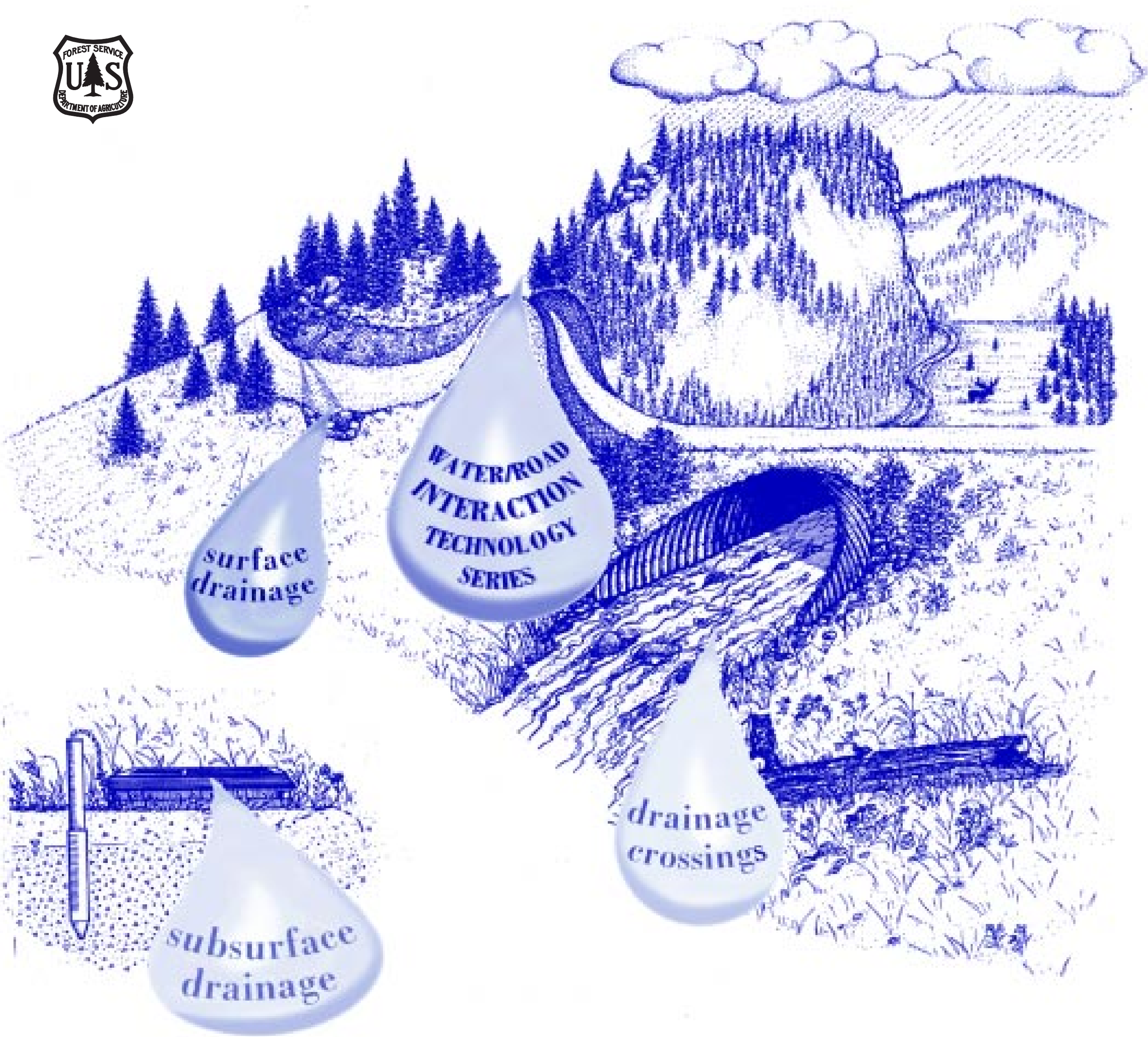
United States
Department of
Agriculture

Forest Service

**Technology &
Development
Program**

7700—Transportation Systems
2500—Watershed and Air Management
September 1998
9877 1806—SDTDC

Water/Road Interaction: Introduction to Surface Cross Drains



Water/Road Interaction: Introduction to Surface Cross Drains

Ronald L. Copstead, P.E.
USDA Forest Service
Pacific Northwest Research Station

David Kim Johansen, P.E.
USDA Forest Service
Willamette National Forest

Jeffry Moll, P.E.
USDA Forest Service
San Dimas Technology and Development Center

USDA Forest Service
San Dimas Technology and Development Center
San Dimas, California

September 1998

ABSTRACT

Copstead, Ronald L.; Johansen, David Kim; Moll, Jeffry. 1998. Water/Road Interaction: Introduction to surface cross drains. Report 9877 1806—SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program. 15 p.

A variety of surface cross drains that are used on forest roads are described, including cross drain dips, waterbars, and open top culverts. The applicability of different designs is given. Factors to consider when designing surface cross drains for forest roads are discussed, including location, geometry of dips, orientation, and erosion control. Some of the work that has been done to develop guides for cross drain spacing is discussed, and suggestions are made as to how to apply this work.

Keywords: Forest roads, drainage, cross drains, road erosion

ACKNOWLEDGMENTS

Information for and technical review of this manuscript were provided by the Water/Road Interaction core team including Larry Cronenwett, Bill Elliot, Tom Moore, Richard Sowa, Bill Hartsog, and Dave Gibbons. Many of their comments and suggestions have been incorporated into this report.

CONTENTS

INTRODUCTION

One element of the interaction between water and roads in forested areas is concentration and flow of water on native or aggregate surfaced roads. Roads with sustained grades have the potential to concentrate runoff to the point where erosion, sedimentation, and unstable slopes cause large changes in stream habitat quality, stream channel development, surface and groundwater distribution, and consequently plant and animal health, and population composition and distribution. A brief introduction is presented to devices and surface shaping techniques designed to direct runoff to the surrounding area in a way that minimizes effects to the watershed. Existing technology, design criteria, and guides on use for surface cross drainage are also presented.

WHAT ARE SURFACE CROSS DRAINS

Surface cross drains consist of surface shaping and devices designed to capture water that collects on and drains down the road and release it in a manner that minimizes effects to adjacent areas and the watershed. Surface shaping includes broad-based (driveable) dips (Figure 1), waterbars, and rolls in profile (twist of crown or inslope templates to outslope and back again). Devices include open top or slotted culverts (Figure 2)(Kochenderfer 1995), metal waterbars (Figure 3), and rubber water diverters (Figure 4)(Gonzales 1998).

WHEN AND WHERE TO USE

For low-volume roads, surface cross drains provide an economical alternative to using ditches and culverts (Cook and Hewlett 1979). Surface cross drains can be designed into any shape road surface template to divert water collecting on and running down the traveled surface. They may also be used to relieve ditches and the inside edge of insloped roadways without ditches. Ditch dams are used to direct ditch water into the cross drain (Figure 5).

Surface cross drains should be planned as part of an overall drainage strategy that may include ditch relief culverts. Broad-based dips are used primarily for draining the road surface, and are not usually relied on for draining ditches, although this can be done for small-flow quantities. Rolls in profile can often be used on grades too steep for broad-based dips. Waterbars are usually installed as simple erosion-control measures on roads, skid trails, and fire lines—especially on roads that have been closed to traffic. Open top culverts provide road surface drainage for traveled way surfaces without requiring large-profile shape changes, and also allow minimal localized grade increases on steeper road sections (Kochenderfer 1995).

One study of the number and type of distresses associated with broad-based dips relative to drainage using inside ditches with culverts for cross drainage concluded by proposing a decision-making guide as to which type of cross drainage to install (Eck and Morgan 1987). The applicability of the proposed guide was limited to the Appalachian region of the United States, but probably could be adapted to other locations.

In areas of cut slope instability, frost heave slough, or erodible ditches, properly located and constructed surface cross drainage can result in less erosion and disturbance to the surrounding watershed than relying completely on insloped roadways with ditches and culverts. In these locations, the surface cross drains can also reduce the need for maintaining the roadway surface accompanied by its associated sediment pulse–by reducing ponding and erosion caused by concentrated surface flow. In summary, surface cross drains can provide effective cross drainage, while reducing the risk associated with plugged ditch relief culvert inlets, which can divert water over the road in unplanned or undesirable locations.

WHAT TO CONSIDER

Road surfacing material properties, local climate, road grade, road service level (amount and type of traffic) and road service life are the primary factors affecting the applicability and location of surface cross drain types. **Surfacing material characteristics** affect the ability of dips to retain their shape, and the rate of in-filling for any type of cross drain. For example, a rock surfaced road will result in much less sediment than a soil surfaced road. A decomposed, granitic soil surface of poorly graded sand and fine gravel will produce more sediment than a cohesive, silty sand surface. **Climates** with intense rainfall and rain-on-snow events result in higher runoff volumes and thus create the potential for more erosion and sedimentation than do milder climates. If all else is equal, steeper road **grades** exhibit greater surface flows and erosion than milder grades.

Road service level (higher-service-level roads are designed for more traffic and for larger or special purpose vehicles) should be considered when determining surfacing material and dip geometry. High levels of traffic, or heavy vehicles, require dips that are deeper, longer, and surfaced with higher quality materials. For these situations, the design

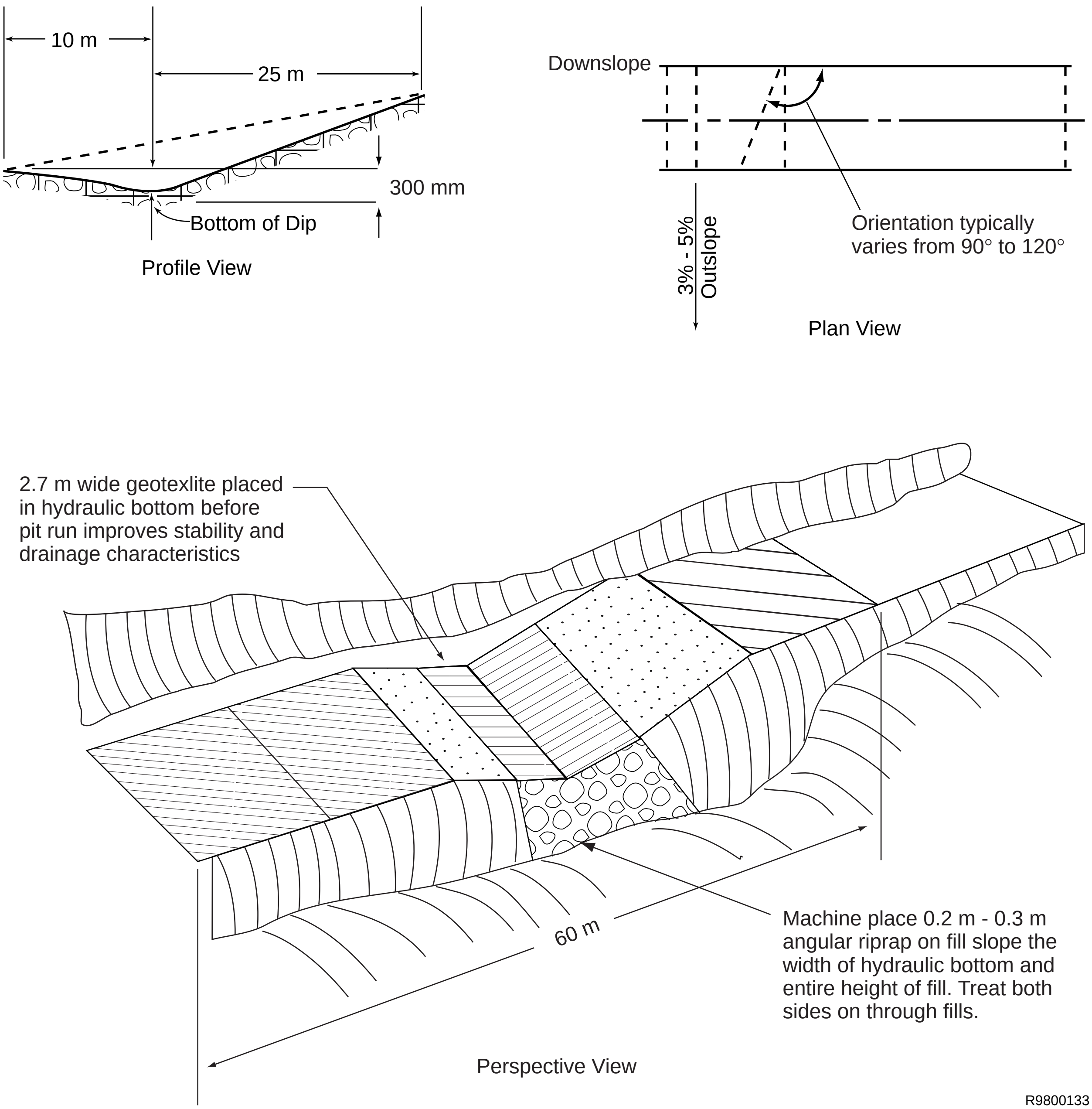


Figure 1—Broad based dip typically used on forest roads. Dimensions are shown only for example. Actual designs should be planned after considering local site conditions.

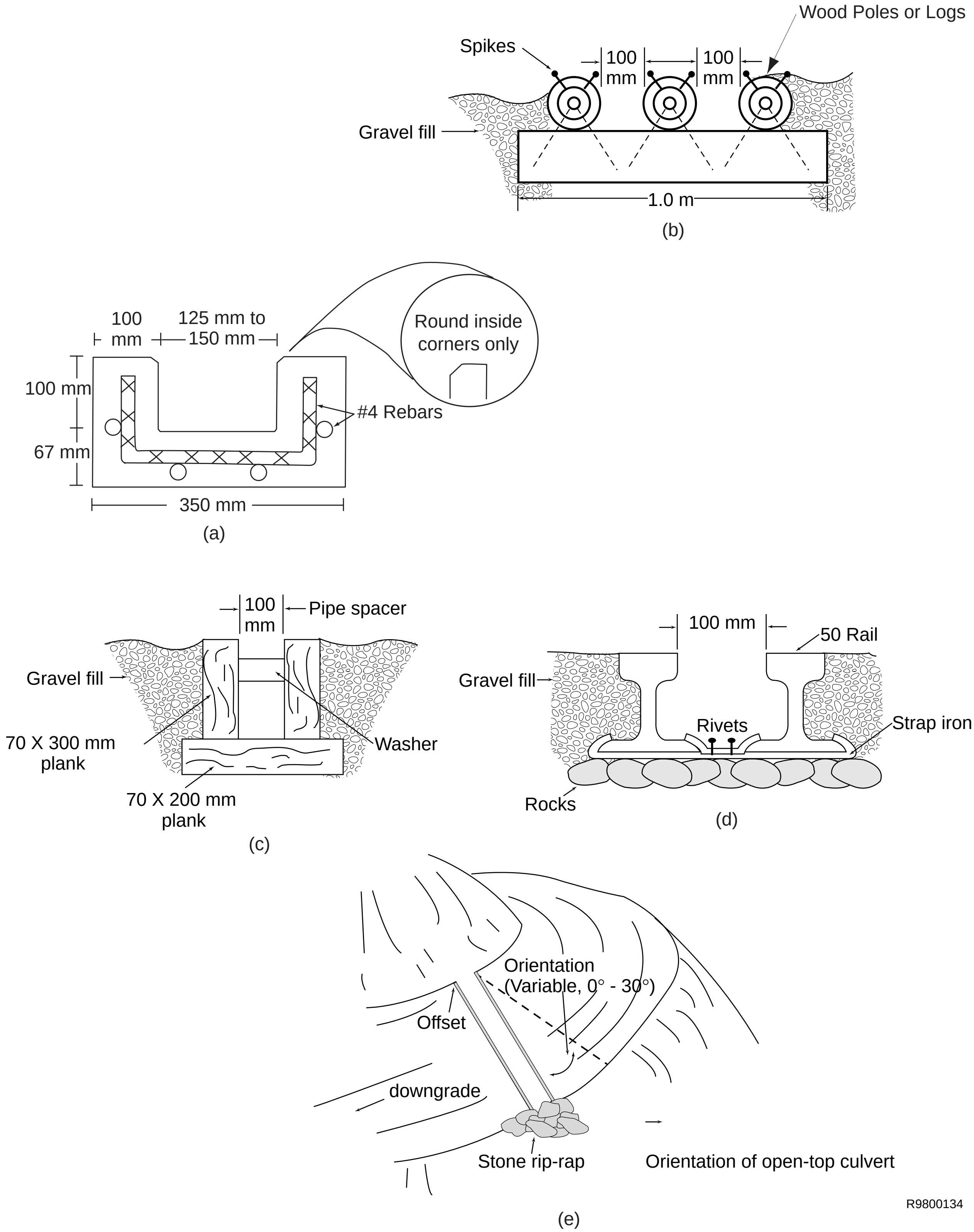


Figure 2—Various open top culvert surface cross drain designs: (a) concrete, (b) pole, (c) wood box; (d) rail culvert, (e) orientation is typically up to 30 degrees from perpendicular to the direction of travel.

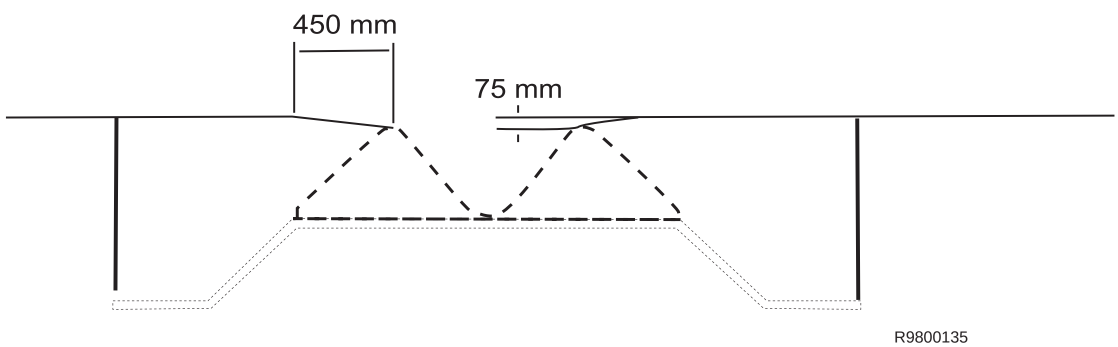
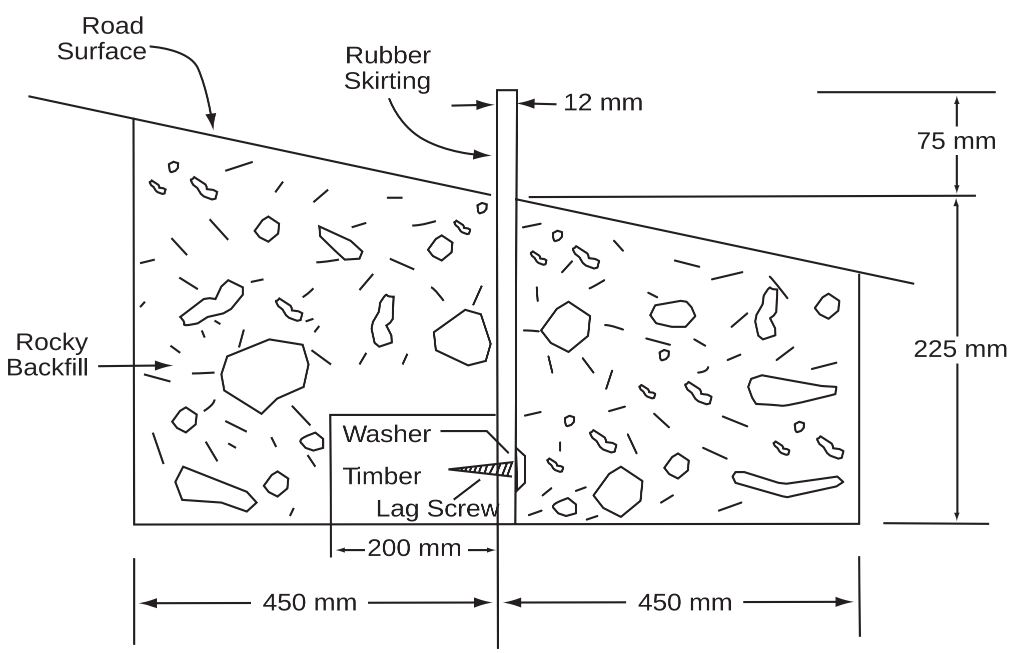


Figure 3—Metal waterbar cross drain design.

(a)



(b)

Figure 4—Rubber water diverter cross drain design: (a) installation on a crowned road surface, (b) typical design details.

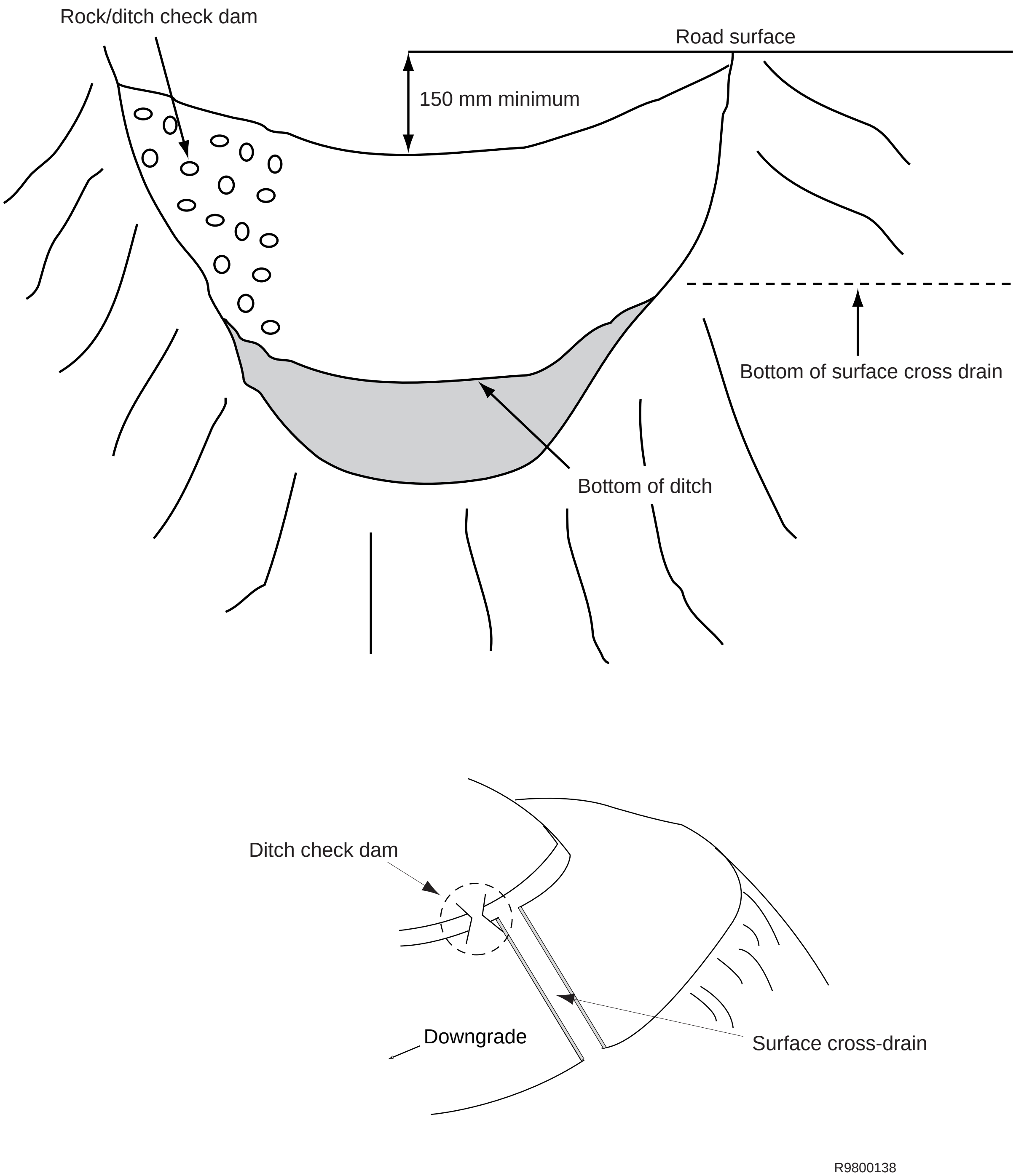


Figure 5—Ditch dams are used for directing runoff toward surface cross drains.

freeboard (hydraulic depth) of a dip should be about 300 millimeters (Figure 1)(Hafterson 1973). Depths less than this will render the dip ineffective after a short time because ruts will cut through the top of the dip, especially if lower quality materials are used. On the other hand, passage of vehicles such as log trucks, lowboys, and recreational vehicles that are large or that include trailers should also be considered. Vehicle frames can be twisted or "racked" if the orientation angle is not 90 degrees (Figure 1). If the dip geometry cannot be designed to satisfy hydraulic requirements and still meet requirements for vehicle passage and safety, then other types of drainage should be planned.

Dips are less susceptible than open top drains to being filled with sediment because they have a larger **holding capacity**. Most surface cross drains reduce the ability of a road to carry traffic (reduced travel speed and user comfort) relative to insloped roads constructed with ditches and culverts. Dips can result in localized increases in the effective road grade by one and one-half to two times (Figure 6).

DESIGN CRITERIA

Proper design and location of surface cross drainage are required in order to prevent water concentration, erosion of traveled way surfaces, erosion of fill slopes, instability of fill slopes, longitudinal rutting, siltation, and ponding (Eck and Morgan 1987). Factors affecting performance of surface cross drains are shown in Table 1. Design criteria for successful road surface cross drainage follow from the basic principles of erosion caused by rainfall and the need to meet transportation objectives. The factors controlling this type of erosion are amount and form of precipitation, soil type, topography, and the type and extent of any vegetative cover. For road surfaces, these factors correspond to local climate, road-surface material properties, road grade, distance between drains, position on the slope, the location of road cuts and fills, and any vegetative cover on the road surface that may be present. Transportation objectives may include the need to support a variety of traffic types without compromising erosion control and slope stability objectives. Table 2 relates the advantages and disadvantages of different types of surface cross drains.

Cross Drain Locations

A road design variable that has received substantial attention is the distance between cross drains on continuous, monotonic grades (Table 3). Water must be drained before it concentrates to volumes that will cause erosion or unstable hillslopes, but transportation needs may not allow the undulating or outsloped roadway that would meet these hydraulic requirements. Figures 6 and 7 graph several surface cross drain spacing guidelines. Figure 6 shows relationships between dip spacing, overall road grade, and approach grade resulting in dip geometry that would allow reasonable driving conditions (Hafterson 1973). These relationships define a lower bound on dip spacing based on geometric and traffic considerations. Other published guidelines (Figure 7) define upper bounds on the distance between contiguous surface cross drains in terms of soil characteristics and road grade. Many guides used in the USDA Forest Service are based on a study, completed between 1958 and 1962, of roads on the Boise National Forest (Packer 1967).

Table 1—Factors affecting performance and erosion of surface cross drains.

Performance (ability to provide adequate drainage and support expected traffic)	• Spacing (i.e., properly locating sufficient cross drains for the expected runoff volume) • Storm intensity (peak runoff) • Erodibility of surfacing material (affects sediment conveyed and ability to keep drain functional) • Traffic volume, type, and weight (consider hardening to increase strength) • Strength of cross drain surfacing material • Drain geometry (freeboard, runout distance, approach grade)
Erodibility (consider lining to reduce erodibility)	• Soil and surfacing type • Grade and location on slope • Fill height • Frequency of maintenance (affects ponding and drain function)

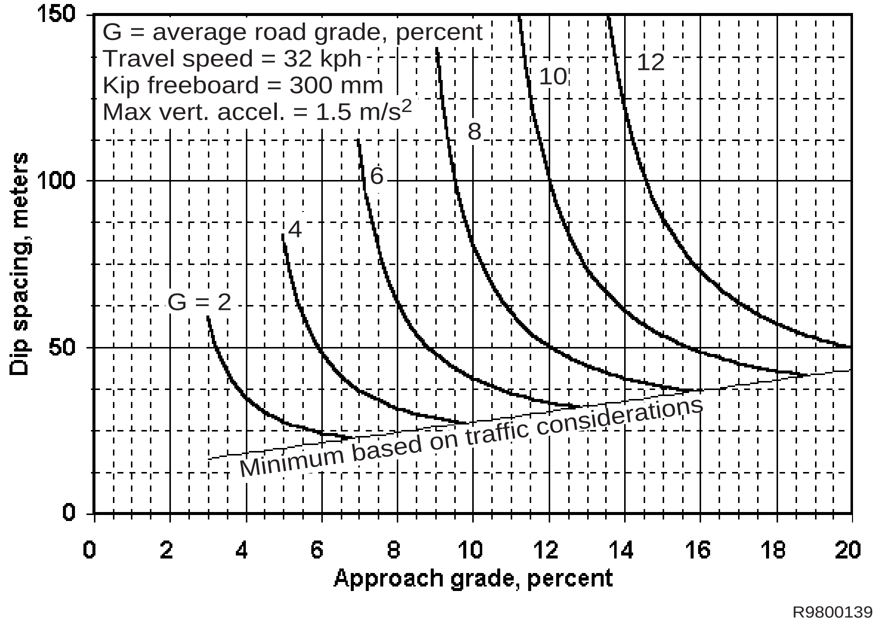


Figure 6—Constraints on broad based dip geometry and location as a result of the need to accomodate traffic (Hafterson 1973). Approach grade is the local slope on the uphill side of the bottom of the dip.

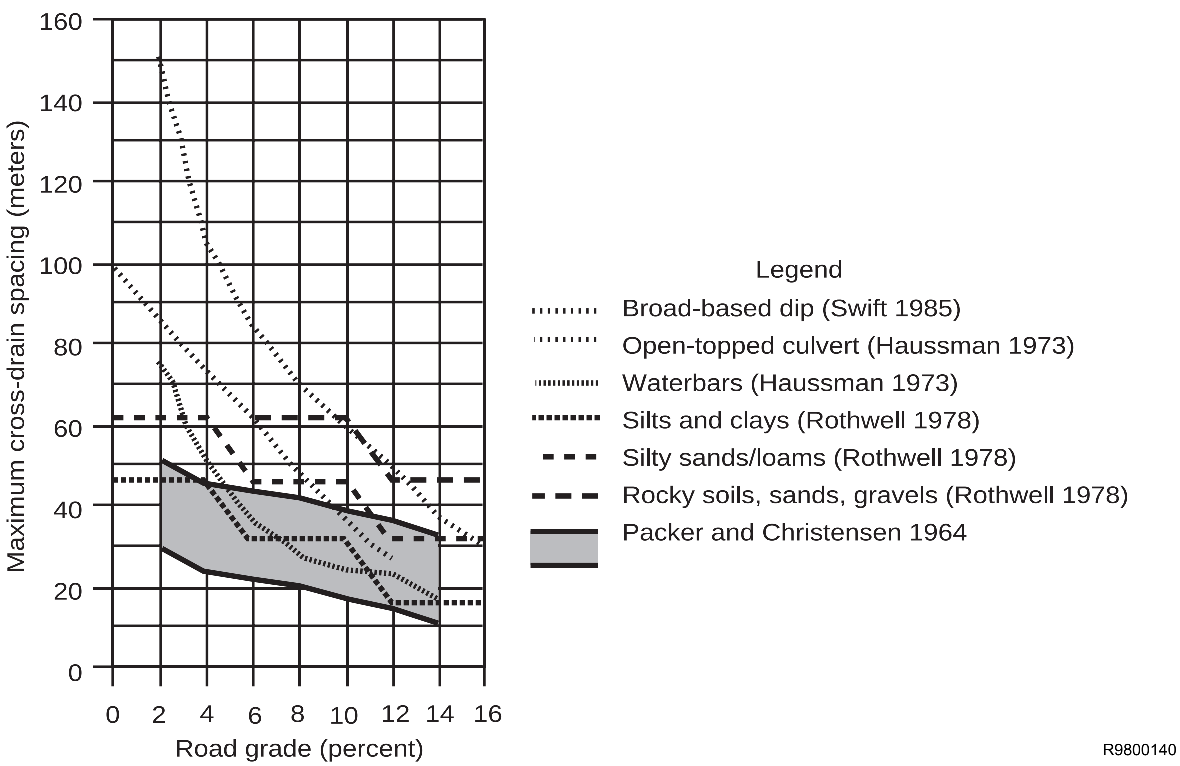


Figure 7—Typical maximum distances specified in various published guidelines for locating surface cross drains. These maximum distances are often used for guidance on the location of ditch-relief culverts.

Table 2—Advantages and disadvantages of different types of surface cross drains.

Type	Advantages	Disadvantages
Broad based dips	• Lower cost[a] than ditches and culverts • Can disperse water	• Can impede some traffic • Erodes and ruts unless armored
Drain dips and waterbars	• Lowest cost[a] surface cross drain • Easy to construct	• Difficult for some traffic (worse than broad based dips) • Erodes and ruts unless armored with rock
Open top culverts	• Stays in place • Okay for traffic	• Higher cost[a] • Lower durability • Requires hand maintenance • Potential for approach problems
Slotted metal pipe	• Stays in place • Does not impede traffic	• Vulnerable to plugging or filling with sediment, debris, or loose surface rock • Requires hand maintenance (flushing)
Flexible rubber strip	• Stays in place • Does not impede traffic	• Low capacity • Erodible unless armored • Low durability, limited life

[a] Guidance on cost estimates is included in some published material (Kochenderfer 1995) (Gonzales 1998). Site-specific cost estimates are best prepared, however, in accordance with regional Cost Estimating Guides by experienced estimators familiar with local conditions and construction practices, equipment, material, and labor rates.

Table 3—Range of published surface cross drain spacing recommendations for native soil surfaced roads.[a]

	Maximum surface cross drain recommendation (meters)			
Road grade (percent)	2 - 5	5 - 10	10 - 15	15 - 20
Haupt 1959	41 - 76	24 - 41	18 - 24	14 - 18
Haussman 1973	95 - 150	60 -95	35-60	
Packer 1967	23 - 51	17 - 44	11 - 39	
Rothwell 1978	46	31 - 61	15 - 46	
Swift 1985	67 - 85	37 - 67	6 - 37	

[a]These guides generally do not specify climate or location, but caution the practitioner to consider the variety of conditions that may be encountered.

[b]Includes additional reductions for slope location, side-slope angle, and aspect that typically would need to be applied according to this guide. (See Table 4, note a.)

Criteria were proposed for the longitudinal flow distance that would limit 83 percent of road surface erosion rills to 25 millimeters or less. This work was based on measurement of 25 topographic and road characteristics for 720 road segment sites over a two-year period and indicated that the most important factors influencing erosion of road surfaces were the percent of water-stable soil aggregates in the road surface that were larger than 2 mm in diameter, and road grade (Packer 1967).

A guide that is widely used and that has become the basis for most of the regional and local guides used in the USDA Forest Service was written by Packer and Christensen and is based on these measurements (Packer and Christensen 1964). The cross drain spacing guidance in this pocket-sized publication is presented as a table of minimum distances between cross drains on a continuous grade for each of six soil groups, which are derived from bedrock lithology. Road grade covered by the table ranges from 2 to 14 percent. The user enters the table with known road grade and soil group. After obtaining the minimum distance from the table, adjustments are made based on the location of the road on the slope, directional aspect, and steepness of the sidehill slope. As an example, if a road is on the lower one-third of a 20 percent hill slope with a south aspect, the guide recommends reducing the distance between cross drains by 25 meters from the tabled value. This would result in a cross drain spacing ranging from 0 to 25 meters.

Although this guide and the guides based on it were written with practical field application in mind, they may not be appropriate in locations outside the northern Rocky Mountain region where the supporting data were obtained. Factors that were not included in this work were the infiltration and water-holding capacity of the soil and surfacing materials, the shape and surface angularity of the road surfacing materials, and climatic factors such as total precipitation amounts or snowmelt characteristics. Neither were allowances made for vegetative cover if it existed. Of the factors omitted, the properties of surfacing materials and climatic factors are probably most important because designers usually make the conservative assumption that vegetative cover does not exist on roadway surfaces.

The soil group classification used for the Packer and Christensen guide, which apparently considers only parent material bedrock lithology, may not adequately consider local soil erodibility that is dependent on local climatic, physical, chemical, and biological factors. In general, erosion of exposed soil surfaces (including native surfaced roads) decreases with increasing organic content and cover and clay size fraction. Erosion also depends on soil texture, moisture content, compaction, pH, and composition or ionic strength of eroding water. Based on our field observations of cross drain spacing applications in seven regions of the USDA Forest Service, no single existing guide encompasses the range of road surface soils found across all locations. It is common for cross drain spacings to exceed the maximum recommended in Packer and Christensen's guide (50 meters) (Packer and Christensen 1964) and in other guides based on this guide, without experiencing appreciable erosion. This may be because road surfacing material (which is applied in part to protect against surface erosion) may not have been taken into account, or it could be a result of differences in climate, topography, or traffic.

In many cases, geometric and physical constraints (e.g., suitability for vehicular traffic and ease of maintenance) require cross drain spacing greater than the 25 meters calculated for the example above (Figure 6). Therefore, Packer and Christensen's guide would preclude the use of road designs employing surface shaping for large percentages (80 to 90 percent) of the combinations of road grades and soil groups listed. Other guides give maximum spacings, which seem to correlate better with what has been used successfully on native surface roads in areas having erosion resistant soils, or on aggregate surfaced roads (Swift 1985).

Another modification that has typically been made to guides derived from the Packer and Christensen guide is to redefine the spectrum of soil erodibility in terms of the Unified Soil Classification System (USCS), which more easily relates to information that may be available to the practicing engineer (for example, see Baeder and Christner 1981). This is based on the idea that soils can be grouped into approximate erodibility classes based on grain size, distribution and cohesiveness (Gray and Leiser 1982). We have converted Packer and Christensen's soil categories to this grouping based on soil erodibility and use this grouping to recommend maximum surface cross drain spacing based on the USCS soil types and road gradient (Table 4).

New cross drain spacing guidelines using the Water Erosion Prediction Program (WEPP) to model surface erosion from roads have been derived (Morfin et al. 1996). Approximately 50,000 iterations of the WEPP were made for input ranges of local climatic conditions, surfacing material characteristics, maintenance frequency, distance between cross

Table 4—Guidelines for maximum distance[a] between contiguous surface cross drains based on USCS soil erodibility groups[b].

Road Grade	Group 1 GW, GP, Aggregate Surfacing	Group 2 GM, GC	Group 3 CH, CL	Group 4 MH, SC, SM	Group 5 & 6 SW, SP, ML
percent	------------------	------------------	*meters*	------------------	------------------
2	120	97	75	52	29
4	103	84	65	45	26
6	88	71	55	39	23
8	74	60	47	33	20
10	61	50	39	28	17
12	50	41	32	23[c]	14[c]
14	42[c]	34[c]	26[c]	19[c]	11[c]

[a]Distance between cross drains should be reduced according to the following (based on Packer and Christensen 1964):

Reduce the distance by:	If the road is located:
5 meters	in the middle one-third of a slope
11 meters	in the bottom one-third of a slope
3 meters	on an east or west exposure
6 meters	on a south slope.

If, after applying the above, the resulting distance is less than 20 meters, set the distance between cross drains at 20 meters and apply aggregate surfacing and erosion protection measures, such as vegetative seeding of road, fills, shoulders, ditches, and embankments.

[b]Adapted from the distance recommendations summarized in Table 3, and soil erodibility hierarchy suggested by Gray and Leiser.

[c]Not recommended for dips because they may require approach grades steeper than 15 percent.

drains, and road grade typical for U.S. National Forests. The output of these analyses is the distance that the sediment plume travels from the road. One way that this effort was made usable by field personnel is through a computer based lookup table (Elliot et al. 1998). It is hoped that this product will serve the dual purposes of facilitating the determination of proper cross drain spacing and helping to predict probable sediment yields based on local values for the above factors. The advantage of this computer based tool is that it is specifically applicable as a cross drain spacing guide for a wider range of conditions than paper based guides can be. In all cases, however, suitability of a particular location for broad based dip design should be reviewed by a soil scientist or geotechnical specialist to evaluate the stability of fill slopes. Preliminary results based on 7,000 of the runs from the above-described WEPP modeling effort show recommended distances between cross drains generally less than the figures shown in Table 4, indicating that the table may be conservative (Morfin et al. 1996).

Some guides point out that there is no set spacing that should be followed in any specific setting (Schwab 1994). It is pointed out that “frequent cross-ditches are optimal,” but that the spacing of cross-drains should fit the natural drainage requirements of the terrain. Certainly, it should be recognized that cross drain spacing guides apply only to the surface erosion aspect of the location of surface cross drains. Where roads are located in areas of highly dissected and variable terrain, cross drain locations may be required more frequently, and located more carefully, than would be the case in areas where surface erosion is the predominant concern.

Location, geometry, orientation, and erosion-protection considerations for surface cross drains are given in Figures 8 through 11.

Because of the cost involved in planning, constructing, and maintaining surface cross drains, it is important to determine their location so that

Checklist for Surface Cross Drain Locations

- ❒ Surface cross drains should be located at intervals close enough to prevent volume concentration that causes surface erosion or unstable slopes.
- ❒ Locate cross drains far enough above stream crossings to avoid releasing drainage water directly into live streams. Surface and ditch water should be diverted and dispersed before it enters streams using lead-out ditches, settlement ponds, ditch dams, surface shaping, or other measures.
- ❒ Where overtopping of the road could occur, a dip or grade roll should be designed to ensure that the overtopping flow crosses the road at a point that minimizes erosion (erodible-resistant surfacing is often added), and so that flow is not diverted along the road or away from its natural flow path.
- ❒ Cross drains should be located above breaks in vertical profile from shallow to steep grades to prevent the shallow grade surface drainage from gaining velocity and erosive power on the steep grade.
- ❒ Whenever possible cross drains should be located to release water on convex slopes or other stable areas that will disperse water rather than channeling it.
- ❒ Dips should not be used within the confines of curves with a radius of less than 30 meters on roads open to traffic because they may create unsafe conditions for vehicle travel.
- ❒ Surface dips are not recommended for grades over ten percent because of the steepness of the dip approach grade that would be required (see Figure 6).

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Figure 8—Checklist for location of surface cross drains.

Checklist for Surface Dip Geometry

- ❒ Cross drains should be constructed with an outslope grade of 3 to 5 percent or equal to the existing out-slope grade. In colder climates where snow and ice create driving hazards, the outslope grade should be reduced.
- ❒ For drivable dips, the minimum freeboard should be 150 millimeters with a roll-out length of at least 6 meters. If the dip is unarmored, freeboard should be increased to allow for the tendency of the dip to lose its shape due to traffic (Figure 1).
- ❒ Drain dips and drivable water bars negotiable by high-clearance vehicles have steeper rollout grades. The recommended minimum depth is 150 millimeters with a rollout distance of at least 1 m.
- ❒ The above values are minimums to be maintained. If maintenance cannot be performed to maintain this minimum geometry, freeboard and roll-out length should be increased so that ruts that cut through the top of the dip do not reduce freeboard below these minimums.
- ❒ The above values should be adjusted according to local climate. Freeboard and run-out distance should be increased for surface dips and waterbars where run-off volumes could be higher.

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Figure 9—Checklist for surface dip geometry.

Checklist for Orientation of Surface Cross Drains

- ❒ Dip orientation (skewed or perpendicular to the road centerline, Figure 1) depends on the type of traffic expected, length of the dip, and road grade. If dips are shorter and the traffic will include larger trucks with longer frames, then the dips should be oriented perpendicular to the direction of traffic. Dips skewed from perpendicular to centerline more effectively drain steep road grades, are more comfortable for vehicle occupants, and, if long enough, will not cause severe twisting of truck frames.
- ❒ Open-topped culverts, and slotted culvert pipes may be oriented from 60 to 90 degrees to the direction of travel.
- ❒ Waterbars are typically used in closed-off areas with little traffic, and should be oriented to lead the flow from the surface. One rule of thumb is to add five to the percent road grade and orient the waterbar at that many degrees off perpendicular.

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Figure 10—Checklist for orientation of surface cross drains.

Checklist for Control of Erosion in Surface Cross Drains

- ❒ Cross drains should be armored where soils are highly erodible or provide poor traffic support during wet weather use. (USCS groups CH, CL, MH, SC, SM, SW, SP, ML).
- ❒ Permanent erosion control measures (armoring, flow spreaders, vegetation) should be used at all cross drain outlets in USCS soil groups CH, CL, MH, SC, SM, SW, SP, ML).

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Figure 11—Checklist for control of erosion in surface cross drains.

economic and resource objectives will be met, while minimizing the cost of maintaining and repairing forest roads. Further studies are being planned to compare cross drain locations to the various recommendations and to what may be needed to adequately protect resources and transportation facilities.

Typical Materials, Construction, and Maintenance

Specifications for surface cross drains are usually described by drawings or by written specifications developed by an engineer (USDA FS 1996).

Waterbars, broad based dips, and drain dips are excavated into road surface materials. Rock aggregate and grass are often used to stabilize the crest and trough areas (Kochenderfer and Helvey 1987). Adding geotextile material to the construction of dips (Figure 1) can substantially improve the stability and drainage characteristics of these installations.

Open topped culverts have been made from a variety of materials, including dimension lumber, small logs, half metal culverts, railroad rails, concrete, or shaped soil-cement mixtures (Gonzales 1998) (Figure 2). Slotted metal pipes can be either steel or aluminum (Kochenderfer 1995).

Surface cross drains can be built and maintained with standard construction equipment such as a dozer or grader.

A road grader or dozing blade is needed to shape cross-drain dips. Open topped culverts, slotted metal pipes, and other suface drain devices require hand labor to replace backfill against the structures, or to excavate deposited sediment. Occasionally pipes need to be replaced, which requires a backhoe to excavate the damaged structure. Care must be taken to avoid building up a soil berm at the outlet of surface cross drainage structures during maintenance operations.

Regular maintenance of surface cross drains is required. The capacity of surface cross drains is quickly reduced as sediment and debris in storm runoff settle in these drains. Surface cross drains should be inspected, cleaned out, or reshaped to original capacity after each storm.

Routine surface maintenance (primarily blading) can be more time consuming, and thus costly, where reshaping of dips is necessary. This is also true for other types of cross drains where care must be taken not to push surface material into the drain, leave it piled in front of or at the outlet of the drain, or dislodge installed cross drain structures such as sheet metal waterbars.

UNIT CONVERSIONS

Multipy	by	To get
mm (millimeters)	0.0394	in. (inches)
cm (centimeters)	0.394	in. (inches)
m (meters)	39.4	in. (inches)
m (meters)	3.28	ft (feet)
hectares	2.47	ac (acres)
m^3 (cubic meters)	1.31	yd^3 (cubic yards)

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