Economic Analysis of Broad-Based Dips Versus Aluminum Pipe Culverts on Low-Volume Roads

RONALD W. ECK and PERRY J. MORGAN

ABSTRACT

There is currently some controversy regarding the relative benefits and costs of culverts and broad-based dips as drainage devices on low-volume roads where no intermittent or permanent streams exist. A research project was undertaken in the Monongahela National Forest to attempt to determine, by using an economic analysis, under what conditions broad-based dips were more appropriate than 18-in. aluminum pipe culverts. Construction cost data for each of the drainage devices were acquired from Forest Service records and a survey of contractors. Eighty percent of the contractors preferred culverts to dips. The type of drainage structure specified in project plans affected contractors' bids. Typical culvert costs were around $500 per structure, whereas dips averaged around $350 per device. Maintenance costs had to be estimated on the basis of discussions with private foresters, because no actual maintenance cost data were available. Annual maintenance cost per culvert was estimated at $8.33 whereas that per dip was $10. To gain insight relative to road user attitudes toward broad-based dips, a truck driver questionnaire was utilized. Almost 90 percent of the respondents reported feeling physical discomfort when passing through a dip; one-half of the drivers suggested eliminating the use of dips entirely. It was found that the additional travel time through a dip can be neglected; excess vehicle operating costs were estimated at $0.077 per vehicle per dip. Broad-based dips were less expensive than pipe culverts for roads carrying traffic volumes in the range of 5 to 10 vehicles per day. At higher volumes, the increased road user costs associated with dips made culverts the more economical alternative.

In order to meet the continuing demand for timber and mineral resources, there has been an increase in the number of logging and mining roads being constructed. As a result of budget constraints, the financial resources available to build these low-standard roads (which may serve only 0 to 50 vehicles per day) are severely limited. Although it is in the best interests of the operators to construct roads that are cost-effective, these roads must also protect the natural environment. The problem is not limited to logging and mining roads, however; similar goals apply to the low-volume roads being built to stimulate economic and social benefits in developing nations.

One of the primary concerns in locating and designing low-volume roads is drainage. There must always be adequate drainage if a road is to remain usable. Roadway drainage begins with the removal of surface runoff from the roadway itself. In addition, drainage design must consider (a) the removal of excess water from under the roadway; (b) provision of roadside ditches of proper size, shape, and slope; (c) the prevention of side-slope and ditch erosion; and (d) the passage of water flowing in all natural and man-made drainage channels. These considerations imply the need for a variety of drainage structures or devices.

Several types of drainage devices are used for controlling water flow on low-volume roads; probably the most common type is the culvert. Culverts, as shown in Figure 1, are closed conduits that carry surface water across or from the road right-of-way. A second device is the broad-based dip, a depressed outsloped section of roadway that acts as a water catchment and drainage channel. Dips can be used instead of culverts for cross drainage where no intermittent or permanent streams are present. Figure 2 shows the plan and profile of a typical broad-based dip.

Currently, there is some controversy among foresters and engineers regarding the relative benefits and costs of each of these devices. One school of thought suggests that metal culverts are superior for most drainage needs. The initial cost of culverts is high compared with simple drainage devices but they have relatively long lifetimes, require relatively little maintenance, and are essentially unnoticed by road users.

Others promote broad-based dips because of their several advantages. Dips have a relatively low initial cost and, unlike culverts, they can be used without the expense of a ditch line. When high flows exceed the design capacity of a culvert, there is the potential for increased ditch scour, extensive erosion of the road surface, and mass failure of roadway fills. In such cases, dips located just downgrade of the culvert can serve as a safety overflow device. Properly constructed dips have low maintenance costs and, like culverts, do not increase wear on vehicles or reduce hauling speeds. However, a disadvantage of broad-based dips is that equipment operators need special training in order to be able to construct them properly. Thus, dips are often not built according to the intended specifications.

R.W. Eck, Department of Civil Engineering, West Virginia University, Morgantown 26506. P.J. Morgan, City of Huntington, Huntington, W.Va. 25717.

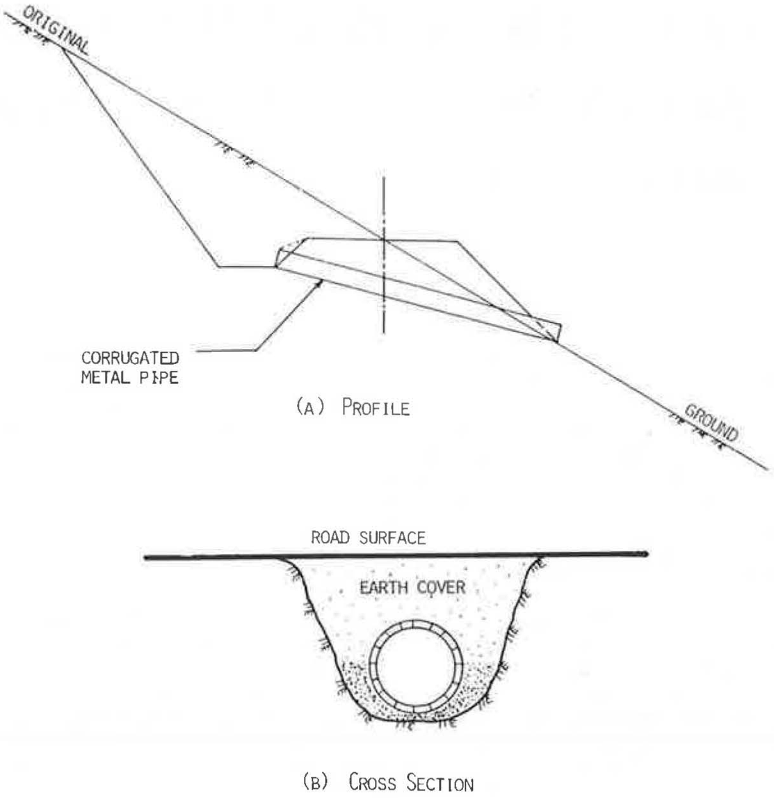


FIGURE 1 Profile and cross-section views of typical ditch relief culvert used on forest roads.

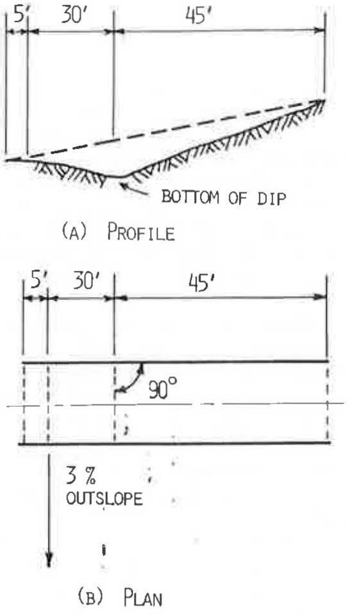


FIGURE 2 Plan and profile of broad-based dip currently used by national forests in North Carolina.

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. Although dips and culverts each have their place as a drainage device on low-standard roads, there are certain conditions under which one is more appropriate than the other. Apparently, however, no formal engineering economic analysis has ever been made of this issue.

COSTS ASSOCIATED WITH DRAINAGE STRUCTURES

There are three major cost categories pertinent to the evaluation of the two types of roadway drainage structures under discussion here: construction, maintenance, and road user costs. In this section a summary of published qualitative and quantitative data relative to broad-based dips is presented. Data on culverts will not be presented here because their design criteria are relatively well established and their costs can be determined by using standard construction estimating procedures.

Construction Costs

Although engineers and foresters appear to agree that the initial cost of dips is less than the cost of metal culverts, there is limited documentation in the published literature comparing the costs of the two devices. Koger (1) reported on a study in which the construction of three dips was observed. He found that a dip could be constructed by an operator using a 105-hp tractor in approximately 3 min. Total construction cost was estimated at $1.17, which does not include the time required to move the bulldozer to the next broad-based dip or any materials, such as gravel surfacing. The results of this study are open to question for several reasons. The sample size of three is too small to determine a reliable average cost. The reported construction time of 3 min also appears unrealistic, because the construction of a dip involves creating a structure that is relatively detailed.

Kochenderfer and Wendel (2) presented perhaps the most detailed information available up to that point on the construction and operation of broad-based dips. On the study roadway, 6 hr was required to construct 19 broad-based dips; installation of two culverts required 5 hr. The total cost of a graveled dip averaged $128.

Maintenance Costs

Both dips and culverts require periodic maintenance to ensure that the devices remain in working order. Because culverts are the traditional drainage structures on many roads, maintenance crews are generally familiar with the procedures for maintaining ditches and culverts. The training and experience of equipment operators must be considered in the maintenance of dips. Hewlett et al. (3) noted that properly constructed dips should require little maintenance except under heavy traffic or off-season use. It was reported that some dips held up under weekly automobile trips for 15 years without reshaping or maintenance. However, traffic must be limited during unfavorable weather to reduce soil erosion and maintenance costs.

In the U.S. Forest Service Transportation Engineering Handbook (4), it is noted that dips are intended for low-volume, low-speed roads where there may be extended periods of nonuse. When properly constructed, dips provide a relatively maintenance-free structure. Although the initial cost of a dip may be cheaper than purchasing and installing a culvert pipe, unless the dip is properly designed and constructed, the total cost (including maintenance) may be more than if a pipe culvert had been installed. Several disadvantages of dips were noted, including low travel speeds, poor riding comfort, difficult blading of the traveled way, and possible adverse effects on water quality.

Maintenance costs are obviously an important factor in decision making. To date, however, no published maintenance costs comparing culverts with broad-based dips have appeared in the literature.

Road User Costs

The volume and types of vehicles traversing a road can influence the drainage device selected. Culverts should be used exclusively on roads open to automobile traffic. This is because vehicles with low ground clearance may have trouble negotiating broad-based dips. Because of the ground clearance problem, dips of the design being discussed here should not be used on paved roads.

Culverts could be said to be invisible to the road user in that they can go unnoticed by vehicle operators. However, the associated ditch and headwall can pose hazards to vehicles that stray from the roadway. In contrast, dips have a definite impact on the road user. Most vehicles will have to slow down to negotiate the rather abrupt change in grade. Cook and Hewlett (5) noted that an improperly designed short dip will cause a jolting of the driver and the vehicle regardless of the reduction in speed. Furthermore, the vehicle will undergo some twisting action, which, in extreme cases, could cause damage to the vehicle, the load, or both. The cost of vehicle damage and wear, time loss, and additional fuel consumption attributable to dips must be considered in comparing the two drainage devices. In an attempt to obtain specific data on this issue, Hafterson (6) sought a dip design that would be hydraulically efficient as well as comfortable to drivers. Relationships were developed between vehicle speed and vertical acceleration with a view toward driver comfort. The dip was correlated to vertical curvature and limits for the maximum sharpness of curvature were determined by using vehicle underclearance as a criterion.

As is apparent from the preceding discussion, the information found in the literature was of a general and sometimes subjective nature. Little, if any, quantitative benefit/cost data or economic analyses were available to permit an objective comparison to be made between dips and culverts. This points to the need for additional research concerning the economics of broad-based dips. It must be emphasized that for valid comparisons to be made between culverts and dips, it is necessary to examine maintenance and road user costs in addition to construction costs.

STUDY OBJECTIVES

A research project was undertaken in the Monongahela National Forest (West Virginia) to determine, by using an engineering economic analysis, under what conditions conventional metal culverts are more appropriate than broad-based dips on low-volume roads. To address this overall goal, several specific objectives were established:

- To conduct a literature review to acquire qualitative and quantitative information relative to the use and performance of broad-based dips and conventional metal culverts on low-volume roads (a brief synopsis of this review was presented in the preceding section);
- To conduct an economic analysis of 18-in. aluminum culverts (the typical device used in the study area) and broad-based dips, considering construction, maintenance, and road user costs; and
- To recommend, on the basis of the foregoing, specific conditions under which culverts, broad-based dips, or both should be installed.

DATA COLLECTION

The primary component of the data collection effort was input from practitioners. The objective here was to contact persons with experience or knowledge in design, construction, maintenance, operations, or all of these aspects of logging roads to acquire information about broad-based dips and 18-in. aluminum pipe culverts. Persons providing input for this part of the study can be categorized as Forest Service personnel, private foresters, logging-road contractors, and log haulers. Persons contacted included those both within and outside West Virginia but the study was generally confined to the Appalachian Region of the eastern United States.

Contact with Forest Service personnel was through telephone conversations, personal interviews, and field trips. These interviews supplied valuable insight about technical details and cost information; field trips provided an opportunity to observe at first hand the performance of dips and culverts.

Based on conversations with Forest Service personnel, two lists of persons or firms were developed: those involved with road construction and maintenance, for example, private foresters and contractors, and those involved in log-hauling operations. It was decided to telephone those on the first list to request information about drainage, construction, and maintenance procedures and costs. In order to ensure that the same type of information was received from each conversation, a questionnaire was designed to be administered during the telephone conversations. Questions asked pertained to the labor, materials, and equipment required to build and maintain dips and culverts. Relatively detailed cost information for each of these three items was also sought from contractors. From the telephone survey, bid prices for the construction of both broad-based dips and 18-in. aluminum culverts were obtained.

Because the data were confidential, respondents were encouraged to give estimations for construction and maintenance costs; however, several contractors were willing to provide actual bid prices.

As noted earlier, although the literature mentions a number of road user consequences of broad-based dips, there was little, if any, hard data available, especially in the area of drivers' perceptions of broad-based dips. However, because broad-based dips must be traversed by log-hauling vehicles, the investigators believed that any criteria for determining need and location should also include input from vehicle drivers. A one-page questionnaire, which could be administered by telephone or in person, was developed to obtain information on truck drivers' experiences with and perceptions of broad-based dips. Specifically, the survey form sought information on the type of driving done by the vehicle operator and on the impacts of dips on road users (e.g., vehicle damage and time loss). More details about the truck driver questionnaire are contained in the full research report (7).

One of the findings of the literature review was the implication that broad-based dips result in an extra cost to road users. Lost time, increased fuel consumption, and wear and tear on the vehicle can occur when a vehicle reduces speed to traverse a dip. In an attempt to determine whether broad-based dips result in a loss of time or other resources to the log hauler, a pilot study was formulated to analyze travel times of logging trucks over both dipped and undipped sections of a logging road in the Monongahela National Forest (West Virginia).

The approach selected for the study was to determine how long it took to travel a measured distance. Two adjacent 100-ft sections of an active logging road of 4 percent grade with similar surfacing and other characteristics, one containing a broad-based dip and the other not, were marked in the field. One stopwatch was used to record travel time over the dipped section and another for the undipped section.

For the vehicles checked during a 1-day period, the time loss due to the dip was negligible (on the order of 1 sec per dip). Given that a logging truck typically makes only two or three round trips per day over the haul road (in the Appalachian Region), an extremely large number of dips would be required to have any significant effect on truck travel time. Because any time loss that results from a broad-based dip would be too insignificant to justify the expense of a large-scale study of the type described here, it was decided not to pursue a full-scale travel-time study as originally planned. Note that the study just described did not attempt to evaluate the increased fuel consumption and wear and tear on the vehicle brought about by the existence of the dip; for this evaluation, the published literature was consulted.

RESULTS

Construction Costs

Thirteen contractors from the central Appalachian Region responded to the survey on drainage device construction and maintenance procedures and costs. Eleven firms provided actual cost figures; two others furnished only qualitative information. Although cooperation from the contractors was generally excellent, there were a few firms that could not be reached by telephone and several others that elected not to participate in the study. However, it is believed that the firms providing data formed a representative sample of logging-road contractors.

In response to the question of whether the firm had a preference for dips or culverts, 80 percent of the contractors said that they preferred culverts. Those favoring dips cited economics as the primary reason. One specifically remarked that there was no ditch line to worry about. In contrast, a wide variety of reasons was given by those preferring culverts. Most frequently cited was the opinion that dips require more maintenance than culverts. Several others mentioned hidden costs incurred by trucks hauling construction material as they traverse the dips (additional wear and tear on the truck) and those associated with maintaining dips during the construction period. Three firms mentioned that although dips look simple, there are so many variables involved that it is difficult for equipment operators to install them properly.

This same theme was found in responses to the question about whether the type of drainage structure specified in project plans has an effect on the contractor's bid. Eight firms noted that their bids were affected when dips were specified. Although two contractors stated that dips would be less expensive than culverts, the majority of firms indicated that they would increase their bid where dips were specified. The main reason given was that dips were harder to bid on because they involve more guesswork than pipe culverts. The difficulty of constructing dips was mentioned several times. One contractor noted that although he currently did not like to install dips, once he had learned how to install them properly, he would probably prefer them to culverts. These results suggest that contractors' attitudes toward broad-based dips might improve if they could acquire hands-on experience or training in proper field construction of them.

Although contractors were in general agreement about the types of equipment used to construct dips and culverts, there were different practices in terms of the labor requirements. In general, construction of a culvert requires a backhoe, a tamper, and hand tools. Construction of a dip typically requires only a small bulldozer or grader. All but one contractor reported that three persons (a foreman, a laborer, and an equipment operator) were required to construct a culvert. Labor requirements for broad-based dips ranged from one to five persons, with the typical value being two (a foreman and an equipment operator). This wide variation in personnel requirements may be due to the just-mentioned practice by some contractors of intentionally bidding high on broad-based dips. That a foreman, an equipment operator, and three laborers would be required to build a dip appears somewhat extravagant when the literature reports the construction of many successful dips by a single bulldozer operator.

The reported time required to construct each drainage device was surprisingly similar. Construction time for culverts ranged from 2 to 5 hr with a mean of 3.2 hr. Dip construction time ranged from 1 to 7.5 hr with a mean of 3.2 hr. In both cases, the median construction time was 3 hr. Once again, it is believed that the time to construct a dip has been intentionally inflated in certain cases.

Contractors were asked to furnish estimated cost figures for constructing dips and culverts. The cost data are summarized as follows [the culvert used is an 18-in. aluminum corrugated metal pipe (CMP)]:

Cost Category	Cost ($) Culvert	Cost ($) Broad-Based Dip
Mean	546	373
Median	530	300
Range	230-805	68-1,000
Standard deviation	153	227

It is apparent that the average reported cost of a broad-based dip is significantly less than that of a pipe culvert. Also apparent is the wide variability in cost of broad-based dips. Reasons for this variation have been discussed previously.

To validate the cost data compiled from the contractor survey and to supplement the survey's admittedly small sample size, additional sources of cost data were sought. A principal source was data compiled for the researchers by Monongahela National Forest engineers for a sample of 16 road projects in the forest. However, these data were limited to culverts (average length, 25.3 ft) and did not include broad-based dips. The cost per pipe culvert varied from $391.50 to $765 with a mean cost of $527.10 per culvert ($23.0 per linear foot of culvert). Note that this is virtually identical to the median culvert cost ($530) determined from the contractor survey.

A third source of drainage structure cost data was a bid tabulation for the Falls Road project, also provided by Monongahela National Forest engineers. Falls Road was (through summer 1984) the only project in the Monongahela National Forest for which dip construction was identified as a bid item. It should be noted that the item to be bid was for excavation only; stone surfacing was not included. The bid tabulation also included cost data for 18-in. CMP culverts. A summary of the dip and culvert construction cost information derived from the Falls Road bid tabulation is as follows:

Cost Category	Cost ($) Culvert	Cost ($) Broad-Based Dip
Engineer's estimate	547	70
Mean	632	500
Range	426-760	200-1,000
Standard deviation	161	356

Note that the average costs of both culverts and dips are significantly higher than those determined from the contractor survey data. As before, the dips demonstrate a greater variability in cost.

For the economic analysis, it was necessary to have a single typical cost for dips and culverts. On the basis of the preceding discussion, it was decided to use the following drainage device construction costs in the economic analysis: 18-in. CMP culvert, $530; broad-based dip, $350.

Maintenance Costs

Data on drainage device maintenance costs were not readily available. None of the contractors responding to the telephone survey indicated that they had experience with maintenance of drainage structures. Maintenance cost data could not be obtained from Monongahela National Forest engineers because records were not kept of the type of data requested by the researchers. The only maintenance cost data that could be obtained were those acquired through telephone conversations with private foresters or those estimated by the researchers on the basis of the literature review. The costs that were obtained or estimated were on a per-mile rather than a per-structure basis.

According to estimates provided by private foresters, approximately $100 per mile per year would be required to maintain ditches and culverts. This cost includes maintaining the ditch line as well as checking and cleaning the heads of culverts. The cost was based on an average of 12 culverts per mile; thus the average annual maintenance cost per culvert was $8.33.

Because no maintenance cost data could be found for broad-based dips, the costs were estimated by the researchers. According to private foresters, a bulldozer or motor grader should be able to dig 4 to 5 mi of ditch line per day (average of 4.5 mi per day). Under the assumption that two to three passes of the grader or bulldozer might have to be made to maintain the dip, it appears reasonable to expect that 1.5 mi of dipped road could be maintained per day. Assuming a dip spacing of 200 ft, this would mean that 40 dips could be maintained daily or 5 dips per hour during an 8-hr work day. In Monongahela National Forest in summer 1984, costs for a bulldozer and operator were approximately $50 per hour. Because such maintenance should be done once a year, the annual dip maintenance cost was estimated at $10 per dip.

Truck Driver Survey

The last of the three cost elements to be considered in the economic analysis was the road user costs. Before the road user cost estimates are actually presented, however, a brief review of the results of the truck driver questionnaire will be given to provide a driver's perspective of the impacts of broad-based dips.

All respondents drove single-unit, or straight, trucks; no tractor-semitrailer operators responded. Although the predominant truck in Appalachian forests is the single-unit variety, there are at least a few tractor-semitrailers in operation. Just over three-fourths of the respondents (78 percent) drove tandem rigs (two rear axles), whereas 22 percent drove triaxle trucks (three rear axles). The average wheelbase for the tandems was 213 in. compared with 268 in. for the triaxles.

A high percentage of respondents (89 percent) made either two or three round trips (between loading point and mill) per day. On logging roads having no broad-based dips, drivers estimated that they traveled at an average speed of 13.8 mph. It is interesting to note that the average reported speed for roads with dips was exactly one-half this value, or 6.9 mph. All respondents said that dips caused them to be delayed in traveling over logging roads.

Almost 90 percent of the respondents reported feeling physical discomfort when passing through a broad-based dip. Reasons given ranged from "throws driver around cab" to "bouncing, jarring and twisting of truck causes driver to feel off-balance." Slightly more than one-third of the drivers indicated that a dip had caused damage to a truck or load. A cracked or broken frame was the most frequent complaint. One driver reported that trucks get "hung up" in deep and narrow dips.

Three-fourths of the respondents thought that some dips scare drivers because they look like they might damage the truck or the load. A variety of suggestions was given on how to build dips that would be less intimidating to drivers. Half of the drivers suggested eliminating the use of dips entirely.

It was clear from the survey results that truck drivers in general have a negative attitude toward broad-based dips. One limitation that must be kept in mind when evaluating the results is that it was not known whether the dips with which respondents were familiar met appropriate standards. One timber purchaser contacted by telephone noted that properly constructed dips created no problems for trucks or drivers. However, the firm had sometimes experienced vehicle damage and other problems because of improperly constructed dips. It is the researchers' belief that more than a few dips are improperly constructed. These dips, because of the problems they create, might tend to be remembered by drivers and cause them to dislike all dips even though the majority of drainage structures can be traversed with no problems. It is interesting to note that the possibility of trucks overturning in dips located on horizontal curves, which had been cited by some engineers as a possible problem, was not even mentioned by survey respondents.

The data collection section presented results from a pilot study conducted to assess the effects of dips on vehicle travel time. It was found that, for dips built according to standards, the vehicle delay attributable to a dip is on the order of a few seconds. On this basis, a vehicle would have to traverse 10 or more dips to decrease its travel time by 1 min. Although drivers have reason to believe that they are being delayed at each dip, the overall impact is minimal. The investigators believe that the travel-time effects of dips are not an issue, because the travel time saved on an undipped road is not sufficient (unless the truck makes a large number of round trips per day) to cause an increase in the number of round trips that can be made per day.

Road User Costs

The road user consequences, either beneficial or adverse, of drainage structures on forest roads occur primarily through the operating cost of motor vehicles, the change in highway accidents, and the change in travel time. Because of the low traffic volume on forest roads, motor vehicle accidents are rare events, and in most cases accident data are not generally available. Therefore, accident costs have not been included as a road user consequence in this study. No evidence could be found either in the literature or during the data collection task to indicate that the accident experience with broad-based dips was any different from that with culverts.

Culverts can be said to be invisible to road users in that vehicles can traverse them at the design speed of the roadway and neither vehicles nor drivers are subjected to any extraordinary forces or sensations. An exception to this statement would be the situation in which the roadway is constricted by severe erosion of the culvert inlet or outlet, thus causing the vehicle to reduce speed while traversing the culvert. However, this is a correctable situation, so it is not appropriate to include such excess travel-time costs in the economic analysis.

Dips, on the other hand, because of their shape, require that all vehicles reduce speed while traversing the drainage device. It was shown earlier that the extra time involved to negotiate a broad-based dip was negligible. Because this conclusion was based on limited field data, it was decided to confirm these results by using data from Winfrey's (8) comprehensive text on highway economics. Winfrey (8) presents tables showing the excess hours consumed (excess above continuing at initial speed) per speed-change cycle, in which speed-change cycle consists of the reduction in speed and the return to the initial speed. Although separate tables were not developed for the three-axle single-unit truck typically found in log-hauling operations, Winfrey noted that for highway economic analysis purposes, the three-axle single-unit truck could be put in the same class as the 40-kip tractor-semitrailer. To provide a conservative estimate of excess time, an initial speed of 15 mph and a reduced speed of 5 mph were assumed based on the 13.8 mph and 6.9 mph speeds reported in the truck driver survey. Under these conditions, there would be 0.00134 hr consumed per cycle, or 0.08 excess min per dip. On a per-dip basis, this is a negligible quantity. However, it was believed worthwhile to examine the effect of a large number of dips. Assumptions were made that (a) the typical log-haul road contains 17 dips (this was the average value for 19 sites examined in a related study) and (b) the typical logging truck makes five passes (2.5 round trips) per day over these dips. The time lost by drivers under these conditions is

(17 dips/trip) x (5 trips/day) x (0.08 min/dip) =
6.8 min/day.

Because the driver cannot put this small increment of time to any productive use in terms of increasing the number of round trips made per day, it was concluded that under typical conditions in Appalachian forests, the additional travel time through a broad-based dip can be neglected for purposes of economic analysis.

Although broad-based dips do not produce a significant increase in travel time, there is an increase in fuel consumption and wear and tear on vehicles brought about by the presence of a dip. Because project resources did not permit the monitoring and collection of actual logging truck operating costs, vehicle running cost data available in the literature had to be used to estimate the road user impact of dips. Relatively little is known about the factors that affect log-hauling costs. Cost data available presented general information based on hauls between landings and the mill. Such data were not detailed enough to permit computation of the additional cost generated by traversing a broad-based dip. Fortunately, Winfrey (8) included data that could be adapted to the situation. He presented a table containing the excess cost in dollars of speed-change cycles (excess cost above continuing at initial speed) for a 40-kip tractor-semitrailer operating on a high-type pavement in good condition. If an initial speed of 15 mph and a reduced speed of 5 mph are assumed, the table yields an excess cost of $19.42 per 1,000 speed-change cycles. The cost includes fuel, tires, engine oil, maintenance, and depreciation. However, the cost was based on an 18-cent/gal price of gasoline and other unit prices typical of the mid- to late 1960s. Recalculation of this figure using current costs was complicated because Winfrey (8) did not provide a detailed breakdown of the cost components for the speed-change situation. Thus, current costs had to be estimated in the following manner.

An updated (1977) version of Winfrey's data was found in the literature (9). The 1977 cost per 1,000 speed-change cycles for trucks with an initial speed of 15 mph and a reduced speed of 5 mph was $45. Based on U.S. Department of Labor consumer price index information, the 1977 cost figures were converted to current (spring 1984) dollars by multiplying them by 1.7. This yielded an excess cost of approximately $77 per 1,000 speed-change cycles, or $0.077 per dip. If the typical conditions used earlier (17 dips traversed, five passes per day) are assumed, the excess cost per vehicle may be determined:

(17 dips/trip) x (5 trips/day) x ($0.077/dip) =
$6.54/day.

This value probably represents an underestimate of the actual excess costs incurred because it does not account for the additional vehicle wear and tear created by the twisting motion induced by the broad-based dip.

It must be emphasized that the road user costs for broad-based dips just described represent costs over and above those incurred on a road without dips. In this analysis, the actual road user costs for a section of forest road will not be calculated. The road user costs presented here represent the extra cost attributable to broad-based dips.

Overall Evaluation

The total cost associated with a drainage device represents the sum of construction, maintenance, and road user costs. For the purposes of this analysis, the equivalent-annual-cost approach was used to compare culverts with broad-based dips. Assuming, as noted earlier, that only the additional road user costs incurred by dips are of interest, the equivalent annual cost (EAC) of a CMP culvert would be

$$\text{EAC} = \text{construction cost} \times (\text{crf-i-n}) + \text{annual maintenance cost} \tag{1}$$

The cost for a broad-based dip would be

$$\text{EAC} = \text{construction cost} \times (\text{crf-i-n}) + \text{annual maintenance cost} + \text{additional annual road user cost} \tag{2}$$

where

crf = capital recovery factor applied to convert the initial cost (a present value) to an annual cost,
i = discount rate, and
n = expected life of drainage structure.

Given the difficulties associated with selecting an appropriate discount rate and given that high rates tend to favor projects with low costs initially but high costs later, whereas low rates tend to favor projects with high costs initially and low costs later, it was decided to perform the economic analysis with three different discount rates: 5, 10, and 15 percent.

Because of the large number of variables affecting drainage device durability, it is difficult to specify a single value for n. However, on the basis of discussions with practitioners, it appeared that 20 years was a reasonable lifetime for aluminum pipe culverts. Because of the lack of any information to the contrary, it was assumed that, with proper maintenance, broad-based dips would also have an expected life of 20 years.

The following costs were derived earlier for use in Equations 1 and 2:

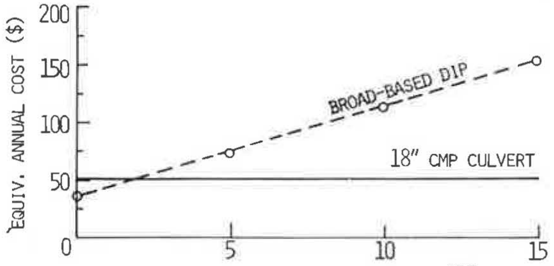
Cost	Culvert ($)	Broad-Based Dip ($)
Construction	530.00	350.00
Annual maintenance	8.33	10.00
Road user	--	0.077/vehicle

It should be noted that road user cost is a function of traffic volume. For the purpose of this study, it was assumed that hauling takes place only during good weather, that is, May 1 through September 30 of each year. This represents a period of 100 working days. It was recognized that depending on the manner in which the timber or mining operation is managed, there could be a variety of different traffic conditions. Two scenarios were considered in the analysis presented here:

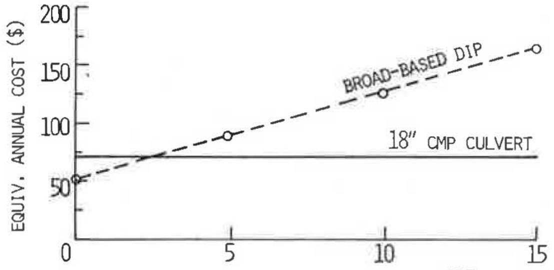
1. Traffic volume remains constant for each year of the 20-year life of the structure, and
2. Traffic uses the road for the first 3 years of its existence to harvest timber, but then no additional traffic, other than perhaps a negligible amount of administrative traffic, uses the road for the next 17 years.

Traffic volumes in five-vehicle-per-day increments from 0 to 15 vehicles per day (the range of traffic volumes experienced by the study sites) were considered in this analysis. Other scenarios could be developed by applying the procedures outlined here. Using appropriate compound interest factors, equivalent annual drainage device costs were calculated for these traffic volume increments for the two scenarios just described.

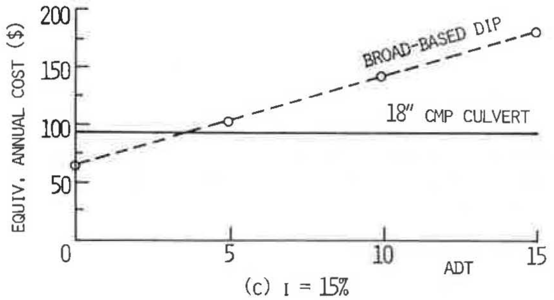
Plots were made of equivalent annual cost versus average daily traffic (ADT) (daily traffic volume during the hauling period as opposed to annual ADT) to determine the traffic volumes at which one device is less expensive than another. Results for the first scenario for discount rates of 5, 10, and 15 percent are shown in Figure 3. Because of the high



(A) I = 5%



(B) I = 10%



(C) I = 15%

FIGURE 3 Relationship between average daily traffic and equivalent annual cost for dip and culvert, Scenario 1, for various interest rates.

road user costs incurred by assuming constant traffic volume over the entire 20-year life of the structure, it can be seen that dips are less expensive than culverts only when traffic volumes are in the range of less than five vehicles per day. This represents a worst-case condition for traffic, because most logging roads with dips would not carry the same volume year after year; there would be gaps of several years or more when no harvesting (and therefore, no hauling) occurred.

The second scenario was believed to represent expected traffic conditions more realistically. Once again, plots were made of equivalent annual cost versus ADT. These results are shown in Figure 4 for discount rates of 5, 10, and 15 percent. The plots indicate that dips are the lower-cost drainage device in an ADT range of about 8 to 12 vehicles per day and less. When traffic volumes exceed approximately 15 vehicles per day, culverts become more economical than broad-based dips because of the user costs incurred with dips.

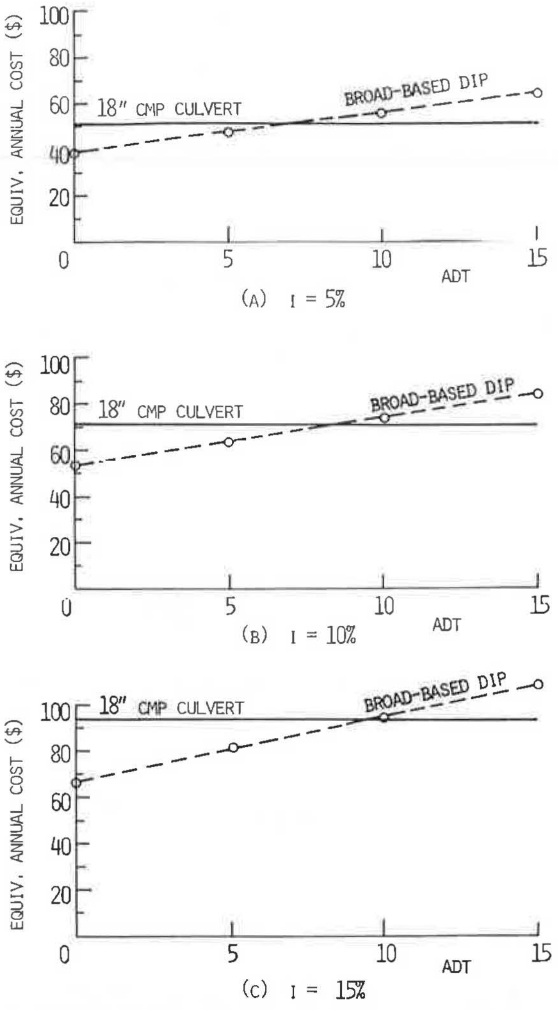


FIGURE 4 Relationship between average daily traffic and equivalent annual cost for dip and culvert, Scenario 2, for various interest rates.

CONCLUSIONS AND RECOMMENDATIONS

The results of the economic analysis confirmed what had been learned from the literature review and practitioner input tasks of the study. That is, broad-based dips are less expensive than pipe culverts for roads carrying traffic volumes in the range of 5 to 10 vehicles per day. At higher volumes, the increased road user costs associated with broad-based dips make culverts the more economical alternative. It is recommended that any road handling in excess of 15 vehicles per day, whether subjected to this traffic level for 2 years or for 20 years, use strictly culverts because of the high user cost associated with dips. Dips are appropriate on roads with traffic volumes less than 5 vehicles per day, assuming that their use is not ruled out by design, soils, or hydrologic factors. For traffic volumes between 5 and 15 vehicles per day, the decision to use a dip or culvert is influenced by the nature of vehicle use of the road. If the road is used each year for the life of the road (assumed to be 20 years), the high road user costs associated with broad-based dips make culverts the preferred drainage device. If the road is to be used only during the first few years of its life and then "put to sleep" for some period of time, broad-based dips are the more economical drainage structure.

It must be emphasized that there are certain conditions under which one drainage device is more appropriate than the other and a decision based solely on an economic analysis could lead to serious problems in terms of greatly increased future maintenance or road user costs. The decision whether to use a culvert or a dip in a particular situation should be based on both economics and physical factors such as design elements, soils and geology, hydrology, and traffic factors. The authors have developed a framework, incorporating economics and other factors, that can be used in deciding whether to use metal pipe culverts or broad-based dips to handle cross drainage on low-volume roads. A paper describing the decision-making framework is in preparation.

This study indicated an important aspect that could influence the use of broad-based dips: the negative attitude toward them on the part of contractors and truck drivers. There was evidence that contractor attitudes would improve if they could gain experience in dip construction. Hands-on workshops in proper field construction of broad-based dips are recommended as one way of providing this experience. Such workshops should also improve the quality of dips constructed by those contractors already having experience.

It was noted in the economic analysis that the additional road user costs incurred by traversing a broad-based dip were underestimated because of the difficulty in estimating vehicle damage associated with the dip. Additional research in this area appears warranted. A truck could be instrumented with strain gauges or other devices to monitor the motion of the truck frame and other components as the truck negotiates a number of different broad-based dips. By correlating this movement with loading condition, material properties, and other factors of this nature, one should be able to specify better the dimensions of a "tolerable" dip.

In the economic analysis, the cost data with the greatest uncertainty were those for dip maintenance. It is recommended that dip maintenance cost data be acquired for a large number of dips. Not only would this provide more accurate cost data so that the economic analysis could be refined, but it would also yield a better understanding of dip maintenance procedures and frequency.

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