Culverts Versus Dips in the Appalachian Region: A Performance-Based Decision-Making Guide

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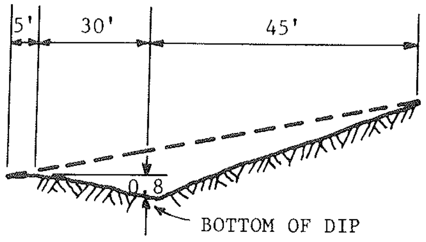
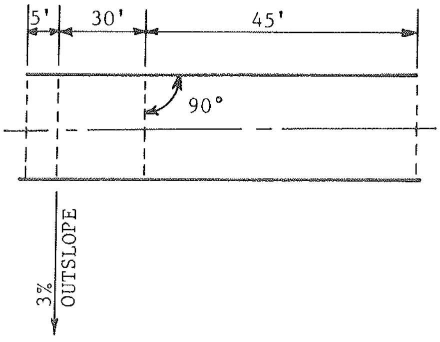
Based on a literature review and field survey, specific factors that need to be considered in the decision to use culverts or broad-based dips for cross-drainage on low-volume roads were identified. Detailed roadway and environmental information was collected at 19 field sites in the Appalachian region to assess the performance of dips and 18-inch aluminum pipe culverts under a variety of conditions. Performance was rated as either acceptable or unacceptable by a survey team that made a field examination of the drainage structure. Overall, 227 culverts and 255 broad-based dips were assessed. Failure rates for culverts and dips were 7.5 percent and 27.5 percent, respectively. Distress types noted for the culverts rated as unacceptable were sloughing of the cut slope, clogging of pipes and inlets, and erosion of the fill slope. The most common distress types for the dips rated as unacceptable were erosion of the fill slope, rutting, siltation, and ponding. A number of specific conclusions regarding the design and location of dips and culverts were presented to document cases in which one device was more appropriate and cost-effective than another. A decision-making framework, in the form of a flowchart, was developed to assist engineers and foresters in selecting the appropriate drainage device for a particular application.

Drainage is one of the primary concerns in locating and designing low-standard roads that may serve only 0 to 50 vehicles per day (vpd). Drainage must always be adequate if a road is to remain usable. Several types of drainage devices are used to control water flow. Probably the most common type of device is the culvert, which is a closed conduit that carries surface water across or from the road right-of-way. Another device is the broad-based dip, which is a depressed out-sloped section of roadway that acts as a water catchment and drainage channel. Dips can be used instead of culverts for cross-drainage in locations in which no intermittent or permanent streams are present. The plan and profile of a typical broad-based dip are shown in Figure 1. The dip under discussion here should not be confused with low water stream crossings that are frequently found on paved low-volume roads.

Some controversy currently exists regarding the relative benefits and costs of dips and culverts. Some suggest that metal culverts are superior for most drainage needs (*1, 2*). The initial cost of culverts is high compared with simple drainage devices, but culverts have long lifetimes, require relatively little maintenance, and are essentially unnoticed by road users.



(a) Profile



(b) Plan

FIGURE 1 Plan and profile of a broad-based dip currently used by USFS national forests in North Carolina.

Others promote broad-based dips because they have several advantages (*3, 4*). Dips have a relatively low initial cost, and unlike culverts, dips can be used without the expense of a ditch line. It has been reported that properly constructed dips have low maintenance costs and, like culverts, do not increase wear on vehicles or reduce hauling speeds (*3, 5*). However, one disadvantage of broad-based dips is that equipment operators need special training to be able to construct dips properly. Therefore, dips are often not built according to intended specifications.

Design criteria have been established for both broad-based dips and culverts, although actual device dimensions and other details may vary from one geographic region to another. Most drainage devices, if constructed according to specifications and if placed at an appropriate location, will perform satisfactorily for many years. However, if the device is not built according to specifications or it is not properly located, serious problems can result.

An improperly placed or poorly constructed culvert could result in clogging of the pipe or erosion of the roadway or fill

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slope. Both of these situations can generate siltation and sedimentation, which would consequently degrade the forest vegetation and water quality. A clogged culvert not only increases the likelihood of the roadway washing out in the vicinity of the structure, but it may also introduce the possibility of damage to down-grade drainage structures.

A poorly constructed dip can result in a number of problems, including erosion, siltation, rutting, or ponding of the dip or roadway. Erosion necessitates actions to protect the fill slope and immediate down-grade streams, and replace lost material. Siltation calls for the removal of debris (mostly soil and rock particles) from the dip. Rutting and ponding often require that the dip be reconstructed, because these two types of distress create a build-up of mud or water that eventually creates an impassable roadway. If allowed to continue unabated, the economic costs associated with all of the problems just mentioned can be quite high.

Based on a limited field survey and discussions with forest road designers, builders, and users in the Appalachian region, it became apparent that whereas dips and culverts each have their place as a drainage device on low-standard roads, there are certain conditions in which one is more appropriate than the other. However, no formal engineering study had ever apparently been made of this issue. A need exists to objectively determine through the use of actual field data and an engineering economic analysis, under what conditions conventional metal culverts are more appropriate than broad-based dips on logging roads in the Appalachian region.

STUDY OBJECTIVES

A research project was undertaken to answer this question. Several specific objectives were established to address the overall goal:

- Based on a literature review and field survey, specific factors were identified that had to be considered in the decision to use culverts or dips.
- An experimental design was to be developed to collect detailed data at a number of field sites in the Appalachian region to assess the performance of dips and culverts under a variety of conditions. It should be noted that only aluminum culverts were considered in this study, because they were the only type of drainage device used in the Monongahela National Forest in West Virginia, where the field investigation was conducted.
- An economic analysis was to be conducted of 18-in aluminum culverts and broad-based dips, in which construction, maintenance, and road user costs were considered. The results of the economic analysis are presented elsewhere (*5*).
- Based on the field study and the economic analysis, specific conditions were to be recommended under which culverts or broad-based dips should be installed.

DATA COLLECTION

The factors involved in the performance of a drainage device must be known in order to develop guidelines to assist in the selection of the most appropriate type of cross-drainage. Based on a literature review, field survey, and discussions with practitioners, those factors that affected performance and that needed to be considered in the selection of a dip versus a culvert were identified. In order to establish a convenient framework for decision-making and to formulate the experimental design for the field study, the factors just mentioned were grouped into several major categories, as shown in Figure 2.

In order to determine specific situations in which one drainage structure was more appropriate than another, a field study was designed to evaluate the performance of a large number of broad-based dips and 18-in aluminum pipe culverts in the Monongahela National Forest. The experimental plan was formulated in such a manner that the effects of the variables that influenced dip and culvert construction, performance, and maintenance could be assessed.

Sites were sought that would provide variety in some of the factors, but be similar in others so that the effects of individual variables on drainage device performance could be isolated.

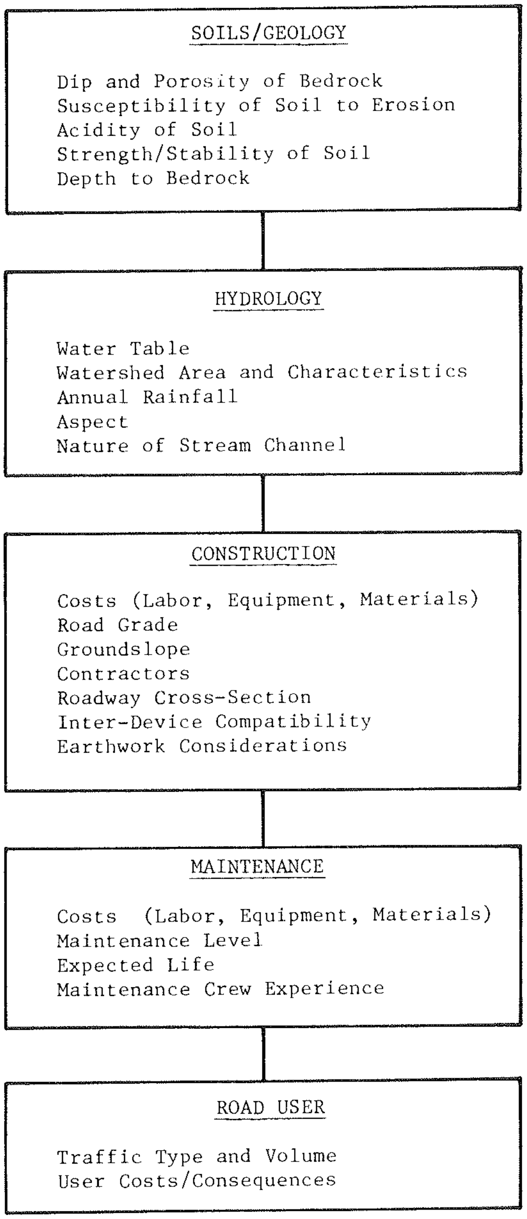

FIGURE 2 Preliminary framework of factors to consider in the selection of broad-based dips or culverts.

Another criterion was that plans and drawings had to be available for the roads selected for study. It was also thought to be desirable that the study roads be associated with active timber sales, although this was not mandatory.

Given these criteria, the investigators met with engineers, soil scientists, and timber sales personnel from the Monongahela National Forest Headquarters in Elkins, West Virginia, to discuss specific study sites. Although a large number of sites were proposed by U.S. Forest Service (USFS) personnel, time and resource constraints limited the actual number to 19. A summary listing of the characteristics of each site is provided in Table 1. Plans, drawings, and appropriate U.S. Geological Survey (USGS) quadrangle sheets were acquired for each of the study sites. Average annual precipitation was estimated from published information (*6*). These items were used to assist in planning the field work and to supplement the data acquired in the field.

Once the field sites were identified, efforts centered on the selection of specific data items to be collected in the field. Information was sought in regard to each study site as a whole and to the individual drainage structures that comprised a site. Data pertinent to the overall site included average annual rainfall, general soil conditions, length, number of broad-based dips, number of 18-in aluminum pipe culverts, traffic volume data, timber sales data, and actual project construction and maintenance costs. Both average daily traffic (ADT) and total number of truck trips necessary for timber removal were sought in the traffic category. The number of truck trips could be computed given the volume of timber sales and the typical number of board feet of timber per truck load.

Information pertinent to individual drainage structures included spacing from a previous structure, type of upgrade structure, road gradient, roadway cross-section, ground slopes, aspect, watershed location, fill height, presence of cut-fill transitions, cross-drain purpose, road surface type and depth, horizontal curvature, and structure performance. Actual device construction and maintenance costs were sought whenever possible.

A study procedure was developed to acquire the desired data efficiently. This procedure basically consisted of a two-person field party that walked over the roads of the study site, recorded the previously mentioned qualitative roadway and environmental information, and made simple measurements to quantify certain roadway and drainage parameters. About 3 weeks were required to complete the structural performance field study.

Two types of data collection forms were prepared and tested to document the information collected in the field. The first form consisted of a summary of information that related to the

TABLE 1 CHARACTERISTICS OF ROADS IN MONONGAHELA NATIONAL FOREST THAT WERE SELECTED FOR FIELD STUDY

Project Sites (USFS Road Name and Number)	Length (miles)	Number of Broad-Based Dips	Number of 18-inch Aluminum Culverts	Avg. Annual Rainfall (Inches)
1. Stuart Camp, 91-B	0.09	2	1	49.0
2. Stuart Camp, 91-C	0.43	9	0	49.0
3. Suart Camp, 91-D	0.32	6	1	49.0
4. Stuart Camp, 319	0.10	2	0	49.0
5. Peach Orchard, 297	0.77	6	1	38.7
6. Four Mile, 969	1.31	14	11	45.7
7. Sue, 796	0.63	10	0	45.7
8. Sue, 796-C	0.95	11	7	45.7
9. Music Run, 907	1.22	0	20	59.7
10. Hacking Run, 914	0.52	6	7	56.5
11. Galford Run, 90	3.16	0	41(15)[a]	47.1
12. Galford Run, 90-A	3.30	39(15)	16(5)	47.1
13. Stony Run, 757	1.54	17	13	47.1
14. Divide, 790	1.77	0	8	47.1
15. Leatherwood, 368	6.52	34(7)	54(13)	54.6
16. Jobs Run, 117	2.35	46	13	53.8
17. Lick Drain, 929	4.40	47	29	53.8
18. Red Run, 244	3.60	0	67	53.8
19. Warner Run, 916	3.64	63	16	50.1

[a] Numbers in parenthesis represent number of drainage structures studied for those instances where it was not possible to survey all structures.

overall project. One form was completed for each project. The form was designed to be completed by Forest Service personnel and the researchers (using the maps, plans, and drawings furnished by the Forest Service) before the field surveys were conducted.

The second data form was completed in the field by the two-person study team. Information about the location and environment of each individual drainage structure was recorded. One form was used for each structure. It should be noted that because of time, resource, and weather constraints, a complete set of data could not be acquired for all sites.

Performance was rated as either acceptable or unacceptable by the survey team after completing an examination of the drainage structure. Unacceptable structures were those that required, in the opinions of the field party, immediate maintenance attention. When a structure was determined to be unacceptable, a note was made of its distress type, which could have been one of the following:

- Rutting of dip or roadway,
- Siltation of dip,
- Erosion of fill slope,
- Corrosion of pipe,
- Ponding of dip,
- Clogging of inlet or pipe,
- Sloughing of cut-slope, or
- Construction problems.

Before the field work was begun, special efforts were made to ensure that the survey team understood the types of distress. Distress types were defined both in words and by photographs (taken during the field trips) that depicted an example of a particular condition.

The format of the data on soils, which consisted of such items as soil name, geologic formation, soil erosion potential, and other information, was developed based on unpublished USFS guidelines of soil characteristics for drainage and road building in the Monongahela National Forest. The soil found at each cross-drain was identified by use of a combination of descriptions of soil color and texture made in the field, and information from USDA county soil surveys and USFS documents. Once the soil types and geologic formations were identified, the USFS rating guide for soil sensitivity groups in Monongahela National Forest was used to determine relevant soil characteristics. However, the coarse fragment content of the soil was determined visually. Estimates of depth to bedrock and depth to seasonal high water table had to be obtained from USDA county soil surveys.

DATA ANALYSIS

The data were initially categorized in such a manner that the performance of 18-in metal culverts could be examined separately from the performance of broad-based dips. Of the 482 structures studied, 227 were culverts and 255 were broad-based dips. When study sites were selected, an attempt was made to examine an approximately equal number of dips and culverts. Seventeen of the 227 culverts were rated as unacceptable, which represents a failure rate of 7.5 percent. The overall failure rate for dips was 27.5 percent. The performance of the culverts that were studied was therefore substantially better than that of the dips.

The distress types noted for the culverts that were rated as unacceptable were sloughing of the cut slope, clogging of pipe or inlet, and erosion of the fill slope. The most serious problems were sloughing of the cut slope and clogging of the pipe or inlet. Sixteen of the 17 failures involved sloughing problems. Fifteen of the failed culverts were clogged; only three culverts were noted to have erosion of the fill slope. Sloughing of the cut slope and clogging are related distresses; the material that sloughs off the slope gets deposited in the inlet or pipe and clogs the structure.

The most common distress types for the broad-based dips that were rated as unacceptable were erosion of the fill slope, rutting, siltation, and ponding. Of the 70 failed dips, 48 were noted for erosion of the fill slope, 35 for rutting problems, 34 for siltation, and 27 for ponding. Four dips were noted for construction-related distress. Only one dip that failed was noted for sloughing of the cut-slope.

In order to assist in specifically determining which factors affected drainage structure performance, the data were organized into the following groups: design factors, soil and geologic factors, hydrologic factors, and traffic factors. The various factors that comprised these categories were analyzed individually to determine if each had a substantial effect on structure performance.

Substantial factors were those that were judged by the researchers to yield a relatively high failure rate; all other factors were considered secondary. This terminology was arbitrarily selected by the investigators for their convenience in describing the data tabulations; no statistical significance should be attached to the results.

The researchers used a statistical method known as the normal approximation to the binomial to compare the overall performance of culverts and dips with the performance of these devices when categorized by the various factors (*7*). Plots were prepared by use of the appropriate statistical equation and the aforementioned overall structure performance rates for 18-in culverts and broad-based dips. The plots depicted statistical significance as a function of the number of failed and number of total structures within a given sample set. The following three statistical regions were identified:

- Values that indicated a significantly better structural performance when compared to the overall situation,
- Values that indicated a significantly worse structural performance, and
- Values that indicated no significant change in structural performance.

Design Factors

The following items were considered as design factors:

- Road grade,
- Roadway cross-section,
- Structure spacing,
- Road surface type,
- Immediate up-grade (on-roadway) structure,
- Fill height,
- Horizontal curvature,
- Cross-drain skew, and
- Cut-fill transitions.

Appropriate groups of data were developed for each factor and the frequency of device failure was determined for the groups. Roadway cross-section and cross-drain skew were determined not to have a substantial effect on drainage device performance.

An examination of structure performance versus road grade indicated that culverts performed best when the road grade was 7 percent or less. The culvert failure rate was only 2.5 percent for road grades less than or equal to 7 percent. The failure rate was 13.1 percent for road grades greater than 7 percent. Broad-based dips demonstrated a somewhat comparable trend in that they also performed better as the road grade decreased. However, dips tended to perform best when the road grade was less than or equal to 3 percent. The dip failure rate was 32.3 percent for grades between 3 and 9 percent.

Drainage structure spacing is a design factor that depends on the road grade. Mean spacings for acceptable and unacceptable culverts and dips, respectively, are presented in Figures 3 and 4 for different road grades. Those devices that did not have an adjacent drainage structure were deleted from this particular analysis. The spacing of failed structures was generally greater than the spacing of acceptable structures. The data also indicated that the mean spacing for acceptable culverts was relatively close to the design spacing value. The mean spacings for unacceptable dips deviated more widely from the design value.

Structure performance versus road surface type was also examined. As was expected, broad-based dips generally performed better when armored with gravel than they did in an unsurfaced condition. The failure rate for unsurfaced dips was 37.3 percent compared to 19 percent for dips armored with stone. The data were insufficient to evaluate which type of gravel surfacing performed better because only seven dips were armored with 3-in quarry stone. Based on information acquired during practitioner input, there appeared to be some disagreement between engineers as to whether 3/4-in crusher run or 3-in quarry stone was a more appropriate surfacing for logging roads in the Appalachian region. Additional research into this issue could prove to be fruitful.

Culverts or dips located on horizontal curves had a higher frequency of failure than structures located on tangent sections of roadway. However, dip performance appeared to be more adversely affected by curvature than that of culverts. The failure rate for dips located on curves was 40 percent, compared to about an 8 percent failure rate for culverts located on curves.

Fill height is another design factor that affects structure performance. The failure rate generally increased as the height of the fill increased for both dips and culverts. Closer examination indicated that the failure rate increased dramatically for dips when the fill height was greater than 3 ft, as shown in Figure 5. The failure rate for fill heights less than or equal to 3 ft was 18.9 percent, compared to a rate of 67.2 percent for fill heights greater than 3 ft.

Culvert and dip performance versus type of drainage structure immediately up-grade from the one in question was investigated. Drainage structures that were located in a sag were separated from the other structures in this analysis. This was done in order to specifically examine structure performance at sag locations, which practitioners had indicated were locations that were critical to dip performance. The analysis indicated that sag locations had a 45.5 percent failure rate for broad-based dips and a 9.7 percent rate for culverts. Based on these results, it is recommended that if it is necessary to locate a drainage structure in a sag location, a culvert should be used because it will probably perform better than a broad-based dip.

Although it was difficult to determine from the data which type of structure was better in terms of drainage, it was noted that dips were more sensitive than culverts to the existence of an up-grade drainage structure. When no structure was located up-grade from a dip, the failure rate was 41.1 percent. By contrast, when no structure was located up-grade from a culvert, the failure rate was only 8.7 percent.

Notably few study site drainage devices were located at cut-

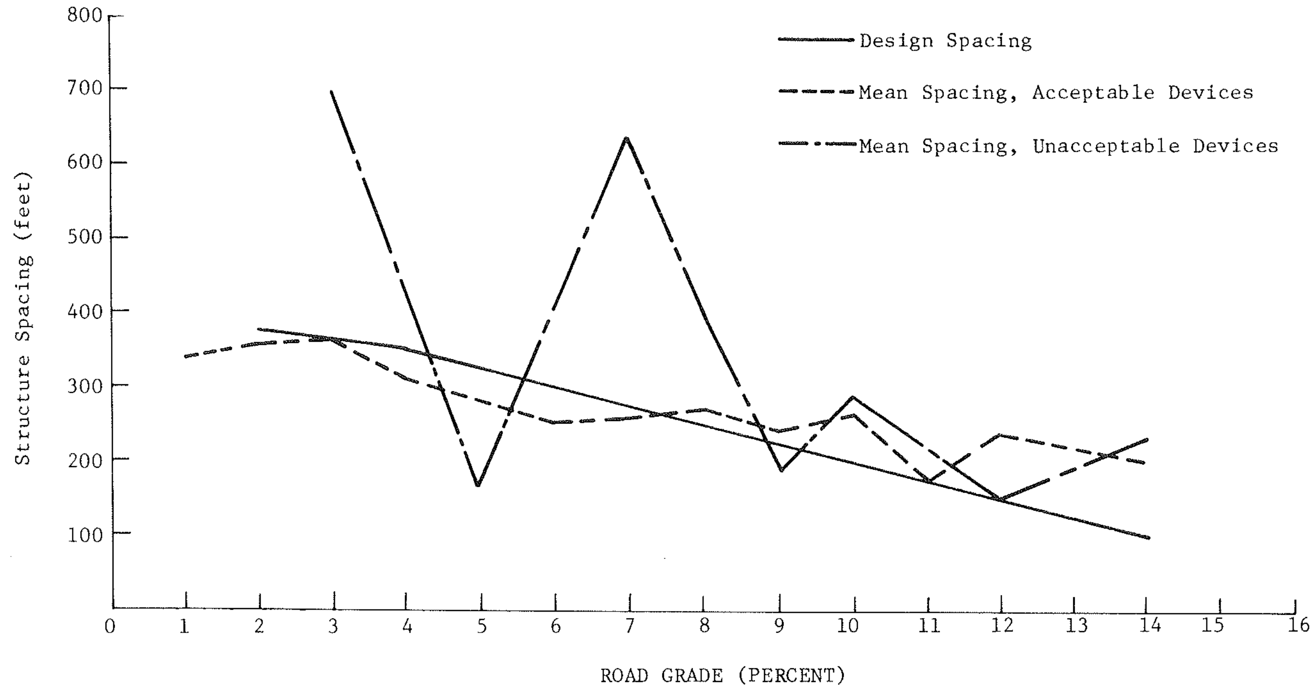

FIGURE 3 Mean culvert spacing versus road grade.

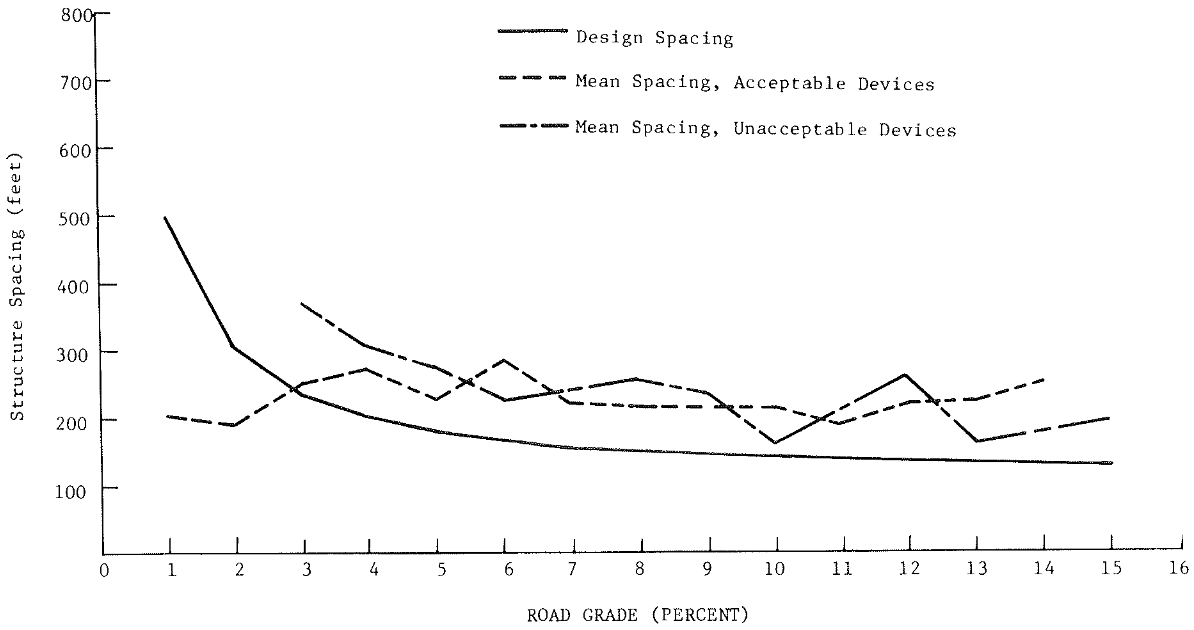

FIGURE 4 **Mean spacing of broad-based dips versus road grade.**

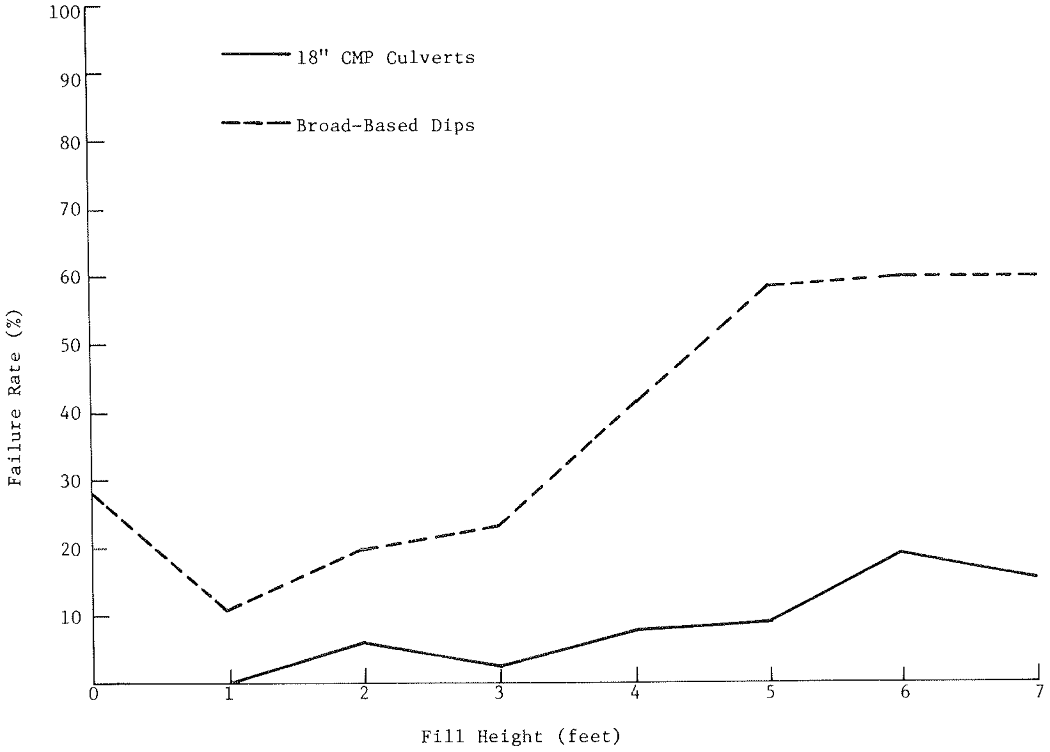

FIGURE 5 **Drainage structure performance versus fill height.**

fill transitions. This may be an indication that designers have learned from experience to avoid placing drainage structures at cut-fill transitions. Based on a very small sample size, it appears that culverts should be used when drainage structures must be located at cut-fill transitions. Although only four dips were located at cut-fill transitions, two of them failed. However, none of the five culverts at cut-fill transitions failed.

It should be noted that a limitation of the analysis just described was the assumption that all drainage grades, frequency and amount of flow, and other parameters of this nature were the same for the sites under consideration. A comparison of failure rates based on a single variable, such as whether or not an up-grade drainage structure exists, could be misleading unless other flow characteristics are considered.

Soil and Geologic Factors

The following items were considered soil or geologic factors:

- Soil type,
- Geologic formation,
- Soil erosion potential,
- Ground slope,
- Suitability of soil as road material,
- Coarse fragment content, and
- Depth to bedrock.

Soil erosion potential, soil suitability for road building, coarse fragment content, and depth to bedrock were analyzed but were determined not to be significant factors in drainage structure performance.

Structure performance versus specific type of soil was examined initially. However, the number of different soil types studied was so large that it was difficult to determine which soils contributed to acceptable or unacceptable structure performance. Therefore, soils were reclassified according to soil series. For example, any soil type that had Berks in its title was classified as a Berks soil. The performance of 18-in metal culverts was essentially independent of soil series. However, certain soils tended to contribute to poor dip performance. Soils associated with high failure rates for broad-based dips were generally gravel-sand-silt mixtures, gravel-sand-clay mixtures, sand-silt mixtures, and silty or clayey fine sands that were typically derived from interbedded sandstone, siltstone, and shale.

It should be noted that the soil data collected in this study were admittedly general in nature. Laboratory testing would have been desirable to determine specific reasons why the specific soils series had such high failure rates. It is believed that the high failure rates may be related to the fineness of these soils, the poor bearing strength of shale fragments present in several of these soils, and other characteristics of the underlying geologic formation.

Because soil characteristics are closely related to and vary with the underlying geologic formation, an analysis was made of the influence of geologic formation on drainage structure performance. This analysis revealed that culvert performance is independent of geologic formation. Dips, however, demonstrated high failure rates in the interbedded sandstone, siltstone, and shale formations.

The ground slope was also examined because of its suspected relevance to structure performance. Because water is transmitted to drainage structures from higher elevations, it was believed that the ground slope above the drainage structure was critical. Culvert performance worsened as the ground slope increased. However, the same trend was not true for dips.

The poor performance of culverts on steeper ground slopes may result from material such as rocks, limbs, and other unstable materials rolling down these steep slopes and becoming lodged in the culverts. High cut slopes, which are undesirable for culverts, may be needed when the ground slopes are steep. Because dips are not enclosed like culverts, they do not exhibit these characteristics, and are not as dependent on changes in the ground slope as culverts.

Hydrologic Factors

Hydrologic factors affect the quantity of water that passes through a drainage structure. These factors are obviously an important component of dip and culvert performance. The following items were considered hydrologic factors:

- Aspect,
- Watershed location,
- Average annual precipitation,
- Presence of seeps or springs,
- Cove location,
- Soil wetness,
- Surface water yield,
- Ground water yield, and
- Depth to seasonal high water table.

Soil wetness, surface water yield, ground water yield, and depth to seasonal high water table were examined, but no substantial differences between devices were indicated.

A limitation of the data was that the aspect was classified as either north or south to ease the tabulation of data, and because these exposures had been identified by practitioners to be an important determinant of dip performance. However, the classification of aspects into such broad categories could have influenced the results of the study. For example, a drainage structure located on an east-northeast exposure could have received the benefit of the drying effect of solar radiation because its exposure was closer to the east than to the north. However, in this study the exposure would have been classified as a north aspect.

Results indicate that culverts and dips located on a north aspect both had higher failure rates than those with a southern exposure. This can be attributed to moisture- and water-related problems that are exacerbated by the lack of solar radiation and its drying effect. The failure rate for dips with a north aspect was not as great as had been anticipated, which could be a result of the data limitation just described.

Watershed location was another factor that was studied. The location of the drainage device in the watershed was classified as belonging to either the upper, middle, or lower third of the watershed. The purpose of this breakdown was to provide a rough estimate of the relative amount of runoff handled by the device. As the watershed location went from high to low, failure rates increased for both culverts and dips. This suggests that the greater the volume of water handled by the drainage structure, the greater the likelihood of failure.

The average annual precipitation indicates the variability in the quantity of water handled by drainage devices from project to project. The analysis of this factor was made difficult by the fact that rainfall data were estimated using available meteorological information instead of collecting specific data from each site. Two study roads would therefore be assigned the same quantity of precipitation that was determined from the nearby weather station although they were several miles apart and probably received slightly different amounts of rainfall. However, it was believed that the relative, rather than the absolute, amount of annual precipitation would be of greater value in this study.

Culverts and dips both experienced an increase in failure rate as the average annual precipitation increased. This result had been expected, because structures in regions of high precipitation carry large volumes of runoff, and are prey to ground water or moisture-related problems.

Two locations that tend to cause problems for drainage structures were identified from the literature review and practitioner input. Drainage structures located in coves or where springs or seeps are present will be generally exposed to larger quantities of water than they would at other locations. The Forest Service tends to avoid locating dips where springs, seeps, or coves exist. It was the opinion of the researchers that the reason three of the twenty-two 18-in aluminum culverts failed where seeps or springs were present was that these pipes were undersized. A larger pipe would probably have functioned properly in these three locations.

Traffic Factors

One would intuitively expect drainage structure performance to be related to the magnitude of traffic using the roadway. Data were available in this study for average daily traffic and total truck traffic. Values for ADT were determined from estimates furnished by forest rangers for the projects within their particular jurisdiction of the Monongahela National Forest. The data indicated that the volume of traffic did not affect culvert or dip performance. This latter finding was unexpected; however, the available data did not yield a specific explanation. Because broad-based dips are actually part of the road surface, it had been hypothesized that an increase in traffic would correlate with an increase in the failure rate for dips.

Perhaps a better measure of the traffic load applied to a drainage structure is the total number of truck trips made to date on the logging road. The total number of truck trips was derived by dividing the quantity of timber (in board-feet) involved in the timber sale by the average number of board-feet of lumber per truckload. Therefore, in this case traffic volume could be considered a surrogate measure for the weight applied to the roadway. Both the number of vehicles and their weights have an impact on roadway and drainage structure performance.

Culvert and dip performance were not affected by changes in traffic volume. This finding was unexpected. An important factor for which data were not available in this study was the condition of a dip when it received traffic. A dry dip can withstand many more load applications than a wet one. It is hypothesized that the amount of truck traffic could be an important factor in the prediction of dip performance under certain conditions. Additional research is warranted in this area.

THE DIP VERSUS CULVERT DECISION

Information was provided in the preceding section on the performance of metal culverts and broad-based dips in relation to certain design, soil, hydrologic, and traffic factors. An earlier study compared culverts and dips on an economic basis in terms of construction, maintenance, and road user costs (*5*). The findings of each of these aspects in the overall study were combined to develop guidelines that would assist in the identification of those conditions in which aluminum pipe culverts are more appropriate than broad-based dips for intermittent cross-flows on Appalachian logging roads. The results are presented in this section in the form of a guided decision-making scheme. It should be noted that the guidelines (and the research findings from which they were developed) are based on dips and culverts that were constructed to USFS standards. The guidelines are not directly applicable to drainage devices that were not constructed to these standards.

The approach taken was to identify those forest road situations in which broad-based dips were not an appropriate drainage device. By a process of elimination, a drainage location that did not possess any of these characteristics would be a likely candidate for the installation of a broad-based dip. A list was developed of conditions that had been identified in the drainage device performance study as being strongly associated with poor dip performance. The traffic volume criteria from the economic analysis and certain other conditions that had been identified from practitioner input were added to this initial list. This list of conditions formed the decision-making framework for the dip versus culvert decision. A review of the list indicated that a flowchart might be the most appropriate format for presenting the guidelines on dip and culvert usage. The decision-making flowchart is shown in Figure 6.

The user begins the decision-making process by identifying the drainage location of interest on a logging road and noting its characteristics. Characteristics for which information is needed include:

- Road surface type,
- Volume and type of vehicular traffic,
- Hauling schedule,
- Stream characteristics,
- Water table characteristics, and
- Roadway design elements, such as curvature, grade, and cut-fill characteristics.

By considering one drainage location at a time and answering "yes" or "no" to questions about the characteristics just noted, the analyst follows the flowchart until one of two possible outcomes is reached: (a) a culvert is recommended for the particular location or (b) use of a broad-based dip appears feasible. In the latter case, a soil scientist or geotechnical engineer should be consulted for advice on the suitability of the soil for dips. Although it was initially intended to develop specific soil and geologic criteria for dip installation, this proved to be impossible for several reasons. Although a variety of soil and geologic combinations had been examined in the field study, insufficient data existed about any single combination to permit firm conclusions to be drawn. The results were similarly limited because they were based on a relatively cursory field observation of soil characteristics instead of on a more thorough or quantitative analysis of soil properties. Finally, the type of soil data the typical user would have available was not known.

The traffic volume criteria that appear in the guidelines were based on results of the economic analysis (*5*). It is recommended that culverts should strictly be used on any road that carries an excess of 15 vpd no matter if it is subjected to this traffic level for 2 or 20 years, because of the high user cost associated with dips. Dips are appropriate on roads with traffic volumes less than 5 vpd, assuming that their use is not precluded by a design, soil, or hydrologic factor. For traffic volumes between 5 and 15 vpd, the decision to use a dip or culvert should be influenced by how much the road is used by log-hauling vehicles. If the road is used each year for the life of the road (assumed to be 20 yrs), the high road user costs associated with broad-based dips make culverts the preferred drainage device. In cases in which the road is to be used for timber harvesting only during the first few years of its life and then closed for a period of time, broad-based dips are the more economical drainage structure.

Once the decision of whether to use a dip or a culvert has been made, the user should repeat the process by identifying the next

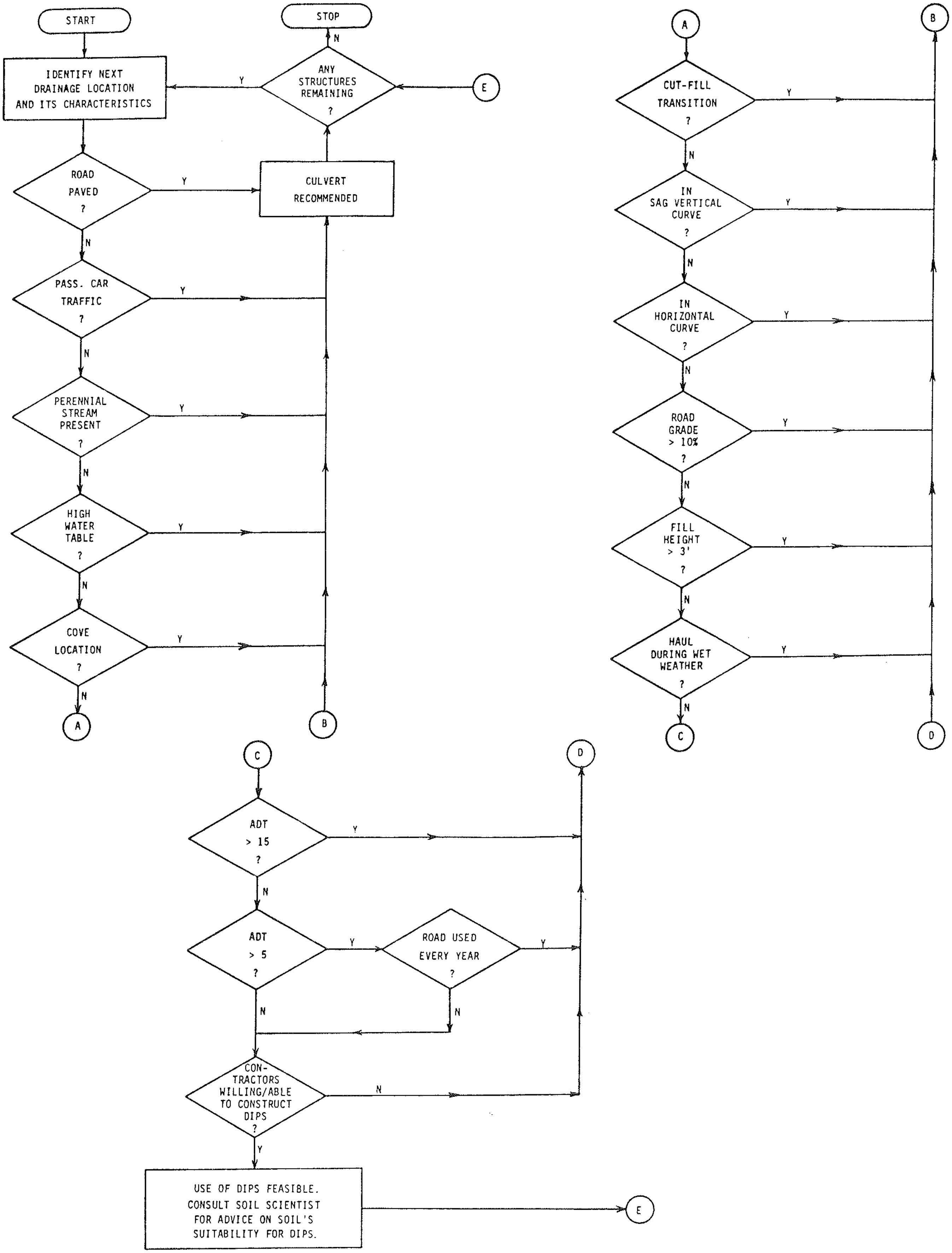

FIGURE 6 Decision-making flowchart for the selection of either broad-based dip or 18-in aluminum culvert for use on forest roads in the central Appalachian region.

drainage location on the road and proceeding through the list of questions again. This procedure should continue until all drainage locations are evaluated. It should be noted that the decision-making framework presented here is based on the assumption that the optimal design of the road will include a mix of dips and culverts. There may be certain situations in which a road may be built in which dips or culverts are used exclusively for legitimate reasons. For example, if local contractors have neither the ability nor the desire to build broad-based dips, all drainage devices on the road would be culverts.

It must be emphasized that the flowchart described earlier is only a guide or aid in the selection of the type of drainage to use on forest roads. The user's experience and familiarity with haul road design and drainage, and with the region in which the road is located, will play a major role in determining how effectively the flowchart meets its intended objectives. It must also be kept in mind that the development of the flowchart was mostly based on data from the central Appalachian region. Users in other regions of the country may find certain items on the flowchart inappropriate or may feel a need to include an additional decision-making capability. Such modifications can be handled relatively easily and would increase the flexibility of the flowchart as a decision-making tool. For example, the flowchart presented here applies to 18-in, corrugated aluminum pipe culverts. If steel culverts are being considered, it might be appropriate to check the pH of the soil. An acidic soil could significantly shorten the life of a steel culvert.

CONCLUSIONS AND RECOMMENDATIONS

Neither dips nor culverts are a panacea for drainage problems on logging roads; each device has its unique strengths and limitations. However, certain situations exist in which one device may be more appropriate and cost-effective than the other. These conditions have been documented, and a decision-making framework was developed to assist engineers or foresters in selecting the appropriate drainage device for a particular application.

The performance of the culverts in this study was substantially better than that of broad-based dips. Many of the dip failures could be traced to one or more underlying factors that, in retrospect, made the installation of a culvert the more appropriate solution for that location. Culverts, however, generally failed as a result of the pipe or inlet clogging. This demonstrates the importance of a regular culvert inspection and maintenance program to identify and correct problems before they reach destructive levels. Other, more specific conclusions that were drawn from the drainage structure field performance study are as follows:

- Drainage device spacing guidelines that were found in the literature are appropriate for the central Appalachian region. Wider spacing of dips and culverts to reduce costs is not recommended because failure rates increase dramatically.
- Dips armored with gravel perform better than unsurfaced dips.
- Dips should not be installed at horizontal curves.
- Dips should not be installed on fills more than 3 ft high.
- Culverts are preferable to broad-based dips in sag locations.
- The performance of 18-in, corrugated metal pipe culverts is relatively independent of soil characteristics. Dip performance, however, is closely related to the soil's erodibility and other characteristics. The advice of a soil scientist should be sought before a broad-based dip is recommended for a particular location.
- Dip performance is independent of ground slope. Culverts, however, are prone to clogging when ground slopes exceed 45 percent.
- Culverts located on road grades of less than or equal to 7 percent should perform effectively if they are constructed and maintained in accordance with recommended USFS guidelines.

The results of this study unexpectedly indicated that culvert and dip performance was not affected by traffic volume. An important factor for which data were unavailable was the condition of a dip when it received traffic. A dry dip can withstand many more load applications than a wet dip. It would be desirable to extend the results of this study by examining the relationship between traffic volume, dip condition (wet or dry), and structural performance.

Although the results of this study were based on very general soil data, they demonstrated the important role that soil and geologic factors play in the prediction of drainage structure performance. An additional, in-depth study by a soil scientist or geotechnical engineer of specific soil and rock types and their relation to drainage structure performance is warranted.

Broad-based dips armored with gravel generally perform better than unsurfaced dips. The data were insufficient to evaluate which type of gravel surfacing performed better because only a few dips were armored with 3-in quarry stone; the rest were surfaced with crusher-run stone. Based on information acquired during practitioner input, there appeared to be some disagreement between road designers as to whether 3/4-in crusher-run stone or 3-in quarry stone was a more appropriate surfacing for logging roads in the Appalachian region. Given the current high cost of road surfacing materials, additional research into this issue could be fruitful.

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