PRAIRIE GULLY EROSION IN THE REDWOOD CREEK BASIN, CALIFORNIA

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

In this study, gully formation and enlargement in open grassland areas (prairies) were mapped and measured by reviewing aerial photographs taken in 1954 and 1978. Field measurements defined the relationship of gully width to cross-sectional area. Roads traversing prairies were classified according to construction standard, and their lengths were measured. In addition, it was determined whether or not each gully was associated with a road.

Approximately 80 percent of the gully erosion (volumetrically) occurring during the study period was either road-related or probably road-related. Logging roads, the most common type in the basin, accounted for roughly 60 percent of the volume eroded from gullies. Higher standard roads (roads designed for heavier traffic flow) required larger cut and fill slopes and greater drainage alteration, and consequently produced more gully erosion per road kilometer than logging or ranch roads.

There was an apparent relationship between road density (km of road per km^2 of prairie) and gully erosion yield (volume of erosion per km^2 of prairie) for the upper, middle, and lower sections of the Redwood Creek basin. The few largest gullies contributed the vast majority of total sediment. Gullies tended to be relatively inactive after initial formation. When gully enlargement did occur, they widened rather than lengthened upslope. The gully erosion rate on prairies was roughly comparable to that of Garrett Creek, a moderately erosive logged tributary basin and an order of magnitude less than that of Copper Creek, a severely eroded logged tributary basin within the Redwood Creek watershed.

I. INTRODUCTION

The geomorphic processes operating in the Redwood Creek watershed of northwestern California have been the object of intensive study during the last decade. Dramatic processes, such as mass movement, have been extensively studied and erosion from such processes has been quantified (Kelsey *et al.*, 1981; Pitlick, 1982). However, the relative importance of other sources of erosion on hillslopes - gullying, stream channel enlargement, bank erosion, rilling, and sheetwash - is not well defined. A few specific studies (Weaver *et al.*, 1981; Best *et al.*, in press) have quantified fluvial erosion in tributary basins of Redwood Creek. But because such processes are localized and highly variable in nature, fluvial erosion is difficult to quantify in a large watershed such as Redwood Creek.

Gullying on open grasslands is one aspect of fluvial erosion, and it can be realistically quantified using aerial photographs. In this study, gullies in grasslands of the Redwood Creek basin were mapped and measured by reviewing air photographs taken in 1954 and 1978. In addition, it was noted whether or not a road was associated with each gully.

The purpose of this study was to analyze the causes and erosion rates of natural and road-related gullies in the Redwood Creek basin over time. The frequency of gully initiation and the resulting volume of eroded sediment was compared to gully location, site conditions, land use practices, and storms.

II. LAND USE HISTORY

White men first began settling in the area in the mid-1800's and used the prairies for sheep and cattle grazing. Ranchers (and the Indians before them) burned the prairies occasionally, presumably to prevent encroachment of conifers (Lewis, 1973). The main effect of grazing on prairie vegetation was the gradual elimination of long-rooted perennial grasses in favor of shorter rooted annual grasses, which decreased the strength of the vegetation mat (Kelsey, 1978). Thus, grazing-related activities could have increased erosion in at least two ways:

1. By increasing surface erosion in heavily disturbed areas, such as along stream channels and,

2. By decreasing the strength of the vegetative mat, resistance to erosion by raindrop impact, overland flow and streambank sloughing is decreased and gullies can initiate more easily.

Before logging intensified following World War II, most prairie roads were ranching tracks which followed ridgetops. As new areas were logged, high-standard logging roads were built across prairie slopes. Prior to 1954, a considerable volume of sediment had already been eroded from prairies by road-related gullying. However, between 1954 and 1978, twice as much sediment had been eroded by road-related gullying as pre-1954 volumes.

III. STUDY AREA

The 720 km² Redwood Creek basin is in one of the most rapidly eroding, non-glaciated watersheds in North America (Janda, 1977). The basin is unusually elongate, being approximately 100 km long and 6 to 8 km wide in most places (Figure 1). Average annual precipitation varies from about 2,500 mm on the ridgetops to about 1,600 mm in the valley bottom. Five major storms (1955, 1964, 1972 [2], and 1975) occurred in the basin during the study period, each producing instantaneous peak discharges of 1,415 ± 142 m^3/s (50,000 ± 5,000 m^3/s) at the U.S. Geological Survey gaging station at Orick (Harden *et al.*, 1978).

The Redwood Creek basin is underlain by the pervasively sheared rocks of the Franciscan assemblage of the mid- to late-Mesozoic. For much of its length, the position of Redwood Creek strongly reflects the structural control of the Grogan fault, which roughly bisects the basin. The fault juxtaposes quartz-mica schist on the west with clastic sedimentary rocks, on the east. Blocks of greenstone occur both along the Grogan fault zone and within the clastic unit. Most prairies occur on highly sheared sedimentary rocks that are prone to earthflow landslides.

For the purposes of this report, the Redwood Creek basin was roughly divided into thirds (Figure 1). The lower, middle, and upper thirds contain 5.4, 22.3, 23.4 km^2 of grassland respectively (Best, 1984). Almost all of the grasslands (referred to as prairie) lie on the east side of the Redwood Creek basin (Figure 2). In the lower basin, prairies are continuous along the eastern watershed divide, with occasional tongues extending downslope. These are bordered by Douglas-fir forests, with lesser amounts of hardwood and redwood. In the middle and upper sections of the basin, prairies are more numerous. They occur on all sections of the slope, and are most often bordered by oak woodlands.

IV. STUDY METHODS

The mapping and measurement of gullies for this study were done from aerial photographs, with some field checking. The primary measurements were made using stereo pairs of 1978 color air photographs (1:6,000 scale) and 1954 black and white photos (1:20,000 scale enlarged to approximately 1:6,000 scale). True scale was obtained by comparing reference points on the 1978 photographs with rectified U.S.G.S. orthophotographs (1:24,000 scale).

In this study, gullies were differentiated from natural channels by defining gullies as having a discernable (on an air photograph) break-in-slope between the hillside and the channel wall, as opposed to a smooth, convex gradation from hillslope to channel. It was assumed that incised channels represent relatively recent formation or enlargement, while smooth channel sideslopes represent more older or more gradual, formation. Obviously, the transition between "gully" and "non-gully" is gradational, but the primary interest is in delineating areas of active erosion, not rigidly categorizing gullies and non-gullies.

To measure the volume of a gully on an aerial photograph, the feature was divided into segments of roughly uniform width. The length and average top width of each segment were then measured with vernier calipers which enabled measurements to be taken on gullies with a top width as small as 0.6 meters (2 feet). To account for existing voids, the volumes from

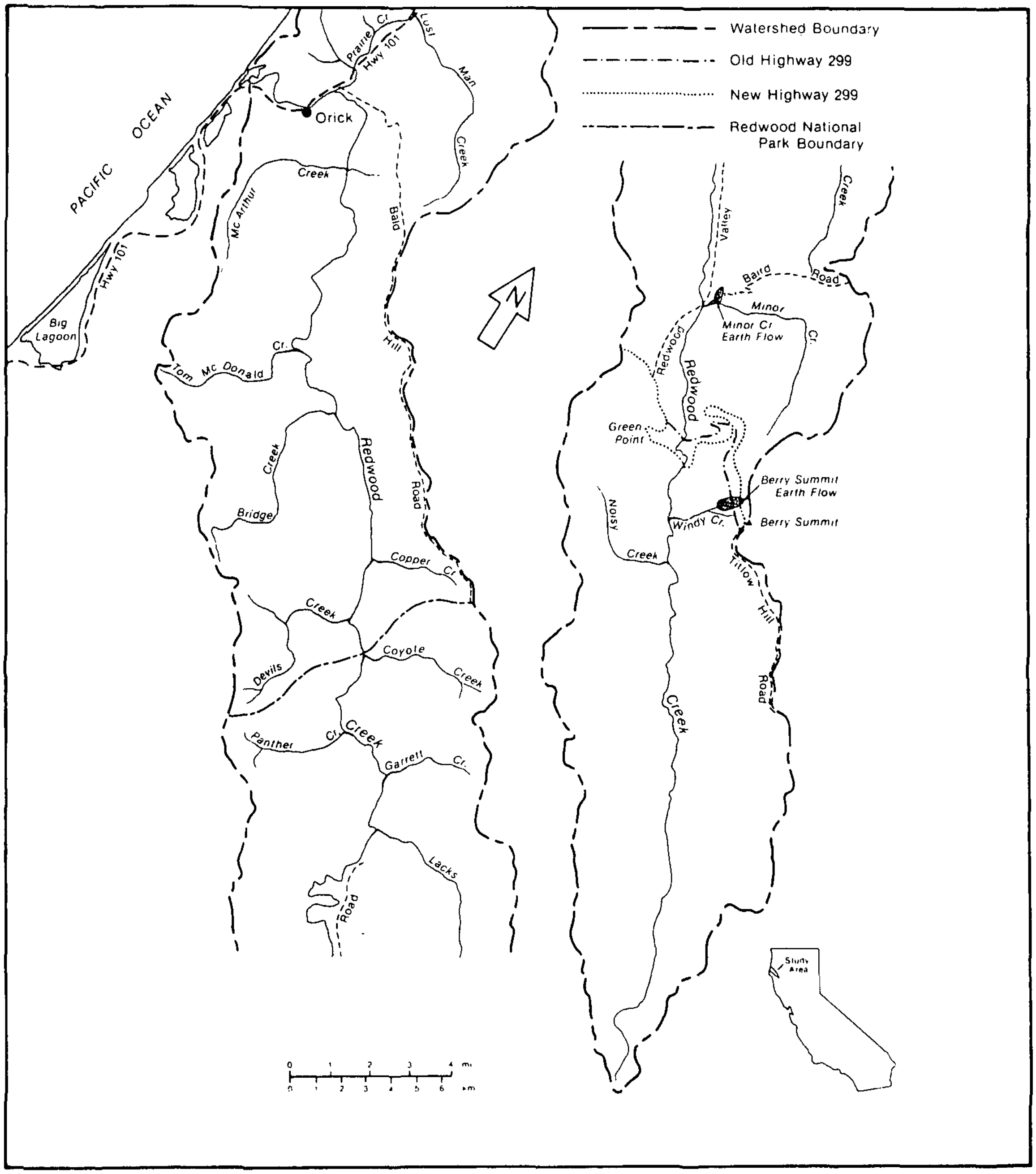

Figure 1: Redwood Creek basin. The dividing point between the lower and middle basins is Redwood National Park Boundary. The dividing point between the middle and upper basins is new Highway 299.

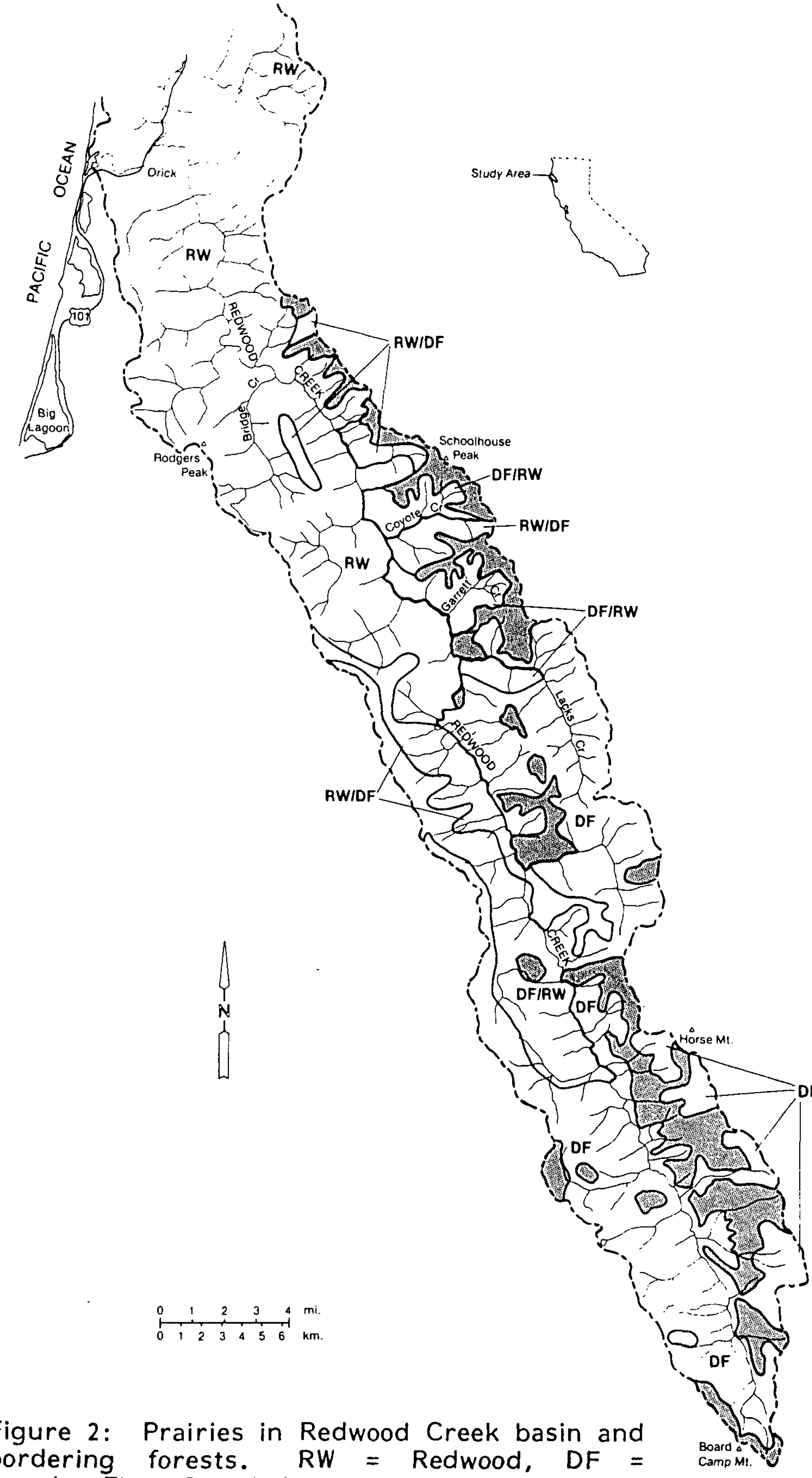

Figure 2: Prairies in Redwood Creek basin and bordering forests. RW = Redwood, DF = Douglas Fir. Stippled areas are prairies.

gullies which cut into channels or swales were underestimated from 5 to 10 percent. The length measurement was multiplied by 1.05 to correct for slope (this assumes an average slope of 30 percent [Pitlick, 1982]).

Two methods of measurement were used in this study. Routon (written communication, 1982) surveyed gullies in the lower basin, which comprise 14 percent of the total number of gullies in the entire basin. He estimated the average gully width and depth to calculate the volume. A modified method was used by this author because of the difficulty involved in accurately estimating average width and depth. Only the top width was measured, which was the most well defined parameter visible on air photographs.

In order to determine a relationship between top width and cross-sectional area, 155 cross-sections were measured on 24 gullies in the field (Figure 3). This represents 3.7 percent of the total number of gullies measured on aerial photographs. The sampling procedure was made as unbiased as possible by measuring cross-sections at regular length intervals along a gully and by sampling as many different areas of the basin as possible, given time and access constraints. Figure 4 shows the correlation between top width and cross-sectional area, along with the linear regression equations. Two regression lines were calculated because of the apparent change in gully characteristics when the top width was either greater or less than 3 m. The regression line for gullies with a top width less than or equal to 3 m has a coefficient of determination (r^2) equal to 0.58, indicating a wide variability in shapes among the smaller gullies. The regression line for gullies with a top width greater than 3 m has an r^2 of 0.86, indicating a greater degree of uniformity among larger gullies.

The appropriate regression equation was applied to the top width measurement of each gully to obtain a cross sectional area which was then multiplied by length to obtain a volume.

As a check for accuracy, aerial photograph measurements were compared to this author's field measurements and to field measurements of seven gullies on Counts Hill prairie completed by a Redwood National Park geologist (Spreiter, unpublished data, 1983). Discrepencies ranged from 20 percent on smaller gullies to between 5 and 10 percent on larger gullies. The net discrepency was a 5 percent underestimate by the air photograph measurements.

An error factor of plus or minus 10 percent is estimated for the methodology used in obtaining gully volumes. Because of poor resolution on 1954 air photos, the error in estimating gully enlargement may be as high as 30 percent, but it is much less for larger gullies.

The degree to which gullies were road-related was also evaluated. Four classifications were used based on the degree of confidence of the judgement; the criteria for each are listed in Table 1. This classification carries with it a degree of uncertainity in that an indeterminate amount of erosion categorized as road-related might have occurred without the presence of a road.

Figure 3: The author (right) and Dave Best measure the top width of a gully in the prairies of Redwood National Park.

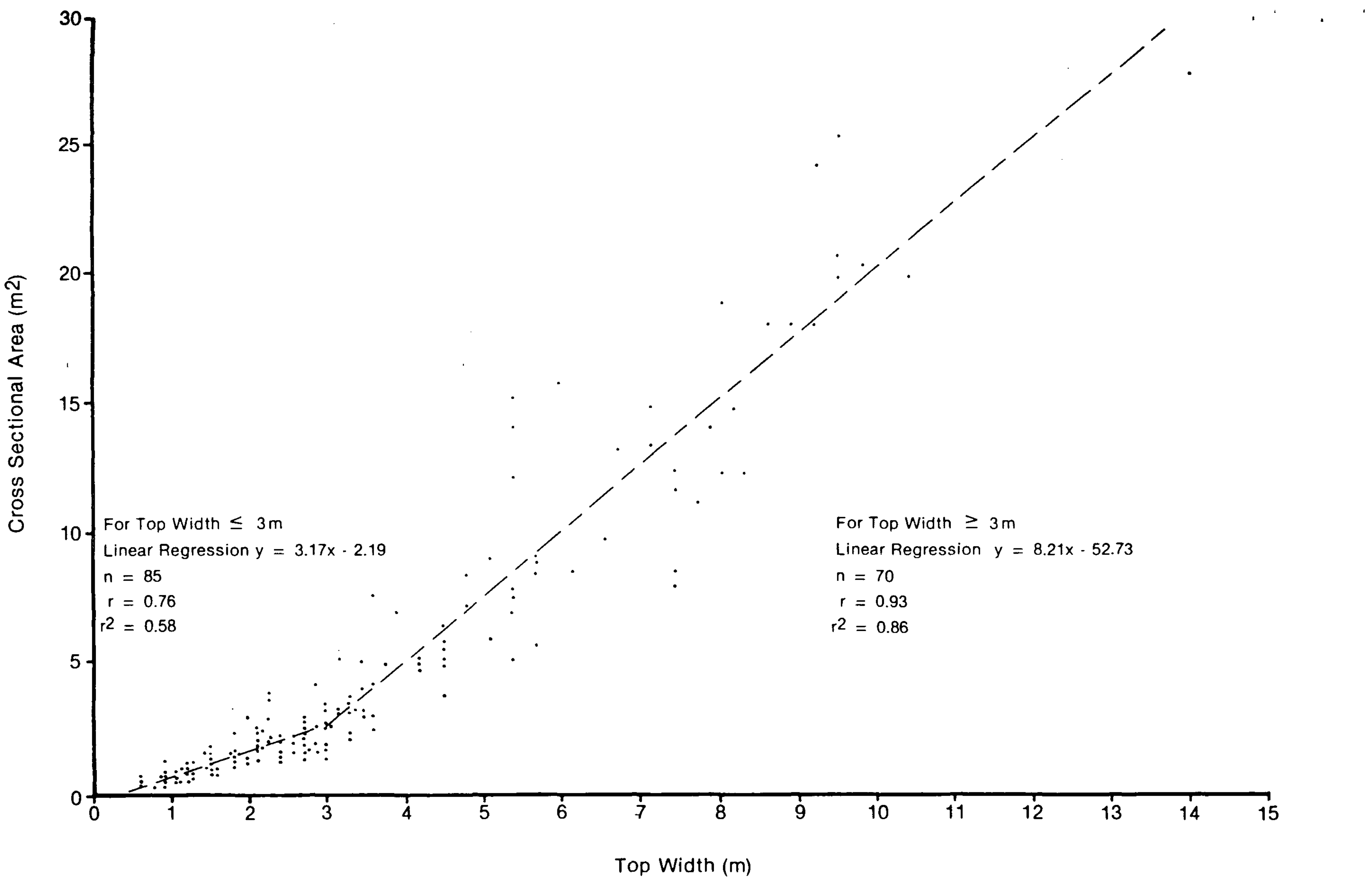

Figure 4: Correlation between top width and cross-sectional area of gullies. Two linear regression lines were calculated because of apparent change of slope characteristics when top width is greater than or less than 3m.

TABLE 1

Criteria For Classifying Prairie Gullies By Road Association

Classification	Criteria
1. Road-Related	Gully starts at a road or within 46 meters (150 feet) of a road; both gully and road are absent on 1954 photos.[1]
2. Probably Road-Related	Gully begins within 46 meters (150) feet downslope of a road; road and gully are present in 1954. Or, gully begins 46-122 meters (150-400 feet) downslope from a road, and road and gully are absent in 1954.
3. Probably Not Road-Related	Gully begins more than 46 meters (150 feet) downslope of road, road and gully present in 1954. Or, gully begins more than 122 meters (400 feet) downslope of road, and road and gully absent in 1954.
4. Not Road-Related	Gully pre-dates road. Road appears to play no role in gully formation.

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1 Often the specific cause is evident; for instance, field observation reveals that an inboard ditch diverts flow from a stream channel at a road crossing onto a slope.

V. FACTORS CONTRIBUTING TO GULLY FORMATION

A. Physical Processes

For the three sections of the Redwood Creek basin, gully formation appears to be a function of road density. For individual prairies, however, their susceptibility to gully formation depends on variations in other site conditions. Differences in soil type, drainage density, hillslope gradient, and bedrock geology also appear to influence gully formation.

1. Soils

Much of the prairie land is underlain by thick soil and colluvial mantles. Gordon (1980) found two distinct soil types on prairies of the lower basin.

Xeralfs have subsoils that are very rich in silt and clay, imperfectly drained, and often associated with mass movement features. Because of these soil characteristics, overland flow is more important and more likely in initiating gullying. In addition, typically high rates of mantle movement associated with Xeralfs weaken the vegetation mat, allowing gullies to form more easily.

Non-Xeralf soils are loamy textured throughout, well-drained, and associated with relatively stable prairie areas. Undisturbed prairie areas underlain by non-Xeralfs exhibit smooth, well developed swales and channels, rather than gullies. Large gullies can develop on non-Xeralf soils where surface flow is concentrated, such as at road diversions or downslope of xeralf soils (Popenoe, personal communication). The Xeralf and non-Xeralf groups of soils roughly correspond to Kneeland and Wilder groups of soils, respectively, of the Humboldt County soils maps (Alexander, 1959-1962).

Why prairies occur in this moist, conifer-dominated region is not completely understood; it is probably a combination of soils, underlying geology, and aspect. Most prairies exhibit signs of varying degrees of mantle flow, such as hummocky, irregular topography, and slump ponds. The more active areas exhibit tension cracks, headscarps, and other earthflow characteristics.

2. Drainage Density

Drainage density is an important factor in determining gully formation and yields. The greater the drainage density, especially for low order streams, the greater the potential for stream diversion by roads or earthflow activity. Because the drainage density is constant in the Redwood Creek basin, except for a slight increase in the upper basin (Iwatsubo *et al.*, 1975) drainage density does not account for the observed differences in gully yields in the different sections of the basin.

3. Hillslope Gradient

It is difficult to quantitatively assess the relationship between hillslope gradient and gully erosion because prairie slopes are typically irregular and variable. Therefore, an "average" gradient number is not very meaningful. Field observations suggest that the gradient at the point of gully initiation may be more important than average slope. Often a gully is initiated on a steeper slope and remains roughly the same size as the slope lessens. Accurately quantifying slope at the point of gully formation would require extensive field work and is beyond the scope of this study. Best (personal communication, 1983), in studying logged conifer regions of the Redwood Creek basin, found that little gully formation occurred on slopes less than 20 percent. Above 20 percent, there was a very poor correlation between increasing slope and increasing gully formation. The exception to this was on roads, where gullying occurred on gradients as low as 10 percent. Presumably this reflects the intense concentration of water often diverted onto roads and inboard ditches and the lack of a protective vegetative mat (Figure 5).

4. *Bedrock Geology*

Bedrock geology is an important factor in controlling prairie location. Almost all prairies are located in the highly sheared, sedimentary rocks found on the east side of the basin, and the dominant aspect is south west. Local variations within this unit, such as degree of shearing, influence the character of the soil and the colluvium mantle which in turn influences susceptability to gully erosion.

B. Erosional Processes Operating on Prairies

The dominant erosional processes operating on prairies appear to be mass movement and gullying. Because of the thick vegetative cover (Hektner, personal communication, 1983), sheetwash and rainsplash erosion are probably negligible on most prairies. Sheetwash and rainsplash erosion may be significant in areas with exposed soil such as active mass movement features and localized areas of intensive livestock use. Little change was observed in swales and first order streams (excluding gullies) during this study, implying negligible erosion (compared to gully erosion) from these sources.

The dominant mass movement process operating on prairie areas are large, lobate earthflows as described by Harden *et al.*, (1978). Iverson (1984) gave a detailed account of movement of an active earthflow near the mouth of Minor Creek (a tributary to Redwood Creek). Kelsey (1978) described the gully networks commonly incised on such features. Gully activity appears to parallel mass movement activity: gullies on active earthflows tend to have raw, steep sideslopes, while gullies on inactive earthflows tend to have well-vegetated, gently sloping sideslopes. On Minor Creek, Nolan (written communication, 1983) found that gully enlargement contributed approximately one-tenth as much sediment to the channel as mass movement. Kelsey (1977), monitoring an active earthflow in grasslands of the neighboring Van Duzen River basin, found that gully enlargement contributed about the same amount of sediment to the channel as mass movement.

Most gullying in this environment probably occurs in a matter of hours or days during large storms. Weaver *et al.* (1981) attributed most of the gully erosion found in their study to the 1972 and 1975 storms. In addition, there is an eyewitness account by a rancher of a large gully forming during a single storm on a lower basin prairie (Lane, personal communication, 1981).

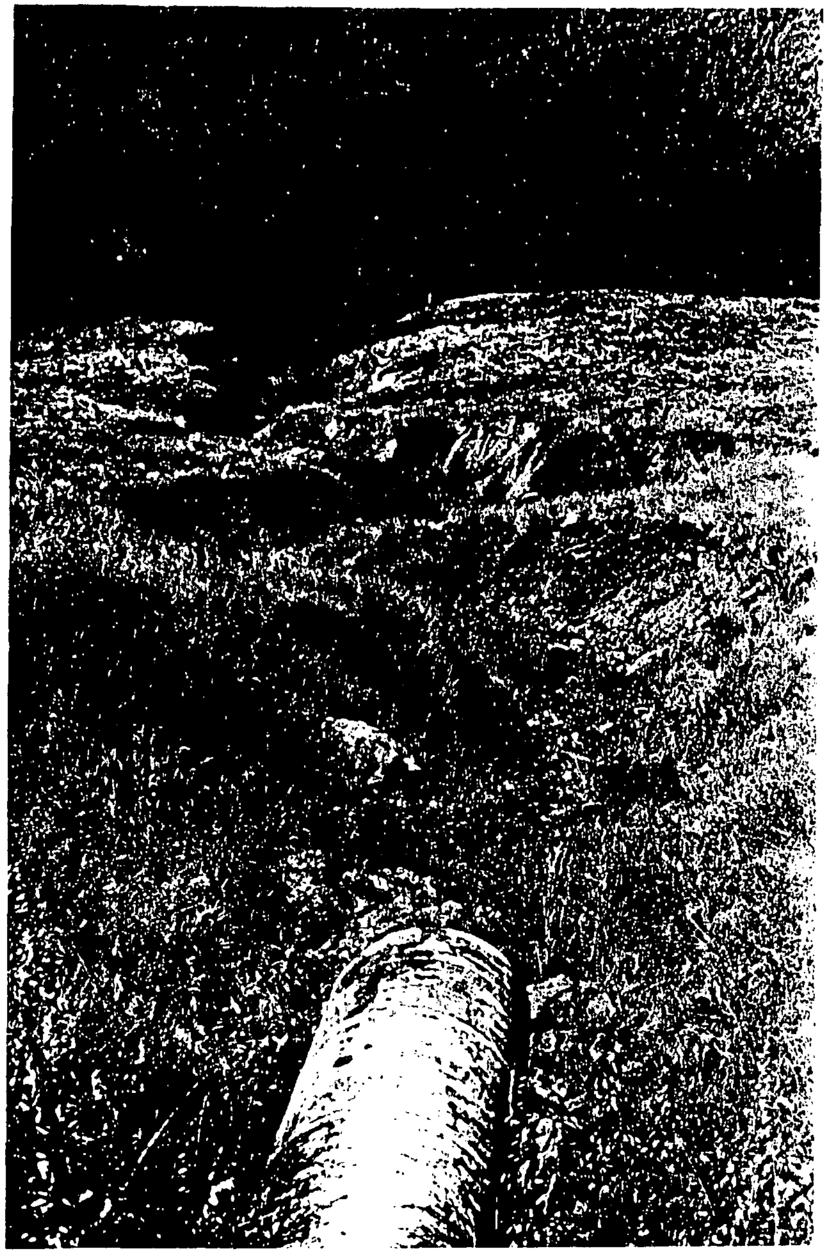

Figure 5: Lack of a protective vegetative mat and an intense concentration of water diverted off roads can cause gullying to occur on gradients as low as 10 percent. Note that this gully formed on a topographic high point rather in a swale.

C. Road Classification

Other studies (Weaver *et al.*, 1981; Weaver, Hagans and Popenoe, in press; Best *et al.*, in press) have found roads to be the principal cause of gully erosion. For this reason roads crossing prairies were classified and mapped, and their lengths were measured.

Each road was classified according to its probable purpose. Unpaved roads that had no apparent relationship to logging activities were called ranch roads. Roads were classified as either main or secondary logging roads (where the primary use appeared to be logging). Because the distinction between secondary and main haul roads was a subjective one, each road system was considered individually. The main stem of the road system was called a main road, with branches or spur roads classified as secondary. Both road width and the degree to which a road conforms to topography were also considered, but these factors were commonly difficult to quantify on air photographs, especially in older road systems. No distinction was made between maintained and unmaintained roads.

Major roads are individually identified on Figure 1. Bald Hill, Titlow Hill, and Redwood Valley Roads are all two-lane, paved, and well maintained roads. Baird Road is a two-lane rocked road, and is also well maintained. Old Highway 299 is two-lane and paved, but most of the road crossing prairie areas has not been maintained since August 1971, when the new Highway 299 was completed. New Highway 299 is a well maintained, three-lane state highway with extensive cut and fill slopes.

Photo copies of 1978 aerial photographs delineating each gully and road, along with the measurement data, are available for inspection at Redwood National Park offices, Arcata, California.

VI. RESULTS

A. General Characteristics of Gully Erosion

A total of 641 gullies were mapped on prairie lands of the Redwood Creek basin. Of these, 337 were classified as road-related or probably road-related, while 304 were not road-related or probably not road-related. The majority of the gullies were continuous; that is, they contributed sediment directly into higher order streams.

1. Gully Enlargement

Only 32 percent of the gullies greater than 850 cubic meters (30,000 cubic feet) present in 1954 enlarged during the study period, in spite of a series of intense storms*. This indicates that most gullies, both not road-related and road-related, are relatively inactive after initial information. Some of

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* *Only gullies larger than 850 cubic meters (30,000 cubic feet) were used because of the uncertainty involved in evaluating gully enlargement in the smaller gullies.*

the road-related gullies are now inactive because of further streamflow diversion by roads onto adjacent slopes. In other cases, field observations suggest that channel armoring prevents further downcutting. (Channel armoring occurs when the fines are winnowed out of channel bed material, leaving a progressive concentration of larger clasts [Figure 4].) The predominant process of gully enlargement was channel widening, rather than channel lengthening. Though significant headcut advancement is an important process in other environments affected by gullying (Heede, 1971), it was rarely observed during this study period.

2. Gully Sediment Yields

Table 2 summarizes the volume of sediment removed by gullying in the Redwood Creek basin and is subdivided by cause classification. Note the difference in the relative importance of causes between the pre-1954 and the study period gully erosion. Of the pre-1954 erosion, 46 percent of the total volume is road-related or probably road-related. This figure increases to 80 percent for the study period of 1954 to 1978. This change probably reflects increased road building, coupled with numerous high intensity storms during the study period.

For the study period, the sediment yield for prairie areas is 4,900 m^3/km^2 or 200 m^3/km^2 per year. Most of the gullying probably occurred during several intense storm events, therefore a rate "per-year" is misleading in that it implies a steady, rather than episodic, process.

It can be seen from Figure 6 that a few very large gullies dwarf the smaller ones in terms of sediment volume contribution. The 32 largest gullies (5 percent of the total number) accounted for 43 percent of the total volume (see line 1) and 30 percent of the gullies accounted for over 85 percent of the total volume (see line 2). Among gullies with volumes of 2,800 m^3 (100,000 ft^3) or greater, two-thirds are road-related or probably road-related.

3. Gully Erosion in Undisturbed Areas

Gully erosion yields vary a great deal locally; certain trouble spots account for much of the gully erosion in the basin. One undisturbed (by roads), but highly erosive, prairie on the north slope of Lacks Creek accounted for almost half of the not road-related gully erosion measured in the basin during the study period. The prairie is only 2.2 percent of the total prairie area in the basin, yet it contributed 45 percent of the not road-related and probably not road-related gully erosion. The area is designated as an active earthflow by Nolan, *et al.*, (1976). Field observations suggest that shifting ground allows sufficiently high streamflow to suddenly overtop low divides and initiate gullying. Locally, a few large gullies exist side by side, indicating this process is very active.

B. The Effect of Road Types on Gully Erosion

Roads can initiate gullying in at least three ways: (1) by diverting stream flow from channels onto adjacent hillslopes, (2) by concentrating stream flow

TABLE 2

Prairie Gully Volumes By Cause Classification
For The Entire Redwood Creek Watershed

(percentage of the total in parenthesis)

Cause Classification	Volume (m^3) Pre-1954	1954 - 1978	Totals
Road Related	52,264 (22.3)	183,045 (73.7)	235,309 (48.7)
Probably Road-Related	55,124 (23.5)	13,098 (5.3)	68,221 (14.1)
Probably Not Road-Related	37,675 (16.1)	28,103 (11.3)	65,778 (13.6)
Natural	89,279 (38.1)	24,165 (9.7)	113,444 (23.6)
TOTALS	234,341 (100.0)	248,411 (100.0)	482,752 (100.0)

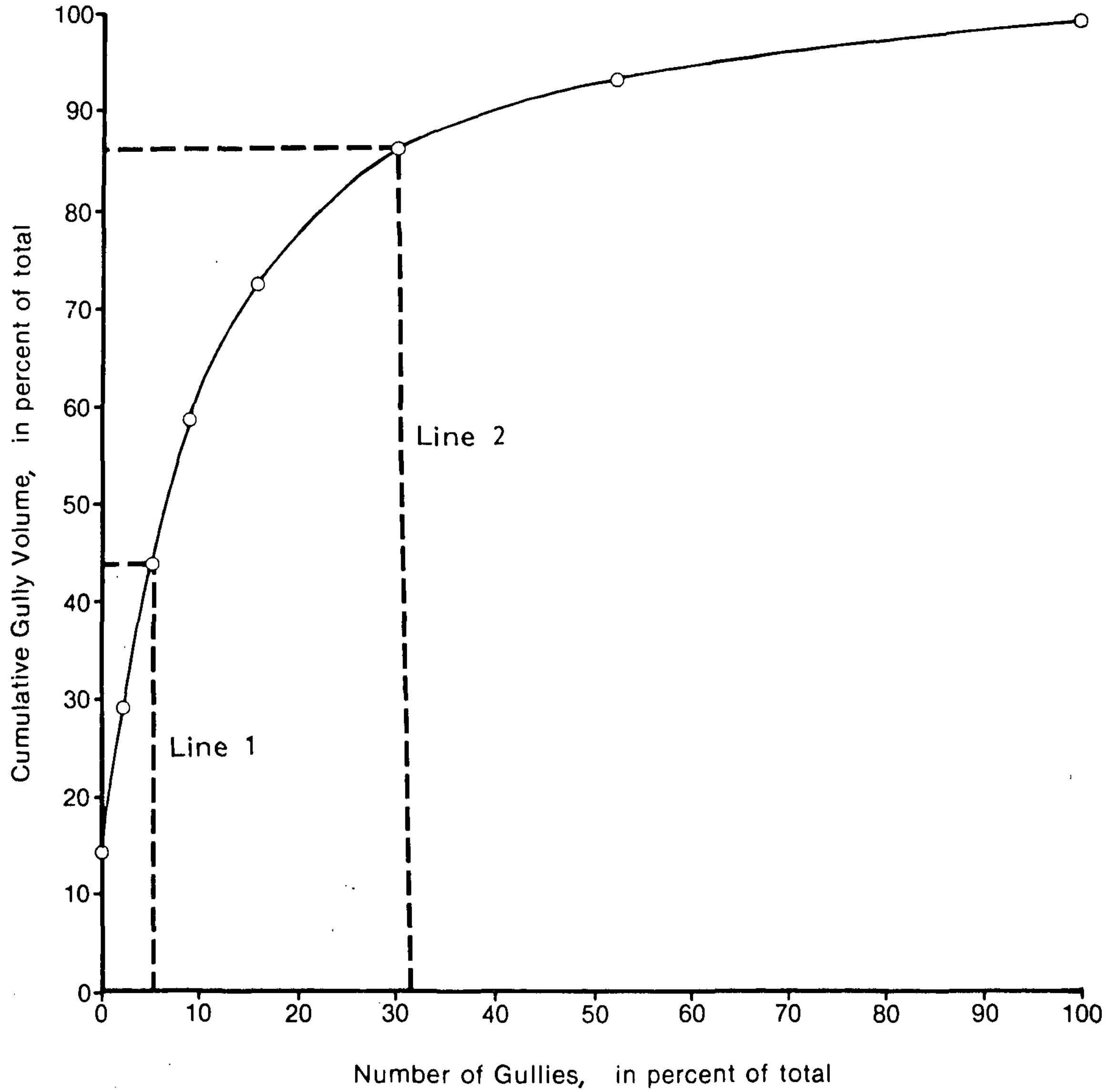

Figure 6: Sediment volume contribution by number of gullies in percent of total.

with inboard ditches then overloading existing stream crossings, and (3) by misplacing culverts which may focus stream power on unprotected areas (Figure 5). In addition, the interception and alteration of subsurface flow by cut and fill slopes may have more significant effects on gully initiation.

Table 3 summarizes the relationships between different road types and gully erosion. There is a good general relationship between road standard* and the intensity of gullying. Road position on the slope is also important.

1. Ranch Roads

Ranch roads account for one-quarter of the total road mileage on prairies, yet they are responsible for only 9.4 percent of the road-related gully erosion. Ranch roads tend to have smaller gullies and fewer gullies per road km than other road types. These statistics reflect the low standard of ranch roads. Ranch roads most often follow ridgetops rather than cut across slopes. Streams are crossed at their headwaters thus limiting the chance for flow diversion. Road cuts and fills are minimal.

Although they are of a relatively higher standard, the Bald Hill and Titlow Hill Roads account for relatively little gully erosion. This is because both roads lie either on or very close to the drainage divide and thus intersect few channels carrying significant flows. The northern section of the Titlow Hill Road, which crosses lower and steeper prairie slopes, accounts for nearly all of the gully erosion associated with this road.

2. Logging Roads

Logging roads produce relatively little gully erosion per km of road when compared with the major highways. Because they are the most numerous road type, however, logging roads are the biggest single cause of gully erosion on prairie lands. Gully erosion associated with logging roads varies greatly by locale. The largest gully in the basin formed downslope from where a logging road crossed three not road-related, inactive gullies. In many instances, gullies begin at road switchbacks. The inboard ditch ends at such bends and the accumulated water is directed onto the slope.

3. Old and New Highway 299

Both old and new Highway 299 have very high volumes of gully erosion per km of road length. Much of the erosion comes from gullies incised on the large earthflow near Berry Summit (Figure 7). Large gullies were present in 1954, where old Highway 299 crossed the earthflow. New 299 was constructed upslope of the old 299 in 1971. Between 1971 and 1978, several

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* *"Road standard" refers to the level of traffic activity for which a road is designed. For increased traffic flow, a higher standard road must be constructed. This requires a wider, straighter, and less steep road than a secondary route, as well as greater landscape alteration.*

TABLE 3

Prairie Gully Erosion Associated With Each Road Type
(Numbers in parentheses are percentages of the total for that column)

Road Type	Road Lengths (Km)	Number of Gullies Associated With Road Type	Total Volume of Sediment Removed by Gullies by roads (m³)	Mean Gully Volume (m³)	Number of Gullies per Road Kilometer	Volume of Gully Erosion per Road Kilometer m³/Km	Ranking of Relative Road Standard
Ranch Roads	38.61 (24.7)	34	22,124 (9.4)	651	88	573	9
Secondary Logging Roads	49.16 (31.5)	67	50,629 (21.5)	756	1.36	1,030	8
Main Haul Logging Roads	42.98 (27.5)	80	73,687 (31.3)	921	1.86	1,714	7
Bald Hill Road	7.84 (5.0)	8	5,905 (2.5)	738	1.02	753	3
Titlow Hill Road	2.58 (1.7)	6	2,348 (1.0)	391	2.32	910	5
Redwood Valley Road	1.51 (1.0)	6	2,835 (1.2)	472	3.97	1,877	4
Baird Road	2.05 (1.3)	14	17,983 (7.7)	1,284	6.83	8,772	6
Old Highway 299	3.16 (2.0)	16	16,995 (7.2)	1,062	5.06	5,378	2
New Highway 299	4.71 (3.0)	26	36,977 (15.7)	1,423	5.52	7,851	1
Miscellaneous Roads	3.53 (2.3)	6	5,826 (2.5)	971	1.70	1,650	
TOTALS	156.13 (100.0)	263	235,309 (100.0)	895	1.68	1,507	

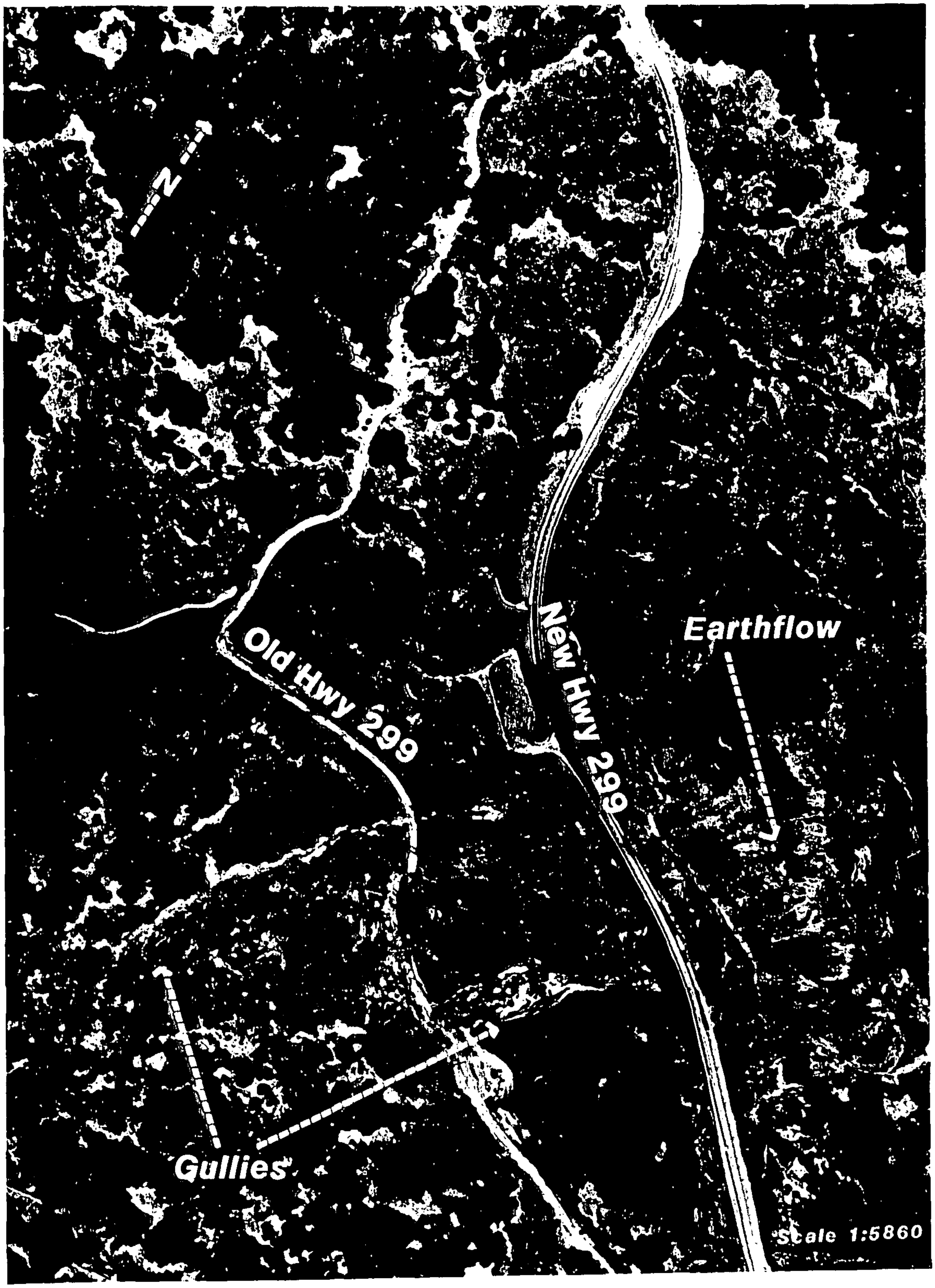

Figure 7: Earthflow and large gullies near Berry Summit on old and new Highway 299.

large gullies formed in the earthflow between the two roads. A few new gullies also formed below old Highway 299 during this time period, possibly because the old highway was no longer being maintained. Numerous small gullies are now present in the section of the earthflow above new Highway 299, which appeared stable prior to highway construction. At Green Point (Figure 1), on the west side of the basin, new Highway 299 has again apparently triggered earthflow movement (along with a large incised gully) above the road.

Almost all of the gully erosion associated with old Highway 299 occurs on the Berry Summit earthflow. New 299, however, has initiated many gullies even in relatively stable prairie areas (Figure 6). This reflects the extremely large cuts and fills and subsequent alteration of hillslope drainage patterns involved in constructing the new highway.

4. Baird Road

Baird Road is a relatively low standard road, yet it has a surprisingly high volume of gully erosion associated with it. This is due to at least two factors: (1) the road crosses steep prairies low on the slope and intersects numerous stream channels carrying significant flows, and (2) the road itself has a steep gradient. Field observations suggest the road has many stream crossings with a high diversion potential. Best *et al.* (in press) defines diversion potential as *"a measure of the probability that a diversion would occur if flow at a crossing exceeds the capacity of the culvert...For crossings with a high diversion potential, the road surface slopes steeply (greater than 5 percent) away from the stream crossing and there is no well defined berm [to prevent backed up water from continuing downslope via an inboard ditch]."*

Baird Road crosses the head of an active earthflow but does not appear to have initiated any large gullies below the road. As with new 299, earthflow movement above the road appears to have increased, allowing a few small gullies to form.

C. Road Density and Gully Yield

There is an apparent difference in gully erosion yields (volume of gully erosion per km^2 of prairie) for the three sections of the basin. The gully erosion yield for the upper basin is a little more than half that of the middle basin, which in turn is half the yield for the lower basin. To explain these variations, road densities were compared for the three sections of the basin.

Table 4 shows road lengths for the upper, middle, and lower thirds of the Redwood Creek basin. Road densities for each section of the basin were obtained by dividing total road lengths by prairie area. In Table 5, road densities and gully yields have been divided by the values for the lower basin to aid in comparison. Table 5 shows a close association between road density and gully yield for the three sections of the basin.

VII. GULLY EROSION: COMPARISON WITH OTHER STUDIES

Table 6 compares the basin-wide prairie gully erosion rate found in this study with gully erosion rates found in other studies in northwestern California.

TABLE 4

Road Lengths In Prairies Of The Redwood Creek Basin

Road Type	Upper Basin Length (km)	Middle Basin Length (km)	Lower Basin Length (km)
Ranch Roads	7.27	31.11	.21
Secondary Logging Roads	12.58	23.92	12.68
Main Haul Logging Roads	12.66	22.48	7.84
Bald Hill Road	.69	7.15	
Titlow Hill Road	2.58		
Redwood Valley Road			1.52
Baird Road		2.05	
Old Highway 299	1.92	1.24	
New Highway 299	1.58	3.13	
Miscellaneous Roads	2.07	1.47	
TOTALS	40.66	87.61	27.88

TABLE 5

Comparison Of Road Density With Gully Yields
For The Lower, Middle And Upper Section
Of The Redwood Creek Basin.
(Gully Yields are for the 24-year period between 1954 and 1978)

Section	km^2 of Prairie	Gully Yields m^3/km^2	(In terms of lower basin)	Road Density km/km^2	(In terms of lower basin)
Upper	23.4	3,183	(.29)	1.74	(.34)
Middle	22.3	5,097	(.46)	3.93	(.76)
Lower	5.4	11,161	(1.00)	5.16	(1.00)

TABLE 6

A Comparison of Gully Erosion Rates From Different Studies In Northwestern California

(parenthesis denote most erosive locale within the Redwood Creek and Van Duzen River basins)

Study	Gully Erosion Rate $m^3/km^2/yr$	Terrain and Locale	Methodology	Study Period
This study	200	Grasslands of the Redwood Creek basin	Air photo interpretation	1954-1978
	(2,120)	(North slope Lacks Creek)	(Air photo interpretation)	(1954-1978)
Kelsey (1977)	16,130	Grasslands of the Van Duzen River basin	Estimation based on Donaker Creek gaging measurement	1941-1975
	(69,820)	(Donaker Creek, on active earthflow)	(Stream gaging measurement)	(1975-1976 water years)
Weaver *et al.*, (1981)	6,000	Logged conifer forest of Copper Creek, Redwood Creek basin	Field mapping	water years 1972-1979
Best *et al.*, (in press)	375	Logged conifer forest of Garrett Creek, Redwood Creek basin	Field mapping	1956-1980

The comparison is tentative because of the different methodologies and time periods covered in each study; however, an order of magnitude comparison is valuable.

Erosion studies conducted in Copper Creek (Weaver *et al.*, 1981) and Garrett Creek (Best *et al.*, in press) reveal large differences in gully erosion rates associated with intensive logging activity in conifer regions of the Redwood Creek basin. The prairie gully erosion rate is comparable to the Garrett Creek rate and an order of magnitude below the Copper Creek rate. It appears that logged conifer areas produce more gully erosion than prairies, probably because of the higher road densities and ground disturbance due to skid trails (Weaver and Hagans, in press) associated with the logged areas. However, undisturbed conifer areas exhibit essentially no gully erosion, while undisturbed prairies do.

The grasslands of the Van Duzen River basin are two orders of magnitude more erosive, in both basin-wide and most erosive locale case rates, than the grasslands of the Redwood Creek basin. Kelsey (personal communication, 1983) believes the different rates reflect differences in bedrock geology and earthflow activity rather than degree of road disturbance. The Van Duzen River basin is underlain by the Eel River melange of the Franciscan assemblage, a highly erosive rock type. Large, highly active earthflows with extensive gully networks occur in the Van Duzen grasslands on a scale not seen in the Redwood Creek basin.

VIII. SUMMARY

1. Seventy-five percent of the sediment removed by gullying on prairies in the Redwood Creek Basin between 1954 and 1978 is road-related, while another 5 percent is probably road-related.

2. Thirty percent of the gullies contributed over 85 percent of the total sediment. Road related gullies tend to be larger than not road-related gullies, and two-thirds of the largest gullies (over 2,830 m^3) are road related.

3. There were different volumes of gully erosion per km of road length associated with the different road types. Ranch roads have the lowest associated gully volumes. Baird Road and New Highway 299 have the highest yields, with a volume 14 times greater than that for ranch roads.

4. There is an apparent relationship between gully erosion and road density for the upper, middle, and lower sections of the Redwood Creek basin. While not systematically inventoried, other site conditions probably have less influence on gully erosion yields than road density.

5. In the Redwood Creek basin, the gully erosion rate for prairies is roughly comparable to the Garrett Creek (relatively least erosive) rate and an order of magnitude less than the Copper Creek (relatively most erosive) rate, for disturbed conifer areas. Grasslands of the Redwood Creek basin are two orders of magnitude less erosive than grasslands of the nearby Van Duzen River basin.

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United States Department of the Interior

NATIONAL PARK SERVICE
REDWOOD NATIONAL PARK
1111 SECOND STREET
CRESCENT CITY, CALIFORNIA 95531

IN REPLY REFER TO:
N30

October 1, 1986

Redwood National Park is ending this summer's estuary management activities at the mouth of Redwood Creek near Orick, California. With the onset of winter rains and departure of most young fish to the ocean, estuary management is no longer necessary.

During the spring and summer, the National Park controlled water levels in the estuary to maintain rearing habitat for juvenile salmonids while preventing flooding of adjacent private property. The special habitat created by fresh and salt water at the mouths of rivers and creeks is important in the life cycle of young king salmon and steelhead trout.

Early September fish counts revealed that few juvenile salmon and steelhead were using the estuary and most had entered the ocean. At the summer peak, nearly 4,500 juvenile king salmon and 25,000 juvenile steelhead trout were in the estuary, much fewer than had been observed over the last five years of record. In total, the National Park Service adjusted the water level seven times in 1986 to prevent backwater flooding of adjacent private property.

Thank you for your continued interest in the park.

Sincerely,

Douglas G. Warnock

Douglas G. Warnock
Superintendent

United States Department of the Interior

NATIONAL PARK SERVICE
REDWOOD NATIONAL PARK
1111 SECOND STREET
CRESCENT CITY, CALIFORNIA 95531

IN REPLY REFER TO:

N30

October 14, 1987

Redwood National Park is ending this summer's estuary management activities at the mouth of Redwood Creek near Orick, California. With the departure of most young fish to the ocean, estuary management is no longer necessary.

During the spring and summer, the National Park controlled water levels in the estuary to maintain rearing habitat for juvenile salmonids while preventing flooding of adjacent private property. The special habitat created at the mouths of rivers and creeks is important in the life cycle of young king salmon and steelhead trout.

Late August fish counts reveal that most of the juvenile king salmon had entered the ocean. At the summer peak, nearly 117,000 juvenile king salmon were in the estuary, more than had been observed at one time over the previous five years of record. In total, the National Park Service attempted to adjust the water level 19 times in 1987 to prevent backwater flooding of adjacent private property. Thank you for your continued interest in the park.

Sincerely,

Douglas G. Warnock

Douglas G. Warnock
Superintendent