TFW-MAGI-99-001

TFW Effectiveness Monitoring Report

FOREST ROAD DRAINAGE AND EROSION INITIATION IN FOUR WEST-CASCADE WATERSHEDS

by:

Curt Veldhuisen and Periann Russell

June 1999

Prepared for
the Timber/Fish/Wildlife Monitoring Advisory Group
and the Northwest Indian Fisheries Commission.

This project was partially funded by
the Washington Department of Ecology through the Centennial Clean Water Fund

Abstract

This monitoring project was undertaken to evaluate erosion initiation a! road drainage release sites along forest roads in four watersheds located across western Washington. A primary goal was to evaluate the effectiveness of regulatory approaches--Washington Forest Practices Rules and Watershed Analysis--at preventing road drainage erosion. 'The influence of numerous terrain attributes, geologic and hydrologic factors on erosion initiation was explored as well. Monitoring covered 4-5 road segments in each watershed; most involved roads located in relatively steep terrain and built prior to the 1970s. These road segments allowed evaluation of 200 "drainage sites", here defined as points where road runoff is diverted (sometimes unintentionally) away from the roadway onto a hillslope. Crossing structures involving any type of stream were not evaluated as drainage sites.

Among all drainage sites, we found gullies at 35%. Most gullies were less than 60 feet long and about half delivered sediment to a stream Landslides were found at 15% of drainage sites, most of which where drainage had been temporarily diverted due to a ditch obstruction. Eighty percent of landslides reached a stream. The prevalence of erosion features (gullies plus landslides) tended to increase with hillslope gradient at the drainage release point. Gullies were found across the range of slope gradients. Although several landslides were found in the 60-79% slope range, the remaining major-ity occurred where slopes were 80% or steeper. Hydrologic influences to erosion initiation were explored by evaluating the road surface area draining toward each release site Among drainage sites involving slopes of less than 60%, erosion features were no! associated with the contributing road surface area, but rather with sites where sub-surface flow was intercepted by the road cut. In contrast, the contributing road surface area appeared to influence erosion initiation on slopes of 60-79%. Where drainage was released onto slopes of 80% or steeper, erosion initiation was common (66% of sites) across the range of road surface areas and slopes, suggesting that such steep hillslopes are fairly sensitive to most any quantity of road runoff. Drainage sites in areas underlain by hard geologic materials (e.g., basalt) experienced somewhat less erosion initiation within comparable road drainage contributions as sites in softer materials (e.g., glacial sediments).

We compared erosion initiation among two sub-groups of roads built prior to 1974 to evaluate the effectiveness of post-construction drainage upgrading practices. Though total erosion rates were fairly similar between the sub-groups, we found the upgraded roads to have slightly fewer landslides, but more gullies. Despite the limited extent of this test, this implies that a critical approach to drainage upgrading may be needed to achieve the sediment reduction benefits that justify the upgrading of older forest roads.

Present Fores! Practices Rules, designed as they were to prevent erosion <u>within</u> the roadway, were generally found to be ineffective at preventing erosion <u>below</u> drainage sites along monitored roads. We found that Watershed Analysis (WA) erosion assessments did not specifically identify the extent of road-drainage erosion features we found. In addition, WA landslide hazard maps were not very effective at predicting the locations of erosion initiation, though this appears to result primarily from map resolution limitations. From our monitoring data we developed criteria for identifying sites needing closer drainage spacing than required by existing spacing rules.

TABLE OF CONTENTS **PAGE**

LIST OF TABLES AND FIGURES

Tables

Figures

ACKNOWLEDGEMENTS

This project was funded through a Centennial Clean Water Fund Grant from the Washington Department of Ecology. Grant initiation and administration was provided by the Northwest Indian Fish Commission's Timber/Fish/Wildlife Monitoring Program; administrator Dave Schuett-Hames was very helpful throughout the project. We also appreciate the contribution of the TFW Monitoring Advisory Committee toward project advising, oversight and review.

Field monitoring would not have been possible without the cooperation of the forest landowners and agencies listed below that provided access to field sites. Numerous individuals at these organizations contributed by supplying watershed analysis information, GIS products and anecdotal information on road management history

Champion Pacific: Mike Liquori, Doug St. John, Matt 'Walsh
Mt. Baker/Snoqualmie National Forest: Roger Nichols
Olympic Resource Management: Brian Carbaugh, Tim Raschko
Rayonier: Julie Dieu, Scott Katzer, Bill Peach
Weyerhaeuser: Kate Sullivan, Warren Sorenson, Joan Persinger

Lastly, we appreciate our field assistants that helped in rain and shine: Matt Rubino and Andy Heiser.

INTRODUCTION

Road Drainage Release and Erosion

In Washington watersheds used for forestry, logging roads at-e often responsible for erosion that can affect water quality and fish Ihabitat. Discrete erosion features, such as gullies or landslides, commonly occur where sizable volumes of road runoff are released. Roadside ditches accumulate runoff from road surfaces and/or subsurface flow intercepted along the road cut. In some cases, accumulated runoff may trigger erosion within the roadway, such as incision into the ditch. Erosion may also be triggered below the roadway when drainage water is diverted either at an intentional drainage release point or inadvertently, due to drainage malfunction such as a blocked ditch (Dyrness 1967). Because erosion occurring below a road is typically less conspicuous than erosion within the roadway, the frequency and overall impacts of erosion occurring below drainage outfalls may be inadequately recognized (Pentec 1991).

Washington Regulatory Approaches

Washington Forest Practice Rules attempt to minimize erosion from road runoff by 1) limiting the road length along which runoff is accumulated, and 2) avoiding discharge onto unstable locations (WAC 222-24-025 (6&7) in WFPB 1995). Thouyh the stated objective of drainage spacing restrictions is to avoid erosion&the roadway, reducing the accumulating road length is likely to reduce erosion below release points as well. Present rules include two sets of spacing standards that require closer drainage spacing with increasing road gradient (Table 1). The distances included within the Standard Rules text (WAC 222-24-025 (7)) presumably apply to general west-side conditions. The shorter "Additional recommendation" distances that appear in the Board Manual are intended for use in areas with "site specific evidence of peak flows or soil instability". In addition, the text in WAC 222-24-025 (6) provides narrative guidance to avoid diverting road runoff onto "erodible soils or over till slopes unless adequate outfall protection is provided". Although these guidelines have been in place for many years (Appendix I), relatively little information is available that documents: (1) how many existing forest roads comply with these rules, and (2) whether compliance with these rules is successful at limiting erosion from road drainage.

Since 1992, Watershed Analysis prescriptions have created basin-specific strategies to supplement standard rules in basins where this process has been applied. Analyses commonly identify road segments or portions of the hillslopes termed "Mass Wasting Map Units" where road-related landsliding has been documented. Information on past erosion supports focused management prescriptions that may involve road construction, maintenance and/or improvement. As yet, there is little data available by which to judge the effectiveness of the Water-shed Analysis approach to reducing erosion from road runoff or other contributing factors.

Another strategy for reducing road drainage et-osion may result from recent research (Montgomery 1994) that explores factors that influence-erosion initiation at drainage release points along forest roads. This study, conducted on ridge-top logging roads in western Oregon and Washington, found that gully and landslides at drainage release points could be predicted as

Table 1. Forest Practice Rules standards for **maximum cross-drain** spacing distances in western Washington (WFPB 1995).

Road gradient[1]	Maximum cross-drain spacing distances under: Standard Rules (WAC 222-24-025(7))	Additional culvert spacing recommendations[2]
0-4%	1000’	1000’
5-6%		840’
7%		600’
8%	800’	
9-10%		460’
11-12%		380’
13-14%		320’
15%		280’
16%	600’	
17-18%		250’
>18%		No guidance provided

1 – Average sustained road gradient.

2 For roads with "... site specific evidence of peak flows or soil instability... ". Distances are reproduced from Table 3 (page M- 17) in the Board Manual (1995).

a function of both the contributing road surface area draining toward the release point and the local hillslope gradient. Although this study offers a relatively simple approach to identify road conditions that produce erosion, broader testing would be required prior to widespread implementation within a regulatory format.

Monitoring Questions

The goal of this project was to collect information that would help determine the effectiveness of forest practice rules and Watershed Analysis prescriptions at preventing erosion initiation at road drainage release points, exclusive of stream crossings. The project was framed by three primary Monitoring Questions:

1. How common are landslides and gullies at cross-drain locations and where do they occur?
   a) Which on-site characteristics (e.g., slope gradient, road surface area, sub-surface flow interception, slope form, rock types, climate) correspond to sites more prone to erosion initiation?
   b) Can roads of similar erosion susceptibility be defined on the basis of Erosion Situations (i.e., the combination of road construction type and the corresponding terrain/geologic attributes)?

2. Are Washington regulatory standards for location of "cross-drains" effective at preventing erosion initiation?
   a) If there are locations where regulatory approaches are ineffective, are there site-specific attributes (e.g., items in #la above) that will allow their identification?

3. Does Watershed Analysis identify locations of road drainage erosion and address them effectively?
   a) Are erosion features concentrated where roads pass through areas mapped as High or Moderate mass wasting hazard?
   b) Do mass wasting and surface erosion assessments identify hazards from erosion from drainage release points in adequate detail for field identification?
   c) Are prescriptions typically specific enough to direct managers toward appropriate action?
   d) Are prescriptions being implemented properly to provide reduced resource impacts in most cases?

Note: These Monitoring Questions have been modified somewhat from those in the Monitoring Plan to better cover the intended scope of the study.

General **Hypotheses**

Monitoring questions were addressed by testing the following hypotheses regarding erosion at road drainage release points:

A Erosion features (i.e., landslides and gullies) will be found at both intentional release points and elsewhere, due to temporary drainage malfunction.
B. Erosion response to road drainage will differ between basins due to differences in geology and precipitation inputs.
C. Differences in erosion response will correspond with factors involving both hillslope conditions (slope gradient, form and geology) and runoff generation (surface and subsurface flow).
D. Differences in erosion response will correspond with different Erosion Situations.
E. Erosion features will be more common where drainage spacing exceeds standards provided in Washington Forest Practices Rules.
F. Differences in erosion response will correspond with Mass Wasting Map Units and associated hazard ratings.

STUDY LOCATION AND METHODS

Study Watersheds

Monitoring occurred in four Watershed Administrative Units (WAUs) located west of the Cascades that have been covered by Watershed Analysis (Figure 1, Table 2). The WAUs were selected to provide a broad geographic range and represent climatic and landform attributes typical of forested areas of western Washington The four watersheds include a northern and southern representative of both the coastal and western Cascade Mountains (Figure 1).

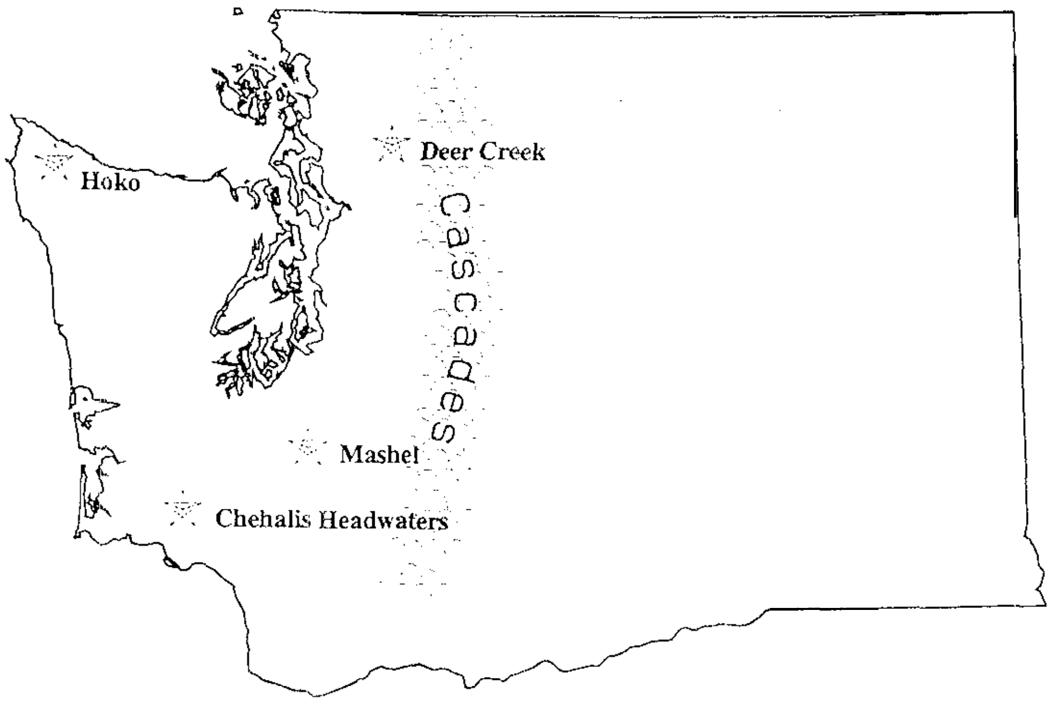


Figure 1. Location of Watershed Administrative Units (WAUs) in Washington involved in road monitoring project.

Table 2. Watershed Administrative Units involved in road monitoring project

Watershed (WAU#)	Year Analysis completed	Location & central township	Primary landowner(s)	Contact
Deer Creek (050201)	1996[1]	NW Cascades: T.31N., R.7E.	USFS – Baker/Snoq. NF John Hancock Insurance[2]	Roger Nichols Tim Raschko
Mashel (110204)	1996	SW Cascades: T.16N., R.5E.	Champion Pacific	Mike Liquori
Chehalis Headwaters (230115)	1994	Willapa Hills: T.11N., R.5W.	Weyerhaeuser Co.	Kate Sullivan
Hoko (190302)	1997	NW Olympics: T.31N., R.13W.	Rayonier	Julie Dieu
1 - Assessment completed in 1996. Prescriptions nearing finalization at time of this report.				
2 - Hancock forest lands are managed by Olympic Resource Management, Inc.				

Land ownership within the four WAUs is predominantly industrial and interest shown by landowners was an important factor in WAU selection.

Each watershed contains a sizable network of forest roads, including many that pass through steep terrain. 'These WAUs were generally roaded and logged initially in the 1940s through the

1970s. The US Forest Service ownership in the eastern portion of the Deer Creek WAU is a minor exception in that the initial timber-harvest phase extended well into the 1970s and 80s (Roger Nichols, USFS, personal communication), As a result, most of the roads in each of the WAUs were built prior to the initial Forest Practices Rules in 1974. The past two decades have seen reduced rates of new road construction and increased activity in upgrading of drainage and earthwork (e.g. fill-slope pull-back) along many existing roads.

Key geologic and hydrologic attributes of the WAUs are summarized in Table 3. The geologic settings of all WAUs are dominated by Tertiary volcanic and sedimentary rock types. Volcanic rocks in the Hoko and Chehalis basins consist of Crescent formation basalts, which underlay the steeper terrain, in contrast to the breccias in the Mashel, which are considerably softer. Glacial sediments cover extensive portions of the Deer Creek basin, and smaller portions of the Hoko and Mashel basins. The climates of these WAUs are fairly typical of mountainous portions of western Washington; each receives moderate to high precipitation annually, mostly coming as rain. The two coastal basins (Chehalis, Hoko) receive both greater amounts of total precipitation (Table 3) and greater storm rainfall intensities (Miller et al. 1973). The Cascade watersheds (Deer, Mashel) experience a greater hydrologic influence of fall/winter rain-on-snow and spring snowmelt runoff. All watersheds experienced large rainfall events during the three winters prior to monitoring (Table 3). Storm precipitation data presented in 'Table 3 should be viewed as generally indicative of conditions at the road segments, since recording stations are far enough from monitoring sites (i.e., 10-20 miles) to experience considerable differences in rainfall intensity. With the possible exception of the Mashel values (from Longmire), weather station rainfalls probably underestimate the amounts at the monitoring sites, which are located at higher elevations.

Table 3. Geologic and precipitation characteristics of road monitoring sites

WAU	GEOLOGY	PRECIPITATION: prevalent form(s)	average annual total	large precipitation events[1] in Water Years[2] 96, 97 & 98: date	4-day rainfall	greatest 24-hour
Deer	Tertiary sedimentary & volcanic rock, glacial-lacustrine and outwash sediments (Ts, Qs)	rain, snow	80-100"	11-8-95	8.2"	5.0"
				2-8-96	7.5"	3.4"
Mashel	Tertiary volcaniclastics & sedimentary rock, glacial till (Tvba, Tpg, Qt)	rain, snow	70-90"	11-29-95	11.9"	6.0"
				2-8-96	11.0"	3.5"
Chehalis	Tertiary volcanics: breccias and basalt flows (Tcb)	mostly rain	100-120"	2-8-96	10.3"	3.4"
				4-23-96	8.4"	5.2"
Hoko	Tertiary basalts & sedimentary rock, glacial till (Tcb, Qt)	mostly rain	120-130"	3-19-97	13.1"	5.7"
				1-23-98	9.1"	4.9"

1 From precipitation data collected Longmire (Mashel), Darrington (Deer), Frances (Chehalis) and Forks (Hoko) recording stations (NCDC 1995-98). For a variety of reasons, actual amounts of rainfall may have been considerably different from these values at the monitoring sites.

2 - The "Water Year" is the 12-month period beginning October I of the previous calandar year.

Road Segment Selection

All monitored road segments consist of rock-surfaced logging roads that are driveable and receive regular maintenance (e.g., grading ditch clearing). The available field time allowed us to monitor four or five road segments per WAU, each chosen to represent locally problematic "Erosion Situations". The "Erosion Situation" concept is defined as a combination of a road construction type and a terrain setting. Erosion Situation #1 serves as an example: "Sidecast roads built prior to 1974 on the slope break between lacustrine sediment deposits and bedrock". Eight Erosion Situations were identified from preliminary discussions with land managers and are documented in the Monitoring Plan (Russell and Veldhuisen 1998a). During field reconnaissance, we found it difficult to find road segments that represented a given Erosion Situation for a sufficient length. Although we could find short road lengths of any Erosion Situation, seldom were both the road and landscape conditions consistent enough over a sufficient road length to cover enough drainage points to serve as a monitoring segment. Given this limitation, the monitoring segments chosen provide fairly uniform road conditions with respect to construction and maintenance but cover more variable terrain than was originally intended. Discussions with local road managers and review of mass wasting maps from the Watershed Analyses were very useful during the segment screening process. 411 segments cross some steep terrain (Table 4) and contain one or more erosion feature.

Once a road segment was selected for monitoring an easily identifiable starting point was selected, typically a road junction. From there, data collection proceeded until IO-15 non-stream crossing drainage sites had been included. The only exception was the Hoko road #6220.1, an older spur with a recently constructed extension that contained only eight drainage sites in total. Due to the mixed construction standards, this road was unsuitable for analyses by Erosion Situation, but was included in other analyses. The substantial differences in drainage spacing among roads resulted in segment lengths ranging from 0.5 to 2.2 miles (Table 4).

Field Data Collection

Field data collection at each segment involved two scales of observation: 1) local conditions associated with each "drainage site" where road drainage is released; and 2) general observations that indicate the road's effectiveness along the entire segment relative to several road design functions. The following discussion provides a brief description of field methods; for further details on data collection protocol, consult the Field Methodology document (Russell and Veldhuisen 1998b).

"Drainage sites" were identified as locations whet-e concentrated road runoff is [released from the roadway, typically involving a culvert, or in some cases, a water bar, "ditch-out" or "low spot" (Figure 2). As is typical of Washington forest roads, all segments had an inboard ditch to carry road runoff, including runoff from the road surface and, in many cases, subsurface flow intercepted along the cutslope. Subsurface flow interception was identified as present or absent

Table 4. Characteristics of Road Sample Segments.

Road - locations shown on Appendix 2	Appr year built[1]	Status[2]	Segment length (miles)	Average tread width (feet)	Average road gradient	Average culvert spacing (feet)	Prevalent slope position	Hillslope gradient[3]	
								ave.	max.
DEER									
Mud Lk. Rd	50s	U	1.1	21'	10%	308'	lower&mid	44%	80%
Rick Cr. Rd.	L 50s	N	2.2	20'	6%	605'	mid	54%	70%
USFS #17	L 50s	U	1.0	22'	3%	219'	mid	56%	80%
USFS #1810	L 60s	U	0.8	18'	9%	400'	upper&mid	70%	80%
MASHEL									
Champ. #3a	40s	N	1.8	27'	2%	1550'	mid	65%	74%
Champ. #3b	50s	U	1.3	32'	2%	354'	mid	38%	85%
Champ. #31	60s	N	1.5	26'	6%	718'	mid	53%	90%
Champ. #326	L 40s	U	1.0	24'	5%	394'	mid	39%	80%
CHEHALIS									
Wey. #1150	50s	N	1.6	34'	4%	961'	upper&mid	82%	95%
Wey. #1270	70s	U	1.3	25'	3%	496'	mid	64%	120%
Wey. #1060	70s	N	2.2	23'	6%	825'	mid	69%	97%
Wey. #2500	L 60s	U	2.1	28'	8%	572'	lower&mid	71%	95%
HOKO									
Raynr. #9000	30s	U	1.4	25'	3%	501'	lower	56%	80%
Raynr. #9202	50s	U	0.9	20'	3%	455'	mid	69%	85%
Ray. #6220/ 6221	70s	U	1.7	16'	14%	884'	mid&lower	53%	75%
Ray. #6220.3	90s	C	0.5	18'	18%	324'	upper&mid	46%	70%
Ray. #6220.1	60s& 90s	N/C	0.8	15'	7%	669'	upper	54%	80%

1 - L = late, e.g., "L40s" indicates the road was built in the late 1940s

2 Drainage status: U = upgraded, N = not upgraded, or C = built to current standards.

3 - Based on slopes at drainage release points

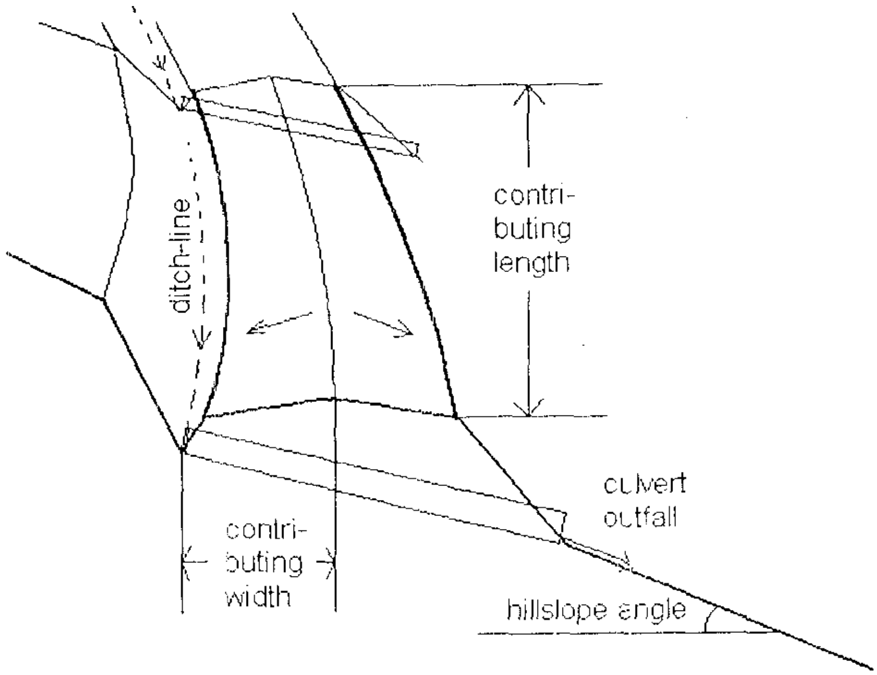


Figure 2. Illustration of typical drainage site: runoff is collected in an in-board ditch, then routed through a culvert onto the hillslope below. The road area that contributes surface runoff *is* equivalent to the *contributing* length multiplied *by* the *contributing* width. Because the tread surface in the case illustrated is crowned, only the inner portion of the tread contributes runoff to the ditch.

based on water in ditches between trains and/or wet site vegetation. Culverts that function as stream crossings were not analyzed with other drainage sites because the presence of a stream channel would prevent a clear determination of whether the road runoff would have initiated a landslide or gully. Channel enlargement or upslope extension to a cross-drain was noted where obvious, but were not evaluated as separate erosion response types due to various inherent difficulties in assessment.

Data collected at each drainage site included the structure type (culvert, water bar, etc.), size, and presence of a flume or outfall energy dissipator. Road dimensions collected included road width, contributing length and the average ditch gradient. The portion of the total tread width that drains toward the ditch was estimated to the nearest 10% to allow calculation of the contributing road surface area. Numerous attributes were documented at the area directly below the drainage release including hillslope gradient and form (i.e. concave, planar or convex), vegetation type, and ground surface roughness. The presence or absence of a gully or landslide was recorded, with the dimensions of the erosion feature, material eroded (i.e. side-cast vs. *in-situ* soil), and activity level. All of these drainage site attributes were collected on a table-style field form, which was supplemented by a field sketch of the segment.

Effectiveness Summary forms were completed after field monitoring of each road segment. The data form prompts comments on the segment-scale effectiveness of the existing road conditions at providing five key road drainage and stability functions: I) Runoffcontrol, 2) Stream crossing, 3) Cut and fill practices, 4) Location and engineering relative to unstable slopes, and 5) Surface erosion control. The observer documented how well the segment provides each function, any evidence of past shortcomings, and a conclusion indicated with a Yes/No effectiveness rating for each function. Conclusions were based on the overall extent of ongoing deficiencies.

Quality Assurance

Because many of the data items are qualitative in nature or involve some interpretation, quality assurance was considered critical to minimize potential bias. In addition to creating a detailed field methodology document for field consultation (Russell and Veldhuisen 1998b), the primary approach to data quality was extensive field calibration between the two primary contractors prior to monitoring. The contractors spent several field days refining the field methodology and did the first two road segments together. A portion of one road segment was evaluated independently by both contractors, to identify and better define criteria for data elements prone to inconsistency. Field conditions at all of the remaining road monitoring were interpretted by one or the other primary contractor, The few subsequent questions and concerns were resolved verbally as they arose. For data items derived from direct measurement, the levels of precision and accuracy provided by standard field measurement techniques (e.g. hip chains, clinometers, etc.) werejudged to be adequate for these purposes, given the extensive past field experience of the contractors.

Data Analysis

Field data were entered into spreadsheets, with individual drainage sites serving as the primary data element for analysis. Most analysis involved manipulation of spreadsheet data via comparisons and frequencies. We were not able to use conventional statistical analysis, because segments were chosen to fit Erosion Situations, rather than randomly. lnitial analysis relied primarily on sorting drainage sites to identify whether differences in erosion response correspond with various potentially contributing factors. An important secondary analytical tool was the hillslope gradient/drainage area X-Y plot (to be referred to subsequently as a “slope/area” plot), as used by Montgomery (1994)~ This plot type was particularly useful because it illustrates how a group of erosion features relate to simple indices of hillslope erodibility (i.e., gradient) and runoff accumulation (i.e., road surface area).

We found that the IO-15 drainage sites evaluated in each road segment allowed a decent characterization of conditions on that road. However that number was insufficient to evaluate the influence of hillslope gradient, drainage areas or other characteristics on an individual segment basis. This was not a major limitation, because most analyses could be done using various pools of individual drainage sites, combined on the basis of watershed, various terrain attributes, Erosion Situations, compliance with cross-drain spacing regulations and mass wasting hazard ratings from Watershed Analysis.

A great number of hypotheses were tested using our data, including many secondary hypotheses not listed above. The following discussions document the findings regarding key hypotheses as well as certain productive secondary hypotheses. The remaining, secondary hypotheses that could not be supported one way or another or adequately tested are listed in Appendix 3.

RESULTS AND DISCUSSION

Erosion Response at Drainage Sites

Erosion feature frequency and delivery

Among all drainage sites, SO% were associated with either a gully (35%) or landslide (15%)(Table 5). Most "erosion features" (i.e., a gully or landslide) had delivered sediment to a stream channel, including 80% of all landslides (Table 6). The majority of gullies extend less than 60 feet below the drainage release point (Figure 3) before infiltrating and few of these relatively short gullies reach streams. However, a sizable minority (18%) of gullies extends over 100 feet below the outfall, resulting in higher levels of concern for both reaching a stream and then contributing larger volumes of excavated sediment. Among the 29 landslides encountered, only six (21%) occurred at deliberate drainage release points. 'The remaining majority (79%) had presumably resulted from incidental drainage diversions resulting from storm-related ditch blockages. Based on vegetation and other field indicators, most landslides inventoried had occurred within the past decade, though many appeared to pre-date the 1996197 storm events. Due to advance revegetation and uncertain drainage conditions, some landslides older than approximately 20 year may have been missed

Table 5. Frequency of gullies and landslides among drainage sites in each watershed

	Erosion Response Category						Total sites	Total sites with a gully or landslide	
	Gully		Landslide		No erosion feature				
Watershed	#	%[1]	#	%[1]	#	%[1]	#	#	%[1]
Deer	17	*33*	10	*20*	24	*47*	51	27	*53*
Mashel	17	*34*	6	*12*	27	*54*	50	23	*46*
Chehalis	20	*42*	8	*17*	20	*42*	48	28	*58*
Hoko	16	*31*	6	*12*	29	*57*	51	22	*43*
Total – all WAUs	70	*35*	30	*15*	100	*50*	200	100	*50*

1 – Percent among total sites in each watershed

Table 6. Proportion of gullies and landslides that delivered sediment to a stream in each watershed. The total numbers of erosion features are shown in Table 5.

Watershed	Delivery (%)	
	Gully	Landslide
Deer	47%	50%
Mashel	53%	100%
Chehalis	60%	100%
Hoko	81%	83%
Total all WAUs	63%	80%

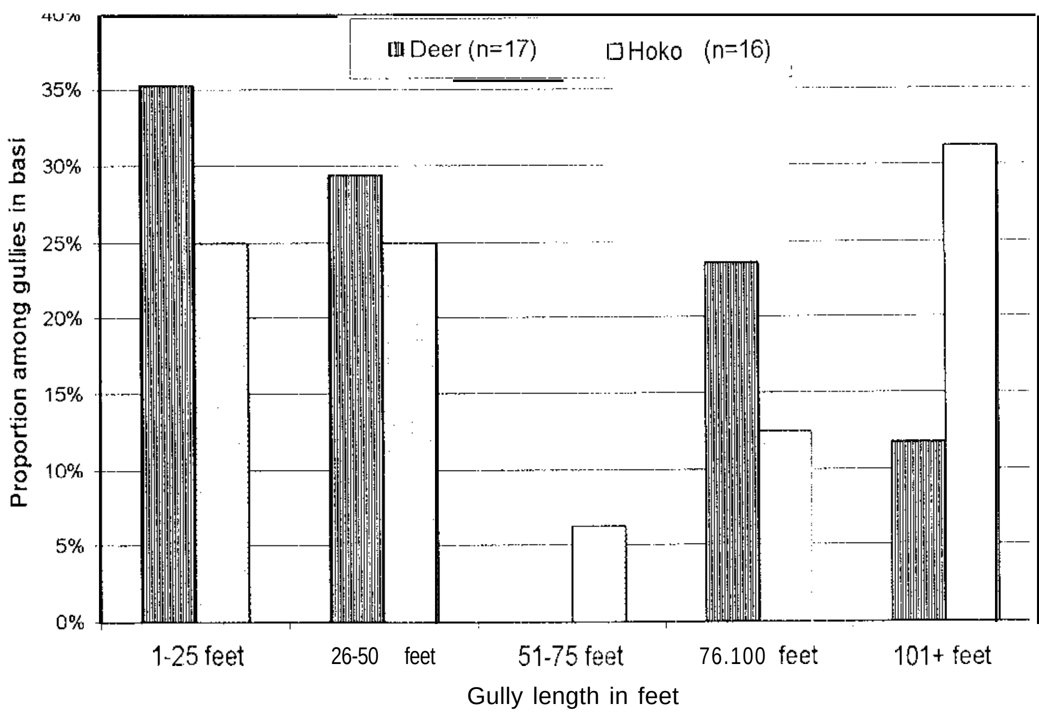


Figure 3. Distribution of gully lengths encountered in the Deer and Hoko road segments. Although most gullies are less than 60 feet long, a sizable minority extends substantially further downslope. The available gully lengths for the Mashel and Chehalis segments, tbough incomplete, suggest a similar trend.

Erosion response among WAUs

Despite the substantial differences among WAUs in terms of geology, hydrology, road construction and ownership (Tables 2. 3 and 4), overall rates of erosion response to road drainage were not substantially different between the four WAUs. The combined frequencies of gullies and landslides ranged from 43-58% of drainage sites inventoried in each WAU (Table 5). The Chehalis had a somewhat higher frequency of erosion features (Table 5), though it stands out as having a high number of release points involving steep slopes (Table 4), a subject of further discussion later. The Chehalis also had slightly more gullies than other basins, while Deer Creek had a relatively high number of landslides. There was little to suggest any overriding response to the hydrologic differences between the rain-dominated coastal basins (Chehalis, Hoko) vs. the more rain-on-snow influenced west-Cascade basins (Deer, Mashel).

Erosion responses relative to terrain and road drainage characteristics

Hillslope gradient effects

Among the combined data set, the frequency of erosion features increases strongly with increasing hillslope gradient at the drainage release point (Figure 4). On slopes less than 60%, gullies *were* found at approximately one third of drainage sites. though no landslides were encountered. The occurrence of gullies and the absence of landslides suggest that this gradient range is insufficiently steep for soil to slide, even with the contribution of road runoff. Gullies are least frequent within the gentlest slopes (O-1 9%), but occur commonly on slopes between 20 and 59%. On slopes of 60% or greater the frequency of gullies increases substantially, and landslides are found at a number- of sites. Landslide frequency increases substantially for sites involving slopes exceeding 80% (Figure 4), the range which contained the greatest total erosion response.

Combined hillslope gradient/road surface area effects

Given the strong overriding influence of slope gradient on erosion initiation, many subsequent analyses utilized slope/area plots such as Figure 5 as a means of characterizing secondary influences to et-osion occurrence. Our assumption was that the influence of secondary factors that could influence erosion initiation, such as geologic type or slope form, would be indicated by a shift in the surface area required to initiate erosion. Fiyure 5, which shows drainage sites from all four WAUs, serves to illustrate certain erosion tendencies that pertain across all watersheds. Inspection of erosion responses as a function of slope in Figure 5 illustrates certain differences between three hillslope gradient categories: 0-59%, 60-79% and SO+%. These slope categories capture not only the differences in erosion response discussed previously, but important differences in sensitivity to runoff generated from road sut-face and subsurface sources

Among drainage sites involving slopes of 0-59%, there is little evidence that gullying increases in response to either slope gradient (Fiyure 4) or road sut-face area (Figure 5). Such increases would be expected based on both physical principles and empirical observation by Montgomery (1994). We suspect that much of the variability in erosion response within this slope range results from localized gains or losses of ditch-flow via either sub-surface flow interception or infiltration, as is discussed further in the following section

For drainage sites in the 60-79% range, erosion features are less common at sites that receive runoff from a relatively small road surface area, Although there is no consistent surface area threshold, the downward-sloping line indicated in Figure 5 distinguishes the road surface areas below which erosion features were found at less than 50% of sites. This apparent response to road surface area suggests that slopes in this range are quite sensitive to increased water inputs such as road runoff especially as slopes approach 80%. The implications for road drainage design are discussed in the subsequent "management recommendations" section

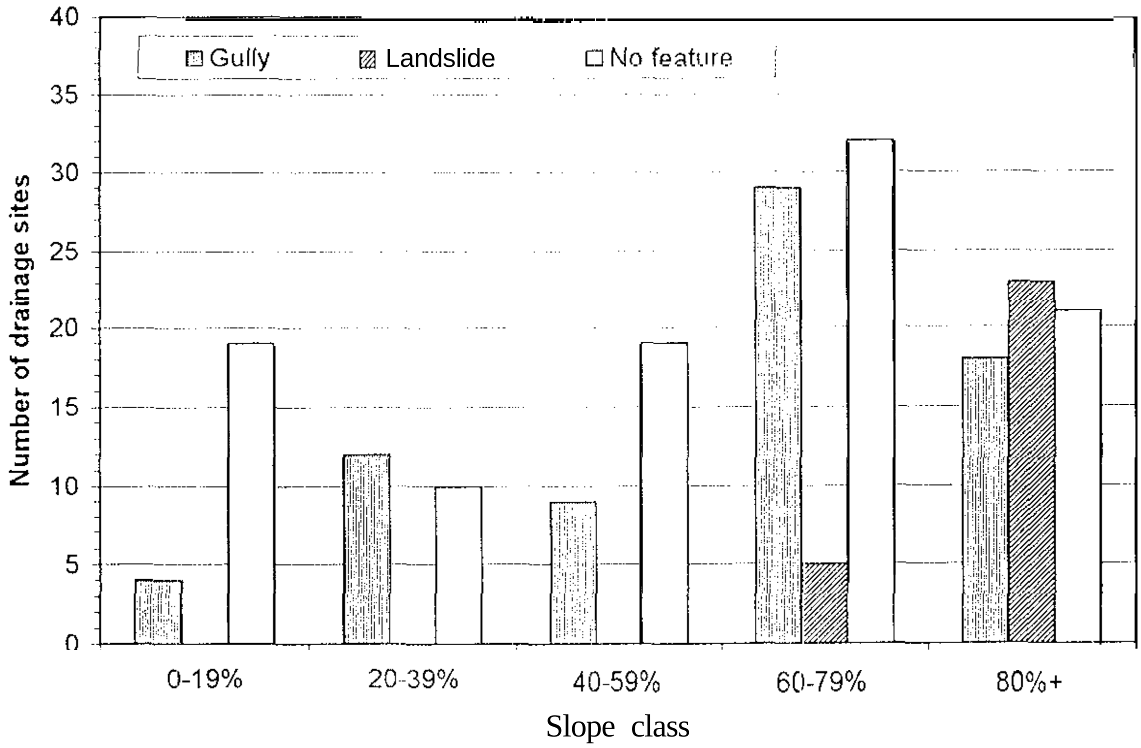


Figure 4. The proportion of sites with erosion features increases substantially relative to hillslope gradient. In particular, note that most landslides were associated with slopes of 80% and greater. A positive correlation is apparent between slope gradient and gullying, but is less consistent.

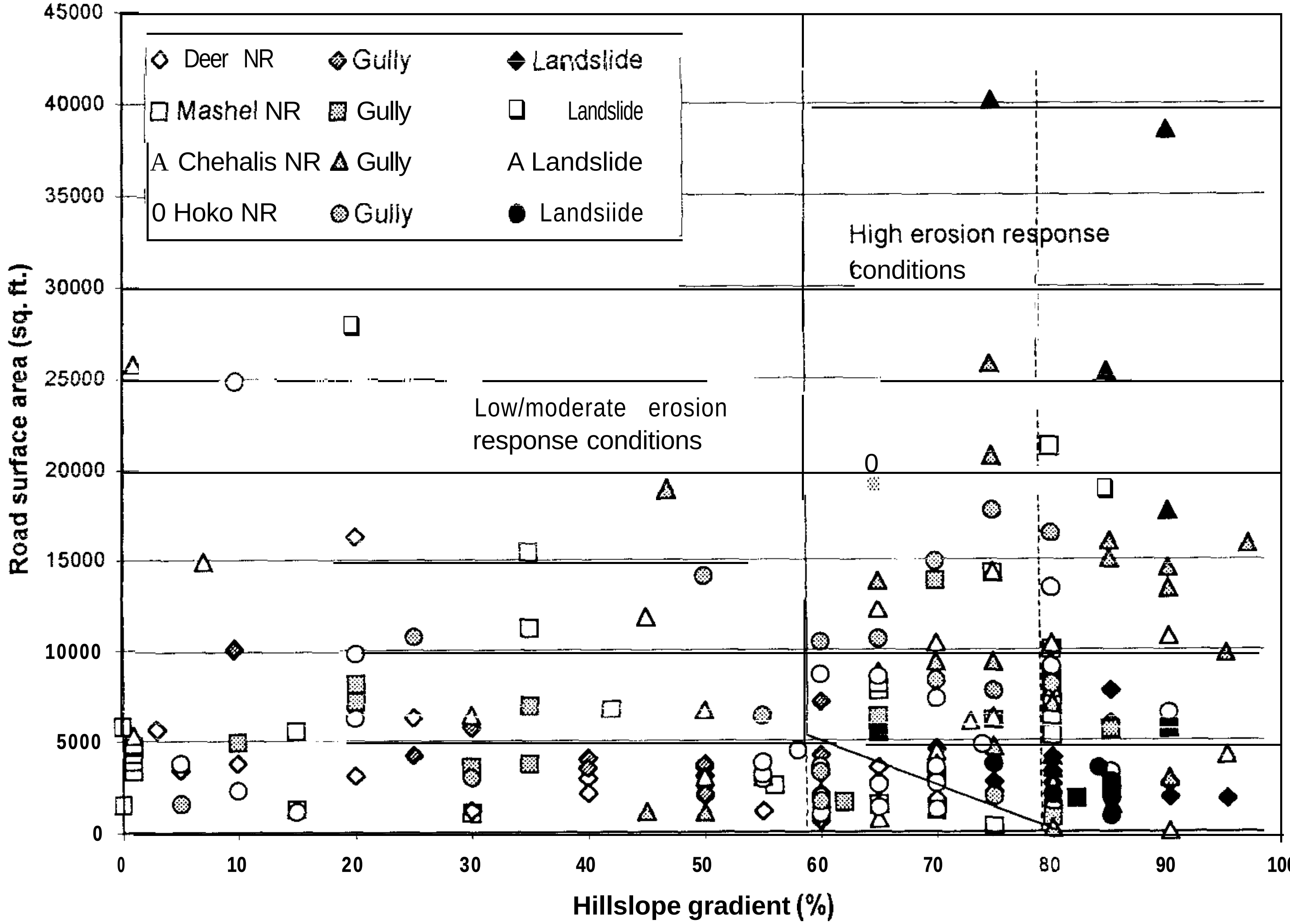


Figure 5. Plot of slope vs. road surface area of drainage sites from all four **WAUs.** The marker shape indicates the watershed (see legend). The marker fill indicates the erosion response: hollow markers had no erosion response **("NR"),** gray-shaded centers indicate a gully, while solid centers indicate a landslide. Four outlier points are not within range of values shown.

For sites with slopes of 80% and greater, the many gullies and landslides were found across the range of slopes and road surface areas sampled (Figure 5). Given that undisturbed slopes of 80% and greater are normally considered to be marginally stable, it is also notable that nearly one-third had no erosion feature (including the study's steepest site a: 120%!), even with the addition of road drainage water. Such sites may remain stable due to rapid infiltration and dispersal of road runoff, or the presence of very rocky soils with a high angle of repose. Despite these exceptions, these data illustrate that release of road runoff onto slopes of 80% or greater, whether deliberately or not, is quite likely to initiate erosion

Subsurface flow interaction effects

One surprising observation from Figure 5 is that numerous gullies occur at drainage sites characterized by both low slope gradients and relatively small road surface area. We suspect that many of these gullies result from supplementation of road surface runoff with inputs from interception of shallow groundwater. As shown in Figure 6, many of the low gradient erosion sites with small surface areas occurred below ditches observed to receive seepage inputs. This suggests that the addition of subsurface flow may substantially increase the likelihood of gully erosion at the release point. The added flow from seepage appears to have the greatest effect on slope gradients below 60%, where seeps were associated with three-fourths of the erosion features encountered. Cutslope seepage contribution was associated with numerous erosion features on high slopes as well, including many with low road surface areas (Figure 5). However, because half of the erosion features on higher slopes had no seepage contribution evident, we conclude that road surface runoff alone is commonly sufficient to trigger erosion.

Similarly, the potential for loss of road runoff due to ditch infiltration may explain several of the sites where very large surface areas failed to produce any erosion feature. At some non-eroded drainage sites located below very long contributing road lengths. the road was noted to pass through very rocky soils, which would be very porous and thus allow substantial infiltration. Other supporting field observations involved unexpected changes in scour along long unrelieved ditch-lines. In these situations, scour increased gradually with increasing ditch length, as expected, but then began to decrease, even though accumulate?. road runoff would have continued to increase. We suspect that ditch infiltration was occurring in the areas where scour was decreasing.

Although one might expect little difficulty in field locating road segments most subject to subsurface gains and/or- losses in ditch-now, positive identification of such segments may not be possible from one-time field observations. Road engineers note that some roads that intercept substantial subsurface flow during heavy precipitation conditions may show little or no sub-surface flow during drier periods when road surveys occur (Warren Sorenson, Weyerhaeuser road engineer, personal communication). Recent research (e.g., Bowling and Lettenmaier 1998, Wemple 1998) may guide a system that uses field indicators or models to identify of where such processes contribute the greatest flow inputs.

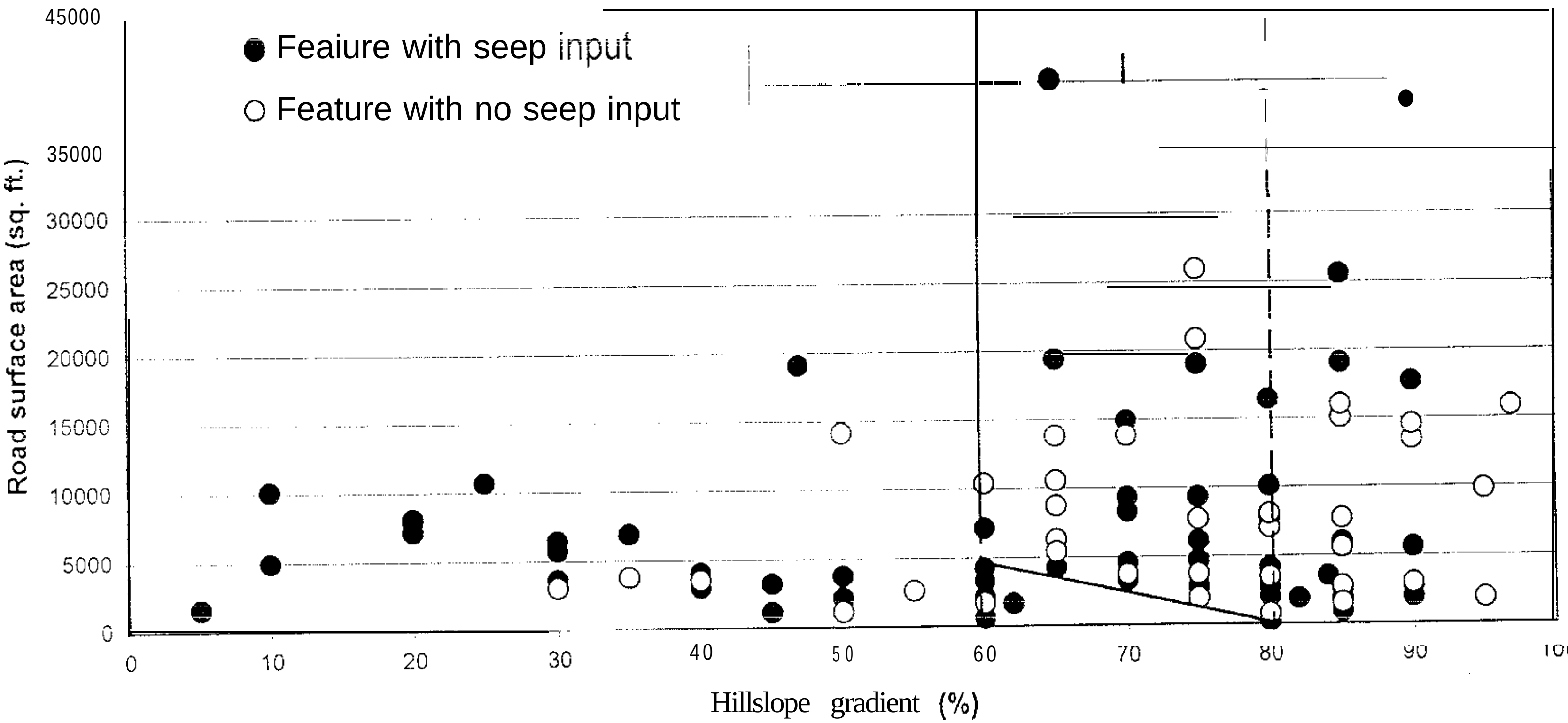


Figure 6. Slope/area plot of drainage sites with an erosion feature that shows the influence of seepage inputs. Note that most erosion sites with relatively small road surface area had seepage contribution, including 65% of the sites with less than 10,000 square feet of contributing road surface area.

Slope form effects

An analysis of erosion response by slope form (i.e., concave, planar or convex) identified several potentially useful findings. Among release points involving either concave or planar hillslopes, approximately half produced an erosion feature (Figure 7). Although the 20% erosion rate among convex sites appears to be considerably smaller, this interpretation is weakened by the very small number of sites involving a convex slope form, only five out of the 200 total.

The fact that gullies were found at about one third of both concave and planar sites (Figure 7) indicates limited sensitivity of gully formation in response to slope form. Landslide rates showed a greater response toward slope form, occurring at 21% of concave sites, in comparison to 13% of planar slopes and *none on* convex (Figure 7). Despite these differences in response rate, landslides on planar slopes account for 57% of all landslides encountered, due partly to the overall prevalence of planar slopes among release sites. Still, the number of landslides found on planar slopes was somewhat surprising, since most Watershed Analyses emphasized concave slopes as the dominant slope form associated with road failures.

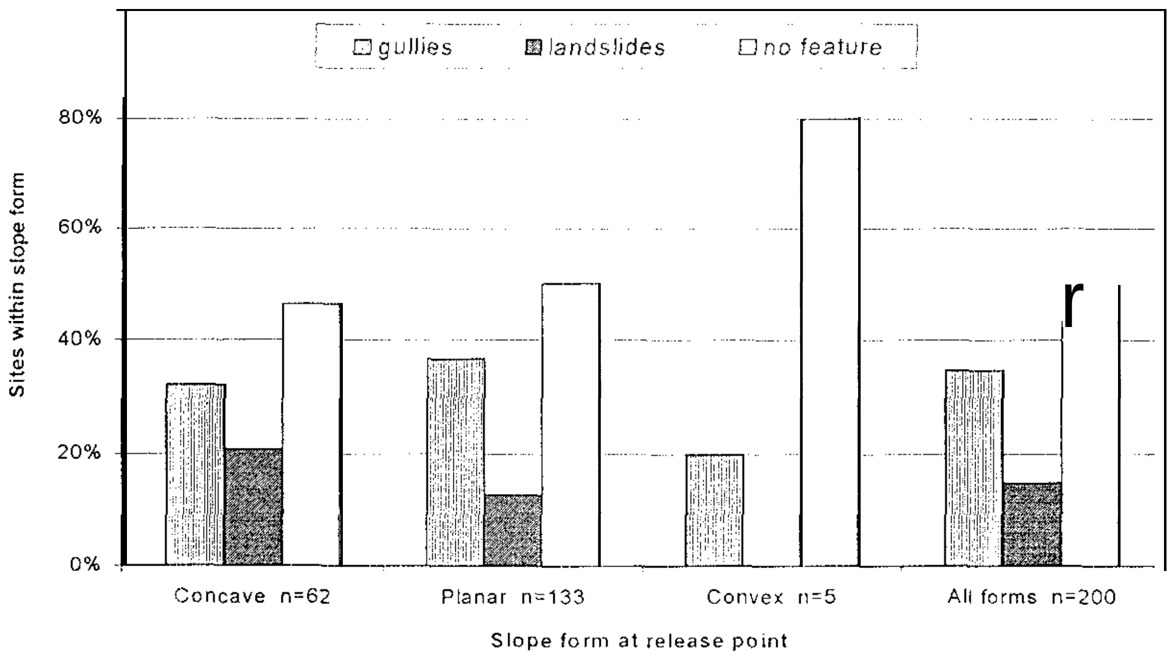


Figure 7. Erosion response among drainage sites involving concave, convex and planar slope forms. Gullies were found on all slope forms, while landslides were most common on concave or planar slopes. Note that the sample size of convex drainage sites was very small.

Geologic material effects

We compared erosion responses among the various geologic settings included in this study. Across the range of geologic types involved, we found erosion features at roughly half of all sites, with a range of 43-58% (Table 7). While it is tempting to characterize the erodibility of each geologic type simply from differences apparent in Table 7, such an interpretation would be problematic due to considerable differences in slope gradients and construction practices sampled within each geologic type (Table 3). Additionally, the sample sizes for glacial sediments, glacial till and breccia are quite small (Table 7).

To evaluate geologic influences while minimizing the sampling bias, we combined various geologic types on the basis of approximate material strength Geologic materials were divided into two broad strength categories--"hard" and "soft"--based on qualitative assessment from field observation (Table 7). We recognize that the strength within individual geologic types will be quite variable, but we believe these categories describe the typical strength of the material reasonably well

Table 7. Geologic materials and erosion responses to road drainage release

Geology and symbol	WAU & road segments	Strength category[1]	Erosion Response Category			Total sites	Sites (%) with a gully or landslide[2]
			Gully	Land-slide	No erosion response		
Glacial sediments (Qs)	Deer-Mud Lk.	soft	6	1	5	12	58%
Chuckanut sandstone (Ts)	Deer-Rick Cr.. #17&1810	soft	10	9	20	39	49%
Puget Group[3] (Tpg)	Mash.-#3a, 3b, 326	soft	13	3	21	37	43%
Glacial till (Qt)	Hoko-#9000	soft	5	0	6	11	45%
Breccia (Tvba)	Mash.-#31	hard	5	3	7	15	53%
Crescent basalt (Tcb)	Cheh.-all, Hoko-all but #9000	hard	31	14	43	88	51%

1 - Average material strength based on field observation.
2 - Percent of sites with gully or landslide by geology.
3 - Puget Group consists of inter-bedded sedimentary and volcanic materials.

Again we found that the slope/area plots for the soft (Figures 8) and hard strength groups (Figures 9) generally follow the patterns described previously for all drainage sites (Figure 5). For sites on slopes exceeding 80%, erosion features are common in either strength group and include most of the landslides encountered. However, among sites where slopes are less than 80%, several differences were noted between geologic materials that justified further analysis.

Among 0-59% sites, gullying is noticeably more frequent in soft materials (41%) compared to hard (28%)(Table 7), and 80% of the gullies in soft materials were associated with seeps. Further inspection revealed that gullies in soft material segments comprise most of the seep-associated gullies on low-gradient slopes discussed previously. The finding that gullies occur more frequently in weaker rocks may reflect the influence of finer-textured soils that can be easily incised or possibly a greater tendency for more shallow sub-surface flow to be intercepted along road cuts. In contrast, the plot showing erosion response in hard materials (Figure 9) indicates minimal influence of either road surface area or seepage contribution upon gully formation. It is possible that some gullies in hard material may have resulted from a drainage malfunction that diverted flow temporarily from a larger road surface area or possibly even an obstructed stream-crossing culvert. The relative lack of gully initiation in hard materials may also reflect the presence of rocky soils that are highly pet-meable and/or resist incision, at least within the lowest slope range.

The second difference pertains to erosion response on slopes of 60-79%. Within this slope range, the critical road surface area appears to be somewhat greater for hard materials relative to soft The previous slope/area relationship identified from Figure 5 provides a good fit for soft materials (Figure 8). However, for hard materials, the critical surface area is roughly double, sloping up to 10,000 square feet at a 60% slope (Figure 9). The physical explanation for this difference between hard and soft materials is likely the same as those previously discussed for slopes under 60%: hard materials are associated with coarse-textured soils which drain more rapidly, are less prone to incision, and thus require greater water input for erosion initiation.

Erosion response relative to Erosion Situations

Our original sampling approach used the Erosion Situation concept to account for landscape differences in our sampling scheme. However, we found it diff cult to locate road segments of adequate length that fit each Erosion Situation, In addition, when the results from several roads chosen to represent a given Erosion Situation were combined, no apparent relationships were evident, probably due to internal variability.

Since the Erosion Situation approach was ineffective as a means of characterizing terrain, we used analyses by geologic type and slope form described previously as an alternative approach to evaluating the influence of primary terrain variables on road drainage erosion. To evaluate the influence of road construction and drainage practices, we compared erosion response on the basis of past road upgrade treatment, Among the 15 of our road segments that were built in the 1970s or prior, ten had undergone subsequent drainage upgrading, while five had not (Table 4). Evaluation of roads built to current standards was precluded by an insufficient sample size. Although there were no records to document the specific nature of work done to upgraded roads,

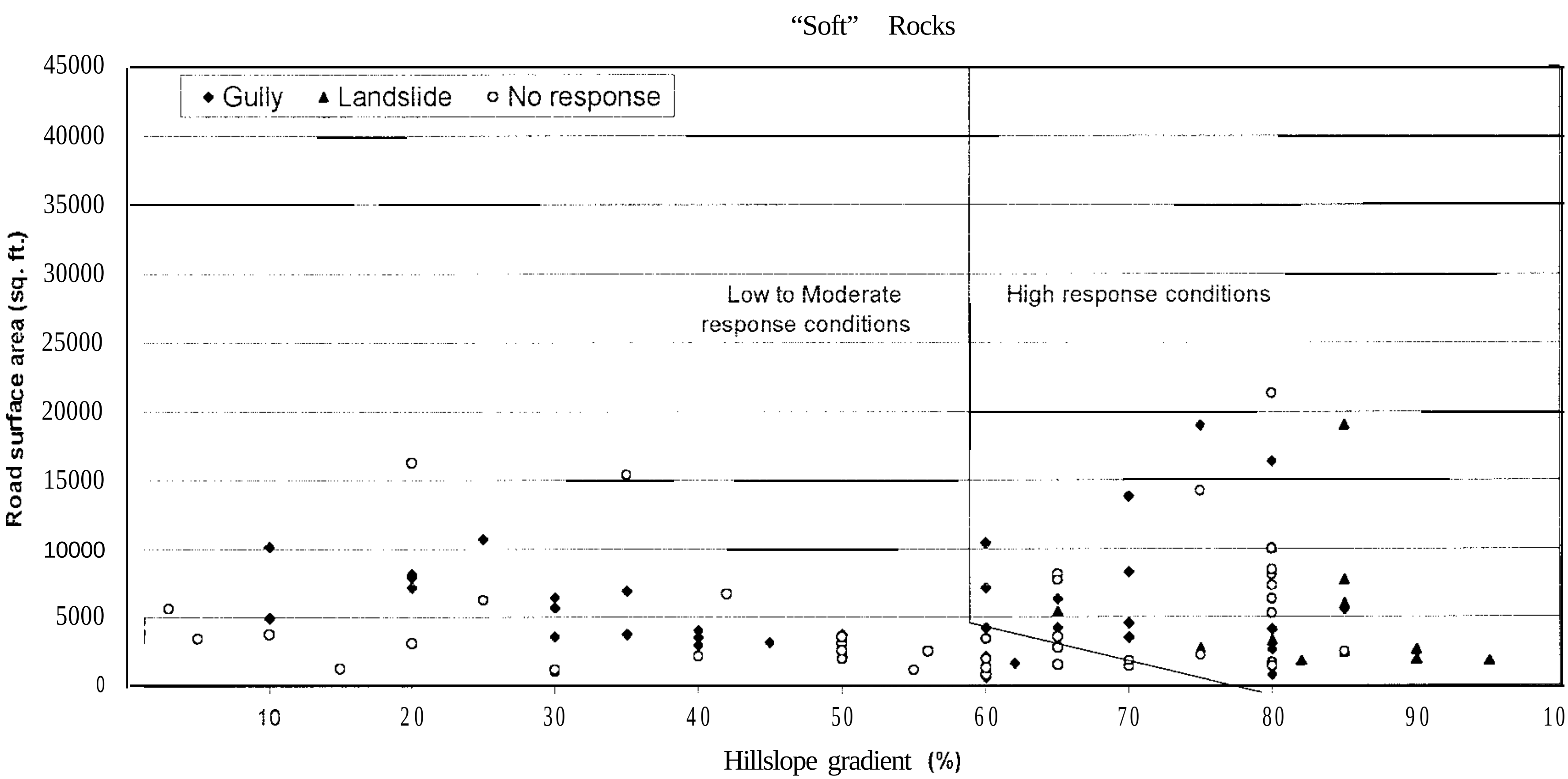


Figure 8. Slope/area plot of erosion response at sites in soft geologic materials, such as glacial sediments, sedimentary and interbedded sedimentary/volcanic rocks.

“Hard” Rocks

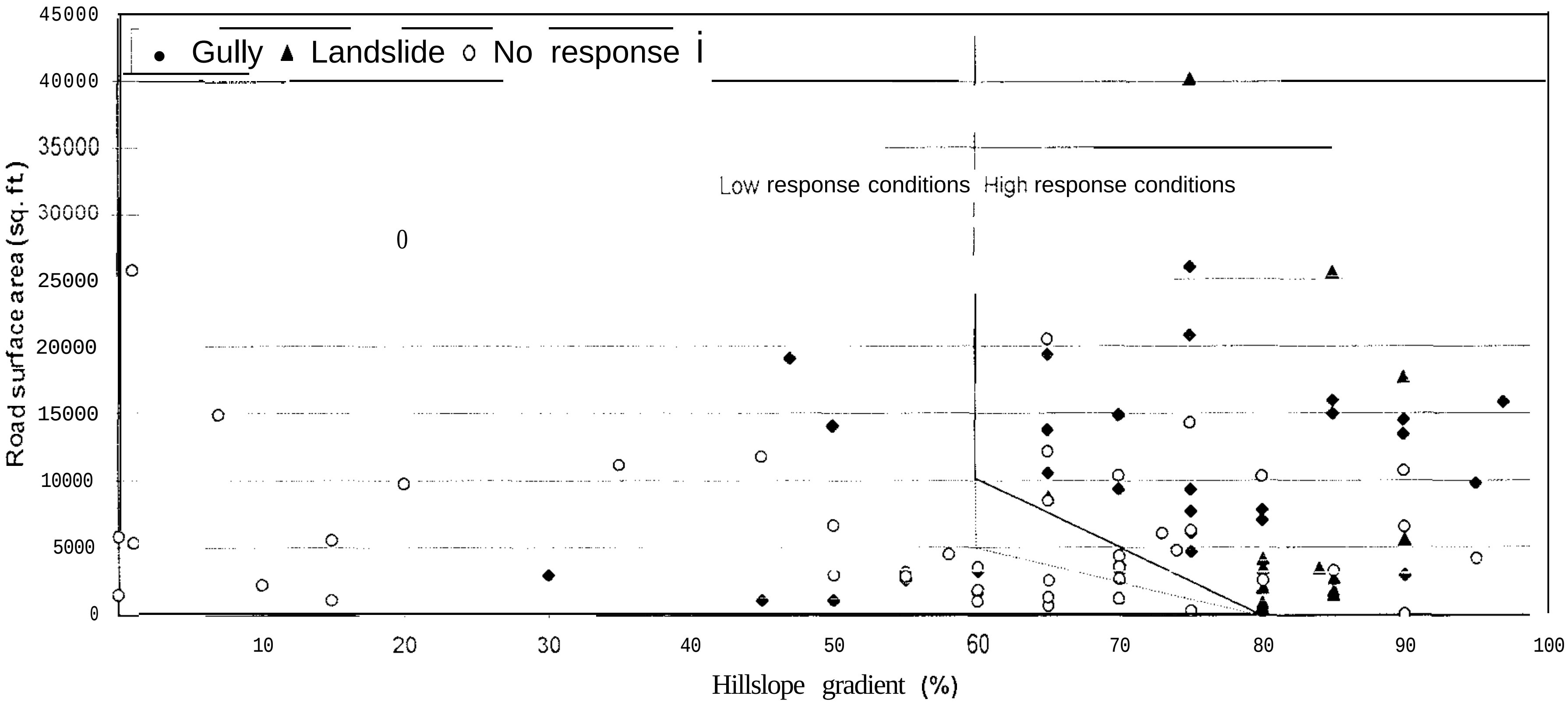


Figure 9. Slope/area plot of erosion response sites in “hard” geologic materials, such as basalt and breccia. For slopes of 60-79X, the road surface area required to trigger erosion is greater compared to sites in soft materials (Figure 8). Two outliers are not shown, both sites with no erosion response.

it presumably consisted of adding cross-drains and certain amounts of side-cast pullback. Segments were. combined into upgraded and non-upgraded on this basis, to allow comparison When drainage sites for the two upgrade categories were displayed on slope/area plots, little difference was apparent. Further analysis was needed to overcome differences in sample size and slope distributions between road categories.

Drainage sites in each of the upgraded categories were subdivided into three slope categories, with divisions again at 60% and SO%. Although the frequency of erosion features was fairly similar between non-upgraded (51% with a gully or landslide) and upgraded (55%) sites, upgraded roads were found to have more gullies but fewer landslides. These differences are further clarified in Figure 10. The higher frequency ofgullies on upgraded roads is entirely due to the considerably greater gully rate for upgraded sites involving slopes in the 0-59% slope range. For the two slope categories above 60%, gully rates are 'very similar between upgrade types (Figure 10). Interestingly, lower landslides frequencies were found on upgraded road sites in both of the steeper slope categories. Recall that no landslides were found at any of the drainage sites where slopes were less than 60%, among any road type.

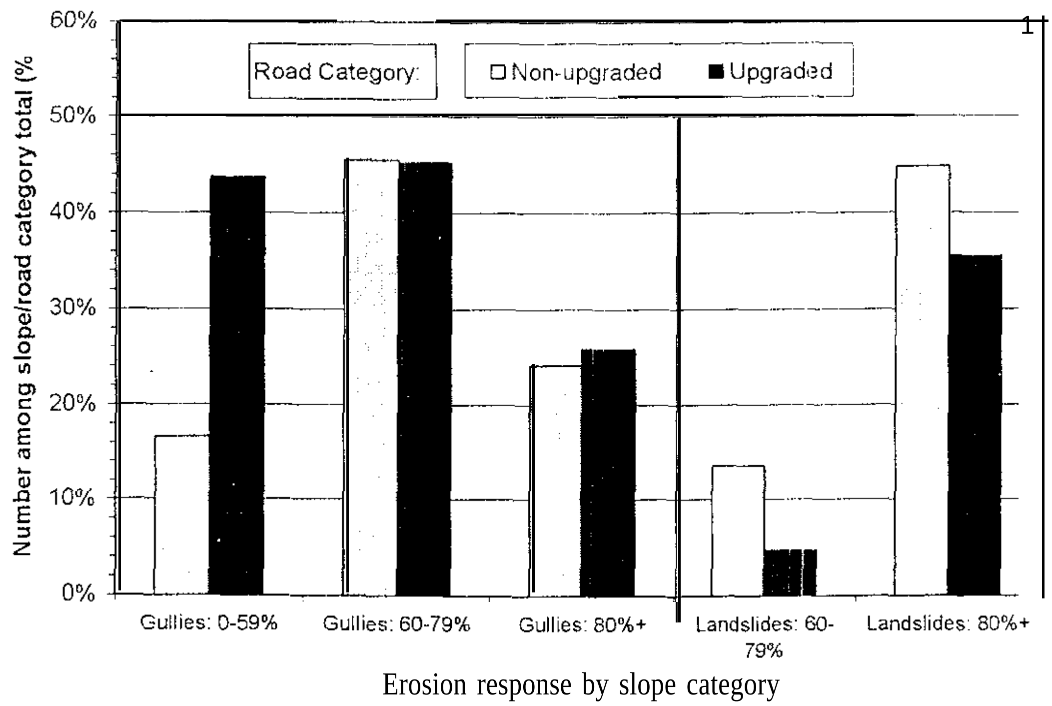


Figure 10. Comparison of the frequencies of erosion features among older roads where drainage systems have been upgraded vs. non-upgraded. Comparisons are between drainage sites within each of three slope categories. No landslides were found at any site within the 0-59% slope range.

The reduced rates of landsliding observed would be both the predicted and intended result if the road upgrading process selected gentle hillslopes as preferred locations for additional drainage release sites. The addition of low gradient drainage sites would I-educe both the proportion of steep drainage sites as well as the runoff volume delivered to them, while simultaneously increasing drainage diversion onto gentler slopes that are less prone to instability. These added low gradient drainage sites may represent many of the relatively high number ofgullies on upgraded sites involving 0-59% slopes. Still, it's not obvious why the gully rate for 0-59% slopes would be so much greater for upgraded (44%) relative to non-upgraded roads (I 7%), since reduced drainage lengths should result in smaller runoff volumes per site. It's likely that roads selected for upgrading were chosen preferentially among those noted to have many erosion features and that monitoring recorded both the pre-treatment an?. any post-treatment erosion features.

If this interpretation holds—that drainage upgrades result in reduced landsliding but increased gullying—this raises the question ofwhether adding cross-drains to older roads creates a net erosion benefit. Although our data set does not allow a direct comparison of the resource effects of gullies vs. landslides, we generally observed landslides to produce substantially greater sediment volumes and disturbance down-slope compared to gullies. This would likely suggest a net benefit from upgrading older roads. Other factors, such as the timing of sediment inputs (i.e., chronic vs. episodic) could be important in the comparison of resource impacts as well. Future re-measurement of these or other segments following additional storm events might provide a clearer view of how drainage upgrading influences erosion initiation.

Erosion response relative to cross-drain erosion Guidelines

As discussed in the introductory section of this report, Forest Practices Rules (i.e. WFPB 1995) specify maximum distances between cross-drains (Table 1) as a primary strategy to minimize erosion from road runoff. Data from monitor-ed road segments allowed us to test the effectiveness of these guidelines in reducing erosion. This assessment was complicated by the presence of two sets of spacing distances: the "Standard Rules" (Table 1, middle column) that appeared in the original 1974 Rules, and the "Additional recommendations" (right column) added to the rules in 1982 (Appendix 1). Among the drainage sites evaluated, 89% were within the standard spacings, while 78% also met the stricter Additional guidelines. We chose the Additional Recommendation spacings as the testing criteria, in part because most sample segments pass through potentially unstable terrain Although most road segments were initially constructed prior to 1974 (Table 4) when the standard spacing rule came into effect, many have been upgraded since 1982, when this spacing guideline was incorporated.

Our analysis found minimal evidence that erosion response differed substantially on the basis of compliance with the Additional spacing rule. Among the comparisons made for drainage sites within each WAU, results were notably inconsistent (Figure 1 1). Erosion rates for sites out of compliance were similar but slightly higher among Mashel and Chehalis sites, considerably higher among Deer sites, but considerably lower for Hoko. The comparisons among sites in all WAUs found essentially the same proportion of erosion features among sites in compliance (50%) relative to those out ofcompliance (51%). Further perspective is given by the observation

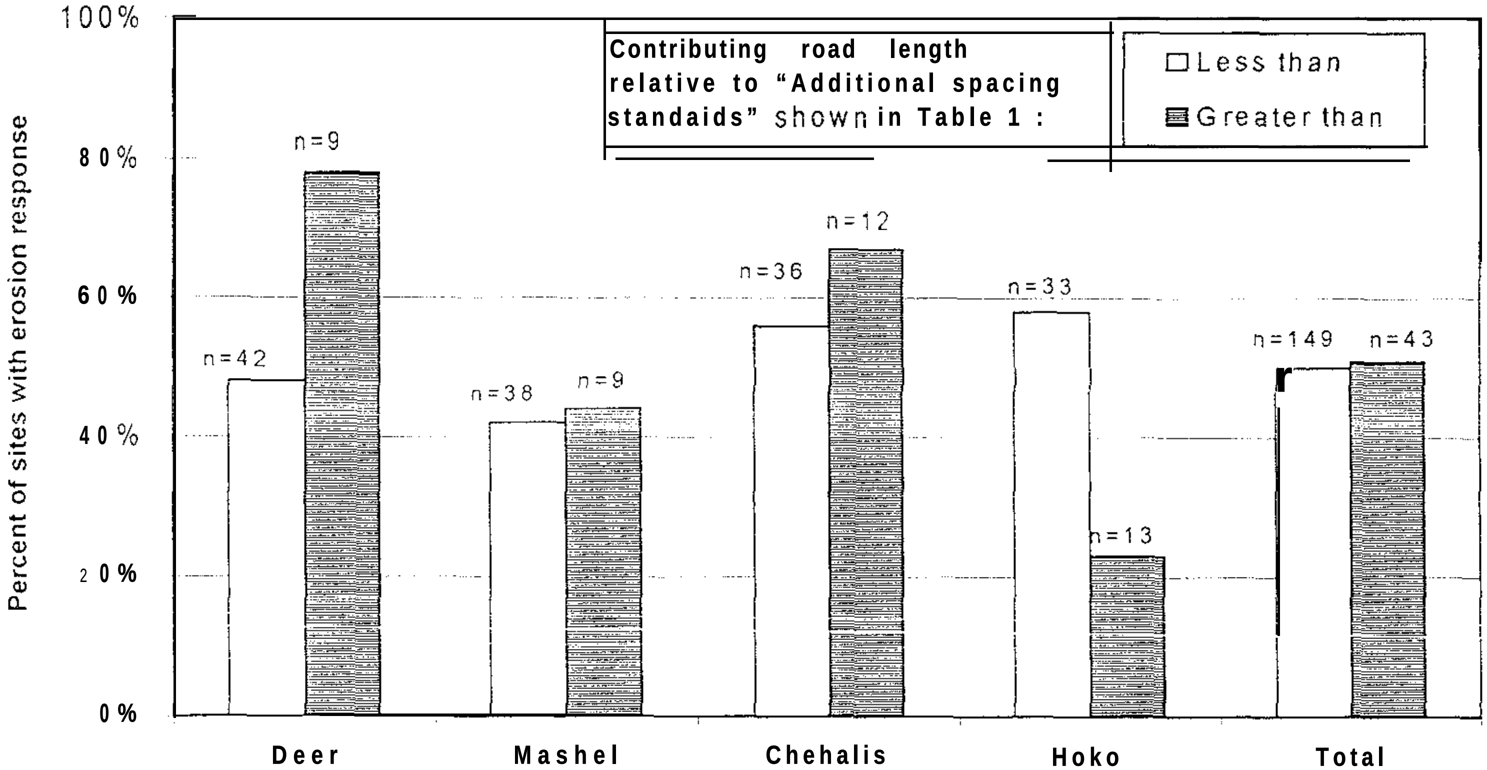


Figure 11. Erosion responses for drainage sites where cross-drain spacing was less than vs. greater than spacings specified in the "Additional culvert spacing recommendations" in Forest Practice Rules (WFPB 1995). The erosion response rates shown in these comparisons are inconsistent among the individual WAUs, and nearly the same for the combined group. Values for "n" indicate tbe number of drainage sites in each category.

that 75% of the total sites with an erosion feature were sites in compliance with the strictest standard spacing rules. Together, these results suggest that present cross-drain spacing standards are generally ineffective at preventing erosion below drainage release sites. Because erosion response was closely associated with hillslope gradient among all the watersheds monitored (Figure 4), we see little potential for reducing erosion by simply adjusting the existing road-gradient-based guidelines. Rather, our findings support a secondary set of hillslope-gradient-based guidelines to identify and guide drainage practices at drainage sites where the existing guidelines would be inadequate, as is further discussed in detail in the Management Conclusions and Recommendations section

It is important to note that we did not evaluate the success of the road gradient-based guidelines at preventing erosion within the road prism, which is the stated goal of cross-drain spacing guidelines. As noted in the introduction, the approach of present regulations toward preventing erosion below roads is to prevent drainage release onto unstable slopes unless "adequate outfall protection is provided". Among all drainage sites included in this study, energy dissipation features were relatively uncommon, occurring at only 13% of all sites. Of these, about one fourth (27%) had an erosion feature, in most cases gullies. Among the remaining majority of sites without an energy dissipator, 53% had an erosion feature, which appears to be a considerably higher rate. Although the small number of sites with dissipators precludes a more detailed investigation, this difference suggests that energy dissipators may reduce the frequency of-outfall erosion, but are not consistently effective.

Erosion response relative to Watershed Analysis erosion hazard ratings

The attempt to evaluate the predictive value of mass wasting maps toward road drainage erosion encountered the same sampling problem that undermined the Erosion Situation concept: i.e. road segments crossing a variety of slope conditions. This test was further complicated by difficulties imposed by the resolution of hazard map boundaries, as identifying the correct Mass Wasting Map Unit (MWMU) for each drainage site by MWMU map proved unreliable. The problem of map resolution has been anticipated by many mass wasting analysts who normally recommend that map unit boundaries be considered approximate until verified or refined using field observations. However, field validating or revision of the MWMU at each drainage site in this study would have been cumbersome, requiring detailed knowledge of the numerous MWMU definitions for each WAU. At a more general level, we found MWMU maps to be reliable tools for locating monitoring segments located in potentially unstable terrain, however.

Given the impracticality of assessing individual map units, we instead evaluated the effectiveness of the associated mass wasting hazard rating on the basis of unverified mapped boundaries. This allowed easier map-to-dr-ainaye site location, since it eliminated many boundaries resolution issues between MWMU polygons of the same hazard. The results, shown in Table 8, suggest only limited value of mapped hazard areas in predicting the location of erosion at cross-drain outfalls.

Interestingly, only one of the 30 landslides found was within areas mapped as High hazard (Table 8), although this does not necessarily indicate inaccurate hazard ratings, Although our road segments cross many High hazard areas, cross-drains were seldom located in these areas (only 9% of the total sites). Many High hazard polygons are narrow, as they are designed to delineate inner gorges along steep headwater streams. Where roads cross through these features, road runoff is normally diverted into a stream-crossing culvert, rather than onto the steep adjacent hillslopes. Because Moderate hazard polygons are more broadly mapped, they captured a much larger portion (58%) of the total drainage sites, and contained the highest landslide rate (18%, see Table 8) and most of the remaining landslides. It is quite possible that many of the landslides in areas mapped as Moderate or Low hazard actually originated in unmapped "inclusions" of High hazard terrain, as has been found elsewhere (e.g., Murray Pacific 1996).

Although hazard ratings were designed to identify the potential for landslide impacts, mapped polygons appear to be slightly more effective at predicting gully locations, which occur somewhat more often in High and Moderate, relative to Low hazard areas (Table 8).

Table 8. Erosion response by mass wasting hazard at drainage release points

Mass wasting hazard rating[1]:	Erosion Response Category							Total sites with a gully or landslide
	Gully		Landslide		No feature		Total	
	#	%[2]	#	%[2]	#	%[2]	#	%[2]
High	7	*39*	1	*6*	10	*56*	18	*44*
Moderate	44	*38*	21	*18*	51	*44*	117	*56*
Low	19	*29*	8	*12*	38	*59*	65	*42*
Total number	70	*35*	30	*15*	100	*50*	200	*50*

1 – Hazard rating as indicated by polygon locations on hazard maps. We were not able to correct for map inaccuracies.

2 – Percent among hazard rating totals

Effectiveness of Watershed Analysis

In the process of this project, we reviewed per-tinent sections of the four Watershed Analysis reports--mass wasting and surface erosion module reports, causal mechanism reports, and prescriptions----to determine whether they had identified the erosion processes we had found via the more focused monitoring efforts, This assessment differs from previous sections in that it pertains to activities at the WAU scale, and is more qualitative in nature. The findings regarding our remaining monitoring question are presented below.

Are erosion features concentrated where roads pass through areas mapped as High or Moderate mass wasting hazard?

Mass wasting hazard maps from Water-shed Analysis showed limited success at identifying terrain subject to erosion at cross-drain outfalls, as documented in the previous sub-section. This may be par-tly due to map resolution problems. Also, hazard ratings account for, in addition to inherent stability, the potential for delivery to public resources, which was not consider-ed in our analyses,

Do mass wasting and surface erosion assessments identify hazards from erosion from drainage release points in adequate detail for field identification?

Road related landslides were recognized as an important resource impact in all WAUs, and road construction and drainage were typically implicated as triggers. Road triggers were listed in rather general terms and included little detail of which factor-s were most important within that particular WAU. For instance, the distinction between erosion due to drainage design vs. drainage maintenance problems was hardly mentioned in any analysis, In addition, our limited data suggest that the common emphasis on concave slope forms as sites of instability may be overstated and lead to an underestimation of road-related erosion on planar slopes.

In contrast to the well-documented impacts of road-related landsliding, gully erosion was barely mentioned in any of the four analyses. We do not know if this is because gullies were simply overlooked, were uncommon at sample sites or were not judged to deliver sufficient sediment volumes to justify a more thorough evaluation. It should be noted that none of the standard procedures direct erosion analysts to evaluate gullying or road drainage issues in general. From our findings, we suggest that the Watershed Analysis assessment methods be modified to require field investigation of gullying at cross-drain outfalls and the extent of sediment deliver-y that results. The surface erosion module would be the most logical place to incorporate this effort.

Are prescriptions typically specific enough to direct managers toward appropriate action?

Nearly all prescriptions for existing roads were specific to the road portions that pass through High or Moderate hazard areas. The greatest detail in road prescriptions applies to new road construction activities. New construction prescriptions generally rely on further field review and design from a slope stability specialist, but provide little additional guidance toward drainage considerations, though several exceptions should be noted. Several Mashel prescriptions dictate a 200-foot maximum cross-drain spacing distance for Moderate hazard MWMUs #3&4. Deer Creek prescriptions for MWMUs #1, 6, 7 & 8 provide the most sophisticated cross-drain spacing rule found: <450 feet on 40-60% side-slopes and <160 feet for 60+%, values derived from Montgomery's research (Paul Kennard, Tulalip Tribe geologist, personal communication). Interestingly, these spacing distances are somewhat similar to those recommended in Table 9 below for soft geologic materials. This spacing prescription is not limited to specific MWMUs, but applies to all roads where seepage into the ditch can be observed. Roads with seepage were not listed in the analysis, but rather are to be identified in the field

Prescriptions for existing roads generally rely on development of owner-specific Road Maintenance Plans, the contents of which we did not explore. Given the lack of basin-specific input on triggers from the Causal Mechanism Reports (CMR), the effectiveness of these plans would largely depend on the skills and knowledge of the persons putting the plan together. If designers of road maintenance plans attend assessment meetings or communicate directly with the analysts, they may be able to incorporate other field observations that are not recorded in CMRs.

Are prescriptions being implemented properly to provide reduced resource impacts in most cases?

Most of the roads we monitored had not undergone full implementation of prescriptions, though road upgrades in the Chehalis and Mashel WAUs were partially completed (Table 4 shows the status of monitored road segments). In all cases, the basin-wide road upgrade requirements were sufficiently extensive and costly to require several years to implement. Most landowners had not retained sufficient documentation of what road work had been completed and where, in order to determine which roads had been completely treated. However, substantial road upgrade work had taken place prior to Watershed Analysis on many road segments, including several in the Hoko and Deer WAUs. Further monitoring upon completion of repairs and upgrades, ideally after other large storms, would be beneficial to adequately test this question.

CONCLUSIONS AND RECOMMENDTAIONS

Monitoring Conclusions and Recommendations

Drainage Site Analysis

We found the approach of evaluating individual drainage sites to be very useful for road evaluation. This approach lends itself well to future remeasurement. especially for new or newly upgraded roads, since it will allow identification of any new drainage features. Based on our experiences, we recommend refinement in describing certain attributes, including sub-surface flow interception, slope position, and sediment delivery. *Rather* than describing such refinements here, we encourage anyone wishing to use this methodology to contact the authors directly.

Because determining the contributing road surface areas to each site is critical to accurate interpretation, rhis method is best for evaluating erosion features that have occurred relatively recently, when road drainage patter-ns can still be clearly identified As an example, the contributing road area could be substantially misinterpreted if an erosion feature had resulted from a plugged culvert that was cleared prior to monitoring.

Erosion Situations

The use of Erosion Situations as a basis for segment selection was problematic, due to the inherent variability of landscape attributes. To collect a adequate number of drainage sites matching a giver Erosion Situation would require selection of individual drainage sites on numerous roads, rather than use ofcontinuous road segments. Rather, we recommend choosing road segments by slope position, geologic type or other broader scale attributes.

Effectiveness Summaries

We encountered substantial difficulty in applying the Effectiveness Summary approach. The main problem was the lack of structure for interpretation and pre-established criteria by which to evaluate each of the five key functions. Without consistent criteria for guidance, we found it difficult to develop consistency between different observers. Other problems with this approach were related to difficulties in interpreting the importance of past drainage and erosion problems on old roads, relative to more recent features (or the lack thereof). In western Washington, features such as landslides, gullies, and drainage problems are obscured quickly by road repair efforts, weathering, and revegetation.

We believe that the Effectiveness Summary approach could be made practical, but requires considerable additional development effort Our experience indicates that such a method would benefit from the following conditions:

- Evaluations use set descriptions of which features are to be observed and how;
- Criteria are fixed on how to determine success vs. failure, preferably based on quantitative rules;
- Interpretation is limited to relatively recent erosion features, perhaps only those from within the past five years or so;
- Monitoring crew can maintain close communication with local road engineers that designed and/or supervised construction and maintenance of the roads being monitored.

In fact, the Monitoring Advisory Group is presently sponsoring the development of a road monitoring methodology capable of evaluating several key road functions in consistent and measurable ways.

Further Monitoring Needs

Future re-monitoring of the same segments could provide valuable information on erosion response to ongoing changes in maintenance practices. However, we suggest waiting another 3-5 years to allow for additional storm events since implementation ofpost-Watershed Analysis road practices.

In addition, further road monitor-ing to expand on the findings cf this project could be beneficial. One could apply our methodology to a monitoring project designed to further evaluate:

- Influence of subsurface flow interception on road erosion. Ongoing research might provide field-indicator-based models to predict areas of subsurface flow interception for use during dry-season monitoring.
- Effects ofgeologic conditions. Monitoring sites could be chosen to supplement data enough to evaluate geologic materials individually, rather than grouping them, as we did.
- Response to various drainage upgrade treatments. This may require additional sites or possibly remeasurement of existing sites. One key question would be whether gullies will persist or refill with soil after the contributing road surface areas are reduced.
- Watershed Analysis erosion hazard ratings and/or prescriptions. This would require greater efforts toward field verification of hazard unit locations during monitoring and/or greater focus on prescription requirements and implementation than were possible here.
- Road drainage erosion for conditions east of the Cascades,

We would recommend that each monitoring project be designed to focus on only one of the above issues, to avoid some of the confounding and sample size problems we encountered.

Management Conclusions and Recommendations

Erosion Response to road drainage release

Overall Frequency of Road Drainage Erosion

- A gully or landslide was found at half of all drainage sites monitored. Differences between monitored basins were only modest, and correspond with differences in the average hillslope gradient at drainage sites.

- Gullies were found at 35% of sites and about half deliver to streams. Although most were relatively short, about one-fifth were 100 feet or longer. Reducing this will require a more sophisticated understanding of gully initiation.

- Landslides were found at 15% of sites and most delivered to a stream. The majority of landslides occurred at accidental rather than intended drainage sites. Reducing such landslides will depend upon improvements in various aspects of road management, including road location and construction, improved drainage design and storm-proofing measures, and improved drainage maintenance.

Effects of terrain and hydrologic factors

- We found that the hillslope gradient at a drainage release point plays a critical role in the likelihood of erosion initiation as well as the type of erosion process involved (i.e., gully, landslide). Three slope gradient categories capture primary differences in both erosion response and contributing factors:

  For drainage sites involving 0-59% slopes, gullies were somewhat common (33% of sites), especially where contributing road length intercepts subsurface flow and drains onto soils derived from glacial sediments or other soft rock types. The contributing road surface area was not a good predictor of erosion response sites in this slope range.
  For sites involving slopes of 60-79%, gullies were more common (44% of sites) and landslides were occasionally (8%) encountered. In this slope range, erosion response appears to be considerably mot-e sensitive to the contributing road surface area. A predictive tool for determining critical road surface areas is presented below.
  - The release of road runoff onto hillslope gradients of 80% or greater commonly resulted in either a landslide (37%) or gully (29%). Because hillslopes in this range are typically only marginally stable, contribution of road drainage water should be avoided.

- Gullies wet-e more common at sites where the ditch collects sub-surface flow relative to those where none was observed, especially among sites with slopes less than 60% This suggests that shorter spacing between drainage structures should be used on road lengths noted to intercept subsurface flow

- Most drainage sites discharge onto concave or planar slope forms rather than convex slope forms. Erosion response rates were only slightly more common among concave sites relative to planar sites.

- Although our monitoring sites included few drainage sites on convex slopes, the convex form would tend to disperse moisture inputs into the soil laterally. and thus should contribute to fewer gullies or landslides. We recommend choosing convex slopes for drainage release sites in situations where other placement considerations (e.g. road grades, adequate soil depth) allow.

Effects of road upgrading

- The frequency of erosion features at roads that had been upgraded (addition of drainage features and/or sidecast pull-back) were fairly similar to that found at non-upgraded roads. Upgraded roads were found to have somewhat fewer landslides, but somewhat more gullies, especially at drainage sites on low slopes. This may be due to the formation of new gullies following upgrading or perhaps tendency to select roads for upgrading that are observed to have many gullies already. Further monitoring is needed to clarify the net erosion effects of road upgrading, so as to avoid unintended erosion that could result from the upgrading of older roads.

Effects relative to Forest Practices Rules for drainage release

The Washington Forest Practices Rules address erosion at cross-drains through use of two guidelines. First, WAC 222-24-025(6) prohibits drainage discharge onto "erodible soils" without "adequate outfall protection". Secondly, WAC 222-24-025(7) specifies maximum spacing distances between drainage features to limit runoff accumulation (Table 1).

- Among our monitoring sites, energy dissipation requirements for discharge onto potentially erodible soils appears to be both seldom applied (1 3% of sites) and only moderately effective when applied properly. Because most monitored roads were constructed prior to Forest Practices Rules implementation in 1974, this indicates that many older roads are not retro-fitted with energy dissipators.

- Because the few sites with energy dissipators had somewhat lower rates of gullying, we suspect that energy dissipators might have prevented some of the shorter gullies encountered, which probably resulted from outfall energy However, we doubt that even effective dissipators would have prevented any of the landslides or longer gullies associated with greater sediment delivery since these features likely resulted from excess runoff volumes for the site conditions.

- Although most drainage sites we monitored comply with Forest Practices standards for drainage spacing (89% comply with standard spacings, 78% with "Additional Recommendations"), frequencies of erosion features were fairly similar between sites in compliance vs. those out of compliance. From this, we conclude that the existing spacing rules are ineffective at preventing erosion below drainage release points. Monitoring data were used to develop secondary drainage spacing guideline:,, which are provided below.

- Because road maintenance activities soon obscure evidence of storm-triggered scour in ditches or on tread surfaces, we could not determine whether standard spacing rules are effective at preventing erosion within the roadway, the purpose for which they were intended.

Effects relative to Watershed Analysis

- Mass wasting hazard maps without field verification were not effective at predicting road drainage erosion at a scale necessary to rate individual drainage sites. Our results reinforce findings elsewhere (i.e., Murray Pacific 1996) that additional field effort is needed to verify and delineate hazardous terrain for use of hazard ratings for site-scale field operations.

- Watershed Analysis erosion assessment modules from the four monitored WAUs failed to document the magnitude of erosion at drainage outfalls that we encountered. This may be partly because the assessment methodology does not explicitly require an evaluation of gully erosion or road drainage systems in general. It appears that 'Watershed Analysis would benefit from additional focus on road drainage, either through changing the standard assessment methods or through additional road evaluation concurrent with or subsequent to the assessment.

Secondary Guidelines for Selecting Road Drainage Release Sites

The following guidelines are designed to help road managers predict or identify erosion potential associated with drainage release sites on various slopes.

- For drainage sites on slopes between 0-59%, erosion potential is low to moderate for gully initiation, depending on the presence of subsurface contribution to ditch flow Within this slope range, the contributing road length appeared to be of minimal importance. Due to the importance of subsurface flow contributions, it is especially important to provide frequent cross-drainage along road portions with seepage to avoid excess drainage accumulation in the ditch-line. This concern pertains especially to roads in softer rock types, due both to greater susceptibility to gullying and possibly a greater tendency for subsurface flow interception. Where minimal subsurface flow is encountered, cr-oss-drain spacing should follow standard rules to avoid ditch erosion.

- For drainage sites on slopes between 60-79%, erosion hazard is moderate to high, but can be reduced by minimizing the contributing road surface area. If drainage release onto slopes in this range cannot be avoided, observe the spacing guidelines shown in Table 9.

- For drainage sites on slopes of 80% and greater, erosion hazard is high for both landslides and gullies, regardless of geologic type or road surface area. It is now common knowledge that construction of roads across such steep slopes should be avoided unless no alternative is present. However, if no better road location can be found or the road is pre-existing, a very well though-out and site-specific design should be used. Cross-drains should be placed either at very short spacings, and/or drain onto carefully selected portions of the hillslope with locally gentler slopes or non-erodible materials, such as talus. Equally important on very steep slopes is to avoid storm-driven accidental drainage diversion through a "storm-proofing" approach to drainage design and maintenance. An example is to use water bars at each culvert to divert water over the road at the intended location, rather than allowing diversion down the ditch if the culvert plugs.

Table 9. Guidelines for placement of cross-drains that **drain** onto **hillslopes of 60-79%**[1]

Soft geologic materials (glacial sediments, sedimentary and other relatively weak rock types) Determine maximum road surface area as a function of the local slope at the drainage point, using the following equation that describes the sloping portion of the line in Figure 8: $As = 250 * (80 - G)$, where: As = maximum road surface area in square feet. and G = hillslope gradient in percent For example, for a drainage release point onto a slope of 70%, the maximum road area would be: 250 * (80 - 70) = 2,500 square feet. This is equivalent to 250 lineal feet for a 20-foot-wide road (shoulder to ditch) if crowned or 125 lineal feet if insloped.
Hard geologic materials (basalt, breccia, and other hard rock types) Maximum road surface area can be determined from the following equation that describes the sloping portion of the line in Figure 9: $Ah = 500 * (80 G)$, where Ah = maximum road surface area in square feet, and G = hillslope gradient in percent Given the same 70% example used above, the maximum surface area in hard materials would be 5,000 square feet, which is equivalent to lineal distances of 500 feet if crowned or 250 feet if insloped under the assumptions above.
1 - Data from this study does not support use of either equation above for sites outside of the 60.79% slope range.

Three major limitations pertain to the applicability of the rules above. First, although these rules define conditions associated with higher and lower potential for erosion, one should expect that the erosion response at many individual sites will deviate from the general predictions. The level of erosion reduction to be expected can be gaged from examination of Figures 5, 8, and 9, which show considerable intermixing of erosion feature and non-eroded sites. Second, although we believe that these rules are appropriate for use in road drainage design, they have not been tested in a predictive mode. The third limitation involves the integration of these guidelines with the standard rules for cross-drain location discussed in the introduction. At this time, it is appropriate to use the preceding guidelines only where they result in shorter cross-drain spacing relative to standard rules. In situations where standard rules require shorter cross-drain spacing than rules above, the standard approach should be used.

Miscellaneous Recommendations

During field monitoring, we made several observations regarding road drainage that may be useful:

- Flumes on culverts are likely to reduce gullying into the road fill, but appear to increase erosion on the hillslope below, presumably due to increased flow velocities. Installing an energy dissipation structure (e.g., a log or boulder) below the flume outfall may be helpful to off-set this additional energy.

- Maintenance debris from grading or ditch clearing should not be pushed over the road shoulder over steep road shoulders or onto steep slopes (>60%). Improper disposal of maintenance debris can negate considerable efforts to design and construct stable roads through difficult terrain.

- Soon after new roads are built, it is beneficial to review them during rainy or wet conditions to determine which portions of the ditch-line intercept subsurface flow, particularly those areas that were not evident during road layout or construction. Adding drainage features at these locations prior to the first major rainstorms may prevent sully initiation that would be difficult or impossible to restore after incision

Extrapolation of Results to Other Areas

Although this project involved monitoring in four WAUs in order to maximize applicability to other areas, there are limitations in extrapolating these findings to other areas. The rates of erosion found here may not reflect rates across larger areas, either in other parts of the study WAUs or elsewhere. This is because roads wet-e chosen to represent relatively steep and problematic terrain, rather than average or a cross-section of conditions. However, the general similarity among the results from all WAUs suggests that the recommendations provided here may be applicable to other areas, especially in the absence of comparable information from more similar locations.

REFERENCES

Bowling, L.C. and D.P Lettenmaier. 1997. Evaluation of the effects of forest roads on streamflow in Hard and Ware Creeks, Washington. Timber/Fish/Wildlife document TFW-SH20-97-001. Olympia, Washington.

Cavenham Forest Industries Division and Rayonier Timber Operating Company. 1997. Hoko Watershed Analysis and Prescriptions. Available from Department of Natural Resources, Olympic Region, Forks, Washington.

Dyrness, C. T. 1967. Mass soil movements in the H.J. Andrew:; experimental forest. U.S. Forest Service Pacific Northwest Forest and flange Experiment Station. Research Paper PNW-4%. 12p.

Department of Natural Resources. 1996. Mashel Watershed Analysis and Prescriptions Available from South Puget Regional office, Enumclaw, Washington.

Miller, J.F, R.H. Frederick and R.J. Tracey. 1973. Precipitation frequency atlas of the western US.; Volume IX Washington NOAA Atlas 2, 43 p.

Montgomery, D.R. 1994. Road surface drainage, channel initiation, and slope instability. Water Resources Research, 30(6): 192.5-l 932.

Murray Pacific Corporation 1996. Connelly Creek Watershed Analysis - First Supplemental Report Consultants report prepared for the Washington Department of Natural Resources, Olympia.

National Climate Data Center. 1995, 1996, 1997 & 1998. Climatalogical Data and Hourly Precipitation Data for Washington. Monthly summaries distributed from N.C.D.C., Asheville, North Carolina.

Pentec Environmental. 1991. Methods for testing effectiveness of Washington Forest Practices Rules and Regulations with regard to sediment production and transport to streams. Timber/Fish/Wildlife document TFW-WQ8-91-008. Olympia, Washington. 124 p.

Russell, P. and C. Veldhuisen. 1998a. Monitoring Plan Road drainage and erosion initiation in four west-Cascade Watersheds. Unpublished document available from the Northwest Indian Fish Commission, Olympia, Washington

Russell, P. and C. Veldhuisen. 1998b. Field Methodology fool- Road Monitor-ing Project. Unpublished document available from the Northwest Indian Fisheries Commission, Olympia, Washington.

Stillaguamish Tribe. 1996. Deer Creek Water-shed Analysis and draft prescriptions. Available from DNR Northwest Region, Sedro Woolley, Washington.

Washington Forest Practices Board. 1974, 1976, 1982, 1988, 1993, 1995. Washington Forest Practices-Rules, Board Manual and Act (various versions). DNR, Olympia, Washington.

Wemple, B. C. 1998. Investigations of runoff production and sedimentation on forest roads. PhD. dissertation, Oregon State University, Corvallis, Oregon.

Weyerhaeuser Company. Chehalis Headwaters Watershed Analysis and Prescriptions Available from DNR Central Region, Chehalis, 'Washington

APPENDIX 1. Summary of past changes in regulatory standards for forest road construction in the Washington Forest Practices Rules.

Road construction practices and standards have changed over time, due to improved technology and appreciation of the potential for impacts from roads to forest and fisheries resources. Though road construction techniques have evolved since the transition to truck hauling from prior railroad transport, road construction practices were not formally regulated prior to 1974, when the Forest Practices Act was passed. Since 1974, The Forest Practice Rules have been updated numerous times. Below is a brief description of changes in road construction standards as they pertain to road stability and drainage.

PI-e-1974 road construction practices:

- Tractors commonly used for construction
- Located roads to minimize construction/earth removal (chose the shortest route to timber, follow topography as much as possible)
- Excavated rnaterial sidecast on a range of slopes, including very steep areas (80%+)
- Machinery was not capable ofremoving organic debris from sidecast material
- Culverts were installed mainly at stream crossings, with very few ditch-relief culverts
- The standard drainage design strategy was to route road runoff into the ditch, then directed to the closest stream crossing

1974 Initial Forest Practice Rules provided initial guidelines for road location and design:

- Maximum road widths
- So-called "balanced" approach to excavation, i.e. partial-bench construction preferred to large through-cuts and through-fills.
- Cut and fill limited to slopes of normal angle of repose or less
- End haul or overhaul construction required where potential for mass wasting is present
- Removal of organic debris from side-cast material
- Avoid locating roads on steep, unstable slopes or known slide-prone areas
- Road drainage via outsloping the road tread and/or ditch on uphill side
- Installation of relief cross-drains at all low points along ditch
- Implementation of original cross drain spacing guidelines (Table 1, column 2)
- Minimum culvert size recommendations

Forest Practice Rules were updated in 1976, 1982, 1988, 1993 & 1995, including a few additions pertaining to road construction. Highlights of the 1982 revision:

- Added language: "Do not locate roads on excessively steep or unstable slopes or known slide prone areas" (to be determined by Department of Natural Resources).
- New cross-drain spacing guidelines to require more frequent ditch relief based on site-specific evidence of instability (Table 1, column 3).
- Minimum culvert size upgraded.

Highlights of the 1988 Revision

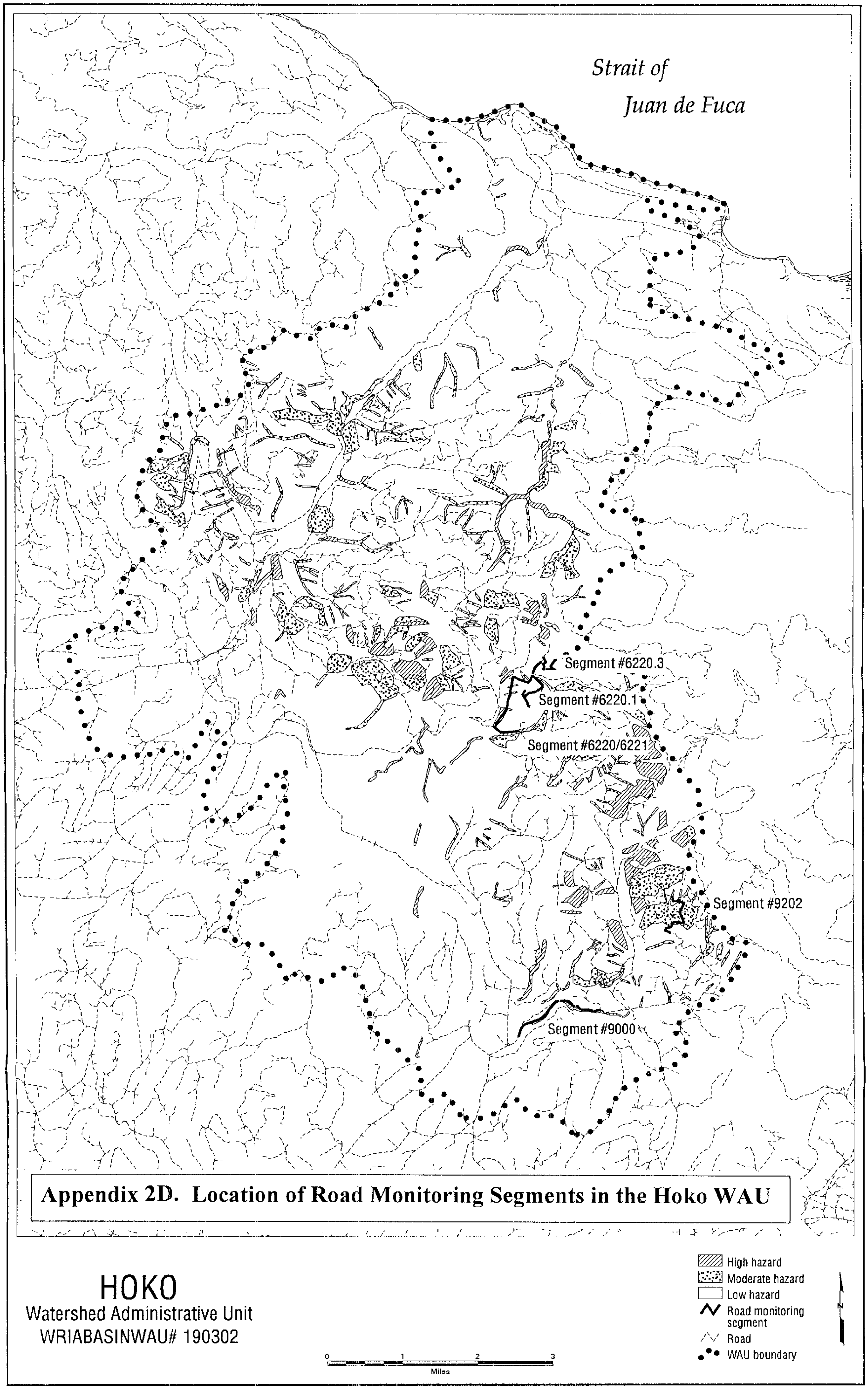
- Introduction of "Road maintenance and abandonment plan" requirement
- Minimum culvert size upgraded (again)

APPENDIX 2. Maps (four 11x17") of the WAUs showing monitoring segments and mapped mass wasting hazard areas.

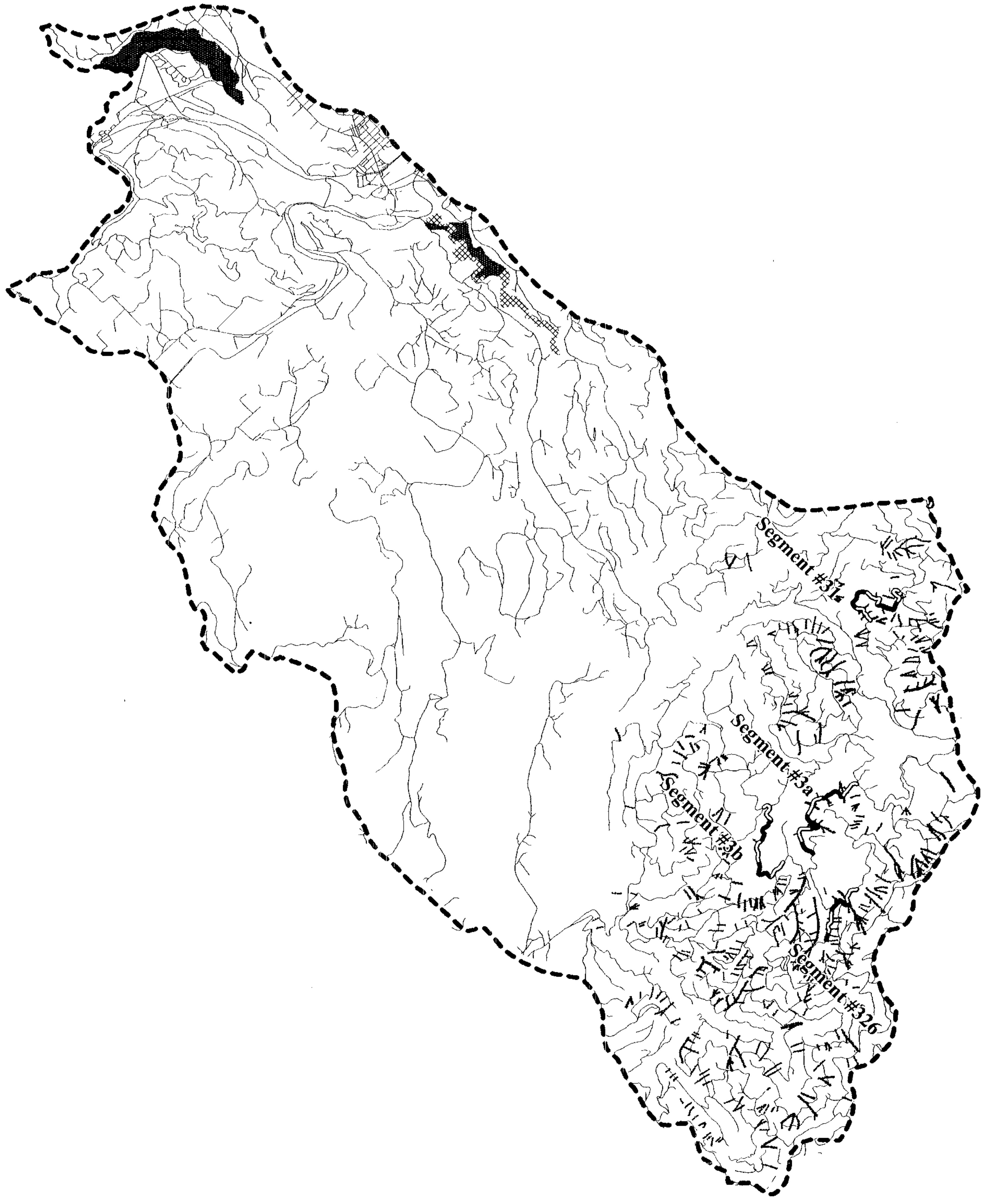
APPENDIX 3. Unsupportable hypotheses from this study

The following are hypotheses that either could not be supported or could not be analyzed credibly using our data.

- Standard rules for cross-drain spacing are effective at minimizing erosion within the road tread or ditch
- Gully formation is positively correlated with length of slope gradient -gully may stop at or near reduced slope angle
- Gully may stop where water leaves side-cast material onto the natural slope
- Gully formation is inversely related to surface roughness, vegetation density or maturity
- Gully depth or volume respond to seepage inputs or other factors above
- Landslides are more likely where road drainage is released onto side-cast relative to in-place soils.
- Landslides are less likely where road drainage is diverted onto a hillslope with mature vegetation relative to immature.
- Landslide area or volume varies in response to slope gradient, contributing road surface area, or other factors.
- Channel extension occurs where drainage outfall is a short distance above natural channel head.
- Additional flow contributed by road drainage at stream crossings may result in channel enlargement.



Appendix 2D. Location of Road Monitoring Segments in the Hoko WAU



Appendix 2B. Location of Road Monitoring Segments in the Mashel WAU

Mashel

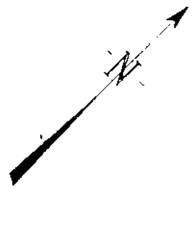
Watershed Administration Unit
WRIABASINWAU# 110204

Pierce County, Washington

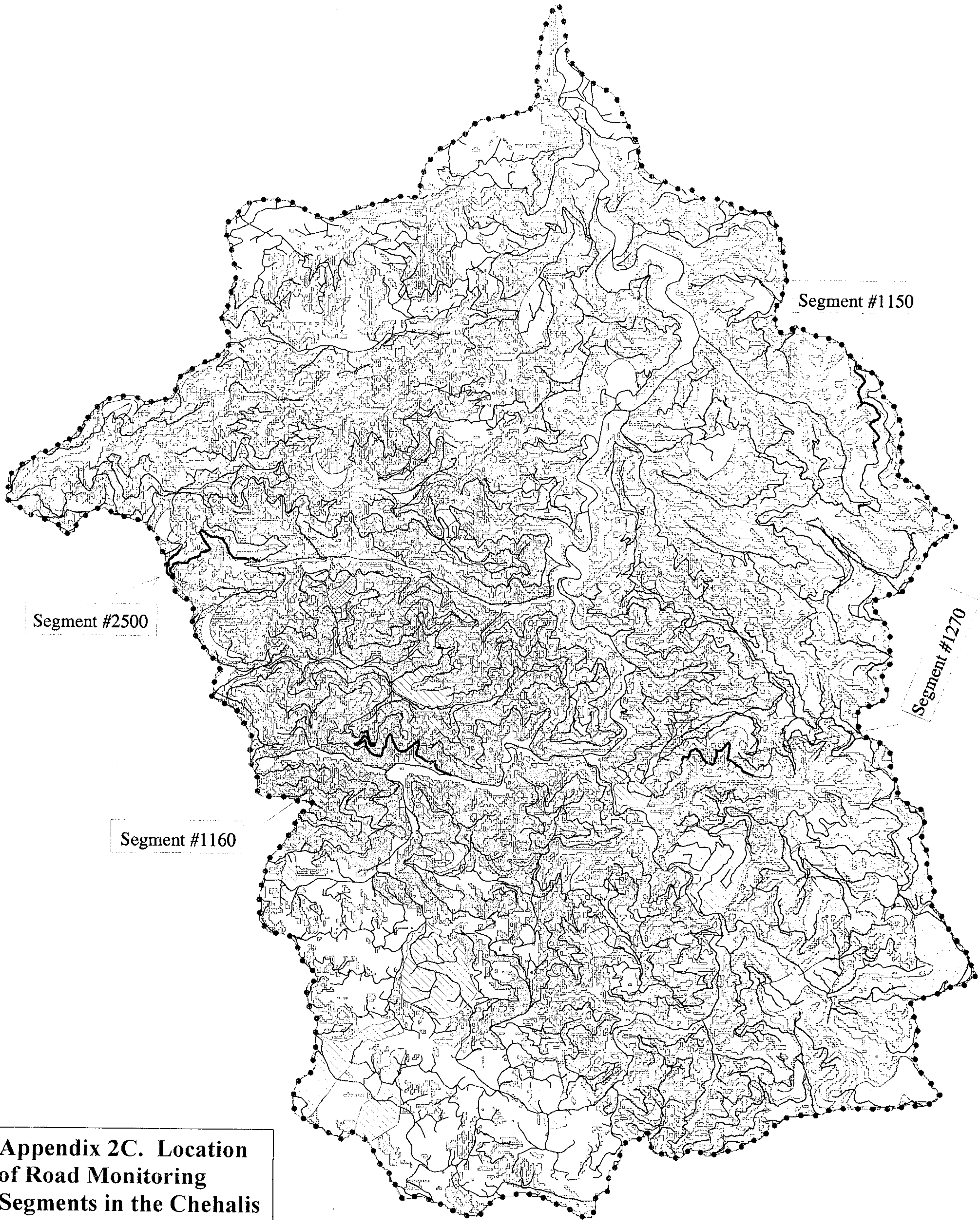
Legend

Road Monitoring Segments
All other Roads

High Mass Wasting Hazard
Moderate Mass Wasting Hazard



Date: 11/23/98
Champion Pacific Timberlands, Inc.



Appendix 2C. Location of Road Monitoring Segments in the Chehalis Headwaters WAU

Chehalis Headwaters

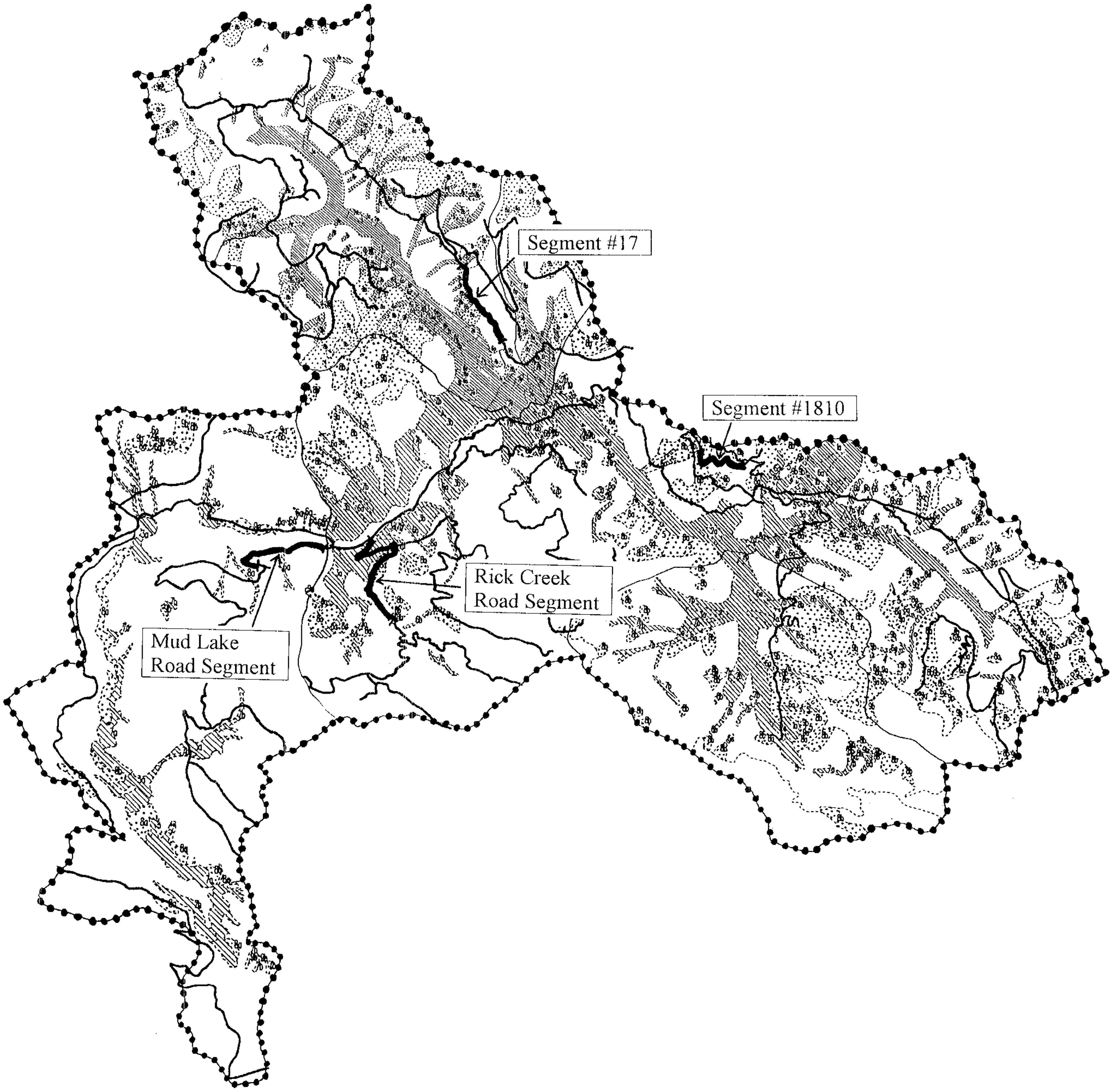
Watershed Administrative Unit

Legend

- Watershed Boundary
- Road Monitoring Segments
- Roads
- Very High Hazard
- High Hazard
- Moderate Hazard

N

Scale: 1" = 5300'



Appendix 2A. Location of Road Monitoring Segments in the Deer Creek WAU

Deer Creek

Watershed Administrative Unit

Legend

Watershed Boundary
Road Monitoring Segments
Roads

High Hazard

Moderate Hazard

N

Scale: 1" = 7100'