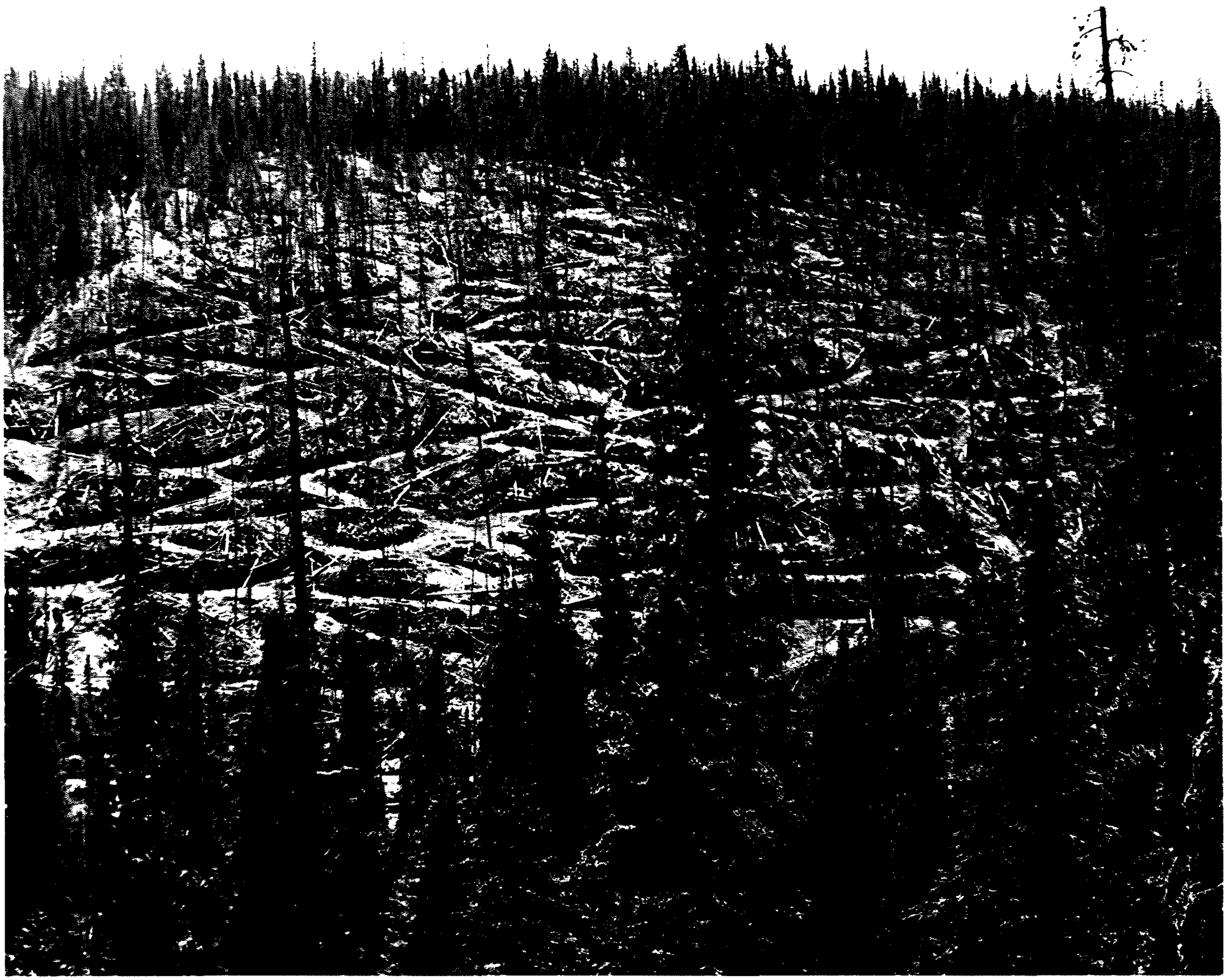
Environment Canada / Environnement Canada

Forestry Service / Service des Forêts

Watershed management guidelines for logging and road construction in Alberta

R.L. Rothwell



Northern Forest Research Centre • Edmonton, Alberta • Information Report NOR-X-208

WATERSHED MANAGEMENT GUIDELINES FOR LOGGING AND ROAD CONSTRUCTION IN ALBERTA

R.L. ROTHWELL

INFORMATION REPORT NOR-X-208
SEPTEMBER 1978

Based on Information Report A-X-42 (1971)
Newly revised and edited by R.L. Rothwell,
R.M. Waldron, and P.A. Logan

NORTHERN FOREST RESEARCH CENTRE
CANADIAN FORESTRY SERVICE
FISHERIES AND ENVIRONMENT CANADA
5320 - 122 STREET
EDMONTON, ALBERTA, CANADA
T6H 3S5

Rothwell, R.L. 1978. Watershed management guidelines for logging and road construction in Alberta. Fish. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-208.

ABSTRACT

This report provides watershed management guidelines for logging and road construction to minimize erosion, sedimentation, and deterioration of water quality. The guidelines, which have been developed specifically for Alberta's foothills and mountainous region, are based on an extensive literature survey of research and practices in North America.

RESUME

Ce rapport fournit des lignes directrices sur la gestion des bassins-versants et il touche l'exploitation et la construction de routes pour minimiser l'érosion, la sédimentation, puis la détérioration de la qualité des eaux. Les lignes directrices, mises au point spécifiquement pour les contreforts et régions montagneuses de l'Alberta, se fondent sur une étude extensive de la littérature relative à la recherche et aux pratiques suivies en Amérique du Nord.

CONTENTS

	Page
Introduction	1
Erosion and Watershed Damage	1
Precipitation	1
Soil Properties	1
Topography	2
Vegetation	2
Watershed Management Guidelines for Logging	2
Cutting Methods	2
Landings	4
Skid Roads	4
Tractor Logging	4
Cable Logging	5
Log Hauling	6
Cleanup	6
Skid-Road Drainage	6
Soil Stabilization	8
Watershed Management Guidelines for Road Construction	11
Road Gradient	11
Road Width	11
Aspect	11
Side-Hill Slopes	12
Topography	12
Geology and Soils	12
Stream Protection	12
Stream Crossings	13
Cuts and Fills	14
Drainage	15
Equations to predict peak flow	15
Culverts	18
Ditches and grades	19
Subsurface Drainage	19
Berms	21
Road Maintenance	21
Grading	21
Drainage	22
Putting roads to bed	22
Traffic	22
Appendix 1. Surface Water Quality Objectives	24
Appendix 2. Correct and Incorrect Methods of Installing Culverts	26
Appendix 3. Sample Calculations for Determining Peak Flow and Culvert Size	28
Talbot Formula	28
Burkli-Ziegler Formula	28
Rational Formula	29

Page

Appendix 4. Sample Calculations for Determining the Water-Carrying Capacity of Roadside Ditches Using Manning's Formula 35

Glossary 37

References 39

FIGURES

1. Unnecessary soil disturbance and exposure caused by unplanned tractor logging of a mature spruce-fir stand on steep slopes. . . . . Front Cover

2. Erosive power of water is proportional to its flow velocity squared. 2

3. Hypothetical impact of large clear-cuts and short cutting cycles on watershed disturbance. 3

4. Hypothetical impact of smaller clear-cuts and longer cutting cycles on watershed disturbance. 3

5. Skid roads should not be constructed in draws or creek bottoms. 5

6. Soil disturbance caused by high-lead and tractor logging. 6

7. Skid roads should not be allowed to run straight up and down slopes. 7

8. Soil disturbance caused by a tractor on wet soil. 7

9. High-lead cable logging system. 8

10. Skid-road patterns for cable and tractor logging on steep slopes. 8

11. Truck skidding of logs for long distances should not be substituted for regular logging. 9

12. After logging operations, culverts should be removed from streams to prevent them from being washed out. 9

13. Typical side-hill cross section. 12

14. Slope obstructions to slow runoff and trap sediment. 13

15. Logging debris placed along roadside to act as sediment traps and to enhance revegetation of disturbed areas. 13

16. Road bank slumping in unstable glacial till caused by excess water. 16

17. Erosion of unstable fill slopes can be reduced by seeding to grass and placing obstructions along the slope to slow runoff. 16

18. Road bank erosion caused by uncontrolled runoff from upslope areas. 17

19. Structures to control debris. 19

Page

20. Open-top culverts. 19

21. Rolled grade and cross drain. 20

22. Hydrologic problem and water table relations in roads crossing peatland approximately parallel to the contour. 20

23. Planimetric view of well-drained swamp road crossing. 20

24. Good and poor road location sites for avoiding subsurface drainage problems. 21

25. Possible slide zone due to seepage between fill material and an impervious zone. 21

26. Berms. 21

27. Berm specifications. 21

28. Construction of cross drains. 22

29. Cross drains should extend the full width of the road bed. 23

30. Culvert installed with too much fall. 26

31. Culvert correctly installed by lowering the ditch to the natural flow line. 26

32. Culvert installed with the outlet high above the natural flow line. 26

33. Culvert outlet extended using a pipe spillway beyond the toe of the slope. 26

34. Culverts should not be installed where ditches are lower on each side of the fill than the outlet. 27

35. Culvert correctly placed on the natural flow line of water. 27

36. When the fall below the outlet end is solid rock, the natural flow line is on a level with the rock. 27

37. Culvert size versus drainage area for rainfall intensities of 1.00-1.75 in. (25-44 mm)/h (Talbot formula). 31

38. Rainfall intensity-duration-frequency for different return periods in the Hinton-Edson Region, Alberta. 33

39. Shallow roadside and V-shaped ditch showing measurements used in determining water-carring capacity using Manning's formula. 35

TABLES

Page

1. Comparison of northeastern U.S.A. and western Idaho spacing guides for cross drains on skid roads with various road gradients 10

2. Spacing guide for cross drains and berms for various soil types and road gradients 10

3. Cross-drain spacings required to prevent hill or gully erosion deeper than 2.5 cm on secondary logging roads built on various soil types and road gradients in the upper topographic position of north-facing slopes having a gradient of 80% 10

4. Grass species successfully used for revegetation in erosion control and land reclamation 11

5. Recommended widths for stream filter belts 13

6. Protective strip widths required below the shoulders of 5-yr-old logging roads built on soil derived from basalt, having 9.1-m cross-drain spacing, zero initial obstruction distance, and 100% fill slope cover density 14

7. Back slope and fill slope angles for different soil materials 15

8. Maximum road crowns recommended for heavy rainfall areas 22

9. Description of watershed north of Edson, Alberta used in sample calculations 29

10. Summary of runoff coefficients C for the Talbot, Burkli-Ziegler, and Rational formulas used for the prediction of peak flows from small watersheds less than 5 mi^2 (13 km^2) in area 30

11. Culvert diameter requirements for the watershed described in Table 9, using different runoff coefficients and the Talbot, Burkli-Ziegler, and Rational formulas for peak flow prediction 34

12. Roughness coefficients of different vegetative surfaces for use in the calculation of time of concentration, Rational formula 34

13. Carrying capacity of shallow and V-shaped ditches and minimum culvert size at various slope gradients 36

INTRODUCTION

Most serious erosion and sedimentation problems on forested lands originate from logging operations and road construction (Dunford 1960; Dyrness 1965; Fredricksen 1965; Garrison and Rummell 1951; Haupt 1959a,b; Haupt and Kidd 1965; Hoover 1952; Reinhart *et al.* 1963; Schultz, C.D. and Company Limited 1973; Trimble and Sartz 1957; Weitzman and Trimble 1952). Main causes are logging on steep slopes, skidding straight up and down slopes, constructing roads that change or disturb the natural flow of drainage channels, roads with steep gradients, and drainage systems inadequate to divert water from road surfaces. The prospect of increased timber harvesting in most forest regions of Alberta makes necessary more specific criteria governing logging operations and road construction to ensure adequate protection of our water resources.

The basic tenet of these guidelines is that serious erosion and sedimentation can be prevented only by minimizing soil disturbance and controlling surface runoff. This requires an understanding of soil erosion processes and the implementation of well-planned logging operations and road construction. The guidelines and examples cited in this report illustrate what can be done and the benefits that result. If implemented, these guidelines should reduce erosion, sedimentation, and deterioration of *water quality* (Appendix 1).

The first section of this report briefly discusses erosion and *watershed damage*. The second and third sections present watershed management guidelines for logging and road construction, including road maintenance. Italicized technical terms appearing in the text are defined in the Glossary beginning on page 37.

EROSION AND WATERSHED DAMAGE

Erosion is the wearing away of the land surface by water, wind, ice, and gravity. There are two general types—geologic erosion and accelerated erosion. Geologic erosion is a gradual process that occurs under natural conditions. Accelerated erosion is usually caused by the removal of vegetation through cultivation, grazing, fire, logging, or road construction. Geologic erosion can be beneficial because it aids in the soil-formation process. Accelerated erosion is destructive because it proceeds at a rate greater than soil formation.

In these guidelines, we are concerned only with water erosion, which results from the forces of flowing water and abrasion when *surface runoff* passes over soil with insufficient vegetative cover. Water erosion is the primary agent of watershed damage in logging and road construction. The chief factors governing the rate and severity of water erosion are precipitation, soil properties, topography, and vegetation.

Precipitation

The intensity and duration of rainfall affect the dispersion of soil particles and the amount and velocity of surface runoff. The impact of raindrops breaks down *soil aggregates* and displaces soil particles. Fine particles suspended in surface runoff seal soil pores, leading to lessened infiltration and increased runoff. Closely allied with rainfall intensity is the total amount of rainfall. If high-intensity rainfall is of short duration, there may be little erosion because no runoff is produced. However, where both intensity and amount of rainfall are high, serious erosion can, and usually does, occur.

Soil moisture at the time of rainfall is also an important factor in soil erosion. Rainfall on a wet soil will produce a different pattern of runoff and erosion than the same intensity or duration of rain on a dry soil. There is usually less erosion on dry soils because they are able to hold more water.

Soil Properties

Soil characteristics that affect erosion are infiltration capacity and stability. Infiltration is the rate at which water enters the soil. It has a direct effect on erosion by determining the volume of water available for surface runoff. It is chiefly affected by rainfall intensity and soil surface condition. Where rainfall intensity exceeds infiltration capacity, and duration is sufficient, excessive surface runoff and erosion can result. Soil surfaces that are fully vegetated usually have a high infiltration capacity. Vegetation protects the soil and aids in development of *soil porosity* and water adsorption, whereas soil surfaces bare of vegetation are characterized by low infiltration capacity, *soil compaction*, and soil loss.

Soil stability is the resistance of soil particles to detachment, transport, and dispersion from the forces of raindrops and flowing water. There has been no definitive explanation of soil stability; however, research indicates that soil stability and erodibility are closely related to water-stable aggregation. Most researchers have attempted to express erodibility in terms of ease of dispersion (Middleton 1930), ratio of soil particle surface area to aggregated silt and clay (Andre and Anderson 1961), and mean water-stable aggregate size (Wooldridge 1964). In general, soil stability increases with size of *water-stable aggregates* and a favorable mixture of silts and clays as binding agents.

Topography

Degree and length of slope are two topographic features that affect runoff and erosion. The velocity and erosive power of surface runoff increase with degree of slope. If the velocity of surface runoff is doubled, its cutting power is increased four times, that is, the erosive power of water is proportional to its flow velocity squared (Fig. 2). Length of slope has similar

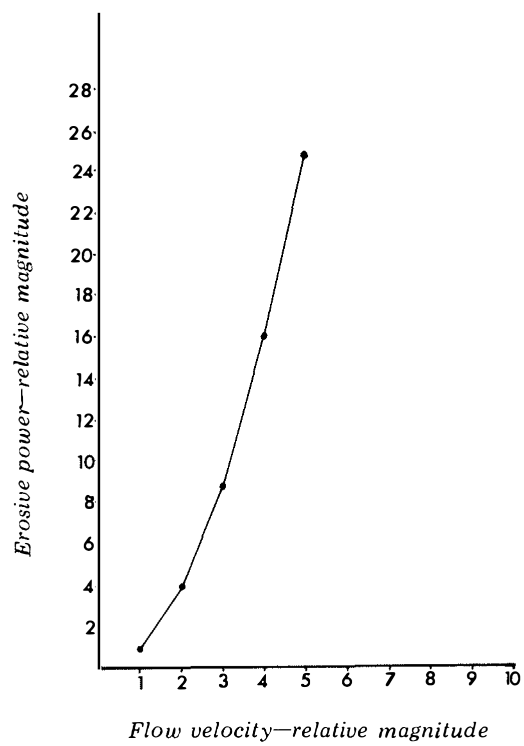


Fig. 2. Erosive power of water is proportional to its flow velocity squared (after Kittredge 1948).

effects, although modified by surface conditions, *soil permeability*, rainfall intensity, and slope steepness. Doubling the horizontal length of a slope can increase erosion three times (Baver *et al.* 1972).

Vegetation

Vegetative cover diminishes the effects of rainfall and steep topography on erosion. Vegetation reduces total rainfall, rainfall intensity, and raindrop impact through interception; decreases runoff velocity and erosive power; increases *aggregation*, soil porosity, and biological processes associated with vegetative growth; and dries soil by evapotranspiration. Numerous studies have indicated that forest cover is one of the most effective vegetation types for maintaining and protecting soil from erosion (Kittredge 1948; Tennessee Valley Authority 1962; Ursic 1963).

WATERSHED MANAGEMENT GUIDELINES FOR LOGGING

Watershed damage from logging can be minimized by careful planning. A West Virginia study comparing the effects of commercial clear-cut, *diameter limit*, and *selection cutting* (*extensive* and *intensive*) (Reinhart *et al.* 1963) shows the value of careful planning. In a clear-cut watershed with unplanned skid roads and no provisions for road drainage, water *turbidity* was 56 000 ppm. In contrast, water turbidity for the intensive selection cut with planned skid roads was 25 ppm, slightly higher than on an uncut watershed where water turbidity was 15 ppm. Analysis indicated that differences were caused primarily by skid-road location and road construction.

Cutting Methods

It is not the cutting of trees that results in watershed damage, but the method by which they are removed from the forest. In numerous studies, all trees in a watershed have been cut and left on the ground, with no significant increase in erosion. In general, soil disturbance and the potential for erosion increase with the number of stems or volume removed per unit area. On this basis, the following cutting methods have been ranked according to severity of disturbance:

Cutting method	Degree of disturbance
Clear-cutting	High
Seed tree	
Shelterwood	
Group selection	
Selection	Low

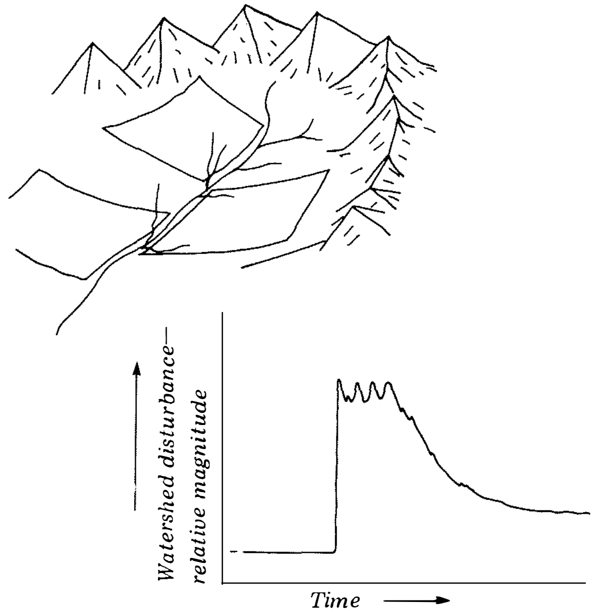


Fig. 3. Hypothetical impact of large clear-cuts and short cutting cycles on watershed disturbance.

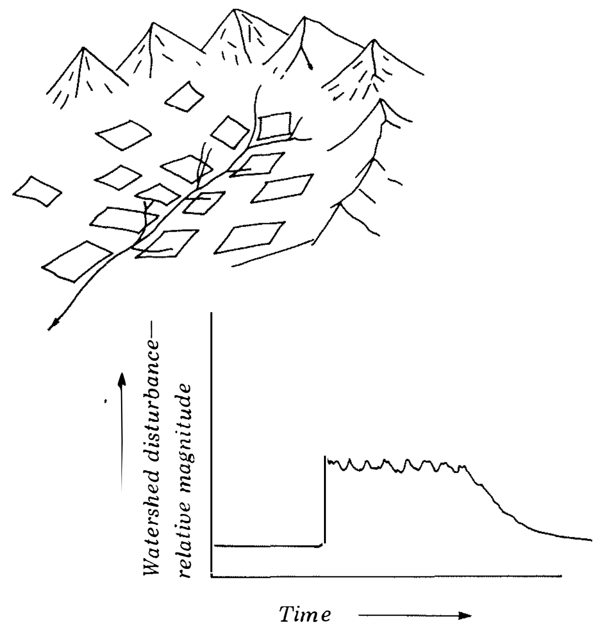


Fig. 4. Hypothetical impact of smaller clear-cuts and longer cutting cycles on watershed disturbance.

If clear-cutting is employed, careful consideration should be given in the logging plan to size and distribution, both areal and temporal, of the cutting blocks. Generally speaking, increasing the size of clear-cut blocks and shortening the cutting cycle will increase the potential for watershed damage.

Large clear-cuts and a short cutting cycle concentrate the disturbance in area and time and increase the impact on watershed values (Fig. 3). Furthermore, large cut blocks may create habitats that are difficult to revegetate, thereby prolonging the recovery period. Smaller cut blocks and longer cutting cycles may result in the same total amount of disburbance, but distribution in time and area diminishes impact (Fig. 4). In addition, residual vegetation maintains a forest environment that reduces and slows runoff, erosion, and the amount of sediment entering streams. Unfortunately, there are no conclusive data available to show optimum sizes, shapes, and orientation of clear-cut areas to minimize soil disturbance and runoff. Types of clear-cutting often used are *patch clear-cutting*, *alternate clear-cut strips*, and *progressive clear-cutting*. Patch clear-cutting and alternate clear-cut strips oriented along rather than across the contour are probably the most advantageous for watershed management, since slope length over disturbed soil surfaces can be short, and the uncut patches or strips act as barriers to runoff and as sediment traps. Alternate clear-cut strips are best used on smooth, regular terrain, and patch clear-cuts on rugged and irregular terrain. Progressive clear-cutting is the least desirable cutting method for watershed management because it maximizes the potential for soil disturbance, overland flow, and erosion.

When cutting areas are planned, belts of undisturbed vegetation should be maintained along drainage channels to prevent stream-bank damage and sediment transport into streams. Undisturbed vegetation does not have to be mature timber. Belts of *riparian vegetation* and undisturbed ground cover should be just as effective. However, timber removed should be felled away from the stream channel to minimize damage. Trimble and Sartz (1957) recommend leave strip widths ranging from 20 to 60 m[1], depending on slope. The Alberta Forest Service requires that no green timber shall be cut within 60 m of the high-water mark on any main watercourse (DePape and Phillips 1977).

---

[1] All metric values in the report have been converted from the original English units.

Landings

As one of the busy spots in logging, landings should be located and constructed to allow efficient operation and strict control of watershed damage. Soil disturbance in a logged area can be partly controlled by careful location of landings, because they affect the arrangement and density of skid and truck roads. Landings should be located in such a way as to minimize skid-road and truck-road mileage.

Although specific recommendations must vary with forest type, topography, and logging method, some points to consider in locating landings are slope, size, and access. The side slope of landings should not permit logs to slide or roll when unhooked, but should be steep enough for good drainage so as to avoid accumulation of water and mud. Size and access should not restrict work efficiency and thus prolong soil disturbance and compaction. Favorable locations for landings are on benches, ridges, and gentle slopes. Landings should not be located where serious erosion and sedimentation can occur.

Skid Roads

Close attention should be given to the planning of skid roads. A haphazard system of skid and truck roads can occupy 20% of a logged area, while a well-planned system need occupy only 10% (Haussman 1960). Skid roads should be laid out so that timber can be removed with a minimum of traffic and disturbance. Once located, they should be marked in the field and supervised to see that they are used. Tractor operators should not be allowed to locate skid roads because this usually results in unnecessary disturbance (Fig. 1).

Creek bottoms or draws should not be used for skid roads because logs skidded across, down, or along stream channels cause erosion and deterioration of water quality (Fig. 5). Furthermore, operations are hampered by wet conditions and may have to be halted because of high water. On steep terrain, it is advisable to establish skid roads in advance of timber cutting. Trees can then be felled away from the road, facilitating skidding and limiting disturbance.

Skid roads should not have long continuous grades or grades in excess of 25-30%, because runoff and erosion increase with degree and length of slope. Optimum grades for tractor operation (crawler and wheeled) range from 12 to 18% (Bureau of Land Management, n.d.). Steeper grades can be avoided by locating skid roads along the contour or running them diagonally across the slope. When excessively steep grades are unavoidable, *water bars* or equivalent structures (see Skid-Road Drainage, page 6) should be used to divert runoff to undisturbed areas.

The time of year and the weather should be considered in skidding and logging operations. Soil disturbance and road damage can be reduced if operations are limited to periods when soils are not highly saturated. Accordingly, low-elevation sites with relatively dry soils, good access, and gentle slopes are best logged in the spring. High-elevation sites can be logged later in the season after snowmelt when soils and roads are less easily disturbed.

Tractor Logging

In tractor logging, crawler or wheeled vehicles are used to skid logs. This method is usually preferred over others because of its efficiency and economy. However, because tractor logging can cause more soil disturbance, exposure, and compaction than other methods (Fig. 6) care must be exercised.

On slopes between 12 and 18%, wheeled or rubber-tired skidders are more efficient and should produce less soil disturbance than tracked vehicles because of their higher mobility and lighter weight. However, on steeper slopes (30%), tracked vehicles have greater traction and pulling power and cause less soil disturbance. Wheeled vehicles on steep slopes frequently lose traction, and their wheels spin and dig into the soil surface more than those of tracked vehicles. In general, tractor efficiency decreases and soil disturbance increases on steeper slopes, because vehicles are forced to maneuver straight up and down slopes or to establish trails by cut-and-fill operations (Fig. 7).

Soil compaction is another factor that must be considered in tractor logging. The heavy weight of tractors repeatedly passing over skid roads and landings compacts surface soils, which reduces infiltration and increases runoff and erosion. Steinbrenner and Gessel (1955) observed that four passes with an HD20 tractor reduced macropore space by 50% and infiltration rate by 80%. Reduced infiltration also results in site deterioration, because less moisture is available for plant growth (Silen and Gratkowski 1953). Excessive compaction can be reduced by keeping skid-road traffic to a minimum and by preventing tractors from operating on wet soils that are easily compressed or disturbed (Fig. 8).

Fig. 5. Skid roads should not be constructed in draws or creek bottoms. This skid road was poorly located, too close to the small tributary, and crosses the main stream without a culvert or temporary bridge. The gradient is too great for a stream crossing, and there are no provisions for preventing sediment discharge into the main stream.

Logs should be skidded in a downhill direction, butt end first, rather than uphill, because soil disturbance and frictional resistance are less. The ends of the logs should also be elevated off the ground, because this reduces frictional resistance and prevents gouging of the soil surface, as in ground skidding. Calvert and Garlicki (1965) report that when skidding logs butt or top foremost in a random fashion, 110% more force is required to skid the logs on the ground than when they are suspended by one end. In practical terms, a load may be more than doubled by the addition of an *arch* or *A-frame* to a tractor when skidding.

Extra care should be taken in skidding on erodible soils to prevent the formation of ruts or troughs that could become gullies. These areas should be skidded when soils are dry. Furthermore, studies (Calvert and Garlicki 1965; Darwin 1965) show that more power is required to skid over wet ground than on dry ground. When skidding on wet ground, logs tend to gouge and dig into the soil surface.

Cable Logging

Cable logging is a system of transporting logs from stump to landing by means of steel cable and winch. The method has many modifications, including the *ground-lead* and *high-lead* logging systems, and is most used in the coastal and interior forests of British Columbia. These methods are usually preferred on steep slopes, wet areas, and erodible soils where tractor logging cannot be carried out effectively (Fig. 9). Uphill yarding, common to most cable operations, creates less soil disturbance because the lift imparted to logs reduces frictional resistance. Furthermore, the pattern of yard trails downhill from a landing radiates outwards, which disperses runoff evenly over the slope

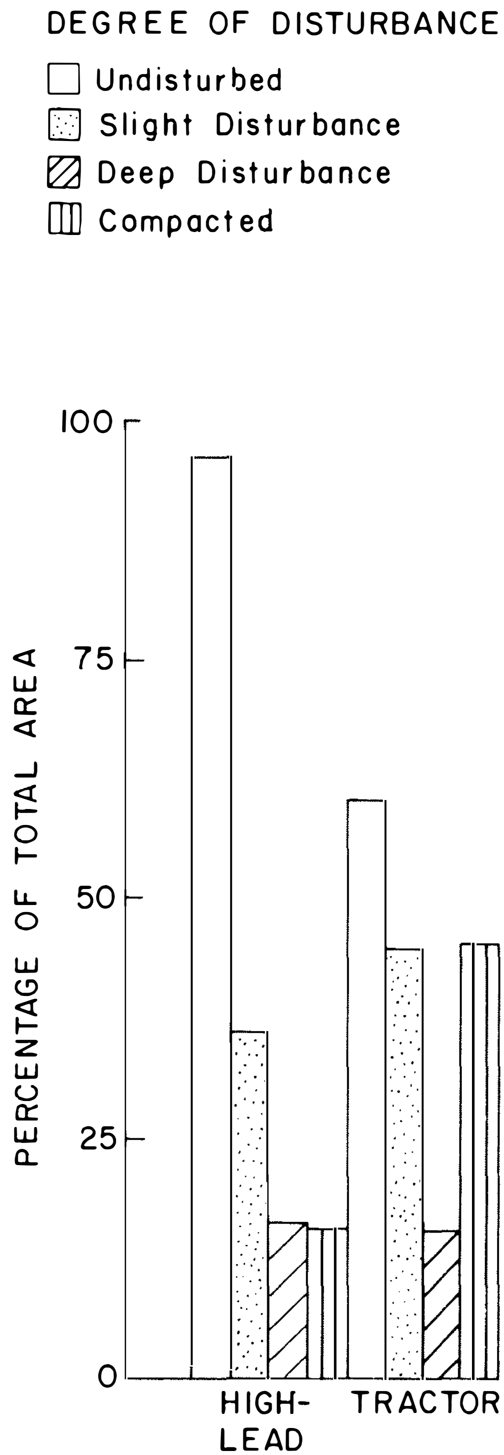


Fig. 6. Soil disturbance caused by high-lead and tractor logging (after Dyrness 1965).

and reduces erosion potential. Tractor skid trails and skid roads have the opposite effect, converging on the landing downslope and concentrating runoff and increasing erosion (Fig. 10).

Downhill yarding, because it concentrates surface runoff on slopes, should be avoided in cable logging. Where a full circle is yarded around a spar pole, as is done on side slopes, it is preferable to have the long yarding distance on the downhill side and the short distance on the uphill side. Where excessive downhill yarding is unavoidable, high-lead logging may be preferable.

How useful cable methods can be in other regions of Canada has not been fully investigated. Cable methods have been successfully used in European forests, where the topography and smaller timber sizes are similar to forests in Alberta and Eastern Canada. Portable spars could be employed to extract sawtimber from steep slopes and wet areas, but such operations may be uneconomical because of the small size of the timber.

Log Hauling

Tree-length truck hauling is a common method of removing trees from the forest. Trees should be loaded for transport so that their ends do not drag on the road surface, which is highly disturbed and subject to easy soil movement. Another hauling method used in some places is tree-length skidding behind trucks, sometimes for distances of 5-8 km. Because of the damage done to roadbeds and the increased potential for erosion (Fig. 11), this practice must not be substituted for hauling.

Cleanup

After logging, cutover areas and roadsides should be cleaned up and measures taken to prevent and control erosion. In order that water quality may be maintained, all logging debris (branches and tree tops) should be removed from stream channels. Temporary fills and log and open-top culverts should be removed to prevent them from being washed out (Fig. 12).

Skid-Road Drainage

A series of *water bars* to divert runoff onto undisturbed vegetation will help prevent accumulation of runoff on skid roads and landings. A general rule for spacing water bars is

Fig. 7. Skid roads should not be allowed to run straight up and down slopes because serious erosion and gullies may occur. Gullies that formed on the upper section of this skid road could have been prevented by following the contour in locating the road and by providing skid-road drainage.

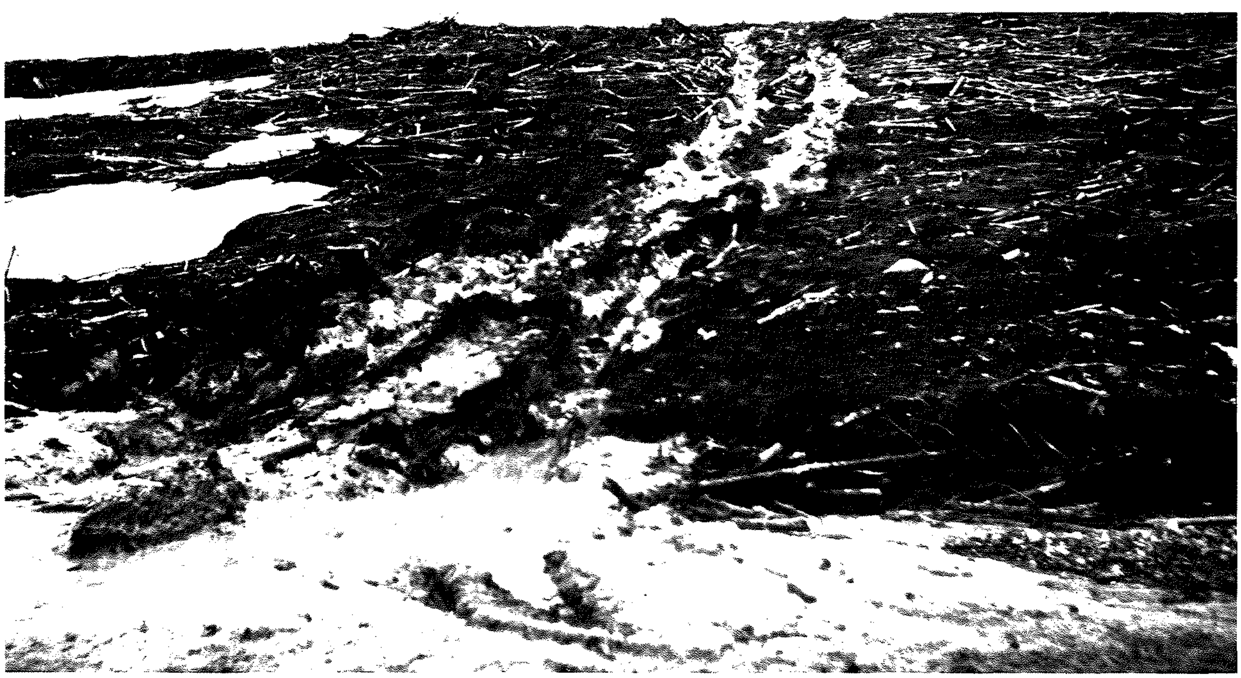


Fig. 8. Soil disturbance caused by a tractor on wet soil.

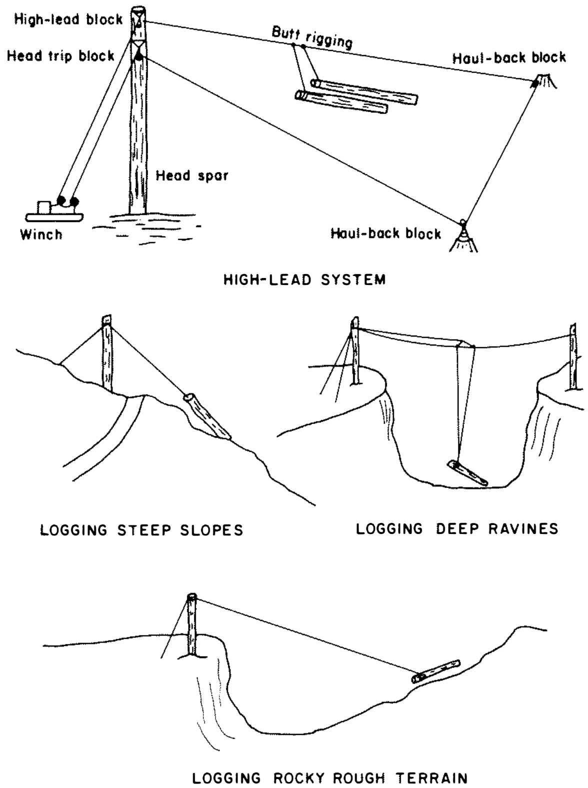


Fig. 9. High-lead cable logging system.

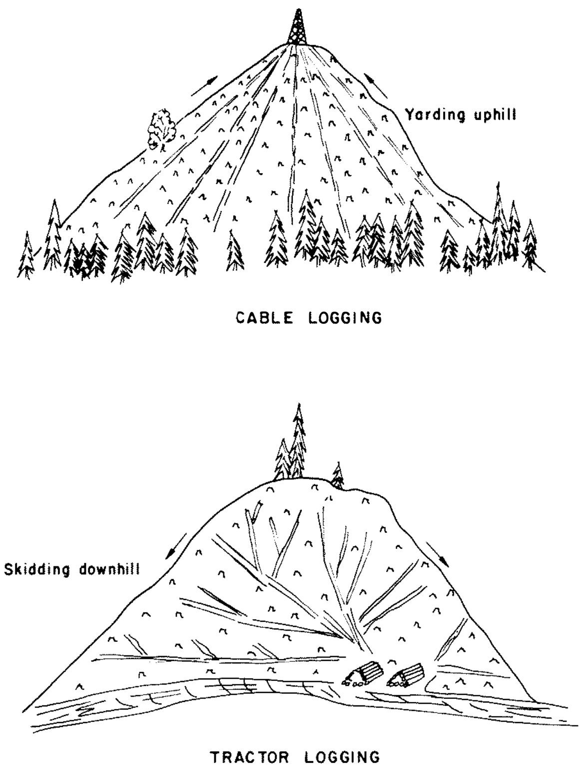


Fig. 10. Skid-road patterns for cable and tractor logging on steep slopes.

that the distance in metres between each structure should be equal to 305 divided by the road grade. This rule is consistent with information developed for *cross drains* in specific regions of the U.S.A. and Canada (Tables 1, 2, 3).

Soil Stabilization

After skid roads and landings are no longer in use, they should be protected from erosion by seeding to grass. Vegetation protects the soil from raindrop impact and aids soil aggregation. Haupt and Kidd (1965) report no serious erosion from a grassed haul road subjected to a high-intensity rainstorm of 71.6 mm/h for 10 min.

Specific recommendations on grass species and fertilizer formulations to use in revegetation are difficult to make because of the diversity of climates and soil conditions. The species listed in Table 4 have been found to be successful in many different regions and conditions (Geale 1963; Haupt and Kidd 1965; Heede 1968; Hodder 1970; Klock 1973; Lesko 1974a, b; Orr 1970; Peterson and Etter 1970; Zinke 1962). In most situations, spring sowing and fertilizer applications have been more successful than operations in the summer or fall. Where large areas are involved, hydroseeding techniques are used to apply seed, fertilizer, and mulch in one or two operations. Care must be taken, however, because seed germination can be reduced by exposure to some fertilizers or by mechanical damage to seed during hydroseeding (Hodder 1970).

To determine fertilizer formulations it is best to compare available nitrogen, phosphorus, potassium, and sulphur in the soils to be treated with the requirements of the species to be sown. Soil fertility analyses can usually be obtained through service agencies of provincial governments and universities. Furthermore, many different kinds of mulches can be used to improve conditions for germination. The use of straw with an asphalt binder has been successful in many places.

In many regions, the soil is scarified after logging to expose mineral soil and ensure favorable seedbed conditions for forest regeneration. Scarification can cause serious erosion. This

Fig. 11. Truck skidding of logs for long distances should not be substituted for regular hauling because road surfaces are highly disturbed and subject to easy soil movement by water or wind.

Fig. 12. After logging operations, culverts should be removed from streams to prevent them from being washed out. This log culvert is in the process of being washed out, resulting in a large amount of fill material being deposited into the stream.

Table 1. Comparison of northeastern U.S.A. and western Idaho spacing guides for cross drains on skid roads with various road gradients

Road gradient %	General rule	Northeastern U.S.A. (after Haussman 1960)	Western Idaho (after Kidd 1963) Granitic soil ravine	Granitic soil hillside	Basaltic soil ravine	Basaltic soil hillside
		Spacing guides (m)				
2	152.5	76.2				
5	61.0	41.2				
10	30.5	24.4	19.8	15.2	27.4	24.4
15	20.3	18.3				
20	15.2	13.7	15.2	10.7	21.4	19.8
30	10.2	10.7	12.2	7.6	18.3	15.2
40	7.6	9.2	9.2	6.1	15.2	12.2
50	6.1		6.1	4.6	12.2	10.7
60	5.1		4.6	3.0	7.6	6.1
70	4.4		3.0	3.0	4.6	4.6

Table 2. Spacing guide for cross drains and berms[1] for various soil types and road gradients (after Geale 1963)

Road gradient %	Spacing guide (m) Soil types: Erodible soils, silts and clays	Normal soils, loams	Rocky soils, sands, gravels
Gentle (under 5%)	45.8	61.0	no erosion likely
Moderate (5-10%)	30.5	45.8	61.0
Steep (over 10%)	15.2	30.5	45.8

[1] See page 21 for the discussion on berms.

Table 3. Cross-drain spacings required to prevent hill or gully erosion deeper than 2.5 cm on secondary logging roads built on various soil types and road gradients in the upper topographic position[1] of north-facing slopes[2] having a gradient of 80%[3] (after Packer 1967)

Road gradient %	Hard sediment	Basalt	Granite	Glacial silt	Andesite	Loess
	Spacing guide (m) Soil types					
2	50.9	47.0	41.8	41.2	32.0	29.0
4	46.4	42.4	37.2	36.6	27.4	24.4
6	43.9	40.0	34.8	34.2	25.0	22.0
8	41.8	37.8	32.6	32.0	22.9	19.8
10	39.0	35.1	29.9	29.3	20.1	17.4
12	36.3	32.3	27.1	26.5	17.4	14.6
14	32.9	29.0	23.8	23.2	14.0	11.0

[1] On middle topographic position, reduce spacings 5.5m; on lower topographic position, reduce spacings 11.0 m.
[2] On south aspects, reduce spacings 4.6 m.
[3] For each 10% decrease in slope steepness below 80%, reduce spacings 1.5 m.

Table 4. Grass species successfully used for revegetation in erosion control and land reclamation

Common name	Scientific name
Kentucky bluegrass	*Poa pratensis*
Wheatgrasses	*Agropyron* spp.
crested	*A. cristatum*
intermediate	*A. intermedium*
nordan	*A. desertorum*
pubescent	*A. trichophorum*
Redtop	*Agrostis stolonifera*
Timothy	*Phleum pratense*
Alberta fescue	*Festuca arundinacea*
Perennial ryegrass	*Lolium perenna*

hazard can be limited, however, by restricting scarification to gentle slopes and small areas and maintaining protective belts of forest vegetation around scarified areas until they have stabilized. Access roads into such areas should have good drainage and structures to trap sediment.

WATERSHED MANAGEMENT GUIDELINES FOR ROAD CONSTRUCTION

Logging roads are among the chief source of erosion and sedimentation in forest lands (Haupt 1959a,b; Hoover 1952; Love and Benedict 1948; Packer 1959, 1967; Trimble and Sartz 1957). Most of this damage occurs during or shortly after road construction when soils are disturbed and before plant cover can provide protection (Haupt and Kidd 1965). Fredricksen (1965) reported that suspended sediment loads in a small watershed increased 250 times above normal during road construction.

Little can be done to alter the basic agents of erosion—rainfall, soil, and runoff. However, road location, road gradient, road width, and cut and fill heights can be adjusted to minimize erosive forces. Often, poor road design and location are the chief causes of excessive erosion. Typical examples are roads that disturb the natural flow of drainage channels, roads with steep gradients and inadequate drainage, and roads with excessive or unstable cuts and fills.

Road Gradient

Gentle-to-moderate grades ranging from 3 to 5% are most desirable for logging roads (Haussman 1960; Hutnik and Weitzman 1957; Stewart 1963). Other advantages of low grades are faster hauling times and reduced truck maintenance costs (Bureau of Land Management, n.d.; Gignac 1962; U.S. Department of Agriculture 1960a). In general, grades should not exceed 8-10%. Where cut and fill operations are excessive, maximum grades of 15-20% may be permissible for short distances.

In laying out a road, long, continuous grades should be avoided because they allow the buildup of runoff in roadside ditches and on road surfaces. The effects of such grades can be reduced by close spacing of culverts and deep roadside ditches. Similarly, long, level stretches of road are to be avoided, for draining them may also be difficult (see Drainage, page 15).

Road Width

Road widths should be sufficient to satisfy work and safety requirements. Road right-of-way clearings should also be wide enough to allow road surfaces to dry quickly. On narrow rights-of-way, shade slows drying of road surfaces, which results in poor drainage and unsatisfactory road conditions. Right-of-way clearing should vary with tree height and slope. Increased tree height requires wider clearing because of the long shadows cast by trees. Increased slope steepness requires less right-of-way clearing because of the greater exposure to solar radiation.

Aspect

Southerly aspects are preferred for road location because they receive more sunshine and dry faster than other aspects. This means less traffic damage and lower costs of road maintenance. Disadvantages of south-facing slopes are often sparser vegetation and poorer conditions for vegetation to reestablish, which means that runoff and erosion could be more severe.

Side-Hill Slopes

Side-hill slopes are good road sites because of favorable cross drainage and the construction advantage of *balanced cross sections*. This technique involves balancing the quantities of soil removed from cuts with those placed in fills (Fig. 13). This advantage is lost on steep slopes where the excavated materials must be cast over the side to ensure a solid roadbed, or on gentle slopes where fill material must be borrowed and hauled in.

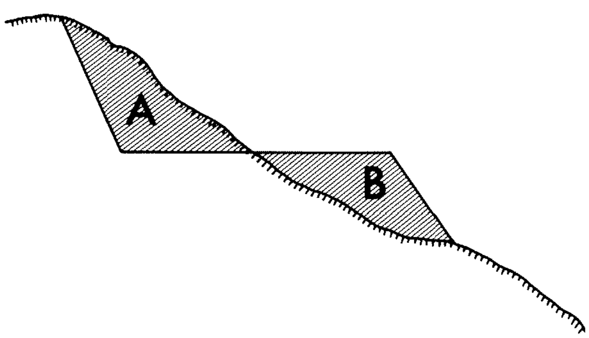


Fig. 13. Typical side-hill cross section illustrating how cut material, A, equals fill material, B.

Topography

Topography often determines the route for a road. Roads can be located in three general places: valley bottoms, hillsides, and ridges. **Valley-bottom routes** have the advantage of low gradients, good alignment, and little earth movement. Disadvantages are flood hazard, number of bridge crossings, and proximity to stream channels. **Hillside routes** have the advantage of distance from streams, which eliminates flood and stream damage. Disadvantages are higher grades, more excavation, poor alignment from following grade contours, and cut banks that expose soil to erosion. **Ridge routes** have the advantages of good alignment, good drainage, light excavation, and fair grades. Disadvantages are secondary roads that may have adverse hauling grades, and greater total road mileage.

Ridge routes and hillside routes are good locations for stream protection because they are removed from stream channels, and the intervening undisturbed vegetation acts as a protective barrier. Wide valley bottoms are good routes if stream crossings are few and roads are located away from stream channels.

Geology and Soils

The geology and soils of an area must be considered in locating a road. All available geologic and soil maps for a proposed route should be examined so that potential trouble spots such as rock outcrops, unstable slopes, old slides and slumps, and erodible soils can be avoided. Construction on or through slides and slumps can cause new ones. Seeps, clay beds, and concave slopes are poor road sites because water drainage may result in sliding and slumping of the roadbed. *Alluvial fans* and flood plains should also be avoided.

Knowledge of soils along a road route is important because soil properties will affect the design and disposition of drainage structures. *Granular soils* are preferable for construction and maintenance because of their high permeability, low capillarity, and high internal friction. These qualities help in producing a well-drained and stable soil material.

Stream Protection

Roads should not be located in or adjacent to stream channels. Such sites will increase erosion, sedimentation, and deterioration of water quality. Roads should be located far enough upslope to prevent transport of sediment into stream channels. Wherever possible, a filter belt of undisturbed vegetation should be maintained between roads and stream channels to slow runoff, facilitate infiltration, and filter out sediments. The width of the belt will depend upon precipitation, vegetation, soils, and slope steepness. A general rule developed in the northeastern United States is that filter belt width should increase 0.6 m for every 1% increase in slope steepness (Table 5).

Where vegetation has been removed or disturbed, sediment flows can be prevented from entering a stream by a protective strip of obstructions located downslope from the road (Figs. 14, 15). Packer (1967) has shown that the most important factors affecting sediment

Table 5. Recommended widths for stream filter belts (after Trimble and Sartz 1957)

Slope of land (%)	Width of belt (m)
0	7.6
10	13.7
20	19.8
30	25.9
40	32.0
50	38.1
60	44.2
70	50.3

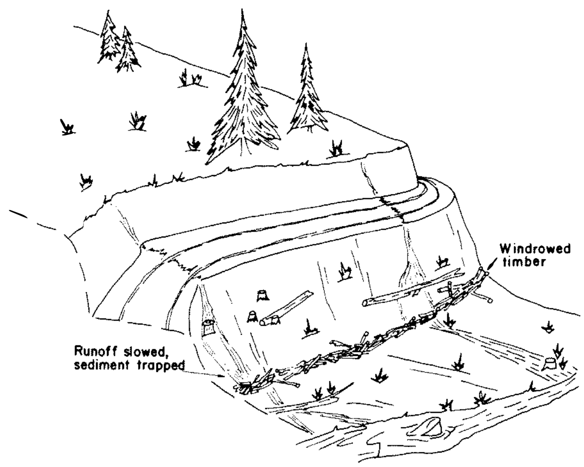


Fig. 14. Slope obstructions to slow runoff and trap sediment.

movement are the spacing between downslope obstructions and the interaction between spacing and kind of obstruction. Earlier work by Haupt (1959a,b) also indicated that erosion and sediment flows increased with greater spacing between downslope obstructions. Effectiveness of obstructions decreases in the following order: depressions and mounds, logs, rocks, trees and stumps, slash and brush, and herbaceous vegetation (Packer 1967). Table 6 gives protective strip widths for different types and spacings of obstructions along a slope; note that zero obstruction distance occurs when the first obstruction is located at the outlet of a cross drain. Tables 5 and 6 can provide a general idea of the width of filter belts or protective strips required when local information is lacking.

Stream Crossings

Streams can be crossed by fords, culverts, or bridges. Utmost care should always be taken to minimize disturbance and damage to watercourses. Approaches to crossings should be on nonerodible materials. Rock, crushed gravel, or other resistant materials may have to be hauled in if not available locally. To prevent discharge of sediments into streams, gradients of approaches to stream crossings should be the same as the road gradient for at least 15 m on each side of the stream.

Roads should be aligned so that all crossings are made at right angle to the stream course. Crossings at other angles result in greater disturbance and increase the possibility of bridge abutments being washed out. Stream channels should not be straightened or changed in direction because the resulting damage might be severe. The lasting success of such alteration is doubtful.

Fig. 15. Logging debris placed along roadside to act as sediment traps and to enhance revegetation of disturbed areas.

Table 6. Protective strip widths required below the shoulders[1] of 5-yr-old[2] logging roads built on soil derived from basalt[3], having 9.1-m cross-drain spacing[4], zero initial obstruction distance[5], and 100% fill slope cover density[6] (after Packer 1967)

Spacing between obstructions m	Protective strip widths (m) Ground conditions					
	Depressions or mounds	Logs	Rocks	Trees and stumps	Slash and brush	Herbaceous vegetation
0.5	11.1	11.8	12.5	13.7	14.1	14.5
1.0	12.0	13.4	14.8	16.3	17.6	19.0
1.5	12.5	14.6	16.9	19.1	21.5	23.8
2.0		15.7	18.7	21.6	24.8	27.7
2.5		16.3	20.0	23.8	27.7	31.3
3.0				25.7	30.3	34.8
3.5						37.8

[1] For protective strip widths from centerlines of proposed roads, increase above widths by one-half the road width.

[2] If storage capacity of obstructions is to be renewed when roads are 3 years old (i.e., new obstructions installed), reduce protective strip widths 7.3 m.

[3] If soil is derived from andesite, increase protective strip widths 0.3 m; if from glacial silt, increase 0.9 m; if from hard sediments, increase 2.4 m; if from granite, increase 2.7 m; and if from loess, increase 7.3 m.

[4] For each 3-m increase in cross-drain spacing beyond 9.1 m, increase protective strip widths 0.3 m.

[5] For each 2-m increase in initial obstruction distance beyond zero (or the road shoulder), increase protective strip widths 1.6 m.

[6] For each 10% decrease in fill slope cover below a density of 100%, increase protective strip widths 0.3 m.

Where water quality is important, culverts or bridges should be used. Culverts can be used when peak flows are not extreme and depth of fill not very great; otherwise, a bridge is necessary. Bridge sites should be located where stream channels are straight, unobstructed, and well defined. Stream channels that are not well defined are poor choices, for the channels change frequently, and the stream bed material is highly erodible. Bridges also require good clearance above peak flows to prevent jamming of logs and debris. An idea of clearance required for a bridge can be obtained by looking for high-water marks along the stream channel. Bridge abutments should be well spaced to prevent undercutting that may result from constriction of water flow.

Cuts and Fills

A large proportion of erosion on roads can be traced to soil exposure caused by cut and fill slopes. Wollum (1962) observed in Oregon that back slopes accounted for 29% of total ground area disturbed by roads. Disturbance can be lessened if roads are located on benches, ridges, and moderate slopes. A maximum cut and fill limit of 3 m should be adopted; this will tend to restrict roads to more moderate slopes.

Steep road cuts should be used if the total area of soil exposed to erosion can be reduced (Table 7). The degree of steepness that can be obtained is determined by the stability of the soil. Stability is affected by soil particle size and shape, and soil water content. The more granular a soil, the greater is this stability, owing to high internal friction between particles. Stability also increases with the size of individual particles; sandy soils are more stable than fine alluvial material. The stability of fine soils increases with soil water content but only to a certain point, after which it decreases. When this occurs, road cut slopes should be flattened to prevent slumping.

Road fill sections should be adequately compacted to prevent extreme settling or failure. When first excavated and loosely distributed, soil increases in volume by about 20% because of a decrease in bulk density. However, when the same soil is used in a roadway or fill it will be compressed into less volume than when first dug. Therefore, fills should have what appears to be extra material and be well compacted. The use of slash or organic material in a fill with solid material is not satisfactory and is likely to cause settling or failure (Wallis 1963). After construction, excess fill material should not be left in the high-water zone of a stream.

Table 7. Back slope and fill slope angles[1] for different soil materials (after U.S. Department of Agriculture 1960b)

Back slopes		Fill slopes	
Flat ground cuts under 0.9 m	2:1	Common for most soil types	1½:1½
Most soil types with ground slopes under 55%	1:1	Alluvial soils	2:1
		Ballast	1:1
Most soil types with ground slopes over 55%	¾:1	Clay	4-1:1
		Rock, crushed	1-¼:1
Hardpan or soft rock	½:1	Gravel	1:1
Solid rock	¼:1	Sand, moist	1½-1:1
		Sand, saturated	2:1
		Shale	1½:1

[1] 2:1 = 2 m vertical rise in 1 m horizontal.

Soil loss from cut-and-fill slopes can be reduced by placing debris along slopes or at the toe of slopes perpendicular to the expected flow of runoff (see Stream Protection, Page 12). The most effective step to prevent erosion of road cuts and fills is to seed them to grass as soon as possible (Figs. 16-18).

Drainage

The function of a drainage system is to intercept, collect, and remove surface and subsurface runoff from roads. Excess water on roads will weaken grades, erode surfaces and slopes, and cause slides.

The design of road drainage systems is an integral part of the road plan and should not be considered a separate task. Many drainage problems can be minimized in road location by avoidance of clay beds, seeps, springs, concave slopes, muskegs, ravines, draws, and stream bottoms. For control of runoff, roadside ditches, intercepting ditches upslope, culverts, and cross drains can be used.

Culverts should be installed at all points along grades and where natural drainages intersect a road at intervals sufficient to prevent excessive buildup of runoff on road surfaces and in roadside ditches (Tables 1, 2, 3). Unfortunately, very little quantitative information exists on the spacing of culverts or cross drains that collectively considers soils, topography, and precipitation. The general rule of dividing 305 by the road gradient can serve as an initial guide for determining the spacing (in metres) between culverts. Appendix 2 illustrates correct and incorrect methods of culvert installation.

Culverts should be large enough to carry *peak flows* from drainage areas and discharge from roadside ditches. If culverts are too small, they become overtopped or clogged, resulting in ponding of water, flows over road surfaces, and eventual road failure. A survey of existing culverts on a watershed can provide useful information for determining the size of culverts needed for a new road. Where a comparable road does not exist, examination of areas with similar rainfall, topography, vegetation, and soils is helpful. When such surveys are made, the high-water marks and the diameter, length, slope, and age of culverts should be noted. Also, signs of erosion at culvert outlets from high-velocity exit of runoff or sedimentation in culverts from low-velocity flows should be considered. If possible, culverts should be inspected at both high- and low-water stages.

Equations to Predict Peak Flow

To determine the culvert size required to drain an area, an estimate of peak flow is necessary. Many empirical formulas have been developed to predict peak flows. Most of them utilize parameters of rainfall intensity, watershed area, and runoff coefficients that incorporate the factors of soil, vegetation, and topography. However, these formulas are simplifications of a complicated process and should be carefully used. Because of this, the final decision as to culvert size should be a matter of judgment based on all the local information and experience available.

One type of formula used makes peak flow a function of watershed area:

$$Q = CA^{M}$$

where Q = peak flow
C = runoff coefficient
A = watershed area

Values of "M" recommended for use with this formula range from 0.50 to 0.85.

Fig. 16. Road bank slumping in unstable glacial till caused by excess water. Slumping such as this can be reduced by cutting roads at the natural angle of repose and seeding to grass.

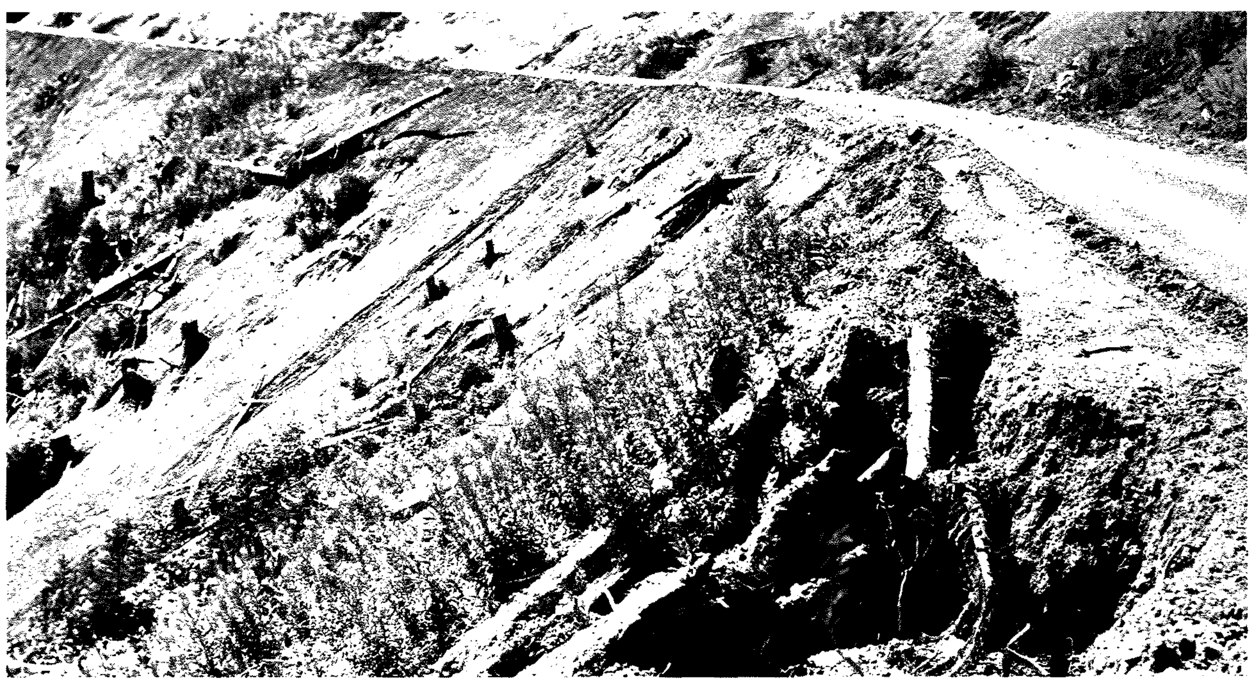


Fig. 17. Erosion of unstable fill slopes can be reduced by seeding to grass and placing obstructions along the slope to slow runoff.

Fig. 18. Road bank erosion caused by uncontrolled runoff from upslope areas. Seeding of the cut bank to grass and use of intercepting ditches would have reduced runoff velocity and erosion.

The Talbot formula ($A = M^{0.75} CR$), which is used for forest roads (Bureau of Land Management n.d.; Haussman 1960), gives the cross-sectional area of a waterway rather than peak flow and uses an exponent of 0.75. The Talbot formula is designed for a maximum rainfall of 4 in. (101 mm)[2] /h and flow velocities of 10 ft (3 m)/s. R is a reduction factor for rainfall intensities of less than 4 in. (101 mm)/h. In practice the formula overestimates culvert requirements. The greatest difficulty, and the weakness of the method, is the selection of correct runoff coefficients, which are too general to consistently describe rainfall-runoff relationships.

A second group of formulas is represented by the Burkli-Ziegler equation:

$$Q = Aci(S/A)^{0.25}$$

where Q = peak flow
A = watershed area
c = a runoff coefficient
i = average rainfall expected in inches per hour
S = average slope of watershed

This type of equation is an improvement over the previous group in that watershed slope and rainfall are considered as two separate items. However, the method also has the weakness of using runoff coefficients that are too general and inclusive. In British Columbia this formula is considered to give "reasonably good results" (Forest Club, U.B.C. 1971) if watershed area and slope have been accurately determined.

---

2 Only English units can be used in the Talbot, Burkli-Ziegler, and Rational formulas. Metric equivalents are presented here for comparative purposes only.

The most widely used prediction equation for peak flows in small watersheds (i.e., 5 mi^2 or 13 km^2) is the Rational formula:

$$Q = CiA$$

where Q = peak flow
C = runoff coefficient
i = rainfall intensity in inches per hour of a storm whose duration is equal to the time of concentration
A = watershed area

The selection of rainfall intensity is based on the time of concentration, which is the length of time required for water at the most remote part of the basin to reach the outlet or point of interest in the stream channel. During a storm, once maximum intensity has occurred for a period equal to the time of concentration, additional rainfall does not increase peak flow, but only prolongs its duration.

The formula assumes that rainfall intensity is uniform in time for the duration of the storm, that rainfall is uniformly distributed in space over the watershed area, and that a single runoff coefficient can be selected to represent runoff processes for the whole storm. Such assumptions are true for small areas, but on larger areas temporary surface storage of water can cause serious errors. Furthermore, the problem of selecting a "C" is still difficult, as experience shows it to change from storm to storm. One advantage of the Rational method is that its physical meaning is reasonably well defined. Examples of how to use these formulas are given in Appendix 3.

Culverts

Galvanized corrugated iron pipe is probably the most commonly used culvert material. It has the advantages of durability, easy installation, and expansion; additional sections can be added if a wider road is desired at a future time. Wooden-staved culverts are seldom used anymore because of their costs, higher labor requirements for assembly and installation, and shorter life. Other culvert materials include paved corrugated pipe, corrugated metal arches, multiplate culverts, reinforced concrete pipe, and reinforced concrete boxes. Corrugated pipe paved with bituminous or asphalt coatings is used to prevent corrosion where stream waters are acidic (pH <5.0). Acidic stream waters can reduce the average life period of iron culverts (57 years) by almost half (Stoeckeler 1967a). Corrugated metal arches are useful for shallow fills and limited headroom, especially in place of bridges for crossing small streams. Multiplate culverts are used on streams where openings of 180 cm or greater are required. Reinforced concrete pipe may be necessary where soil or water conditions cause corrosion of metal pipes. Reinforced concrete boxes may be required on streams to provide upstream access to migratory fish.

When corrugated metal culverts are installed, trenches should have an even grade and be free of rocks that might damage the pipe when the trench is filled and compacted. Culverts should be covered with well-tamped fill, equal in depth to half the diameter of the pipe but never less than 30 cm. Fill material should not be humped to cover culverts, for this is ineffective and poor workmanship. Minimum grade for a culvert should be 3% and not less than the road above it. A useful guide is that a culvert should be inclined 2% more than the road grade above. Where large amounts of silt are expected, a grade of 20% may be desirable to make the culvert self-cleaning. However, the grade should not be so great that water can back up and cause road damage.

Culverts should have sufficient camber, or bend, to compensate for the settling of fill material. The weight of settling fill will cause culvert ends to bend slightly upwards or tear apart at the joints. The inlets and outlets of culverts should be protected to prevent them from becoming clogged or damaged. Conditions that require debris control around inlets are the presence or likelihood of logging slash upstream, sandy or silty stream bottoms, and erodible soils. Figure 19 shows different structures that can be used to control debris. Culvert outlets should be provided with aprons of rock or resistant material to reduce the energy of outflow. For prevention of erosion on large fills, aprons and downspouts may be necessary to transport water over unstable soil materials.

Secondary and temporary roads can be drained inexpensively with open-top culverts (Fig. 20). Open-top culverts should be placed at angles across a road to provide gradient to the culvert and to ensure that no two wheels of a vehicle hit the ditch at once. This protects the ditch and keeps it self-cleaning (Simmons 1951). This kind of culvert is economical and efficient for 3 to 4 years. Open-top culverts can be built from many materials.

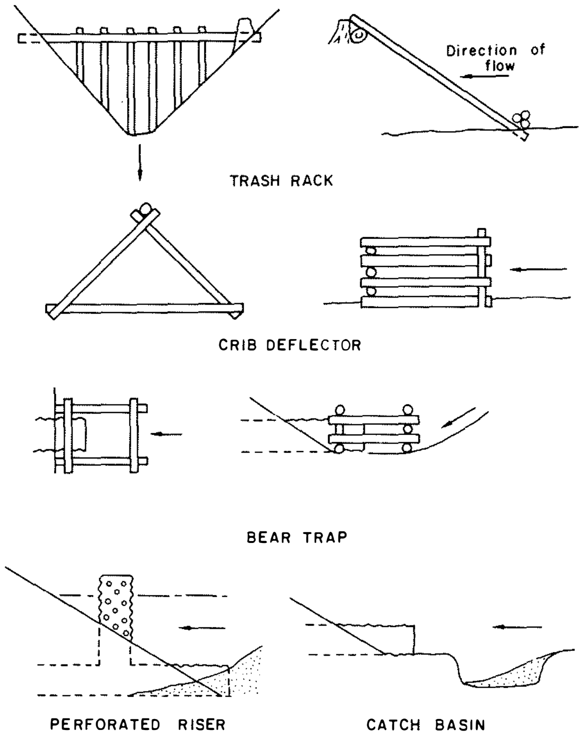


Fig. 19. Structures to control debris.

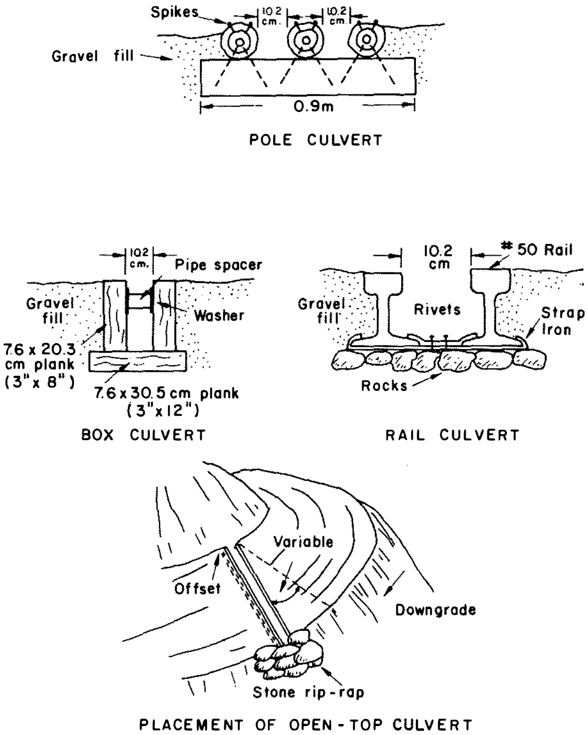


Fig. 20. Open-top culverts (after Simmons 1951).

Ditches and Grades

Roadside ditches are as important as culverts for controlling and dispersing runoff from roadways. They should be large enough to carry runoff from moderate storms. A standard ditch used on secondary logging roads is a triangular section 45 cm deep, 90 cm wide on the roadway side, and 30 cm wide on the cut bank side. Minimum ditch gradient should be 0.5%, but 2.0% is preferred to ensure good drainage. Runoff should be frequently diverted into culverts to prevent erosion or overflow. Ditches may have to be deepened for excessive rainfall and for draining ponds, springs, and swamps. The carrying capacity of a ditch can be calculated by using Manning's formula (Appendix 4).

An alternative to larger roadside ditches is an intercepting ditch constructed upslope to reduce runoff entering roadside ditches. Intercepting ditches are built above the back slope, on a gentle contour grade to the nearest drainage channel above a culvert. Intercepting ditches also reduce slumping of road cuts by preventing soil from becoming water-saturated.

Outsloping and rolled grades are two other methods of controlling runoff on roads. Outsloping is grading the road so that it slopes downward from the toe of the road cut to the shoulder. The slope should be just enough to move water off the road, about 3-4 cm/m. If outsloping is apparent to the eye, it is too great. Outsloping is preferable on contour roads where it will reduce the number of culverts required for drainage. For safety, outsloping should not be used in steep country or where conditions are wet and slippery.

Rolled grades are a series of gently rolling dips constructed into a road to facilitate drainage (Fig. 21). It is essential that the dips have an adverse slope on the downhill side. The bottom of the dips should slope gently from the cut bank to the road shoulder. Dips should not be used to carry constantly running water.

Subsurface Drainage

Subsurface water is infiltrated water, which takes the form of seepage, springs, high water tables, and capillary water. Drainage of subsurface water can be difficult and expensive.

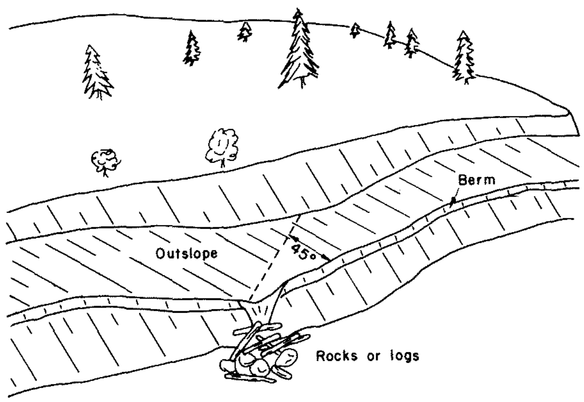


Fig. 21. Rolled grade and cross drain (after Haussman 1960).

It is best to obviate such a problem by locating roads on well-drained high ground and avoiding hollows, bottoms of slopes, and deep road cuts. Unfortunately, there are many times when subsurface drainage problems cannot be avoided, especially where access is required into swampy or peatland areas.

Road construction into wetland areas requires special techniques because of high water table levels, which can be 10-50 cm below the ground surface during the growing season. Subsurface water flow in peatlands is substantial, even when gradients are very small. In construction, road beds undergo compaction and act as barriers to subsurface flow, raising water table levels and causing permanent or temporary flooding on the uphill sides of roads.

Installation of culverts on the ground surface does not prevent flooding, which can kill trees and weaken roadbed materials. Stoeckeler (1965) described a technique used in Europe to prevent flooding, in which a collector ditch is made above a road (Figs. 22, 23). The ditch creates an opening for the upper end of the culvert and is excavated about 100 m long and 0.5-1 m below the original level of the swamp to allow an unimpeded flow of water. In some cases, ditches are cut parallel to a road on both sides. This provides for drainage of the roadbed itself and makes the roadbed more stable.

A certain amount of subsidence will be caused by the drainage of water from peat deposits (Stoeckeler 1965). The amount of subsidence is closely related to the depth of peat. Accordingly, culverts must be placed deep enough to allow for drainage after subsidence.

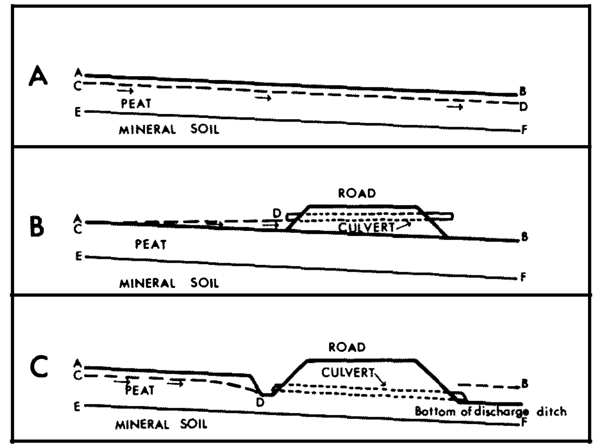


Fig. 22. Hydrologic problem and water table relations in roads crossing peatlands approximately parallel to the contour. Arrows indicate principal zone of water flow. A. Undisturbed swamp before road construction. B. Poorly sited culvert does not relieve damming action of road. Temporary or permanent pool of stagnant water results. C. Problem is solved when collector ditch is cut on upper side of the road and culvert is set with its bottom about a metre below swamp surface (after Stoeckeler 1965).

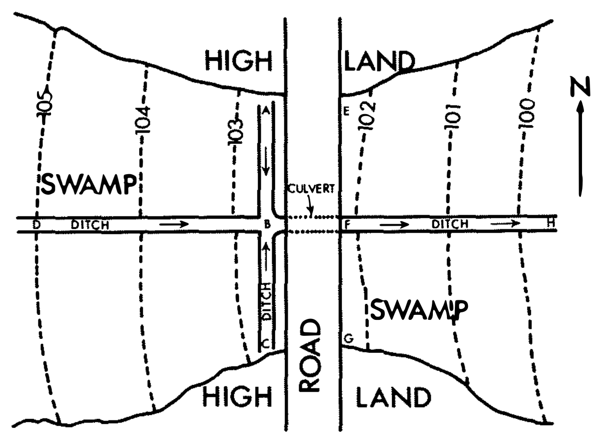


Fig. 23. Planimetric view of well-drained swamp road crossing. European method of positioning collector and discharge ditches and culverts avoids backwater, flooding, and drowning of timber on upper side of road (left half of figure) (after Stoeckeler 1965).

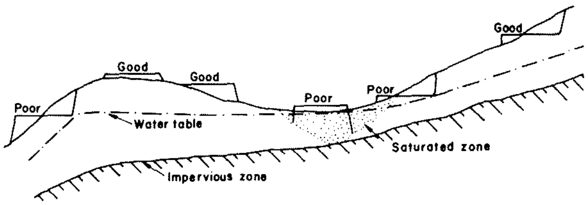


Fig. 24. Good and poor road location sites for avoiding subsurface drainage problems.

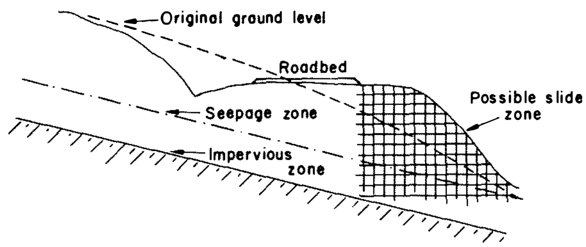


Fig. 25. Possible slide zone due to seepage between fill material and an impervious zone.

On better-drained sites, subsurface drainage problems are most likely to occur in hollows and at the bottom of slopes or where road excavations intersect contact springs or water tables (Fig. 24). In fill sections, slides frequently occur because a seepage zone has lubricated the plane between the fill material and an impervious zone (Fig. 25). Subdrains or perforated pipes can be set into trenches to drain water or to lower water tables. Where seeps or springs appear on cuts and fills, a perforated pipe can be inserted into the cut or fill to facilitate drainage. The effects of subsurface water on subgrades can be reduced by a layer of coarse sand or gravel in the subgrade if soils are of high capillarity or subject to frost action. The *Culvert Reference Guide* (Westeel Products Ltd. 1962) contains more explicit solutions to these and other subsurface drainage problems.

Berms

Berms are earthern or soil-cement curbs constructed along road shoulders to prevent drainage of water onto large fills or unstable slopes. Breaks can be made in berms where drainage is necessary and where there is no danger of erosion (Figs. 26, 27). Care should be taken during maintenance operations and snow removal not to damage berms. An alternative

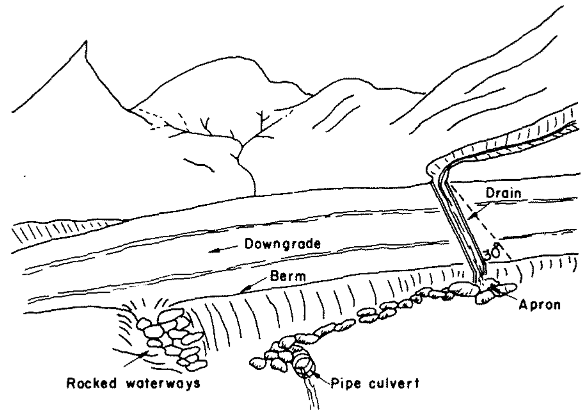


Fig. 26. Berms (after Packer and Christensen 1964).

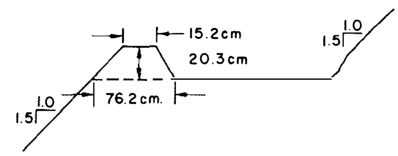


Fig. 27. Berm specifications (after Packer and Christensen 1964).

to constructing berms is to inslope roads and divert runoff into ditches and across roads by regularly spaced open-top or closed culverts. This technique is useful on curving sidehill road locations.

Road Maintenance

Maintenance of roads is essential to their continued use and safety and should be considered a normal operating procedure.

Grading

Roads should be graded frequently and crowned to ensure good surface drainage and minimum soil loss (Table 8). Most serious damage to roads is caused by excess water. If ruts and potholes are allowed to persist with running and standing water they weaken road subgrade materials. When roadside ditches are cleaned of silt and debris, undercutting of back slopes should be avoided, for this results in materials sloughing and blocking ditches. Where ditches and back slopes have stabilized, steps should be taken to ensure that vegetation is not removed. Similarly, machine operators should be careful not to damage culvert inlets. Crimped or torn culvert inlets and tops reduce culverts' carrying capacity and strength.

Table 8. Maximum road crowns recommended for heavy rainfall areas (after Simmons 1951)

Road gradient %	Height of crown at road centre (cm)	
	3-m road width	5-m road width
0-5	6.2	10.4
5-10	4.8	5.2
>10	3.5	5.2

Drainage

Regular inspections during or after storms will ensure good drainage because problems will be detected before they become serious. Inspections to detect 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 snowmelt.

Putting Roads to Bed

Secondary roads that are closed or seldom used should be "put to bed", that is, provisions should be made for erosion control. Open-top culverts should be replaced with cross drains to control and direct runoff from road surfaces. Cross drains should be constructed to serve standard autombiles travelling at speeds of 25-30 km/h. In the spacing of cross drains, guides outlined in Tables 1, 2, and 3 should be followed. Steps to follow in the construction of cross drains are

1. Excavate roadbed to a minimum depth of 15 cm next to the cut bank and 20 cm at the road edge, with a definite adverse grade on the downgrade side of the cross drain (Fig. 28).

2. Spread excavated material on the roadbed below the cross drain to a depth of not more than 8 cm.

3. Extend the cross drain to the full width of the road so that the water drains downhill from the toe of the cut bank to the shoulder (Fig. 29).

4. Tie the cross drain into the cut bank at the upper end of the cross drain.

5. Ensure that the long axis of the cross drain forms an angle of not less than 30° with a line perpendicular to the center line of the road.

Traffic

After logging operations, logging roads should be completely closed to travel. Where this is not feasible, traffic should be regulated, especially during wet weather when roads are easily damaged. Periodic inspections for damage and necessary repairs should be made.

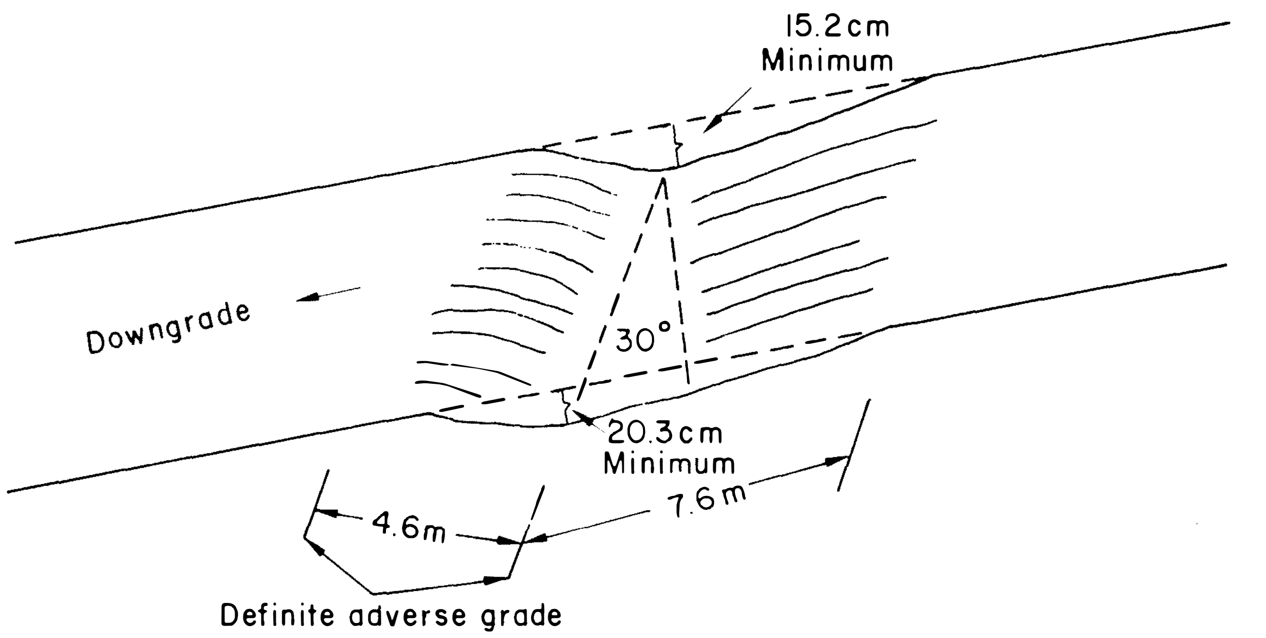


Fig. 28. Construction of cross drains (after Packer and Christensen 1964).

Fig. 29. Cross drains should extend the full width of the road bed so that water drains downhill from the toe of the cut bank to the shoulder. This cross drain is wrong because it attempts to direct flow in an uphill direction, causing water to collect in the roadside ditch.

APPENDIX 1

SURFACE WATER QUALITY OBJECTIVES[1]

These objectives represent water quality suitable for most uses either through direct use or prepared for use by an economically practical degree of treatment. They apply to surface waters except in areas of close proximity to outfalls.

There are many instances where the natural water quality of a lake or river does not meet some of the suggested limits. In these cases, the limits obviously will not apply. It should be noted, however, that where the natural existing quality is inferior to desirable criteria, it would be unwise to permit further deterioration by unlimited or uncontrolled introduction of pollutants. Naturally occurring circumstances are not taken into account in these objectives and due consideration must be given where applicable (e.g., spring runoff effect on colour, odour, etc.).

1. **Bacteriology (Coliform Group)**

   (a) In waters to be withdrawn for treatment and distribution as a potable supply or used for outdoor recreation other than direct contact, at least 90 per cent of the samples (not less than five samples in any consecutive 30-day period) should have a total coliform density of less than 5,000 per 100 mL and a fecal coliform density of less than 1,000 per 100 mL.

   (b) In water used for direct contact recreation or vegetable crop irrigation the geometric mean of not less than five samples taken over not more than a 30-day period should not exceed 1,000 per 100 mL total coliforms, nor exceed these numbers in more than 20 per cent of the samples examined during any month, nor exceed 2,400 per 100 mL total coliforms on any day.

2. **Dissolved Oxygen**

   A minimum of five mg/L at any time.

3. **Biochemical Oxygen Demand**

   Dependent on the assimilative capacity of the receiving water, the BOD must not exceed a limit which would create a dissolved oxygen content of less than five mg/L.

4. **Suspended Solids**

   Not to be increased by more than 10 mg/L over background value.

5. **pH**

   To be in the range of 6.5 to 8.5 pH units but not altered by more than 0.5 pH units from background value.

6. **Temperature**

   Not to be increased by more than 3°C above ambient water temperature.

7. **Odour**

   The cold (20°C) threshold odour number not to exceed eight.

8. **Colour**

   Not to be increased more than 30 colour units above natural value.

9. **Turbidity**

   Not to exceed more than 25 Jackson units over natural turbidity.

---

[1] *Quoted from* Alberta Department of the Environment. 1977. Alberta water quality objectives. Water Quality Br., Stand. Approvals Div.

10. **Organic Chemicals**

Constituent	Maximum Concentration (mg/L)
Carbon Chloroform Extract (CCE) (includes Carbon Alcohol Extract)	0.2
Methyl Mercaptan	0.05
Methylene Blue Active Substances	0.5
Oil and Grease	substantially absent, no irridescent sheen
Phenolics	0.005
Resin Acids	0.1

11. **Pesticides**

To provide reasonably safe concentrations of these materials in receiving waters an application shall not exceed 1/100 of the 48-hour $T1_m$. No pesticides can be used in Alberta unless they have been registered under the Pest Control Products Act. Any pesticides used on, in, or near water (within 100 linear feet) [30.5 m] must be approved by a Department of Environment permit issued under The Agricultural Chemicals Act.

12. **Toxic Chemicals**

Constituent	Maximum Concentration (mg/L)
Arsenic	0.01
Barium	1.0
Cadmium	0.01
Chromium	0.05
Cyanide	0.01
Lead	0.05
Mercury	0.0001
Selenium	0.01
Silver	0.05

13. **Radioactivity**

Gross Beta not to exceed 1,000 pCi/L.
Radium 226 not to exceed three pCi/L.
Strontium 90 not to exceed 10 pCi/L.

14. **Inorganic Chemicals**

Constituent	Maximum Concentration (mg/L)
Boron	0.5
Copper	0.02
Fluoride	1.5
Iron	0.3
Manganese	0.05
Nitrogen (Total Inorganic and Organic)	1.0
Phosphorus as PO_4 (Total Inorganic and Organic)	0.15
Sodium (as percent of cations)	between 30 & 75
Sulphide	0.05
Zinc	0.05

NOTE: The predominant cations of SODIUM, CALCIUM and MAGNESIUM and anions of SULPHATE, CHLORIDE and BICARBONATE are too variable in the natural water quality state to attempt to define limits. Nevertheless, in order to prevent impairment of water quality, where effluents containing these ions are discharged to a water body the permissible concentration will be determined by the administrative authority in accordance with existing quality and use.

15. **Unspecified Substances**

Substances not specified herein should not exceed values which are considered to be deleterious for the most critical use as established by the administrative authority.

APPENDIX 2

CORRECT AND INCORRECT METHODS OF INSTALLING CULVERTS

Culverts should be installed in the direction of natural flow, and the culvert grade should be slightly higher than the natural flow line of water. If the grade is too low the culvert partially fills with sediment, and capacity is reduced. If too high, ponding upstream and damage to the roadway embankment could result.

Installation on Side Hills

INCORRECT

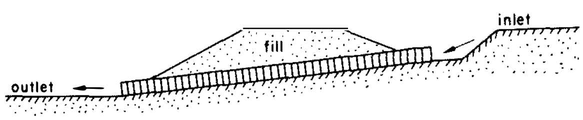


Fig. 30. Culvert installed with too much fall. Because of erosion at the bottom, culvert will not last as long as it should.

CORRECT

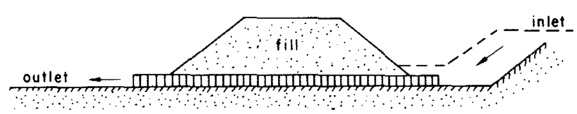


Fig. 31. Culvert correctly installed by lowering the ditch on the right to the natural flow line, indicated by the dotted line. Although this culvert is longer than the one in Fig. 30, repair costs should be reduced.

INCORRECT

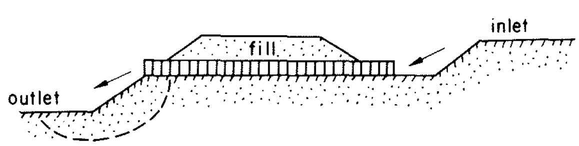


Fig. 32. When a culvert is installed with the outlet high above the natural flow line, the outlet must be extended beyond the toe of the slope to prevent washing away of the fill.

CORRECT

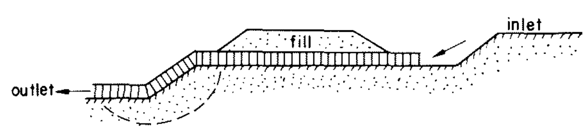


Fig. 33. Culvert outlet extended using a pipe spillway beyond the toe of slope to prevent erosion and washing away of the fill.

Installation on Level Ground

INCORRECT

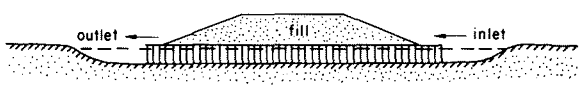


Fig. 34. Culverts should not be installed where ditches are lower on each side of the fill than the outlet, because this will cause water to collect to a depth indicated by the dotted line, and the culvert to fill with sediment.

CORRECT

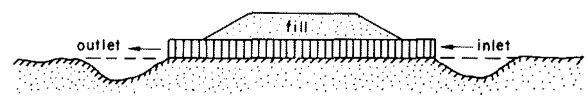


Fig. 35. Culvert correctly placed on the natural flow line of water; this should prevent the culvert from filling with sediment. Flow through and away from the culvert will not occur until the ditches are filled to the level indicated by the dotted line.

Installation on Bedrock

CORRECT

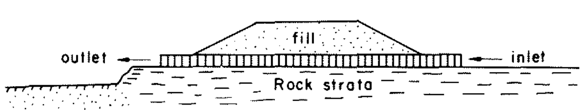


Fig. 36. When the fall below the outlet end is solid rock, the natural flow line is on a level with the rock.

APPENDIX 3

SAMPLE CALCULATIONS FOR DETERMINING PEAK FLOW AND CULVERT SIZE

Examples of how to use the Talbot, Burkli-Ziegler, and Rational formulas[1], and a comparison of their results and differences are given in this appendix using data from a watershed and culvert installation north of Edson, Alberta (Table 9). This same exercise may be carried out for most areas, because all data were obtained from topographic maps, local weather records, and field observations.

Talbot Formula

The Talbot formula ($A=M^{0.75}$ CR) is popular because it is simple and easy to use. It gives the cross-sectional area of a waterway required for drainage, rather than peak flow in cubic feet per second (cfs). Peak flow is a function of watershed area, M. This means that peak flows can be expected to increase with watershed size.

The formula is designed for a rainfall of 4 in. (101 mm)/h and a flow velocity of 10 ft (3 m)/s. The formula can be adjusted for lesser rainfall intensities, for example, for 1 or 2 in. (25 or 51 mm) of rain per hour by multiplying $M^{0.75}$ by 0.25 or 0.50 respectively.

The selection of a runoff coefficient in Talbot's formula is important, because it incorporates all the factors of slope, infiltration, and vegetation. Haussman (1960) recommends a coefficient of 0.70 for most forest conditions in the northeastern U.S. (Table 10). This means that 70% of the rain in a given storm ends up as water or runoff in the stream channel.

Using the data from Table 9, the culvert size required for drainage is determined as follows:

$$A=M^{0.75}\ CR$$

Known

M = watershed area = 2.7 mi^2 = 1728 acres
C = runoff coefficient from Table 10 = .70
R = reduction factor for rainfall intensities less than 4 in./h is equal to expected rainfall intensity divided by formula rainfall intensity of 4 in./h. Based on local weather records, an expected rainfall intensity of 1.75 in./h was selected. R = 1.75/4.

Unknown

A = culvert cross-sectional area, ft^2 = ?

Solution[2]

$$A = (1728)^{0.75}\ (.70)\ (1.75/4) = 82.08\ \text{ft}^2$$
$$\text{Culvert diameter} = (82.08/.7854)^{0.50}\ (12) = 123\ \text{in.}\ (312\ \text{cm})$$

Table 11 provides culvert diameter requirements for the watershed described in Table 9 for runoff coefficients between 0.05 and 1.00. Figure 37 shows the relationship between culvert size, drainage area, and runoff coefficients for different rainfall intensities varying from 1.00 to 1.75 in. (25-44 mm)/h.

Burkli-Ziegler Formula

The Burkli-Ziegler formula ($Q = Aci(S/A)^{0.25}$) requires more data and is not as simple as the Talbot formula. It gives peak flows in units of cubic feet per second and also makes peak flow a function of watershed size. However, it is an improvement over the Talbot formula because watershed slope and rainfall intensity are considered separate parameters. This allows easier application of the formula to a wide range of climatic and ground conditions.

Topographic maps are required to determine watershed area and average slope. The average slope is defined as the difference in elevation between the watershed outlet (i.e., culvert installation) and the most remote point in the basin, divided by the maximum length of travel of water in the basin.

The selection of runoff coefficients is very important. The values recommended (Forest Club, U.B.C. 1971) have been adopted from European sources and are representative of

---

[1] Only English units can be used in the Talbot, Burkli-Ziegler, and Rational formulas. The metric equivalents presented throughout this appendix are for comparative purposes only.

[2] Calculation of expoential powers can be obtained easily by electronic calculators or slide rules. Area of circle = d^2 0.7854.

Table 9. Description of watershed north of Edson, Alberta used in sample calculations

Area	2.7 mi^2 or 1728 acres (7.0 km^2 or 700 ha)
Relief (H)	1000 ft (305 m)
Maximum elevation	4750 ft (1449 m)
Elevation at outlet	3750 ft (1144 m)
Maximum length of travel (L)	2.2 mi or 11,616 ft (3.5 km or 3500 m)
Slope of main channel (S) (S = H/L)	0.086, 86 ft/1000 ft (26 m/300 m)
Vegetation	White spruce, lodgepole pine forest
Topography	Watershed located on benchland area, moderate to steep hills with deeply incised stream channels. Slopes ranging from 10 to 40%.
Rainfall intensity	Available data show intensities of 0.6-7.2 in. (15-183 mm)/h for different durations and return periods (Fig. 38). Maximum 1-day rainfall for a 5-yr period is 2.0 in. (51 mm).
Road drainage	Road stream crossing at outlet of watershed. Existing culvert 36 in. (91 cm), in place for 15 yr.
Streamflow	Measured stream discharge for 1973, 1974 show maximum discharge of 30 cfs (850 dm^3/s)

alpine or montane regions. The runoff coefficients range from 0.10 for flat meadows to 0.80 for meadow above timberline with slopes greater than 50% steepness (Table 10).

Using the data from Table 9, the culvert size required for drainage is determined as follows:

$$Q = Aci(S/A)^{0.25}$$

Known

A = watershed area = 1728 acres
i = rainfall intensity = 1.75 in./h
c = runoff coefficient from Table 10 = 0.30
S = average slope/1000 ft = 86 ft

Unknown

Q = peak flow (cfs) = ?

Solution

$$Q = (1728)(0.30)(1.75)(86/1728)^{0.25}$$
$$Q = 428.49 \text{ cfs}$$

From Table 11, the size of culvert required to carry such a flow is 78 in. (198 cm).

Rational Formula

The Rational formula (Q=CiA) is the most widely used method of predicting peak flows from small watersheds (5 mi^2 or 13 km^2). The formula makes peak flow a function of watershed size, but also includes considerations of rainfall intensity-duration-frequency relationships, travel time for water through a watershed, roughness of flow surfaces, and the length and slope of the main channel. Runoff coefficients also differ from those of other

Table 10. Summary of runoff coefficients C for the Talbot, Burkli-Ziegler, and Rational formulas used for prediction of peak flows from small watersheds less than 5 mi^2 (13 km^2) in area

Talbot formula (after Haussman 1960)

C	Terrain description
1.0	Impervious—100%
0.8-0.7	Steep slopes, heavy soils, and moderate cover
0.6-0.5	Moderate slopes, heavy to light soils, and dense cover
0.4-0.3	Gentle slopes, agricultural soils, and cover
0.2	Flatland, pervious soil

Burkli-Ziegler formula (after Forest Club, U.B.C. 1971)

Elevation	Character of land	Flat 0-20%	Middle slope 20-50%	Steep slope 50%+
		c	c	c
Above timberline	Meadow	0.40	0.60	0.80
	Rock	0.50	0.70	0.90
Alpine forests	Forest	0.20	0.30	0.50
Hilly to flat country	Meadow	0.10	0.30	0.50
	Forest	0.50	0.15	0.30

Rational formula[1] (after Frevert *et al.* 1955)

Topography and vegetation	Open sandy loam	Clay and silt loam	Tight clay
	C	C	C
Woodland			
Flat (0-5% slope)	0.10	0.30	0.40
Rolling (5-10% slope)	0.25	0.35	0.50
Hilly (10-30% slope)	0.30	0.50	0.60
Pasture			
Flat	0.10	0.30	0.40
Rolling	0.16	0.36	0.55
Hilly	0.22	0.42	0.60
Cultivated			
Flat	0.30	0.50	0.60
Rolling	0.40	0.60	0.70
Hilly	0.52	0.72	0.82

[1] Coefficients for the Rational formula can be combined to obtain an average for a basin of different kinds of terrain. For example, for a basin with 20% woodland and hilly sandy loam, 30% woodland and rolling clay and silt loam, and 50% cultivated and rolling tight clay,

$$C = 0.20 \times 0.30 + 0.30 \times 0.35 + 0.50 \times 0.70 = 0.52$$

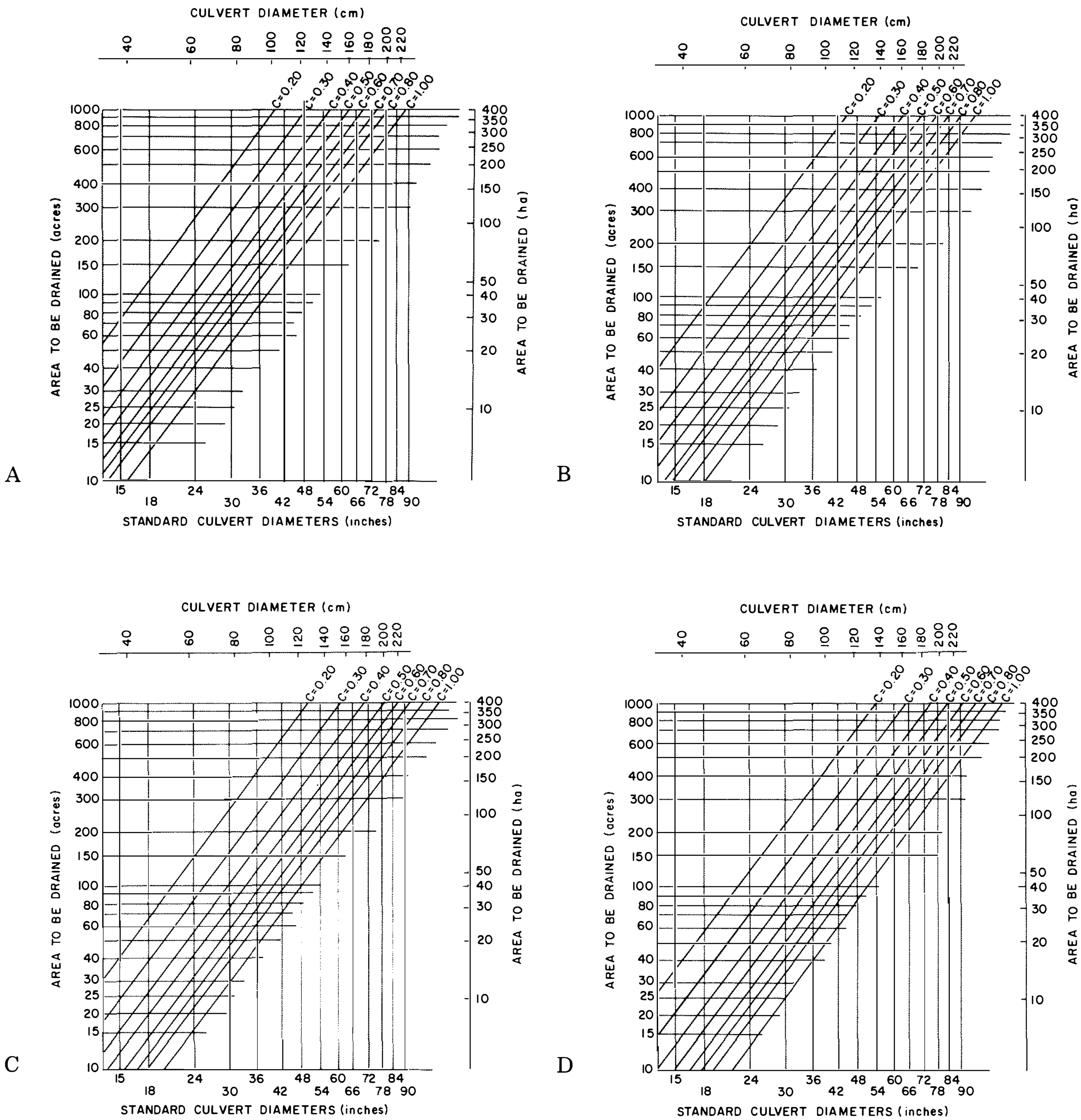


Fig. 37. Culvert size versus drainage area for rainfall intensities of A, 1.00 in. (25 mm)/h; B, 1.25 in. (32 mm)/h; C, 1.50 in. (38 mm)/h; and D, 1.75 in. (44 mm)/h (Talbot formula). Since only English units can be used in the Talbot formula, the metric equivalents are presented for comparative purposes only.

methods in that they can be combined to obtain an average value for a watershed of different topographic and vegetative types (Table 10).

The limitations of the Rational formula must be understood. It assumes the following: at peak flow all areas of a watershed contribute to streamflow; rainfall intensity is uniform for the duration of a storm; rainfall is uniformly distributed over the watershed; storm duration is equal to or greater than the time of concentration, which is the length of time for water at the most remote part of a basin to reach the outlet; and a single runoff coefficient describes all runoff processes for a whole storm. When these conditions apply, runoff per unit area will reach a maximum at the time of concentration and then will remain constant.

These assumptions can be true for small areas or highly impermeable surfaces (storm sewers, parking lots), but on large areas the movement of water is slowed by temporary storage on the ground and in stream channels, which can lower or delay peaks. Furthermore, the selection of runoff coefficients is difficult, because experience shows that rainfall-runoff relationships do change from storm to storm.

The method requires more work and data than the other two formulas, but its theory and assumptions are well defined, allowing a greater degree of judgment and flexibility in its application. Using the data from Table 9, one can determine the culvert size required for drainage as follows:

$$Q = CiA$$

Known

A = watershed area = 1728 acres
C = runoff coefficient for a hilly woodland watershed with 10-30% slopes and sandy loam soils from Table 10 = 0.30
L = maximum length of travel for water = 11,616 ft
H = difference in elevation between watershed outlet and most remote point in basin = 1000 ft
S = slope = H/L = 1000/11,616 = 0.086
n = roughness coefficient for a coniferous forest from Table 12 = 0.80.

Unknown

T_c = time of concentration, minutes = ?
i = rainfall intensity for a storm of return period[3] 10 yr and equal in duration to the time of concentration (in./h) = ?
Q = peak flow (cfs) = ?

Solution

T_c = time of concentration
$T_c^{2.14} = 2Ln/3(S)^{0.50}$
$T_c^{2.14} = 2(11,616)(.80)/3(.086)^{0.50}$
$T_c^{2.14} = 21,125.46$
$\log T_c = \log 21,125.46/2.14 = 2.021$
$T_c = 10^{2.021} = 105$ min

i = rainfall intensity for a storm of return period 10 yr and equal in duration to the time of concentration, in inches per hour is obtained from Fig. 38. The rainfall intensity corresponding to a rainfall duration of 105 min is 0.74 in./h (19 mm/h)

Q = CiA
Q = (0.30) (0.74) (1728)
Q = 383.62 cfs

From Table 11, the size of culvert required to carry such a flow is 75 in. (190 cm).

A comparison of the results in Table 11 shows that the Talbot formula recommends larger culvert sizes (i.e., higher peak flows) than either the Burkli-Ziegler or Rational formulas. This is because the Talbot formula assumes runoff or peak flows as a function only of watershed area. The other two formulas, as well as using watershed area, also include parameters of rainfall intensity-duration-frequency, watershed slope, and land use condition. For small areas or low levels of runoff, watershed size is probably the most dominant factor affecting runoff. This is why all three formulas give similar results for the lower runoff coefficients.

---

3 An event that has an n-year return period is one that will be equalled or exceeded once every n years on the average over a long period of time. However, this does not mean that if such an event occurred this year that a similar or greater one will not occur for another n years (Fig. 38).

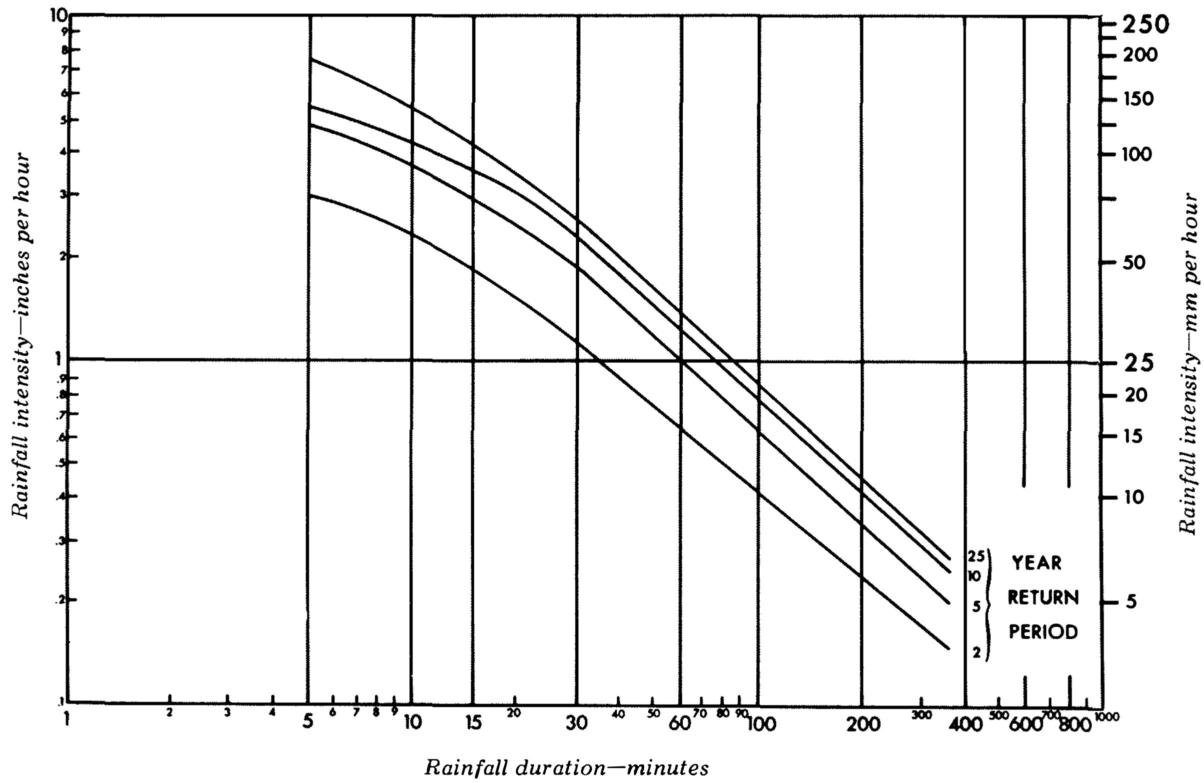


Fig. 38. Rainfall intensity-duration-frequency for different return periods in the Hinton-Edson Region, Alberta (derived from Bruce 1968). Metric equivalents are presented for comparative purposes only.

The Rational formula is recommended as a first choice for estimating peak flows because it incorporates both watershed characteristics and a frequency factor for rainfall-runoff events into its estimates. Furthermore, because its physical meaning is reasonably well defined, it may be applied with more judgment and flexibility and for both long- and short-term planning. However, when rainfall data are not available, the Burkli-Ziegler formula is recommended as a second choice, as it also includes estimates of rainfall intensity and watershed slope. If used carefully it can give results similar to those obtained with the Rational formula. The Talbot formula is the simplest to apply, but should be carefully used as it can grossly overestimate culvert requirements.

It should be remembered that these formulas are oversimplications of runoff processes. They do not consider the factors of temporary water storage on watersheds or soil water flow and the flow medium (soil). Culvert size predictions are based on estimates of maximum rainfall-runoff events, which are hard to obtain because rainfall intensity-duration data are lacking, sparse, or of short record in most forest areas. However, these formulas are useful when combined with local experience and a survey of existing culvert installations and watershed characteristics. Using this approach, the practitioner can readily develop some awareness of rainfall-runoff relationships in an area. If nothing more, the formulas can be used for first approximations and for setting maximum limits for culvert sizes.

Table 11. Culvert diameter requirements[1] for the watershed described in Table 9, using different runoff coefficients and the Talbot, Burkli-Ziegler, and Rational formulas for peak flow prediction[2]

Runoff coefficients	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.05
					Culvert diameter—in.						
Talbot formula	146	139	131	123	113	103	92	80	65	46	32
Burkli-Ziegler formula	123	118	113	107	101	95	87	78	67	51	39
Rational formula	118	113	108	103	97	91	84	75	64	49	38
					Culvert diameter—cm						
Talbot formula	371	353	333	312	287	262	234	203	165	117	81
Burkli-Ziegler formula	312	300	287	272	256	241	221	198	170	130	99
Rational formula	300	287	274	262	246	231	213	190	162	124	96

[1] Diameter sizes for Burkli-Ziegler and Rational formula calculated using the formula:

$$D = (2.159Qn/S^{0.50})^{0.375}$$

where: D = diameter, ft
Q = discharge, or peak flow, cfs
S = slope of culvert = .017
n = roughness coefficient for culvert = .021

which is a form of the Manning formula describing a round pipe with full flow (Corrugated Metal Pipe Institute, n.d.). Equation for Talbot formula is the same as that used in the example on page 28.

[2] The rainfall intensities used are those shown in the sample calculations: 1.75 in. (44 mm)/h and 0.74 in. (19 mm)/h.

Table 12. Roughness coefficients of different vegetative surfaces for use in the calculation of time of concentration, Rational formula (after Bruce and Clark 1966)

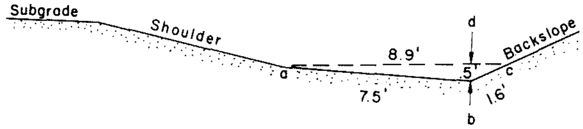
Type of Surface	Value of n
Smooth, impervious	0.02
Smooth, bare packed soil	0.10
Poor grass, row crops, or moderately rough bare soil	0.20
Pasture	0.40
Deciduous timberland	0.60
Coniferous timberland or deciduous timberland with deep litter or grass	0.80

APPENDIX 4

SAMPLE CALCULATIONS FOR DETERMINING THE WATER-CARRYING CAPACITY OF ROADSIDE DITCHES USING MANNING'S FORMULA

Figure 39 illustrates a shallow roadside and a V-shaped ditch. A shallow ditch is used primarily on better-class roads where extreme topography is not encountered, while a V-shaped ditch is more commonly used on logging roads.

A



B

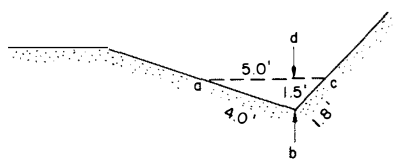


Fig. 39. Shallow roadside (A) and V-shaped (B) ditch showing measurements used in determining water-carrying capacity using Manning's formula.

The water-carrying capacity of these two types of roadside ditches can be determined using Manning's formula:

$$Q = A(1.486/n)R^{0.67}S^{0.50}$$

Q = discharge (cfs)
A = cross-sectional area of the ditch, ft^2
R = hydraulic radius, which is equal to A divided by the wetted perimeter of the ditch running full
n = coefficient of roughness; for ditches in good condition n is 0.03, for ditches in poor condition n = 0.40 (Gray 1970)
S = slope or gradient of the ditch (ft/ft)

Shallow Ditch

A = ac x 1/2 bd
= 8.9 x 1/2 (.5)
= 2.22 ft^2
Wetted perimeter = ab + bc
= 7.5 + 1.6
= 9.1 ft
R = 2.22/9.1 = .244
n = .03
S = 10% = 0.1
Q = 2.22 (1.486/.03) $.244^{0.67}$ $0.1^{0.50}$
= 13.58 cfs

V-Shaped Ditch

A = ac x 1/2 bd
= 5 x 1/2 (1.5)
= 3.75 ft^2
Wetted perimeter = ab + bc
= 4.0 + 1.8
= 5.8 ft
R = 3.75/5.8 = .646
n = 0.03
S = 10% = 0.1
Q = 3.75 (1.486/.03) $.646^{0.67}$ $0.1^{0.50}$
= 43.90 cfs

The above examples are based on a 10% slope. The carrying capacity of the shallow roadside and V-shaped ditch at gradients up to 20% are presented in Table 13. The minimum size of culvert necessary to carry the flow from each ditch is also shown. It is evident that the carrying capacity of the shallow ditch is much less than that of the V-shaped ditch. Water flow in the V-shaped ditch will be faster owing to the smaller surface area (wetted perimeter). Thus, culverts required to service shallow ditches are smaller than those required for V-shaped ditches.

Table 13. Carrying capacity of shallow and V-shaped ditches and minimum culvert size[1] at various slope gradients

Slope gradient	English Measure				Metric Units			
	Shallow ditch		V-shaped ditch		Shallow ditch		V-shaped ditch	
	Carrying capacity	Culvert size	Carrying capacity	Culvert size	Carrying capacity	Culvert size	Carrying capacity	Culvert size
(%)	(cfs)	(in.)	(cfs)	(in.)	(dm^3/s)	(cm)	(dm^3/s)	(cm)
1.0	4.29	18	13.88	24	121.48	46	393.04	61
2.0	6.07	24	19.63	30	171.88	61	555.86	76
3.0	7.44	24	24.04	30	210.68	61	680.74	76
4.0	8.59	24	27.76	30	243.24	61	786.08	76
5.0	9.60	24	31.04	30	271.84	61	878.96	76
6.0	10.52	24	34.00	30	297.89	61	962.78	76
7.0	11.36	30	36.72	30	321.68	76	1039.80	76
8.0	12.14	30	39.26	30	343.77	76	1111.72	76
9.0	12.88	30	41.64	36	364.72	76	1179.12	91
10.0	13.58	30	43.90	36	384.54	76	1243.12	91
11.0	14.24	30	46.04	36	403.23	76	1303.71	91
12.0	14.87	30	48.05	36	421.07	76	1360.63	91
13.0	15.48	30	50.05	36	438.35	76	1417.26	91
14.0	16.07	30	51.94	36	455.05	76	1470.78	91
15.0	16.63	30	53.76	36	470.91	76	1522.32	91
20.0	19.20	36	62.08	42	543.69	91	1757.92	107

[1] Culvert flowing full, with water surface at the inlet at the same elevation as the top of the culvert, the outlet not submerged, and the culvert at a slope of 2.4%. Diameter determined using Table 3 in the *Culvert Reference Guide* by Westeel Products Ltd. (1962). Note that the diameters are to the closest standard culvert sizes, i.e., 15, 18, 24, 30, 36 . . . 90 in. (38, 46, 61, 76, 91 . . . 229 cm).

GLOSSARY

AGGREGATION. The physical and biological processes by which soil particles are bound together. Processes involved are soil wetting and drying, soil freezing and thawing, physical activity of roots and animals, decay of organic material, effects of adsorbed cations, and soil tillage.

ALLUVIAL FANS. A cone-shaped deposit of alluvium made by a stream where it runs out onto a level plain or meets a slower stream. Fans generally form where streams issue from mountains upon the lowland.

ALTERNATE CLEAR-CUT STRIPS. A series of strips into which a stand is divided. Alternate strips are cut; the uncut strips serve as a seed source for reproduction. After reproduction is ensured, the uncut strips are cut.

ARCH, OR A-FRAME. A large wishbonelike steel frame, mounted on wheels or crawler tracks, with a heavy pulley arrangement at the apex. Used in skidding behind a tractor to carry the front end of logs.

BALANCED CROSS SECTION. A road cut where the volume of excavated material approximately equals that required as fill on the downhill side of the road (Fig. 13). Such a cross section causes a minimum of soil disturbance.

CLEAR-CUTTING. Removal of the entire stand in one cut.

CROSS DRAINS. A shallow ditch, water bar, or trench cut across a road at an angle to divert surface runoff from the road.

DIAMETER-LIMIT CUTTING. Removing all merchantable trees above a specified diameter at breast height, with or without the elimination of cull trees.

GRANULAR SOILS. Soils with sand content exceeding 52%, including sand, sandy loam, and loamy sand textural classes. Capillarity of such soils is low because of large pore size, continuity of pores, and small particle surface area. Height of capillary rise of water in sandy soils is 2-3 times less than in finer-textured soils. Permeability of granular soils is high because of large, noncapillary pores. Permeabilities for sandy soils can range from .0001-1.0 cm/s, compared to values of .0001-.000001 cm/s for silts and clays (Harr 1962). High internal friction of granular soils results from packing and angular shape of soil particles. Interlocking forces between particles make granular soils stronger and more resistant to stress than finer-textured soils.

GROUND-LEAD LOGGING. Cable logging with a low-speed, stationary machine, with the lead block about a metre off the ground.

GROUP SELECTION CUTTING. A modification of the selection method in which mature timber is removed in small groups rather than by single trees.

HIGH-LEAD LOGGING. A modification of ground-lead logging wherein the main lead block is placed on a spar tree, generally 30-38 m above the ground, to give a lifting effect to the incoming logs.

PATCH CLEAR-CUTTING. A series of clear-cuttings made in patches. In the first cut, portions of the stand are selected that for some reason should be cut before the rest of the stand. In succeeding operations, patches are enlarged or new patches are created elsewhere in the stand. Patches separated by time intervals can be recognized as individual stands.

PEAK FLOW. Maximum stream discharge occurring from snowmelts or rainstorms.

PROGRESSIVE CLEAR-CUTTING. Clear-cuts succeeding the initial cut are of the same shape and size and immediately to the windward, acting as a seed source and minimizing windfall. The time between successive cuts is short, resulting in an area with little or no forest cover (i.e., no residual blocks or strips of forest as in patch clear-cutting or alternate clear-cut strips).

RIPARIAN VEGETATION. Vegetation growing close to a watercourse, lake, swamp, or spring, and often dependent on its roots reaching the water table (i.e., willows, alders).

SEED TREE CUTTING. Removal of the mature timber in one cut except for a small number of seed trees left singly or in small groups.

SELECTION CUTTING. Removal of mature timber, usually the oldest or largest trees, at relatively short intervals, commonly 5-20 years, repeated indefinitely. By this means the continuous establishment of natural reproduction is encouraged and an uneven stand is maintained.

Extensive. A management program in which harvesting and killing of culls are limited to marked trees in the sawlog portion of the stand—trees larger than 11.0 in. (27.9 cm) dbh. Cutting cycle is 10 yr.

Intensive. A management program in which cutting and cultural work are done throughout the range of dbh's above 5 in. (12.7 cm). Cutting cycle is 5 yr.

SHELTERWOOD CUTTING. Any regeneration cutting in a more or less regular and mature crop, designed to establish a new crop of trees under the protection of the old.

SOIL AGGREGATES. Soil particles held together by internal forces in a single mass, such as a clod prism, block, or granule.

SOIL COMPACTION. Decrease in soil macropore space owing to pressure or force exerted on the soil surface.

SOIL PERMEABILITY. The ease with which gases and liquids penetrate or pass through a bulk mass of soil or a layer of soil. Usually expressed in centimetres per second.

SOIL POROSITY. The volume percentage of the total bulk of soil not occupied by solid particles.

SURFACE RUNOFF. Water that flows over the ground surface and into streams and rivers.

TRACTOR LOGGING. Any system of logging in which a tractor operating as a mobile unit furnishes motive power in skidding logs.

TURBIDITY. The degree of opaqueness, or cloudiness, produced in water by suspended particulate matter, either oganic or inorganic. Measured by light filtration or transmission and expressed in Jackson Turbidity Units (J.T.U.).

WATER BARS. Logs of small diameter laid at a slight angle to the direction of skid trails and staked in place in order to divert surface runoff into undisturbed areas.

WATER QUALITY. The biological, physical, and chemical properties of water make it suitable for given specified uses. Definition of water quality for forest areas is difficult because of the wide range of downstream uses.

WATERSHED DAMAGE. Disturbances or changes to the physical and/or biological environment of an area, considered to be detrimental. Watershed damage from forest harvesting and road construction could include accelerated erosion, site deterioration from loss of topsoil, increased suspended sediment and sedimentation in streams, and increased stream water temperatures.

WATER-STABLE AGGREGATE. A soil aggregate that does not break down when subjected to the action of water, such as falling drops or agitation in wet-sieving analysis.

REFERENCES

Alberta Department of the Environment. 1977. Alberta water quality objectives. Water Qual. Br., Stand. Approvals Div.

Alberta Environment Conservation Authority. [1977]. The environmental effects of timber harvesting operations in the Edson and Grande Prairie Forests of Alberta. Inf. Bull. No. 7. [Public hearings on the environmental effects of forestry operations in Alberta].

Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. Forests and water: Effects of forest management on floods, sedimentation and water supply. U.S. Dep. Agric., For. Serv., Gen. Tech. Rep. PSW-18/1976.

Andre, J.E. and H.W. Anderson. 1961. Variation of soil erodibility with geographic zone, elevation and vegetation type on Northern California wildlands. J. Geophys. Res. 66:3351-3357.

Anonymous. [n.d.] Design of culverts for small drainage areas in Southern Ontario (0.1 to 10 square miles).

Baver, L.D., W.H. Gardner, and W.R. Gardner. 1972. Soil physics. 4 ed. John Wiley & Sons. New York.

Bell, M.A.M., J.M. Beckett, and W.F. Hubbard. 1974. Impact of harvesting on forest environments and resources: a review of the literature and evaluation of research needs. Environ. Can., Can. For. Serv., Pac. For. Res. Cent. Victoria, B.C.

Bethlahmy, N. 1967. Effect of exposure and logging on run-off and erosion. U.S. Dep. Agric., For. Serv. Intermt. Res. Note INT-61.

Bjorkbom, J.C. and G.R. Trimble. 1958. Sow seed on logging roads to control erosion. North. Logger 7(7).

Bockheim, J.G., T.M. Ballard, and R.P. Willington. 1975. Soil disturbance associated with timber harvesting in southwestern British Columbia. Can. J. For. Res. 5:285-290.

Bruce, J.P. 1959. Rainfall intensity-duration-frequency maps for Canada. Can. Dep. Transp., Meteorol. Br., Tech. Circ. Ser. Circ.-3243 Tech.-308.

———. 1968. Atlas of rainfall intensity-duration-frequency data for Canada. Can. Dep. Transp., Meteorol. Br. Climatol. Study. No. 8.

Bruce, J.P. and R.H. Clark. 1966. Introduction to hydrometeorology. Pergamon Press. Oxford.

Bureau of Land Management. [n.d.] Forest engineering handbook. Oregon-Washington State Office.

Calvert, W.W. and A.M. Garlicki. 1965. Skidding forces and horsepower requirements in relation to logging conditions. Can. Dep. For., For. Prod. Res. Lab. Ottawa. Intern. Rep. OP-6.

———. 1967. Skidding forces and horsepower requirements in relation to logging conditions. Can. Dep. For. Rural Dev., For. Prod. Lab. Ottawa. Intern. Rep. OP-18.

Canada Department of Agriculture. 1976. Glossary of terms in soil science. Can. Dep. Agric., Res. Br. Publ. 1459.

Corrugated Metal Pipe Institute. [n.d.] Solving drainage problems with steel pipe. Port Credit, Ont. Tech. Man.

Csizmazia, J. and J.A. McIntosh. 1969. Logging small trees in Alberta. Can. Dep. For., For. Prod. Res. Br. Contrib. No. P-81. Reprinted from B.C. Lumberman, Nov. 1964.

Darwin, W.N., Jr. 1965. Skidding coefficients on an alluvial soil. For. Prod. J. 15:302.

Davis, R. 1977. Controlling the water quality impact of timber harvesting operations in the eastern slopes. Pages 320-335 *in* Alberta Watershed Research Program Symposium Proceedings, 1977. Fish. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-176.

DePape, D. and W.E. Phillips. 1977. The environmental effects of timber production in Alberta: An institutional and legislative analysis. Alberta Environ. Conserv. Auth. Inf. Bull. No. 3. [Public hearings on the environmental effects of forestry operations in Alberta].

Dunford, E.G. 1960. Logging methods in relation to streamflow and erosion. Pages 1703-1708 *in* Proceedings, 5th World Forestry Congress.

Dyrness, C.T. 1965. Soil surface condition—following tractor and highlead logging in the Oregon Cascades. J. For. 63:272-275.

Dyrness, C.T., C.T. Youngberg, and R.H. Ruth. 1957. Some effects of logging and slash burning on physical soil properties in the Corvallis Watershed. U.S. Dep. Agric., For. Serv., Pac. Northwest For. Range Exp. Stn. Res. Pap. No. 19.

Fredricksen, R.F. 1965. Sedimentation after logging road construction in a small Western Oregon Watershed. Proceedings, Federal Inter-Agency Sedimentation Conference, 1963. U.S. Dep. Agric. Misc. Publ. No. 970.

Frevert, R.K., G.O. Schwab, T.W. Edminster, and K.K. Barnes. 1955. Soil and water conservation engineering. John Wiley & Sons, Inc. New York.

Forest Club, U.B.C. 1971. Forestry handbook for British Columbia.

Garrison, G.A. and R.S. Rummell. 1951. First-year effects of logging on ponderosa pine forest range lands of Oregon and Washington. J. For. 49:708-713.

Geale, C.H. 1963. Guides for controlling erosion. Alberta Dep. Lands For. Edmonton, Alberta.

Gignac, T. 1962. Some aspects of forest truck road location and construction. Woodlands Rev., Pulp Pap. Mag. Can. Conv. Issue, 1962. Index No. 2124(B-8-b).

Goodell, B.C. 1964. Water management in the lodgepole pine type. Pages 117-119 *in* Proceedings, Society of American Foresters Annual Meeting. Denver, Colo.

Gray, D.M. 1970. Handbook on the principles of hydrology. Secr. Can. Natl. Comm. Int. Hydrol. Decade. Ottawa.

Harr, M.E. 1962. Groundwater and seepage. McGraw-Hill Book Co. Toronto.

Haupt, H.F. 1959a. A method for controlling sediment from logging roads. U.S. Dep. Agric., For. Serv., Intermt. For. Range Exp. Stn. Misc. Publ. No. 22.

———. 1959b. Road and slope characteristics affecting sediment movement from logging roads. J. For. 57:329-332.

Haupt, H.F., H.C. Rickard, and L.E. Finn. 1963. Effect of severe rainstorms on insloped and outsloped roads. U.S. Dep. Agric., For. Serv., Intermt. For. Range Exp. Stn. Res. Note INT-1.

Haupt, H.F. and W.J. Kidd, Jr. 1965. Good logging practices reduce sedimentation in Central Idaho. J. For. 63:664-670.

Haussman, R.F. 1960. Permanent logging roads for better woodlot management. U.S. Dep. Agric., For. Serv., Div. State Private For., Eastern Reg. Upper Darby, Pa.

Heede, B.H. 1968. Conversion of gullies to vegetation-lined waterways on mountain slopes. U.S. Dep. Agric., For. Serv., Rocky Mt. For. Range Exp. Stn. Res. Pap. RM-40.

Henderson, C. [n.d.] Timber harvest cut block design. Alberta Energy Nat. Resour., For. Serv. Edmonton, Alberta.

Hetherington, E.D. 1974. The 25-year storm and culvert size: A critical appraisal. Environ. Can., Can. For. Serv., Pac. For. Res. Cent. Victoria, B.C. Inf. Rep. BC-X-102.

Hodder, R.L. 1970. Revegetation methods and criteria for bare areas following highway construction. Prepared for Montana State Highw. Comm. Plann. Surv. Sect.

Hoover, M.D. 1952. Water and timber management. J. Soil Water Conserv. 7:75-78.

Hutnik, R.J. and S. Weitzman. 1957. Gentle-grade roads mean faster skidding. U.S. Dep. Agric., For. Serv., Northeast For. Exp. Stn. For. Res. Note No. 71.

Jeffrey, W.W. 1961. Prerequisites and priorities for watershed research in the Eastern Rockies, Alberta. Can. Dep. For. Unpubl. rep.

———. 1965. Experimental watersheds in the Rocky Mountains, Alberta, Canada. Pages 502-521 *in* Symposium of the International Association of Scientific Hydrology. Budapest. No. 66.

Johnson, H.J., H.F. Cerezke, F. Endean, G.R. Hillman, A.D. Kiil, J.C. Lees, A.A. Loman, and J.M. Powell. 1971. Some implications of large-scale clearcutting in Alberta—a literature review. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-6.

Kidd, W.J., Jr. 1963. Soil erosion control structures on skidtrails. U.S. Dep. Agric., For. Serv., Intermt. For. Range Exp. Stn. Res. Pap. INT-1.

Kidd, W.J., Jr. and H.F. Haupt. 1968. Effects of seedbed treatment on grass establishment on logging roadbeds in central Idaho. U.S. Dep. Agric., For. Serv., Intermt. For. Range Exp. Stn. Res. Pap. INT-53.

Kittredge, J. 1948. Forest influences: The effects of woody vegetation on climate, water, and soil, with application to the conservation of water and control of floods and erosion. McGraw-Hill Book. Co. New York.

Klock, G. 1973. Mission Ridge—A case history of soil disturbance and revegetation of a winter sports area development. U.S. Dep. Agric., For. Serv., Pac. Northwest For. Range Exp. Stn. Res. Note PNW-199.

Kochenderfer, J.N. 1970. Erosion control on logging roads in the Appalachians. U.S. Dep. Agric., For. Serv., Northeast. For. Exp. Stn. Res. Pap. NE-158.

Lager, K.F. 1966. Prevent logging damage to streams. B.C. Dep. Recreation Conserv.

Lesko, G.L. 1974a. Preliminary revegetation trials on tar sand tailings at Fort McMurray, Alberta. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-103.

———. 1974b. Species suitability for sand dune reclamation at Lesser Slave Lake, Alberta. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-86.

Love, S.K. and P.C. Benedict. 1948. Discharge and sediment loads in the Boise River drainage basin, Idaho, 1939-40. U.S. Geol. Surv. Water Supply Pap. 1048.

Lull, H.W. and K.G. Reinhart. 1967. Increasing water yield in the Northeast by management of forested watersheds. U.S. Dep. Agric., For. Serv., Northeast. For. Exp. Stn. Res. Pap. NE-66.

Mattice, C.R. 1977. Forest road erosion in northern Ontario: A preliminary analysis. Environ. Can., Can. For. Serv., Great Lakes For. Res. Cent. Sault Ste. Marie, Ont. Inf. Rep. O-X-254.

McCraw, W.E. 1963. Truck road standards and hauling costs. Can. Dep. For., For. Prod. Res. Br. Contrib. No. P-32. Reprinted from B.C. Lumberman, Aug. 1963.

———. 1964. Relative skidding production of track and wheel skidders. Can. Dep. For., For. Prod. Res. Br. Contrib. No. P-57. Reprinted from Can. For. Ind. 83(4):63-68.

McCraw, W.E. and R.M. Hallett. 1970. Studies on the productivity of skidding tractors. Can. Dep. Fish. For., Can. For. Serv. Ottawa. Publ. No. 1282.

Middleton, H.E. 1930. Properties of soils which influence soil erosion. U.S. Dep. Agric. Tech. Bull. No. 178.

Mitchell, W.C. and G.R. Trimble, Jr. 1959. How much land is needed for the logging transport system? J. For. 57:10-12.

Orr, H.K. 1970. Runoff and erosion control by seeded and native vegetation on a forest burn: Black Hills, South Dakota. U.S. Dep. Agric., For. Serv., Rocky Mt. For. Range Exp. Stn. Res. Pap. RM-60.

Ottens, J. 1975. Environmental costs in logging road design and construction. Environ. Can., Can. For. Serv., Pac. For. Res. Cent. Victoria, B.C. Inf. Rep. BC-X-108.

Ottens, J. and J. Rudd. 1977. Environmental protection costs in logging road design and construction to prevent increased sedimentation in the Carnation Creek watershed. Environ. Can., Can. For. Serv., Pac. For. Res. Cent. Victoria. B.C. Inf. Rep. BC-X-155.

Packer, P.E. 1959. Water management problems in the northern Rocky Mountain region. U.S. Dep. Agric., For. Serv., Intermt. For. Range Exp. Stn. Res. Pap. No. 57.

———. 1967. Criteria for designing and locating logging roads to control sediment. For. Sci. 13:2-18.

Packer, P.E. and G.F. Christensen. 1964. Guides for controlling sediment from secondary logging roads. U.S. Dep. Agric., For. Serv., Intermt. For. Range Exp. Stn. and North. Reg. Pocket Handb.

Packer, P.E. and H.F. Haupt. 1965. The influence of roads on water quality characteristics. Pages 112-115 *in* Proceedings, Society of American Foresters.

Peterson, E.B. and H.M. Etter. 1970. A background for disturbed land reclamation and research in the Rocky Mountain Region of Alberta. Can. Dep. Fish. For., For. Br., For. Res. Lab. Edmonton, Alberta. Inf. Rep. A-X-34.

Peterson, R.M. 1960. Stabilization of cut and fill slopes. Third Annual Technical Work Planning Conference of Forest Service Scientists. San Dimas, Calif.

Reinhart, K.F., A.R. Eschner, and G.R. Trimble, Jr. 1963. Effect on streamflow of four forest practices in the mountains of West Virginia. U.S. Dep. Agric., For. Serv., Northeast. For. Exp. Stn. Res. Pap. NE-1.

Rice, R.M. and J.R. Wallis. 1962. Logging effects on streamflow and sedimentation in a High Sierra watershed. For. Ind. 89:38-40.

Rosco Metal and Roofing Products. 1959. Corrugated steel culvert pipe. R.A.I.C.-A.I.A., File No. 12-N.

Rothwell, R. 1977. Suspended sediment and soil disturbance in a small mountain watershed after road construction and logging. Pages 285-300 *in* Alberta Watershed Research Program Symposium Proceedings, 1977. Fish. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-176.

Schultz, C.D. and Company Limited. 1973. The environmental effects of timber harvesting operations in the Edson and Grande Prairie Forests of Alberta. Alberta Dep. Lands For. Edmonton, Alberta. Vols. 1 and 2.

Silen, R.R. 1955. More efficient road patterns for a Douglas-fir drainage. Timberman 56(6).

Silen, R.R. and H.J. Gratkowski. 1953. An estimate of the amount of road in the staggered setting system of clearcutting. U.S. Dep. Agric., For. Serv., Pac. Northwest. For. Range Exp. Stn. Res. Note No. 92.

Simmons, F.C. 1951. Northeastern logger's handbook. U.S. Dep. Agric., For. Serv., Northeast. For. Exp. Stn. Handb. No. 6.

Singh, T. and Y.P. Kalra. 1976. Water quality of a range watershed in southwestern Alberta prior to aspen clearing. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-168.

———. 1977. Impact of pulpwood clearcutting on stream water quality in west cental Alberta. Pages 272-284 *in* Alberta Watershed Research Program Symposium Proceedings, 1977. Fish. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-176.

Smith, R.B. and E.F. Wass. 1976. Soil disturbance, vegetative cover and regeneration on clearcuts in the Nelson Forest District. Environ. Can., Can. For. Serv., Pac. For. Res. Cent. Victoria, B.C. Inf. Rep. BC-X-151.

Society of American Foresters. 1964. Forest terminology. Soc. Am. For. Wash., D.C.

Steinbrenner, E.C. and S.P. Gessel. 1955. The effect of tractor logging on physical properties of some forest soils in southwestern Washington. Soil Sci. Soc. Am. Proc. 19:372-376,

Stewart, S.V. 1963. Watershed management. Guidelines prepared for British Columbia Forest Service. Unpubl.

Stoeckeler, J.H. 1963. A review of forest swamp drainage methods in northern Europe. J. For. 61:99-104.

———. 1965. Drainage along swamp forest roads, lessons from northern Europe. J. For. 63: 772-776.

———. 1967a. Size and placement of metal culverts critical on peatland woods roads. U.S. Dep. Agric., For. Serv., North. Cent. For Exp. Stn. Res. Note NC-37.

———. 1967b. Wetland road crossings: drainage problems and timber damage. U.S. Dep. Agric., For. Serv., North. Cent. For. Exp. Stn. Res. Note NC-27.

Storr, D. 1963. Maximum one-day rainfall frequencies in Alberta. Can. Dep. Transp., Meteorol. Br., Tech. Circ. Ser. Circ.-3796 Tech.-451.

Striffler, D.W. 1965. The selection of experimental watersheds and methods in disturbed forest areas. Pages 464-473 *in* Proceedings of the International Association of Scientific Hydrology Symposium. Budapest. No. 66.

Swanson, R.H. and G.R. Hillman. 1977. Predicted increased water yield after clear-cutting verified in west-cental Alberta. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-198.

Swanson, R.H. and P.A. Logan. (Comps.). 1977. Alberta Watershed Research Program Symposium Proceedings, 1977. Fish. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-176.

Tennessee Valley Authority. 1962. Reforestation and erosion control influences upon the hydrology of the Pine Tree Branch Watershed 1941-1960. Div. For. *and* Div. Water Control Plann.

Toogood, J.A. and J.D. Newton. 1955. Water erosion in Alberta. Univ. Alberta. Edmonton, Alberta. Bull. No. 56.

Trimble, G.R., Jr. and R.S. Sartz. 1957. How far from a stream should a logging road be located? J. For. 55:339-341.

U.S. Department of Agriculture. 1954. A guide to erosion reduction on national timber sale areas. For. Serv., California Reg.

———. 1957. A guide to the Coweeta Hydrologic Laboratory. For. Serv., Southeast. For. Exp. Stn.

———. 1960a. Logging road handbook—the effect of road design on hauling costs. For. Serv. Agric. Handb. No. 183.

———. 1960b. Preconstruction guide. For. Serv., Reg. Six. Portland, Oreg.

Ursic, S.J. 1963. Planting loblolly pine for erosion control in north Mississippi. U.S. Dep. Agric., For. Serv., South. For. Exp. Stn. Res. Pap. SO-3.

Wallis, J.R. 1963. Logging for water quality in Northern California. U.S. Dep. Agric., For. Serv., Pac. Southwest. For. Range Exp. Stn. Res. Note PSW-N23.

Weitzman, S. and G.R. Trimble, Jr. 1952. Skid road erosion can be reduced. J. Soil Water Conserv. 7:122-124.

———. 1955. Integrating timber and watershed management in mountain areas. J. Soil Water Conserv. 10(2).

Westeel Products Ltd. 1962. Culvert reference guide. Publ. No. 74.

Williston, H.L. 1967. Improving loblolly pine survival in roadbank stabilization. U.S. Dep. Agric., For. Serv. Tree Plant. Notes 18(3): 18-20.

Wollum, A.G., Jr. 1962. Grass seeding as a control for roadbank erosion. U.S. Dep. Agric., For. Serv., Pac. Northwest. For. Range Exp. Stn. Res. Note No. 218.

Wooldridge, D.D. 1964. Effects of parent material and vegetation on properties related to soil erosion in Central Washington. Soil Sci. Soc. Am. Proc. 28:430-432.

Zinke, P.J. 1962. The emergency treatment of burned chapparral watersheds. Agric. Exp. Stn., Univ. California. Los Angeles County Farm Advisor, March 15, 1962.