconstruction.

Table 2 summarizes construction and reconstruction for cost range and for unit costs (16).

TABLE 2

CONSTRUCTION AND RECONSTRUCTION COSTS
OF LOGGING ROADS IN EPA REGION X

a -- cost per kilometer, thousands of dollars
b -- cost per mile, thousands of dollars

	Oregon		Washington		Idaho		Coastal Alaska	
	a	b	a	b	a	b	a	b
				Construction Costs				
Average	11	17	8	13	7	11	43	70
Minimum	<1	1	<1	<1	<1	<1	25	40
Maximum	199	320	68	110	39	62	75	120
				Reconstruction Costs				
Average	5.5	.5	3.5	6	3	5	6	10
Minimum	<.5	<.5	<.5	<.5	<.5	<.5	4.5	7
Maximum	15.5	25	18	29	15	24	8.5	14

The estimated total average annual investment, all ownerships, in construction and reconstruction of logging roads is about $156,000,000 (16). By states, the approximate investment is as follows:

Oregon	$59 million construction
	18 million reconstruction
Washington	36 million construction
	6 million reconstruction
Idaho	18 million construction
	4 million reconstruction
Alaska (Coastal)	15 million construction
	Less than one million reconstruction

These costs and investments include a range of variations in the types and usage of water quality control measures including the structures needed for this control. Some measures appear to be used consistently by most people, others more sporadically, and some only rarely or by only some organizations.

EFFECT OF LOGGING ROADS ON WATER QUALITY

Water pollution is defined as man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water (PL 92-500, Sec. 502(19)). Implicit in the definition are various uses of water to be protected. Water quality generally relates to a degree of excellence of conformance to standards established for various uses.

The discussions in this section are based on the assumptions that:

(a) Construction, reconstruction and use of logging roads will continue in the future.

(b) The use of logging systems requiring low density road systems will increase in some areas.

(c) Impacts on water quality caused by roads can be reduced but not completely eliminated.

(d) It is usually cheaper and more effective overall, to prevent problems from occurring than to correct problems afterward.

(e) Consistent application of preventive technology that applies to areas of potential hazards will result in significant reductions of water quality impacts.

(f) Current water quality standards probably do not adequately reflect realistic upper limits for nonpoint sources of water pollution in some areas.

GENERAL WATER QUALITY PROBLEMS AND PROTECTION CONCEPTS

Forest lands are the best source of high quality water on a yield per hectare basis. In comparison to runoff from other major land uses as agriculture, grazing, etc., runoff from forests is high in yield and generally of good quality. It is well documented that the quality of this water may be affected by the number and location of forest roads in watersheds and the manner in which they are constructed and maintained (1, 5, 17, 18, 19, 20).

Potential water quality impacts caused by logging roads are best dealt with by prevention or by minimizing their effects, rather than attempting to control them after the fact (21). For example, controlling sedimentation from a mass soil movement and channel scour area often is virtually impossible after the occurrence (short of a massive correction and/or backstop system).

Practices designed to prevent short-term and long term problems may sometimes cost more initially; however, evaluation of available alternatives and options now in use should result in workable solutions.

Hartsog and Gonsior (22), in a report analyzing the performance of a road project in Idaho, indicate that, "a gap remains between the possible and achieved results in many road projects." In some instances where all apparent practical measures were taken to achieve a quality result, problems still occurred. Similar gaps between possible and achieved results were observed during the EPA field review of logging roads in Region X.

The above information suggests that:

(a) A strong preventative approach is not necessarily free of failure, and supplemental backstop corrective measures usually are also necessary to minimize sedimentation, and

(b) Although much progress is being made in recognizing the potential water quality impacts of roads, additional improvements are still necessary to minimize many of the common recurring road problems.

LOGGING ROAD SEDIMENT

Sediment has consistently been identified as the most significant pollutant resulting from timber harvesting (1, 19, 20, 23, 24, 25). Sediments are produced from forest lands by surface erosion, mass soil movement, and channel erosion. Logging road activities may influence all of these and especially accelerate the surface erosion and mass soil movement.

There is considerable evidence that logging roads are the primary source of accelerated erosion and sedimentation caused by silviculture activities. Packer (23) concluded that, "of man's activities that disturb vegetation and soil in mountainous terrain, few cause more damage to the quality of water than the construction of roads." Many others have substantiated Packer's conclusion.

In central Idaho, Megahan and Kidd (17) reported that nearly 84 percent of all sediment resulting from surface erosion on logging roads was produced during the first year after construction. Sediment production decreased substantially after the first year to less than 10 percent the second year, and less than 3 percent annually for the remaining four years of the study. The Frewing Committee Report on Management of Forest Resources in the Bull Run Watershed near Portland, Oregon (40), indicates that on the basis of regional statistics, 70 percent of the sedimentation in streams resulted from road construction rather than any particular type of logging practice.

In a study by Fredriksen (38) in the Oregon Cascades, 1.65 miles (2.66 kilometers) of road were constructed in a steep 250 acre (101 hectare) watershed. Immediately after construction, storms caused the stream to carry 250 times (1,850 mg/l) more sediment than the undisturbed watershed nearby. Within two months, the sediment content diminished to only slightly above preconstruction levels. This research and other similar research (17, 26, 27) and field observations as shown in Figures 7 and 9, all demonstrate the essential need for a concurrent erosion control plan with road construction.

The most common and significant water quality impact from forest roads in much of the Region results from mass soil movements as discussed in the section on major physiographic and soil variations. In most cases, mass soil movements are caused by undercutting unstable slopes, improperly constructing embankments, wasting of excavated materials on steep unstable slopes, and drainage system failures (5, 28). Evaluation of the mass failure potential of a road corridor is essential to minimize water quality impacts.

The compacted surfaces of logging roads often carry road surface runoff, with sediment during storms (1). Roads increase surface erosion by baring soil and concentrating runoff. The amount of surface erosion associated with roads is proportionate to the road density. It is well documented that as the miles of road increase in a watershed, the potential for water quality degradation also increases. Rosgen (29) used road density as a factor in evaluating and predicting response of a watershed to logging and road building activities.

To minimize water quality impacts from roads, prevention and control measures must be considered in every part of road planning, design, construction, maintenance, and use. The erosion control plan (plan of implementation for minimizing erosion such as seeding, mulching, terracing, use of structural measures, etc.) must be part of the planning process with erosion control measures being applied concurrently with construction, whenever practical.

Water Quality Problem Areas

It is obvious from field reviews of road activities in much of the Region that road construction is being extended further into rugged topography. Many of the easily accessible commercial forest sites have been harvested. Therefore, as the difficulty of construction (because of topography, geology, soils, climate, etc.,) increases, the potential of water quality impacts near sources of good quality water in mountainous watersheds also increases. As suggested by Tarrant (30), the key to producing multiple benefits from the forest, including good quality water, is the amount of care that the forest watershed manager can and will exert in all his activities.

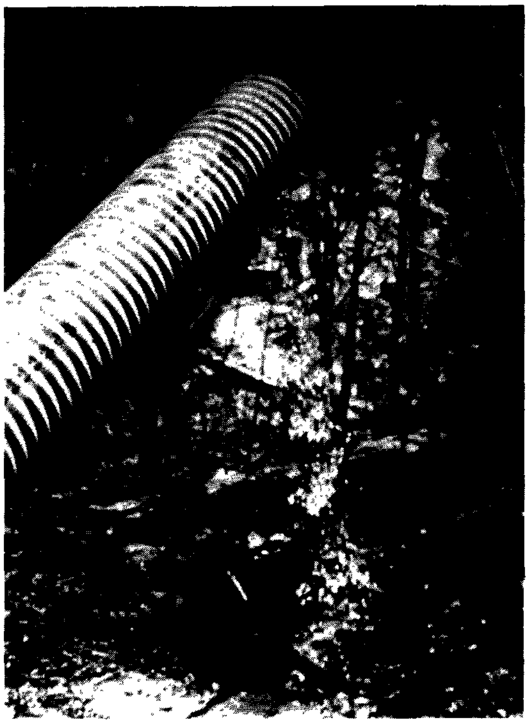
Several recurring water quality problem areas were observed during field reviews of logging roads in the Region. The most frequently recurring problems or problem situations are summarized below. Most of the items listed are interrelated. For example, an adequate reconnaissance survey should identify and assess potential location, stability and drainage problems. The items are separated only for discussion purposes to identify the most frequently observed water quality related aspects of logging road planning, design, construction, maintenance and use problems. This listing is not intended to be comprehensive or to include all of the problems related to roads. Also, items are not listed on the basis of priority.

Reconnaissance Survey, Location, Unstable Slopes and Drainage. The lack of an adequate reconnaissance survey causes many water quality-related road problems. Many potential water quality impacts can be identified, minimized, or eliminated as a result of an adequate reconnaissance survey. Site specific information on such factors as geology, soils and climate should be obtained during the survey, as discussed in Part II. Proper road location initially will avoid or minimize water quality impacts. In general, as the proximity of roads to streams and water bodies increases, the potential of degrading water quality also increases.

In steep or unstable topography, road construction often causes greater soil disturbances, especially mass movement, than any other forest activity. In many instances, stability is an inherent problem because of the limitations of the site. Water volume and velocity controls detachment and transport of soil particles. Water running long distances (over 427 meters, 1,400 feet) observed in some areas along roadsides, in ditches, or down the roadbed is one of the most common occurrences that degrade water quality in the Region. Erosion from long transport distance is shown in Figure 14. Lack of energy dissipators at culvert outlets to prevent water from being discharged directly on fill slope is also a common cause of erosion and subsequent sedimentation; culvert outlets with and without dissipators are illustrated in Figure 15. Adequate subsurface drainage is essential to reduce mass movement events. Water adds a buoyancy to the soil mass reducing shearing resistance resulting in mass failures. Avoiding concentrations of water in road cuts and fills will help minimize mass failure problems.

Erosion First Year After Construction, Season of Use. Because freshly-exposed material is highly susceptible to erosion, it is estimated that approximately one-half to two-thirds of the erosion from a road occurs during the first year after construction, except for mass failure related discharges. An example of first year damage is shown in Figure 16. Heavy road use during periods of precipitation and soil saturation may result in immediate water quality degradation, as shown

FIGURE 14 EROSION FROM LONG WATER TRANSPORT.



WATER QUALITY IMPACT FROM LACK OF ENERGY DISSIPATOR.

MINIMAL WATER QUALITY IMPACT WITH USE OF CULVERT DISSIPATOR.

FIGURE 15 CULVERT OUTLETS

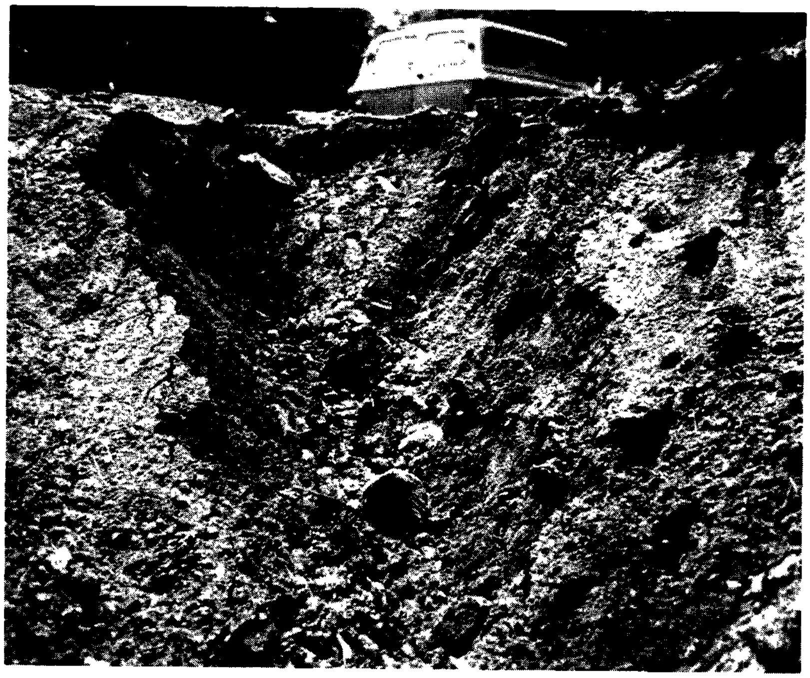


FIGURE 16 FIRST YEAR DAMAGE TO LOGGING ROADS.

FIGURE 17 SEASON OF USE DAMAGE

in Figure 17. Use of logging roads by hunters and recreation visitors produce similar-type impacts. The degradation is usually short-term or until rainfall or snowmelt decreases. However, the combined impacts of such activities on watersheds may result in significant deterioration of both water quality and the roadbed.

Road Density. The miles of road constructed is related to the timber harvesting method. Detailed aspects of the relationship between logging systems and roads is beyond the scope of this report. However, it is generally recognized that harvesting methods that reduce the kilometers (miles) of road result in less water quality impacts (18, 26).

Sources of Surfacing Materials. Locating adequate sources of surfacing materials for roadbeds is a problem in many parts of the Region. The highly weathered nature or absence of accessible rock materials creates the problem. The disturbance due to excavation and removal may cause water pollution problems. Streambeds and water bodies, such as beaches in areas as southeast Alaska, are often used as sources of surfacing materials. However, removing the accumulated alluvial gravels from these areas may produce serious sedimentation and water quality impacts where removal is done below the existing water level.

Channel Crossing. Roads are often required to cross streams in order to take advantage of the landform or to minimize construction and related difficulties. This is one of the primary causes of water quality problems associated with roads. Immediate and long term water quality impacts often occur in these areas, from disturbance within the stream and from blockages of culverts and failures. The number of road channel crossings in a watershed is an important factor in evaluating water quality response to disturbance (29).

DETERMINING POTENTIAL FOR POLLUTION FROM LOGGING ROADS

An appreciation and understanding of the intent and objectives of some of the commonly used stream classification systems is essential for water quality protection in areas with logging road activities. Consideration of water quality and stream classifications should be part of all phases of logging road planning, design, construction and use.

It has been recognized for sometime that the type of water uses to be protected are important in determining necessary quality criterion. The classification of water bodies on the basis of desired use is often a convenient and useful mechanism for decision making by land managers and regulators. As noted earlier in this report, the FWPCA Amendments of 1972, identify uses of water to be protected.

States in Region X have various types of stream and lake classifications relating to kind of water use, most refer to this use or zoning as a stream classification system. The systems are related to such uses as domestic supply, fishery, recreation, industrial, agriculture, and aesthetics. Inherent in any use classification related to natural resources are potential conflicts requiring the establishment of priorities. The use priorities are included as part of the water quality standards of the States.

Some of the stream classification systems used in the Region are presented in Table 3. The number of classes varies from two to five. The system of the Department of Fish and Game in Alaska is based on streams being specified as important for anadromous fisheries. The system however, is not all inclusive and lack of classification does not indicate unimportance. Specification of a stream is usually related to a significant project or action that has a potential for impacting anadromous fishery values. The major elements of systems used by other states in the Region are included in Table 3.

The differentiating criteria used in most of the systems have many common parameters. For example, value for domestic use, importance for angling or other recreation, and use by significant numbers of fish for spawning, rearing or migration are used in most systems. The continuity of water flow as intermittent or perennial is also included in some systems.

OTHER USE CLASSIFICATIONS

Standards

The water quality standards of the States in the Region are also related to water use classifications. The designated use for which waters of the various States are to be protected include, but are not necessarily limited to, domestic and industrial supplies, irrigation and stock watering, fish and wildlife, recreation and aesthetic qualities. The States have general and special standards for specifically designated waters.

TABLE 3

COMPARISON OF SOME STREAM CLASSIFICATION SYSTEMS USED IN REGION X

States	Alaska	Idaho	Oregon	Washington	Forest Service, Region 6
Legislative Basis.	Alaska Statutes 16.10.010.	Administrative Decision of Dept. of Fish & Game.	State Forest Practices Act.	State Forest Practices Act.[2]	Administrative Decision of Regional Forester.
Number of Classes.	None.	I thru V.	I and II.	I thru V.	I thru IV.
Differentiating Criteria.	The Dept. of Fish & Game may classify waters as important for spawning or migration of anadromous fish.	Aesthetics. Availability (road access). Use (fishing pressure). Fish productivity. Size.	Value for domestic use. Important for angling, or other recreation. Use by significant numbers of fish for spawning, rearing or migration routes.	Value for domestic use. Important for angling or other recreation. Use by significant numbers of fish for spawning, rearing or migration. Water flow continuity.	Direct source for domestic use, including recreation sites used by large numbers of fish for spawning, rearing or migration as a major influence on water quality. Water flow continuity.
Requirements.	Written approval for activities in specified streams of anadromous fishery value.	None.	Notification of operation. Requires reforestation, cleanup and protection (more stringent depend- on class).	Plan of operation, reforestation, cleanup and protection (more stringent depending on class).	Streams must be classified as streamside management units, cleanup and protection (more stringent depending on class). Timber falling, yarding.
Activities Controlled.	Instream activities in specified anadromous streams as obstruction, diversion, and pollution of spawning beds.	None.[1]	Timber harvesting including reforestation, felling, bucking, yarding, decking, and hauling road construction. Treatment of slash & site preparation. Application of Chemicals Pre-commercial thinning.	Application of chemicals. Disposal of slash. Road construction and maintenance.[3] Harvesting. Reforestation.	Man-caused woody debris into streams. Roads. Livestock grazing.

1/ Rules and regulations for Stream Channel Protection Act (Title 42, Chapter 38, Idaho Code) specifies minimum standards for stream channel alterations.

2/ Act will govern all forest practices after Jan. 1, 1975. Information in table from interim guidelines for 1974 prepared by Ad Hoc Committee sponsored by State Department of Natural Resources. Formal rules and regulations will be adopted Jan. 1, 1975.

3/ State hydraulics project approval law (for channel alteration) and Shoreline Management Act controls some activities on forest land.

The designations include lakes, streams, segments of streams, or river basins. Various classes related to the uses as AA, A, B, C through G inclusive are also used to identify specific bodies of water.

The criteria in the water quality standards are related to the classes. A detailed discussion of water quality standards is beyond the scope of this report. The concepts and principles related to use classifications are introduced only for completeness. References 31, 32, 33, 34, provide detailed information on State water quality standards.

Basin Plans

Basin plans are developed to document pollution problems for some of the States in the Region. Most of the States have a continuing planning process (Sec. 303(e) FWPCA). The process provides the method for the States to coordinate their water quality management planning, programming, and management. The basin plans identify and document the nature, source and extent of water quality impacts and procedures for minimizing the impacts. Stream segments in the basin are classified as part of the plan development. The classification of segments is based upon measured instream water quality when available. Basin stream segments are classified as water quality limited or effluent limited. These stream classifications are used to identify water quality problem areas and assist in setting priorities for pollution abatement.

The definitions of classified basin stream segments are as follows:

Water Quality Limitation. Any segment where it is known that water quality does not meet applicable water quality standards and/or is not expected to meet applicable water quality standards even after the application of the effluent limitations required for point sources of pollution (FWPCA--Sections 301(b)(1)(A) and 301(b)(1)(B)).

Effluent Limitation. Any segment where it is known that water quality is meeting and will continue to meet applicable water quality standards after the application of the effluent limitations required for point sources of pollution.

WATER QUALITY RISK ANALYSIS

A rational assessment of the potential water quality impacts of roads is an important ingredient of an effective water quality control program. The following discussion is intended to highlight the conceptual framework of risk analysis. More detailed information and evaluation techniques are covered in Part II of this report.

A number of different risk analysis procedures are being used to assist in estimating the potential consequences of road construction activities (and other silvicultural activities). The following examples illustrate some of the analytical approaches.

A risk analysis procedure to evaluate the potential for waste discharge caused by logging roads is proposed by Jones and Stokes (21). A number of risk factors and evaluation criteria are identified, and the relationship of various practices to potential water quality degradation is explained. A somewhat arbitrary correlation was developed between the factors and those road practices suitable for such an analysis. However, on the basis of much of the available research and field observations, the basic risk factors are accurate and do apply to road activities in Region X.

Rosgen (29), in northern Idaho, uses a watershed response rating system which considers six criteria for evaluation: surface erosion hazard, mass wasting hazard, recovery potential of the land, stream channel stability, stream recovery potential, and road impact index (road density times the number of stream crossings). This system is designed to help analyze the hydrologic response of a watershed to climatic events and man's activity on the land. As part of this system, recommended prescriptions are developed as needed for minimizing potential impacts of roads (and other activities) on water quality (and other resources).

A geologic hazards approach was used for the Portland, Oregon Bull Run watershed (11). As discussed earlier, Kojan et al (3) developed a system of risk analysis based on geologic hazard and mass erosion susceptibility.

The following concepts are included in most of the risk analysis systems:

(a) identification of potential problems (i.e., water quality impacts);

(b) identification of significant factors;

(c) evaluation criteria;

(d) estimating the probability of problem (water quality impact) occurrence;

(e) estimating the potential magnitude of impact occurrence;

(f) suggested criteria or solutions for preventing or minimizing impacts.

However, it must be recognized that such analyses are not "cure alls". Rather they should be viewed as aids to recognizing and assessing potential water quality impact hazards in advance in order to address them before the fact. Any such analyses still require judgment and the "risk ratings" derived are dependent upon the quality of the investigative work and the predictive capabilities. The art of predicting the location and magnitude of road-triggered events is neither precise nor refined. For example, problems are not always evident; the capability for predicting mass-wasting on a site specific basis is not well-developed except in the most obvious situations; and predicting the magnitude of problem occurrence with a high degree of accuracy is not now practicable.

An evaluation of some of the risk systems being used suggest the following conclusions:

(a) Risk analysis is an important feature of a strong water quality management program.

(b) Although such systems cannot be viewed as highly accurate predictive devices, they are a rational basis for improving the probability of anticipating major water quality impacts (and thus an aid for preventing or minimizing the impacts).

(c) Multi-professional (i.e., geology, soils, hydrology, engineering, forestry) skills are needed to develop high quality analyses and prescriptions--especially in high risk situations or areas.

(d) Some form of detailed site evaluation is necessary.

SURVEILLANCE AND MONITORING

MONITORING NONPOINT SOURCES OF POLLUTION

This chapter will present an overview of some important aspects of water quality monitoring relative to nonpoint sources of pollution. The emphasis is on logging road activities; however, many of the concepts presented apply to other silvicultural activities and other nonpoint sources of pollution. The discussion is not intended to develop a how to do it approach, or solve the many contemporary problems associated with various aspects of water quality monitoring. It is intended to emphasize some of the fundamentals and complexities involved in monitoring related to logging road activities.

Comprehensive water quality monitoring is a difficult, expensive and time consuming process. It involves many interrelated variables such as time of sampling, frequency, flow characteristics, climate and such physical considerations as soils, geology and topography. Nonpoint sources of pollution are not confined to discernible, confined and discrete conveyances. As a result, nonpoint source pollution presents uniquely difficult monitoring problems, because of the wide variability of many physical factors.

Measurement of a highly variable, diverse system such as found in any natural system requires a great deal of effort. Careful consideration must be given to determining if the end results are worth the costs involved. In many instances, the cost to obtain high quality data are considered prohibitive and therefore something much less than optimum is considered acceptable. The less than optimum level of sampling is generally utilized in everything other than a research study, with the end result being the data is almost useless in determining the cause-effect relationships necessary to evaluate management activities.

The FWPCA Amendments of 1972 is the first national legislation to recognize pollution problems of a nonpoint source nature. It is recognized that the kind of pollution control for nonpoint source areas as silvicultural activities, cannot be the same as those for conventional collection and treatment of polluted effluents immediately prior to discharge into water bodies. The treatment and control methods generally relate to the forest management system. They may include a combination of practices and methods for minimizing pollutant discharges.

The concepts for the control of pollution from point sources, or discernible, confined and discrete conveyances, are clearly identified in the Act. The control regulations include, but are not limited to (a) effluent limitation for point sources; (b) application of best practical control technology; (c) compliance schedules to meet effluent limitations; and (d) compliance monitoring.

There are some similarities between point sources and nonpoint sources pollution problems. The basic goal for both is to reduce water pollution. The effects they cause are similar--they degrade the chemical, physical, and biological integrity of water. The major differences between point sources and nonpoint sources are their mode of entry into the aquatic environment, timing of pollution input, the levels of the dispersion of material downstream, and most of all, the extreme variation caused by a number of factors both natural and man caused. These differences limit the application of conventional pollution control methodology of treatment prior to discharge.

Many of the transport pathways for pollutants from nonpoint sources are not fully understood. However, it is feasible to apply the principles of best preventative techniques which are somewhat similar in concept to best practicable technology for control of point sources of pollution. Best preventative techniques are those procedures, methods, techniques and structural measures which are currently available for preventing or minimizing water quality impacts. Much of the information presented in Part II includes best preventative techniques for logging road activities.

Some of the common needs for water quality monitoring are to: (a) evaluate the presence of pollution; (b) define causes or sources of pollution; (c) evaluate data for development of preventative measures; and (d) determine the natural background quality of water in the watershed, and to be able to distinguish between natural and man-caused sediment inputs in a system of extreme variability.

Road construction and maintenance have short-term impacts during and immediately following construction and generally decreasing long-term impacts during the life of the roads. However, in some instances road cuts are progressively less stable as roots rot and exposure causes weathering. The major pollutant is eroded mineral sediments. Significant, localized pollution problems can be caused by 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 used in the maintenance program; and nutrient elements (principally nitrogen and phosphorus) from soils and plant and animal matter or from fertilizers. Thermal pollution can also occur by removing shade cover and exposing streamflow to solar heat. Of all these pollutants, sediment is the most serious cause of water quality degradation (19).

In many instances, it is difficult to determine what pollution results from logging roads, what is caused by other man related activities, and what is the natural background level. The most convenient and conventional approach is to monitor or quantify water quality in an area without logging road construction, as was discussed earlier related to work by Fredriksen (38). The approach obviously has limitations after initial roading of an area is started. The subsequent water quality impacts from road construction are difficult to separate. Consequently, the most effective approach for documenting water quality related to roads and other silvicultural activities is to monitor as small a watershed as practical for cumulative impacts. Larger watersheds should be used to document long term trends.

The principal needs to increase effectiveness in nonpoint source monitoring are: (a) a better definition by forest land managers and regulators of what and where monitoring should occur; (b) a better understanding and definition of the probability of sedimentation in undisturbed areas within a defined time frame; and (c) a better definition of pollution levels and impacts. Some important aspects of nonpoint source monitoring that must be recognized in developing a monitoring system are:

a. Sediment is the most significant pollutant from nonpoint sources on forest land in the Region.

b. Stream systems have naturally-caused sediment for any defined time frame.

c. Land management objectives should be related to a defined time frame in order to identify water pollution impacts.

The above indicates that general prescription approaches for monitoring nonpoint sources are of limited value. Monitoring activities should be related to a predefined purpose.

PARAMETERS AND FREQUENCY

Monitoring should normally be limited to those parameters most likely to be significantly affected by logging roads and related silvicultural activities. The most significant ones are sediment and turbidity. Temperature, dissolved oxygen, nutrients, and chemicals such as deicers, oils and pesticides may require monitoring in special situations. Stream flow should also be measured to assist in interpreting water quality data.

The sampling frequency must be carefully established so that all the ranges of water quality experienced from logging road and related activities are observed. Monitoring schemes must be built on knowledge of how and when the pollutant is likely to be produced. For example, it is known that sediment enters streams primarily during storm events or during the rising stage of streams. It is also documented that chemicals as deicers and oils used in dust-coating roads have the greatest potential for entering streams during and immediately after rainfall and runoff. For water temperature monitoring, the sampling should be geared to diurnal variations including mid-summer, midday periods during clear hot weather (19).

Monitoring Approaches

Two types of monitoring approaches may be used to document water quality in a forested watershed--long-term or trend monitoring and short term monitoring.

Long Term Monitoring. This type of monitoring is designed to establish representative water quality for runoff and document long-term fluctuations. The monitoring stations should be on major drainages within a watershed to represent the combined effect of all activities within a drainage. The information will give an overview of the quality of water within the yield area.

Many long term monitoring stations already exist in the Region and are operated by the EPA, U.S. Geological Survey, U.S. Forest Service, State Agencies, Universities and various timber industries. In special interest areas as municipal watersheds where logging roads are constructed over a period of time, it may be desirable to establish long-term stations to document water quality impacts. The information may be used in developing preventative and corrective measures.

Short Term Monitoring. This type is designed to monitoring project activities before implementation (to establish existing quality), during implementation (to establish the effect of the activity on quality as a control) and after implementation (to establish time frames for return to pre-disturbance conditions or recovery as a measure to quantify degradation).

Short-term monitoring stations should be located near activities to be monitored. The paired-station approach, one station upstream and one station downstream, is the most convenient and conventional. It is appropriate for monitoring many road activities. The shortest possible time should occur between the two sample intervals.

The potential limitations of the paired-station approach are (a) In situ changes in pollutant concentration due to past natural--or--man caused activities; (b) locating downstream stations to insure adequate mixing, yet avoiding unrelated sedimentation or other pollutants from instream areas; (c) the approach does not indicate the frequency of changes or their meaning at water use points; (d) in order to achieve any degree of statistical significance in the sampling procedure a number of samples will be required. In addition, it may not be possible to utilize this technique in certain instances. Many small watersheds where monitoring is desirable occupy a position in the upper reaches of a drainage system. It may not be possible to establish a station upstream and downstream of an activity in such a situation where a stream originates within the activity area.

It is essential to understand the limitations and applications of any monitoring approach prior to its use. Recognizing its limitations, the paired station approach is still appropriate for monitoring logging road activities in many instances, because the major impact during the first year after construction generally occurs within a short time. The approach is shown graphically in Figure 18.

The technique of paired watershed analysis may also be used in monitoring logging road activities as used by Fredriksen (38). This method is not without limitations, however it does have advantages in certain instances. The largest disadvantage is one of long calibration time. The principal advantage of the approach is that the control watershed may more accurately represent natural levels of water quality.

Parameters

The water quality parameters most likely to be influenced by road activities include sediment, turbidity, and temperature. In some instances, specific conductance, dissolved oxygen and stream discharge may be affected. The key parameters are discussed below:

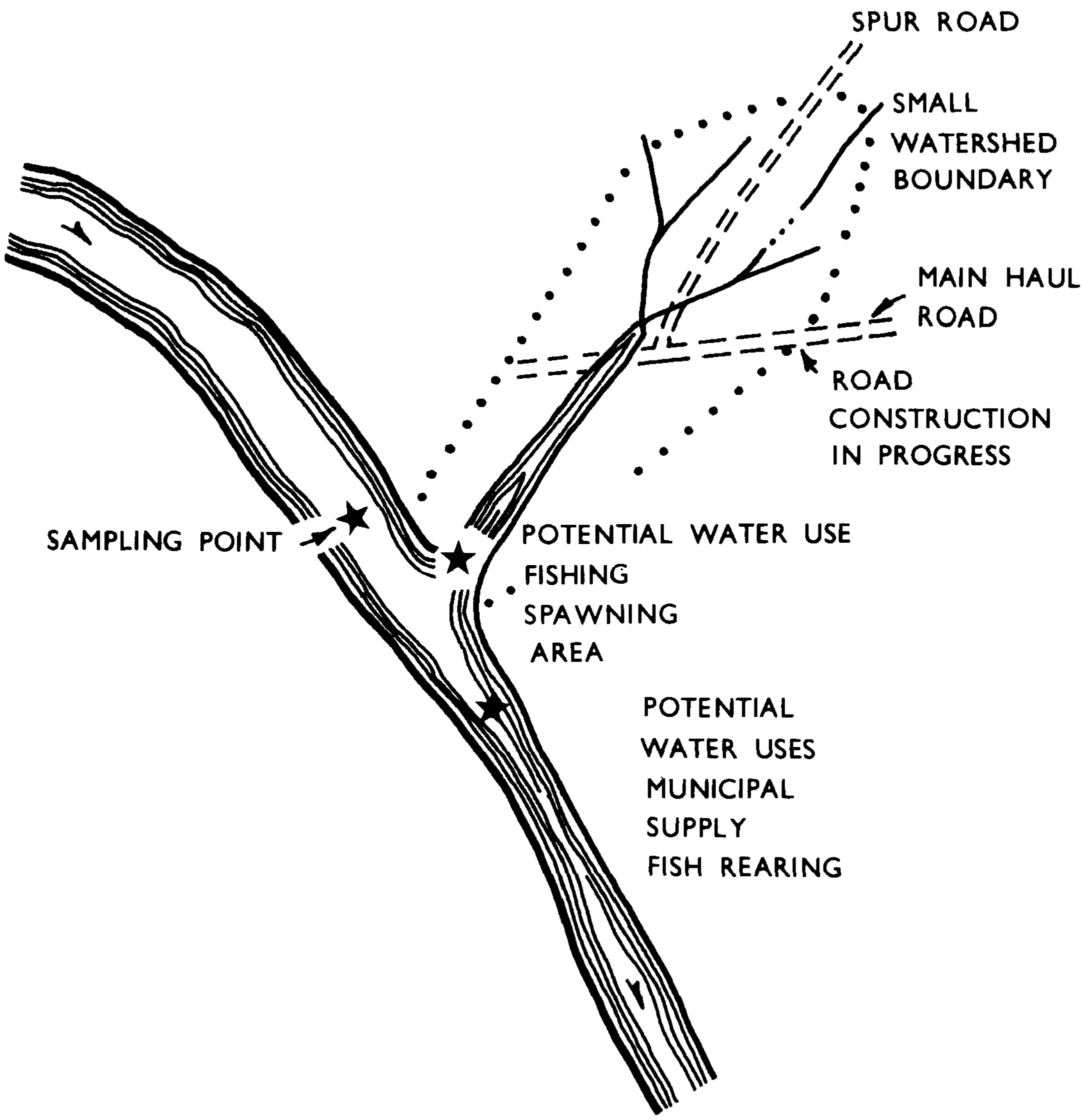


FIGURE 18 WATER QUALITY MONITORING APPROACH FOR CUMULATIVE IMPACTS

Sediment. As previously discussed, sediment is the major pollutant related to logging road activities. Detail quantification of sedimentation sources, rates, etc., present difficult problems because of wide variability of flow, soil, and geologic characteristics of an area. Many of the problems involved in monitoring and interpreting sediment transport and deposition data are well documented in literature (1, 12, 19, 24, 36, 46, 47).

To evaluate the relative contribution of sediment sources and transport processes that affect streams in the forest, problems in monitoring sedimentation characteristics should be recognized. They involve determining where in the watershed the characteristic should be measured or identified, and how well the sample represents time and spatial variations (37). In evaluating the contribution of sediment sources from roads and other forest activities, environmental characteristics such as the hydrology of the soil, the landform which the soil occupies, the erosional processes, and the high sensitivity of each process to change must be considered in surveillance and monitoring activities. Erosion is but one of the three basic processes of sedimentation, the other two are sediment transport and deposition. Each of these basic processes may in turn serve as a source of sediment or be involved in the transport process, depending on the particular measurement of sediment delivery being considered.

Much of the available information on sedimentation from forest land activities including roads has come from subjective evaluations or observations of muddy streams during and following road construction and use. In some instances, research has provided quantitative data on sediment production from forest roads built prior to other types of man caused disturbances in an area (17, 26, 38, 39). Most of the quantitative information that's available on impacts of forest roads on water quality have been obtained from experimental watersheds. Some of these watersheds have had complete timber harvest operations (24, 38). Others have been located in soils and geologic materials that are of relatively minor importance making the transportability of some of the information questionable. More baseline information on various common road activities and other forest land management practices is needed to better understand and quantify water quality impacts associated with logging road activities.

Turbidity. It is a measure of an optical property of water normally expressed in Jackson Turbidity Units (JTU). Turbidity may be related to the suspended sediment content of the water although the correlation may be quite variable from stream to stream and even for the same stream at different locations and times of the year. Turbidity gives only a crude index to sediment content, unless a specific correlation for a stream is developed.

Temperature. The purpose of water temperature monitoring is to determine whether shade removal or ponding increases 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.

In some instances, it may be well to consider measurements of monitoring outside the standard water quality parameters discussed above. As discussed, these parameters are so highly variable it may be advisable to evaluate both source area and end results for a measurement of the impact of the logging road activity. Analyzing source areas is particularly important where mass failures are involved. In addition, measurement of changes to the aquatic system or biological monitoring should also be considered. Such things as measuring channel erosion and degradation, and changes in particle size distribution of deposits may be helpful in determining effects of logging road activities on the aquatic system and other water uses.

USE OF WATER QUALITY DATA

Good water quality data can provide a means of assessing the effectiveness of various erosion control measures and engineering design features. The information should encourage designers and contractors to make a more conscientious effort to prevent water quality degradation. Water quality information may also be helpful in controlling construction and related road activities.

There are several sources of water quality data that can be used by planners or engineers to assess the potential water quality impacts of roads and other silvicultural activities. The Environmental Protection Agency, U.S. Forest Service, U.S. Geological survey, State water pollution control agencies, and universities in the Region all have water quality data related to various aspects of forest land management.

Most of the groups have inventories of data collected. The EPA's STORET System also contains data of most of the other agencies and groups. The system is a comprehensive source of water quality data and may be useful for planners and engineers, especially during the planning and design phases of logging roads. Data can be retrieved at Region EPA Offices (19).

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PART II

Engineering Design And Technical Criteria For The Control Of Sediment From Logging Roads and The Control Of Pollution From Road Maintenance Chemicals

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 need for these 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 and long term harvest patterns, 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 annual 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.

Specifically including design criteria to minimize sediment can broaden the design criteria spectrum under some conditions. In these circumstances additional first cost may not result in companion annual 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 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 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 road 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 forest 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 mid-slope road mileage be minimized and further where these roads are necessary across steep side slopes, "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 area 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 section 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 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 discussion that follows is in the order that a logging road develops namely: (1) planning and reconnaissance, (2) design, (3) construction and (4) maintenance. These divisions do not 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, ownership, product and goals. Small landowners may find it economic to retain consultants or to seek help from governmental or university sources when the need for engineering or other specialists occurs.

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 unrecorded knowledge is also possessed by individual experienced forest engineers. There are no doubt many successful techniques of sedimentation control omitted from the chapters that follow.

SUMMARY AND CONCLUSIONS

There is an abundance of information 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.

Minimizing 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. Contractual 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 the proper and efficient clearing of steep slopes in a manner that reduces the opportunity for mixing of clearing slash and organic debris with excavated material. End haul projects on narrow roads have resulted in increasing unit excavation costs. New equipment that will produce more yardage at less unit cost is needed.

The key to a successful maintenance program is the 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 location and design practices. In some cases, abandoning the road may be preferable to removing slide debris and correcting the problem. Where it is necessary to remove slide debris, it should be placed in selected spoil areas.

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 constructed outside of the roadway corridor for sediment transport minimization 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 minimization of sediment creation and transport may be coincident.

RECOMMENDATIONS

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

Several methodologies (e.g. Universal Soil Loss Equation) have been developed for prediction of soil loss under various conditions. However, none have been specifically developed or tested for use in a forest environment. Additional research is required to test the available equations for use on forest logging roads.

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 for stream crossing design purposes.

Organizations should assign responsibility and authority to experienced engineers at the local level for planning and designing 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.

An equipment research program directed toward the modification of current equipment or development of new equipment for excavating narrow roads in steep terrain is needed. The goal of the research should be relative economy in the earth excavating and loading operation for end haul projects as compared to the costs of these operations using presently available equipment.

ROUTE PLANNING AND RECONNAISSANCE

Route Planning and Reconnaissance is 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 is detailed in several references. 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). 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" (5). 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" (8). 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" (9). The Boise National Forest's 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" (10).

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 (11). "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" (12). (Bureau of Land Management Roads Handbook)

R. D. Forbes in Forestry Handbook provided one estimate of 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" (13). Any estimate of engineering costs should recognize the individual circumstances of the project under consideration.

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 following discussion of route planning and reconnaissance begins when the forest land manager has determined that a road is required. The manager has made some preliminary decisions about 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.

The first part of this chapter covers engineering planning aspects and the engineer's communication with land management. The second part discusses the field reconnaissance by geotechnical, forest and civil engineering personnel. The last part (third) 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.

ROUTE PLANNING

MANAGEMENT-ENGINEERING DIALOGUE

After the engineers' introduction to the Forest Land Manager's road requirement, a dialogue often develops 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 and 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 watersheds. Management gave special instructions to minimize watershed damage. Road standards had, to some extent, been established by the forest management and 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" (14).

The China Glenn Road experience demonstrates the need for communication when roads in ecologically sensitive areas are envisioned. In some cases (particularly in steep terrain), small soil and geologic disturbances may result in measurable ecological differences including the presence of stream siltation. In these circumstances the responsible forest engineer continues the dialogue and provides "feed back" to the forest land manager by evaluating the terrain's in situ condition. The engineer will evaluate the terrain for 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 include determination as to whether or not existing technology is equal to the ambient circumstances within a particular road corridor.

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, aerial photographs and photo interpretation equipment, 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 constructing a stable road; or
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; or
3. A road might be constructed into the general area with companion modification of the harvest procedure; or
4. Management's road might be constructed pending confirmation by field reconnaissance; or
5. Management's road can be constructed with relative ease pending confirmation by a brief field reconnaissance; or

6. Managements' road cannot be constructed with the allocated dollar amount.

State of the Art Techniques

Within the past few years, some forest land owners have become keenly aware of the hazards of sediment production. As a result of 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 representation. This information shows geomorphic provinces, timber species associations and geomorphic sub-provinces. The smallest mapping unit is approximately 10 miles square (15).
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" (16). 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" (17). 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" (17).

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 (18). 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 (19).

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

   a. "Workload Analysis - Geo-technical Investigation for Timber Sale Roads" (9).

   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 geotechnical investigation. Figure 19, taken from Appendix E of the Siuslaw National Forest <u>Implementation Plan</u> 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 named "The Stability Index (SI)". It is intended to describe the general 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" (20).

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 (21). This design approach attempts to reduce the

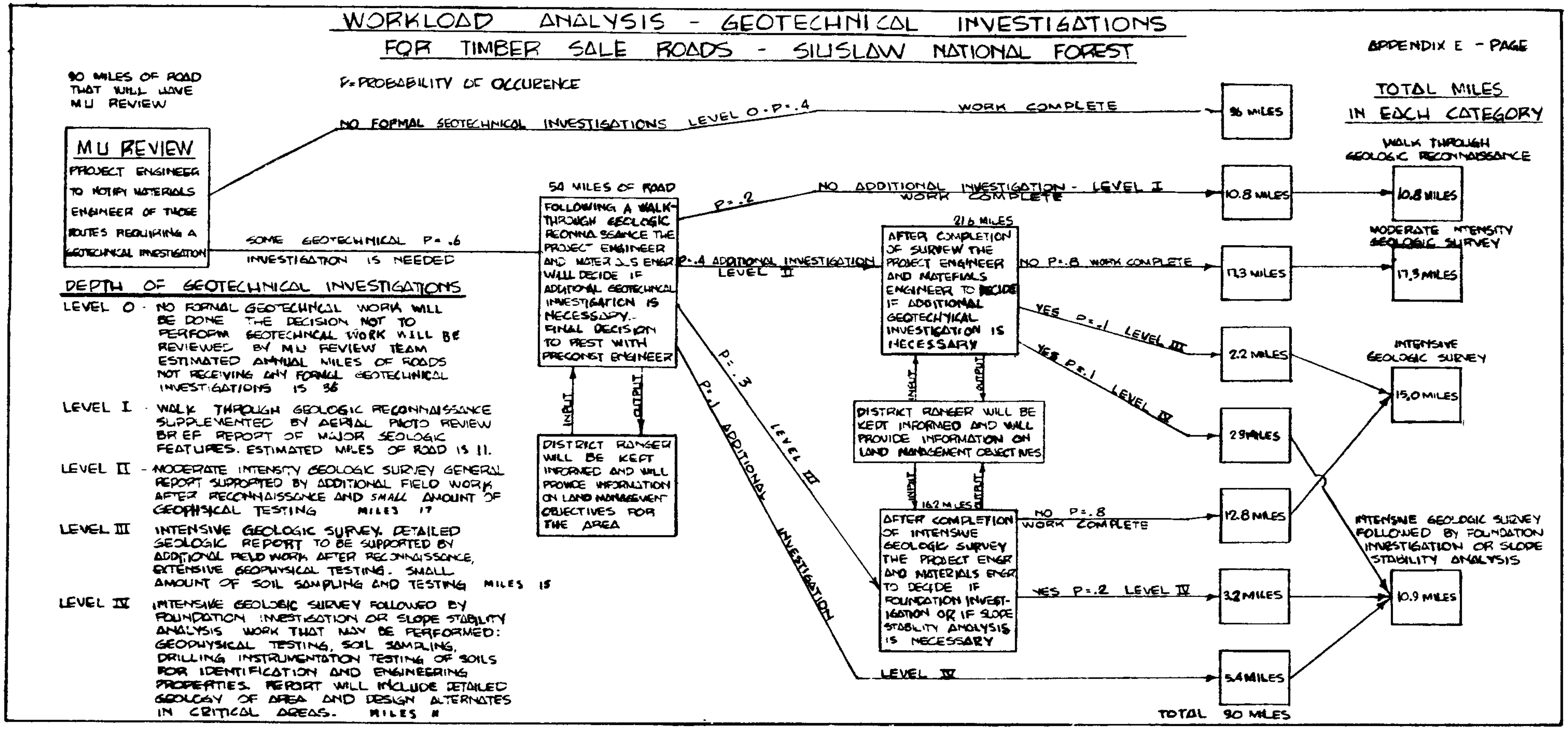

WORKLOAD ANALYSIS - GEOTECHNICAL INVESTIGATIONS
FOR TIMBER SALE ROADS - SIUSLAW NATIONAL FOREST
APPENDIX E - PAGE
90 MILES OF ROAD THAT WILL HAVE MU REVIEW
P=PROBABILITY OF OCCURENCE
MU REVIEW
PROJECT ENGINEER TO NOTIFY MATERIALS ENGINEER OF THOSE ROUTES REQUIRING A GEOTECHNICAL INVESTIGATION
NO FORMAL 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 GEOPHISICAL 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

FIGURE 19

use of intuitive techniques and to substitute a more rational approach. The procedure uses soil strength properties together with 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:

> "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" (22).

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 landslides and snowslides 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 (23).

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" (24). He suggests that control can be accomplished by direct methods of slope stabilization or by avoiding areas of known or expected instability.

Roads and 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 also 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 guidelines for erosion control reported a tendency for an excess of roads with the increased use of heavy construction equipment, "especially if the construction chance is easy." This publication further stated: "Too many roads within an area completely destroy the protective soil mantle" (10).

Fredriksen studied erosion and sediment resulting from timber harvest and road construction in watersheds within the H. J. Andrews Experimental Forest (2). A watershed harvested by clearcutting using Skyline logging without roads yielded less sediment than a watershed harvest by patch clearcutting, high lead logging and parallel logging roads.

Although harvest method - road relationships are not exclusively the forest engineers domain, nor 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 about 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 determining what harvest method is compatible to the type and location of road that can be constructed in the proposed corridor.

A detailed discussion of the road-harvest method relationship is beyond the scope of this report. Harvest systems and road location, density and standards are interrelated. As neither the harvest system nor the road network are independent of each other, both must be considered in the evaluation of total system impacts. 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.

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 necessary.

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 (8). 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"(9).

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" (5). 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 "State of the Art Techniques" in this Chapter, the Siuslaw National Forest has a procedure for determining the depth of geo-technical 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, sedimentation problems have been related to the following oversights or errors.

1. Inadequate geo-technical information.
2. Lack of engineering input.
3. Application of rigid rules regarding horizontal curvature and vertical gradients.
4. Over-roading or misplaced roads due to a lack of or a poor land management and transportation plan.
5. Road locations that 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.

FACTORS AFFECTING SURFACE EROSION

Surface erosion includes sheet erosion and channel erosion. Sheet erosion, including rill erosion, involves the detachment and removal of soil particles by overland runoff, while channel erosion involves removal and transport of material by concentrated flow. The concentrated flows may be contained in large mainstem channels, small tributary drainage channels, or road ditches (25).

Many factors with often complex interrelationships are involved in surface erosion. The primary factors involve precipitation characteristics, soil characteristics, topography, and cover conditions (26, 27, 28, 29, 30).

Precipitation intensity and amount affect both sheet and channel erosion. The higher the rainfall intensity or snowmelt, the greater the detachment and transport of soil particles through sheet erosion and the greater the rate of runoff which is reflected in increased channel flows. As runoff discharges increase, velocities likewise increase.

The erodibility of a particular soil depends upon its resistance to detachment and, once detached to its resistance to transport. The resistance to detachment is primarily controlled by particle-size and aggregation, while the resistance to transport is primarily governed by particle-size. Clays, for example, have very small particle-size and are easily transported by water, but are not easily detached because of high aggregation. Coarse sands or gravels are noncohesive, but are not easily detached or transported because of much larger particle-size. Silts, including fine sands, 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. Silts become less erodible as either the sand and gravel or the clay fractions increase. Also, for a given increment of silt, increases in the clay-to-sand ratio decrease the erodibility (31, 32). Adverse effects upon water quality, however, may be increased with increasing clay content because of the extremely poor settling characteristics of clay thus causing turbidity.

The capability of runoff to detach and transport soil material increases rapidly with increases in runoff velocity which is controlled by topography, among other factors (33). Theoretically, doubling velocity enables water to move particles 64 times larger, carry 32 times more material in suspension, and increase the erosive power 4 times (25).

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.

Sheet erosion is greatly affected by cover conditions. Raindrops striking bare soil act like minature bombs to break up soil aggregates and splatter soil particles as much as 2 feet into the air. Raindrops also compact exposed soil surfaces resulting in 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 feet per second and 1 inch of water over an acre of area weighs more than 110 tons. Sheet erosion is reduced by maintenance of a dense ground cover. Vegetation is the most effective means of providing this cover. Vegetation acts to absorb and disperse raindrop impact and stabilizes the soil surface with a dense mat of roots. Mulches and other forms of ground cover can also be quite effective (34, 35).

Channel erosion is also affected by cover conditions, both in the channel and in the tributary drainage area. Poor areal cover not only results in high rates of sheet erosion but also results in high channel flow. Noncohesive, fine-grained soils such as silts and fine sands erode readily when channel velocities exceed 2 feet per second. Good grass cover in the channel may enable more than doubling of these velocities before serious erosion develops. Riprap cover or other means of channel protection may protect the channel from scour for velocities up to 10 feet per second or more (25).

The relationships among the principal factors controlling soil erosion, notably sheet erosion, have been embodied in several somewhat similar predictive equations (25, 26, 27). Most of the equations presently available have been developed for cropland areas. Of these, the "Universal Soil Loss Equation" for predicting sheet erosion, as presented by Wischmeier and Smith in USDA-ARS Argriculture Handbook 282 (26), has gained the most widespread acceptance. The available predictive methodologies still fall far short of accurate prediction of soil erosion or resultant downgradient sediment production in a forested environment. Additional research is needed to test the available equations for use on forest logging roads, or, if necessary, for development of new prediction techniques.

SURFACE EROSION AND MASS WASTING CONSIDERATIONS

Roads seriously impact the hydrologic functioning of watersheds. In many areas of highly decomposed granitic soil, 90 percent of the increased sediment caused by use of the forests has been attributed to roads (36). Higher runoff rates, increased surface erosion, and mass wasting account for these increases. Much of the soil movement can 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.

During the planning process discussed in a previous section, 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 to detailed investigative programs involving field explorations and laboratory analyses.

A broad-based team of technical specialists should evaluate the available information to develop a road design that best suits the intended purposes while also 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 in this report. Some of the information that should be considered to guard against stream pollution 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 (36).

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 any savings realized from an incomplete or inadequate reconnaissance (12).

Aids

Aids are of primary value during the planning phase. However, use should be made of all available aids, including topographic maps, geologic and soils maps and reports, aerial photographs, and others during the reconnaissance investigations to gain an overall perspective of the route or routes being considered and to obtain any detailed information they may provide. During these investigations, aids should only be used as supplements, however, and not substitutes for field investigations. As a minimum for simple cases where these aids offer sufficient information for design purposes, their accuracy should be field checked. Some of the available aids and potential applications are described in the following sections.

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, or geologic and hydrologic features are easily identifiable from such photographs.

Small-scale aerial photographs provide a broad 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.

Large-scale aerial photographs can be used to refine interpretations made from the small-scale photos as well as enable 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. Small-scale mass movement or erosion activity can often be identified.

Topographic Maps. Topographic maps of various scales are available for most areas. Such maps, particularly the 7½- and 15-minute series, are quite useful for road location and design purposes (37). Information on slope gradients and other topographic features can generally be obtained with a reasonable degree of accuracy, particularly if overstory 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.

Soil Surveys. Numerous types of soils are exposed during road construction in EPA, Region X. They are formed from many different parent materials including glacial till, alluvial deposits, and granite. These soil materials all have various unfavorable physical and chemical properties that affect road performance, stability against surface erosion and mass wasting, and revegetation. Soil or geologic characteristics and related topographic conditions that may affect subsequent road behavior include steep slopes, aspect, shallowness to rock or other restrictive layers, unfavorable pH, low fertility, fine soil 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 national forests. This provides a wealth of information on a broad scale that is well suited to route selection, as well as for 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 EPA, Region X, and the Forest Service has published soil surveys for many of the national forests (16, 17). New surveys are continually being developed by these agencies and older surveys are continually updated. The Weyerhaeuser Company has recently completed and published an extensive soil survey of their land holdings as well as of contiguous adjacent lands.

In addition to providing information on many of the individual soil properties, 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; potential for surface erosion; 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.

Geologic Maps. Geologic maps or reports of various degrees of detail are available for many areas. The maps range in scale from state or areawide to much smaller areas, such as portions of counties or 7½- or 15-minute topographic quadrangles. Depending upon the degree of detail, geologic maps may include information on topography, descriptions and extent of surface outcrop materials, 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.

Other Aids. Several other less used but often equally important aids are of value. These include precipitation intensity-duration maps (38, 39), vegetation maps, hydrographic studies, or other general or detailed reports available for the study area or similar areas.

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 reconnaisssance is to confirm inferences made from other information sources and to gather otherwise unavailable or more detailed information needed for either road location or design. Only in rare cases will published information be detailed and accurate enough to be suitable for final design purposes.

During field reconnaissance, the applicable published information on 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.

The depth of the field reconnaissance is dependent upon the amount of data already available, the importance of the road, and the magnitude of the impacts the road is expected to generate. Generally, more than one field reconnaissance trip will be necessary. These field investigations may be phased and include a preliminary field reconnaissance and soil survey of the corridor by a team of experienced specialists. The team should include an experienced soils engineer, engineering geologist, or similar specialist. The preliminary reconnaissance and soils survey should establish the surface erosion and mass wasting potential within the corridor and areas adjacent to the corridor and potential access of eroded or wasted materials to streams. This preliminary work should also include delineating areas of potential hazard and, where possible, outlining alternate routes to avoid 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 degree of mass 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.

Surface Erosion. Numerous factors affect the potential for soil erosion from forest roads and contribution of such sediments to streams. These factors, which were discussed in a previous section, 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, types and severity; and up-gradient and down-gradient vegetation. Roadway design, including slope protection and drainage provisions, can also have a significant influence.

By far the most important factor influencing surface soil erosion is soil texture and aggregation, although several other characteristics are involved (32). Silt-size particles are the most erodible, and the erosion potential decreases as the percentage of sand or larger and clay-size particles increases. Clay-size particles, however, have more adverse effects upon water quality because of their extremely poor settling characteristics.

Detailed evaluation of the soil texture, aggregation, and other characteristics affecting erosion would be somewhat difficult in the field. However, in many cases experienced field personnel could make a reasonably accurate estimate of the necessary information by visual inspection and by use of shake, pat, kneading, and other types of simple field tests. One such field classification guide to estimate inherent soil erosion potential is shown in Table 4 (40). This guide is based, in part, on the Unified Soil Classification System. This system is presented in Table 5 (41) along with field identification procedures and several simple tests used in classifying soils according to the system.

There are numerous procedures which may be used during a field reconnaissance to obtain soil samples for textural identification. Among these are small hand augers. With the use of extensions, these augers can be used to obtain small samples from depths of 3 to 15 feet. However, these augers are of limited use in soils containing large percentages of gravel or in bedrock. Shallow samples for textural identification can be obtained from hand-dug pits in coarser grained soils. Also, information on shallow as well as deeper soil strata can be obtained from natural or man-made exposures within or near the corridor and these soil conditions correlated with those along the proposed route.

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

TABLE 4. GUIDE FOR PLACING COMMON SOIL AND GEOLOGIC TYPES INTO EROSION CLASSES (40)

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[1/]	SM	Silt (Unconsolidated)(B)	Silt (Consolidated) (B)	Silty clay loam(A)	Clay loam (A)	Loamy sand (C)	Coarse sand (C)	Fine gravel (C)	Rock (C)
	ML	ML	OL	OL	Silty clay(A)	Silty loam (A,B)	Sandy loam (B)	SW SP		Cobble (C)
			MH	MH	Clay, varying with type, cohesiveness & compaction (A)					Gravel (C)
				CL	Sandy clay(B)	Sandy clay (B)	Sand (B)			GW, GP
					SC, GM OH, CH	CH, GM	GC			

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

1/ SM, ML, etc. refer to the Unified Soil Classification System.

TABLE 5 UNIFIED SOIL CLASSIFICATION
(Including Identification and Description)

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.	Gravels More than half of coarse fraction is larger than 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 samller 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 partical 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).		
	(For visual classification, the 1/4 in. size may be used as equivalent to the No. 4 sieve size)				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.		

The No. 200 sieve size is about the smallest particle visible to the naked eye.

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

Source: Reference 41.

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 in order to minimize stream sedimentation. 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 the road design. It is particularly important that road locations be fitted to the topography so that minimum alterations of natural conditions are necessary (42).

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. Because of the near proximity to streams, erosion or mass failures are much more likely to result in stream sedimentation than from roads along more distant alignments. 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 (43).

Roads in valley bottoms should be positioned on the transition between the toe slope and terrace to protect the road slopes from flood erosion and allow road drainage structures to function better and discharge less turbid water into live streams. However, road location in these areas should be avoided if it involves undercutting old slides or landflows. Any stream crossings required 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 (44).

Hillside routes have the advantage of being located away from streams which eliminates flood and stream damage, and intervening undisturbed vegetation acts as a barrier to sediment transport. Disadvantages are higher grades, more excavation, longer slopes, poor alignment from following grade contours, and cut banks that expose soil to erosion (43). When locating roads along side hill routes, benches and the flatter transitional slopes should be used if they are stable. Steep, unstable, dissected slopes, particularly in areas of deep plastic soils or weathered or decomposed rock formations, should be avoided because of potential mass stability problems (44).

Ridge routes have the advantages of good drainage, less excavation, and fair grades (43). Other advantages include practically nonexistent up-gradient slopes and large expanses of undisturbed vegetation or logging slash to act as buffer strips for protection against stream sedimentation. Disadvantages are poor alignment in some areas because of excessive dissection of the ridges, and secondary roads that may have adverse hauling grades and greater total road mileage (43). 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 (44).

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 (40). However, Renner's (45) 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 (46) study also 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. 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 this route is an indicator of other factors, such as soil fertility and moisture regime, but most important 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, up-gradient 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, and numerous locational and design factors such as amount of aggregates in the soil, 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 a following section. 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.

Mass Wasting. The most common and perhaps the most significant erosion from forest roads is mass movement. This is caused by undercutting unstable slopes, improper embankment construction, wasting on steep slopes, and drainage system failures (44). 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. These should be investigated, not only within the corridor, but up and downslope of the corridor.

There are several topographic and vegetation indicators that can indicate 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 (24). These can be identified by experienced personnel.

Other important conditions 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. 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 often difficult to determine; however, an experienced engineering geologist or similar specialist familiar with the area and its geologic history can often provide good approximations after a field reconnaissance. A geophysical survey may be applicable in some areas to evaluate overburden thickness but they are often expensive (47, 48). It must be realized that a geophysical survey cannot be used to 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; locating areas which exhibit some thickness of soft, spongy, highly organic materials; or from a geophysical survey. In unconsolidated materials the water table may be located by relatively shallow explorations such as hand-dug pits, hand-auger holes, or by probing.

After compilation and interpretation of the data obtained during the reconnaissance, areas that 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. Such an investigation should be specifically tailored to the field conditions at each site.

The conditions encountered during construction may vary somewhat from those encountered in the geologic reconnaissance due to the complicated nature of deposition and formation of soils and bedrock. Provisions should be made to alter the design during construction according to the actual conditions encountered.

In addition to in situ factors as discussed above, the design of the road can have a very significant effect on mass stability. Roads that impose themselves on the landscape because of poor location or overdesign (e.g. excessive width, large cuts and fills to avoid occasional steep gradients, large radii curves, etc.) rather than conform to the landscape are the primary cause of excessive mass stability problems on many roads. In order to avoid designing mass stability problems into roads, road alignments should follow the existing topography to the extent possible and be designed to meet the minimum standards (e.g. minimum width, minimum length and height of cut and fill slopes, etc.) consistent with their intended use.

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 guidelines in the light of actual field conditions.

Harvest Method

Planning aspects of the road-harvest method relationship are discussed in the planning part of this Chapter. Adoption of modern logging methods such as cable, balloon and helicopter appears to be increasing partially due to environmental constraints that have the effect of reducing the miles of spur and secondary roads. In addition to less roads, the advantage from the sediment aspect is that landings for some of these logging methods 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. Downhill yarding can concentrate ground cover disturbance at the road or landing and may create the potential for sediment movement to roadside ditches.

Although high lead systems are used in Alaska, downhill (e.g. Grabinski) 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. However, equipment size may place constraints on allowable horizontal road curvature and equipment weight may require closer scrutiny of the stability of proposed landings or the road itself if it utilizes a road turnout as a landing.

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, and 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 for 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.

Route Placement

In the process of establishing a route, the engineer may ask himself the following questions as a guide 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 or of success?
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 when there is 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 including 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 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 (2), 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 percent 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 percent 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, the terrain and the terrain slope between the road and stream to act as a natural barrier to the transport of sediment should be made. Brown believes there are limits to the value of the buffer strip in dissected terrain because buffer strip function 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"(1). The effectiveness of the buffer strip may vary with the texture of the soils.

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 Frederiksen's studies in Western Oregon watersheds (2), and Jack S. Rothacher and Thomas B. Glazebrook's evaluation of Region 6 flood damage during the 1964-1965 floods (11).

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 the field reconnaissance portion of the Route Reconnaissance section.

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 phenomenon can occur. Megahan observes that conditions are ideal for its occurrence in the Idaho Batholith (49). The potential for this occurrence should be evaluated during reconnaissance so that the designer may recognize ground water effects in his design of drainage features and his evaluations of cut and fill stability.

Field Survey Information

In addition to the normal route traverse and cross sectioning done by route surveyors, there are 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 6 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 topographic data required.
4. The engineer, from his field reconnaisance, may direct the route surveyor to take notes on natural residue and debris that 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 their condition.
   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.
   i. Natural slumps and slides.

Survey notes are one of the designer's basic aids. Recorded observations by survey crews and accompanying sketches, if appropriate, are of great

TABLE 6

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 activity.
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 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" (8). 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.

ECONOMIC EVALUATIONS

The introduction to this report suggested that when sediment control design criteria was the same or parallel to other road design criteria, a road design specifically including sediment control features may cost no more. 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 contributions to improved water quality and quantity"(36).

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. A narrow road constructed full bench with a requirement that the waste be endhauled may cost more than a wider road constructed without full benching and with no specific waste disposal requirement. This latter procedure was often used.

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 can be analyzed by comparing 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 fo· 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" (50).

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 7 and 8 demonstrate the value of an investment in roadway ballast as the annual cost of gravel roads is less than stabilized and primitive roads. On the basis that ballasted roads have less potential for sediment production than primitive roads, the ballast investment pays in terms of sediment minimization as well as minimum annual cost.

TABLE 7

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
	Dollar 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 8

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.

On the basis that the minimum road has less environmental impact, Gardner suggests that the user cost for the environment is represented in Table 9 by the difference in annual cost between two lane paved and one lane gravel roads (51). Ignoring environmental considerations, the lower annual cost road is a two lane paved one when traffic is 20,000 vehicles per year or more. With environmental factors requiring a one lane gravel road, the annual cost is greater for more than 20,000 vehicles per year.

TABLE 9

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

The cost figures shown in the table are not applicable to all of Region X. Gardner's work was published in 1971. However, he does suggest a cost analysis approach that includes environmental considerations.

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 (52).

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" (53).

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 this, culverts and bridges should be designed to survive an anticipated storm event. This means that hydrology studies and site surveys at bridge and culvert crossings are necessary. Hydrology studies and detailed site surveys cost money and the results of these studies may produce large capital expenditures. Even so, 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" (11). This estimate does not include down time cost or other inconveniences which accompanied these losses. The flood damage estimates 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. Seeding slopes 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.

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" (5).

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

When initiating a design, a designer must grasp an understanding of the field work, reconnaissance and planning that has preceded him. He must also understand management objectives and policy. This information may be provided in a number of ways depending upon the organization's structure. In some organizations, the designer has been a part of the reconnaissance, and will be the construction supervisor. In others he may have only limited personal contact with reconnaissance people. Regardless of the organizational size and procedures or the designer's 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 it will be principally a truck haul road, log landing or yarding platform, 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 conditions 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.

The designer must familiarize himself with erosion control and roadway stabilizing techniques. He must also be committed to sediment control and to the exercise of a degree of creative thinking.

This chapter is divided into four parts. The first part discusses matters of the roadway design itself, the second part is devoted to features 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, the third part is devoted entirely to drainage design including ditches, culverts and stream crossings. The last (fourth) part discusses features of the construction specifications, prepared as part of the design task, that support the goal of minimizing sediment.

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 help resolve key details and controls that will appropriately refine and execute the reconnaissance and planning information. This part discusses sediment features of the following roadway design elements: alignment, roadway prism, roadway surfacing, buffer and filter strips.

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 the previous chapter 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. With the aid of field surveys, geotechnical, civil and forest engineering information, he can adjust the horizontal and vertical alignment to the terrain with companion attention to road use requirements.

The potential for generating roadway sediment can be mitigated by utilizing a horizontal alignment that reduces roadway cuts and fills, and avoids or minimizes intrusion upon unstable ground. If necessary, the designer must have flexibility to adjust curve radii 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 with other features.

Vertical alignment, like horizontal alignment, can be used to help control 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 percent will prevent ponding and reduce subgrade saturation.

Roads from log landings provide another opportunity to practice sediment control and preventive maintenance. A 5 percent 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 discussed further under Road Surfacing.

ROAD PRISM

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

Excavation

Back slopes can contribute up to 30 percent of the total road sedimentation and up to 85 percent of the first year road sedimentation (43,4). Sediment can be reduced by slope stabilization techniques as considered in the next part and/or by designing the back slope for the given soil characteristics. The Route Planning and Reconnaissance chapter discusses geotechnical and engineering reconnaissance techniques to develop field data for the design of stable back slopes. There are two approaches to back slope design, one is experience, and the other is rational or technical procedure.

Use of "rules of thumb" or "standard" backslope steepness guides without knowledge of specific soils conditions is dangerous. However, 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.

The route planning discussion in the previous chapter noted that the U.S. Forest Service has adopted a method of specifying cut and embankment slopes developed by Hendrickson and Lund (21). This concise, rational method does not require extensive laboratory equipment to obtain soil type, grain size, and distribution for the unified soil classification. It also considers 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 that accompany the design guide (22).

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 (54).

Vertical cuts in banks less than six feet are being tried in various parts of Region X including Idaho and Alaska. The rationale 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.

Embankment

Numerous researchers suggest that fill slopes are significant initial producers of road sediment. They also point out that fill slope erosion can be drastically reduced by erosion control techniques.

Mass failure of the fill is the other source of sediment. Mass failures can be the result of poor fill material, improper fill compaction, incorrectly designed fill slope, improper foundation preparation, weak foundation support, improper culvert design and installation within the fill, or a combination of one or more of these conditions. 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, can also be applied to embankment design.

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 lack of proper ground preparation by clearing and stripping vegetation and organic material. A further problem has been the presence of too much organic matter in fill material. The next chapter discusses fill placement techniques.

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. This suggests 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 required area of supporting ground that must be utilized to support the superimposed load. The chapter on Construction Techniques discusses fill compaction.

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 also aids in equipment operation when the ground is soft.

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 the third part of this chapter.

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

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 of bituminous surfacing.

There is no doubt that durable surface roads result in less potential for surface erosion. However, surfacing a road does not necessarily eliminate sediment problems. In many parts of the region the logging season carries into wet weather periods and, in lower elevations, logging may continue year around with only occasional winter shut-downs. Log hauling operations during this period place additional demands on roads. It is the designer's 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 percent minimum to insure the movement of surface water. This reduces potential subgrade saturation.

In addition to designing a road base and surfacing to support truck traffic and road crown selection, the following are other design considerations that may directly or indirectly affect 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--spaced, transverse surface depressions are often used as cross drains on steep longitudinal grades. However, they require continual maintenance if they are placed on too flat a grade. A minimum longitudinal roadway grade of 5 percent is suggested for use of water bars.
6. If steep grades in excess of 10 percent are used, asphaltic concrete or bituminous 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 which wears bridge decks, and washes sediment 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 (51).
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 the drainage section.

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 the third part of this chapter. Reservations regarding the ability of vegetation and terrain to act as a barrier to sediment movement as expressed by one writer are mentioned in the discussion on route reconnaissance.

Most of the data developed is based on studies 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" (55).

Haupt pointed out that the method was a tool for 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 20, "Obstruction Spacing", is reprinted from Packer's 1967 Study (56). Packer also discovered that, as the age of the road increased, the distance sediment moved downslope also increased. This was because the 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 spacing. Table 10 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 (46). This field manual is pocket size and contains a complete treatment of the subjects of cross drain spacing, and protective strip widths. It also tells how to apply the information in a manner that will control erosion and sediment. The booklet is geared for use in USDA Forest Service Northern Region.

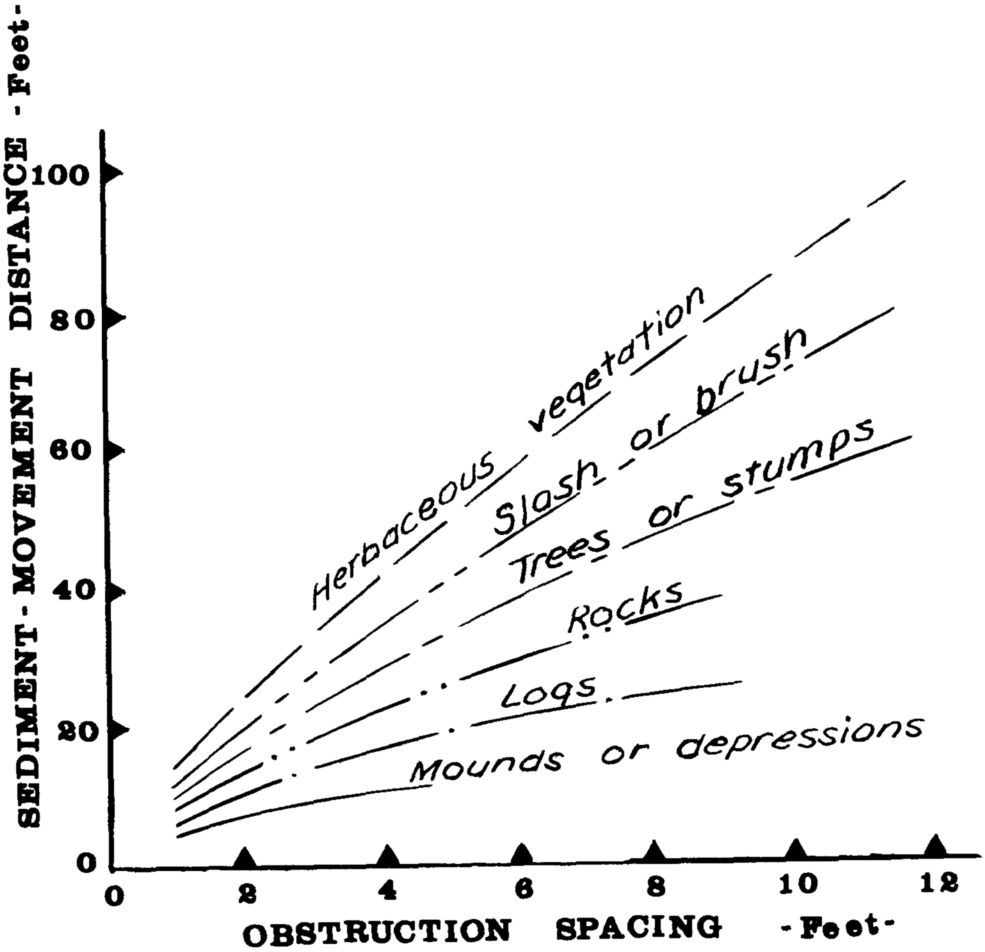


FIGURE 20

Distances of sediment movement down-slope from the shoulders of logging roads built on soil derived from basalt, having 30-foot cross-drain spacing, 100-percent fill slope cover density, and zero initial obstruction distance under varying obstruction spacings and kinds of obstructions.

TABLE 10

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).

Protective-strip widths						
Obstruction spacing	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, increase 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.

SLOPE STABILIZATION

Stream sedimentation can result from surface erosion or mass wasting. Some of the measures which may be utilized to reduce surface erosion and mass failures are discussed in the following sections.

SURFACE EROSION

The construction of forest roads is the major cause of stream sedimentation in the forest harvest system. Large quantities of sediment are produced from roads 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 help establish vegetation and to reduce erosion during this critical period. The various types of slope stabilization procedures and their effectiveness in reducing sedimentation are discussed in the following sections.

Seeding and Planting

Introduction. Numerous studies indicate that forest cover is among the most effective vegetation in maintaining and protecting soil from erosion (43). This cover reduces the effects of raindrop impact; 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 (57).

Revegetation by seeding and transplanting 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 (58).

The decisions as to which plant species and methods to use in EPA, Region X, for roadside stabilization are currently made by a variety of agencies and individuals, usually the Soil Conservation Service, individual county extension agents, landscape architects, and the Forest Service. These decisions depend upon the management objectives, financial problems, and the unique soil and climatic features of each site. Although there are published standard specifications for erosion control using revegetation techniques, the actual methods used by the Forest Service vary from forest to forest and even among districts of a given forest (59).

Revegetation Objectives. The main objective of seeding roadsides is stabilization of soils against surface erosion. Recolonization by native shrubs and herbs is generally encouraged (60). Native plants generally require less expense and maintenance as well as being visually harmonious with the forest landscape although many exotic species are also well suited for this purpose. In addition to physically enhancing the soil, seeded grasses and legumes[1/] improve the organic-mineral balance of road-cut soils. They also act as "nurse plants" to young native species by providing shade thereby reducing evaporation from the soil.

1/ 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.

Grass seeding is usually considered as an erosion prevention treatment applied at a sacrifice to tree regeneration, although tree regeneration is not always sacrificed. In southeast Alaska, grass seeding of exposed mineral soils helps establish spruce and hemlock seedlings by reducing the disruptive influence of frost heave and by retarding alder invasion (61).

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 EPA, Region X, because they absorb large amounts of water from the soil and, in effect, dry it out. They are also more deeply rooted than grasses or legumes.

Seed Mixtures. The proper seed mixture for a particular site is dependent upon many factors. Among these are (1) slope stability, angle, aspect, and exposure; (2) general climatic conditions, including conditions at the time of planting; (3) competitive ability of species to be planted in relation to native weed species or desired ultimate vegetation establishment; (4) susceptibility to foraging by livestock and big game species; (5) visual and aesthetic considerations; and (6) physical and chemical characteristics of the soil. Soil conditions are particularly important because much of the material is often C-horizon soils at best and not well suited for growing vegetation.

Because of wide variations between sites and the adaptability of individual grass and forb species, no specific grass mixtures are recommended in this report. Unless related to individual site conditions, specific mixture recommendations are of little value. Appropriate specialists should be consulted in each case to tailor the seed mixture to site conditions. These specialists include soil scientists, agronomists, ecologists, range conservationists, and wildlife biologists within the Forest Service and Soil Conservation Service; universities; extension agents; landscape architects; and consulting biologists.

Rarely are grasses seeded without legumes, and the choice of legumes is an important decision (62). 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 (59). Seeding a legume requires that one also applies an inoculant of the associated root bacteria. The inoculant is usually "glued" to the legume seeds before the seed mixture is made (63).

Several legumes including big trefoil, white Dutch clover and New Zealand white clover, birdsfoot trefoil, and alfalfa have been found suited for use in the Northwest (59).

However, one problem of including most legumes in a seeding mixture is their high palatability to deer, elk, and livestock. Alfalfa is particularly palatable. Grazing animals will trample out mechanical structures, pack the soil, and create a more erosive condition than existed prior to seeding (10). Legumes should not be included in seed mixtures on sites readily accessible to big game animals, cattle or sheep. The Forest Service Experiment Stations are continuing to search for vigorous, unpalatable legumes to use in seeding mixtures (59, 62, 64).

Planting. Planting in logging road stabilization is for utility, not aesthetics. Where soils are plastic (e.g., silty and clayey), growth of native willows or alders should be encouraged because they inhibit slumping by depleting 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 EPA, Region X, and nearly all root readily from cuttings, as do the alders.

Recent research in Idaho indicates that many native forbs have outstanding qualities for roadway planting. The most promising species is Louisiana Sagebrush (Artemisia ludoviciana).

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 (60). This procedure is not yet used in Idaho or Alaska (64, 65), primarily because of the expense.

Techniques Used in Establishing Plants. Seeding, as mentioned previously, 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 seed and water slurry to the soil, in some cases followed by an application of fertilizer and mulch (63). If seed and mulch are applied simultaneously, much of the seed may stick to the mulch and never contact the ground. A variety of mulches--wood cellulose fiber, ground hay, ground newspaper--have been applied by this method.

Hydroseeding is used in all parts of EPA, Region X, by highway departments. In Oregon and Washington, the Forest Service hydroseeds (60). The use of cyclone seeders and seed blowers is quite common for areas which cannot be hydroseeded because of the expense involved. The Forest Service in Alaska usually uses a cyclone seeder (64). In Idaho, seeding is typically accomplished by using a cyclone seeder. If the seedbed is packed, it may be necessary to drill the seed (10). Drill seeding is superior where it is possible, but it is limited to only the flatter slopes.

Hand planting is generally restricted to critical areas with high priority because of the high cost. Hand planting of grass or legume plants in Washington and Oregon is done in difficult to reach places (60).

Proper seedbed preparation is very important. The soil surface, if not freshly prepared, should be roughened along the contours in order to reduce the chance of rilling and to provide small depressions which retain the seed.

When to Seed or Plant. From the standpoint of minimizing sediment production, roadside revegetation should be started as soon as roads are constructed if conditions are favorable. The highest volume rate of soil movement off road cut and fill slopes is in the one to two months immediately following road construction (66, 67). If this period does not coincide with the season which favors the species being planted, mulches or other temporary stabilization measures should be used in the interim period.

Generally, seeding during the spring or fall is best. Summer seeding should generally be avoided because of limited moisture availability. In western Washington and Oregon, seeding before the fall rains is recommended. One source reported success with seeding in September, another in April (66, 67). In Idaho, seeding should be done in late summer or early fall in order to take advantage of the fall rains (10). 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 (68). For quick temporary cover in Alaska after the recommended planting season, annual ryegrass can be seeded immediately, followed by seeding perennial grasses the next spring or summer (69).

The advantage to seeding and planting prior to fall rains is that the newly introduced plants are not subjected to undue moisture stress as in summer. This is especially true in dry areas such as eastern Washington and Oregon and southern Idaho.

Fertilizers. In all cases, application of fertilizer enhances revegetation. Fertilizer should be applied at the time of seeding and again the following spring. Subsequent fertilizations at one or two-year intervals may be required in some instances, particularly where soils are composed largely of B- and C-horizon materials which are normally very low in nutrients. The fertilizer type and quantity, as with seeding mixtures, should be tailored to the individual conditions encountered at each site. Usually, a nitrogen-phosphorus-potassium fertilizer is sufficient; although if the soil pH is less than 5, an application of lime may be required (69). In general, ammonium phosphate (15%N, 20%P and 0%K), ammonium sulfate (21%N, 0%P, 0%K and 24%S) is excellent. Soil sampling and testing will reveal any serious nutrient deficiencies, and fertilizer types and application rates can be tailored to satisfy these deficiencies.

Because native shrub and grass establishment is the primary goal of roadside grass plantings on Forest Service roads in Washington and Oregon, only one to two fertilizer treatments are applied. Continued fertilizer treatments result in such a vigorous growth of the seeded species that the natives cannot establish on the seeded area (60).

Mulching. Mulching is essential if a good seedbed cannot be prepared, if soil is highly erodible, or if slopes are steep (70). If seed cannot be applied immediately after construction, the application of a mulch alone will greatly reduce soil movement down the slope. 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. Mulches are discussed in more detail in a subsequent section.

Summary. In spite of the variety of revegetation methods used in EPA, Region X, 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. The seed mixtures used in Region X should be tailored to the conditions existing at each site. 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. Hand planting is expensive but necessary in hard to reach spots. Application of slope stabilization measures should be commenced immediately after construction. The best season to seed is generally fall or spring. Applying fertilizer and a mulch consistently improves seed germination and growth and minimizes erosion which can take place before the seedlings are established.

Mulches and Chemical Soil Stabilizers

Introduction. Measures intended for overall surface soil stabilization of broad areas, exclusive of vegetation, can generally be classified as 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 (58, 71). 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 (58, 71). 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 (58). 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 are hay or straw, woodchips, and small stones or gravel. For some types of mulch, 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 (58). In order for mechanical attachment to be effective, the surface of the slope must be free of significant quantities of rock material.

Besides their use for mulch stabilization, many of the chemical stabilizers and netting products are designed to themselves protect slopes 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 (58). 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 to establish vegetation and control erosion. 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. In the following sections, the need for slope protection to aid vegetation establishment and control erosion and the relative effectiveness of various types of mulches, mulch rates, and chemical stabilizers will be discussed.

Need for Slope Protection During Vegetation Establishment. Mulches serve two primary purposes during vegetation establishment: (1) preventing erosion while vegetation is becoming established, and (2) providing a suitable microclimate for vegetation establishment. Both functions are important. If severe erosion occurs, most of the seed is generally washed off the slope, resulting in poor vegetation establishment even if the microclimate is suitable. After vegetation is established, the need for mulch or other protection rapidly declines.

Numerous investigators have concluded that a good mulch or similar cover is essential to protect against erosion for the first few months following construction. Dyrness (66) found that test plots seeded in early fall in Willamette National Forest 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, the only plots that showed consistently high losses by surface erosion during vegetation establishment were the unmulched plots. It was also noted that 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. He 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 (72) in Boise National Forest, Idaho on 80 percent fill slopes yielded much the same results. The results of their research are provided in Table 11. Test plots without treatment or with mechanical or chemical treatment combined with seeding and fertilization lost soil at rates of 70,000 to 100,000 pounds per acre during the first 80 days after treatment. Other plots 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 (73) found that soil losses from simulated rainfall on an unmulched plot was over 20 times that of well protected test plots. Other investigators, including Plass (71) and Barnett, et al (74), have observed similar results.

Research results, however, differ considerably over the value of mulch protection to establishment of vegetative cover. Apparently, this depends on the severity of environmental conditions. In Oregon, Dyrness (66) found that seeded but unmulched plots produced good vegetative cover and that mulch without seeding also produced good vegetative cover. Only the control plots without seeding or mulching produced poor vegetative cover. Similarly, Plass (71) tested the effects of numerous mulches and chemical soil stabilizers on vegetative establishment in the eastern United States and observed that some mulches and chemical soil stabilizers improve the growth and vigor of grasses, while some appear to have the opposite effect.

TABLE 11

COMPARISON OF CUMULATIVE EROSION FROM TREATED PLOTS ON A STEEP, NEWLY CONSTRUCTED ROAD FILL (IN 1,000 LBS. PER ACRE) (72)

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							
		1	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

Description of Treatment Measures:

Plot Number	Type of Treatment
1	Control - no treatment at all.
2	Contour furrows, seed, fertilizer, holes.
3	Contour furrows, straw mulch, seed, fertilizer, holes.
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.

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

Mulch and chemical soil stabilizer application 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.

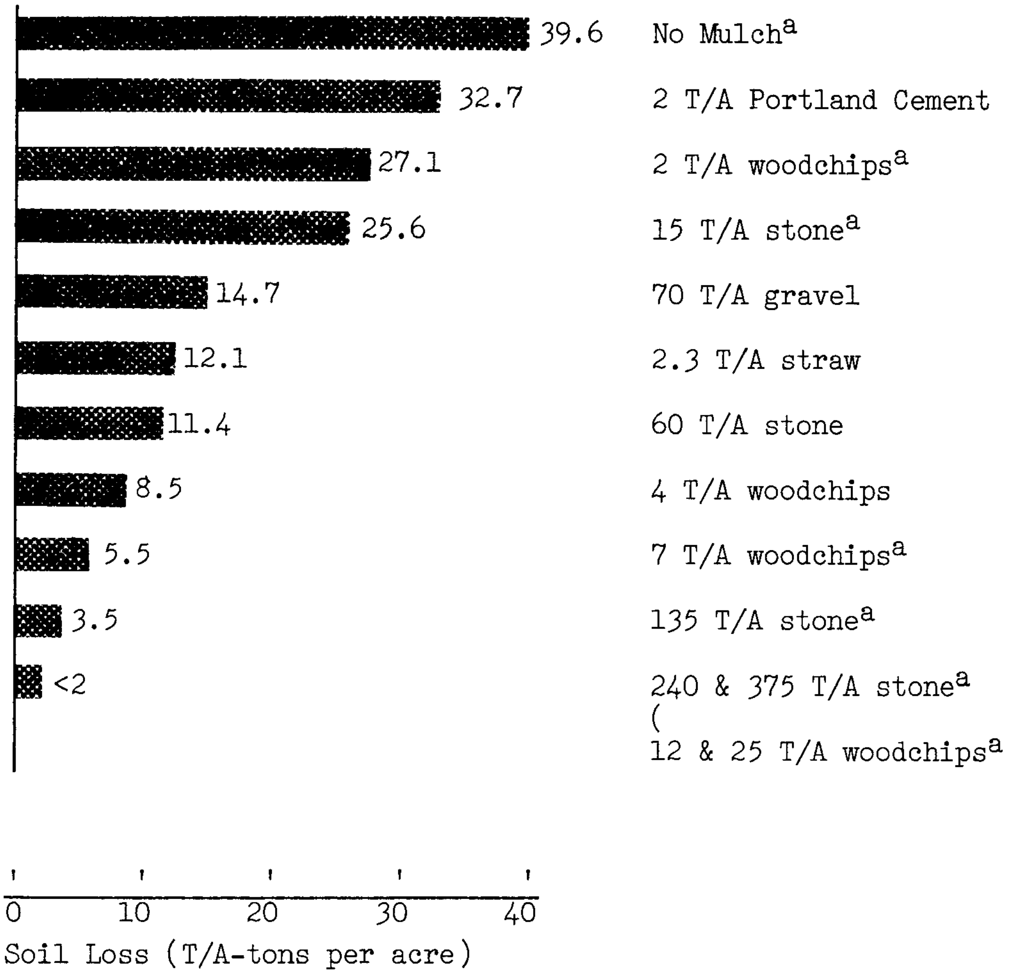
In their tests, Meyer et al (73) concluded that good mulch protection was necessary to establish vegetation. Stands having more than 75 percent of the seedlings necessary for complete cover were established on test plots mulched with 240 and 135 tons per acre stone, 12 tons per acre woodchips, 70 tons per acre gravel, and straw-mulched slopes. Unmulched plots, cement-stabilized plots, and 15 tons per acre stone-mulched plots had very little vegetation establishment.

Other researchers have reached similar conclusions. Heath (75) 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 (76) have stated that using mulch over seedings often made 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 (77) who concluded that mulches aid in turf establishment, particularly under environmental and moisture stress.

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 (73). 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 completely ineffective under others. The performance of several types of mulch products in controlling erosion and establishing vegetation under various conditions are compared in Tables 11 and 12 and Figure 21.

FIGURE 21

SOIL LOSSES FROM A 35-FOOT LONG SLOPE (73)



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

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

Slopes: Uniform 20 percent

Rainfall Rate:

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

TABLE 12

EROSION CONTROL AND VEGETATION ESTABLISHMENT EFFECTIVENESS OF VARIOUS MULCHES (78)[1/]

	Jute	Excelsior	Straw	Straw & Asphalt	Asphalt	Wood Fiber	Sod
Erosion Control							
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.						
Vegetation Establishment							
1.5:1 glacial till cut slope	7.5	9.0	7.5	8.5	7.5	6.0	-
2:1 glacial till cut slope	8.9	9.5	8.0	9.3	8.7	6.2	-
2:1 sandy loam fill slope	9.0	10.0	9.0	10.0	7.5	8.5	10.0
2.5:1 silt loam cut slope	5.0	10.0	-	7.8	6.0	-	-

1/Effectiveness rating: 10.0 = most effective, 1.0 = not effective.

TABLE 12 (cont.)

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.

Application 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/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.

Straw (or hay) is one of the oldest and probably by far the most commonly used form of mulch material. Straw mulch has proven to be quite effective if slope gradient, slope length, and rainfall intensity are not excessive. In his studies, Dyrness (66) found straw mulch applied at a rate of 2 tons per acre to be relatively effective in reducing erosion. Bethlahmy and Kidd (72) found straw mulch to be quite effective when supplemented by mechanical treatment measures or netting (Table 11). Goss et al (78) have noted that straw mulch alone is moderately effective in a number of erosion-prevention applications but that its effectiveness is improved when used in combination with an asphalt tack (Table 12). Straw plus asphalt emulsion was found to be one of the most effective mulches in controlling erosion and establishing vegetation. Meyer et al (73) indicated that straw mulch is moderately effective in preventing erosion but that its performance is considerably exceeded by suitably heavy applications of other mulches (Figure 21).

Several researchers, including Meyer et al (73), have observed a breakdown of straw mulches due to rill formation. Besides problems with rill formation, straw mulches must also be protected from strong winds (58, 78). 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 both rill formation and wind erosion.

Chemical stabilizers, used as the sole means of slope protection, generally cannot be relied upon to be as effective as several other measures (Tables 11 and 12). 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 vegetation establishment (71, 78).

Chemical soil stabilizers, by virtue of their chemical composition, can affect vegetation establishment. Plass (71) 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 (79).

A wide variety of chemical stabilizers, probably totalling 40 or more, with differing performance levels under differing environmental conditions are available. Of the numerous products available some may 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 12) found one such product (Excelsior) to be the most consistently effective product tested for both erosion control and vegetation establishment. Plass (71) 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, are also effective in preventing erosion. Use of jute netting is particularly attractive where high tensile strengths are needed to protect against shallow surface slump erosion during the initial postconstruction period before natural consolidation processes can act to increase the soil strength (Table 12). 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 (78).

Meyer et al (Figure 21) 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 than 2 tons per acre of straw mulch. Resistance to rill formation is a prime advantage of stone and gravel mulches. They tend to impede rill formation by sloughing into them, rather than bridging them as do straw mulches or being washed 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 (73).

Stone mulches also appear to have other advantages. Meyer et al found that grass stands on inert stone and gravel plots were much more vigorous than those 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 makes them uniquely valuable for permanent applications where vegetation cannot be established.

Woodchip mulches appear to have promise for forest applications. Along with stone mulches, Meyer et al (Figure 21) 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 on 35-foot long slopes than 2 tons per acre straw mulch. Woodchip application at a rate of 25 tons per acre ($1\frac{1}{2}$ inches depth) offered good protection under relatively severe conditions of 20 percent slopes as long as 160 feet (73). Crabtree (80) 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 compared to other mulches such as straw or hay, require no tacking to hold them in place, and the raw materials for their manufacture are readily available in forested areas.

An adequate rate of woodchip application and uniform distribution of the mulch material is particularly important. Meyer et al (73) 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. Anchoring the woodchips with asphalt or other materials might improve their performance at some application rates (81).

As mentioned previously, vegetation on woodchip mulched slopes generally exhibits a nitrogen deficiency. Application of about 20 pounds of additional nitrogen per air dry ton of mulch is required when wood products are used.

Wood fibers have proven beneficial in preventing erosion when used alone or in combination with chemical soil stabilizers. The Washington State Highway Department has found that wood cellulose fiber, particularly when used in combination with chemical binding agents to enable them to better resist wind erosion, is an economical and successful alternative in western Washington where straw is not readily available (79). A University of California study (63) 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 losses of 81,000 pounds per acre where no fiber was applied. 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 (71) reported that plots treated with soil stabilizers lacking wood fibers generally did not have as tall or dense vegetative cover as when stabilizers with wood fibers and other mulch products were used. Plass noted that there is a growing trend toward incorporating wood fibers into 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 than 3 to 1 (78). Crabtree (80) found when wood fiber was applied at rates of 1,000 to 1,400 pounds per acre on 3 to 1 slopes in Iowa, it was only poorly to moderately effective in checking erosion.

Mechanical Treatment

Introduction. Mechanical measures can inhibit erosion on slopes. Several such measures are currently being successfully used. They consist of diversions and terraces, either atop or on slope faces; 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 purpose 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 a reduction of effective slope length and an increase in infiltration. These measures can also prevent concentration of flow in erodible areas and 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.

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

Terraces and diversions are not applicable for some soils on steep slopes. During periods of high moisture inflow terraces can become saturated, leading to slump failures. Use of terraces on slopes exceeding approximately 40 percent is not recommended in the Idaho Batholith.

Diversion outlets should be located where water will empty into natural drainage channels or into relatively low-gradient upland areas between drainage channels. Care must be exercised to avoid excessive flow concentration or erosive velocities when conveying or discharging water. Buffer strips of vegetation between points of discharge and stream courses are extremely desirable to allow sediment to deposit.

Serrations. Serrations are steps or benches in steep slopes. The areas between the steps are generally constructed vertical, although they can be sloped. If properly located and designed, serrations reduce slope length and divide the volume of runoff into workable slugs that can be more easily handled. They are usually constructed level to retain precipitation in place, but they can be graded with a longitudinal gradient and an outside edge higher than the inside to function as diversions.

In addition to their function of retarding runoff, benches provided by serrations also improve the microclimate for vegetation establishment on steep slopes. The flat areas better enable vegetation to gain a foothold.

Serrated slopes are a relatively new method of erosion control and are only applicable under certain conditions. These conditions include cut slopes of soft rock or similar material that will stand vertically or near-vertically for a few years in cut heights of approximately a couple of feet. Several states, including the highway departments of Washington (82) and Idaho, are currently using this method successfully in selected areas.

Serrations generally consist of steps of 2 to 4 feet cut vertically and horizontally along the normal, intended slope gradient. After construction, the slope is seeded, fertilized, and mulched as with 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, generally after vegetation has become well established. If the slope material is soft, the slope should be allowed to slough before seeding until about one-third of the steps are filled. Otherwise, grass may be destroyed by the excessive rate of initial slough. This method is not applicable to soil types where the rate of slough is so high that vegetative cover is buried and destroyed.

Roughness and Scarification. Smoothly graded cut-and-fill slopes are attractive to the eye, but they do not benefit erosion control and establishment of vegetative cover. Roughness and scarification serve to increase infiltration and impede runoff (58). If the surface is to be seeded, the roughness or scarification marks retain seed even after severe runoff. These measures also help mulch adhere better to the slope.

Slopes may be roughened by a wide variety of construction methods. Soils can be scarified with a bladed implement having a ripper attachment which loosens surface soils in place without turning them over. Deep-cleated dozers traveling up and down the slope can be used to obtain a satisfactory texture on slopes that are too steep for normal equipment operation. The Washington Highway Department (79) has found that a sheepsfoot roller works well for roughening slopes.

The texture of the roughened slope should trend perpendicular to the flow direction (58). Up and down or angular cross slope roughness texture causes flow concentration, which is harmful. Also, care must be exercised to prevent excessive loosening of the upper soils such that the propensity for rill and slump erosion are increased.

MASS WASTING

Mass wasting is the primary cause of stream sedimentation in many areas of EPA, Region X. Mass wasting problems are most common in the coastal regions where rainfall is greatest, but they are by no means limited to these areas (2, 6, 24).

Mass wasting occurs when gravitational and other forces, such as seepage or seismic, which act on a soil or rock mass are greater than the strength which can be mobilized within the mass. The resulting instability usually involves a net downward migration of the mass until a condition of temporary or permanent equilibrium is attained.

The two primary forms of mass failure are (1) deep, rotational types of soil movement, including slumps and earthflows, and (2) shallow debris movements, including rockslides, debris avalanches, and debris flows. The latter type of movement is more common in mountainous forested areas. Debris movements are likely to develop suddenly in bedded sediments or on shallow, relatively coarse-textured, cohesionless soils on steep hillsides. They are characterized by rapid downslope movement of fractured rock, soil, and/or organic material along a slip surface roughly parallel to the topographic surface. Large rotational slumps, earthflows, or soil creep are most likely to occur in deep, saturated, fine-textured soils on more moderate slopes (19). These will normally extend over a lesser area. Slumps and earthflows are relatively fast moving, but may be preceded or followed by soil creep which can occur over a very long period.

Many factors are responsible for mass failures along logging roads. In some cases, a specific factor can be isolated, but usually a failure is caused by several interrelated factors. By far the greatest proportion of these influences along logging roads are directly or indirectly related to human activity. Specific factors include undercutting of unstable or marginally stable slopes, oversteepening of cut and fill slopes, sidecasting of excavated materials on steep slopes, improper embankment construction (particularly compaction), and drainage system failures (3, 5, 19).

Often the basic causes of mass failures are "overroading" and "overdesign." Overroading or misplacement of roads results from a poor land management or transportation plan. Overdesign of roads results from rigid application of design criteria regarding curvature, width, gradient, and cut and fill slope steepness; or design of roads to higher standards than required for their primary intended uses. By lowering design standards when possible and allowing flexibility in application of alignment, width, grade, and other design criteria, many mass wasting problems can be avoided (6, 19). This is particularly true where it is possible to reduce cut and fill slope heights or roadway widths.

The maximum control of mass wastage is achieved by concentrating on preventive measures prior to and during construction rather than attempting to control problems after the fact. The control of sedimentation resulting from mass movement near a stream is virtually impossible once the mass movement has occurred. Minimization of mass wastage can take place only by thorough planning and reconnaissance investigations as discussed in previous sections.

Unfortunately, of all causes of stream sedimentation, mass movement is the most difficult to predict in advance. No precise universal rules can be developed relating the main causative factors of slope steepness, soil strength, and groundwater conditions. Many predictive methodologies have been developed for local areas but they are based on empirical, or at best semiempirical, factors and usually require modification before they can be applied to areas other than for which they were developed (20, 23). Additional research is needed to improve methods for mass wastage prediction.

Mass wasting problems rarely can be completely avoided. Even with the best of planning and reconnaissance investigations to avoid unstable conditions, a few problems are likely to develop in all but the most stable areas. In other cases, it may be necessary to locate roads in unstable areas because of a lack of feasible alternatives. This can result in serious mass wasting problems unless corrective measures are included in road design.

Many of the potential means of slope stabilization, both structural and nonstructural, and their possible applications are discussed in the remainder of this section. The selection of the proper corrective action to be used in any given situation depends upon the nature of the problem, the foundation conditions at the site, and economic considerations. No attempt is made to provide specific design recommendations or procedures since the actual design of corrective measures is heavily dependent upon the conditions at each location.

The adequate design of structural retention systems involves a high level of professional skill. All designs should include engineering analysis by personnel experienced in soil and rock mechanics. In most cases, design should be preceded by detailed geotechnical investigations to assess the conditions at each site.

Retaining Walls

Retaining walls are used to bring about an abrupt change in grade or to enable the utilization of a steeper overall slope than would otherwise be possible in a particular soil or rock mass. Several types of retaining walls are available. Among the basic types are gravity walls, crib walls, and cantilever walls.

Gravity walls or buttresses are usually constructed of plain masonry, rock rubble, stone, or concrete. The weight of the structure acts to counterbalance and resist earth pressures. This type of wall is usually the simplest and easiest to construct but generally can be used only for relatively low walls (less than 8 to 10 feet in height) with moderate soil pressures (83).

A crib wall is essentially a gravity-type structure made of timber, precast concrete or metal which forms an open structure of some dimension. When this open structure is filled with soil, it becomes relatively large and massive. This type of wall is usually suitable for small- to moderate-height walls (less than 20 feet in height) subjected to only moderate earth pressures (83). Crib walls are usually flexible enough to be used where settlement is a particular problem.

There are three basic kinds of cantilever walls. The first kind 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 kinds are modifications of a cantilever where 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 entire wall. These additions may be used for walls higher than 25 feet with most soil conditions (83).

All retention walls are expensive to design and construct. Of the various forms discussed, crib walls are probably cheapest for forest applications. The great expense of retaining walls reemphasizes the need to study all possible alternatives to the location of roads in areas of potential mass wastage.

Bulkheads

In cases where soil conditions permit, use of sheet pile bulkheads may be advisable. The sheet piles may either be cantilevered or restrained near the top with anchors. In either case, relatively deep penetration into the soil mass is required to ensure stability of the bulkhead. This method of retention is often expensive. However, installation of a cantilever bulkhead is relatively simple and can be done without form work. These walls are usually less than 20 feet in height and include the installation of drainage measures behind the wall (84).

Reinforced Earth

Construction of reinforced earth structures 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 to walls usually less than 15 feet in height.

Rock Rubble Facing

Slope embankments may be lined with rock rubble to protect against shallow surface slumping. Rock rubble protects the slope face from the effects of weathering and provides a ready outlet for groundwater seepage. Surface erosion is also prevented. However, it should be realized that rock rubble, unless applied in large enough quantities to act as a gravity-type retaining wall, offers no significant protection against deep-seated or avalanche-type slide failures.

Lowering Groundwater Levels

Groundwater conditions contribute heavily to slope instability. As the water table rises, buoyant forces on the individual soil particles reduce their interlocking strengths and thus the frictional resistance to sliding. The improvement of surface drainage is one of the cheapest and most effective techniques of lowering groundwater levels and one that is often overlooked. Sag ponds and depressions can be connected to the nearest stream channel with ditches excavated by bulldozers or other means. Improved surface drainage removes water quickly, lowers the groundwater level, and helps stabilize slumps (19).

Another technique is to lower the groundwater level by means of perforated pipes installed in drill holes augered into the slope at a slight upward angle. Such drains are usually installed in road cut banks to stabilize areas above an existing road, or below roads to stabilize fills. Installation of perforated pipe is relatively expensive and there is a risk that slight shifts in the slump mass may render the pipe ineffective. In addition, periodic cleaning of these pipes is necessary to prevent blockage by algae, soil, or iron deposits (19, 85).

A third technique of lowering groundwater levels is installation of an interceptor drain to collect groundwater moving laterally downslope and under the road. A backhoe can be used to install interceptor drains in the ditch along the upslope side of the road (19). The drain can consist entirely of graded granular materials with gradations sufficient to carry the intercepted flow efficiently without becoming plugged with fine native soils; or, preferably, a perforated pipe bedded in granular material.

Deep Rooted Vegetation

The effect of tree root strength on slope stability is not fully understood. However, results of research studies indicate that living tree roots help maintain slope stability. Reports by the Forest Service from southeast Alaska indicate that the number of landslides from cut-over areas increases within 3 to 5 years after logging. This increase is attributed to a reduction in soil shear strength caused by the decay of tree roots following logging. The presence of living tree roots to anchor shallow soils to the underlying subsoil appears to be particularly important in small drainages where winter storms can cause the groundwater level to rise sharply (24). Similar observations have been noted in other areas (6, 20). A contributing factor to gain of soil strength with deep rooted vegetation establishment may be lowering of groundwater levels as a result of water uptake.

Fill Placement

Many measures can be utilized to increase the stability of fill embankments. One of these is proper keying of the embankment to the slope through removal of all vegetation and organic material from the existing surface and scarification of the underlying native soils. On steeper side slopes the excavation of a slot or keyway just ahead of the fill will help to prevent the formation of a failure surface at the interface of the embankment and the slope. The stability of an embankment can be greatly enhanced by compaction of the fill to engineering standards, with special attention given to maintaining proper lift thickness, moisture content, and quality of the fill materials (e.g. exclusion of organic debris, etc.). Studies of mass failures in the Idaho Batholith revealed that liquefaction of fill embankments attributed to minimal compactive effort was the triggering factor in some embankment failures (6).

Fills should not be placed on steep slopes that are themselves marginally stable. Both avalanche-type failures on the hillside below the slope and deep-seated failures either on the upslope or downslope sections of the road can occur. Avalanche-type failures or deep-seated failures of the lower road section are particularly likely if excavated material is sidecast. End-hauling of excavated material to stable areas is necessary to reduce overloading of unstable slopes to an absolute minimum (19).

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" (11).

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.

The Maintenance chapter of this section discusses drainage maintenance but designers and owners should recognize that the designs and suggestions contained under this heading will <u>not</u> 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.

DITCHES AND BERMS

The two primary functions of ditches and berms are 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 to install 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, estimated 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.

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 (86). 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 13 for scour velocities in ditches of various materials.

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 data relating 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

TABLE 13[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 loam (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

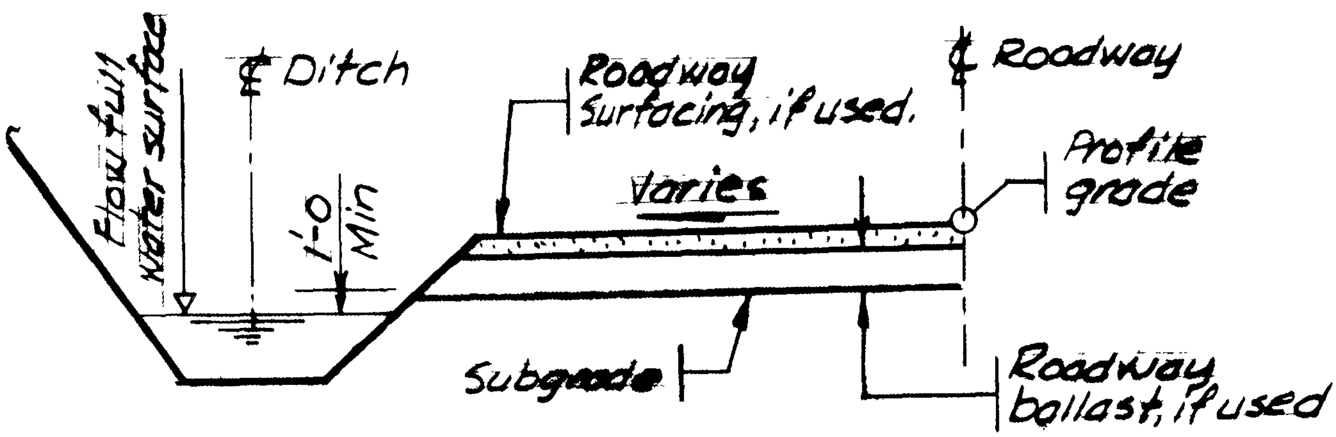
[1/] As recommended by Special Committee on Irrigation Research, American Society of Civil Engineers, 1926, for channels with straight alinement. For sinuous channels multiply allowable velocity by 0.95 for slightly sinous, by 0.9 for moderately sinuous channels, and by 0.8 for highly sinous channels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

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

erosion control device. Plastic sheeting can be used as a 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 coincide with the depth allowance for sediment deposit.

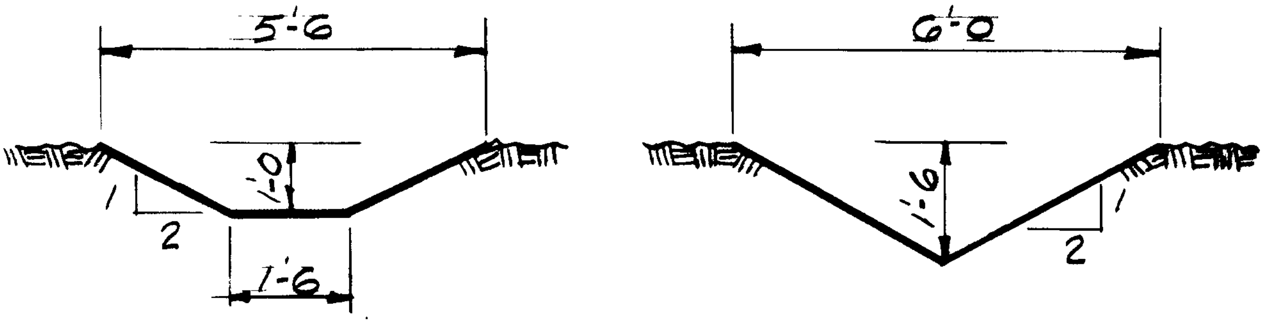
The full flow water surface for roadway ditches should be at least one foot below the roadway subgrade. This position will prevent ditch water from entering the ballast material, removing the fines and destroying the ballast's effectiveness in supporting the roadway surface. Figure 22 shows the water surface level relative to the road subgrade.



DITCH WATER SURFACE-ROAD SUBGRADE
FIGURE 22

The suggested minimum size of interceptor ditches is shown in Figure 23.

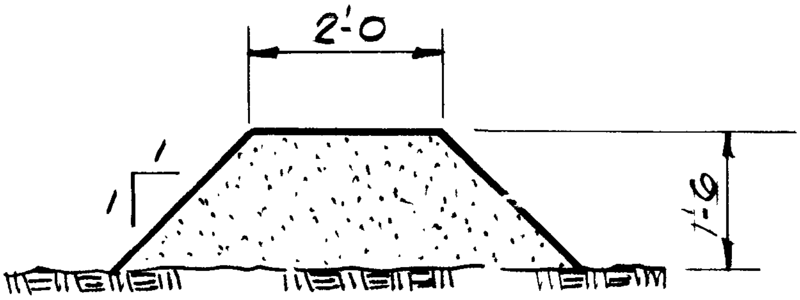
Berms (Figure 24) can be constructed of native material provided that the material contains enough fines to make the berm impervious and the material can be shaped and compacted to about 90% of maximum



TRAPEZOIDAL **TRIANGULAR**

MINIMUM INTERCEPTOR DITCH SIZE

FIGURE 23



BERM

FIGURE 24

density.[1/] An extruded asphalt or portland cement concrete curb can also be used to intercept water at the roadway shoulder edge. The curb occupies less room than does a berm.

Figure 25 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 the Construction chapter.

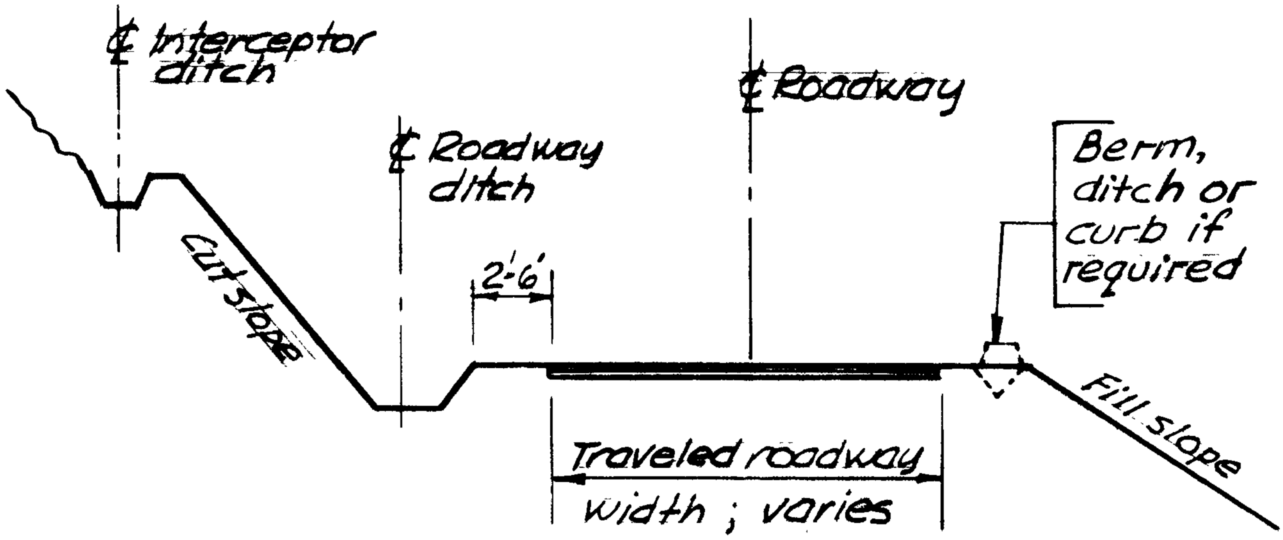
Ditches at the top of slopes may be needed when:

1. The natural ground above slope "daylight" point continues up sharply.
2. Ground cover above "daylight" point has low moisture absorbing ability.
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.

Ditch Profiles

Roadway ditch profiles will generally follow the roadway grade. The minimum grade should be 1 percent. 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.

[1/] 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.



DITCH PLACEMENT

FIGURE 25

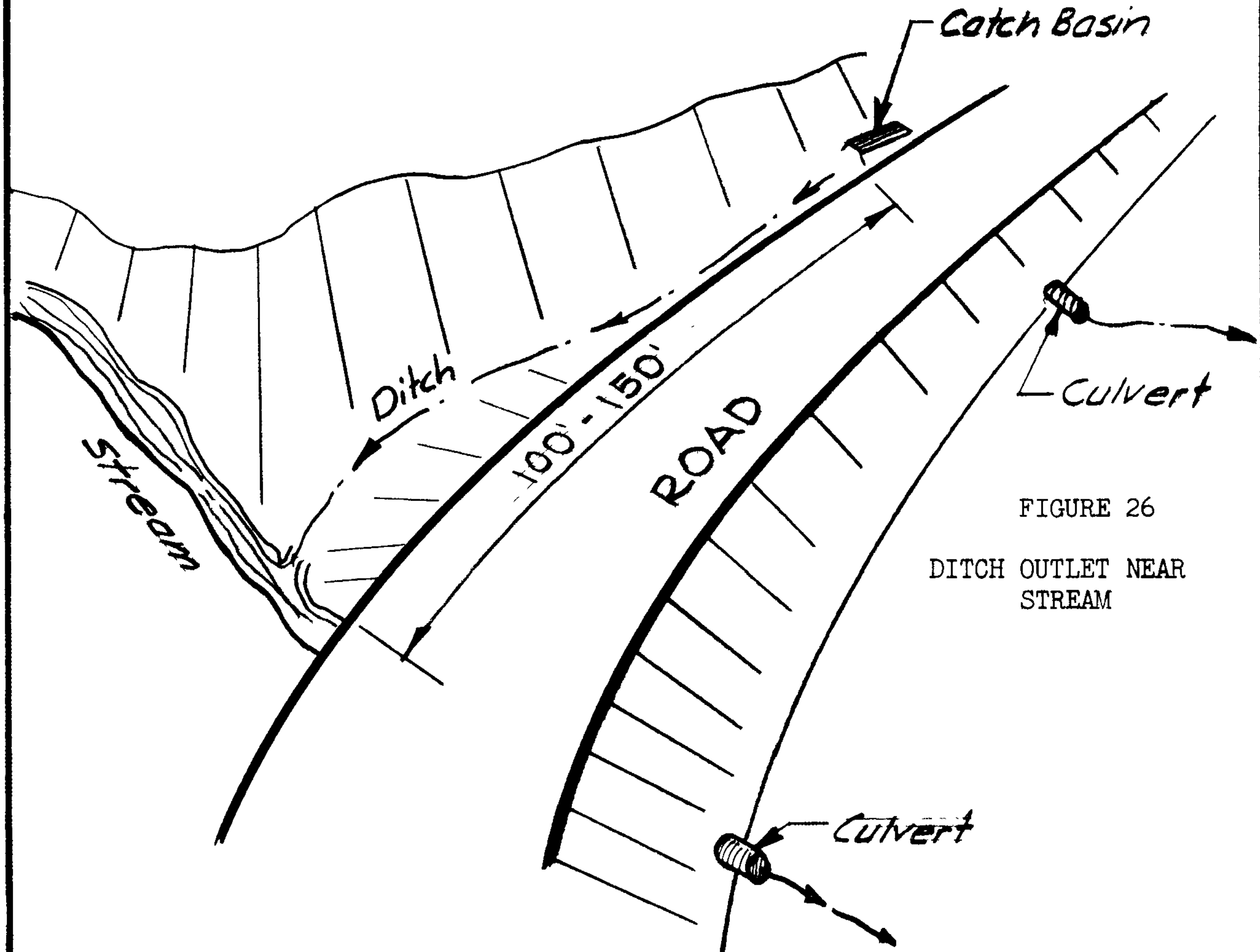


FIGURE 26

DITCH OUTLET NEAR STREAM

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.

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 26. 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 26.

Ditches 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 the following discussion on culverts and catch basins.

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"(5).

Packer studied the control of rill or gully erosion on outslope road surfaces in the Northern Rocky Mountains (56). 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 Sediment from Secondary Logging Roads by Packer and Christensen also contains the table. The table is included herein as Table 14. 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

TABLE 14

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	Cross-drain spacing					
grade (percent)	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: Packer, Paul E., "Criteria for Designing and Locating Logging Roads to Control Sediment," reprinted from Forest Science, Volume 13, Number 1, March, 1967.

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" (46).

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)" (14).

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 percent.
3. Seasonal road use.
4. Spur (light traffic) roads.
5. Favorable geographic area.
6. Non continuous longitudinal grades steeper than 3 percent.
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.

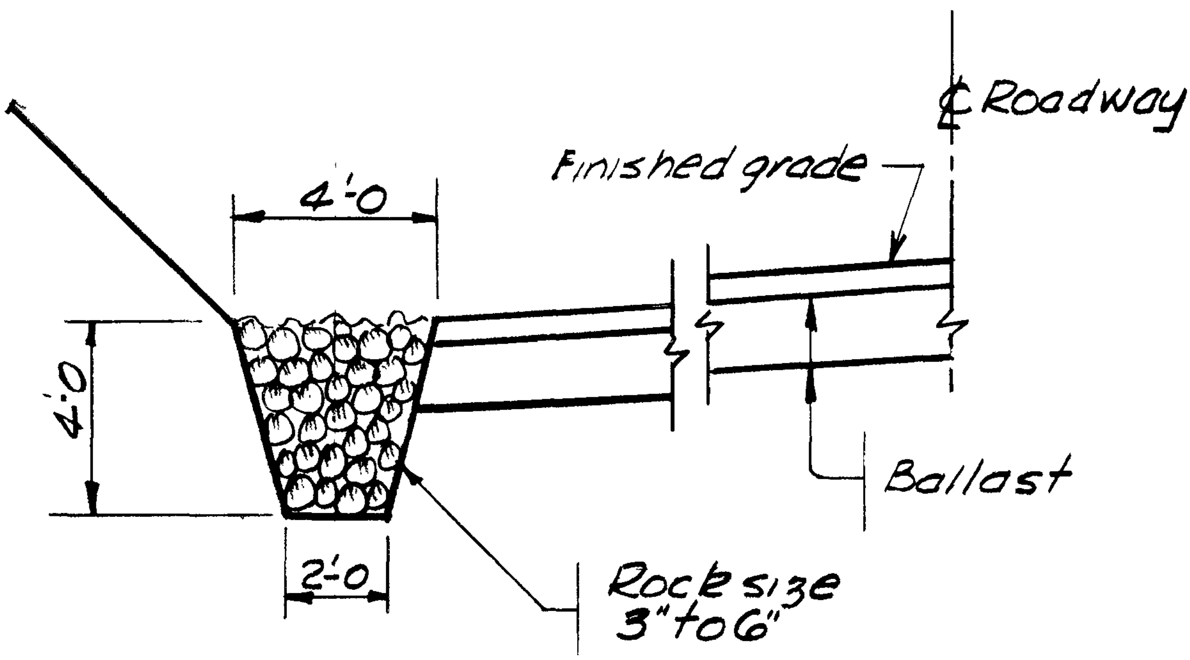
1. Long backslopes.

2. Continuous steep longitudinal grades.

3. Terrain steeper than 20 percent.

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 27. 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-DRAIN

FIGURE 27

Rock sub-drains may be used when longitudinal grades are steeper than 2 percent. 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.

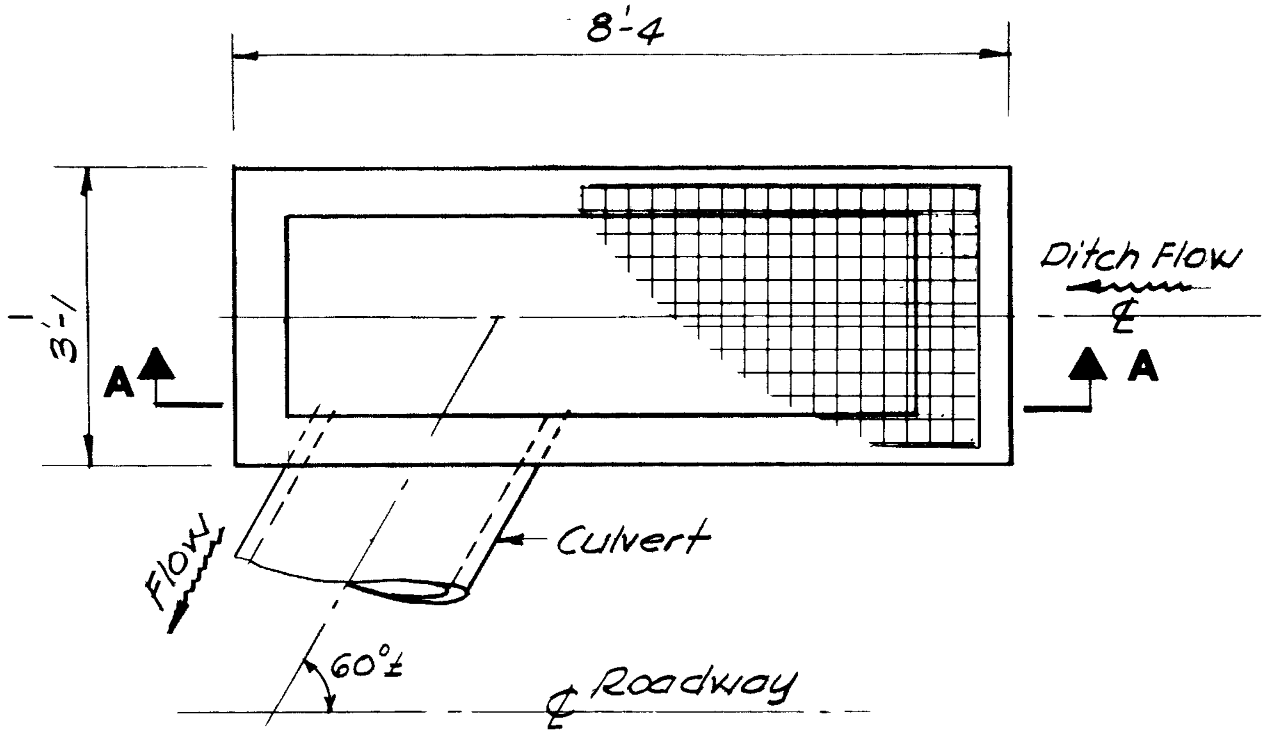
Rock sub-drains can outlet similarly to the open ditch, through a Ditch Inlet Structure, as discussed in the next part, and a cross culvert or to a natural channel.

CULVERTS

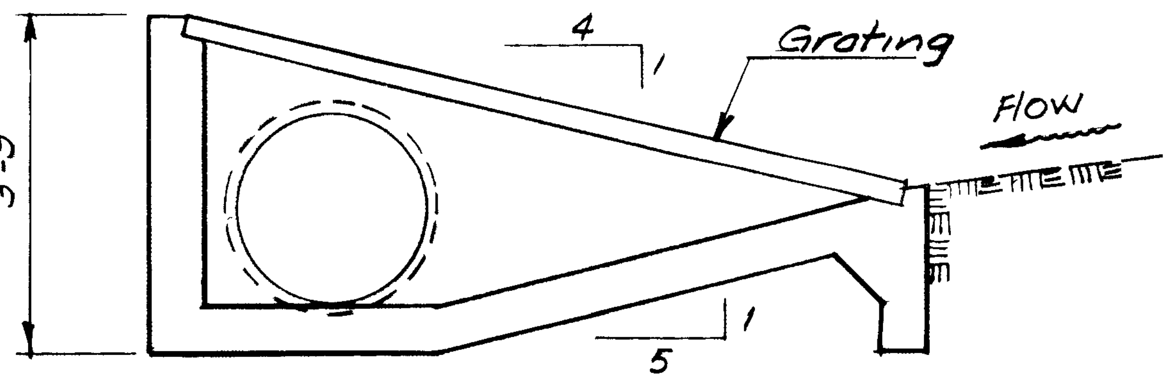
"A culvert is an enclosed channel serving as a continuation of and a substitute for an open ditch or an open stream where that ditch or stream meets an artificial barrier such as a roadway, embankment or levee" (87). Forest road culverts are used primarily to drain the roadway surface (outletting roadside 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" (11).

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 (Figures 28 and 29), 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



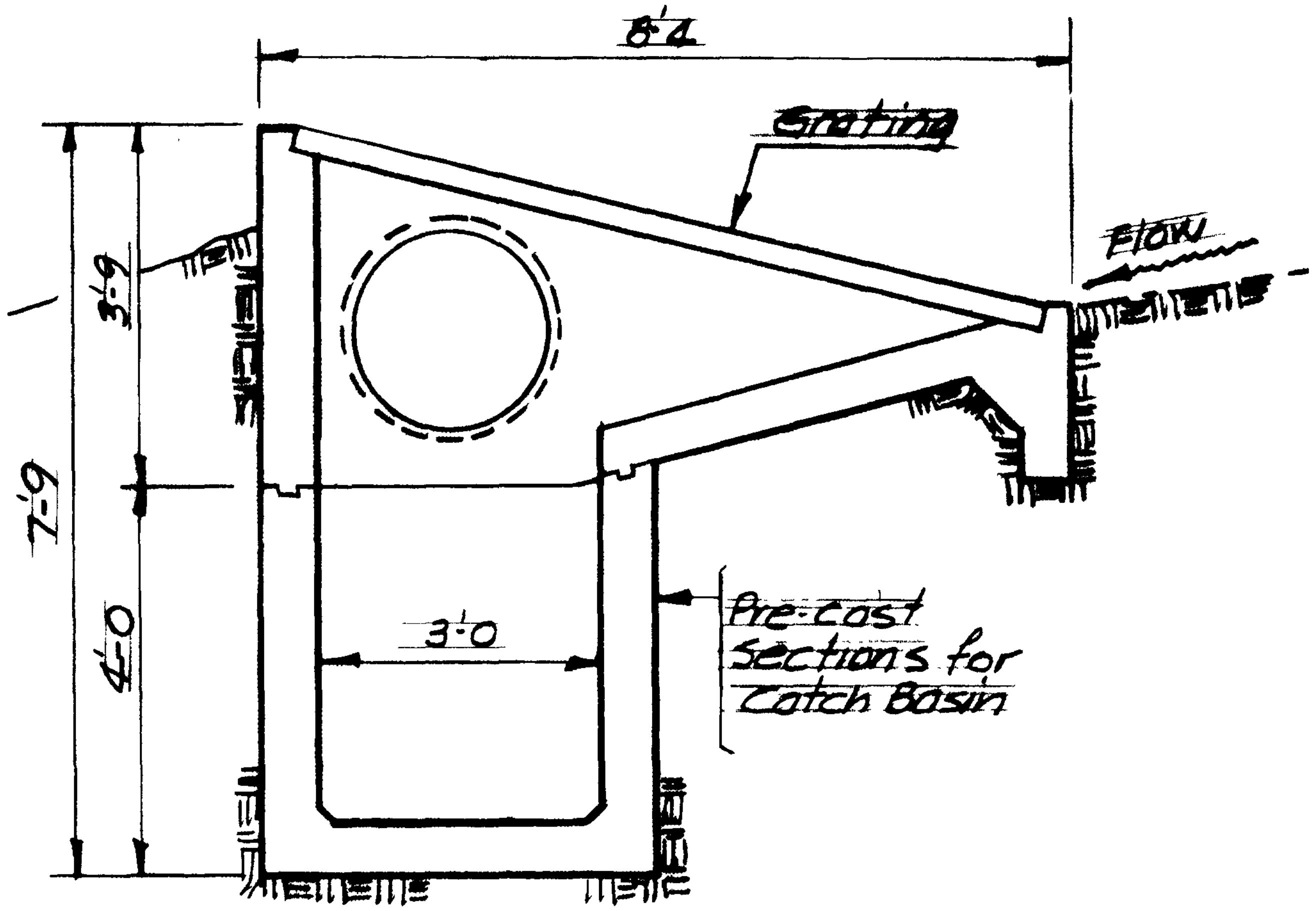
PLAN



SECTION A-A

DITCH INLET STRUCTURE

FIGURE 28



DITCH INLET STRUCTURE
WITH CATCH BASIN

FIGURE 29

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.

The minimum cover depth for a culvert should be determined on the basis of manufacturer's recommendations, appropriate vertical position of culvert relative to ditch bottom and ditch full flow line (1'0 minimum below subgrade), nature of backfill and kind of backfill equipment, anticipated haul truck and other logging equipment loads, and construction equipment 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.....(runnoff and area intercepted)..... and the influence of ditch debris" (11).

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. If the ditch becomes over silted and the catch basin or other intake device fails to function, the sediment should pass through the roadway culvert to an outlet or other necessary downstream sediment collectors. Cleaning culverts is a difficult, expensive, neglected, ignored and often imperfect procedure. Provision for necessary sediment collection before or at the culvert intake and/or at or after the culvert outlet is recommended. Culvert outlet treatments are discussed later in this chapter.

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.

Culverts used to transport 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. (A further discussion of stream crossings follows this section.)

Ideally, outfall ends of culverts under roadways should 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 the 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 purpose. Whether the half round will be satisfactory depends on its anchorage, the quantity and velocity of discharge, and the length and steepness of the embankment. Where discharge and flow velocities are high, splash from half round sections can spill onto the slope, possibly cause slope erosion and sometimes failure of the anchors.

Canvas or "elephant trunk" culvert extensions have also been 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. Determining whether to adopt this alternate is a matter of evaluating the circumstances at the culvert location in question.

Sizing Culverts

The complete hydraulic design procedure for all culverts requires:

1. Determination of the design flow - See discussion below and the paragraphs on stream crossings and hydrology.
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." (Federal Highway Administration.) (88,89)

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

"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" (89). 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 in case one or more culverts become 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 racks or inlet structures for the culverts along the adjacent negative grades.

6. Evaluate the potential for subsurface flow interception by the road excavation and the possibility that this flow will substantially increase peak flow to a culvert.
7. 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.
8. Evaluate stream culvert calculated size relative to potential stream bed constriction. Pipe arch or plate arch culverts have advantages as previously described.
9. 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.
10. For a stream crossing ascertain the performance record of any existing culverts on the stream above and below the point under consideration.
11. From the reconnaissance information, recognize the potential for natural stream bed erosion during storms.
12. Recognize any effects land management's activities may have on water yield to ditches and their associated culverts.

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.

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 determining 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.

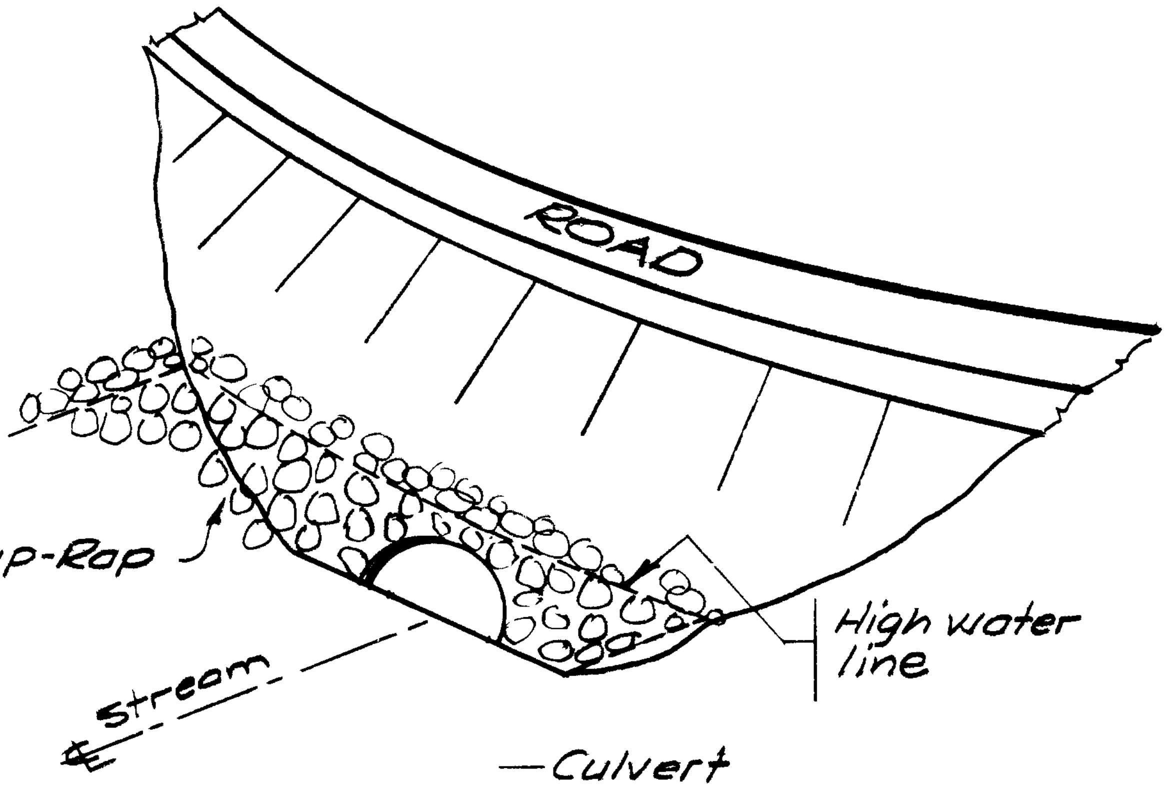
Culvert trenches are often over excavated and backfilled with select material (pea gravel is popular) in order to obtain proper pipe bedding in lieu of shaping the trench bottom for the pipe barrel, or because of unsuitable foundation material. The select backfill is usually placed at least to the spring line (mid height) 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 circumstances of pressure build up and possible culvert blow out. Thus the use of pea gravel backfill for reasons of structural integrity of the culvert could also have the accompanying advantage of minimizing sediment potential. The Ditch Grating Inlet Structure (Figures 28 and 29) will act to reduce the opportunity for water to pass along the outside of the culvert.

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 creating sediment.

Upstream fill slopes will usually require erosion protection by the use of concrete headwalls, rock riprap or gabions. (See Figure 30) 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 form 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 depends on the individual circumstances at the site, 100 feet upstream is offered as a guideline. Clearing of the approach channel should be at least an annual accomplishment.



UPSTREAM EMBANKMENT FACE TREATMENT

FIGURE 30

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, and causing severe road embankment, stream bank erosion or channel changes" (5).

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 discusion is not, however, a complete treatment of the design spectrum for stream crossings.

General

Each stream crossing must receive individual study to determine the best crossing method. Sufficient site data must be available so that the responsible designer can accomplish this individual study. This data will be a part of the findings of the reconnaissance phase supplemented by appropriate topographic, foundation, fisheries considerations 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 method. His task is to meld the use requirements to the site requirements in a manner that will produce a satisfactory result.

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 of foundation work needed within wetted perimeter of stream.
6. Type of streambed material.
7. 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 six items listed above in his design solution. The seventh 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 an 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 cause channel banks to overflow, resulting in erosion of approach embankments. This situation 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. Further, some researchers believe that there are no appropriate models available for the prediction of mountain stream flows.

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. Calculations 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 including water quality and fisheries considerations. 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 (90).

Table 13 gives scour velocities for certain kinds of ditch soils. Values shown in this table 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 Chart for Open Channel Flow includes data for grassed channels. Design charts include a procedure for determining maximum permissible velocities without channel scour (91).

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" (92). Design procedures using various linings are discussed.

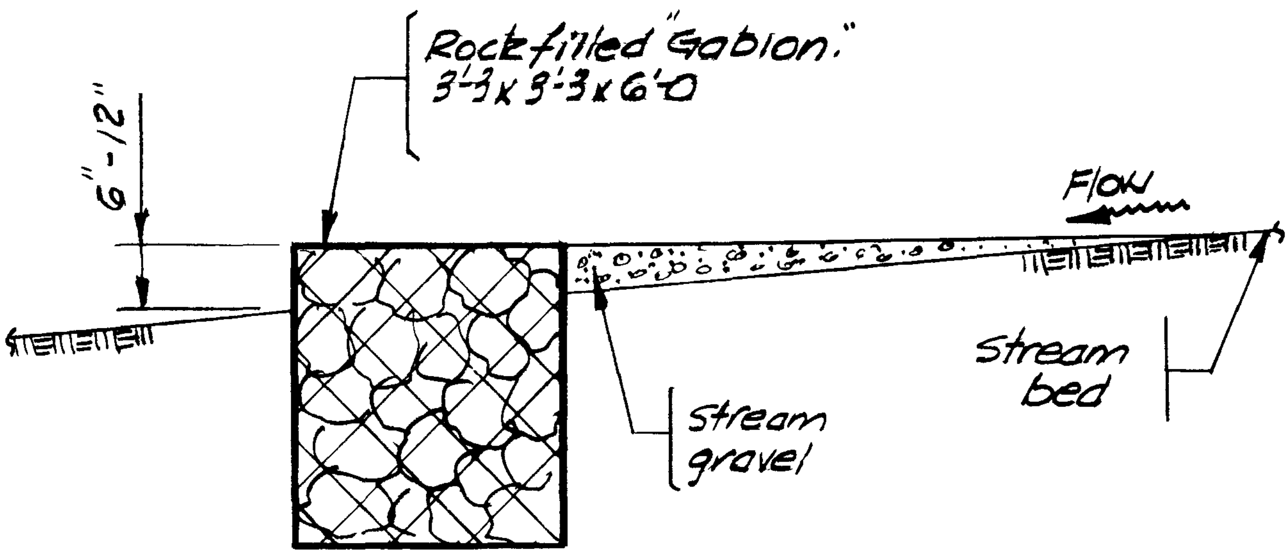
Riprap bank protections should extend a minimum of two feet below the stream bed. This is to prevent erosion of the bank material and subsequent displacement of the riprap.

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 or road relative to stream, foundation conditions, construction cost and maintenance cost, and contemplated road use and life.

Fords. Fords are an attractive alternate for secondary or spur road crossings of small drainages particularly if road use is limited to the dry season when no flowing 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" (93) describes the design use. 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 31 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.



GABION FORD
FIGURE 31

Source: Leydecker, Allen D., "Use of Gabions for Low Water Crossings on Primitive or Secondary Forest Roads"

Culverts. 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 those 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 that subject heading.

Bridges. 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 percent 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. Subaqueous 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. Subaqueous 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 since the falsework may block the stream and is very vulnerable to debris damage. Any delays of construction (changed foundation conditions) that result in falsework 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 in the 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 minimizing sediment potential may not have been a stated design goal, the abutment design is one that clearly accomplishes this. Placing the sheet pile abutments requires 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 lower girder flanges because of vulnerability to drift and debris during high water (94).

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:

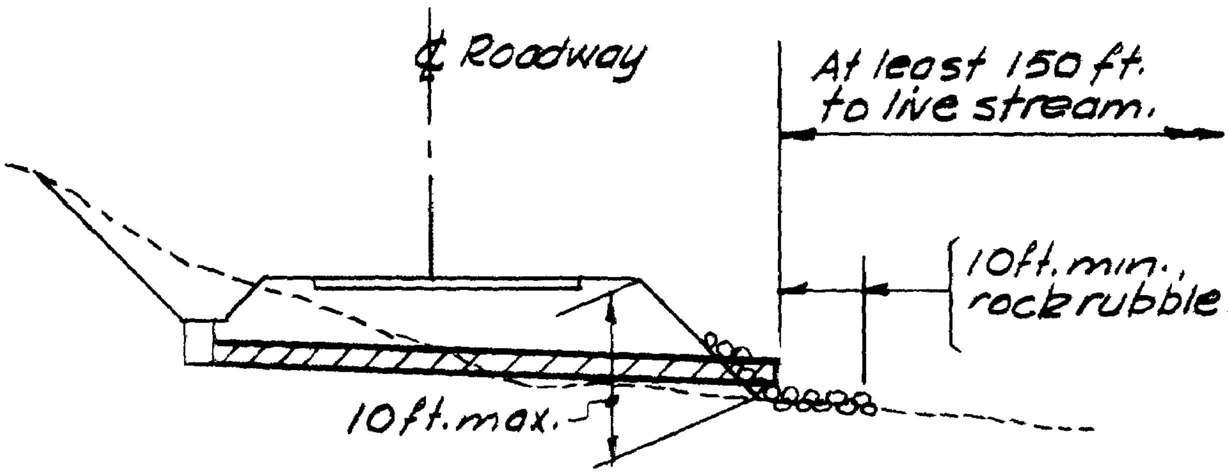
1. Adequately designed and constructed ditches with appropriate linings.
2. A Ditch Inlet Structure with Catch Basin that functions properly to trap sediment. Sediment that is not deposited in the ditch and bypasses the catch basin is considered as flowing through

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.

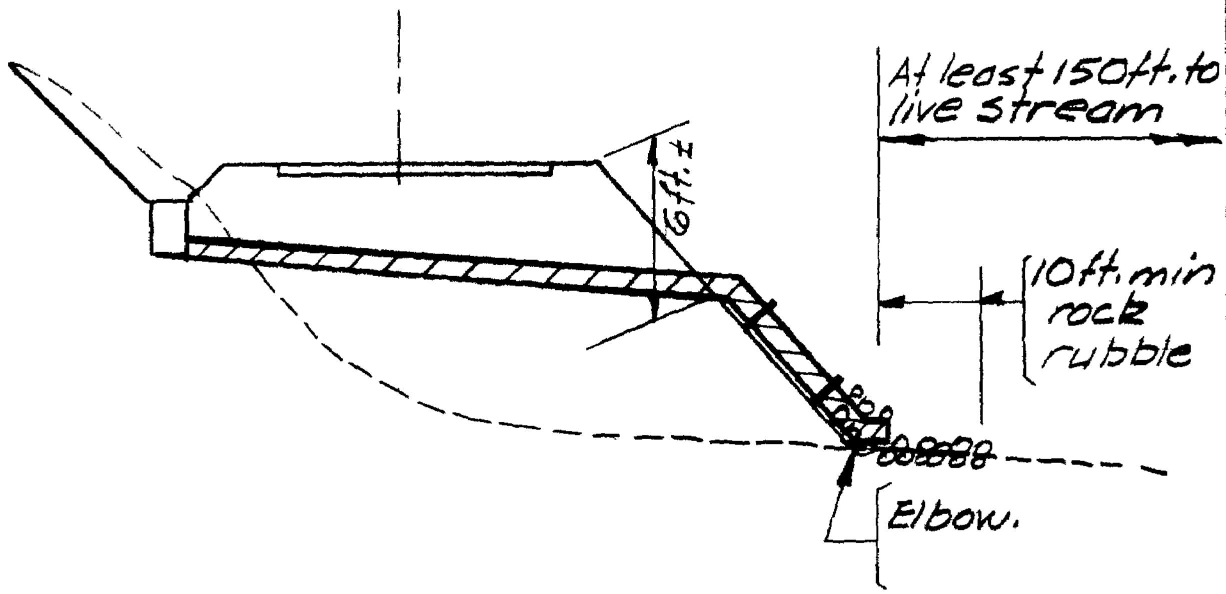
Figures 32 and 33 show two roadway culvert outlet conditions. The culverts shown in Figure 32 outlet at least 150 feet from a live stream. For this condition a short length of lined culvert apron at the outlet point to act as an energy dissipator and a scour inhibitor has merit. The lining can be rock rubble, ten feet minimum in length with a width equal to twice the culvert diameter as shown in Figure 34.

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. However, 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 35. In addition, a further measure might be the placing of slash from the roadway clearing to act as a sediment barrier.

Figure 33 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 36 may be appropriate. If the culvert exit velocity is 10 feet per second or greater, a rock dike as shown in Figure 35 to act as an energy dissipator may be necessary in order to



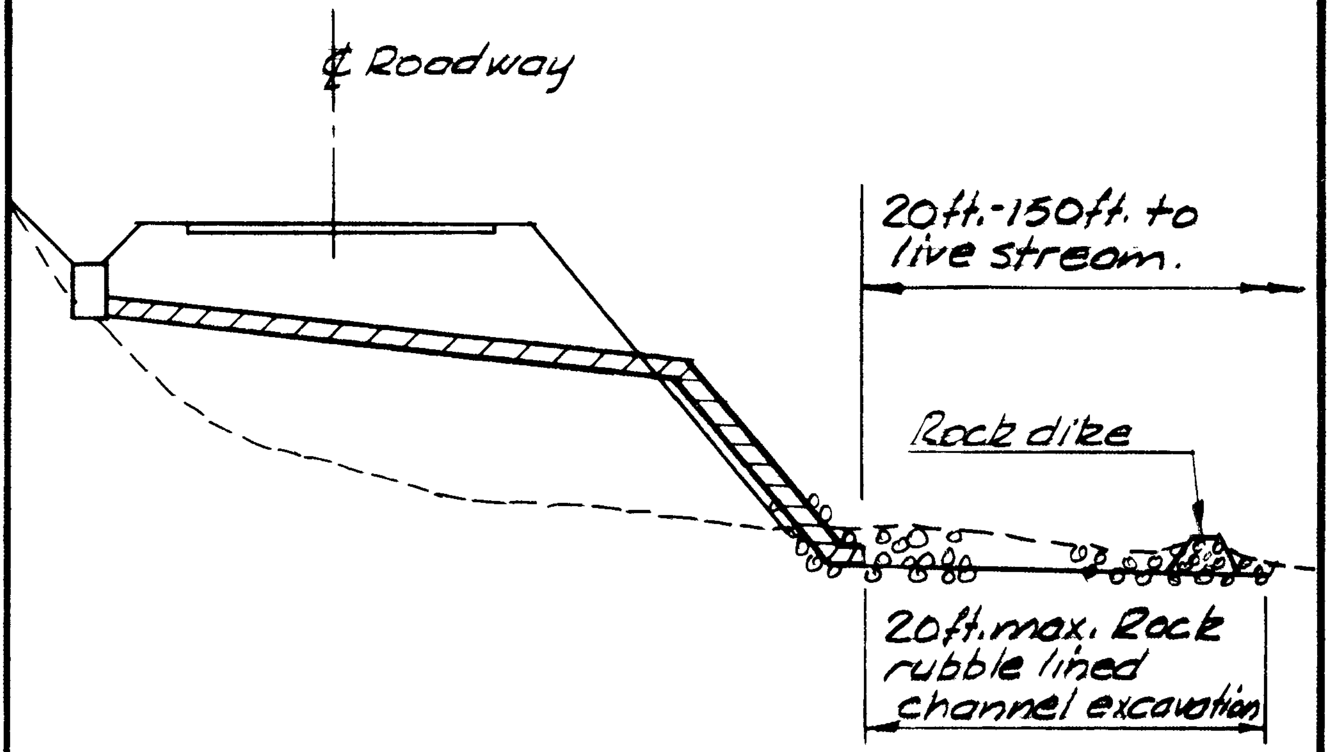
SHALLOW FILL-SHALLOW CULVERT



HIGH FILL-SHALLOW CULVERT

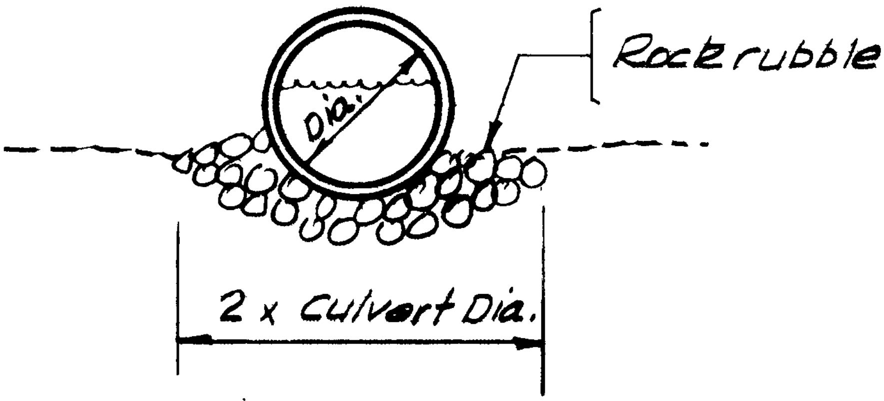
CULVERT OUTLETS

FIGURE 32



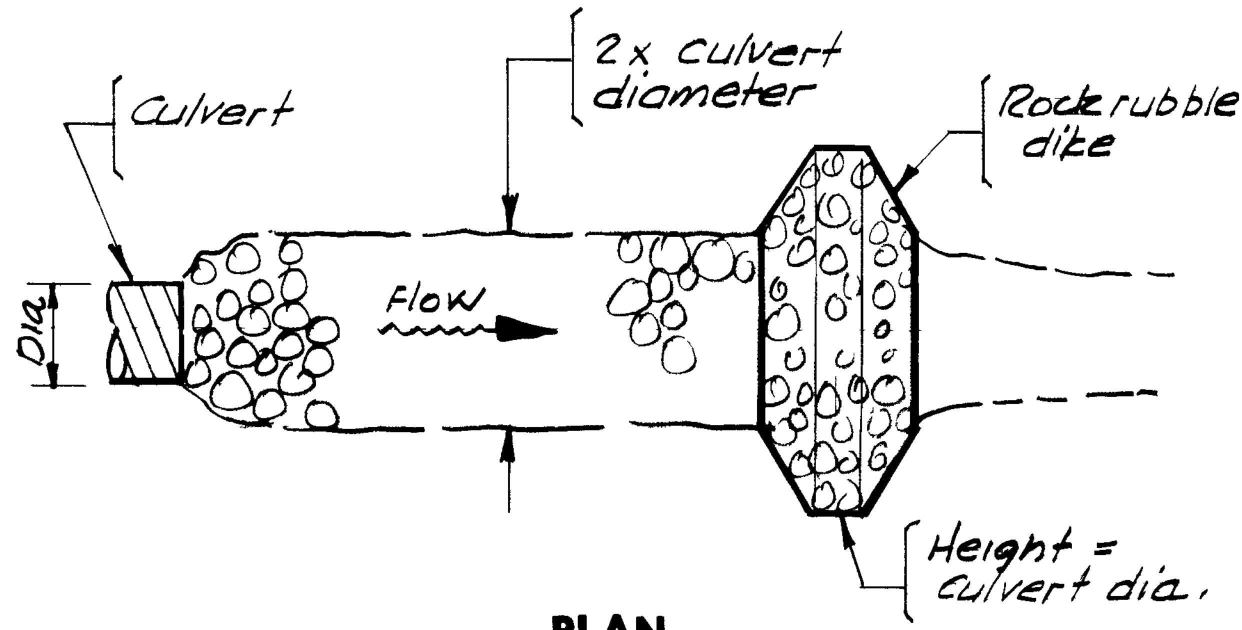
CULVERT OUTLET NEAR STREAM

FIGURE 33



PIPE CHANNEL DETAIL

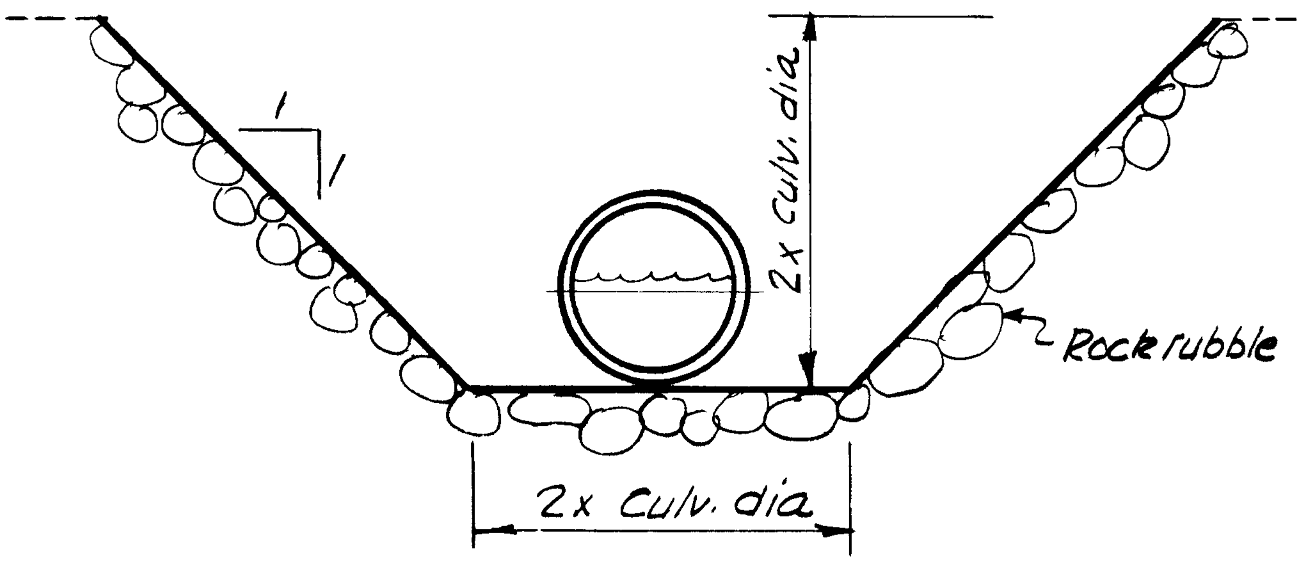
FIGURE 34



PLAN

ROCK DIKE

FIGURE 35



ALTERNATE PIPE CHANNEL DETAIL

FIGURE 36

insure sediment deposit before storm waters intersect the stream.

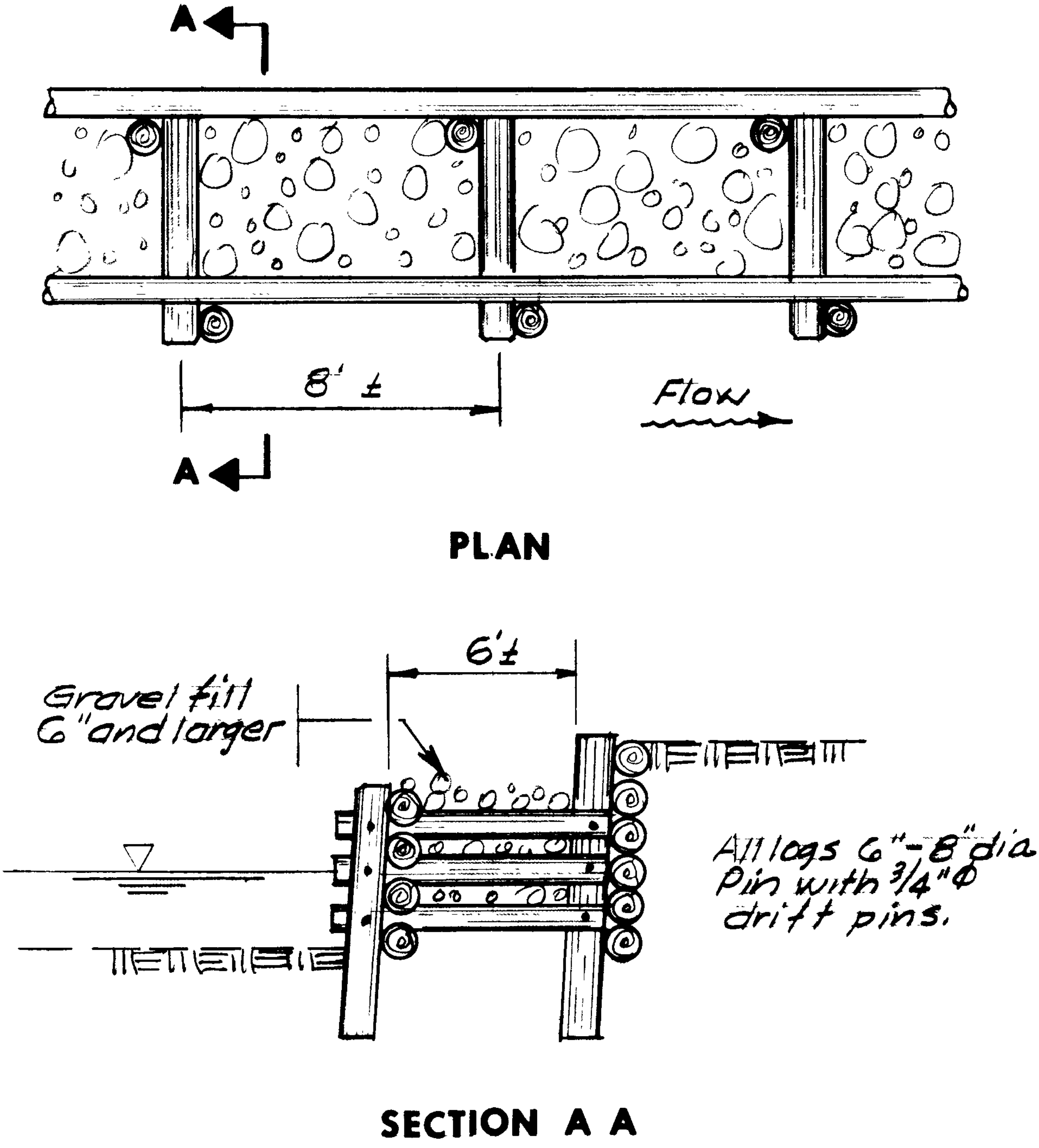
If suitable rock is not available for a channel lining, an alternate might be the use of clearing slash to construct gravel filled crib wall channel linings as shown in Figure 37. Gabions and sacked riprap can also be used but they are costly. The use of slash has the secondary advantage of providing a disposal method for some of the clearing debris.

An outlet treatment for a large culvert with high storm water flows is shown in Figure 38, 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 can be transported. This will happen during construction and for a time thereafter until new vegetation and soils stabilization measures become effective. Figure 39 shows a roadway culvert (or combination of culvert discharges, e.g. collector ditch at toe of slope) discharging into a sediment pond (basin).

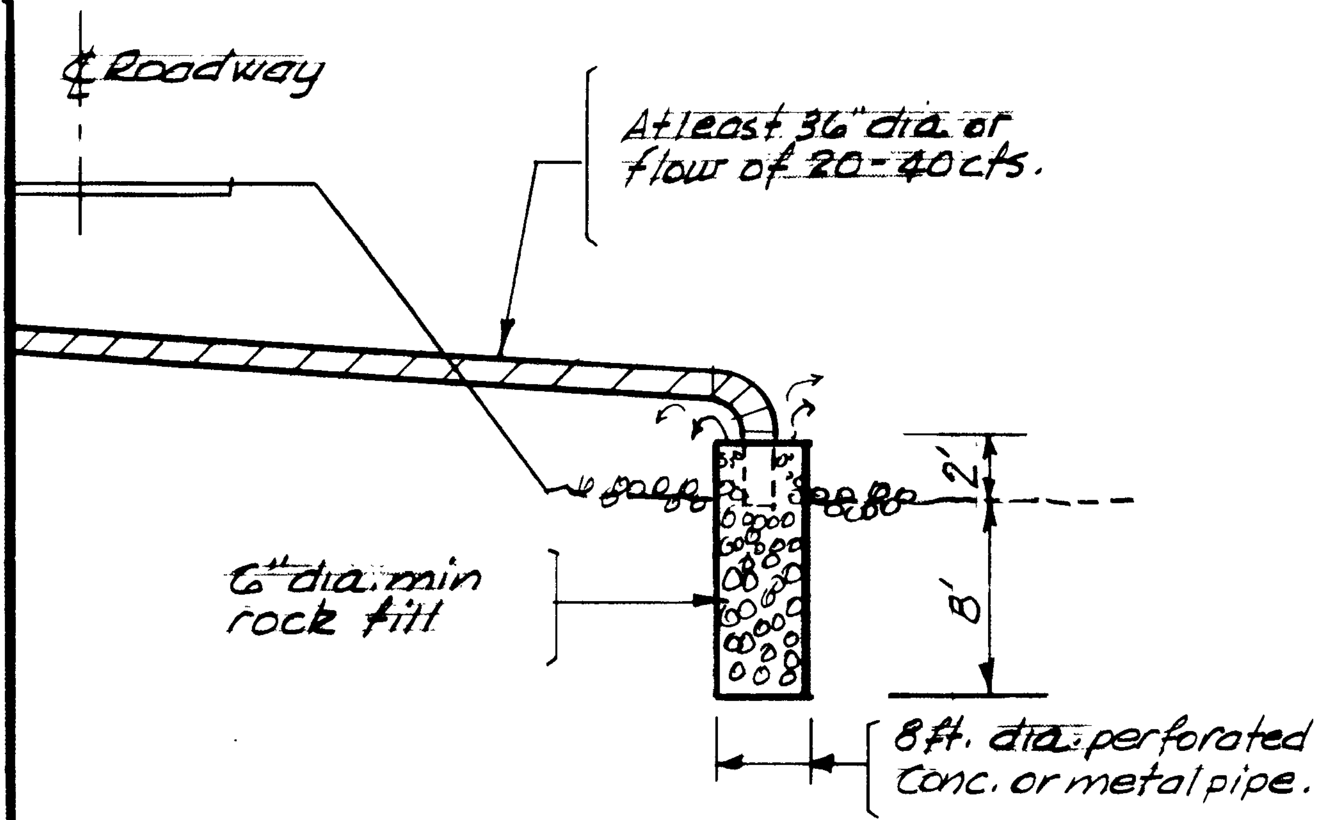
The velocity of flow through the sediment pond should be approximately one foot per second and preferably less in order for settling to take place. Settling velocities of sand and silt in still water are shown in Table 15. The tabulation in this table suggests that the sediment pond should be large enough 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, water quality requirements, etc. After



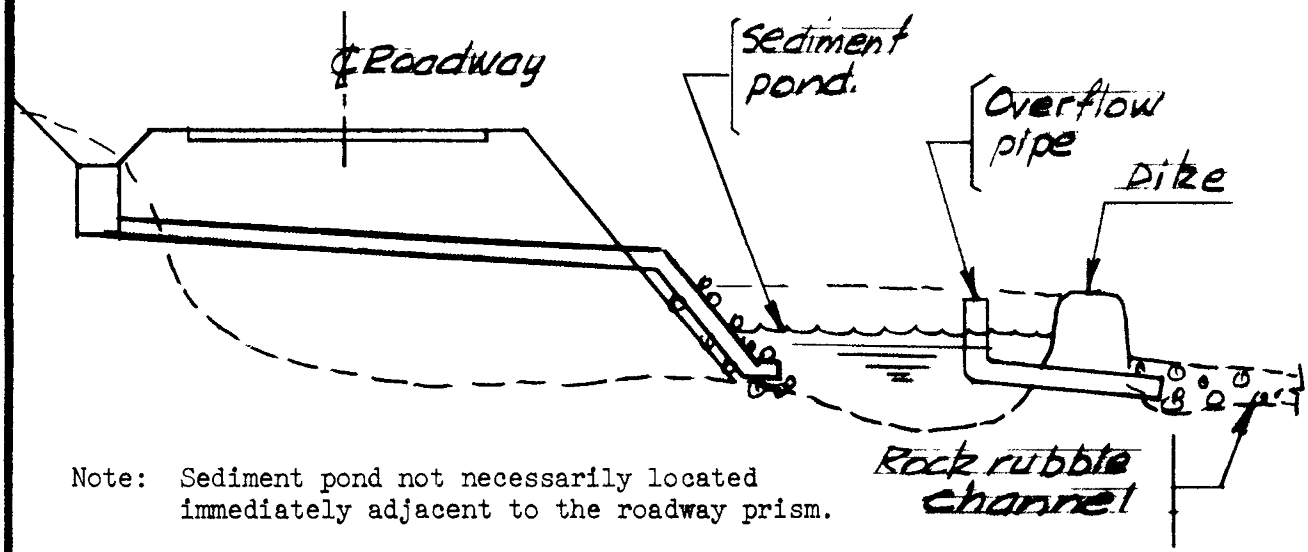
GRAVEL FILLED CRIB WALL

FIGURE 37



ENERGY DISSIPATING SILO

FIGURE 38



Note: Sediment pond not necessarily located immediately adjacent to the roadway prism.

CULVERT OUTLET TO SEDIMENT POND

FIGURE 39

TABLE 15[1]

SETTLING VELOCITIES FOR VARIOUS PARTICLE SIZES
(10.00 mm to 0.00001 mm)

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

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

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 less important. It should be recognized that the circumstance of terrain and road corridor may be such as to preclude the use of a sediment pond in many situations.

HYDROLOGY

Preceding parts of this discussion 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 logging and road building in the forest, and forest location will have a significant effect on the flow volumes he should provide for, with respect to road drainage and stream crossings.

Logging and Roadbuilding

Rothacher reports that an increase in annual stream flow in the Pacific Northwest may be expected after clearcutting. He also points to an increase in early Fall seasonal flows after clearcutting because the soil moisture content is higher in a clearcut 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 clearcutting significantly changes peak flood flows in areas west of the Cascades. Flood flows normally occur after the soil is saturated, "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 clearcut (95).

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 clearcutting, 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" (96).

Bethlahmy is convinced that clearcutting a small drainage will result in greater peak/flows in that drainage. He believes that culvert capacities and bridge clearances in these drainages should be designed to accommodate conditions after logging (97,98).

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 more often: therefore, "our plans and actions must give them adequate consideration" (11). 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 parts on Culverts and Stream Crossings.

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 the route reconnaissance discussion 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" (49).

Megahan believes that total volume of watershed runoff increases when subsurface flow is converted to surface flows. Whether peak flow rates are increased depends 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."

Forest Location

There is little question that total precipitation amounts increase with elevation, except in areas of pronounced rain shadow effects. However, considerable controversy appears to exist as to the effects of elevation on rainfall intensity. Dorroh's (99) evaluation of rainfall data from the southwestern United States indicated that, although both total precipitation and thunderstorm frequency tend to increase with elevation, the heaviest individual rains occur in the valleys. Croft and Marston (100), 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 (101).

Schermerhorn (102) 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. 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, a key parameter for determining peak design flows.

Cooper (103) 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 that average annual precipitations increased about 4 inches for each 1,000 feet increase in elevation and ranged from 8 inches in the lower part of the valley to 28 inches at the higher elevation. Numerous methods of data analyses that attempt to establish other rainfall-elevation relationships indicate 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 ones. 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.

Others believe that much is unknown about rainfall intensities at the higher altitudes and question the applicability of the currently available models. As was previously stated in the discussion on stream crossings, the engineer must cross check his calculated design flows obtained from the USGS or other method.

CONSTRUCTION SPECIFICATIONS

An essential part of the design for any road project are the companion specifications. Preparation of these specifications must not be separate 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.

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, and 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.

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. This is 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, including 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 compensation for the Contractor 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" (8).

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" (5).

CONCLUSIONS

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

CONSTRUCTION TECHNIQUES

As earlier stated, Route Planning and Reconnaissance are regarded by many as the most important phase of logging haul road development. In design, 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" (5).

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.

Manpower 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 fully implement 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 that require individual analysis and the application of the appropriate construction technique in order to minimize erosion or sediment transport.

CLEARING AND GRUBBING

The Forest Service Standard Specifications for Construction of Roads and Bridges and the 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 soils. Flash storms under these conditions can produce instant erosion and sediment problems. This work is a necessary part of the road work. 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 collected from the clearing and grubbing operation can be placed at the toe of embankments or below culverts to act as a filter and retardant to sediment flow.

Attempts to begin excavation prior to the completion of clearing have resulted in mixing slash and organic material 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 suggested in drainage design and as shown on Figure 37.

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.

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" (5).

Road builders on Washington's Olympic Peninsula have found that a shovel can be worked in much wetter weather than 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.

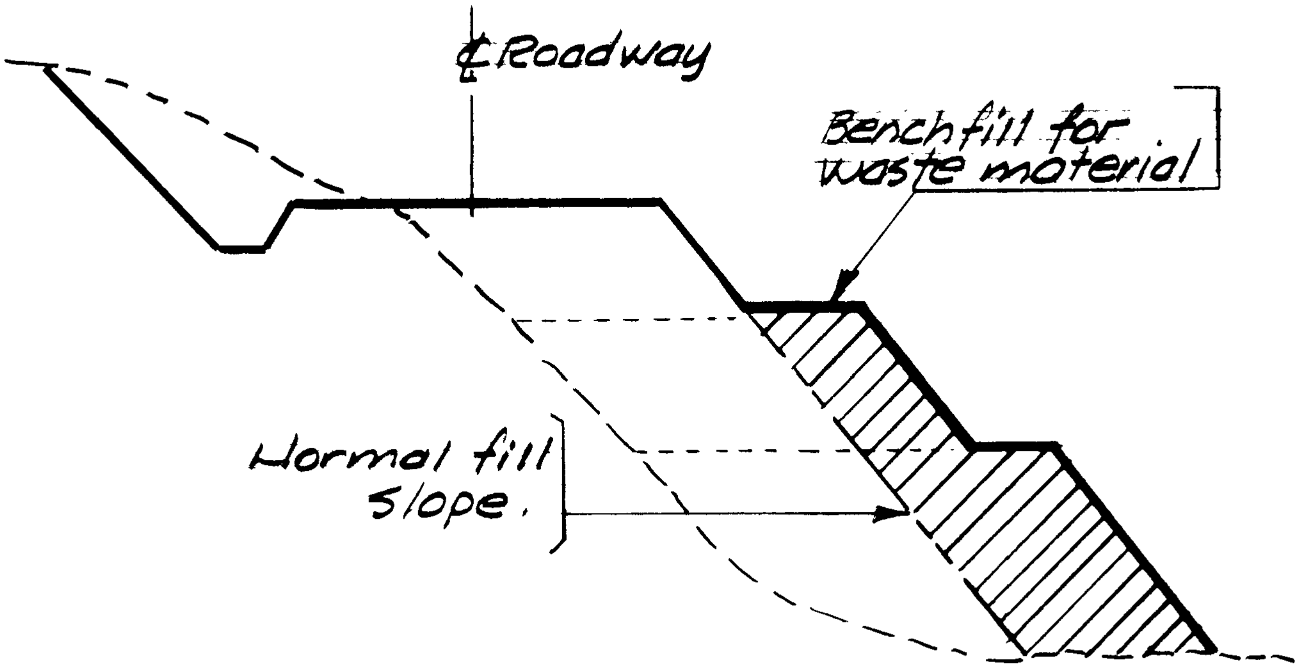
1. Tamping rollers.
2. Smooth wheelpower rollers.
3. Pneumatic-tired rollers.
4. Grid roller.
5. Vibratory rollers.
6. Vibratory compactor.
7. Bulldozer.

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 that it prevents 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. Sidecasting, as a construction method has limited value. 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 40) instead of being end hauled an excessive distance. The width and number of benches will be determined by the height of the fill and the quantity and quality of waste material involved.

Borrow pits should be closed by dikes or dams to prevent sedimentary flows into adjacent streams or have a sediment pond at the outlet end. 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
FIGURE 40

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

DRAINAGE

No other item is as important to the permanence and usefulness of the forest road and the 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" (42).

DRAINAGE DURING CONSTRUCTION

The drainage design discussion 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 consequential 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)" (42).

The previous paragraph mentioned several antidotes to control construction drainage. 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 at hand. 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.

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 a doubt application of this 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. Few 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. Install energy dissipating devices.
4. Place rock rubble rock or matte channel lining.
5. Lay the culvert from the downstream end to the upstream end.
6. Construct ditch inlet structure with or without catch basin.

It is important to note from the above 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. If it is necessary to install a culvert in a live stream, diverting the water by parallel channel or pumping around the work area may be appropriate.

The reader is reminded of the discussion in drainage design 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 (14).

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.

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" (8).

Recommendations from this report include: (1) Constraints on the maximum size of equipment that can be used for a particular road project. (2) Directing and supporting inspectors to enforce 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 is discussed earlier in 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 more economic full bench excavation work on narrow roads with end haul 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 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 (14).

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

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 . . . ." (5).

Some observers believe that problems have occurred due to policies that result in too many miles of road being left open. The decision as to whether a particular road should be left open is not the sole prerogative of maintenance personnel but is related to transportation and land management plans. Blocking primary purpose logging roads off when this purpose is complete can help eliminate road surface damage with attendant sedimentation caused by other uses during wet seasons.

If a road is not to be used again for several years or is to be permanently closed, blocking a road to prevent further use of the road may not be an effective sediment control technique in itself. If the drainage integrity and stability of the roadway cannot also be maintained, additional measures are needed for minimizing sediment. These practices are described in the Intermittent and Short Term Use section of this chapter.

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 readily 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.

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 five parts: (1) drainage system, (2) road surface, (3) remedial measures for slides, (4) intermittent and short term use, and (5) maintenance chemicals.

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 guidelines because there is a wide variance between localities, construction accomplishments, workable seasons and climatic factors. The following are offered as guidelines only, as each area must modify or amend their procedures to suit their circumstances.

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 if adequate filtering to protect watercourses is 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" (43).

In Western Washington and Oregon, a fall inspection prior to winter storms is good practice.

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.

Ditch and culvert surveillance may be necessary on closed roads particularly in seasons immediately after logging operations. The potential for debris blockage, although perhaps less with the road closure, can still exist.

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 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 and 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.

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 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. Snow removal procedures should allow for proper drainage.

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 expresses important provisions or guidelines for road maintenance. The most important guideline consists of management educating the maintenance personnel about 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 when sediment from roadway surfaces is transported to side ditches. When this

Slides cause many problems in conjunction with maintenance and increased erosion potential along the road alignment. Several of these problems are discussed in the following paragraphs.

REMOVING SLIDE DEBRIS

Slide debris deposited on roadways may cause significant increased sediment loads in established roadway drainage systems. In some cases it may cause erosion channels to develop outside of established drainages. The removal of material on the road may be accomplished by heavy construction equipment. Sidecasting of the material should not be allowed.

Slide debris which is located downslope from the logging road poses a different and more difficult problem. Most importantly, the removal operations may trigger further movements. Another problem involved in removing the material is the possibility of damaging surface vegetation and erosion control devices on the downslope side of the road. 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, including that from potential future slides triggered by debris removal, should be made and carefully examined before any removal is carried out.

In many cases removal will probably be infeasible. It may be desirable to leave the material in place and shape and reseed it or take other measures to reduce the potential for surface erosion. Specific rules or guidelines for debris removal should not be formulated. Each case should be evaluated on an individual basis and action taken in response to the conditions encountered at each site.

WASTING SLIDE DEBRIS

Once the slide debris is removed the problem arises as to what should be done 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 in order to limit erosion. Again, it should be emphasized that slide debris material should not be sidecast from the roadway or placed in a noncompacted fill that is susceptible to erosion.

RELOCATION VS CORRECTION

Proper evaluation of the erosion potential and the economics of road relocation versus slide correction is essential, and many factors should be considered before a decision is made. Among these are: what caused the slide, how extensive is it, and will it reoccur? These questions will be discussed in more detail in the following section. Before a decision is made, the amount of surface erosion and mass wasting potential from construction of a newly relocated alignment should be determined. A new road may have a higher total erosion potential than the erosion from the slide debris, particularly if the general terrain is unstable or if the new alignment is of considerable length. New roads, particularly initially, often have a higher erosion potential than the existing ones. Correction of the slide area may involve constructing retaining structures, installing drains, reshaping slopes, and/or replacing fill in the roadway alignment. Slide correction is often more desirable than constructing new roads.

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 soils engineer or 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 intial inspection should be supplemented with a detailed subsurface investigation. This investigation would include drilling deep holes to obtain undisturbed samples for strength testing, and installing 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 it may be occurring. The amount and extent of this investigation is dependent upon the conditions at each individual site. In any event, this work should be accomplished under the auspices of a specialist in either soil or rock mechanics.

INTERMITTENT AND SHORT TERM USE 1/

Problems arising both from overdesigned roads which do not fit the terrain and from inadequately designed roads have been described. Field observations in Region X indicate that sediment control practices are often neglected or ignored for low standard logging roads. These are variously described as "work", "branch", "spur" or "temporary" roads. In most situations they are designed and constructed for relatively low volume of traffic, and intermittent or short term use. As used in this discussion, "temporary" means short term use. Design criteria for such roads usually include minimization of both investment and maintenance costs. Haul costs are generally of secondary consideration.

The principles for incorporating appropriate sediment control features into planning, reconnaissance, design and construction have been described in previous chapters. These principles are applicable to all types of logging roads. For example, a spur road constructed in the wrong location can cause as much water quality damage as a poorly located higher standard road.

Road maintenance procedures and appropriate options discussed previously in this chapter are applicable to low-standard roads. For

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1/ Inclusion of this section in the final report is the result of written comments received following the draft report review; and subsequent written and verbal communication with selected practitioners.

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intermittent or short term use roads, additional options and techniques are available for minimizing sediment production between use periods or after use is concluded. As noted previously in this report, many factors must be considered in order to rationally select suitable options for a specific road.

INTERMITTENT USE

Intermittent use logging roads are those which are planned for a permanent transportation facility but are not intended for continuous use. Intervening time between use periods may range from several months to several years.

In addition to the many elements of consideration described throughout this report, other factors may influence the selection of maintenance options for these kinds of roads. These factors include: type of ballast or surfacing on the roadbed; length of time between use periods; construction method (sidecast or end haul); whether the road existed previously or is the result of a planned design and construction sequence; length of time a previously built road has been in place (demonstrated stability); type of drainage structures; and cost effectiveness.

Even though an objective may be to minimize maintenance during non-use intervals, periodic inspection of a road is needed to assure that the water quality protection measures are performing as expected.

Roadway

Where the interval between use periods is relatively short, one approach is to block the entrance to the road to prevent unplanned use and conduct needed maintenance throughout the non-use period. Techniques for blocking a road include gates and a variety of crude and sophisticated physical barriers constructed from native materials (rock, slash, cull logs, etc.).

A more comprehensive approach, in addition to blocking the road, includes installing a system of water bars and drainage dips (as described in the Drainage Design section); and stabilizing cuts and fills (as detailed in the Slope Stabilization section). Scarification and revegetation of the road surface may also be appropriate--depending upon the type of road surface, the erosion potential and the non-use interval. These measures may be sufficient to stabilize the roadway during non-use periods, but supplemental maintenance may also be needed. Depending upon the drainage design some roadway renovation may be needed prior to re-use of the road.

When the interval between use periods is long, additional options are available. In some cases, the approach described in the previous paragraph may be sufficient.

Another method is to partially restore the original ground profile in order to convert some of the surface water flow created by the road incision back to a subsurface flow and provide more efficient surface runoff capability.

The Panhandle National Forest in Idaho has developed a partial restoration technique, called the "Kaniksu Closure", which involves moving the outer road berm and part of the fill material and placing it into the road cut area. Figure 41 illustrates this method. Where terrain and road conditions permit the use of this technique without loss of significant amounts of soil over the embankment edge, the work can readily be accomplished with an angle-blade bulldozer. Dave Rosgen, hydrologist on the Panhandle National Forest reports that this method is successful on side slopes up to 60 percent in northern Idaho. Following the work, the site is revegetated.

The "Kaniksu Closure" was developed initially to deal with an existing transportation system. Other field practitioners report that this technique has limitations for use in areas with high precipitation; on ballasted or surfaced roads; on end haul constructed roads; in some soil types; and where the interval between use periods is relatively short. (Re-opening the road may result in more re-exposed roadway surface than would result with another method. Unless the interval between use periods is fairly long, this may negate some of the restoration benefits).

Stream Channel Crossings

Stream channel crossings on intermittent use roads deserve special consideration. Culvert installations with substantial fills are particularly vulnerable to failure as a result of debris blockage or simply

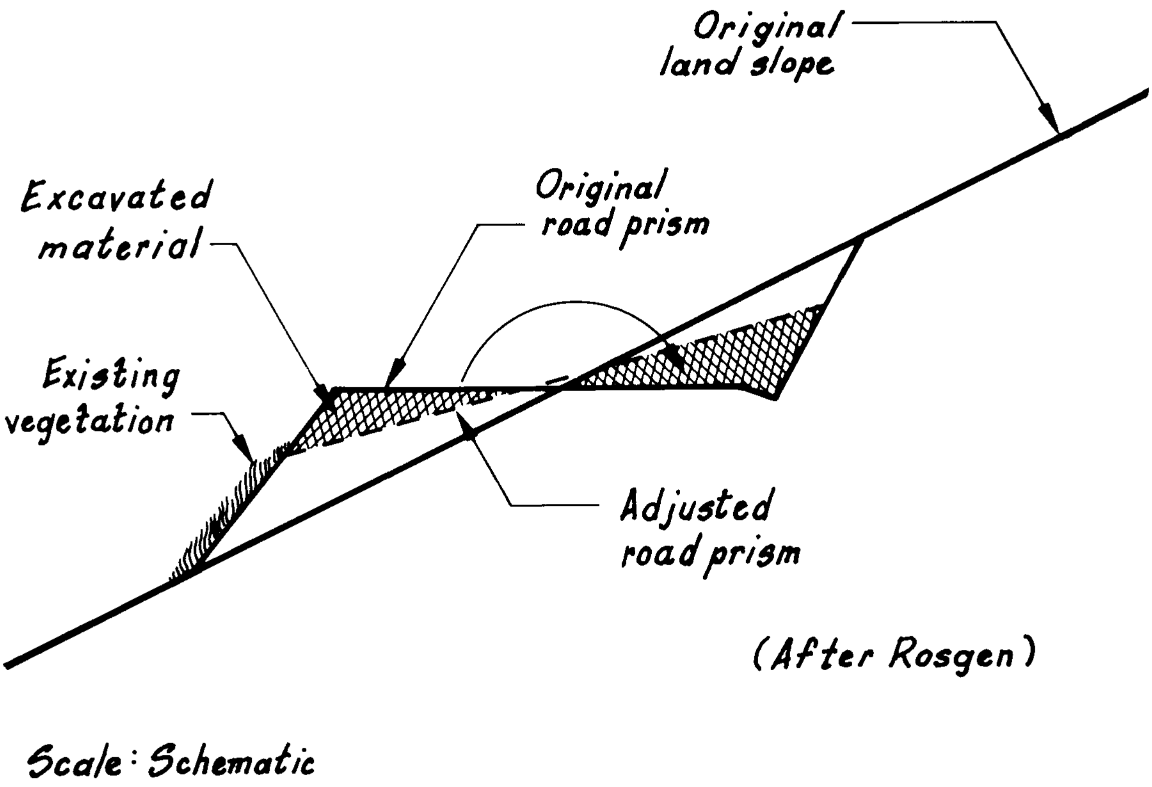

FIGURE 41 "KANIKSU CLOSURE"

from being incapable of handling high runoff events. Such problems occur more often with unattended installations but can also occur--especially during heavy runoff conditions--even when maintenance is attempted.

More options are available if the crossing installation is the result of a planned design-construction sequence than if it is on a road being re-used.

Pre-planned Crossing. For these installations, the basic alternatives are as described previously in this report--culverts; bridges; or in some circumstances, fords.

Techniques for culvert design, installation and maintenance discussed elsewhere in this report are applicable. There are some additional methods used for dealing with intermittent use roads. Information from field practitioners indicates that, where a culvert installation is the best option, important design, construction and maintenance criteria are:

1. Minimize the amount of culvert fill.
2. Use generous culvert end area estimates.
3. Design for a permanent installation.
4. Plan for supplemental maintenance "watch" if there is doubt about the ability of an installation to withstand extraordinary runoff events.
5. If a stable installation is not technically or economically feasible, include subsequent culvert

removal as part of a planned process if it can be accomplished with minimal water quality impact. If not, avoid such sites or select a safer installation.

Another technique is to use "temporary" log stringer bridges in lieu of culverts where the culvert installation requires a large fill. Many of the installation criteria for protecting water quality described in the Bridges portion of the Design chapter are also applicable to temporary bridges. Several different kinds of temporary bridge designs are used in Region X--varying from simple, relatively crude structures to more elaborate bridges designed for heavy traffic and several seasons of use. With short lapses between use periods, it may be more economical to install a longer life "temporary" bridge and leave it in place. With longer intervals of non-use it may be more advantageous to use a minimal cost structure and remove it after use. It should be noted that the practice of placing logs across a stream channel and placing an earth fill over the logs is neither a good water quality management practice nor considered to be a "temporary bridge" as used in this report.

In certain situations (see Stream Crossing Methods subsection), fords may be a suitable channel crossing installation.

Existing Crossings. If a channel crossing installation has functioned satisfactorily for years (demonstrated stability) most field practitioners contacted believe the best solution is to restore the installation to its original stability and leave it in place. The restoration work may involve several elements of the installation other than the crossing structure itself. This may include removal of stream channel debris; and roadway reconditioning (e.g., reshaping, cleaning ditches, reopening drainage, revegetating, etc.) over and on approaches to the crossing.

However, if it is determined that there is a high risk of culvert failure following the use period, the water quality management choices are more difficult. The basic options are continual maintenance or removal of the installation--entirely or partially. Factors which may lead to a "high risk" determination include: restoration to original condition is not feasible; the hydrologic character of the channel and upstream watershed has materially altered; unstable debris; and installation stability has not been demonstrated (e.g., high frequency of failure of similar, nearby installations). Continual, on-site maintenance watch before, during and after high runoff events--until the installation becomes stable--is one way of reducing failure risk.

If continual maintenance is not feasible, most practitioners contacted believe that the best solution is to remove the installation. This can be expensive and difficult to achieve without creating water quality impacts. However, care in timing the removal operation, and use of proper equipment can aid in reducing impacts.

Where the total removal cannot be accomplished without substantial impact because of prohibitive costs or technical infeasibility, a partial solution is a relief dip in the culvert fill. Rosgen reports that this technique has been field tested on the Panhandle National Forest and shows promise. Figure 42 shows this technique in schematic form. The relief dip does not stabilize the fill. Rather, it reduces the impact by directing the course of overflow water and reducing the amount of potential sediment.

SHORT TERM USE

Short term use (temporary) logging roads are those which are not planned for re-use. The general objectives for such roads should be to design a facility which can be safely maintained during its life, which can readily and safely be restored back to as nearly the original ground conditions as feasible; and to plan to make the time period between construction and restoration as short as practicable (within the same season if feasible). Locating temporary roads should be avoided in areas where these objectives cannot be reasonably accomplished.

Roadway

One alternative is to stabilize the road prism as permanently as feasible. Methods for accomplishing this include: blocking the road to further entry; installing a stable system of water bars, drain dips, and outsloping (where suitable); revegetating the cut and fill slopes and road surface; and establishing trees if the site was previously forested. These practices and limitations for using them are discussed elsewhere

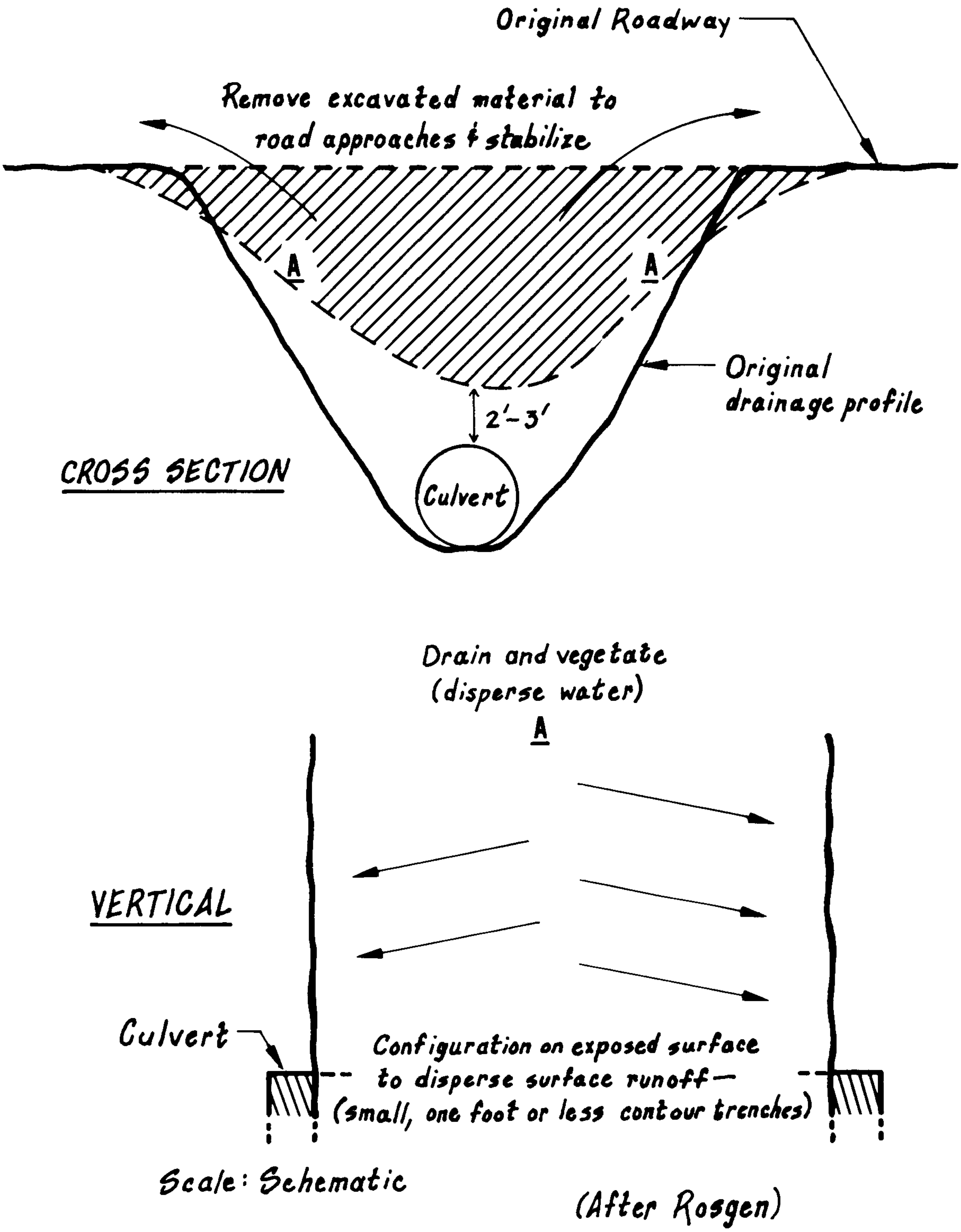

FIGURE 42 MODIFIED CULVERT REMOVAL

in this report. This approach may be most suitable where an existing, stable roadway has been reopened (but no further use is planned). If the watershed character has not been materially altered and if the past performance of these methods has been good for similar sites, they may also be adaptable for newly constructed temporary roads.

The "Kaniksu Closure" method along with tree establishment as appropriate will, in general, result in a more complete restoration of the water handling characteristics of the site. Taking into account the previously described limitations of this method, it can be used for existing and newly-constructed roads. The U.S. Forest Service, Region 6, uses a similar method as one option for obliterating temporary roads constructed under timber sale contract.

A more comprehensive (and usually considerably more expensive) technique is to completely restore the original ground profile. As used by the U.S. Forest Service, Region 6, this method--sometimes termed "deconstruction"--is to temporarily store excavated material and then pack it back into the roadway following completion of use. This technique was developed primarily to deal with critical terrain and high precipitation problems in portions of the Pacific Border Province. The more common practice is to sidecast excavated material and, following use of the road, pull it back up into the road prism with shovel or dragline. When this practice is used in precipitous terrain, it is imperative that it be used only where the roadway excavation and subsequent restoration can be accomplished during the same summer season.

Sometimes the excavated material is endhauled, stored on a stable waste site and then placed back in the road prism following use. In this case, if the restoration cannot be completed during the first season, additional measures may be needed to prevent erosion of the roadway and the waste material.

After "deconstruction" is completed, the restored ground is revegetated, including tree establishment as appropriate.

It is apparent that even temporary logging roads require thoughtful planning and design in order to most effectively achieve desired water quality objectives throughout the life, care, and obliteration of the facility.

Channel Crossings

Sediment control objectives for channel crossings on temporary logging roads should include the following:

1. Design crossings which:
   (a) can be installed with minimal water quality impact;
   (b) remain stable during use; and
   (c) can be readily removed without significant impact.
2. After use, stabilize the channel to prevent soil or debris from moving into the stream during high runoff events.
3. Perform the restoration work in a timely manner.

Generally, temporary bridges are the most suitable for meeting these objectives. Where bridges are not feasible, culverts may be a suitable alternative. In limited circumstances (see Stream Crossing Methods subsection), properly designed fords may be satisfactory.

However, location and construction of temporary roads should be avoided in those situations where there are not suitable alternatives for reasonable accomplishment of the channel crossing objectives.

ROAD MAINTENANCE CHEMICALS

A wide variety of materials is used to maintain logging roads. Chemicals, as deicers, are used on a limited basis compared to dust palliatives. Some of the most common asphalt products and other chemicals used on logging roads are in Table 16. Potential hazards and use criteria are also included. The criteria for minimizing water pollution from many of the chemicals used on logging roads have many common features as shown in Table 16.

DUST PALLIATIVES

Several kinds of materials are used in dust coating logging roads. The most common materials used are oil based. The principal objective is to stabilize soil in the road bed. In many parts of the Region, the soils on roadbeds are very friable when dry, creating excessive dust with continuous road use. Reducing dust emissions is necessary for safety or to improve visibility, aesthetics, and to minimize particulate introduction into air and water.

TABLE 16
CHEMICALS USED ON LOGGING ROADS[1]

Compound	Use	Potential Hazard	Hazard From	Use Criteria
Herbicides	Roadside Vegetation Control	Poisoning, etc.	Spillage, overspray ingestion	Should be: Approved chemicals Applied by qualified applicators
Asphalt Products Emulsified Asphalts	Dust abatement/paving	Coating of gravel beds. Introduction of asphalt into waterway when mixing in tankers.	Spillage, over-application. Siphoning Action, runoff	Standard specifications and spill reporting. Require air gap between pick up & delivery point
Paving Grade	Paving	As above. Fire.	Overheated product	Use specified temperature ranges
Cutbacks	Paving, dust abatement	As above Fire as with paving grades. Introduction of light & middle distillate volatiles	Spillage, over application	
Dustoils Arcadia Reclaimed wasteoil PS-300	Dust abatement	Aquatic life May be toxic to aquatic organisms	Spillage, over application & leaching	Standard specifications & spi spill reporting
Na Cl	Deicing, dust abatement	Detrimental to atmospheric & aquatic plant growth & fishery.	Excess Na(+)ion: through over application & leaching. Cl combines to HCl form in water.	This has received only limited use historically due to most roads being allowed to snow in. Control by rates of application
Ca Cl_2	Dust abatement	Detrimental to fishery	Leaching-Cl combining to HCl form in water, reducing available oxygen.	Not used in wet climates Control by rates of application
Reynolds Road Packer	Soil Stabilizer			Individual project control. Very limited use currently.
Sulfite Waste pulp Liquor	Dust abatement	Fisheries	Spillage, over-application and leaching.	Controlled rates of application.
Portland Cement	Soil stabilizer, concrete	Coating of fish gills decreasing oxygen assimilation.	Introduction of cement into waterway.	Should not use above hatchery installation & control of operation in all cases.

1/ Modified from information from Region 6, USFS - 5/10/74

Pollution from Oil Based Dust Palliatives

Pollution resulting from oil discharges from logging roads or spills related to uses of oils may be in the form of floating oils, emulsified oils, or solution of the water soluble fractions of these oils (104). Floating oils may interfere with reaeration and photosynthesis and prevent respiration of aquatic insects which obtain their oxygen at the surface. Free and emulsified oils may act on the epithelial surface of fish gills interfering with respiration, or they may coat and destroy algae and other plankton. Oil sediments may coat the bottom of waters destroying benthic organisms and altering spawning areas.

The water soluble fraction of oils may be very toxic to fish. Apparently the aromatic hydrocarbons are the major group of acutely toxic compounds in oil residues (104). Because of the wide range of results obtained in toxicity tests for oily substances, safe concentrations for the many compounds used in dust abatement cannot be accurately astablished.

The 96 hour LC_{50}[1] concentrations for various compounds of oil (all not used in dust coating logging roads) range from 5.6 mg/l for nephenic acid to 14,500 mg/l for No. 2 cutting oil (104). Stickleback fish tests

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1/ LC_{50}, TL_{50} - In toxicity studies it is the dosage required to kill 50% of the test population. It is expressed by the weight of the chemical per unit of body weight. The designations are used as reported in the reference cited.

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indicated a toxicity for CSS-1 asphalt emulsion of LC_{50} (96 hour) of 9,000 mg/l. CMS-1 and CMS-2 asphalt emulsion had a LC_{50} of 45 mg/l (105). Both CSS-1 and CMS-2 are used for dust coating logging roads. The toxicity information indicates that a large quantity of these materials are necessary for lethal effects. There is evidence that oils may persist and have subtle chronic effects (104).

Laboratory simulation studies on water solubles removed from surfaces stabilized with emulsified asphalts were conducted by Nielson (106) in the Region. The studies indicated that a large amount (over 40%) of asphaltic material could be washed from a road surface during the first few days after application of an emulsion mix. A much larger amount of leaching occurred during extreme laboratory conditions than is likely to occur in the field. After a few days of curing, the amount removable declined rapidly to approximately two percent of the amount applied. The amount removed remained nearly constant for the study's 30-day duration.

Two rural roads in New Jersey treated with waste crankcase oil were examined by Freestone (107) to determine whether or not oil left the road. Waste crankcase oil is not commonly used for dust coating logging roads; however, some of the study's conclusions may apply to other oil dust palliatives. Analyses indicated that roughly one percent of the total oil estimated to have been applied remained in the top inch of road surface material. Oil penetration below the top inch of the road was minimal. Oil could have left the road surface by several means such as volatilization, runoff, adhesion to vehicles, adhesion to dust particles with wind transport and penetration into the road surface. Oil remaining in the road surface may have also been biodegraded.

Most of the studies related to water quality impacts of oils have been concerned with lethal levels and their effects on the aquatic environment. Many of the studies are documented in water quality criteria reports (104, 108). In a recent study by Burger (109), acute toxicity bio-assays of PS-300 oil on juvenile Coho salmon were conducted on two weight classes. Comparable TL_{50} values of 1,350 and 1,500 mg/l resulted, indicating no definite difference in toxicity due to size or age. With the utilization of reduced concentrations, the most obvious long range effect was that concentrations of 75 mg/l and 40 mg/l were not sub-lethal. Another finding by Burger was that long-term exposure to reduced oil concentrations affected the feeding behavior of the test fish, resulting in weight loss and increased susceptibility to disease.

Control of Pollution from Oil Dust Palliatives

As defined in Standard Methods (110), any amount of oil and grease in public water supplies will cause taste, odor and appearance problems (110,111,112) and may be detrimental to conventional treatment processes. It is virtually impossible to express limits in numerical units for allowable concentrations in waters. Because of the difficulties in establishing safe levels, the maximum allowable concentrations can only be determined by bio-assay procedures and by an evaluation of the chemical composition on a case by case basis. This procedure should be used when water uses must be protected, and dust palliatives pose a significant pollution potential.

Criteria for controlling pollution from oil emulsions are available from a number of sources such as manufacturers, distributors, agencies and groups using large quantities on a continuous basis, water pollution control agencies, literature from research and others.

Oil Spills. The greatest potential for serious water quality impacts associated with the use of oil dust palliatives is the potential of oil spills. Because of the steep and dissected topography, and the use of many minimum standard roads, the potentials of oil spills are increased.

Recent rules and regulations that became effective January 10, 1974, related to Section 311 (j)(1)(c) of the FWPCA as amended, are designed to prevent discharges of oil into the waters of the United States and to contain such discharges if they occur. The regulations endeavor to prevent such spills by establishing procedures, methods, and equipment requirements of owners and operators engaged in storing, processing or consuming oil (Environmental Protection Agency, Oil Pollution Prevention, Federal Register, Volume 38, No. 237 - December 11, 1973). The regulations apply to facilities that store oil on sites.

Owners or operators of facilities that have discharged or could reasonably be expected to discharge oil in harmful quantities (those that violate applicable water quality standards, cause a film or sheen or discoloration of the surface of the water or adjoining shoreline, or cause a sludge or emulsion to be deposited beneath the surface of the water or upon adjoining shorelines) into or upon the waters of the United States or adjoining shorelines shall prepare a Spill Prevention Control and Countermeasure Plan (SPCC Plan). The SPCC Plan if properly prepared and implemented should minimize the water quality impacts of oil spills associated with dust-coating logging roads.

The rules and regulations indicate that the SPCC Plan shall be carefully thought-out, prepared in accordance with good engineering practices, and have the full approval of management at a level with authority to commit the necessary resources. If the plan calls for additional facilities, procedures, methods, or equipment not yet fully operational, these items should be discussed in separate paragraphs and the details of installation and operational start-up should be explained separately. The complete SPCC Plan shall follow the sequence outlined in the Federal Register citation above, and include a discussion of the facilities' conformance with the appropriate guidelines listed. The criteria below summarize pollution control techniques being used or recommended by the various user groups.

Control Practices. Acceptable limits and concentrations of oils in water should be achieved under the following practices and conditions:

a. There is no visible oil on the water surface.

b. Concentrations of emulsified oils do not exceed 1/20 (0.05) of the 96 hour LC_{50} value determined using the receiving water in question and the most important species in the area.

c. Concentrations of hexane extractable substances (exclusive of elemental sulfur) in air-dried sediments do not exceed 1,000 mg/l on a dry weight basis.

d. Dust palliative materials are not dumped into an area where they may flow into streams or bodies of water.

e. Dust palliative materials are not applied during rainy weather or runoff, or during a threat of rain within a 48 hour period after application (this is obviously a judgment factor). Curing time of the product is the important factor.

f. The road surface is watered prior to application to assist in penetration.

g. A small berm or wrinkle is temporarily made on either road shoulder to prevent the material, in its liquid state from running off the road during application.

h. Dust oils are applied only when the roadbed has been properly graded, watered, shaped and compacted, and when the atmospheric temperature in the shade is above 13°C (55°F) and steady or rising.

i. Many of the techniques discussed in Part II for minimizing sedimentation such as buffer strips and drainage design, will also reduce discharges of oil dust palliatives from roads if properly used.

j. Properly prepare and implement a Spill Prevention and Countermeasure plan where necessary.

OTHER CHEMICALS

Salts

Sodium chloride and calcium chloride are the only salts known to be used on logging roads in Region X. Salts are used to control snow and ice (deicing) and dust. The amount of salts used and the degree to which they are used are not quantified. Information received from the U.S. Forest Service, Region 6 (Table 16) indicates that these salts are probably used only to a limited and localized degree in the Region.

Most of the water quality impact information and data on the use of salts on roads relates to snow and ice control on paved highways and streets. A state-of-the-art report, Environmental Impact of Highway Deicing (113) has been published. This 1971 report extracts, summarizes, and references much of the research and information on the subject. Information is also available on the use of salts for dust abatement on unpaved rural roads and on logging roads.

Additives are also commonly used in the salts. These are anti-caking agents, corrosion inhibitors and rust inhibitors.

Because of the much more limited application of salts on logging roads, it is assumed that the total magnitude of potential problems would be far less than on highways and streets. However, for a specific case, the problem could be similar. Therefore, it is assumed that the kinds of water quality impact problems created by highway salting can be extrapolated to logging roads as potentially similar.

Historically, snow plowing, tire chains and a limited amount of sanding have been the principal snow control measures on logging roads. Generally, deicing salts--principally calcium chloride--are used only on paved roads. As more logging roads become paved there may be an increased use or interest in using salt for deicing.

Calcium chloride alone but usually a mixture of calcium and sodium chlorides are used for dust abatement. Wright (114) reported that a 50:40 mixture of sodium chloride-calcium chloride applied at 9,000 pounds per mile, for a 20 foot application width (4/10 kilogram/meter^2), proved both practical and reasonably effective for dust abatement on a logging road in Canada.

Oil palliatives and sulfite pulp liquor waste are used more extensively for dust abatement than salts in Region X. However, petroleum supply shortages may result in a shift from oil palliatives to more salts and pulp liquor use.

Several problems associated with use of salt on highways are pertinent to potential water quality impacts if salts are used on logging roads.

The potential toxicity of water polluted with road salts is two-fold--the salts and the additives. Excessive sodium concentrations in drinking water may be harmful to some people with heart or kidney disease (115). Schraufnagel (116) refers to studies done on chloride levels harmful to freshwater fish life--with the lowest lethal level of 400 mg/l in one study to the highest, 8,100 to 10,500 mg/l in another. (Sea water has a chloride concentration of about 19,000 mg/l).

Evidently, saline concentrations must be at relatively high levels to seriously affect fish life. However, the salt additives present a different picture. The highway deicing report (113) concludes:

> "The special additives found in most road deicers cause considerable concern because of their severe latent toxic properties and other potential side effects. Significantly, little is known as to their fate and disposition, and effects on the environment. The complex cyanides used as anti-caking agents and the chromate compounds used as corrosion inhibitors have been found in public water supplies, ground waters.... The phosphate additives....may contribute to nutrient enrichment in lakes, ponds, and streams...."

In addition to potential toxic effects, deicing salts have resulted in ground water contamination--including public and domestic water supplies, ponds and streams (113). The Public Health Service Drinking Water Standards lists the recommended maximum chloride concentration as 250 mg/l, but chromium and cyanide concentrations of .05 mg/l and .2 mg/l, respectively, are grounds for rejection of the water supply (117).

Several authors and publications have reported the movement of deicing salts from road surface (113, 118, 128). Maximum concentrations of salts may be found at soil surfaces nearest the road. However, salts are readily leached from the soil surface and into subsurface flow. Kunkle (119) reports that the highest concentration of chloride in study streams occurs during summer low-flow--apparently the result of ground water movement into the streams. (Note: concentrations, i.e., mg/l were higher in the summer; total salt delivery was greater in the spring but at a lower concentration because of dilution).

For deicing salts, three major application problems were reported (113); over-application, misdirected application, and improper storage of stockpiled salts.

Two comprehensive documents, Manual for Deicing Chemicals: Application Practices (120) and Manual for Deicing Chemicals: Storage and Handling (121) are recommended source references to consult for specific guidance in storing and applying deicing salts.

Two key needs brought out in the above application practices manual are knowing how much salt is actually being applied (i.e., verifying the calibration) and making only the essential minimum number of applications.

The following practices and procedures should assist in minimizing water quality impacts of salts on logging roads.

1. Limit the use of salt for snow and ice control on logging roads to minimum essential needs.
2. In lieu of salts for ice and snow control, consider snow plowing, chains and sanding to the extent feasible.
3. If there is compelling reason to use salt deicers, the following should be considered:
    a. Use only enough salt to provide a safe driving surface. This includes (1) monitoring the amount of salt actually applied frequently enough to ensure that equipment calibration is resulting in the prescribed application rate; and (2) making only the minimum needed number of applications during each storm.

b. Salt only on steep grades, at major intersections and at stop points.

c. Favor sand-salt mixtures in lieu of straight salt applications.

d. Avoid application near streams or lakes.

e. Avoid spillage off the road surface--i.e., keep the salt on the road.

f. Locate storage areas where ground water--as well as surface water--contamination threat is minimal.

g. Protect salt piles from exposure to moisture.

4. For dust abatement purposes, utilize the following practices:

   a. Apply only enough salt to provide the desired level of dust abatement.

   b. Ensure that the prescribed application rates are what is actually being applied.

   c. Where appropriate, consider items 3 e. thru g. above.

Pulp Wastes

Sulfite waste liquor (SWL) has apparently been used for road dust abatement for many years (122). Pearl (123) reports that the largest use of crude spent sulfite liquor is for roadbinding (including dust abatement) purposes--with an estimated 125 million pounds used annually, nationwide. Authors in other countries have also reported on the use of pulp wastes in road construction (124).

Pulp liquor is a relatively inexpensive and fairly effective dust abatement material for logging roads. It tends to leach out more rapidly than oil palliatives and therefore requires more frequent application to produce a similar degree of dust control. As a result, use of oil palliatives has increased in the past. As previously noted, petroleum shortages could alter this trend.

The pollution characteristics of pulping wastes (pertinent to roads) are their high biochemical oxygen demand (BOD) and their toxicity (125). The exact constituents responsible for toxicity are not well known (125).

The high BOD agents in the waste liquor tend to oxidize quickly on the road surface. This suggests a general pollution-minimizing principle: control the application of waste liquor so that it does not run off the road surface at the time of application.

Strombom states that application rates for pulp wastes vary depending upon the porosity of the surface treated--with as little as 1/10 gallon per square yard (4/10 liter per $meter^2$) on denser road surfaces to 1/2 gallon per square yard (2-2/10 liter per $meter^2$) on porous surfaces (126). A Canadian report describes test results of application rates of about the same magnitude for calcium lignosulfate (pulp liquor) (127).

Practices and methods to help minimize water quality impacts from pulp waste liquors are as follows:

1. Control application--including application rates, use of equipment, and weather conditions--to prevent free runoff of the chemical from the road surface, i.e., ensure that the chemical stays on the road. Some techniques to help achieve control are:
    a. Using temporary retaining berms at the roadway edges;
    b. Making trial applications and evaluations to ensure that the calculated application rate is penetrating correctly;
    c. Not applying the chemical during or immediately prior to rain;
    d. Providing adequate training, performance standards, and supervision for application personnel and equipment.
2. Avoid applying the chemical where the road is close to a stream unless there is an adequate filter strip between the road and the stream.
3. Prevent spillage into or near streams.
4. When cleaning out chemical storage tanks or application equipment tanks, dispose of the rinse waste fluids on the road surface or in a place away from potential water contamination.

Others

There are a number of trade name products developed for use as road-binders. In many cases, the chemical composition of these products is not public information, making it difficult to assess potential water quality impacts. Toxicity tests can be conducted for materials of unknown composition. However, these tests have limited potential for evaluating other than short-term effects on the tested organisms. Knowledge of the constituents of a substance is a key to a comprehensive evaluation.

Impartial groups are available for making evaluations on a confidential basis. Data needed for evaluation of a product are: (a) name and amount of each constituent; (b) associated technical specification detail; and (c) specific directions, if any, for application. Sometimes an evaluation can be made on this basis alone; but in some cases, further toxicity studies may be necessary.

Specific recommended practices should be tailored for each product. However, some general recommended practices are listed below.

1. Ascertain the chemical composition of each product.
2. Evaluate each product for its potential hazard.
3. Do not use products with demonstrated or suspected high toxicity.
4. Incorporate water quality needs into application specifications.
5. Use those practices described previously in this section, as applicable.

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16. Abstracts THIS REPORT IS A STATE-OF-THE ART REFERENCE OF METHODS, PROCEDURES AND PRACTICES FOR INCLUDING WATER QUALITY CONSIDERATION IN THE PLANNING, DESIGN, CONSTRUCTION, RECONSTRUCTION, USE AND MAINTENANCE OF LOGGING ROADS. MOST OF THE METHODOLOGY ALSO IS APPLICABLE TO OTHER FOREST MANAGEMENT ROADS. THE REPORT IS DIVIDED INTO TWO PARTS. THE FIRST PART PROVIDES GENERAL PERSPECTIVE ON PHYSICAL FEATURES AND CONDITIONS IN EPA REGION X WHICH ARE RELEVANT TO WATER QUALITY PROTECTION AND LOGGING ROADS. THE SECOND PART OUTLINES SPECIFIC METHODS, PROCEDURES, CRITERIA AND ALTERNATIVES FOR REDUCING THE DEGRADATION OF WATER QUALITY. TOPIC COVERAGE IN THIS PART INCLUDES ROAD PLANNING, DESIGN, CONSTRUCTION AND MAINTENANCE INCLUDING THE USE OF CHEMICALS ON ROADS. SILVICULTURAL ACTIVITIES ARE ONE CATEGORY OF WATER POLLUTION FROM NONPOINT SOURCES DESCRIBED IN PUBLIC LAW 92-500. OF ALL SILVICULTURAL ACTIVITIES, LOGGING ROADS HAVE BEEN IDENTIFIED AS THE PRINCIPAL SOURCE OF MAN-CAUSED SEDIMENT.

17. Key Words and Document Analysis. 17a. Descriptors

LOGGING ROADS
FOREST ROADS
FOREST MANAGEMENT ROADS
WATER MANAGEMENT:ROADS
WATER QUALITY PROTECTION
FOREST ROAD CHEMICALS
LOGGING ROAD CHEMICALS
NONPOINT SOURCE
NONPOINT SOURCE POLLUTION
SILVICULTURAL ACTIVITIES
WOODLAND ROADS

17b. Identifiers/Open-Ended Terms
METHODS, PROCEDURES, PRACTICES FOR REDUCING WATER QUALITY DEGRADATION FROM LOGGING ROADS AND OTHER FOREST ROADS.
WATER QUALITY CONSIDERATIONS IN LOGGING ROAD PLANNING, DESIGN, CONSTRUCTION AND MAINTENANCE.
IMPACTS OF LOGGING ROADS AND OTHER FOREST ROADS ON WATER QUALITY.
WATER POLLUTION ABATEMENT FROM NONPOINT SOURCES, LOGGING ROADS AND OTHER FOREST ROADS.
ENGINEERING LOGGING ROADS AND OTHER FOREST ROADS TO INCLUDE WATER QUALITY MANAGEMENT.

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