AN ABSTRACT OF THE THESIS OF

Bradley T. Piehl for the degree of Master of Science in Forest Engineering presented on July 25, 1986

Title: An Evaluation of Culverts on Small Volume Forest Roads in the Oregon Coast Range

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A total of 515 ditch relief culverts and 140 stream crossing culverts were randomly selected for evaluation, in the central Oregon Coast Range. The purpose of this evaluation was to compare existing design guidelines to these road drainage installations and also rate their capability of functioning effectively during high flow events. The study area consists primarily of steep slopes, sandstone bedrock and has an extensive road network.

The inlets of 74% of all ditch relief culverts (DRCs) were reduced from original; the average inlet cross-sectional area was 80.6% of original. Almost half of all DRCs have inlet reductions associated with sediment and/or denting. Outlet erosion occured at 38% of all DRCs and had an average volume of 2.5 cubic yards. Outlet erosion increased substantially with fill slopes greater than 40% and for spacings which exceeded USFS (R-6) guidelines. Significant

differences in erosion volumes and spacing were related to land ownership.

In order to evaluate the design capacity of stream crossing culverts (SCCs), 25-year peak flows were calculated using the latest regional analysis for the Oregon Coast Range. The ability of SCCs to pass a 25-year peak flow was then evaluated with two different methods. For almost one-quarter of all stream crossing culverts the estimated 25-year peak flows would be expected to overtop the road. About 80% of all SCCs were unable to pass a 25-year peak flow at a headwater to diameter ratio of 0.75. Significant differences in SCC design were related to ownership. The capacity of most Coast Range SCCs seems to have been seriously underdesigned.

An Evaluation of Culverts on Low Volume Forest Roads in the Oregon Coast Range

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed July 25, 1986

Commencement June, 1987

APPROVED:

Professor of Forest Engineering in charge of major

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Date thesis is presented July 25,1986

ACKNOWLEDGEMENT

My graditude is extended to the Water Resources Research Institute at Oregon State University for funding this study.

Appreciation is expressed to Professors Robert Beschta and Marvin Pyles for guidance and counsel throughout this study.

Thanks go to Barry Rochelle for completing the first season of data collection.

TABLE OF CONTENTS

INTRODUCTION	1
REVIEW OF LITERATURE	5
STUDY DESCRIPTION AND METHODS	12
Study Area	12
General Methods	12
RESULTS AND DISCUSSION	14
Ditch Relief Culverts	14
Stream Crossing Culverts	34
SUMMARY AND CONCLUSIONS	46
General Conclusions	46
Ditch Relief Culverts	49
Stream Crossing Culverts	53
REFERENCES	56
APPENDIX A	58
APPENDIX B	73

LIST OF FIGURES

Figure	Page
1. Distribution of slope positions of ditch relief culverts.	15
2. Comparison of particle size fractions for cutbank and ditch soils.	18
3. Factors affecting the reduction in cross-sectional area of ditch relief culvert inlets.	20
4. Factors affecting the reduction in cross-sectional area of ditch relief culvert inlets, by pipe slope.	23
5. Factors affecting the reduction in cross-sectional area of ditch relief culvert interiors, by pipe slope.	24
6. Factors affecting the reduction in cross-sectional area of ditch relief culvert interiors, by pipe diameter.	25
7. Factors affecting the reduction in cross-sectional area of ditch relief culvert outlets.	27
8. Stability rating of fill slopes of ditch relief culverts, by slope position.	30
9. Stability rating of fill slopes of ditch relief culverts, by percent exceeding Arnold's spacing guidelines.	32
10. Outlet erosion volume vs. fill slope angle for ditch relief culverts.	33
11. Distribution of fill slope angles of ditch relief culverts.	35
12. Stability rating of fill slopes at spacings greater than Arnold's guidelines, by fill slope angle.	36
13. Factors affecting the reduction in cross-sectional area of stream crossing culvert inlets.	38

Figure		Page

14. Distribution of drainage areas of stream crossing culverts. 39

15. Drainage area vs. return interval for stream crossing culverts, at a headwater to diameter ratio of 0.75. 45

LIST OF TABLES

Table	Page
1. Return interval (T), in years, associated with risk of exceedence and project life, where $T=1/[1-(1-R/100)^N]$.	10
2. Ownership distribution of ditch relief culverts and stream crossing culverts.	16
3. Outlet erosion and spacing information, by ownership, (values in parenthesis are standard deviations).	29
4. Comparisons of flow conditions at the culvert inlet for a 25-year design storm, by ownership, (values in parenthesis are standard deviations).	42
5. Percent of SCCs unable to pass a 25-year flow event for selected headwater to diameter ratios.	44
6. Selcted characteristics of ditch relief culverts and stream crossing culverts, (values in parenthesis are standard deviations).	47
7. Ownership and spacing information for ditch relief culverts and stream crossing culverts, (values in parenthesis are standard deviations).	48

AN EVALUATION OF CULVERTS ON SMALL VOLUME FOREST ROADS IN THE OREGON COAST RANGE

INTRODUCTION

The Coast Range of Oregon is intensively managed for timber production and thus requires an extensive road network, with new road construction continuing yearly. Where drainage systems are poorly designed forest roads have experienced fill slope failures, excessive road surface erosion (Burroughs, 1984) and increased sediment production (Beschta, 1978; Brown and Krygier, 1971; Walter, 1985). However, a properly-designed road drainage system--culverts in particular--can reduce the risk of these occurrences. The large amount of annual precipitation, steep unstable land and importance of anadromous fish in this area make the design of road drainage systems for forest roads very important to minimizing management impacts.

Culverts provide the most common means for moving water across a road, and therefore, are an essential component in the design and operation of a forest road drainage system. Culvert failures during storm events can lead to road fill erosion and ultimately failure. The direct costs associated with these failures include the loss of use of the road, and the expense of replacing the culvert and it's associated fill. Additional costs can be incurred when a failure impacts a stream channel and causes adverse changes in water quality and aquatic habitat. Evidence of the importance of this problem is the legal action brought against the Mapleton District of the Siuslaw National Forest by the National Wildlife Federation. This legal action resulted in suspension of logging activities.

The culverts used in forest roads can be grouped into two classifications: ditch relief culverts (DRCs) and stream crossing culverts (SCCs). On forested hillslopes water is routed naturally by subsurface flow through the soil to defined channels, becoming surface flow. Forest roads often convert subsurface flow to surface flow by collecting it in a ditch. This water must be diverted across the road, in many cases this is done with a ditch relief culvert.

Problems associated with ditch relief culvert installations include excessive ditch and fill slope erosion. Both types of erosion are usually a function of how closely the DRCs are spaced. If the spacings are too great the ditch may collect large quantities of water which can cause ditch and road prism erosion severe enough to make the road unusable.

The larger quantities of water collected at long spacings present an equally, if not more important problem at the culvert outlet. The concentrated discharge of water usually exceeds the infiltration rate and proceeds as overland flow which can result in gully erosion. In addition, it can increase the depth of saturated soil locally and in doing so increase the possibility of fill slope failure. In some areas, reducing the spacing enough to control fill slope erosion may not be adequate or feasible. In these cases erosion control devices at the outlet are required: rip-rap, to harden the outfall; downspouts or plastic tubes, to divert the discharge downslope; or a combination of these. Spacing culverts close enough to avoid these problems is important, but if they are placed too close together they will add greatly to the expense of road building and maintenance.

Other potential problems with ditch relief culverts are blockage or damage to the pipe which reduces the amount of water, debris and sediment that can pass through it. There are several ways such blockage can occur, but the result is usually a bent or plugged section of pipe, which reduces its functional capabilities. The pipes can be dented or bent during road construction or by road maintenance crews, logging trucks or other traffic. They can be plugged by sediment, organic debris, logging slash or sluffing of the cutbank. These problems can occur anywhere along the length of the pipe but are most common at the inlet.

Stream crossing culverts are used where forest roads cross flowing streams and ephemeral channels. SCCs should be designed to pass a certain peak flow-rate of water (in Oregon, a flow greater than or equal to the 25-year peak discharge), but also should be able to pass debris, and allow for fish passage where it is important. If culverts are grossly oversized they may be unnecessarily expensive. Conversely, culverts that are undersized may have an increased risk of failure. Historically, culverts have been installed on many small forested watersheds without adequate knowledge of what quantities of water and debris to expect.

Problems that are associated with stream crossing culverts are: erosion at the outlet, blockage to fish passage, organic debris and/or sediment accumulation and inadequate sizing which may result in roadfill failure. This study will evaluate the capability of SCCs to pass a design discharge. The capability of a pipe to pass a design discharge will decrease, if there is any reduction in the control section of the pipe. Physical damage or denting may be incurred during installation and road construction or later during use and maintenance of the road. Blocking of the pipe can be associated with sediment or organic debris.

The objectives of this study were: 1) to develop specific rating criteria for each type of culvert, 2) inventory culvert installations using the developed criteria, and 3) compare the culvert installations against selected design guidelines.

REVIEW OF LITERATURE

The literature available for ditch relief culvert design is very limited. Most of the design guidelines have been based on experience or theoretical relationships. For stream crossing culverts, the main design criteria of interest is the flow capacity of the pipe. Most of the literature available is directed at larger, more developed watersheds than the size and type involved in this study. There are no published findings for the Pacific Northwest that would indicate the effectiveness of the existing design guidelines; past and present culvert design; and installation and maintenance practice for either type of culvert.

An evaluation of the damage caused by the December 1964 and January 1965 storms was conducted by the U.S. Forest Service (Dyson, etal., 1966). The report stated that failure of road drainage facilities was the cause of almost all road damage, and "Plugged ditch relief culverts were a major contributor" to road damage. In evaluating damage to the Maple Creek watershed, which is in the culvert study area, Dyson, et al., found that "roadfill embankment failures were one of the main factors of damage." They also concluded that "Debris which plugged drainage channels and structures was the major contributor to fill and culvert losses" and "culvert size was evidently not a primary cause of such facilities becoming inoperative." Therefore, they recommend that all woody debris be removed above the drainage structure.

In 1953, Arnold, working for the U.S. Forest Service on the Willamette National Forest, developed spacing guidelines for ditch relief culverts based on "experience". Excessive spacing of culverts causes larger quantities of water to flow in the ditch, which can result in accelerated ditch erosion. Controlling excessive ditch erosion was the major objective in these guidelines. To use the guidelines the soil must be classified into one of ten erosion classes. The spacing then varies by road grade, which is assumed to approximate the ditch grade, with steeper road grades having shorter spacing distances between pipes. A rainfall intensity factor (expressed in inches per hour), based on the 25-year 15-minute storm is used to adjust the spacing, with a higher rainfall intensity resulting in shorter spacings.

In 1981, Baeder and Christner revised Arnold's spacing guidelines by using additional factors they felt were important in the Willamette National Forest. The additional factors are slope position, aspect and cutbank failure probability. They reasoned that lower slope positions would have larger quantities of water intercepted by the ditch and would therefore require closer spacing. A higher probability of cutbank failure results in closer spacing, and aspect was viewed as important during snowmelt with south facing slopes having closer spacing. These revisions seem very rational. However, because these adjustments result in either the same or closer spacing than Arnold's guidelines, Baeder and Christner seem to be inferring that Arnold's spacings are not adequate. It is important to note that neither Arnold's original spacing guidelines nor the modified guidelines of Baeder and Christner are based on empirical field data.

The main design emphasis for stream crossing culverts is to size the pipe to pass a certain peak flow. Other considerations, such as fish and debris passage, can have an important effect on the design of SCCs. Historically, forest hydrologists have been unable to accurately estimate peak flows for small forested watersheds. However, Campbell, etal. (1982), recently completed a regional analysis of peak flows for small forested watersheds in Western Oregon. In this work a frequency analysis was completed on gaged watersheds and regression equations were developed to be used to predict certain return period flows for ungaged watersheds. Campbell's equations represent the best available method for estimating peak flows for small ungaged forested watersheds in the Oregon Coast Range.

There are numerous texts (e.g., Portland Cement Association, 1964, Oregon State Highway Division, 1973) that describe various aspects of the hydraulics of culverts. The aspect of pipe hydraulics that is important to this study is the relationship between discharge and headwater depth (HW). The headwater depth is the depth of water just upstream of the culvert inlet, which can be expressed as a ratio of headwater depth to pipe diameter (HW/D), where a value of 1.0 indicates that water is ponded to the top of the inlet, or one pipe diameter (D). If more water is ponded above the inlet, the headwater to diameter ratio increases, the hydrostatic pressure at the inlet increases and the pipe will be able to pass more discharge. It is recommended for roadways that HW/D ratios be no greater than approximately 1-1.5 (Highway Task Force, 1967).

Hydraulic control in a culvert is determined by that characteristic of the pipe which limits the amount of flow that can pass through it. This limitation can be described in terms of three types of control: inlet control, pipe roughness control and outlet control. Inlet control exists where the inlet of the pipe is the limiting factor to flow and is probably most common for culverts in small forested watersheds. Pipe control or pipe roughness control exists when the pipe is not placed at a steep enough slope to insure inlet control. In general, a slope of about 2% is adequate to cause inlet control. Outlet control usually exists where the tailwater elevation, which is related to downstream conditions, is high enough to slow movement of water through the inlet of the pipe.

Nomographs have been developed that allow estimation of the headwater depth to diameter ratio for a range of discharges and pipe diameters (Highway Task Force, 1967, Portland Cement Association, 1964). There are separate nomographs for inlet and outlet control, for different types of pipes (i.e., circular vs. pipe arch, steel vs. concrete), and for several inlet configurations.

Stream crossing culverts are commonly designed to pass a design peak flow, usually a specific return interval (in years). The Oregon State Forest Practices Act requires stream crossings to be designed to pass at least a 25-year peak flow. However, the statistical significance of a 25-year event is not well understood by managers in charge of sizing culverts.

For many years it has been customary to use some form of logarithmic relationship between discharge and return interval (i.e., recurrence interval) to describe the frequency of different flood-peak magnitudes. Assuming a log-normal distribution of annual peak flows, the probability (R) that a peak flow with a return interval of T years will be equaled or exceeded in any N consecutive years is $1-(1-1/T)^N$ (Linsley, Kohler and Paulhus, 1982). The 25-year peak flow is a peak discharge that will occur on the average once in 25 years. However, there is a 64% chance that a 25-year peak flow or greater will occur sometime within the next 25 years. Table 1 illustrates this relationship and can be used in managerial decisions for identifying a desired return interval. The manager selects a desired project life and an acceptable risk of failure. Once specified, the return interval that the structure must be designed for is read directly from the table. When low

Table 1. Return interval (T), in years, associated with risk of exceedence and project life, where $T=1/[1-(1-R/100)^N]$.

EXCEEDENCE PROBABILITY (R), %	EXPECTED LIFE OF PROJECT (N), YEARS				
	1	10	25	50	100
1	100	910	2440	5260	9100
10	20	95	238	460	940
25	4	35	87	175	345
50	2	15	37	72	145
75	1.3	8	18	37	72
99	1.01	2.7	6	11	22

risks of failure are identified, the design return interval becomes very high.

The implementation of Forest Practice rules in Oregon have provided general guidelines for the design, installation and maintenance of culverts. Under these guidelines field personnel are given a large amount of flexibility in the design, location, installation, and maintenance of culverts. This flexibility allows field personnel to match culvert designs with variable field conditions. This can have favorable results, but there exists the potential for mismatching a culvert design with a specific site. However, specific spacing guidelines which are strictly followed have similar problems.

STUDY DESCRIPTION AND METHODS

Study Area

The area of the Oregon Coast Range chosen for this study was Federal, State and Private forestland located in Benton, Lincoln, Lane, Coos and Douglas counties. This area is relatively homogeneous in terms of geology, being almost entirely underlain by the Tyee sandstone formation. Landforms are typified by steep (up to 100%), highly-dissected slopes and sharply formed ridgelines. The Western Oregon Coast Range also represents one of the most intensively managed forested areas in Oregon. This level of management requires a high forest road density. The homogeneity of this area reduces the number of geologic and geomorphic variables influencing road drainage and may limit the applicability of the results to areas outside the study site.

General Methods

A stratified, random sample selection procedure was used to obtain representative samples. The study area was stratified by township and three roads were randomly selected from each township. Each road was divided into a number of sections depending on it's length, with a section of the road randomly selected as the starting point. The first six culverts (DRCs and/or SCCs) on that road were sampled. Using this method 515 DRCs and 143 SCCs were sampled during the summers of 1984 and 1985.

A list of criteria with associated rating procedures was developed to assess potential problems with culverts. Stream crossing and ditch relief culverts function differently; therefore, different criteria were developed for each and the data analysis was done separately. The main data analysis was accomplished by dividing each data base into subgroups (e.g. by owners, installations and pipe characteristics) and evaluating any differences or trends in rating criteria between the subgroups, using descriptive statistics and graphical comparisons. The sample size for each subgroup comparison changed as different variables were compared, because missing data determined the sample size for that analysis.

This study does not attempt to evaluate the changing road drainage design practices over time. It would be useful to evaluate how our road drainage design procedures have evolved in response to past experiences. However, regardless of when these structures where designed and installed they represent what is in place now. Therefore, this "snapshot in time" approach is relevant given the current state of knowledge.

RESULTS AND DISCUSSION

Ditch Relief Culverts

The characteristics of ditch relief culverts that conventionally are viewed as important in the evaluation of their effectiveness are; spacing, road grade, culvert slope, amount of denting and/or plugging, skew angle, slope position, erosion volume, energy dissipation structures and size of pipe. These characteristics were evaluated as well as pipe material, corrugation pitch and depth, and some qualitative features such as fill slope stability, amount of ditch erosion and importance of cutbank slumpage in the ditch. The distribution of slope positions for the DRCs evaluated in this study is shown in Figure 1. The distribution of ownerships is shown in Table 2.

If there is any significant ditch erosion, the ditch should contain coarser material than the cutbank. To determine if this situation was occurring, soil samples from the cutbank and ditch were obtained and analyzed by a wet sieving process to determine the grain size distribution of each sample. Wet sieving was chosen because of the relative ease of the process, which made it possible to analyze more samples. In the wet-sieving process, the material passing the #200 sieve (0.074 mm) was lost. This fine material was a low percentage of the total sample (5-15%). Approximately a 28% random sample of culvert installations were analyzed

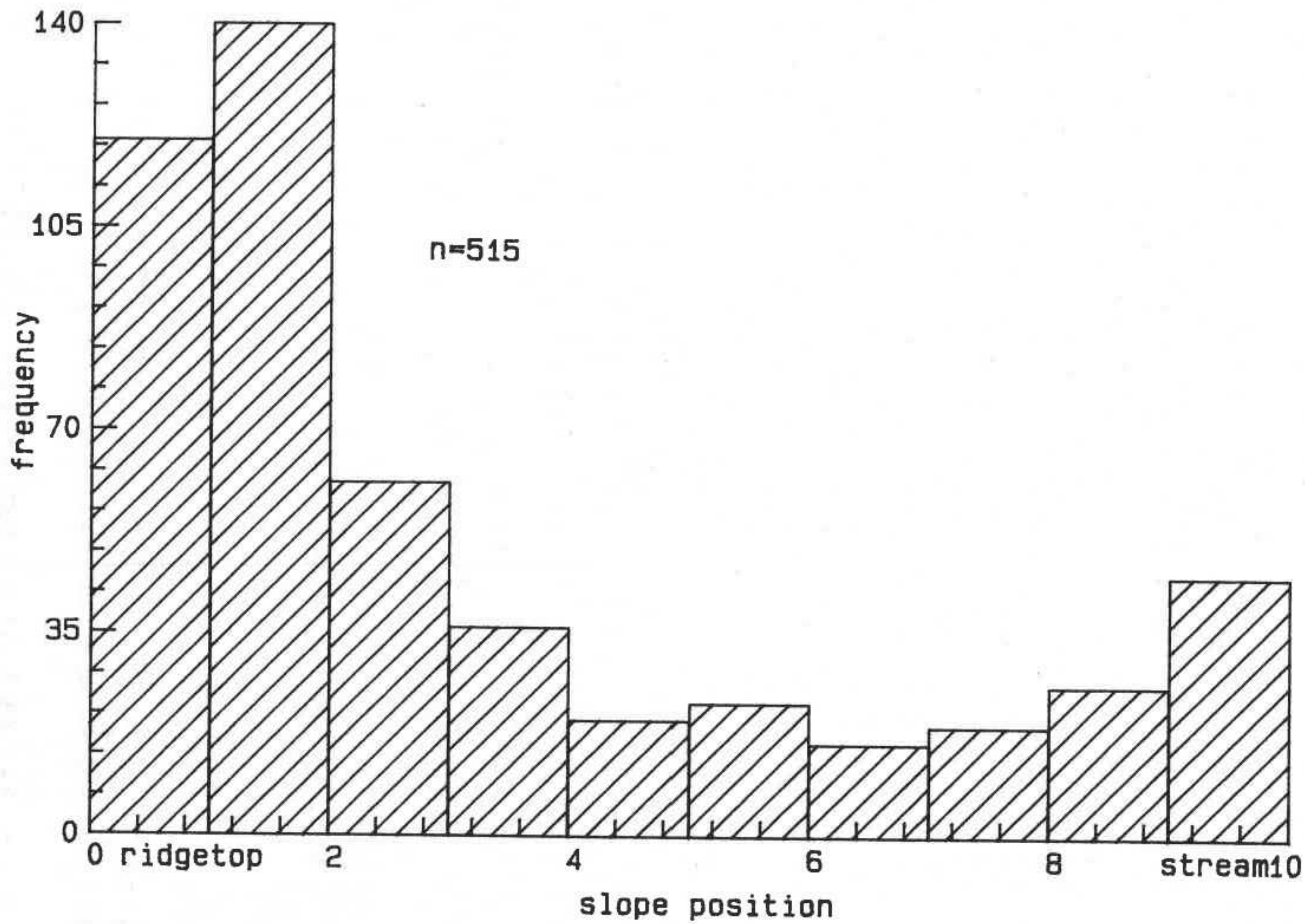

Figure 1. Distribution of slope positions of ditch relief culverts.

Table 2. Ownership distribution of ditch relief culverts and stream crossing culverts.

Ownership	Sampled Road Sections n	Ditch Relief Culverts n	Stream Crossing Culverts n
USFS	52	326	61
BLM	27	118	34
STATE	10	37	16
PRIVATE	10	34	29
TOTAL	99	515	140

with this method. Grain size distributions were compared to determine if any shifts in the distributions could be associated with certain undesirable characteristics.

The soil samples from the ditch and cutbank did not show any dramatic shifts in grain size distribution between the ditch and the cutbank. By comparing the percent change of material held above a #4 sieve (4.76 mm) there is an apparent shift to coarser material from the cutbank to the ditch (Figure 2).

Problems with DRC inlets include; sediment plugging, denting, cutbank sluffing, organic debris blockage or a combination of these. The effect of these problems was evaluated by the amount of reduction in cross-sectional area. These reductions were expressed as a percentage of original, where 100% corresponds to an undamaged pipe. The average cross-sectional area for all DRC inlets was 80.6%, and the range in ownership classes was from 72.9% (Private) to 85.4% (State). Most of the DRCs (90%) had projecting type entrances, only 7% had headwalls and the remaining entrances were scattered among mitered, end section and others.

The inlet cross-sectional area of 74% of all DRCs was reduced from original. Sediment was the main factor of reduction, occurring in 24% of the inlets. Denting was the second most frequent factor of reduction, occurring in 17% of the inlets. Sediment and denting each resulted in an average cross-sectional area of approximately 80% of

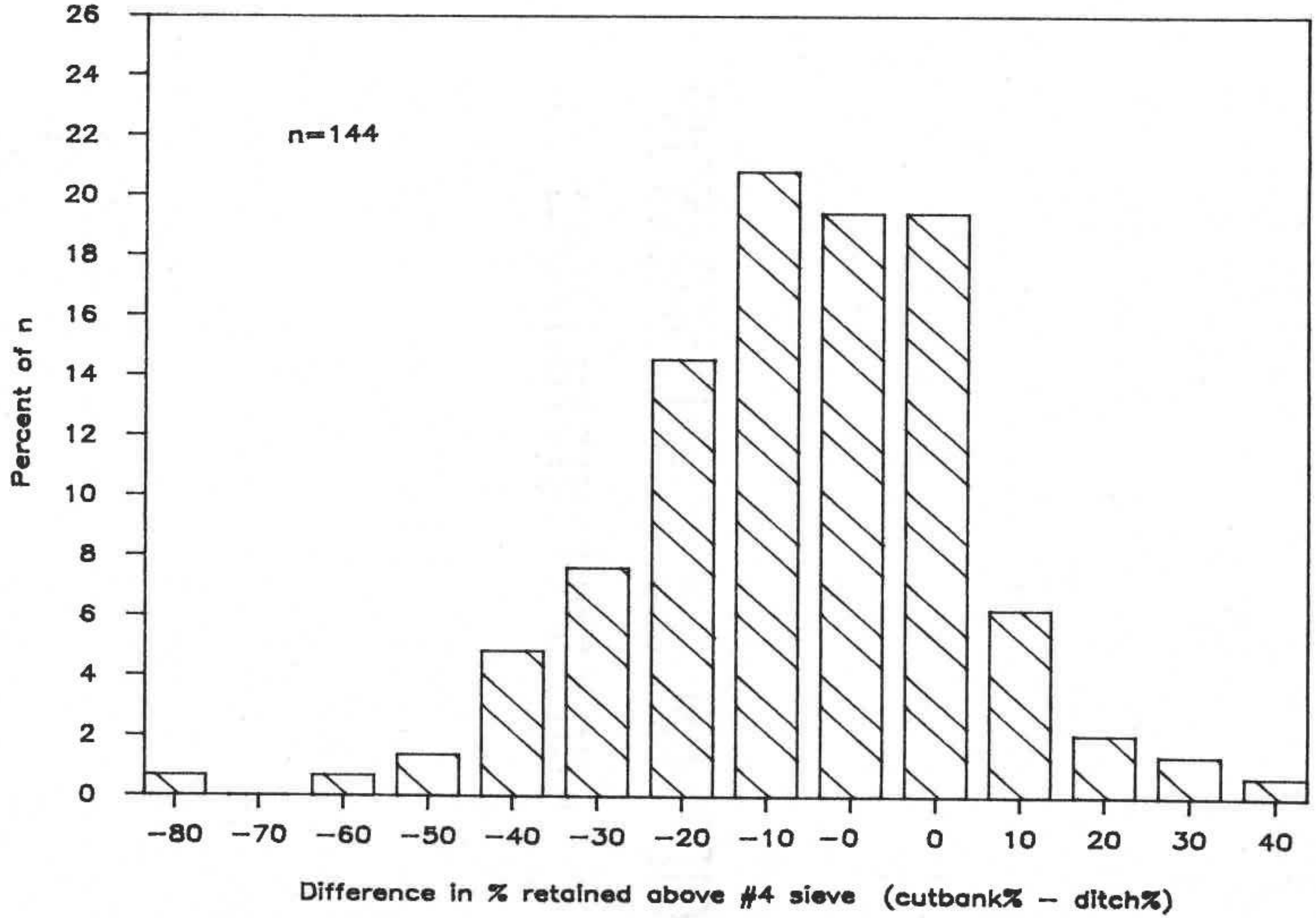

Figure 2. Comparison of particle size fractions for cutbank and ditch soils.

original. Inlets which were reduced by both sediment and denting accounted for 7% of all DRCs but the average cross-sectional area for these pipes was only 60% of original. Nearly half (48%) of all DRCs had their inlets reduced by sediment and/or denting.

Cutbank slumpage severe enough to reduce the inlet was relatively infrequent (10% of all DRCs) but when it did occur it reduced the average inlet cross-sectional area to 56% of original. Organic debris did not occur very frequently (1% of all DRCs) and was not responsible for a large reduction in cross-sectional area (average cross-sectional area=78%). A category was created for any two or more factors, except sediment and denting together, although this category was more frequent (15% of all DRCs) than sediment and denting it was associated with a larger average cross-sectional area (74%). Figure 3 displays these results graphically.

The ditch and road surface profiles were surveyed for up to 50 feet from the pipe inlet. These profiles were analyzed for possible connections with culvert performance. It was found that ditch grade is not associated with any problems at the inlet or outlet. Also, the difference between the road surface elevation and the ditch elevation at the inlet and at 40-50 feet upditch from the inlet could not be associated with other features of the pipe.

Several other characteristics that were evaluated could possibly be related to or associated with factors of inlet

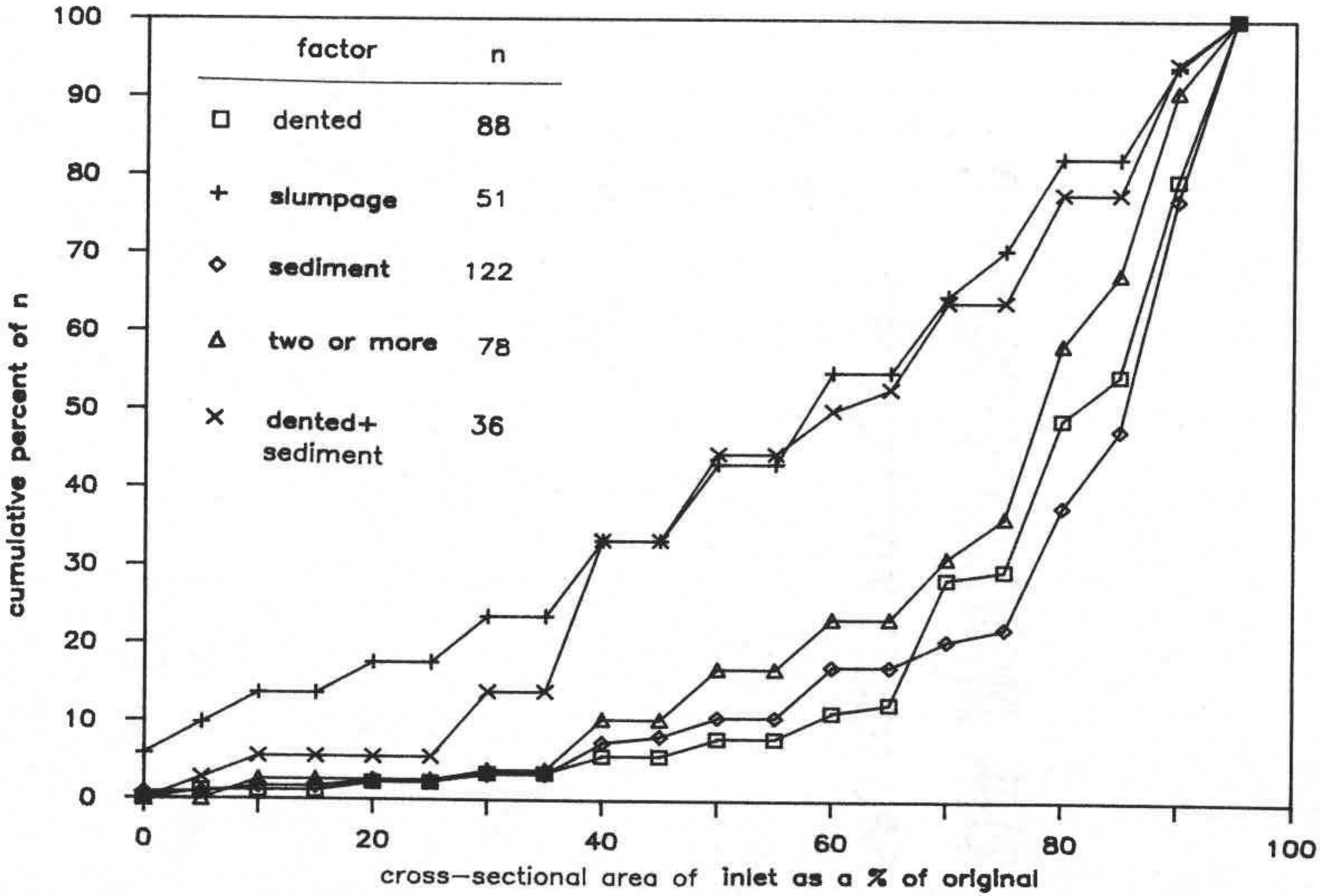

Figure 3. Factors affecting the reduction in cross-sectional area of ditch relief culvert inlets.

reduction, but were found to have no apparent correlation include: pipe diameter, inlet slope and percent exceeding Arnold's guidelines. Other characteristics that were found not to be associated with the inlet as a percentage of original include: pipe diameter, and corrugation pitch, depth and type.

Ditch relief culverts are generally installed with some skew, which is the angular deviation (expressed in degrees) from a perpendicular to the road centerline. In theory, greater skew should help pass water, sediment and debris through the culvert inlet. As the skew angle decreases the flow of water must turn a sharper corner to enter the pipe, which can slow down the water velocity and create a situation where sediment deposition may be a problem. A reduction at the inlet because of sediment accumulation might thus be expected for culverts installed at low skew angles. This relationship was not evident, however larger skew angles were associated with a higher percentage of dented inlets. The skew angle for all DRCs averaged 15 degrees.

Ditch relief culverts should be designed with a pipe slope of at least 5%. A steeper pipe slope is intended to keep the pipe cleaned of sediment and debris due to the greater velocity of water flowing through it. This relationship holds true for sediment, but the steeper pipe slopes have a higher percentage of dented inlets and cutbank slumpage (Figure 4). The pipe slope for all DRCs averaged 10%.

The interiors of culverts are also susceptible to denting and/or plugging. Factors affecting the functional capability of culvert interiors include: crowning, sagging, denting, sediment and debris clogging. The interiors were evaluated in a manner similar to the inlets. The cross-sectional area of the interior averaged 90.5% of original. The main factor for reduction was sediment, which occurred in 22% of all interiors. Denting was a factor of reduction in only 2% of all pipes, and organic debris and a combination of two or more factors occurred in less than 1%.

Certain characteristics of DRCs were related to reductions in the cross-sectional area of the interior and to the possible factors for these reductions. As pipe slope increases the cross-sectional area of the interior, as a percentage of original, increases and sediment as a factor of reduction decreases (Figure 5). Pipe slopes 10% or greater showed this effect the most. As pipe diameter increased, from 12 to 24 inches, the interior cross-sectional area increased dramatically and sediment as a factor of reduction decreased as dramatically (Figure 6). Culverts on private land had the lowest interior cross-sectional areas (83.1% of original), and culverts on state land had the highest cross-sectional area (97.1% of original).

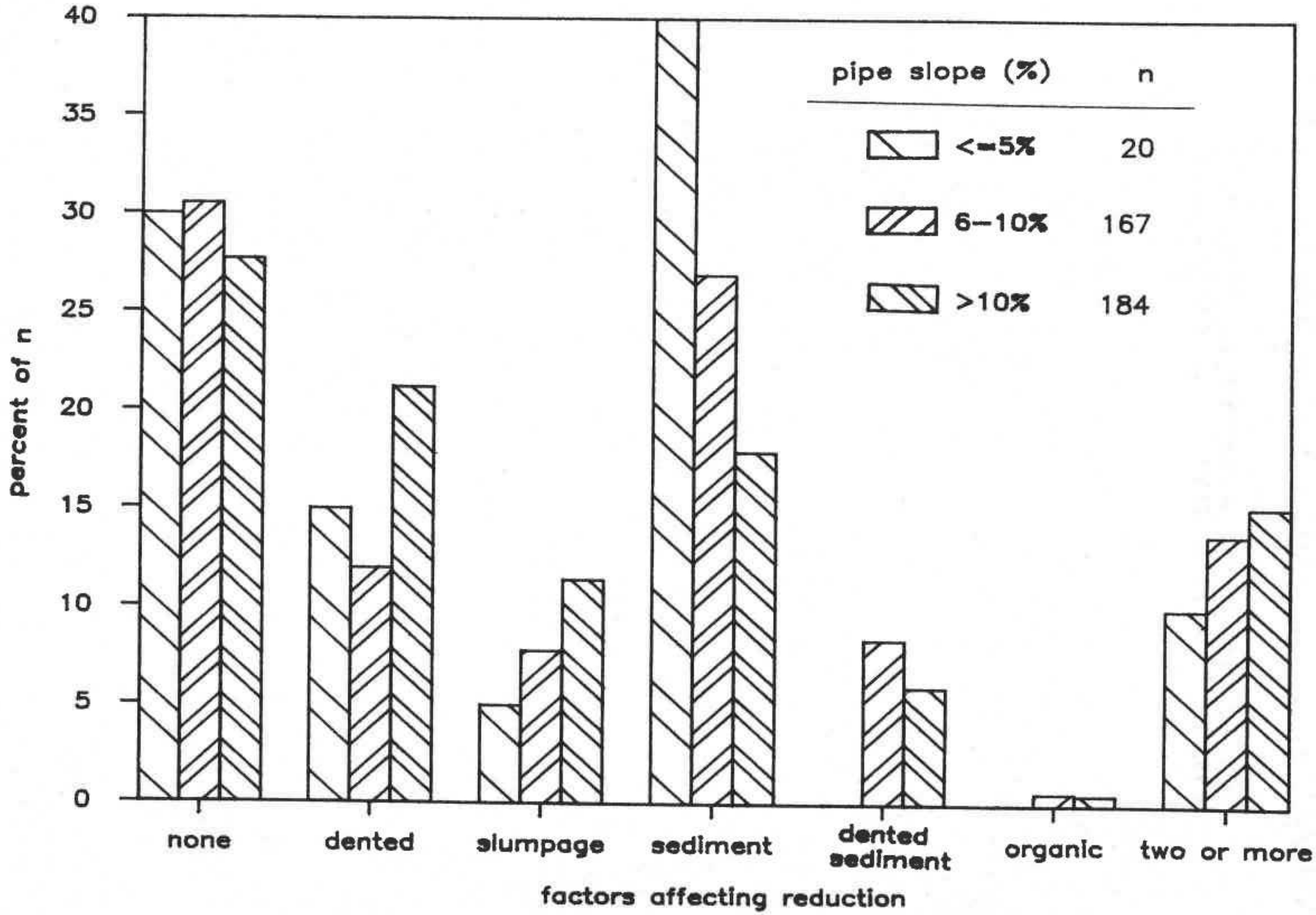

Figure 4. Factors affecting the reduction in cross-sectional area of ditch relief culvert inlets, by pipe slope.

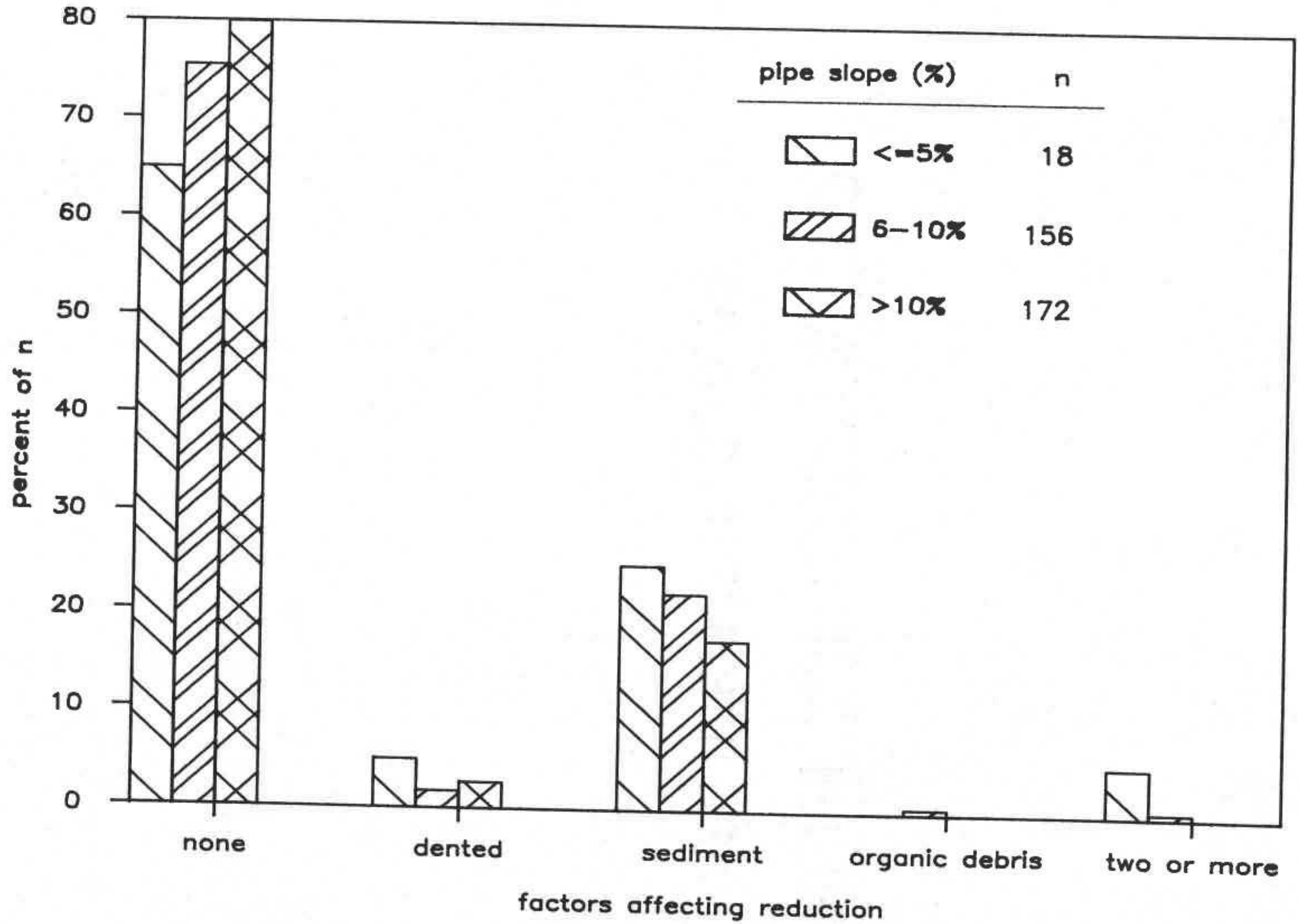

Figure 5. Factors affecting the reduction in cross-sectional area of ditch relief culvert interiors, by pipe slope.

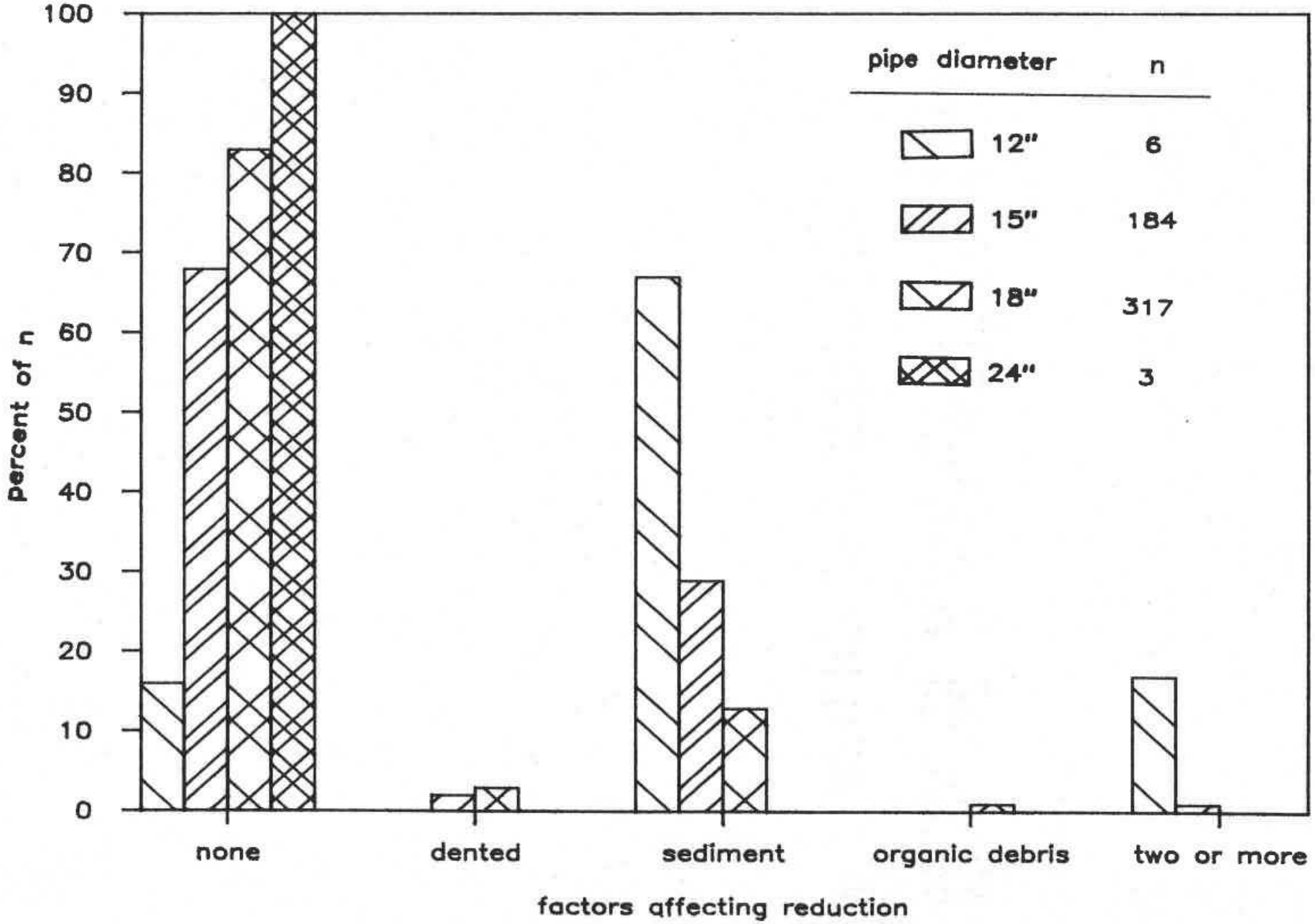

Figure 6. Factors affecting the reduction in cross-sectional area of ditch relief culvert interiors, by pipe diameter.

Other characteristics of culverts that could be possibly related to a reduction in the cross-sectional area of interiors, but were found not to have any correlation include: crowning, sagging, and corrugation pitch, depth and type. Characteristics that could not be associated with factors of reduction of the interior include: pipe diameter, overall slope, road grade and percentage exceeding Arnold's guidelines.

The outlets of DRCs can also be associated with problems in the functioning of culverts. Outlet problems include: denting, sediment, organic debris and live plant blockage. The outlet cross-sectional area of all DRCs averaged 89.5% of original. The most frequent factor of reduction was sediment blockage, which occurred in 19% of all outlets. Denting was the second most frequent factor of reduction occurring at 6% of all outlets, and two or more factors occurred at 4%. Organic debris or live plant blockage only accounted for 1% each. When two or more factors of reduction were noted the reduction in cross-sectional area was substantially higher than other factors (Figure 7).

DRCs on Private land had the lowest outlet cross-sectional area (85.0% of original) and the highest percentage of sediment and denting as a factor of reduction. State owned DRCs had the highest cross-sectional area (94.1% of original). Pipe diameter seemed to affect outlets only at the largest and smallest sizes. Twelve inch pipes had by

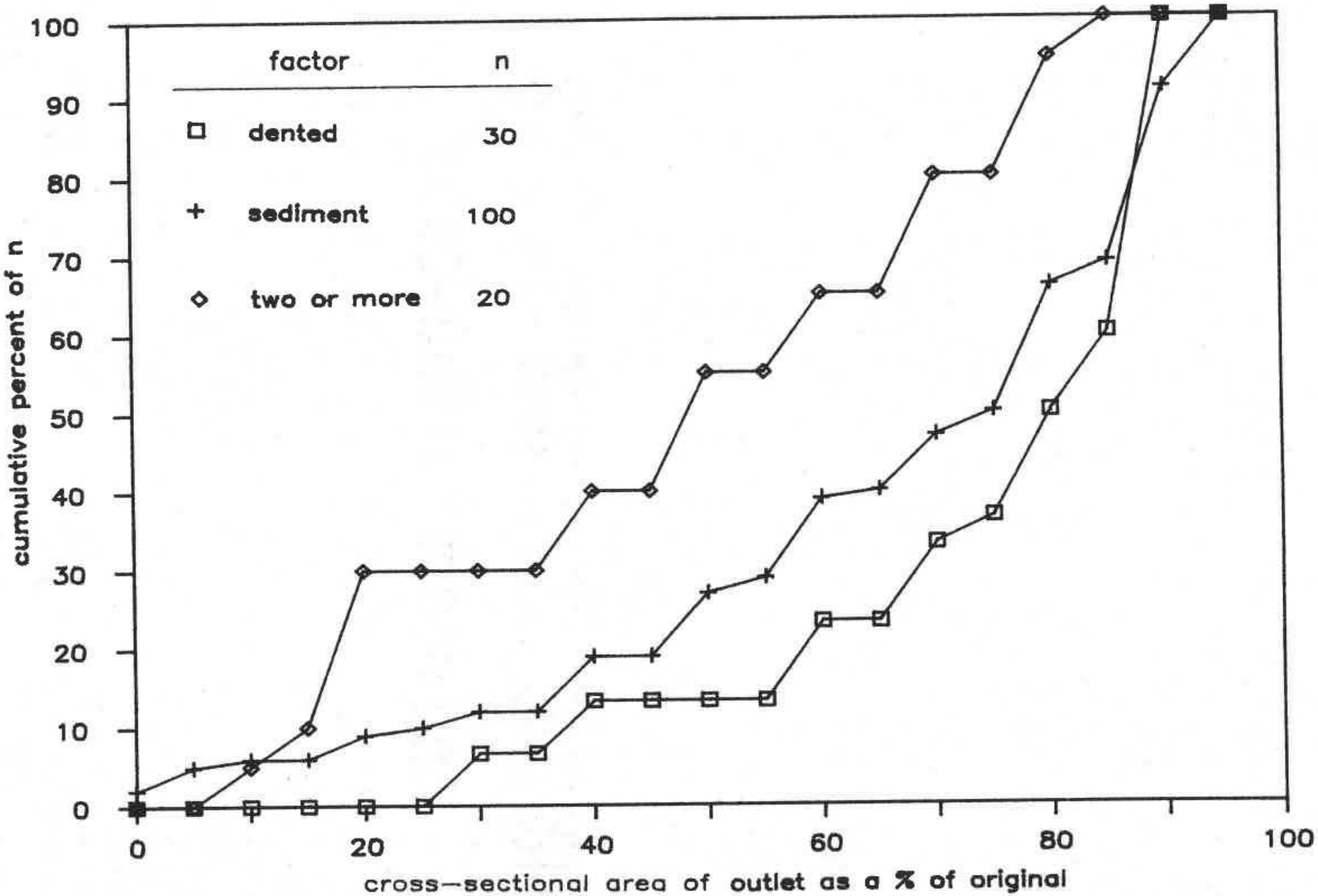

Figure 7. Factors affecting the reduction in cross-sectional area of ditch relief culvert outlets.

far the most denting and 24 inch pipes had the most sediment blockage. However, due to the small sample size of 12 and 24 inch pipes these results are not conclusive.

The adequate functioning of a DRC involves controlling erosion, both in the ditch and below the outlet. Erosion at both locations is related to the spacing between culverts. The amount of material removed by erosion from the road fill and/or hill slope was measured or estimated, and labeled with the general term of outlet erosion. Two outlet erosion volumes, 1,100 and 166 cubic yards, were deemed outliers and were not considered in the following analysis.

Comparing actual spacings with Arnold's (1953) guidelines (using soil erosion class IV) it was found that actual spacings exceeded Arnold's guidelines by an average of 65.0%. Outlet erosion volumes averaged 2.5 cu.yds. for all DRCs and were associated with 38% of all DRCs. Outlet erosion volume and spacing guideline information, analyzed by owner, is shown in Table 3. DRC outlets with erosion control structures (downspouts, etc.) were observed to have similar erosion patterns to those without such structures.

Fill slopes were also rated qualitatively into groups of stable, intermittant erosion and erodible. For all DRCs 60% were classed as stable, 29% as intermittant erosion and 12% as erodible. It was found that the middle slope positions (500-1000 feet from the ridgetop) were rated erodible approximately 5% more often than culverts located closer to or farther from the ridgetop (Figure 8). The

Table 3. Outlet erosion and spacing information, by ownerships, (values in parenthesis are standard deviations). A/

Ownership	Total Samples	Outlet Erosion: Volume in cu. yds.	Outlet Erosion: Number with Volume >0	Comparison with Arnold's Spacing Guidelines: %B/	Comparison with Arnold's Spacing Guidelines: Number Exceeding Arnold's Spacing
USFS	326	2.3 (4.0)	119	31 (82)	273
BLM	118	2.3 (3.9)	43	109 (168)	87
STATE	37	4.0 (5.4)	17	136 (167)	30
PRIVATE	34	3.7 (6.8)	16	169 (200)	31
TOTAL	515		195		421
AVERAGE		2.5 (4.4)		65 (130)	

A/ Spacing guidelines based on Arnold (1953).

B/ [(observed spacing - Arnold's spacing)/Arnold's spacing] x 100

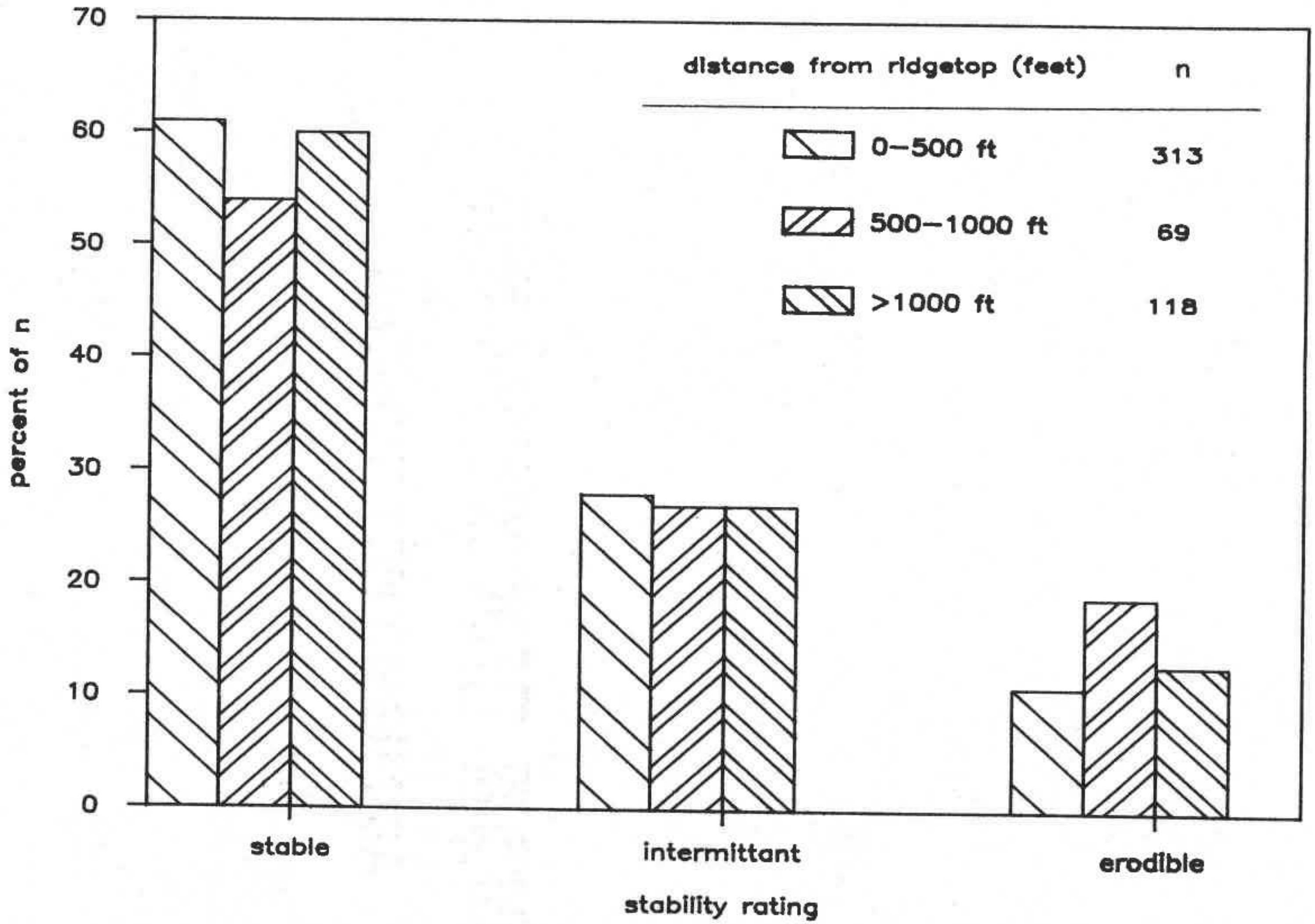

Figure 8. Stability rating of fill slopes of ditch relief culverts, by slope position.

middle slope positions also had the highest frequency of outlet erosion (48%), but the lower slopes (>1000 feet from the ridgetop) had the highest average outlet erosion volume (8.9 cu.yds.). Increasing the spacing, as a percent exceeding Arnold's spacing guidelines, increased the proportion of culverts in the intermittant and erodible categories (Figure 9). Outlet erosion volumes increase with an increase in spacing, expressed as a percent exceeding Arnold's spacing guidelines, but the effect is not evident until Arnold's guidelines are exceeded by more than 100%.

Outlet erosion volume and fill slope erodible ratings increase at greater fill slope angles. The larger outlet erosion volumes (>5 cu.yds.) occurred only on 40 percent or steeper slopes (Figure 10). The DRCs with outlet erosion volumes larger than 5 cubic yards had spacings that exceeded Arnold's spacing guidelines by an average of 187% (481 feet). The DRCs with outlet erosion volumes under 5 cubic yards exceeded Arnold's spacings by an average of only 79% (159 feet).

The ownership distribution for outlet erosion volumes less than 5 cubic yards was nearly identical to the ownership distribution for all DRCs. However, the ownership distribution for outlet erosion volumes greater than 5 cubic yards was different. The percentage of State DRCs increased from 7 to 17%, while the percentage of USFS DRCs decreased from 63 to 52%. The percentage in Private ownerships

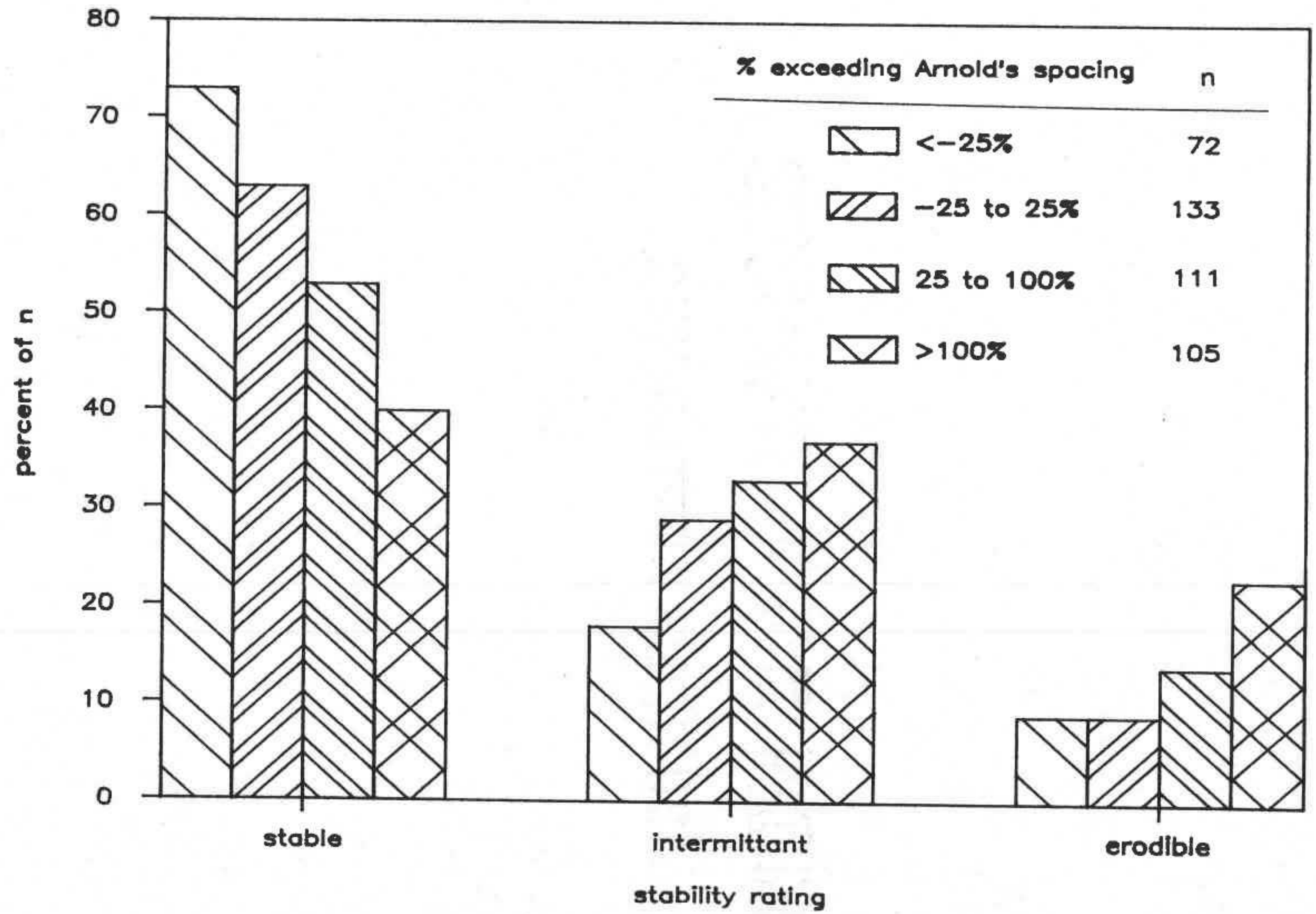

Figure 9. Stability rating of fill slopes of ditch relief culverts, by percent exceeding Arnold's spacing guidelines.

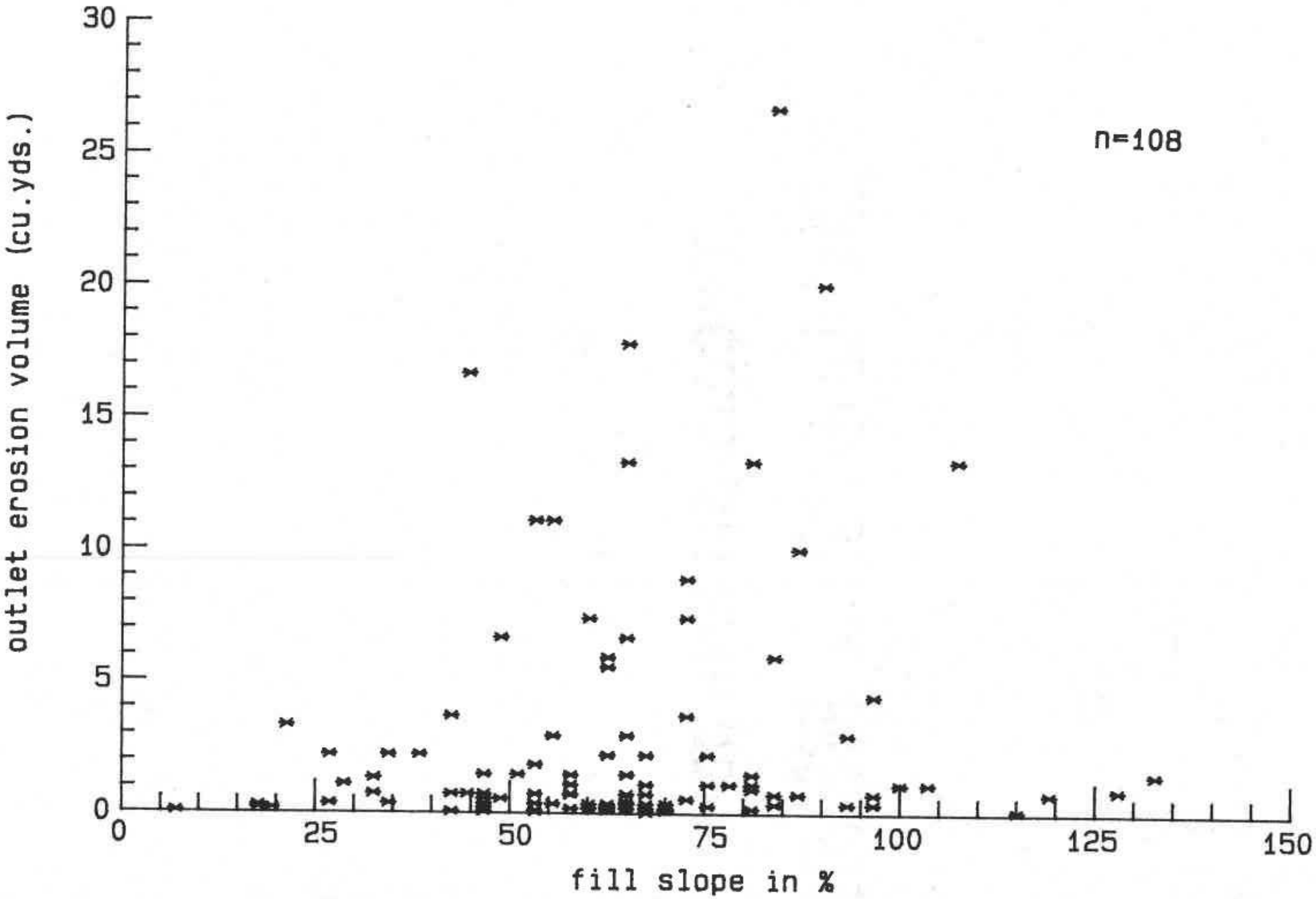

Figure 10. Outlet erosion volume vs. fill slope angle for ditch relief culverts.

increased slightly from 8 to 10%, but had a higher average outlet erosion volume above 5 cubic yards than other owners.

The DRCs that exceeded Arnold's spacing guidelines were divided into two groups of fill slopes greater or less than 40 percent (Figure 11). The two fill slope groups showed dramatic differences in stability ratings, with slopes greater than 40 percent being much more erodible than fill slopes below 40 percent (Figure 12). DRCs on State owned property had the highest percentage in the erodible rating, with Private ownerships having the highest percentage in the intermittant classification.

Stream Crossing Culverts

The characteristics of stream crossing culverts that conventionally are viewed as important in the evaluation of their effectiveness are size of pipe, entrance type, amount of denting and/or plugging, height of road surface above top of pipe and culvert slope. These characteristics were determined in the field as well as pipe material, corrugation pitch and depth, organic debris inventories, particle size inventories and general channel slope above the inlet. In addition, the drainage area for each culvert was determined from maps.

All drainage areas larger than one-half square mile (320 acres) were dropped from the analysis. This selection was done because there were very few drainage areas greater

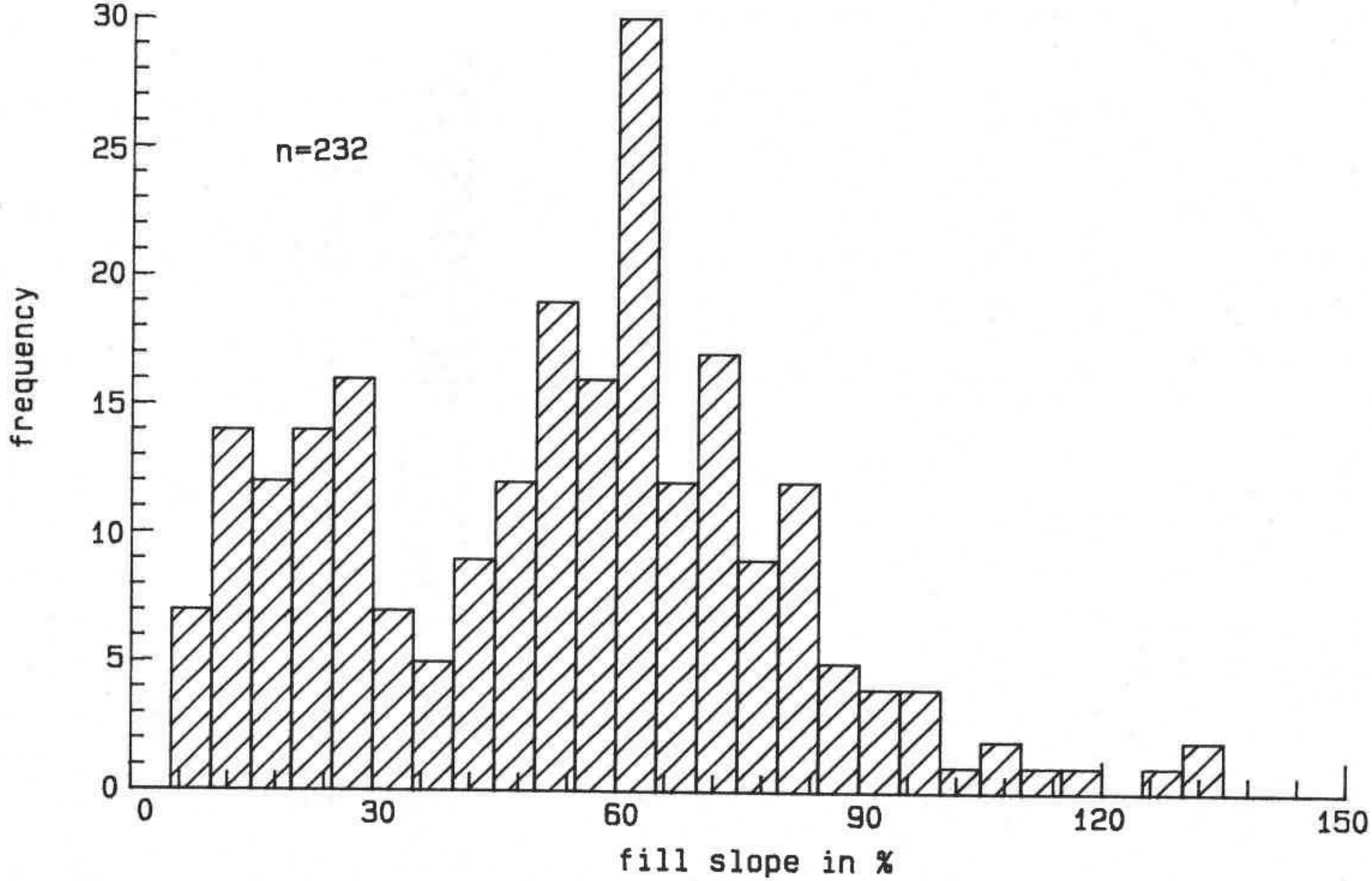

Figure 11. Distribution of fill slope angles of ditch relief culverts.

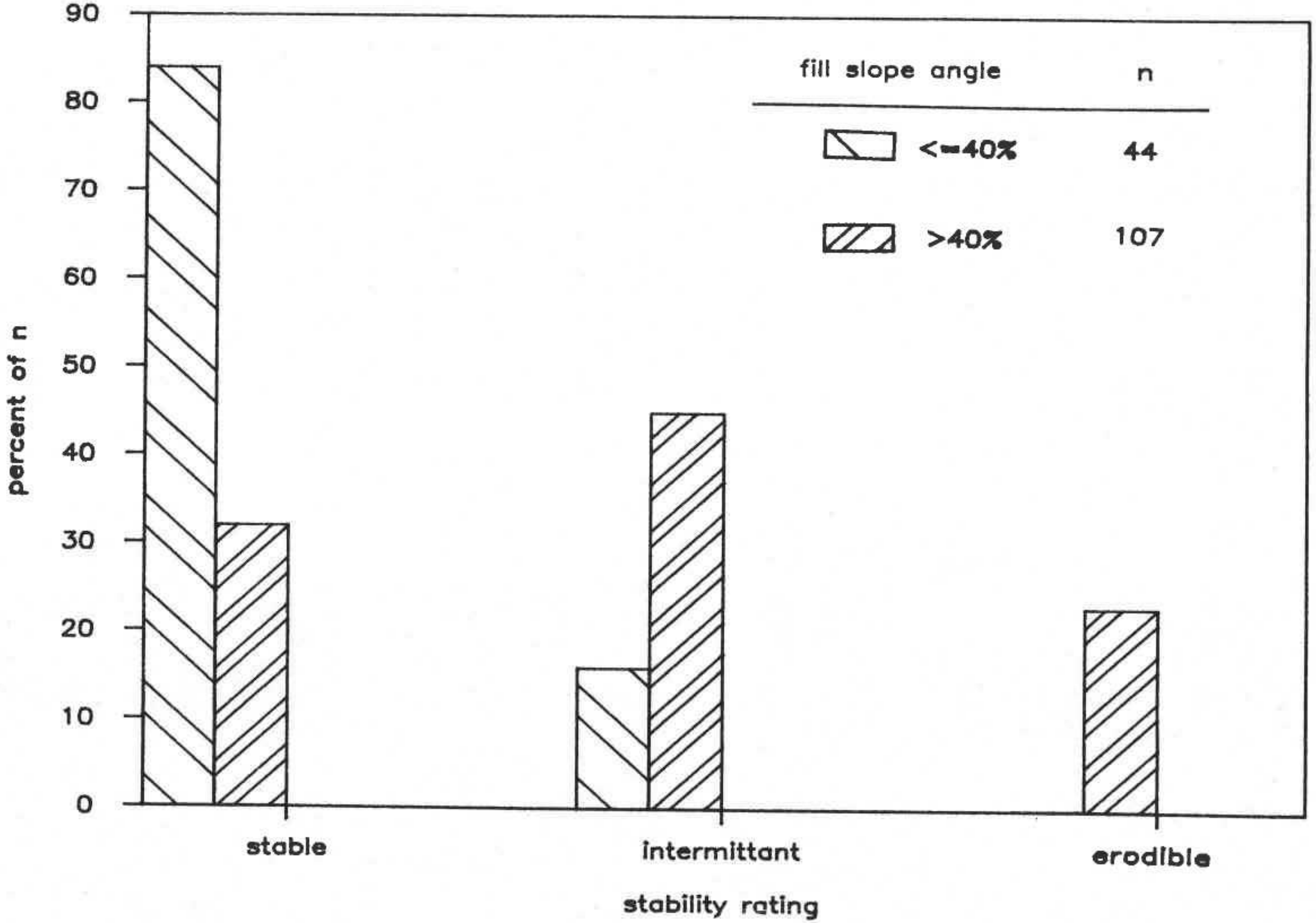

Figure 12. Stability rating of fill slopes at spacings greater than Arnold's guidelines, by fill slope angle.

than one-half square mile and the relatively large culverts associated with these larger drainages represent a separate population which was not adequately sampled in this study. The three SCCs that were excluded had drainage areas of 1363, 571 and 431 acres.

Stream crossing culverts can have their inlets reduced in cross-sectional area by: denting, sediment, rock or debris blockage or a combination of these. The average inlet cross-sectional area was 87.6% of original. Denting and sediment blockage were the most frequent factors of reduction each occurring in 16% of all SCCs. Two or more factors occurred at 13% of all SCCs and organic debris blockage was observed at 9%. Two or more factors and organic debris blockage accounted for a much higher reduction in cross-sectional area than did denting or sediment blockage alone (Figure 13).

To evaluate the adequacy of SCC sizing, a design discharge is required. The Oregon State Forest Practices Law requires that culverts be designed for at least a 25-year peak flow. Campbell's equations (Campbell, et al., 1982) were used to determine the magnitude of the 25-year peak flow. Most of the culverts in this study had watershed areas well below the range of Campbell's work, which lists the lower limit at 185 acres (Figure 14). However, because Campbell's study was directed at small, forested watersheds in Western Oregon it represents the best method available to estimate peak flows.

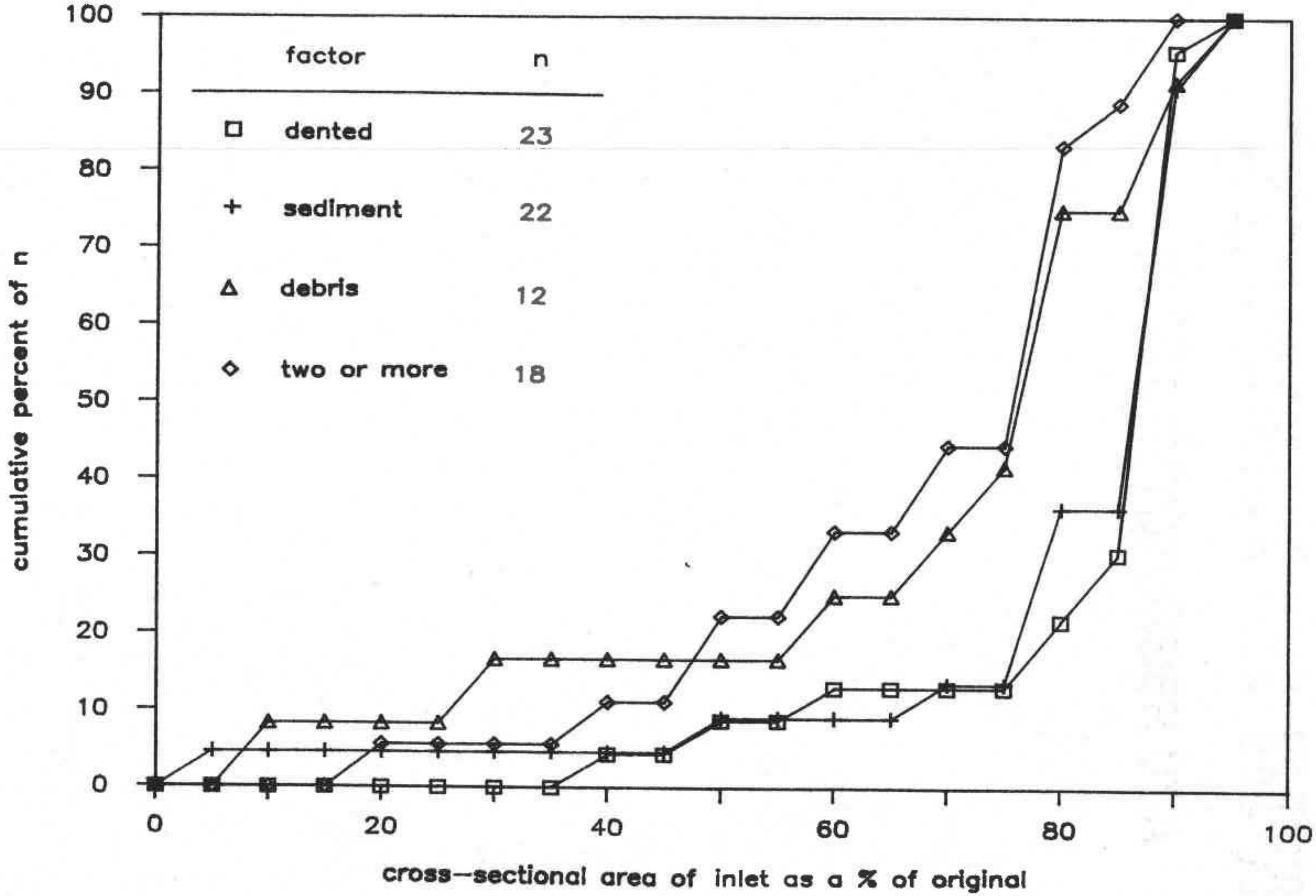

Figure 13. Factors affecting the reduction in cross-sectional area of stream crossing culvert inlets.

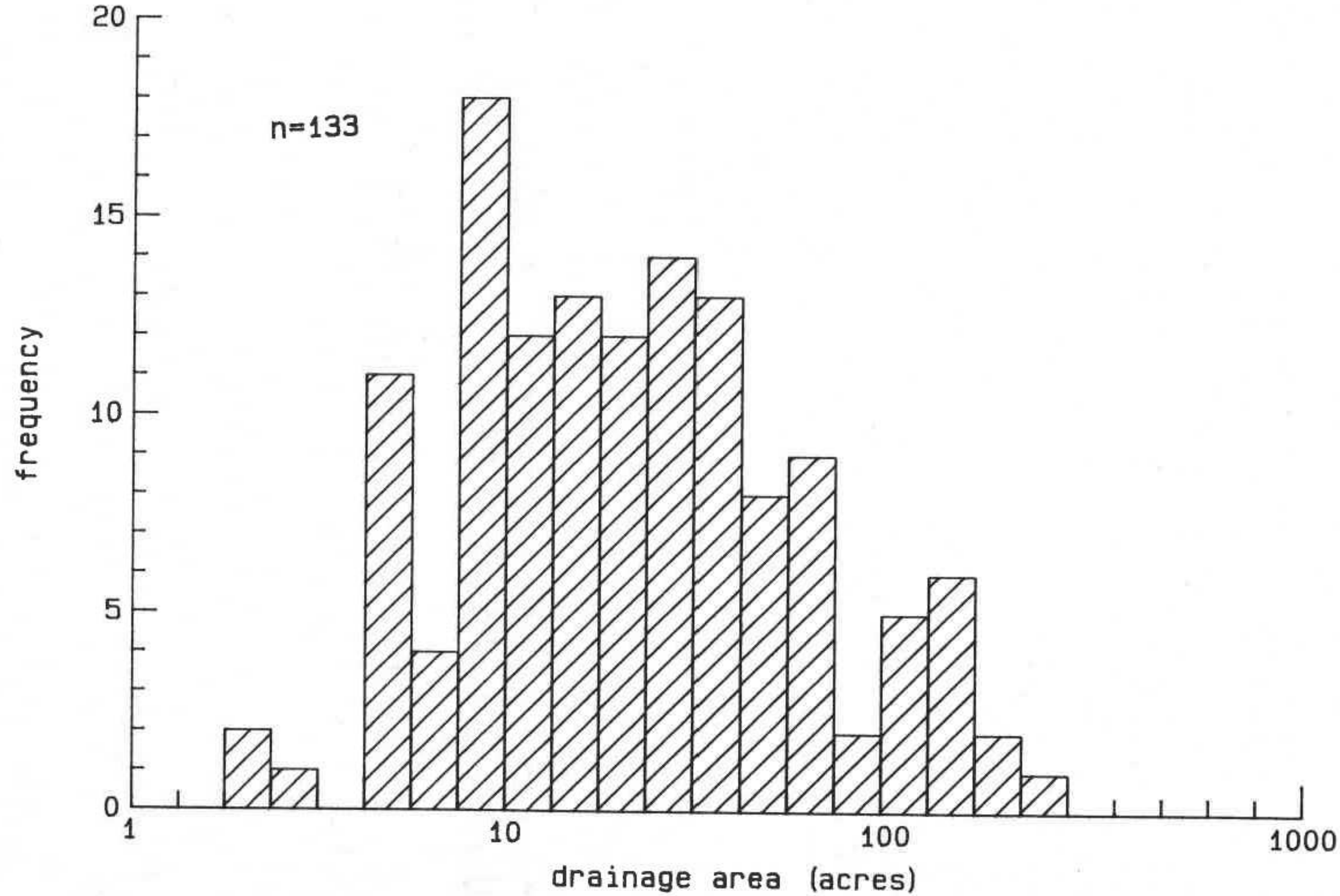

Figure 14. Distribution of drainage areas of stream crossing culverts.

In the following assessment, all SCCs were assumed to operate under inlet control. Field observations and pipe slope measurements suggest that this assumption is reasonable. For pipes under inlet control, reductions in the inlet cross-sectional area are most important in reducing the flow capacity of the pipe. An equation was fit to the inlet control nomograph for round pipes, which calculates either pipe diameter, discharge or headwater/diameter ratio (HW/D), given the other two (Appendix A1). The equation is based on the orifice equation (Streeter and Wylie, 1978) and has an average error of 1% with a maximum error of 5%, compared to the nomograph over a range of HW/D ratios from 0.5 to 6.0.

Two methods were used to determine if the SCCs were adequately sized to pass the 25-year peak flow. Reductions in the inlet cross-sectional area were incorporated by calculating an effective pipe diameter, which is equal in cross-sectional area to that of the reduced inlet. It would be reasonable to expect culverts to not function as efficiently with a dented inlet as with an undistorted inlet of the same cross-sectional area. However, changes in inlet hydraulics as a result of denting and/or sediment accumulation are not known. Therefore, the method of using effective pipe diameters was considered the most reasonable approach to this problem.

The first method used compared the depth of water ponded at the inlet of the pipe, during a 25-year peak flow, to the road surface elevation. This method of analysis assumes that water flowing over the road is not a desirable situation and may cause considerable erosion to the road surface and fill.

To evaluate the frequency of flows overtopping the road, 25-year design flows were determined from Campbell's equations (Campbell, et al., 1982). Headwater to diameter ratios (HW/D) were estimated assuming inlet control using the nomograph formula. HW/D ratios that were calculated to be greater than 7 were assigned the value of 7. This was done to eliminate some extreme values obtained from the equation, which is an exponential function.

The HW/D ratios for the 25-year peak flow averaged 1.9. The HW/D ratio for each culvert was multiplied by the pipe diameter to obtain the headwater elevation, which was then compared to the road surface elevation. For 23% of all SCCs, the 25-year design storm was estimated to have overtopped the road (Table 4).

The second method of evaluating if the SCCs were adequately sized required a calculation of the return interval for three different headwater to diameter ratios (HW/D). The discharges for each pipe were calculated for HW/D ratios of 0.75, 1.0 and 1.5. Discharges for the 10, 25, 50 and 100 year peak flows were also calculated using Campbell's equations. For each HW/D ratio, the return interval was then obtained by non-linear interpolation of the results from Campbell's equations.

Table 4. Comparisons of flow conditions at the culvert inlet for a 25-year design storm, by ownership, (values in parenthesis are standard deviations).

Ownership	n	% Overtopping Road Surface	Average HW/D Ratio	Average Depth of Fill (ft)[A/]
USFS	53	8	1.0 (1.3)	7.1 (5.6)
BLM	33	33	2.2 (2.1)	6.2 (3.9)
STATE	16	25	1.8 (2.0)	2.8 (0.9)
PRIVATE	29	38	3.0 (2.8)	4.1 (2.2)
AVERAGE		23	1.9 (2.1)	5.6 (4.6)

[A/] Depth of fill measured from invert of pipe.

Return intervals greater than 1000 years were assigned 1000 as their return interval. These large return intervals were generally obtained on smaller watersheds where the 10, 25, 50 and 100 year predicted peak flows were very close together. Large return intervals caused pronounced positive skew of the means for each HW/D ratio class, therefore they were not calculated. However, using a cumulative percentage plot it was found that for a HW/D ratio of 0.75, 80% of all SCCs have return intervals less than 25 years. Table 5 summarizes the differences between ownerships at different HW/D ratios.

An interesting trend can be seen in Figure 15, which shows the variability in return interval flows calculated for culverts, assuming a HW/D ratio of 0.75. These data show a trend towards smaller return intervals as drainage area increases. This trend suggests that SCCs installed at larger drainages are more likely to be under-designed than those installed at smaller drainages.

Table 5. Percent of SCCs unable to pass a 25-year flow event for selected headwater to diameter ratios.

Ownership	n	Headwater to Depth Ratio		
		0.75	1.0	1.50
USFS	53	60	25	8
BLM	33	94	61	27
STATE	16	94	50	19
PRIVATE	29	93	48	41
AVERAGE		80	42	21

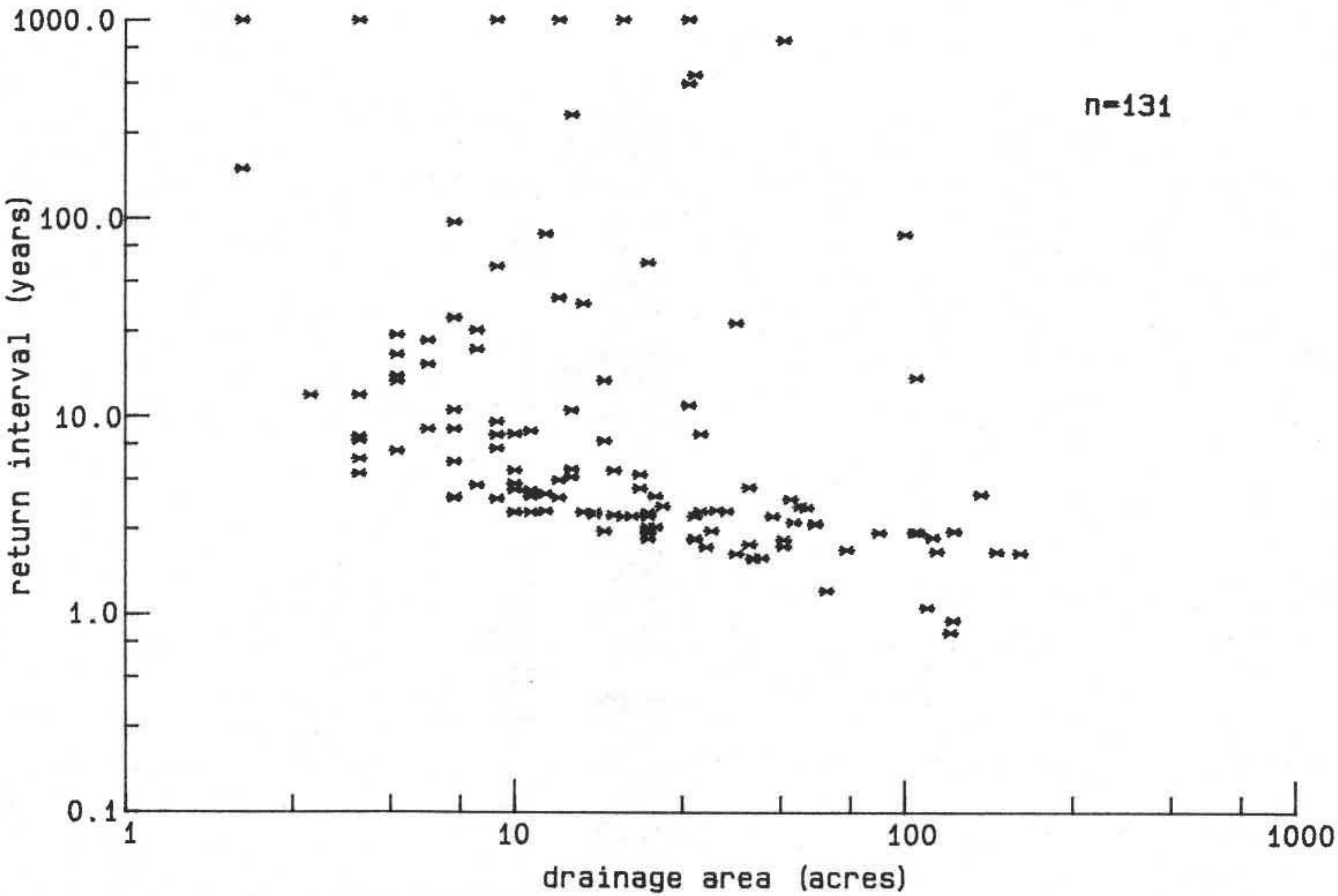

Figure 15. Drainage area vs. return interval for stream crossing culverts, at a headwater to diameter ratio of 0.75.

SUMMARY AND CONCLUSIONS

General Conclusions

The main conclusion of this study is that a rational, or at least consistent, design procedure for either DRCs or SCCs is not apparent. This conclusion is based on a field evaluation of both types of culverts in comparison to existing design guidelines and other criteria.

The two types of culverts were sampled similarly, therefore the relative proportions of each culvert type associated with the various ownerships might also be expected to be similar. However, differences between ownership groups may make certain comparisons invalid. Some descriptive statistics provided in Table 6 indicate that site characteristics of the ownership groups are similar.

SCCs on State ownership have a smaller average drainage area and an average slope position closer to the ridgetop than the SCCs on other ownerships. Therefore, it might be expected that the State ownership will have a lower ratio of DRCs to SCCs than other ownerships. Table 7 shows that this ratio is relatively low for the State ownership culverts. The Private ownership has a larger average road grade, so it might be expected to have more culverts per mile than other ownerships. However, results (Table 7) show that the Private ownership has the lowest number of culverts per

Table 6. Selected characteristics of ditch relief culverts (DRCs) and stream crossing culverts (SCCs), (values in parenthesis are standard deviations).

	Ditch Relief Culverts			Stream Crossing Culverts	
Ownership	Slope Position[A/]	Distance to Ridgetop (feet)	Road Grade %	Drainage Area n	Drainage Area Acres
USFS	3.8 (3.0)	701 (913)	6.8 (3.7)	54	23 (29)
BLM	3.9 (3.0)	720 (881)	7.2 (5.1)	34	50 (47)
STATE	2.5 (2.7)	580 (1009)	7.4 (4.8)	16	12 (8)
PRIVATE	4.2 (2.8)	746 (860)	8.7 (4.7)	29	35 (40)
AVERAGE	3.8 (3.0)	699 (908)	7.0 (4.0)		31 (38)

[A/] 0 = ridgetop, 10 = valley bottom

Table 7. Ownership and spacing information for ditch relief culverts and stream crossing culverts, (values in parenthesis are standard deviations).

Ownership	Sampled Road Sections n	Sampled Road Sections %	Total Culverts per mile	Ditch Relief Culverts n	Ditch Relief Culverts %	Stream Crossing Culverts n	Stream Crossing Culverts %	Ratio of DRCs to SCCs
USFS	52	52.5	8.3 (3.6)	326	63.3	61	43.6	5.3
BLM	27	27.3	5.6 (2.0)	118	22.9	34	24.3	3.5
STATE	10	10.1	6.0 (2.8)	37	7.2	16	11.4	2.3
PRIVATE	10	10.1	4.2 (2.5)	34	6.6	29	20.7	1.2
TOTAL	99			515		140		
AVERAGE			7.0 (3.3)					3.7

mile, substantially less than any other ownership. The Private ownership also has a very low DRC to SCC ratio, which indicates that they do not install as many DRCs as other ownerships.

It was observed in the field that very long ditchlines were diverted onto hillslopes on State and Private roads. Another situation, encountered frequently in the field, was that culverts designed as DRCs were functioning as drainage structures at small stream crossings. The implications of this are less efficient functioning of these culverts and greater probability of failure during high flow events.

Ditch Relief Culverts

The soil analysis indicated that ditchline samples tended to be slightly coarser than cutbank samples. The sandstone derived soil that was present throughout the study area is not very competent. Rock sized pieces can fall apart quickly when exposed to water, especially flowing water. The wet sieving process broke down many of these apparent "rocks" to smaller particles. It is reasonable to expect that these rocks will behave similarly in a ditch with flowing water. Because this study was conducted in the summer, which is generally dry, the ditches were being loaded with rocks from dry ravel which will be broken up and transported in the rainy season. A larger shift between the grain size distribution of the ditch and cutbank might be hypothesized during the rainy season. It may also be expected that a more dramatic shift would occur in other, more competent material. However, the evidence to support a substantial shift in grain size distribution is not present in this data.

The inlet of a ditch relief culvert is usually the most important feature of the pipe in determining the quantity of water that the pipe can pass. Potential problems were more commonly associated with the inlet than with any part of the pipe. Sediment and/or denting are the major problems at the inlets of DRCs. It was noted in the field that many inlets were being damaged (bent, dented, ripped, etc.) by maintenance. When such conditions occur, maintenance may actually create problems, such as sediment accumulation, especially if the culverts are substantially dented.

Where sediment deposition and inlet denting occur together the result is a larger inlet reduction than with each separately. A possible explanation is that physical denting may be severe enough to change the flow of water and create a situation where sediment deposits at the inlet. Cutbank slumpage severe enough to reduce the inlet occurred rather infrequently but when it was present accounted for a large reduction in cross-sectional area.

As both skew angle and pipe slope are increased, sediment as a factor for the reduction of an inlet's cross-sectional area tends to decrease but physical denting increases. The cause of more physical denting occurring with pipes placed at increased skew angles, or pipe slopes greater than 9 degrees is not known. However, physical denting must be reduced before the assumed advantages of greater skew angles or pipe slopes will be beneficial.

The interiors of DRCs generally match their original conditions. The average cross-sectional area of the interior increases with larger pipe diameters. Sediment as a factor for reduction decreased with increasing pipe diameters and pipe slopes greater than 9 degrees.

The outlets of most DRCs are also in relatively good condition. The main factor for any reduction in flow capacity is sediment accumulation, which is generally associated with low fill slope angles. If most DRCs operate under inlet control, some sediment deposition may not be an important concern.

The evaluation of erosion associated with DRCs shows that ditch erosion is not a problem, but outlet erosion can be serious. The Forest Service was the only ownership where DRC spacing was close to approximating Arnold's (1953) guidelines. Almost half of the State and Private owned DRCs had measurable outlet erosion volumes. Although an outlet erosion volume of 4 cu.yds. occurring at less than half of all DRCs may seem reasonable, the larger outlet erosion volumes are relatively predictable, occurring on fill slopes greater than 40% with spacings exceeding Arnold's guidelines. Furthermore, areas with slopes greater than 40% and erodible fill slopes have relatively frequent outlet erosion and large outlet erosion volumes. Therefore, outlet erosion associated with such roads may be substantial. Exceeding Arnold's spacings by less than 100% caused no large outlet erosion volumes unless the fill slope was steep or highly erodible.

There are several reasons why outlet erosion control structures may have no apparent effect on outlet erosion patterns. They may either ineffective at controlling outlet erosion, or outlet erosion at DRCs where they have been installed may have been even more severe if they were not present. The plastic tubes used as outlet erosion control devices were not found to function properly because they ripped easily. The half-culvert downspouts functioned well when they remained anchored. The extra expense of going to a full-culvert downspout seemed justified only where anchoring was a problem.

In conclusion, the main problems associated with DRCs are excessive outlet erosion and inlet cross-sectional area reduction. Arnold's spacing guidelines seem to work well for controlling outlet erosion. However, if the fill slope is steep and/or highly erodible, and a more stable fill slope can be reached by exceeding Arnold's guidelines by less than 100%, outlet erosion would be reduced by installing the culvert on the more stable slope. A pipe diameter of 18" or 24" with a pipe slope of at least 5% reduces problems with the interior. The source of the denting problem associated with inlets needs to be determined and controlled. Also, cutbank slumpage should be controlled where it is a problem.

Stream Crossing Culverts

The inlets of stream crossing culverts were not reduced substantially in cross-sectional area. Also, this study did not observe that organic debris plugging is a problem, even though such debris is considered a major contributor to culvert problems during large flow events. It would be highly likely that debris which had accumulated at the entrance of SCCs had been removed by maintenance crews since the last large flow event. Most of the streams involved in this study had relatively small drainage areas (average=31 acres).

The analysis of pipe sizing shows several factors of concern. The first method of pipe size analysis, comparing headwater elevation to road surface elevation, provides an estimate of how well the pipe functions during a peak flow event. If the headwater elevation exceeds the road surface the installation can be deemed inadequate. Approximately 25-38% of the SCCs within the Private, State and BLM ownerships were projected to have water overtopping the road surface during a 25-year peak flow event. The depth of fill above the pipe has a large effect on the results of this analysis. However, increasing fill depths above the culverts as a method to decrease their probability of failure is not suggested. It reduces the capability of the pipe to pass debris, increases "piping" through uncompacted fills and requires deep fills.

The second method of pipe size analysis, using specified headwater to diameter ratios (HW/D) to predict return intervals, is an alternative method of examining culvert size that eliminates fill depth as a variable. To utilize this method of analysis, a HW/D ratio must be identified as a design standard. The results of this study, indicate that a design HW/D ratio is not being used systematically in the Oregon Coast Range.

In forested watersheds, large amounts of organic debris can be floated downstream during large flow events. A HW/D ratio of 1.5 has a reduced probability of passing organic debris. Similarly, a HW/D ratio of 1.0 provides little if any clearance to carry floatable debris past the inlet. A low clearance may cause debris to catch on the pipe and reduce the cross-sectional area of the inlet, reducing flow capacity. Because of this concern for inlet plugging by floatable organic debris, a HW/D ratio of 0.75 was assumed to represent the most desirable condition.

Results indicated that 93 to 94% of the BLM, State and Private owned SCCs (assuming a HW/D ratio of 0.75) were not able to effectively pass flows with 25-year return intervals. This analysis strongly suggests that they are underdesigned. Similarly, about 60% of the USFS owned SCCs are not capable of handling a 25-year return interval flow (assuming a HW/D ratio of 0.75).

In conclusion, both types of analysis conducted to evaluate the adequacy of pipe size showed that SCCs have been underdesigned. The cost of using the next larger pipe size seems a reasonable alternative when the reduced risk of road and drainage failure is considered.

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APPENDICES

APPENDIX A

Descriptive Statistics

Table A1. Formula for calculating headwater to diameter ratio for corrugated metal pipes under inlet control.

$$HW/D = Y - 0.00874 - 0.04295(Y) + 0.843e^{-1.884(Y)} - 5.747e^{-6.491(Y)} - 5.16e^{-7.268(Y)} - 91.74e^{-13.771(Y)}$$

$$Y = \frac{8Q^2}{g\,Cd^2\,\pi^2\,D^5} + 0.5$$

Where:

HW/D= Headwater to diameter ratio for corrugated metal pipes under inlet control

Y= Headwater to diameter ratio from orifice equation a/

Q= Discharge (cfs)

D= Diameter of pipe (feet)

g= Acceleration due to gravity (32.2 feet per second)

π= 3.14159

Cd= Discharge coefficient = Cv*Cc

Cv= Velocity coefficient= 0.95 (for square-edged orifice)

Cc= Coefficient of contraction= 0.52 (for sharp-edged projecting)

a/ adapted from Equation 8.4.7 (Streeter and Wylie, 1978)

Table A2. Erosion volumes at outlets of ditch relief culverts, by owner.

Ownership	Sample size	Average	Variance	Standard deviation	Minimum
USFS	119	2.25	15.91	3.98	.01
BLM	43	2.33	15.10	3.88	.15
STATE	17	4.00	28.92	5.37	.19
PRIVATE	16	3.65	46.67	6.83	.07
TOTAL	195	2.53	19.29	4.39	.01

Ownership	Maximum	Median	Skewness	Kurtosis
USFS	18.52	.56	2.67	9.91
BLM	17.78	.74	2.63	9.37
STATE	20.00	1.48	1.80	5.60
PRIVATE	26.67	.92	2.66	9.30
TOTAL	26.67	.74	2.77	11.16

Table A3. Erosion volumes at outlets of ditch relief culverts, by erodibility rating. a/

Rating	Sample size	Average	Variance	Standard deviation	Minimum
stable	32	1.46	7.28	2.69	.02
intermit	109	1.15	3.61	1.90	.01
erodible	53	6.02	43.01	6.55	.02
TOTAL	194	2.53	19.39	4.40	.01

Rating	Maximum	Median	Skewness	Kurtosis
stable	11.11	.37	2.50	8.19
intermit	11.11	.56	3.46	15.80
erodible	26.67	2.96	1.27	3.72
TOTAL	26.67	.74	2.77	11.10

a/ Criteria for erodibility ratings are:
Stable - low erosion potential and/or no outlet erosion
Intermittant - moderate erosion potential and/or moderate outlet erosion
Erodible - high erosion potential and/or large outlet erosion

Note: Tables A4 through A16 present summary statistics for selected characteristics of ditch relief culverts.

Table A4. Slope position (0=Ridgetop, 10=Stream).

```
NUMBER OF OBSERVATIONS = 506  (9 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 3.78
SAMPLE VARIANCE = 8.92
SAMPLE STANDARD DEVIATION = 2.98

MINIMUM VALUE = 1   MAXIMUM = 10   RANGE = 9
LOWER AND UPPER QUARTILES = 2 6
INTERQUARTILE RANGE = 4
MEDIAN = 2

COEFF. OF SKEWNESS = 0.99        STANDARDIZED VALUE = 9.13
COEFF. OF KURTOSIS = 2.58       STANDARDIZED VALUE = -1.92
```

Table A5. Distance from ridgetop (feet).

```
NUMBER OF OBSERVATIONS = 500  (15 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 699.38
SAMPLE VARIANCE = 824713
SAMPLE STANDARD DEVIATION = 908.13

MINIMUM VALUE = 0   MAXIMUM = 4400   RANGE = 4400
LOWER AND UPPER QUARTILES = 120 980
INTERQUARTILE RANGE = 860
MEDIAN = 240

COEFF. OF SKEWNESS = 1.78        STANDARDIZED VALUE = 16.32
COEFF. OF KURTOSIS = 5.50       STANDARDIZED VALUE = 11.44
```

Table A6. Cross-sectional area of the inlet as a percent of original.

```
NUMBER OF OBSERVATIONS = 515  (0 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 80.61
SAMPLE VARIANCE = 525.18
SAMPLE STANDARD DEVIATION = 22.91

MINIMUM VALUE = 0   MAXIMUM = 100   RANGE = 100
LOWER AND UPPER QUARTILES = 70 100
INTERQUARTILE RANGE = 30
MEDIAN = 90

COEFF. OF SKEWNESS = -1.58     STANDARDIZED VALUE = -14.68
COEFF. OF KURTOSIS = 5.07      STANDARDIZED VALUE = 9.60
```

Table A7. Skew angle (degrees).

```
NUMBER OF OBSERVATIONS = 510  (5 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 15.16
SAMPLE VARIANCE = 241.77
SAMPLE STANDARD DEVIATION = 15.54

MINIMUM VALUE = -15   MAXIMUM = 90   RANGE = 105
LOWER AND UPPER QUARTILES = 5 25
INTERQUARTILE RANGE = 20
MEDIAN = 10

COEFF. OF SKEWNESS = 1.30      STANDARDIZED VALUE = 12.01
COEFF. OF KURTOSIS = 5.10      STANDARDIZED VALUE = 9.72
```

Table A8. Culvert slope (degrees).

```
NUMBER OF OBSERVATIONS = 371  (144 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 5.69
SAMPLE VARIANCE = 5.06
SAMPLE STANDARD DEVIATION = 2.25

MINIMUM VALUE = 0   MAXIMUM = 14   RANGE = 14
LOWER AND UPPER QUARTILES = 4 7
INTERQUARTILE RANGE = 3
MEDIAN = 5

COEFF. OF SKEWNESS = 0.53      STANDARDIZED VALUE = 4.18
COEFF. OF KURTOSIS = 3.63      STANDARDIZED VALUE = 2.51
```

Table A9. Cross-sectional area of the interior as a percent of original.

```
NUMBER OF OBSERVATIONS = 456  (59 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 90.55
SAMPLE VARIANCE = 486.55
SAMPLE STANDARD DEVIATION = 22.05

MINIMUM VALUE = 0   MAXIMUM = 100   RANGE = 100
LOWER AND UPPER QUARTILES = 90 100
INTERQUARTILE RANGE = 10
MEDIAN = 100

COEFF. OF SKEWNESS = -3.037     STANDARDIZED VALUE = -26.48
COEFF. OF KURTOSIS = 11.91     STANDARDIZED VALUE = 38.84
```

Table A10. Culvert length (feet).

```
NUMBER OF OBSERVATIONS = 491  (24 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 35.15
SAMPLE VARIANCE = 72.83
SAMPLE STANDARD DEVIATION = 8.53

MINIMUM VALUE = 18   MAXIMUM = 115   RANGE = 97
LOWER AND UPPER QUARTILES = 30 40
INTERQUARTILE RANGE = 10
MEDIAN = 34

COEFF. OF SKEWNESS = 2.50      STANDARDIZED VALUE = 22.63
COEFF. OF KURTOSIS = 19.33     STANDARDIZED VALUE = 73.88
```

Table A11. Cross-sectional area of the outlet as a percent of original.

```
NUMBER OF OBSERVATIONS = 508  (7 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 89.47
SAMPLE VARIANCE = 460.13
SAMPLE STANDARD DEVIATION = 21.45

MINIMUM VALUE = 0   MAXIMUM = 100   RANGE = 100
LOWER AND UPPER QUARTILES = 90 100
INTERQUARTILE RANGE = 10
MEDIAN = 100

COEFF. OF SKEWNESS = -2.37      STANDARDIZED VALUE = -21.86
COEFF. OF KURTOSIS = 8.12      STANDARDIZED VALUE = 23.55
```

Table A12. Outlet erosion volume (cu.yds.).

```
NUMBER OF OBSERVATIONS = 195  (320 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 2.53
SAMPLE VARIANCE = 19.29
SAMPLE STANDARD DEVIATION = 4.39

MINIMUM VALUE = 0.01   MAXIMUM = 26.67   RANGE = 26.66
LOWER AND UPPER QUARTILES = 0.22 2.22
INTERQUARTILE RANGE = 2
MEDIAN = 0.74

COEFF. OF SKEWNESS = 2.77      STANDARDIZED VALUE = 15.84
COEFF. OF KURTOSIS = 11.16     STANDARDIZED VALUE = 23.26
```

Table A13. Fill slope angle (percent).

```
NUMBER OF OBSERVATIONS = 232  (283 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 52.57
SAMPLE VARIANCE = 704.83
SAMPLE STANDARD DEVIATION = 26.54

MINIMUM VALUE = 5.23      MAXIMUM = 132.65    RANGE = 127.41
LOWER AND UPPER QUARTILES = 28.6688 70.0036
INTERQUARTILE RANGE = 41.33
MEDIAN = 55.41

COEFF. OF SKEWNESS = 0.26       STANDARDIZED VALUE = 1.63
COEFF. OF KURTOSIS = 2.84      STANDARDIZED VALUE = -0.49
```

Table A14. Roadgrade (percent).

```
NUMBER OF OBSERVATIONS = 510  (5 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 7.04
SAMPLE VARIANCE = 17.67
SAMPLE STANDARD DEVIATION = 4.20

MINIMUM VALUE = 0   MAXIMUM = 19   RANGE = 19
LOWER AND UPPER QUARTILES = 3 10
INTERQUARTILE RANGE = 7
MEDIAN = 7

COEFF. OF SKEWNESS = 0.35       STANDARDIZED VALUE = 3.27
COEFF. OF KURTOSIS = 2.46      STANDARDIZED VALUE = -2.45
```

Table A15. Difference between Arnold's (1953) and actual spacing (feet).

```
NUMBER OF OBSERVATIONS = 421  (94 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 118.79
SAMPLE VARIANCE = 113881
SAMPLE STANDARD DEVIATION = 337.46

MINIMUM VALUE = -738   MAXIMUM = 1699   RANGE = 2437
LOWER AND UPPER QUARTILES = -35 269
INTERQUARTILE RANGE = 304
MEDIAN = 83

COEFF. OF SKEWNESS = 0.84       STANDARDIZED VALUE = 7.08
COEFF. OF KURTOSIS = 6.06      STANDARDIZED VALUE = 12.84
```

Table A16. Difference between Arnold's (1953) and actual spacing (percent).

```
NUMBER OF OBSERVATIONS = 421 (94 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 65.04
SAMPLE VARIANCE = 17012.9
SAMPLE STANDARD DEVIATION = 130.43

MINIMUM VALUE = -92   MAXIMUM = 1041   RANGE = 1133
LOWER AND UPPER QUARTILES = -13 100
INTERQUARTILE RANGE = 113
MEDIAN = 30

COEFF. OF SKEWNESS = 2.72      STANDARDIZED VALUE = 22.83
COEFF. OF KURTOSIS = 14.86    STANDARDIZED VALUE = 49.68
```

Note: Tables A17 through A24 present summary statistics for selected characteristics of stream crossing culverts.

Table A17. Drainage area (acres).

```
NUMBER OF OBSERVATIONS = 133  (7 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 31.24
SAMPLE VARIANCE = 1402.59
SAMPLE STANDARD DEVIATION = 37.45

MINIMUM VALUE = 2   MAXIMUM = 198   RANGE = 196
LOWER AND UPPER QUARTILES = 9 35
INTERQUARTILE RANGE = 26
MEDIAN = 17

COEFF. OF SKEWNESS = 2.27      STANDARDIZED VALUE = 10.69
COEFF. OF KURTOSIS = 7.98       STANDARDIZED VALUE = 11.73
```

Table A18. Cross-sectional area of the inlet as a percent of original.

```
NUMBER OF OBSERVATIONS = 140  (0 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 87.60
SAMPLE VARIANCE = 333.62
SAMPLE STANDARD DEVIATION = 18.26

MINIMUM VALUE = 5   MAXIMUM = 100   RANGE = 95
LOWER AND UPPER QUARTILES = 80 100
INTERQUARTILE RANGE = 20
MEDIAN = 90

COEFF. OF SKEWNESS = -2.31      STANDARDIZED VALUE = -11.20
COEFF. OF KURTOSIS = 8.93      STANDARDIZED VALUE = 14.33
```

Table A19. Culvert slope (degrees).

```
NUMBER OF OBSERVATIONS = 130  (13 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 10.24
SAMPLE VARIANCE = 24.67
SAMPLE STANDARD DEVIATION = 4.96

MINIMUM VALUE = 1.75   MAXIMUM = 30   RANGE = 28.25
LOWER AND UPPER QUARTILES = 7 12.28
INTERQUARTILE RANGE = 5.28
MEDIAN = 10

COEFF. OF SKEWNESS = 1.08       STANDARDIZED VALUE = 5.03
COEFF. OF KURTOSIS = 5.27       STANDARDIZED VALUE = 5.28
```

Table A20. Culvert diameter (feet).

```
NUMBER OF OBSERVATIONS = 142  (1 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 1.99
SAMPLE VARIANCE = 1.20
SAMPLE STANDARD DEVIATION = 1.09

MINIMUM VALUE = 1   MAXIMUM = 8.5   RANGE = 7.5
LOWER AND UPPER QUARTILES = 1.5 2
INTERQUARTILE RANGE = 0.5
MEDIAN = 1.5

COEFF. OF SKEWNESS = 2.58       STANDARDIZED VALUE = 12.57
COEFF. OF KURTOSIS = 12.07     STANDARDIZED VALUE = 22.07
```

Table A21. Culvert length (feet).

```
NUMBER OF OBSERVATIONS = 109  (34 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 42.22
SAMPLE VARIANCE = 105.56
SAMPLE STANDARD DEVIATION = 10.27

MINIMUM VALUE = 20   MAXIMUM = 75   RANGE = 55
LOWER AND UPPER QUARTILES = 35 48
INTERQUARTILE RANGE = 13
MEDIAN = 41

COEFF. OF SKEWNESS = 0.39       STANDARDIZED VALUE = 1.67
COEFF. OF KURTOSIS = 3.29      STANDARDIZED VALUE = 0.62
```

Table A22. 25-year peak flow (cfs) calculated from Campbell, etal. (1982).

```
NUMBER OF OBSERVATIONS = 135  (8 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 18.35
SAMPLE VARIANCE = 2374.41
SAMPLE STANDARD DEVIATION = 48.72

MINIMUM VALUE = 0   MAXIMUM = 470   RANGE = 470
LOWER AND UPPER QUARTILES = 3 14
INTERQUARTILE RANGE = 11
MEDIAN = 6

COEFF. OF SKEWNESS = 6.97      STANDARDIZED VALUE = 33.06
COEFF. OF KURTOSIS = 59.56     STANDARDIZED VALUE = 134.15
```

Table A23. Ratio of headwater depth to pipe diameter (HW/D).

```
NUMBER OF OBSERVATIONS = 134  (9 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = 2.26
SAMPLE VARIANCE = 10.47
SAMPLE STANDARD DEVIATION = 3.23

MINIMUM VALUE = 0.32        MAXIMUM = 13.62       RANGE = 13.29
LOWER AND UPPER QUARTILES = 0.55      1.80
INTERQUARTILE RANGE = 1.24
MEDIAN = 0.91

COEFF. OF SKEWNESS = 2.27       STANDARDIZED VALUE = 10.75
COEFF. OF KURTOSIS = 7.09      STANDARDIZED VALUE = 9.68
```

Table A24. Headwater elevation compared to road surface elevation in feet (negative values indicate headwater elevations below the road surface, positive above).

```
NUMBER OF OBSERVATIONS = 132  (11 MISSING VALUES EXCLUDED)
SAMPLE AVERAGE = -1.80
SAMPLE VARIANCE = 55.60
SAMPLE STANDARD DEVIATION = 7.45

MINIMUM VALUE = -23.66      MAXIMUM = 29.74       RANGE = 53.40
LOWER AND UPPER QUARTILES = -5.09     -0.12
INTERQUARTILE RANGE = 4.96
MEDIAN = -1.80

COEFF. OF SKEWNESS = 0.90        STANDARDIZED VALUE = 4.23
COEFF. OF KURTOSIS = 6.82       STANDARDIZED VALUE = 8.96
```

APPENDIX B

Field Forms

Ditch Relief Culvert Field Sheet

Culvert #__________
Date__________

I. Map Information

A. Slope position ______________

B. Distance to ridgetop ______________(ft)

C. Slope grade ______________(%)

II. Cutbank Characteristics

A. General slope ______________(%)

B. Proportion of cutbank vegetated ______________(%)

III. Ditch Characteristics

A. Proportion of ditch vegetated ______________(%)

B. Description of ditch conditions

noticeable deposition	1
good	2
noticeable erosion	3

C. Cutbank slumpage major factor in ditch conditions? Y N

IV. Road Characteristics

A. Running surface width ______________(ft)

B. Overall road prism width ______________(ft)

C. Road surfacing

<=1/2"	0
<=1"	1
<=2"	2
>2"	3

D. Comments____

V. Inlet Conditions

A. Elevations above invert of pipe inlet

1. ditch dam ______________(ft)
2. road surface ______________(ft)

B. Inlet characteristics

1. catch basin present? Y N
2. if yes, unused volume ______________(ft)
3. oversteepened slope? Y N
4. if yes, % slope ______________(%)
5. entrance type

projecting	1
mitered	2
headwall	3
end section	4
riser	5
other	6

6. cross-sectional area of inlet ___________(%)
7. if less than 100%, reason for reduction

dented	1
cutbank slumpage	2
sediment	3
organic debris	4
2 or more of above	5
dented and sediment	6

8. inlet slope ___________(%)
9. comments___________

VI. <u>Pipe Characteristics</u>

A. Placement

1. skew angle ___________( )
2. overall slope ___________(%)

B. Other

1. pipe material

wood	1
CSP	2
CAP	3
concrete	4
CSP, asphalt	5
CAP, asphalt	6

2. if corrugated

a. type

helical	0
annular	1

b. pitch (inches)

2.0	1
2.5	2
3.0	3
3.5	4

c. depth (inches)

0.50	1
0.75	2

3. pipe diameter __________(in)
4. interior defects? Y N
5. if yes, % of diameter

crowning __________%
sagging __________%

6. cross-sectional area ___________(%)
7. if less than 100%, reason for reduction

dented	1
sediment	2
organic debris	3
2 or more of above	4

8. height of watermark __________(in)
9. length of pipe __________(ft)
10. comments___________

VII. Outlet Conditions

A. Pipe characteristics

1. outlet slope ________(%)
2. distance invert projects (horiz) ________(ft)
3. distance invert projects (vert) ________(ft)
4. outlet capacity as % of original ________(%)
5. if less than 100%, reason for reduction

dented	1
sediment	2
organic debris	3
live plants	4
2 or more of above	5

6. comments ________________________________

B. Characteristics of slope at outlet

1. stability of slope at outlet

stable	1
intermittant erosion	2
erodible	3

2. size of outlet erosion

length__________ft
width__________ft
depth__________ft

3. energy dissipation structures

none	0
downspout	1
other	2

4. if downspout, slope of downspout ________(%)
5. outlet fill slope, general slope ________(%)
6. particle size at outlet

<=1/2"	0
<=1"	1
<=2"	2
>2"	3

VIII. Other

A. Road ownership

USFS	0
BLM	1
State	2
Private	3

B. Distance to nearest upditch diversion _______(ft)

C. Comments ________________________________

D. Soil samples taken? Y N

Stream Crossing Culvert Field Sheet

Culvert #_______
Date_______

I. Upstream Conditions
A. Approximately 10 pipe diameters upstream
1. general channel slope _________(%)
2. organic debris inventory
a. amount

none	0
1-5 pieces	1
5-10 pieces	2
>10 pieces	3

b. size

small (<4" diameter)	1
medium (4-10" diameter)	2
large (>10" diameter)	3
combination of sizes	4

3. typical particle size of bed _________(in)

B. Within 1/2 pipe diameters
1. channel slope __________(%)
2. typical particle size of bed _________(in)

C. Comments ____

II. Inlet Conditions
A. Elevations
1. road surface above invert _________(ft)
2. lowest point above invert _________(ft)

B. Entrance type

projecting	1
mitered	2
headwall	3
other	4

C. Cross-sectional area of inlet __________(%)
D. if less than 100%, reason for reduction

dented	1
sediment	2
rocks	3
organic debris	4
2 or more of above	5

III. Pipe
A. Overall slope __________(%)
B. Pipe characteristics
1. pipe material

wood	1
CSP	2
CAP	3
concrete	4
CSP, asphalt	5
CAP, asphalt	6

2. if corrugated
   a. type

	helical	1
	annular	2

   b. pitch (inches)

	2.0	1
	2.5	2
	3.0	3
	3.5	4

   c. depth (inches)

	0.50	1
	0.75	2
	1.00	3

3. pipe diameter ________(ft)
4. length ________(ft)
5. interior defects

	none	0
	compressed	1
	deformed	2
	crowned	3
	sag	4
	corroded	5
	other	6

6. cross-sectional area of interior _________(%)
7. height of watermark ________(ft)
8. comments ____

IV. Other

A. Elevation of culvert invert in comparison to downstream water surface ________(ft)

B. Road ownership

	USFS	0
	BLM	1
	State	2
	Private	3

C. Comments ____