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COOPERATIVE EROSION CONTROL EFFORTS BASED ON SEDIMENT TRANSPORT TRENDS, REDWOOD CREEK, NORTH COASTAL CALIFORNIA

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ABSTRACT

Water and sediment discharge have been monitored in Redwood Creek, north coastal California, since the mid-1970's. During the last decade of drought, sediment yields in Redwood Creek have decreased from a high of 6100 t/mi^2/yr to <1000 t/mi^2/yr. Remobilization of previously deposited sediment became a major sediment source during low flow years, and supplied at least half the bedload measured at the mouth of Redwood Creek. Land now part of Redwood National Park located at the downstream third of the Redwood Creek basin was heavily logged in the 1970's; however, most bedload sediment (about 70%) still originates from upstream of national park boundaries. Based on an analysis of sediment yield trends, the National Park Service is expanding the focus of its erosion control efforts from within park boundaries to outside its boundaries. This entails working cooperatively with other federal, state and county agencies, several timber companies, and many private landowners. Public education, cooperative agreements and assistance to landowners are being used in an attempt to address existing erosion problems and to prevent future problems upstream of National Park lands.

INTRODUCTION

Redwood Creek drains 278 mi^2 in north coastal California. Redwood National Park encompasses the lower third of the watershed; the upstream two-thirds is privately owned. The 30,000 acres immediately upstream of the park is called the Park Protection Zone (PPZ), where some specific land use restrictions apply (Figure 1). In the early 1970's, sedimentation and erosion from upstream of Redwood National Park boundaries were identified as threats to the park's downstream riparian and aquatic resources (Stone and others, 1969; Janda and others, 1975). In response to legislative mandates stated by Public Law 95-250 in 1978, Redwood National Park undertook studies to measure erosion, sedimentation and sediment transport in the Redwood Creek basin and to differentiate causes of increased soil losses.

To measure sediment transport, the U.S. Geological Survey (USGS) in cooperation with the National Park Service, established seven continuous recording gaging stations (three on the mainstem of Redwood Creek, and four on tributaries to Redwood Creek) (Figure 1). Each tributary station monitors basins with different bedrock types (schist, incoherent sandstone, and coherent sandstone) that are being logged and one pristine, old-growth redwood basin in sandstone that is used as a control watershed. The latter is the only such basin monitored on the

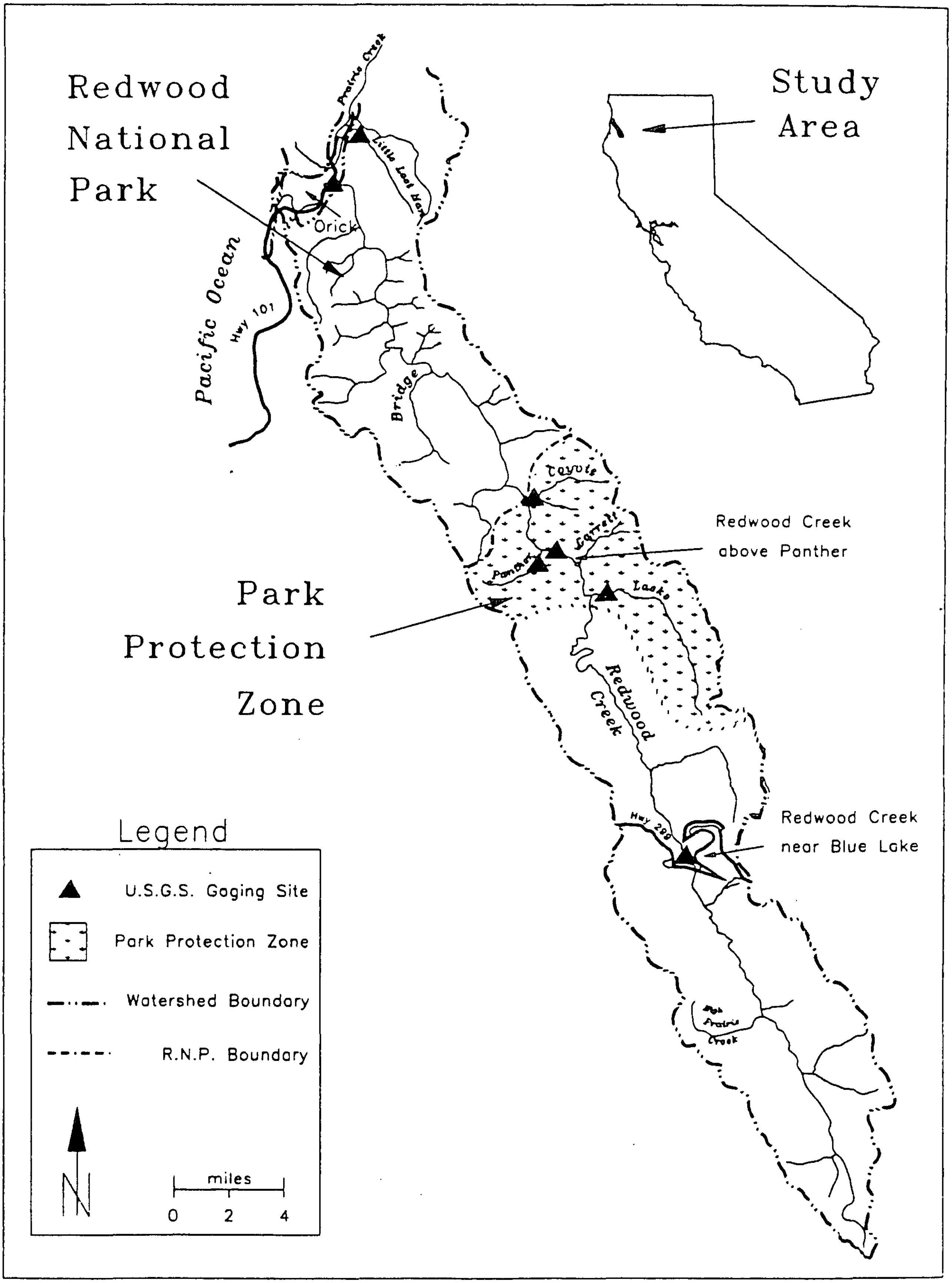


Figure 1: Location map of Redwood Creek basin, showing gaging

north coast of California. Water and sediment discharge were measured periodically at several other stations as well.

One focus of the sediment study was to calculate sediment transport rates, including bedload transport rates, throughout the basin. It was the bedload component of sediment load that caused the most severe channel changes in the past. Sediment transport rates were based on measurements of streamflow, suspended sediment and bedload movement under various conditions at several sites. Using data from the stations, I formulated a bedload sediment balance, which included amounts of sediment entering the park and leaving the park. Study results were used to focus the park's erosion control program on the most critical areas, including upstream, privately owned land. Study results will also be used to predict how long sediment will remain a problem in Redwood Creek and to determine future sedimentation effects on park aquatic and riparian resources.

RESULTS

A. Precipitation

Twenty storage and continuous-recording raingages are distributed throughout the Redwood Creek watershed. Average annual rainfall varies greatly, from 45 inches at low elevations near the coast to over 100 inches at higher inland areas. Major sources of precipitation are large scale regional storms associated with traveling cyclones, but orographic effects significantly increase the amounts of precipitation at higher elevations. Rainfall is strongly seasonal, with 75% of the annual precipitation occurring between October and March. The contribution of summer fog drip may be significant locally. Annual variation in precipitation is high.

Figure 2 shows annual rainfall amounts from 1950-1990 from a storage raingage at Prairie Creek State Park. Average annual rainfall for this station is 67 inches. The last five years are below average in total rainfall amounts. The amount of rainfall directly influences flow magnitudes, and indirectly controls the amount of sediment transport. The last five years have been below average in stream runoff and sediment yield as well (see below).

B. Water Discharge

In most years, runoff was similar at all Redwood Creek mainstem stations (Figure 3). During wet years in the 1950's, the upper basin (Redwood Creek near Blue Lake) produced more runoff. During the 1970's, South Park Boundary was somewhat higher than other stations. Harden and others (1978) describe hydrologic characteristics of six major storms in the Redwood Creek basin.

Lee and others (1975) modelled precipitation and runoff in the Redwood Creek basin for periods before and during intensive

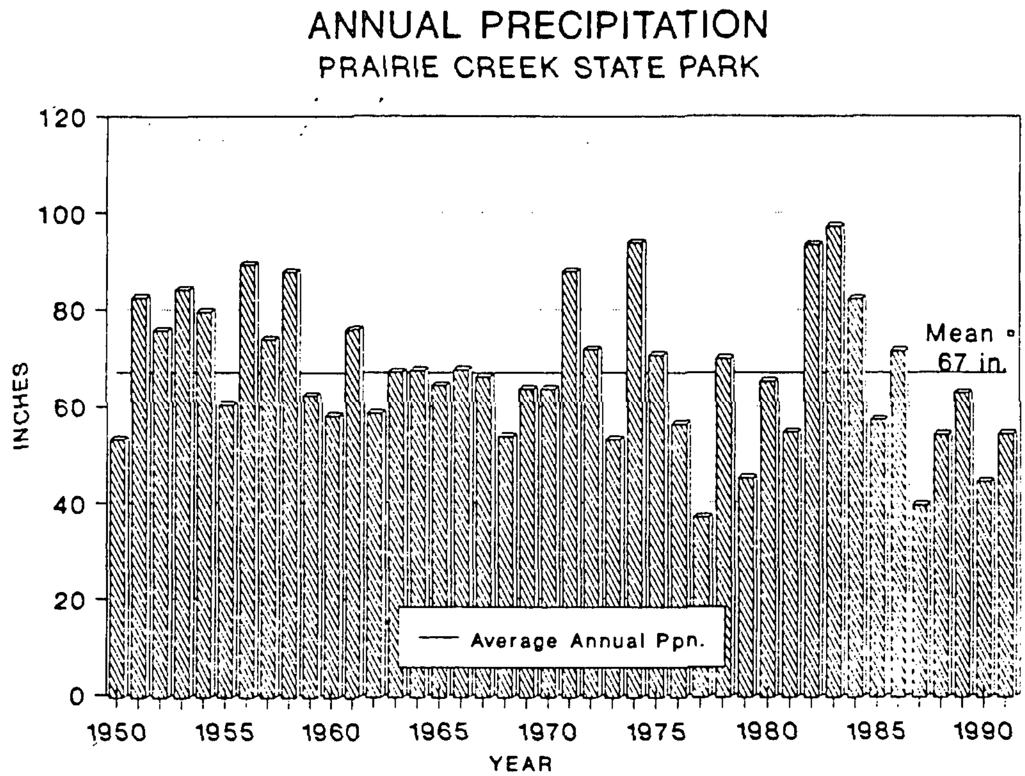


Figure 2: Annual precipitation measured at Prairie Creek State Park, five miles north of Orick.

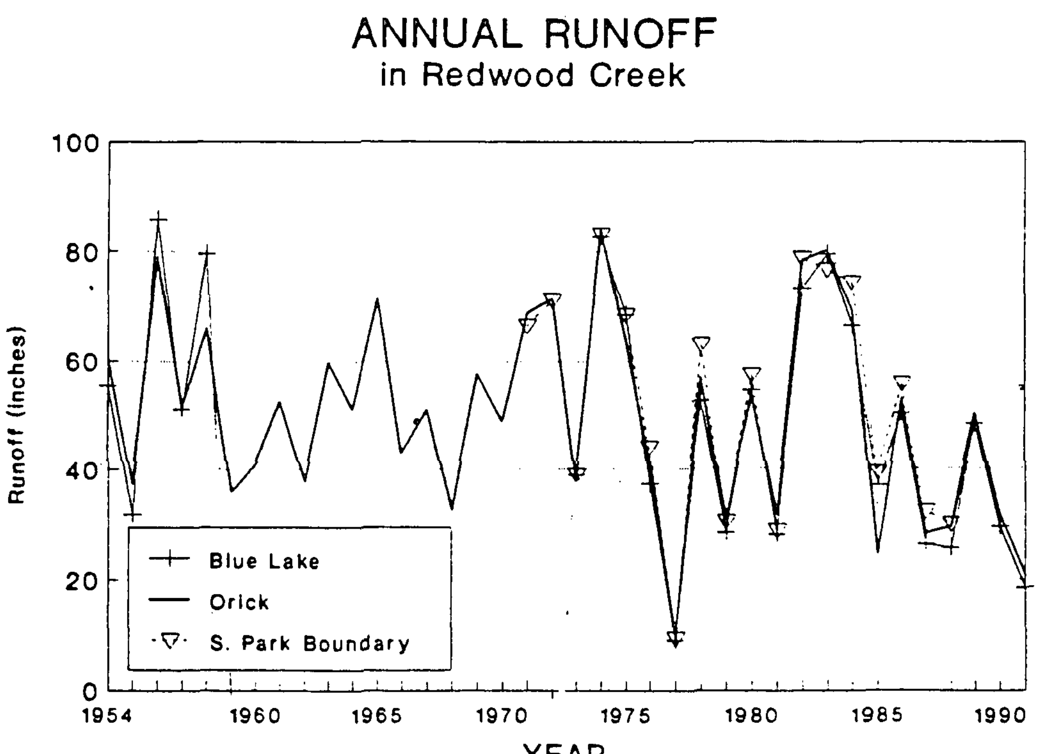


Figure 3: Annual runoff measured at mainstem stations: Redwood Creek near Blue Lake, Redwood Creek at old South Park Boundary (and above Panther Creek), and Redwood Creek at Orick.

logging in the watershed. Their comparisons suggested runoff increased about 20% because of changes in watershed characteristics due to land use activities. King (1979) modelled runoff in the Redwood Creek basin, and found that actual runoff was higher during storm seasons and lower in the summer than the predicted runoff. She suggested that increased ground compaction and alteration of subsurface storage from logging could cause the increased winter runoff, and that channel aggradation with its concomitant subsurface water flow could cause the decrease in summer runoff. Her calculated average runoff/precipitation ratio was 0.728.

Tributary basins showed much more variation in runoff volumes (Figure 4). Coyote Creek consistently produced more runoff during the period of record, and Little Lost Man Creek the least. Differences in precipitation, mean basin elevation, geology, soils, vegetation and degree of land disturbance all influence runoff volumes. The effects of ground disturbance (especially soil compaction) and vegetation removal on runoff production in these basins are not yet known.

Sediment transport is highly dependent upon large flood flows. Water Years 1953, 1956, 1965, 1972 and 1975 had high peak flows (those flows expected to occur every 10 to 50 years). The 5-year recurrence interval flood for Redwood Creek at Orick is about 35,000 cubic feet per second (cfs). Annual peak flows since 1976 have all been less than a 5-year recurrence interval (Figure 5).

C. Sediment Yield

The USGS measured sediment in two ways. Daily suspended sediment samples were collected from October 1 to April 30 at Redwood Creek near Blue Lake and Redwood Creek at Orick. Sediment concentrations and water discharge were combined to calculate sediment transport in tons/day. A sum of tons/day for each day of record from October to April resulted in a value for sediment load. The relationship of sediment load to discharge was then used to estimate sediment loads during the unsampled period (May through September).

Unlike suspended sediment sampling, bedload was sampled periodically, usually during high flows. A bedload/discharge relationship was formulated, and tons of bedload/day calculated. Sediment yields reported in this document represent the sum of suspended sediment and bedload (Qs-total) from USGS annual reports, unless otherwise noted.

Sediment yields from gaging stations monitoring different sized watersheds were compared by using values normalized by drainage area (tons/mi^2/yr) for each station. Figure 6 shows results from Redwood Creek mainstem stations. The horizontal lines represent the long-term annual average sediment yield (USGS, 1981) for Redwood Creek near Blue Lake and at Orick. Sediment yield in

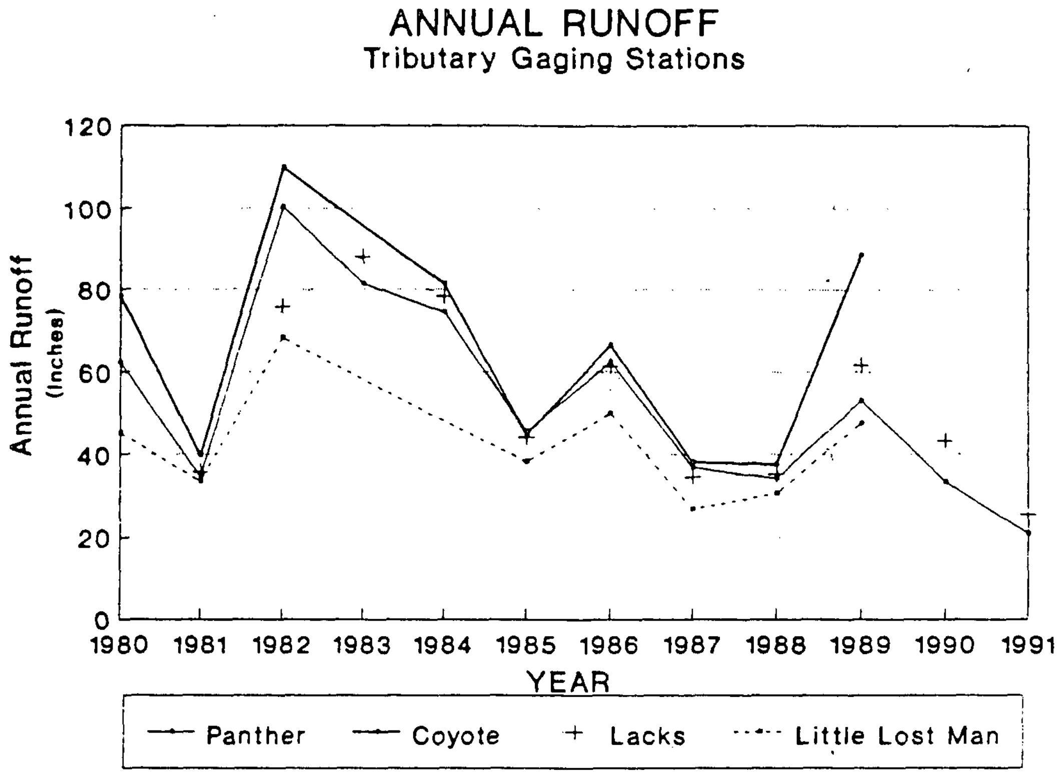


Figure 4: Annual runoff measured in four tributaries of Redwood Creek. Bedrock geology, vegetation, land use and proximity to the ocean differ among the stations.

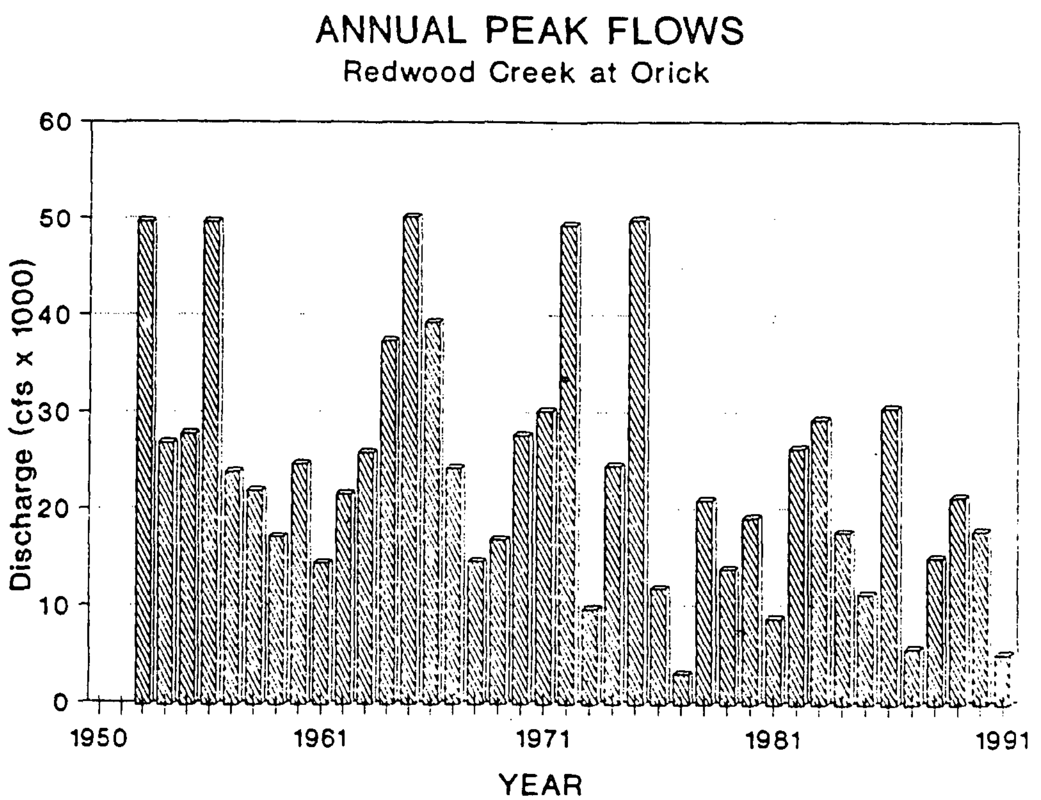
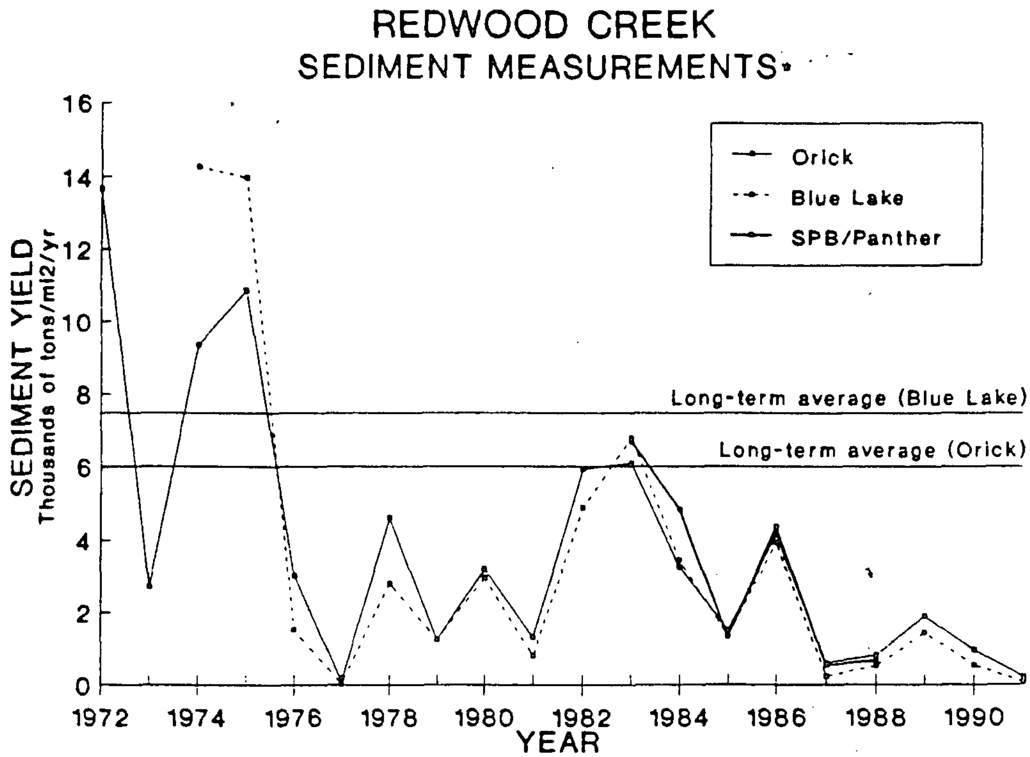


Figure 5: Annual peak flows measured near the mouth of Redwood Creek. The 5-year return interval flow is about 35,000 cfs.



*Bedload plus suspended load after 1973

Figure 6: Sediment yields of Redwood Creek based on USGS suspended sediment and bedload discharge measurements at three stations: Redwood Creek near Blue Lake, Redwood Creek at old South Park Boundary (and above Panther Creek), and Redwood Creek at Orick. The long-term averages at two stations, as determined by the USGS (1981) are shown by horizontal lines. The water year extends from October 1 through September 30.

Redwood Creek since 1977 has been significantly less than the long-term average estimated by the USGS (1981), except in the relatively wet Water Year 1983. Redwood Creek near Blue Lake had much higher sediment yields in 1974 and 1975 than Orick, and then became similar to values at Orick. South Park Boundary had a shorter record, but was higher than the other stations.

There are several implications of the recent low values in sediment yield. Because of the current drought years, it is difficult to distinguish between low sediment yields due to watershed and channel recovery of the upper basin and low yields due to low water flows. Low sediment yields may mean hillslopes are delivering less sediment (less erosion) or sediment may be eroded and stored on the hillslope and in small tributary channels. Monitoring the next large flood will clarify the situation. High flow years (1972 and 1975) resulted in both high sediment transport rates in Redwood Creek and large streambed aggradation. During low flow years of the last decade, sediment transport rates have been low, extensive streambed scour has occurred in upper Redwood Creek, and aggradation continues in the lowermost reaches of Redwood Creek.

Figure 7 shows a shift in sediment transport curves for Redwood Creek at mainstem stations. Not only has total annual sediment transport decreased in Redwood Creek at Orick, but for a specific discharge, sediment load is lower after 1978 than in the early 1970's. This shift suggests less sediment available in the stream channel for transport, and is consistent with the stream channel recovery documented by cross-sectional surveys (Ozaki, 1991). However, the big question of what will happen in the next big flood remains. Presently, it is unclear at this point whether hillslopes have recovered so that they will contribute little sediment in the next flood, or if the next flood will set off another episode of erosion and aggradation in Redwood Creek. Over 1000 miles of logging roads exist upstream of park boundaries, many with a high potential for erosion problems. An inventory of upper basin roads is in progress to help answer the question of future erosion and impacts on Redwood Creek.

Sediment yields in PPZ tributaries (Figure 8) show that Coyote Creek was a high sediment producer in 1980, 1982, and 1989. The gage was discontinued for one year in 1983 (a relatively wet year) due to budget constraints. From 1984 to 1989 sediment yields were similar to the other PPZ tributaries. Lacks Creek showed an increase in sediment yield in 1986. Little Lost Man Creek had an average sediment yield of only 240 $t/mi^2/yr$ during this period. Sediment yields still need to be correlated with bedrock, soils, logging and road construction activity in these basins.

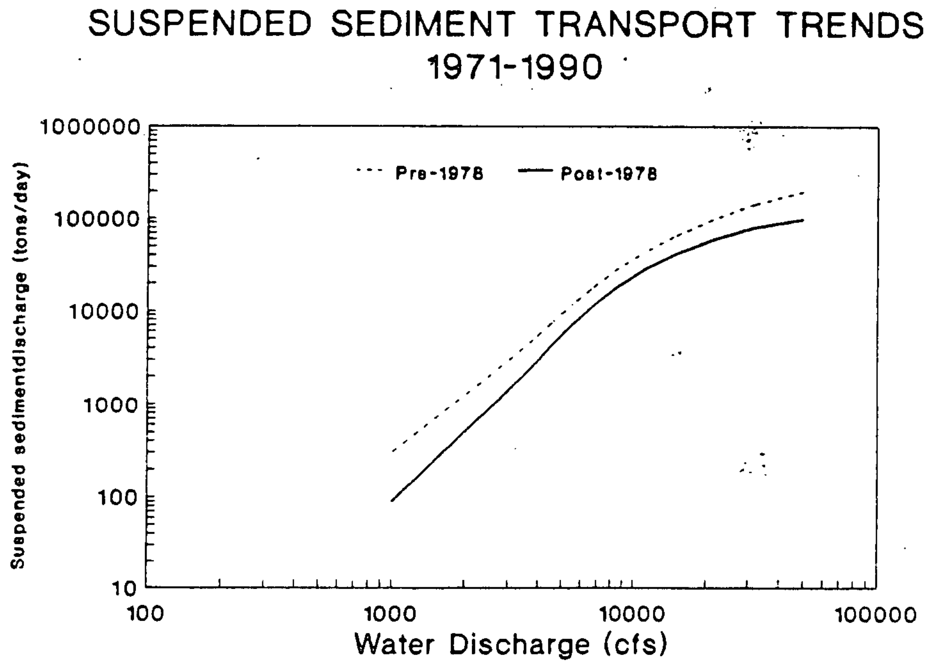


Figure 7: Suspended sediment transport curves for Redwood Creek at Orick, compiled from USGS annual sediment data for two time periods, 1971-1978, and 1979-1990.

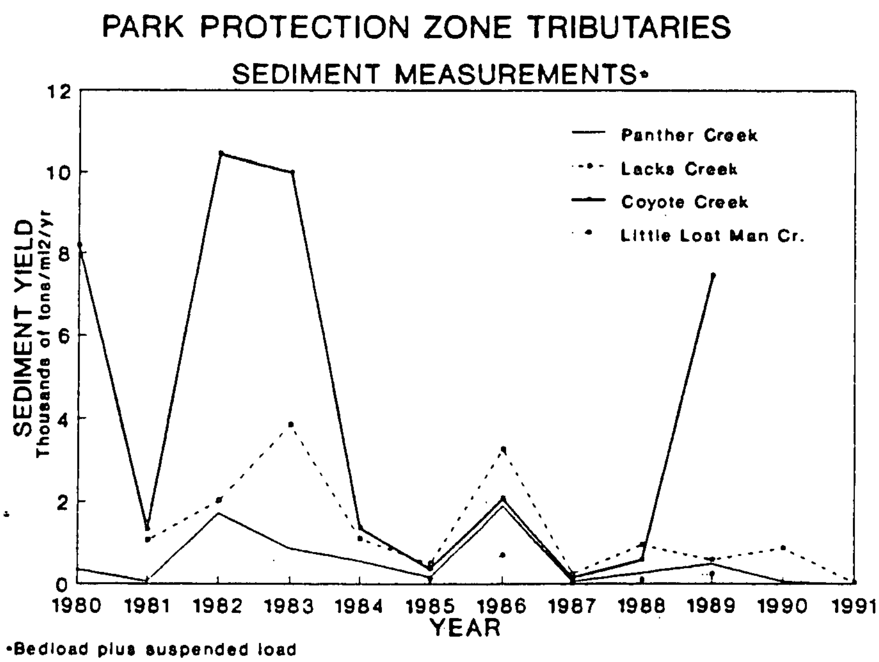


Figure 8: Sediment yields from tributaries of Redwood Creek based on USGS suspended sediment and bedload discharge measurements. The Coyote Creek gaging station was not operating in Water Year 1983, and the sediment yield estimate was based on sediment transport curves from other years and runoff records from adjacent stations.

D. Sediment Balance

It is the bedload fraction of the sediment load that has caused aggradation of the Redwood Creek channel and damage to old-growth redwoods and other trees in the Redwood Creek riparian corridor (Janda and others, 1975; Varnum and Ozaki, 1986). Based on water and sediment discharge records from tributary and mainstem stations, I constructed a balance for the bedload fraction of sediment for the period 1980-1990 to document how much bedload sediment came into the park compared with how much left the park.

Over sixty channel cross sections are located along the length of Redwood Creek, and are resurveyed annually. During the last decade large quantities of sediment have been eroded from the Redwood Creek bed, resulting in net scour of the channel. Channel cross-sectional surveys (Ozaki, 1991) provided data on channel bed scour, and we used the double end area method to estimate the volume of sediment eroded from the bed of Redwood Creek between cross sections.

Figure 9 represents the best estimates to date of the source areas contributing bedload measured at the mouth of Redwood Creek (Redwood Creek at Orick, 1,937,450 tons from 1980-1990). There are, of course, several logistical problems in measuring bedload at gaging stations, especially when peak flows occur at night with many logs floating downstream. As order of magnitude representations, however, Figure 9 is useful as an indicator of bedload source areas. Lacks, Coyote, and Panther Creeks represent most of the contribution from the Park Protection Zone, as measured by USGS stations. Bedload from the other PPZ tributary, Garrett Creek, was estimated based on the adjacent gaged streams (Coyote and Lacks Creeks). The upper basin refers to the area upstream of the Blue Lake gaging station, and the middle basin refers to land between the upper basin and park lands (Figure 1). Sediment yield from the middle basin listed on Figure 9 includes hillslope and tributary contributions based on bedload rates measured in the PPZ, but does not include channel bed scour. Bed scour was computed separately based on channel cross-sectional survey data, and on Figure 9 it is classified as originating within park reaches or upstream of park boundaries. Because the output of bedload sediment measured at the Orick gaging station was known, and all contributions had to add up to 100%, the unknown quantity of bedload coming from park lands was estimated to be 7% (or 133,060 tons).

Sediment yields listed in Figure 9 include assumptions about attrition of bedload as it is transported downstream. The friable nature of the sandstones and schist in the Redwood Creek basin results in the breakdown of bedload to suspended sediment size as it is transported. Attrition was estimated in this study by comparing the volume of sediment eroded from the streambed upstream of the Blue Lake gaging station (measured from cross section surveys, 445,000 tons) to the amount of bedload measured at the gaging station for the same time period (300,000 tons), a

SOURCE AREAS OF BEDLOAD
MEASURED AT REDWOOD CREEK, ORICK
1980-1990

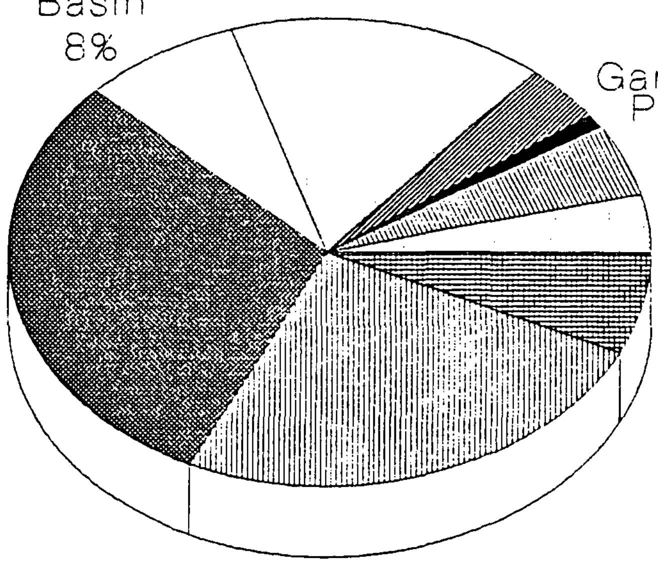


Figure 9: Source areas of bedload that was measured at the Redwood Creek at Orick gaging station by the USGS. The upper basin represents bedload measured at the Redwood Creek near Blue Lake gaging station. Values for Panther, Coyote and Lacks Creeks were based on their respective gaging stations, and values for the middle basin and Garrett Creek were estimated using normalized values from those tributaries. Bed scour, both from upstream and within park boundaries, was estimated from channel cross-sectional survey data. Contribution from park lands was considered to be the unknown "X" needed to balance the pie to equal 100% of the output measured at Redwood Creek at Orick.

decrease of 30% Accordingly, a 30% attrition rate was also applied to the amount of bedload sediment contributed in the reaches between Redwood Creek at Blue Lake and the Redwood National Park boundary.

Sediment input into the park is significant. Of the almost 2 millions tons of bedload transported by Redwood Creek at Orick between 1980 and 1990, about two-thirds came from upstream of the park. Another 25% was derived from streambed erosion from the stream channel within the park. Channel-stored sediment became an important sediment source during this period, and about a half of the bedload measured at Orick could be attributed to channel bed scour along the length of Redwood Creek.

It must be kept in mind that these numbers were generated during a period with no large floods. In the long term, on north coast rivers most sediment is transported during major floods. The relative proportions of sediment source areas may (and probably will) change in the next large flood.

EROSION CONTROL OF UPSTREAM, PRIVATE LANDS

Congress expanded Redwood National Park in 1978 to include previously logged land. Since then, the park has undertaken a large erosion control project on abandoned logging roads and logged lands. To date, over 150 miles of logging haul roads have been rehabilitated, which includes the removal of culverts, excavation of stream crossings and removal of unstable road fill.

The bedload sediment balance described above, although crude, pointed to sediment sources upstream of park boundaries as potential problems to downstream park resources. For example, over 1000 miles of unpaved logging roads are present upstream of the park boundaries. About half the sediment produced in the basin comes from failures of road fills and stream crossings, and diversions of streams at roads.

In 1991 the National Park Service initiated an erosion control project on federal land managed by the Bureau of Land Management upstream of park boundaries. This demonstration project consisted of "erosion proofing" five miles of a haul road, rather than removing it. Culverts were upgraded, and rolling dips were constructed at stream crossings to reduce the threat of failed crossings and stream diversions. Figure 10 shows problems at a stream crossing that were corrected as part of the project. In 1992 a cooperative project with a private landowner will be conducted on land in Lacks Creek, and more cooperative efforts are planned in the future.

Land ownership upstream of the national park is a mosaic of large timber companies, small landowners, the U.S. Forest Service and Bureau of Land Management. Goals of the landowners differ widely, from commercial timber harvest to recreational use. One of the Park Service's goals is to work with the diverse

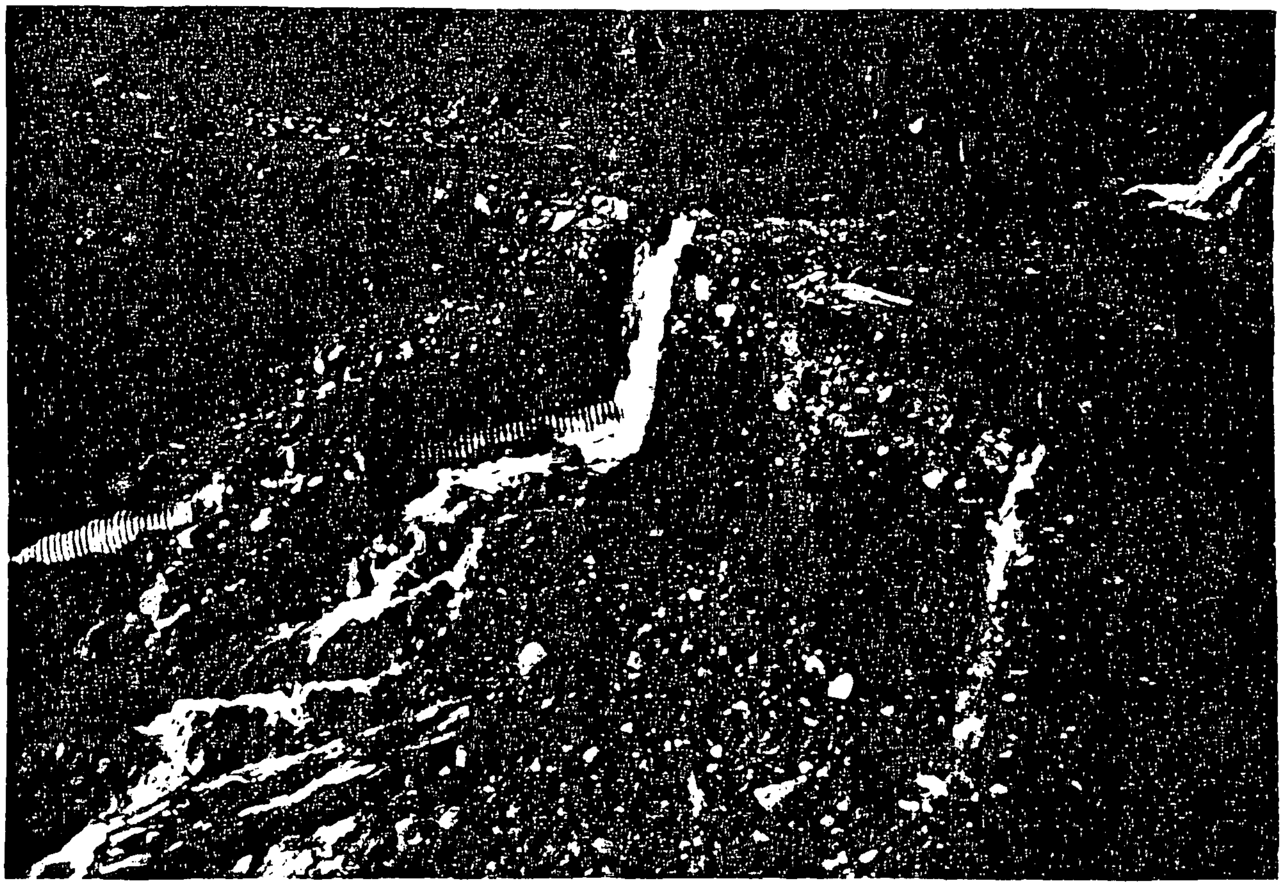


Figure 10: Photograph of unpaved haul road upstream of Redwood National Park showing two typical problems at stream crossings on abandoned roads. The culvert had become plugged, and water was flowing over the road surface instead of through the culvert. The water caused some of the road fill to fail. Secondly, no dip existed on the road at the crossing, so water was able to divert and flow down the road instead of across it. The diverted water can be seen in the foreground. Stream diversions on roads such as these can cause more fill failures or gullies. Erosion control work on this site consisted of installing a larger culvert, and excavating a shallow rolling dip at the crossing to prevent future diversions.

landowners in reducing erosion, which can ultimately benefit many land uses and owners.

It is important to recognize that "erosion proofing" and rehabilitation of logging roads are needed to decrease the amount of sediment delivered to Redwood Creek, but these efforts alone are not enough. Intelligent land use planning and road design are critical to prevent problems from occurring in the first place. The sediment balance points out the major role played by the remobilization of previously deposited sediment. Once sediment enters stream channels, it affects stream resources for many years. It is much more effective to prevent sediment from entering the streams in the first place than to try to deal with the in-channel consequences. For these reasons the National Park Service is planning a program of public education in erosion prevention techniques.

SUMMARY

1. Precipitation, annual runoff, peak flows and sediment discharge have been below average in Redwood Creek and its tributaries during the past decade. Annual runoff and sediment yield in tributaries are highly variable. Of the monitored basins, Coyote Creek produced the most runoff and highest sediment yield, and Little Lost Man Creek the least.

2. The mainstem of Redwood Creek is currently transporting more sediment per unit drainage area than the monitored tributaries. This fact, with supporting channel bed cross-sectional survey data, suggests that channel-stored sediment is currently a major source of sediment in Redwood Creek. About one-half of the sediment eroded from the Redwood Creek basin during a dry period (1980-1990) is due to channel bed scour in Redwood Creek. It is unclear whether the next large flood (greater than a 10-year flood) will reactivate hillslope sediment sources and initiate another cycle of channel aggradation, or whether the recently observed channel recovery will continue.

3. About 70% of the bedload sediment being transported by Redwood Creek past Orick originated from upstream of park boundaries. The upper and middle basin was the most important sediment contributor to Redwood Creek, even during low flow years. It is probably even more important during high flow years.

4. To be most effective in reducing sediment loads to Redwood Creek some rehabilitation efforts need to be shifted to the upper basin. Over 1000 miles of roads located upstream of park boundaries pose a significant erosion threat to downstream park resources. In addition, prevention of problems is critical, because once sediment is deposited in stream channels it represents a sediment problem for years. Public education, cooperative agreements with other agencies and landowners, and

assistance to landowners are being used upstream of the park to accomplish this goal.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES CITED

Best, D.W., 1984, Land use of the Redwood Creek basin. Redwood National Park Technical Report Number 9. National Park Service, Redwood National Park. Arcata, California. 24 pp plus maps.

Best, D. W., Kelsey, H., Hagans, D.K., and Alpert, M. (in press), Role of fluvial hillslope erosion and road construction in the sediment budget of Garrett Creek, Humboldt County, California. U.S. Geological Survey Professional Paper 1454.

Brown, W. M. III and Ritter, J. R., 1971, Sediment transport and turbidity in the Eel River basin, California: U.S. Geological Survey Water-Supply Paper 1986. 70 pp.

Harden, D. R., Janda, R.J., and Nolan, M.K., 1978, Mass movement and storms in the drainage basin of Redwood Creek, Humboldt County, California--a progress report. U.S.G.S. Open-File Report 78-486.

Janda, R.J., K.M. Nolan, D.R. Harden and Colman, S.M., 1975, Watershed conditions in the drainage basin of Redwood Creek, Humboldt County, California as of 1973, U.S.G.S. Open-File Report 75-568. 266 pp.

King, V. M., 1979, Timber harvesting and runoff in Redwood Creek, California: A climatic water budget analysis. M.A. thesis, Department of Geography, University of California, Davis, California, 149 pp.

Knott, J. M., 1971, Sedimentation in the Middle Fork Eel River basin, California, U.S. Geological Survey Open-File Report, 60 pp.

Lee, K.W., Kapple, G.W., and Dawdy, D.R., 1975, Rainfall-runoff relation for Redwood Creek above Orick, California, U.S.G.S. Open-File Report, 14 pp.

Ozaki, V., 1991, Long-term monitoring of channel stability on Redwood Creek, California. Redwood National Park Progress Report. 26 pp plus appendices.

Stone, E.C., Grah, R.F., and Zinke, P.J., 1969, An analysis of the buffers and the watershed management required to preserve the redwood forest and associated streams in the Redwood National Park. Stone and Associates Report. 106 pp.

U.S. Geological Survey, published annually 1974-1990, Water Resources Data for California, Surface Water and Water Quality Records.

U.S. Geological Survey, 1981, unpublished letter to National Park Service, 2 pp.

Varnum, N. and Ozaki, V., 1986, Recent channel adjustments in Redwood Creek California, Redwood National Park Technical Report No. 18, Arcata, California, 74 pp.